Evaluating the Seismic Risk of Reinforced Concrete Buildings of Colleges under Royal University of Bhutan using RVS Method

Tshering Cheki[1], Pema Wangchuk[2], Chimi*[3]

[1]Civil and Environmental Engineering Department, College of Science and Technology, Royal University of Bhutan

[2]Departmen of Planning and Resources, Office of Vice Chancellor, Royal University of Bhutan

[3]Architecture Department, College of Science and Technology, Royal University of Bhutan

Center for Disaster Risk Reduction and Community Development Studies (CDRRCDS)

E-mail: tsheringcheki.cst@rub.edu.bt [1], pemawangchuk.ovc@rub.edu.bt [2], chimi.cst@rub.edu.bt *[3]

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Abstract

Bhutan is located in seismically active Eastern Himalayas and is highly vulnerable to future earthquake disasters. Moreover, most of the colleges under Royal University of Bhutan (RUB) have been upgraded from schools and training institutes. Therefore, an immediate assessment of the vulnerability of educational infrastructure is required to ensure user safety and continuity of education after a disaster. In this study, the Rapid Visual Screening (RVS) methodology of FEMA P-154 and IIT Bombay is used to evaluate all reinforced concrete (RC) buildings of colleges under RUB. A detailed field survey was carried out from late 2024 to early 2025 in all colleges. It shows that 40% of RC buildings are below the commonly accepted benchmark score (S>2) according to FEMA P-154. And similarly, around 49% have scores in the range (0.7 < S < 2.0) according to IIT Bombay's methods, indicating "moderate risk", as this range will have a high possibility of Grade 3 damage and a very high chance of Grade 2 damages during an earthquake. These two different methods of RVS provide similar results due to inadequate seismic detailing, soft-storey irregularities, and ageing materials. The findings provide a classification of buildings based on potential seismic vulnerabilities and recommend priorities for detailed assessment, retrofitting, and mitigation measures for risk prevention and reduction. The study advocates that RVS is an effective preliminary tool for decision-makers to prioritize risk intervention strategies under limited time and resources.

Key Words: *Seismic risk assessment, Rapid Visual Screening, RC buildings, Royal University of Bhutan*

1. INTRODUCTION

Bhutan located in the seismic active Himalayan region, is highly vulnerable to earthquakes due to the active convergence of the Indian and Eurasian tectonic plates and falls in Zones IV and V according to the Bureau of Indian Standards (DDM, 2017a) as shown in Fig. 1**.** The past seismic events in the region, such as the 2009 Mongar earthquake (Mw 6.1) and the 2011 Sikkim earthquake (Mw 6.9), have revealed the vulnerability of Bhutan's infrastructure, particularly public buildings in the health and education sectors (Roberto et al., 2020; Chettri et al., 2021). In Bhutan, the construction industry widely adopts RC structures, which are generally assumed to be earthquake resistant, however, RC structures constructed before the Bhutan Building Rules 2002 are considered more vulnerable to earthquakes due to design inefficiencies and ageing. Despite being located in an active seismic zone, Bhutan still relies on Indian codes until today (Thinley et al., 2014). Academic institutions like colleges function not only as tertiary educational environments but also serve as critical infrastructure during and post-disaster response, like during the Covid-19 pandemic. Their high occupancy with structural and non-structural failure during an earthquake will lead to disastrous consequences. Therefore, ensuring the integrity of academic institutions is critical for the safety of users, educational continuity, and community resilience during and after disasters.

The Bhutan Buildings Regulation 2023 and Development Control Regulations (DCRs) address structural safety against earthquakes but do not place as much importance on non-structural components (NSCs), such as furniture, equipment, architectural elements, MEP fittings, and fixtures, as is done in other parts of the world. NSC are accounted for 82% of investment in office buildings, although they do not support structural loads (Kumar et al., 2020) and are associated with significant casualties during earthquakes, around 55% (Sweet, 2018).

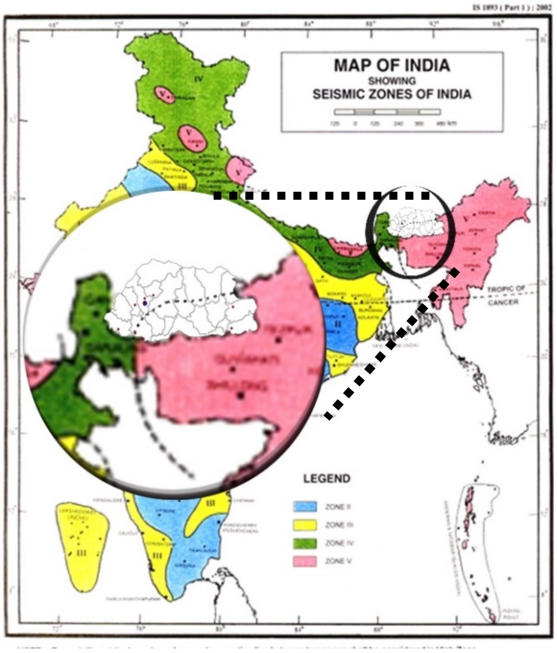

Fig. 1: *Seismic Zone Map Bhutan as per Seismic Code of India (BIS, 2002)*

The detailed and comprehensive structural evaluation for seismic resilience and preparedness are expensive and time-consuming. Thus, many countries have adopted RVS methodology as an alternative during pre- and post-disaster building vulnerability assessments for retrofitting and mitigation works (Ruggieri et al., 2020;ATC, 2015). Therefore, this study presents the application of RVS to assess the seismic risks associated with RC buildings at nine colleges within the RUB. The findings may contribute to university disaster preparedness by identifying vulnerable colleges and prioritizing risk prevention and reduction.

2. METHODOLOGY

2.1 Study Area

The Royal University of Bhutan (RUB) was established in 2003 with nine government and two affiliated colleges spread throughout the country under Royal Charter (Gyeltshen & Dorji, 2020) as shown in Fig. 2. Today it accommodates approximately 9296 students and 1284 staffs in nine colleges (RUB, 2025).

Five colleges, namely, College of Science and Technology (CST), Gedu College of Business Studies (GCBS), Jigme Namgyal Engineering College (JNEC), Sherubtse College (SC) and College of Language and Cultural Studies (CLCS), are located in seismic zone V as per IS code: 1893:2002. The remaining four colleges, namely Samtse College of Education (SCE), Gyalpozhing College of Information Technology (GCIT), Paro College of Education (PCE), and College of Natural Resources (CNR), are located in zone IV. All the colleges except CLCS have been either upgraded from schools and training institutes or rehabilitated from residential and office colonies.

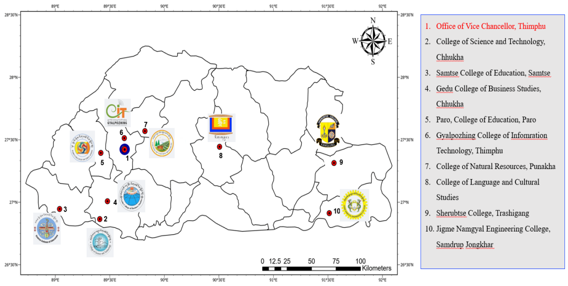

Fig.2: *Map of Bhutan showing colleges under RUB*

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2.2 Rapid Visual Screening (RVS)

RVS is a widely adopted method for preliminary seismic vulnerability assessment of buildings, especially in areas with limited resources and huge inventories (Perrone et al., 2019). It is designed to facilitate quick decision on prioritisation for risk prevention and mitigations (NDMA, 2020; ATC, 2015). According to National Disaster Management Authority of India, 2020, four levels of evaluation can be carried out to determine the vulnerability of structures due to earthquakes. They are RVS, Detailed Visual Study, Simplified Quantitative Assessment, and Detailed Quantitative Assessment.

The Federal Emergency Management Agency (FEMA) has initiated the development of the RVS methodology since 1988 and later updated it in 2002 and again in 2015. This study has used FEMA P-154 because of its simplicity, efficiency, and repeatability, making it suitable for preliminary assessment of diverse structures. It provides a standardised procedure to screen buildings based on visual inspections and basic structural information. It classifies buildings based on construction type, height, age, and observed deterioration or irregularities. The assessment is based on scoring mechanisms and pre-defined modifiers to estimate the probability of failure during seismic motions. The use of data collection form, scoring worksheets, and checklists has made it a benchmark tool for municipal and institutional seismic risk assessments in the United States and followed globally later with modified based on individual country's need and regulations.

Since Bhutan still follows Indian seismic codes for building design and approval, this study has also used the RVS method prepared by Prof. Ravi Sinha and Alok Goyal of IIT Bombay, which is customised to the Indian context from the FEMA P-154 form based on Indian seismic codes (Sinha, R. and Goyal, 2001). The methodology enables authors to validate the findings of study carried out using the FEMA P-154 form. However, there is a slight difference in score modifiers and a difference in the result interpretation method.

2.3 Data Collection

In both FEMA P-154 and IIT Bombay methods, before carrying out the site survey, the data on seismicity, soil maps, and drawing blueprints should be collected and analysed. According to the Indian seismic zone map, zones IV and V have PGA of 0.24g and 0.36 g, respectively (BIS, 2002). Therefore, five colleges falling under zone IV have to fill out a low seismicity form (less than 0.25g) and a remaining four colleges in zone V with moderate seismicity form (0.25-0.5g) out of five categories, namely; low, moderate, moderately high, high and very high FEMA P-154 forms. Whereas in case of IIT Bombay method, forms of Zone IV and V have to fill up among 5 forms, namely; Zone I, Zone II, Zone III, Zone IV and Zone V according to Indian seismic zones.

The team has also conducted tests such as the Electrical Resistivity Tomography Test and Standard Penetration Tests in all colleges to ascertain the soil types according to IS code and U.S. Geological Survey standards, which are one of the major assessing components of RVS. The trainings for data collectors were also carried out in accordance with FEMA P-154 procedure. During a field survey, each building is assigned two technical persons to assess the buildings within 15 to 30 minutes as specified in FEMA P-154 (ATC, 2015). A total of 500 RC buildings (76%) out of 656 buildings were surveyed in all the colleges from the third quarter of 2024 to the end of the first quarter of 2025. To obtain the reliable data inventory, all the RC buildings in the college under RUB are surveyed as shown below in Fig. 3.

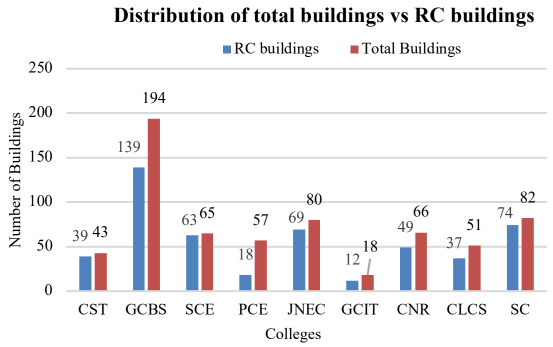

Fig. 3: *Distribution of Buildings in colleges under RUB*

During the field survey, basic data such as building type, number of stories, existence of irregularities, year of construction, etc., are collected besides observing the presence of vulnerability of NSC in each building. The construction year of 2002 is established as Bhutan formally endorsed BBR in 2002, although many engineers unofficially followed Indian code from the late 1990s for concrete building design and construction (Thinley et al., 2014).

3. RESULT AND DISCUSSION

FEMA P-154 categorises buildings into 17 types. This study considered only three typologies that belong to the concrete category. They are C1 (concrete moment-resisting frame structure), C2 (concrete shear wall structure), and C3 (concrete frame structure with unreinforced masonry infill walls). The final score(s) generally range from 0 to 7, with higher scores representing better seismic performance (ATC, 2015). For an example, if the building is rated with final scores as 2, the 2 indicates that there is a probability of 1 in 10^2 or 1 in 100 of building collapsing during an earthquake (ATC, 2015). FEMA P-155 guides the interpretation of the RVS scoring results. Fig. 4 below shows that all RC buildings in PCE, GCIT, CNR and CLCS are above the basic score, whereas JNEC has the lowest, with 26% of RC buildings failing to meet the basic score line.

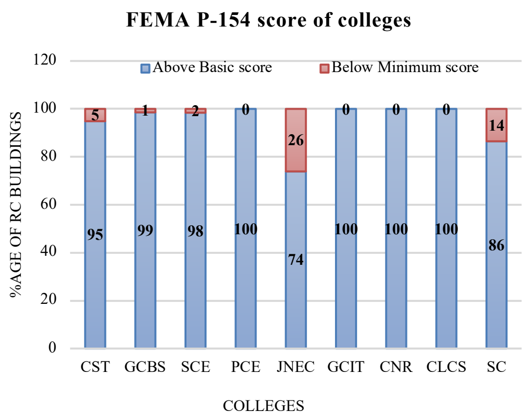

Fig. 4: *FEMA P-154 score of colleges*

Historically, FEMA has established a benchmark of final score(s) as 2 in many RVS programmes in the USA, as it has served as an acceptable preliminary value to differentiate adequate structures from those inadequate, which requires detailed evaluations. Using a higher threshold for the final score indicates a greater emphasis on safety, but it also results in higher costs for retrofitting or mitigation works. In contrast, a lower cutoff value for the final score increases seismic risk while reducing costs for retrofitting and mitigation works (ATC, 2015). Therefore, based on the benchmark of the final score (S) at 2, all RC buildings of GCIT are safe, and only 23% of RC buildings in JNEC managed to be safe, as shown in **Fig. 5.** This may be due to the conversion of a recently developed residential colony to the GCIT campus, and most of the buildings in JNEC are old and were constructed in 2002, besides being located in a higher seismic zone and with a lower grade of soil.

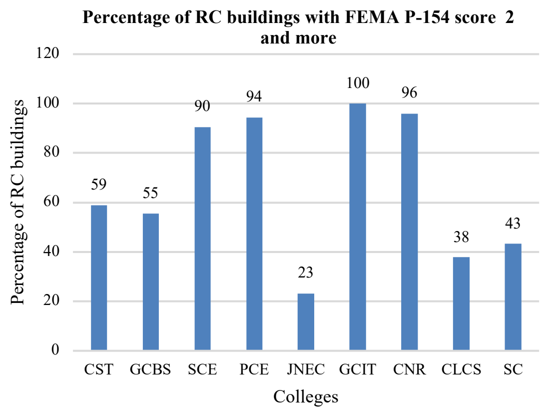

Fig. 5: *Percentage of RC buildings with FEMA P-154 score(s) more than 2*

As mentioned before, the team has also carried out the RVS method prepared by Prof. Ravi Sinha and Alok Goyal of IIT Bombay, which is customised to the Indian context according to FEMA P-154. Unlike FEMA P-154, the IIT Bombay scores generally range from 0 to 3 and do not have any benchmark. However, it has got 5 classifications of damage level based on the final score, as stated in Table 2. These damage classifications are based on the European Macroseismic Scale (EMS-98), which defines building damage to be Grade 1 to Grade 5 as shown in Table 1.

Table 1*: Classification of damage of RC buildings according to EMS-98 (Sinha, R. and Goyal, 2001)*

#	Category	Remarks
1	Grade 5	Total Destruction
2	Grade 4	Heavy structural damage and very heavy non-structural damage
3	Grade 3	Moderate structural damage and heavy non-structural damage
4	Grade 2	Slight structural damage and moderate non-structural damage
5	Grade 1	No structural damage and slight non-structural damage)

Table 2: *Damage classification based on score as per Sinha and Goyal, 2001*

#	Score	Damage Potential
1	S < 0.3	High probability of Grade 5 damage; Very high probability of Grade 4 damage
2	0.3 < S < 0.7	High probability of Grade 4 damage; Very high probability of Grade 3 damage
3	0.7 < S < 2.0	High probability of Grade 3 damage; Very high probability of Grade 2 damage
4	2.0 < S < 3.0	High probability of Grade 2 damage; Very high probability of Grade 1 damage
5	S > 3.0	Probability of Grade 1 damage

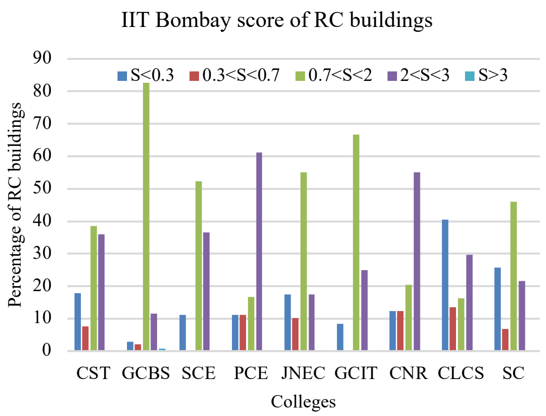

Fig. 6: *IIT Bombay score for each college in RC building in Percentage*

Fig. 6 shows the percentage of RC buildings in each category of score for every individual building according to IIT Bombay's RVS methods. Overall, 48.93% of RUB's RC buildings may have a higher probability of Grade 3 and a very high chance of Grade 2 damage, as most of the buildings score between 0.7 and 2, as shown in Fig. 7.

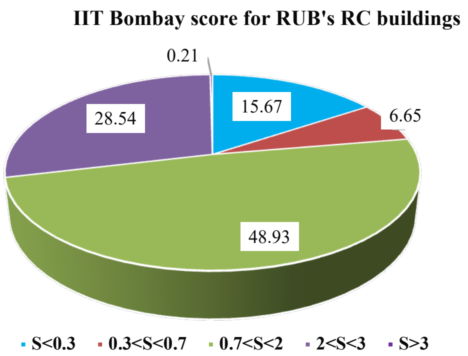

Fig. 7: *IIT Bombay score for RUB's RC buildings*

When doing RVS using both methods, the physical features of the buildings play a big role in deciding the score and predicting how likely they are to be affected by hazards, especially things like roof and cornice fixings and wall cladding, which are part of the NSC of buildings. According to the survey, 69% of RC buildings are classified as good, whereas 2% are classified as distressed, as shown in Fig. 8. This shows that most RC buildings are in satisfactory condition, indicating effective construction practices, while the small percentage classified as distressed highlights potential vulnerabilities that may need to be addressed to enhance overall safety and resilience. The data emphasise the necessity of routine evaluations to maintain continuous structural integrity.

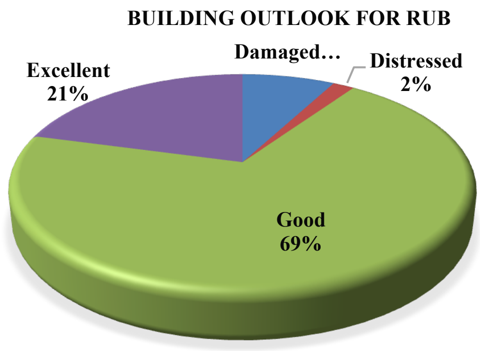

Fig. 8 *RUB's building outlook*

Most of the building is associated with various other hazards, such as landslides, ponding, and surface ruptures, as well as exterior and adjacent falling hazards, as shown in Fig. 9. These are not part of the scoring parameter, but the findings from the RVS form inform management of the associated risk to users from earthquakes and windstorms.

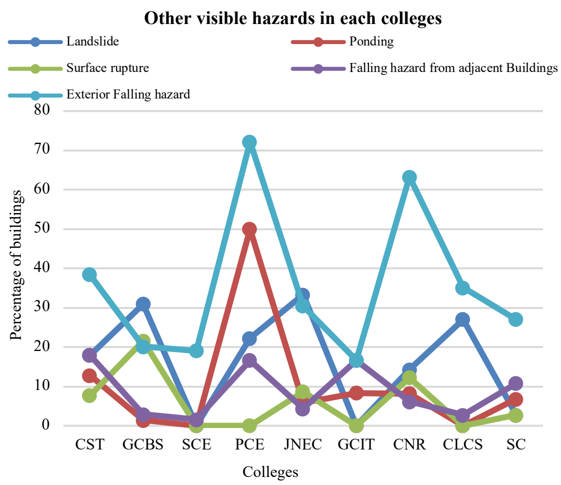

Fig. 9*: Other Hazards observed in RUB colleges*

4. CONCLUSION

The RVS assessment of all nine colleges under RUB indicates that many concrete buildings may be at risk during earthquakes, particularly in colleges with more buildings constructed before BBR2002, referred to as pre-code construction; for instance, JNEC has 26% of its buildings scoring below the basic threshold score of 2 according to FEMA P-154, which is commonly followed in most countries. Further, the IIT Bombay method has classified 48.93% of RUB's RC buildings as having a higher probability of Grade 3 damage and a very high chance of Grade 2 damage, as most of the buildings score between 0.7 and 2. This result indicates that there is an urgent need for retrofitting and mitigation measures particularly in Zone V campuses. Vulnerabilities in NSC (like roof fixtures and wall coverings) and additional hazards such as landslides and ponding increase these risks, putting the important educational buildings at risk while functioning after a disaster.

The study recommends the following points to enhance seismic resilience of RUB colleges: Firstly, prioritize retrofitting or maintaining buildings with scores below the decided threshold, especially in Zone V. Secondly, implement NSC mitigation measures across all colleges as per the manual prepared by the Department of Disaster Management (DDM, 2017b) for schools and according to FEMA-74 guidelines to secure overhead tanks and fixtures, bookshelves, etc. And finally, reform policies to require timely RVS assessment. These approaches will significantly improve user safety while maintaining educational continuity during seismic events, fulfilling RUB's role as an academic institution and potential disaster response center.

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