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## A Technical Note on Sustainable Innovations in Earthquake- Resistant School Building in Nepal - An Overview

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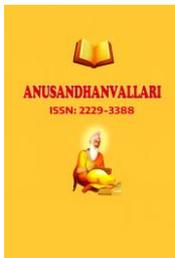
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### Abstract

The purpose of this study is to examine the critical need for earthquake-resilient school infrastructure in Nepal, a country highly prone to seismic activity due to geographic positioning. The study aims to identify effective engineering solutions and strategic frameworks that can transform school safety across urban and rural areas. Using a qualitative review methodology, it analyzes existing literature, post-disaster reconstruction reports, and architectural innovations implemented in Nepal post-2015 earthquake. Findings reveal that high-budget seismic-resilient projects play a vital role in developing scalable, low-cost construction models using local materials and community engagement. The implications suggest integrating technical training, policy enforcement, and adaptive design can significantly reduce structural vulnerability in future school buildings. The novelty of the study lies in its focus on bridging high-investment prototypes with low-budget implementation, offering a sustainable roadmap for safe education infrastructure. This research contributes to disaster-resilient development and inclusive educational planning in seismically sensitive regions.

**Keywords:** Building Innovation, Disaster Preparedness, Earthquake-resistant, School Buildings, Structural Engineering,

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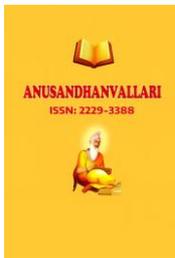
## 1. Introduction

Nepal is a nation defined by its towering mountains, vibrant culture and resilient communities. However, it also faces significant natural challenges due to its location in one of the most seismically active zones in the world. Frequent earthquakes have caused widespread destruction to infrastructure and disrupted essential services, particularly education (Hassan, Mahmoud & Ellingwood, 2020). School buildings in many parts of the country remain highly vulnerable to seismic shocks, often lacking proper structural design and reinforcement. The devastating 2015 Gorkha earthquake exposed this weakness on a massive scale, destroying thousands of schools and impacting the education of over a million children. In the face of these challenges, there is an urgent need to develop and implement earthquake-resilient architectural solutions that ensure the safety and continuity of learning for all students across Nepal (Subedi & Chhetri, 2019).

Schools embody so much more than places to learn, they are symbols of hope and stability. In most of rural and underserved places in the regions of Nepal, schools also serve as reception and refuge centers during emergencies (Corwith, 2020). The improvement of school infrastructure is not only about improving safety during earthquakes for children, but also about community resilience and recovery post-earthquake. Building design and construction of quake-resilient school structures can reduce casualties, reduce damage, but most importantly provide a means for children to learn in a stable environment during times of crisis.

Engineering innovations offer efficient and economically viable methods for enhancing the seismic safety of schools. These methods consist of reinforced masonry, base isolators, shear walls, appropriate foundational systems, and lightweight materials. Also, retrofitting certain vulnerable structures is one of the most important strategies that can be performed with minimal interference to the school's day-to-day activities. But mechanical approaches are not enough. There is an increasing need to raise awareness, to train locals, to participate from the community level, and to implement the national building regulations and standards at the appropriate level (Franco & Tracey, 2019). Both governmental and non-governmental undertakings have developed and initiated numerous projects aimed at the reconstruction and retrofitting of the schools throughout the country. However, problems such as scanty financing, poor geographical conditions, insufficient qualified personnel, and needless red tape often obstruct advancement.

Cooperation from all parties, especially policymakers, engineers, architects, educationalists, and the community, is important for lasting impact (Birli, 2016). This paper analyzes the issue of vulnerability of school infrastructure in Nepal which is heavily affected by seismic activity. It analyzes the country's contemporary structural problems, considers new approaches in engineering design, and proposes policy recommendations towards effectively enduring and environmentally sustainable school infrastructure. When educational facilities are designed



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with seismic safety prioritized, it allows the country to better protect its children and ensure their education without interruptions due to disasters (Petal et al., 2015).

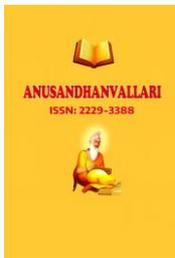
Nepal's educational institutions not only act as academic learning centers but also provide refuge for the community during emergencies (Shrestha & Gnawali, 2021). Unfortunately, the past earthquakes have demonstrated the exposed tragic structural vulnerability and inadequate protection of students in many of these buildings. In the harsh and devastating 7.8 magnitude earthquake in April 2015, roughly 7,000 schools were destroyed (Acharya, 2016). This exposed more than a million students to a colossal education deficit. The subsequent educational void together with the severe mental and bodily suffering, experienced by teachers and students, highlighted the compelling insufficiency of resilient construction towards the urgent infrastructure needs of schools.

The majority of school infrastructure in Nepal's hilly and rural semi-urban areas is blatantly constructed utilizing antiquated techniques and unreinforced bricks (Koedoot, 2018). Unreinforced brickwork is especially infamous in Nepal's eastern region. Due of Nepal's unpredictable earthquakes, these structures are significantly lacking seismically crucial beams and foundations, making it difficult to maintain Nepal's foundation design. Additionally, urban regions adopt costly designs and skimp on earthquake-resistant cauldron implementation, making them ineffective due to a lack of competent labour and lax enforcement. Since there are very few regulations governing these institutions, adherence to the standards is significantly hindered, endangering Nepal's education system (Ahmed et al., 2019).

Reconstruction operations following the 2015 earthquake encountered both possibilities and obstacles. Though there was still much to be done to enhance community design, resource allocation, and material availability, communities made progress in rebuilding schools (Maier et al., 2017). The experience made it clear that catastrophe risk reduction concepts should be emphasized in school construction plans. This is equally vital as good infrastructure quality management, which includes post-implementation review and long-term monitoring.

The translation of social, economic, and cultural values to specific seismic-resilient school construction requirements clearly illustrates that the concern goes beyond mere technology (Harle et al., 2024). Construction techniques that comply with local and international seismic safety standards are rarely known, and when they are, monetary constraints often present obstacles. Ideal solutions involve combining engineering with grassroots initiatives, supported by governmental and international efforts. Broader development programs should embed training on earthquake safety directly into the curriculum designed for masons and builders (Jain, 2016).

With this in mind, the study seeks to understand how Nepal can construct more robust and safer schools which are recalibrated for future earthquakes. Evaluating school infrastructure requires



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primary identifying critical structural flaws and assessing contemporary engineering practices alongside proposing attainable, eco-friendly long-term solutions for seismic safety. In relation to these issues, the study adds to the comprehensive objectives of resilience, equity, and development centered on children enduring disasters.

### **1.1 Role of Technology in Enhancing Earthquake-Resilient School Buildings in Nepal**

Technological advancements have increasingly become critical in addressing Nepal's vulnerability to earthquakes, particularly in the design and construction of resilient school infrastructure (Ray, 2017; Bothara, Ingham & Dizhur, 2024). By leveraging modern tools and techniques, engineers and planners can now ensure safer, cost-effective, and more durable buildings that can withstand seismic shocks. In a country with limited resources and difficult terrain, appropriate technological interventions offer both preventive and responsive benefits.

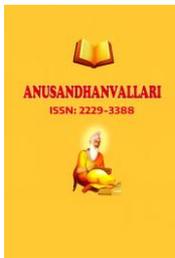
#### ***1.1.1 Advanced Design and Structural Modeling***

The introduction of computer-aided design (CAD) and Building Information Modeling (BIM) have revolutionized construction design with regard to managing earthquake strain (Chakrabarty, 2022). These enable engineers and architects to simulate how buildings will perform structurally with different levels of seismic activity. In Nepal, simulations are invaluable because local soil conditions, altitude, and weather winds greatly influence a building's structural stability (KC et al., 2025). BIM aids in eliminating design omissions despite constructions not yet commenced. It collaborates between architecture, structural, and electrical systems guaranteeing integrated and efficient building designs. This assures timely completion, resource optimization, and effective sustainability.

Using finite element analysis (FEA) software, specialists can anticipate the behavior of a school building's various components, such as its walls, beams, slabs, and columns, during an earthquake (Shroff, 2025). This way, there is minimal guesswork and the best materials as well as construction systems can be selected. For example, multistoried school buildings can have shear walls and moment-resisting frames optimally positioned to provide maximum earthquake resistance.

#### ***1.1.2 Earthquake-Resistant Construction Techniques***

Advancements in technology have also contributed to the improvement of construction methods designed to reduce the seismic effects of earthquakes (Shahjalal et al., 2024). Some of these methods were initially intended for developed countries. However, many are now being designed for cost-effective use in Nepal. An example is the base isolation system where flexible pads or bearings are placed between the foundation and superstructure of a building, allowing it to move independently of the ground (Kerileng & Dundu, 2017). Although pricey, simplified versions are being tested in some pilot school buildings with international organization funding.



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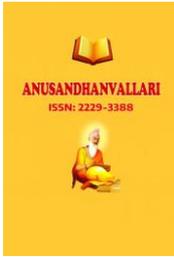
Other reinforced concrete frames, steel bracing, lightweight roofing, and confined masonry have been made easier with local modifications. The technologies improve the structure's ability to withstand seismic forces, and the chances of total collapse are diminished (Sekisov et al., 2021). For existing weak schools, retrofitting with steel jackets, ferrocement wraps, or carbon fiber has been successful. These technologies not only strengthen structural elements, but also save money and minimize disruption to school activities.

## 1.2 Bridging High-Budget Planning with Low-Budget Implementation

The high-budget proposals aim at building advanced earthquake-resilient schools in Nepal which require sophisticated design, technology, and engineering expertise. These projects might include international partnerships and involve complex seismic design as well as the use of materials like reinforced concrete, steel framing, and energy-dissipating foundations (Li et al., 2025). Although these methods are expensive, the investment serves a greater purpose other than constructing a few secure schools. They serve as practical evaluations of the extent to which safety can be prioritized in construction. They provide invaluable information, analyze new approaches, and determine which construction models are efficient and flexible. Most importantly, they demonstrate what can be functional, secure, and scaled down in lower-budget settings. Thus, the underlying purpose of these expenditures is to form guidelines for subsequent efforts, proving the feasibility of varying resource levels when centralizing the framework in engineering for disaster resilience (Rathnayaka et al., 2022).

As time progresses, most advanced technologies introduced in high-end projects get refined and scaled down. For example, additional incorporation of shear walls and cost-effective truss systems has already been adapted to use local materials such as bamboo, stone, and mud bricks. Sourcing local substitutes for imported materials and simplifying intricate practices are a few ways to cut costs tremendously (Helmold & Terry, 2016). This type of localization ensures that the same earthquake resistance engineering is maintained without the need for expensive foreign investments or outside help. In Nepal's rural areas, where resources are limited and construction material transportation is a challenge, these modified methods are extremely beneficial. Furthermore, while taking into account the structure's strength and stiffness, architectural innovations such as the modular classroom push the limits of price (Tenorio et al., 2024).

The financing of human resources is yet another noteworthy benefit of these large-scale projects. Many of these projects involve construction, which is further broken down into training and other capacity development activities that provide training to local contracting and engineering graduates as well as their construction workforce (Johari & Jha, 2020). These employees acquire important knowledge and abilities that they can use to smaller, locally run community initiatives. In addition, school pupils, tutors, and civic leaders become educated on the issues of structural safety and maintenance and custodianship of the building. This process



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of ownership and knowledge transfer enables the integration of safety and responsibility as part of the culture, which endures long after the project has been completed. Ultimately, there is an increasing number of skilled people, which decreases the reliance on expensive external consultants, enabling the community to undertake similar projects at significantly lower costs (Loosemore, 2016).

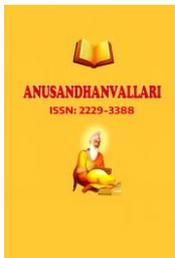
Lastly, big budget frameworks result in the drafting of primary national policies, manuals on construction practices, and codes on the school buildings tailored to Nepal's earthquake exposure. After going through the testing phase and institutionalization, these guidelines become construction benchmarks irrespective of funding. As an example, some standardized school building design for seismic shock resistance has been published, and is being disseminated by government and NGOs. Lower budget local builders can construct using these designs. This is how deep financial investment achieves enduring systemic transformation ensuring even low-budget construction projects for schools are safe. It optimizes the educational infrastructure development paradigm by making safeguards available to every child legally, physically, and regardless of geographically, they can access a safeguard educational environment.

## **2. Review of Literature**

The problem of inadequately designed school facilities in seismically active areas is particularly alarming in developing countries (Ersoy & Kocak, 2016). In places like Nepal where there are frequent and violent earthquakes, the existence of educational structures is crucial for safeguarding children while ensuring minimal disruption to education during natural calamities. School structures are usually built with little oversight and in many cases, they do not adhere to basic standards of earthquake-resistant design, rendering them extremely susceptible to seismic activity.

Every earthquake observation indicates the same outcome: the most disaster-prone structures are school buildings with the weakest construction practices. Some of the easiest problems to identify in school infrastructure are unreinforced, shallow, and unsupported walls, weak lateral supports, and insufficiently stiff foundations. There's great evidence that retrofitting older buildings features and adding earthquake-resistant features to newly built ones improve safety and durability. These features include confined masonry, reinforced concrete frames, detailed joints, and lightweight roofs (Borah, Kaushik & Singhal, 2023).

Alongside technical innovations, community involvement and local capacity development are highlighted by the literature as essential areas. The training of local masons, builders, and members of the school management committees in safe construction techniques significantly improves the survivability of the school structures in the long-term (Paci-Green et al., 2020).



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In addition, fostering students, teachers, and parents' awareness of earthquakes also contributes to a culture of safety in schools.

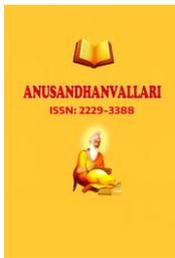
Policies as well as institutional frameworks are very important in ensuring the orderly and safe construction of schools (Leoschut & Makota, 2016). Incorporation of disaster risk reduction strategies into national education and infrastructure development plans fosters adherence to the implementation of safety measures (Sakurai & Sato, 2016). There are, however, still concerns such as lack of funds, isolation of the geographic region, and poor enforcement mechanisms which in conjunction slow down progress in many parts of Nepal.

Despite various efforts to improve school infrastructure in Nepal's earthquake-prone regions, a significant research gap exists in evaluating the practical implementation of seismic-resilient construction techniques at the community level (Bothara, Ingham & Dizhur, 2018). While many studies have focused on technical design standards and post-disaster assessments, limited research has been conducted on how effectively these engineering solutions are being adopted in rural and resource-constrained settings. A thorough analysis that incorporates local construction methods, stakeholder knowledge, and policy enforcement in school building projects is also lacking. In order to develop sustainable, earthquake-resistant school infrastructure that is suited to Nepal's socioeconomic and geographic circumstances, it is imperative that the obstacles and facilitators be thoroughly examined.

### **2.1 Structural Deficiencies in Existing School Buildings**

According to research, a significant number of Nepali school buildings, particularly those situated in remote locations and close to fault lines, are inadequately designed with respect to seismic safety standards. These school buildings are far more vulnerable to earthquakes since they are made of weak, non-reinforced masonry and non-weatherable materials. Furthermore, these schools were frequently built without taking into account the site's geotechnical characteristics, which are crucial for long-term stability (Basu, Misra & Puppala, 2015). These elements paired with poor technical design create a depressing situation where structures cannot withstand even the smallest amount of seismic activity.

The irregularity of plan configuration, which is one of the variables that increases the risk of an earthquake, is another significant issue mentioned in the literature. According to the research, many school buildings are built with asymmetrical layouts, which increases the likelihood of torsional motion when earthquake loads are applied (Stathi et al., 2015). The bracing and main structural elements are severely asymmetrically damaged in the columns and walls as a result of this geometric irregularity. From literature studies, it has been found that these design imperfections combined with the inadequate structural system greatly increase the probability of the building failing in a major earthquake (Harirchian et al., 2021).



An additional concern identified in earlier research is the seismic risks in school construction that are overlooked due to funding limitations. Meanwhile, schools located in rural and economically underdeveloped regions are constructed following cost-efficient construction methods that favor cheap over resilient. Economical construction practices tend to ignore building, let alone advanced protective measures against seismic forces, which renders these educational institutions extremely susceptible (Smith et al., 2023). This highlights the need for additional protective building regulations regarding practical and economical CCC school construction safety issues.

## 2.2 Seismic-Resistant Design Solutions

Several researchers have attempted design practices for Nepalese schools that are seismic resilient and take into considerations the difficulties encountered in earthquake ravaged regions (Gaffney, 2022). One of the most cost-efficient methods to increase seismic resistance of the building is the use of confined masonry, that is, walls with concrete tie-columns (Putra, 2024). This is ideal for low-rise buildings such as schools and is easily integrated with local construction practices. Research Efforts indicate that confined masonry is effective in building soft story collapse mechanisms providing lateral restraint in seismic events.

Another option which is being considered is to place shear walls in some critical regions as far as these can provide significant control for the application of seismic energy on the structure upwards and sideways as well. The resistance of shear walls to lateral forces help limit unwanted movement, therefore shear walls provide control for horizontal forces which are typically the principal cause of damage in earthquakes (Koleci et al., 2024). This is beneficial for multi-storey educational buildings or larger scale school structures which are needed to support higher loads. Research shows that placing shear walls enhances the overall seismic performance of the building.

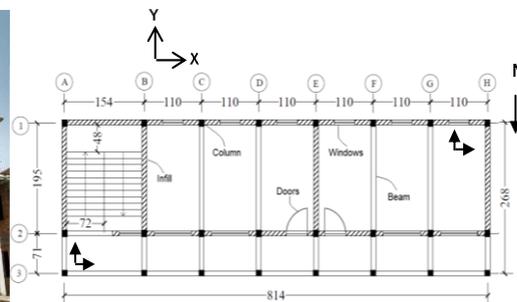
In the case of more important or larger educational institutions, modern engineering practices, including base isolation, have also been considered. Base isolators greatly reduce the earthquake forces transmitted to a structure because they uncouple the building from ground motion (Prakash, Mahalakshmi & Rathod, 2025). While this technology is usually reserved for critical infrastructure because of its cost, its use on school buildings, especially those located in urban areas or high-risk zones could dramatically improve their earthquake resilience. In developing countries like Nepal, studies trying to assess the cost-effectiveness of these systems are still underway, but some promising pilot projects suggest that in certain situations, the long-term safety benefits make the investment worthwhile (Rai et al., 2025).

The figure 1(a) shows a three-storey school building in Kathmandu, constructed with a combination of red bricks and reinforced concrete framing. The structure has a symmetrical facade with rows of doors and windows aligned on each floor, providing proper lighting and

ventilation for classrooms. The building is simple yet functional, with balconies and staircases for vertical circulation. The figure 1(b) is the architectural floor plan of one block of the school, showing the arrangement of structural components such as columns, beams, infill walls, doors, and windows. It highlights the spatial layout, including staircases on one side, classrooms divided by walls, and circulation space. The plan provides precise measurements of different sections, ensuring structural stability and usability. Together, these two images represent both the actual built form of the school and its technical design blueprint, reflecting how planning is translated into construction for educational infrastructure in Kathmandu.



1(a): The building's north elevation



2(b): Plain View

**Figure 1.** School Building in Kathmandu

Source: Building Drawing Texts (2014)

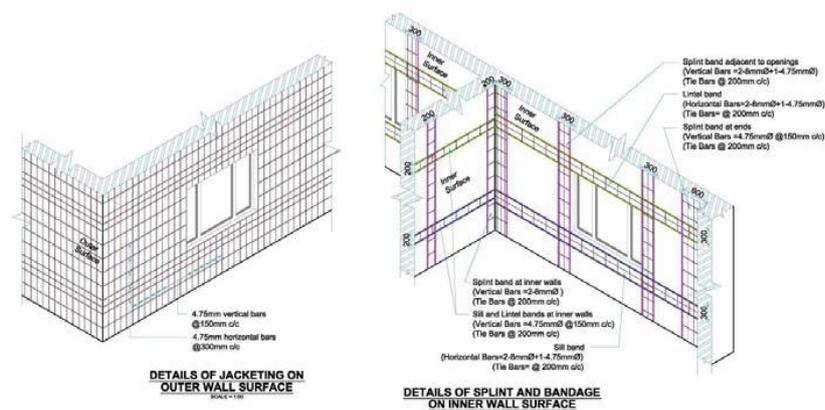
### 2.3 Retrofitting as a Practical Approach

Seismic strengthening measures for existing school buildings are often touted in the literature as one of the most reasonable and effective options if rebuilding them is not feasible (Daly et al., 2017). Methods such as jacketing of braced columns, adding steel bracers, and the walling with ferrocement or carbon fiber wraps has been made to enhance the structural strength of many older buildings. These methods reinforce weak structural elements and improve the building's ability to resist seismic forces without the use of wholesale demolition and reconstruction.

Some aspects of community-based retrofitting have also been elaborated in recent literature. In Nepal, where resources are hard to come by, community involvement on retrofitting is a step in the right direction that helps reduce costs and provides education on the measures related to safety in the event of an earthquake (Bothara, Ingham & Dizhur, 2018). Local workers can be retrained to apply adequate retrofitting methods which adds value to the construction, and to some extent, empowers the community (Furman & Hadjri, 2025). In addition, these efforts help ensure that retrofitting measures are culturally relevant and consistent with local architectural styles, thus sustainable.”

Retrofitting, while advantageous, also comes with a unique suite of obstacles. Past studies state that the absence of appropriate skilled and technical experts distracts the requisite workforce, hence leading to poorly managed and executed retrofitting projects (Srivastava et al., 2020). Furthermore, retrofitting projects can encounter problems due to inadequate funding and poor collaboration among the local authorities, school management, and the construction crews. The effectiveness of retrofitting measures is achieved when there is a structured broad-spectrum strategy for planning, training, resource allocation, and consistent monitoring and evaluation of retrofitting measures taken.

Figure 2 illustrates the typical design of retrofitting measures applied to existing school buildings for seismic strengthening. This shows the jacketing of outer wall surfaces using a mesh of vertical and horizontal steel reinforcement bars (4.75 mm bars placed at 150 mm and 300 mm intervals respectively) to enhance the wall's lateral load resistance. The figure depicts splint and bandage detailing on inner wall surfaces, where vertical and horizontal reinforcement bands are strategically placed around openings (doors and windows), as well as at sill, lintel, and roof levels, to confine masonry and improve ductility. These bands help prevent out-of-plane wall failure and reduce crack propagation during earthquakes. Together, these methods provide a cost-effective retrofit solution by reinforcing critical wall areas without requiring demolition, thereby improving the building's seismic performance and overall safety.

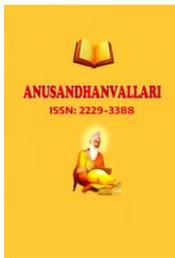


**Figure 2.** Typical design of proposed retrofitting

Source: NSET (2017)

## 2.4 Integration of Local Materials and Indigenous Techniques

In Nepal, the construction of earthquake-safe school buildings has benefited from the widespread literature promoting the use of local materials and indigenous construction methods (Ghimire et al., 2024). Bamboo, for example, is renowned for having remarkable resilience because of its high strength-to-weight ratio and flexible structure. Particularly in rural places,



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bamboo can help build affordable, earthquake-resistant schools with lightweight, flexible roofing systems (Gupta et al., 2023). Properly treated bamboo reinforced with steel can greatly reduce the chance of collapse, according to research.

The usage of compacted earth blocks (CEBs) and stone as sustainable building materials for earthquake-resistant structures has also been studied. Positive outcomes have been obtained when these materials are used with modern structural engineering methods including seismic bands, reinforced concrete columns, and other engineering systems (Padalu et al., 2024). These locally accessible materials provide an affordable and ecologically friendly alternative for building schools in areas where traditional building materials, such as lumber, are scarce or prohibitively expensive. CEBs are especially valued for their thermal insulation, which is essential for preserving pleasant interior temperatures in the hot, dry climate of rural Nepal.

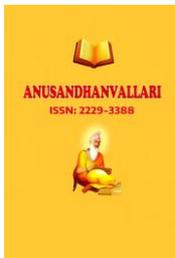
Using indigenous knowledge and traditional forms of construction is equally as important in ensuring the schools are built to withstand earthquakes. Many rural areas of Nepal have dialects with architectural lore that is uniquely geared to the environment and level of seismic threat in the area. Blended with contemporary methods of seismic engineering, such traditions construct suitable and inexpensive buildings at the same time. Research indicates that such people should participate in the planning and building phases, as their expertise will be very useful in solving local problems for effective seismic protection.

## **2.5 Skill Development and Technical Training**

The skills gaps that impact construction workers' capacity to ensure the safety of school buildings are a significant issue in the literature. Masons and builders in isolated and rural locations are frequently not taught how to create structures with earthquake-resistant elements, which leads to risky construction methods (Jain, 2016). According to research, having skilled local masons who know how to use seismic-resistant materials and methods significantly raises the caliber of building. Adequate training in the reinforcement and control of building quality oblique the safe construction of buildings has been found to minimize structural collapse during an earthquake (Idham, 2018).

Use of local trainers has also been shown to enhance the effectiveness of construction designed to withstand earthquakes in the long term. In Nepal, several non-governmental organizations (NGOs) have been involved in training local builders concerning the risks posed by seismology as well as contemporary building practices (Sharma et al., 2018). Often, these trained masons go back to their communities and act as local trainers; dispersing knowledge to increase the number of buildings constructed to required safety standards. This trainer-of-trainers approach has proven effective in increasing capacity and construction standards in rural areas.

In addition, the appropriate instruction of local engineers and architects in the designs of seismic resistant skeletons of structures is critical for ensuring that newly constructed school



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buildings are compliant with seismic safety regulations. As stated in the studies, offering local engineering practitioners further training on recently published seismic codes, educational materials, and technologies pertinent to the structure a system's safety is fundamental in the improvement of the safety status of educational infrastructures (Petal et al., 2015). Programs of this nature sponsored by universities together with governmental institutions or foreign bodies have been recognized as one of the best strategies for supporting local expertise development and upgrading local professional scientific work in seismic protected architecture.

## 2.6 Safety Audits and Monitoring Systems

Research emphasizes the importance of conducting safety audits and monitoring the structure on a consistent basis to maintain the resiliency of school buildings. Post the 2015 Gorkha earthquake, numerous studies highlighted the indispensable contribution safety audits provided in determining schools with the highest vulnerable risk which needed immediate retrofitting or rebuilding (Subedi & Chhetri, 2019). Routine safety audits include a visual assessment, a rough structural check, and a screening of select load-bearing components that must be capable of bearing seismic forces to test their arithmetical strength for seismic resistance (Xiang et al., 2024). Such audits are imperative in providing essential information that assists in devising future risk mitigation strategies as well as prioritizing interventions towards highly vulnerable schools.

Enhanced earthquake resilience in school buildings has also been suggested through innovative measures such as in real-time safety audit systems which monitor the health of the building (Habib, Alnaemi & Habib, 2024). Employing accelerometer and other seismic sensors, movement or any form of structural change during the earthquake can be registered in real-time, free from human interference. That information can later be used to evaluate and quantify the degree of damage the tremor inflicted on the structural integrity of the building and whether evacuation is warranted. Though the cost of installing such systems is steep, research claims these technologies reinforce the safety and reliability of the early warning systems (Esposito et al., 2022).

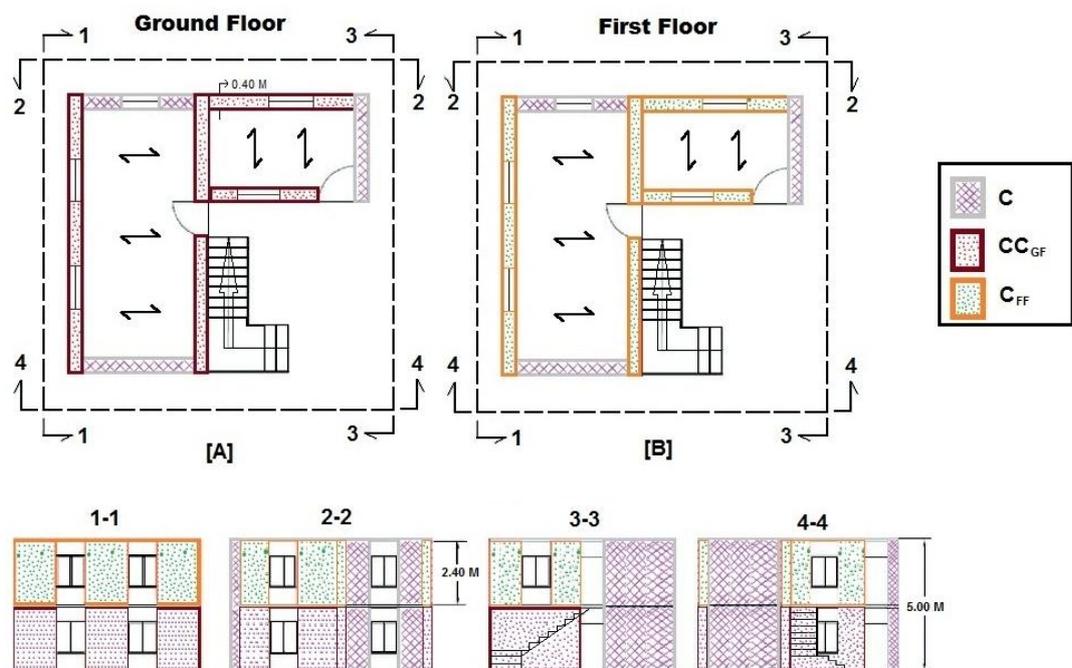
Additionally, literature highlights the role of the community in the overseeing process. In rural regions with limited access to technical skills, community members can be involved with basic inspections, such as reporting damages and checking whether schools are properly maintained over time (Ehren et al., 2017). This method improves the reliability of monitoring systems while also fostering an attitude of disaster readiness in local communities.

A recent architectural sketch in Figure 2 shows a two-story school built with earthquakes resistance. The two floors separated the ground and first floors in both shape and material. Ground-level walls are confined masonry-dark red in the legend-marked CC\_GF and bound together with concrete ties at corners and openings. That grid keeps the walls stiff when

sideways shaking hits. Conventional block sections, noted with a plain-C, fill the gaps but will need extra steel or bonding to match the confined panels strength. Centering the stairwell balances the plan and helps push loads evenly through the frame.

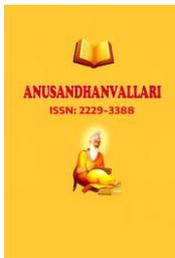
The first floor is wrapped in orange-marked confined masonry, or C\_FF, so the vertical structure from the ground level carries straight through with no breaks. That neat alignment slices the chances of a soft-story failure when the earth starts to shake, a trouble any quake-prone zone knows all too well. Seismic bands gripped at several levels run a horizontal belt around the walls, giving them the extra pull they need to keep from flopping outward when stresses swing.

While the architectural detailing provides a solid basis for seismic resilience, the current design lacks empirical validation. To substantiate the building's performance under seismic conditions, several analytical simulations are recommended. Modal analysis should be performed using tools such as ETABS or STAAD Pro to determine the building's natural frequencies and mode shapes, ensuring they do not align with predominant earthquake frequencies, thus avoiding resonance effects. Additionally, nonlinear push-over analysis can evaluate the structure's capacity to withstand lateral forces, identifying the performance point and ensuring the building meets "Life Safety" or higher performance levels.



**Figure 2.** Earthquake-Resilient School Design for Seismic Safety in Nepal

*Source: Author's own drawing*



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### 3. Discussion and Conclusion

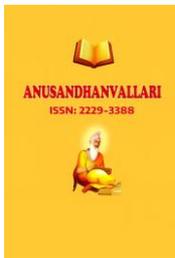
The geophysical location of Nepal lying within the Himalayan belt makes it prone to severe earthquakes which presents a huge challenge to the infrastructure of the nation, in particular, schools. The 2015 earthquake not only propounded a humanitarian crisis but also revealed the deep-rooted issues boiling underneath the poor engineering and construction practices as well as the lack of disaster management frameworks for the school buildings. The results from range of studies focus on the importance of integrated educational infrastructure systems framework and specifically escalated attention towards the modern infrastructural technologies on education systems in them.

The previously constructed schools' lack of structural safety is another significant cause for concern. Most of these institutions are quite risky due to the frequent use of poor building and construction techniques and the lack of seismic compliance. Shear walls, restricted masonry, and locally accessible materials like bamboo or compacted earth blocks are all practical and inexpensive. Furthermore, it appears possible to maintain the older buildings by strengthening their safety features through seismic retrofitting or careful, planned renovation.

Another crucial element is incorporating local knowledge into training. The research firmly supports the idea that community empowerment is facilitated by construction and skill development initiatives that combine traditional methods with modern engineering. In addition to making the school infrastructure more resilient, this encourages long-term community involvement and ownership of safety upkeep. Regular safety assessments and monitoring systems are becoming essential components of a comprehensive seismic safety strategy.

Moreover, child-centered design aspects of resilient schools' construction must be highlighted, too. Other details that need to be accounted for include: the evacuation plans from the educational setting, exits for emergencies, and the rest of the expansion of corridors and classrooms that can be converted into classrooms on demand. The psychological, physical, and 'safe-to-panic' elements must be integrated into the school inelasticity architecture. These aspects, geared towards young individuals' needs, should be viewed as non-negotiable in the context of resilient architecture. These, issues clearly indicate the additional need for policy support and institutional arrangement. Building codes exist but there is legally regulated minimal institutional capacity and political zeal which dictate its compliance. These gaps can be improved by better strategic governance, mandatory school safety provisions, heightened expenditures on education facilities, and DRR mainstreaming in the national educational framework bolsters the impact of the technical measures.

Lastly, in order for Nepal to implement these solutions on a large scale, international cooperation and sponsorships are crucial. There are effective structures in other earthquake-prone nations, such as Japan, Chile, and Turkey, that can serve as models. International



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collaborations offer the financial resources, technical know-how, and educational opportunities required to upgrade Nepal's school infrastructure. It is not only a technical necessity but also an ethical duty to keep schools in the Nepal region earthquake-safe. Schools are more than just buildings; they are places of refuge and learning for kids. Their indiscriminate destruction after disasters causes fatalities and interferes with the recovery of mental health and education. The lessons learned underscore the need to promote earthquake resilient construction techniques, retrofitting vulnerable structures, utilizing local sustainable materials, and enhancing community-level technical capacity.

Every stage of school planning, including site selection, design, building, monitoring, and maintenance, must take seismic safety into account. Existing school buildings must be adapted to comply with contemporary, cost-effective technologies in addition to being designed and constructed. Architects, engineers, local administration, and educators must collaborate to achieve these objectives. Building resilience is the responsibility of schools since increasing public knowledge and educating the populace makes them more resilient to adversity. Schools can serve as platforms for disaster preparedness by including DRR (Disaster Risk Reduction) themes into the curriculum and providing staff and students with training on emergency protocols, frequent exercises, and other procedures. Schools' function as secure knowledge bases can reduce the likelihood of disasters.

In summary, highly resilient and safe school buildings in Nepal can be achieved through policy changes, community involvement, new technological advancements, and continuous efforts. Working on the environment where children learn should be nurturing and strengthening instead of just the policies in dry documents. Enhancing school architectural features to include seismic resilience will transform Nepal's past tragedies into prospects for future security, equity, continuous education, and safety.

#### **Disclosures**

##### **Data Availability Statement**

The data is confidential, but upon request can be disclosed.

##### **Ethics Approval Statement**

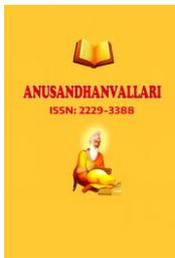
Not applicable

##### **Patient Consent Statement**

Not applicable

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Not applicable



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### **Clinical trial registration**

Not applicable

### **Declaration of Conflicting Interest**

The authors declare no potential conflict of interest in the research work, authorship or further publishing of the article is concerned.

### **Declaration of Originality**

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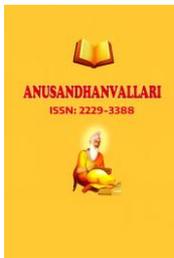
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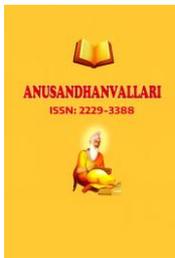
The authors wish to thank all participants for their involvement in this research and extend their sincere appreciation to colleagues for their insightful feedback and encouragement throughout the development of this manuscript. This paper represents the authors' original and independent work, undertaken solely for the purposes of contributing new knowledge to the field. It has not been previously published, presented at any conference, or submitted as part of any academic coursework, dissertation, or institutional report. Furthermore, it does not incorporate or rely on any prior unpublished or assessed material by the authors or others. All data, analysis, and interpretations contained herein are the direct result of the authors' own research efforts, and no portion of this work has appeared in any prior form.

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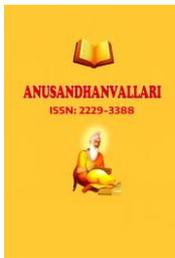
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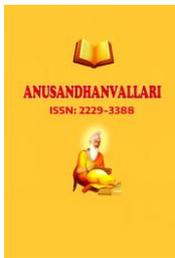
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