
From practice to field guideline: principles for retrofitting URM school buildings in Pakistan

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ABSTRACT

The seismic retrofitting of unreinforced masonry (URM) school buildings in Khyber Pakhtunkhwa (KP), Pakistan, under the *Disaster Resilient School Infrastructure Project* of UN-Habitat, is among the largest coordinated retrofitting initiatives for public education facilities in Pakistan. Implemented in collaboration with the Elementary and Secondary Education Department (E&SED) and supported by Japan International Cooperation Agency (JICA), the programme has repaired, remediated, and strengthened 150 brick and stone-masonry schools across eight high-seismic-risk districts using simplified, life-safety-based methods adapted from international guidelines and local practice.

Building on these extensive field experiences, UN-Habitat is developing a pre-engineered, typology-based *Guideline for Seismic Retrofitting of School Buildings (Masonry Buildings) - Manual for Field Engineers and Technicians* to standardise assessment, risk-based prioritisation, retrofit design, documentation, and construction sequencing across projects. The guideline integrates international seismic principles with locally appropriate construction methods and explicitly addresses institutional, logistical, and socio-cultural constraints that govern deliverability in remote and resource-constrained settings.

This paper presents key lessons from field execution, the technical basis and development framework of the guideline, focusing on (i) simplified risk-based assessment and prioritisation procedures, (ii) standardised

retrofit solutions for common one- and two-storey URM school typologies, and (iii) implementation challenges related to logistics, workforce capacity, and privacy requirements in girls' schools. The paper demonstrates how embedding logistics, coordination, and constructability considerations within the engineering framework enables scalable, replicable, and resilient seismic risk reduction for school infrastructure in Pakistan and comparable seismic regions.

1 INTRODUCTION

Northern Pakistan is situated within in a highly seismically active region influenced by the Himalayan, Hindu Kush, Chaman, and Makran fault systems (Khan, et al., 2016). These tectonic settings have generated multiple damaging earthquakes, most notably the 2005 Kashmir earthquake, which caused over 73,000 fatalities, including approximately 19,000 schoolchildren killed during school hours due to building collapse (EERI, 2006). This event highlighted the unacceptable seismic risk associated with unsafe school infrastructure and the urgent need for systematic risk reduction measures.

School buildings constitute a critical component of social infrastructure, yet a large proportion of Pakistan's public-school stock comprises low-rise unreinforced masonry (URM) buildings constructed without seismic design provisions or adequate construction control. Post-earthquake damage assessments from the 2005 Kashmir earthquake and subsequent regional events have consistently demonstrated the inherent vulnerability of these structures.

Despite the availability of international seismic retrofitting guidelines [(FEMA, 2006), (Arya, Boen, & Ishiyama, 2013), (Schacher & Ali, 2009), (Bothara & Brzev, 2011)], their direct application in Pakistan is constrained by limited technical capacity, resource availability, and site access, particularly in remote and high-risk regions. These constraints necessitate pre-engineered, simplified, standardised, and typology-based approaches that prioritise life safety and are deliverable by field engineers and technicians under constrained conditions. Accordingly, UN-Habitat is developing the *Guideline for Seismic Retrofitting of School Buildings (Masonry Buildings)* (UN-Habitat, under preparation) meeting these requirements. The guideline establishes a unified framework for building screening, risk-based prioritisation, retrofitting design, documentation, and construction sequencing for typical one- and two-storey URM school buildings. It is intended to support the timely implementation of retrofitting programmes within constrained funding cycles and project durations. It integrates international best practice with local construction methods and explicitly accounts for institutional, logistical, and socio-cultural constraints.

This paper presents the technical basis and development framework of the guideline, structured around (i) risk-based building assessment and prioritisation procedures, (ii) standardised retrofitting solutions for common URM typologies, and (iii) implementation considerations, including material supply, construction supervision, and social constraints such as privacy requirements in girls' schools. The guideline aims to support consistent, safe, and replicable retrofitting practice and is intended to be applicable across earthquake-prone regions of Pakistan. The challenge addressed in this paper is how to translate seismic engineering principles into scalable, field-deliverable retrofitting solutions under severe logistical and institutional constraints.

2 OBJECTIVES OF THE GUIDELINE

The guideline is founded on the premise that meaningful reductions in seismic risk for typical school buildings can be achieved through standardised, life-safety-oriented interventions that are feasible under constrained time, budget, and capacity conditions. It prioritises collapse risk reduction over full code compliance and emphasises solutions that can be consistently implemented in the field for common low-rise

unreinforced masonry (URM) school buildings constructed in brick or stone masonry using mud or cement mortar.

The guideline adopts a typology-based approach to standardise assessment and retrofit solutions, thereby reducing reliance on building-specific custom design. Retrofit measures are intentionally simple and constructable, relying on pre-engineered details suitable for application by field engineers, technicians, and local contractors. The selected techniques are contextually adapted, making use of locally available materials, skills, and construction practices. Logistical, institutional, and site constraints are explicitly considered, with practical strategies incorporated to support effective execution in resource- and access-constrained environments.

The overarching objective of the guideline is to enhance the seismic resilience of school buildings by reducing implementation time and cost, mitigating non-technical barriers, and enabling consistent and scalable retrofit delivery. While developed for application in Khyber Pakhtunkhwa, the guideline is intended to be transferable to other earthquake-prone regions with similar hazard and socio-economic conditions.

3 BUILDING TYPOLOGY

The vast majority of school buildings, particularly those constructed before 2007 in KP, follow a largely standardised design. They are simple one to two storey-high rectangular or L-shaped masonry structures, typically with bricks or stones in cement or mud mortar load-bearing walls supporting either RC or inverted T-iron slabs or lightweight roof supported by trusses (Figure 1). Field surveys confirm that most of these schools were built using uniform design templates and similar construction practices. These buildings are mostly rectangular or L-shaped in plan with room size 5 m x 7.5 m; however, over the time, the rooms were subdivided as the need for additional classrooms grew or verandas were closed to create more classrooms.

		
Two-storey high stone masonry building with light metal roof	Brick masonry building with light metal roof	A brick masonry building with RC slab roof, note that the veranda is supported RC beam-column frame

Figure 1: Typical school building typologies with different wall types and roofs

Field observations suggest that at least some masonry school buildings, likely constructed under earlier programmes, were provided with lintel bands or similar horizontal elements (Figure 2). However, complete design records, reinforcement details, and construction specifications were unavailable, making it difficult to verify whether these bands meet the requirements for effective seismic performance.

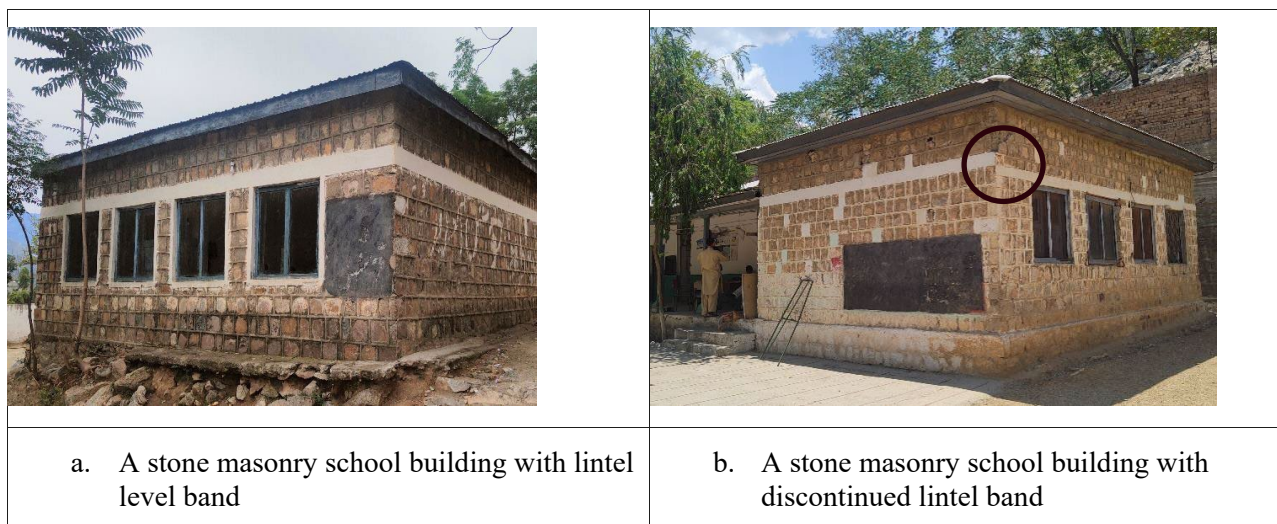


Figure 2: School buildings with bands

4 REPAIR AND REHABILITATION

The experiences indicate that many school buildings were in dilapidated conditions. Therefore, the guideline recommends a health checking of the building followed by repair and rehabilitation of the building before any seismic retrofitting.

5 ASSESSMENT AND PRIORITISATION

The Guideline adopts simplified assessment and prioritisation methods that balance technical rigour with field practicality. Quick Visual Screening (QVS) (FEMA, 1997) supported by basic measurements is used to identify critical seismic deficiencies, with emphasis on load paths, wall integrity, diaphragm behaviour, and connection details. Buildings are prioritised based on seismic hazard, occupancy exposure, observed vulnerability, and potential consequences of failure, enabling transparent and efficient allocation of resources at programme scale.

The methodology provides a structured, qualitative assessment of URM school buildings through an attribute-based scoring system that translates observable deficiencies into a numerical representation of relative seismic vulnerability. The approach integrates engineering judgement, lessons from past earthquakes, and simplified quantification to support consistent and defensible decision-making across varied field conditions.

The framework comprises two components: (i) an engineering assessment, which quantifies structural vulnerability using an attribute-based scoring method; and (ii) societal and contextual factors, which inform prioritisation. Following initial triaging, shortlisted buildings undergo QVS, during which observed deficiencies are documented and scored. The resulting technical score reflects relative seismic vulnerability, with higher scores indicating greater retrofit urgency. Societal and contextual considerations are then applied to establish final retrofit priority. The overall workflow is shown in Figure 3.

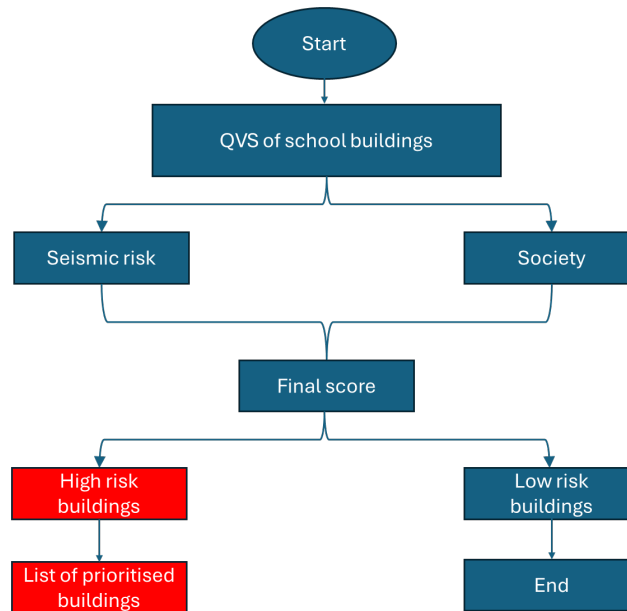


Figure 3: Flowchart of the qualitative assessment process of buildings

To enable consistent and defensible prioritisation at programme scale, a composite prioritisation score, P , is defined that integrates engineering vulnerability with seismic hazard, exposure, and contextual modifiers, as shown in Eq. (1).

$$P = [(B + \sum G \times W) \times H \times E] \times [S \times D] \quad (1)$$

where B is the building typology score; $\sum G \times W$ represents the combined effect of observed structural deficiencies; H is the seismic hazard factor; E is the classroom density (exposure) factor; S is the social prioritisation factor; and D is a discretionary adjustment.

This formulation preserves engineering judgement as the primary driver while allowing contextual realities to be incorporated in a transparent and repeatable manner.

6 RETROFITTING

6.1 Typology-based retrofitting approach

Given the repetition of construction forms, buildings were classified into a number of typologies based on plan layout, number of storeys, construction materials and technologies, and floor/ roof system. For each typology, a set of pre-engineered retrofitting solutions was developed. This principle reduced design effort, improved consistency, and facilitated training and supervision. Typical strengthening details adopted for common typologies are shown in Figure 4.

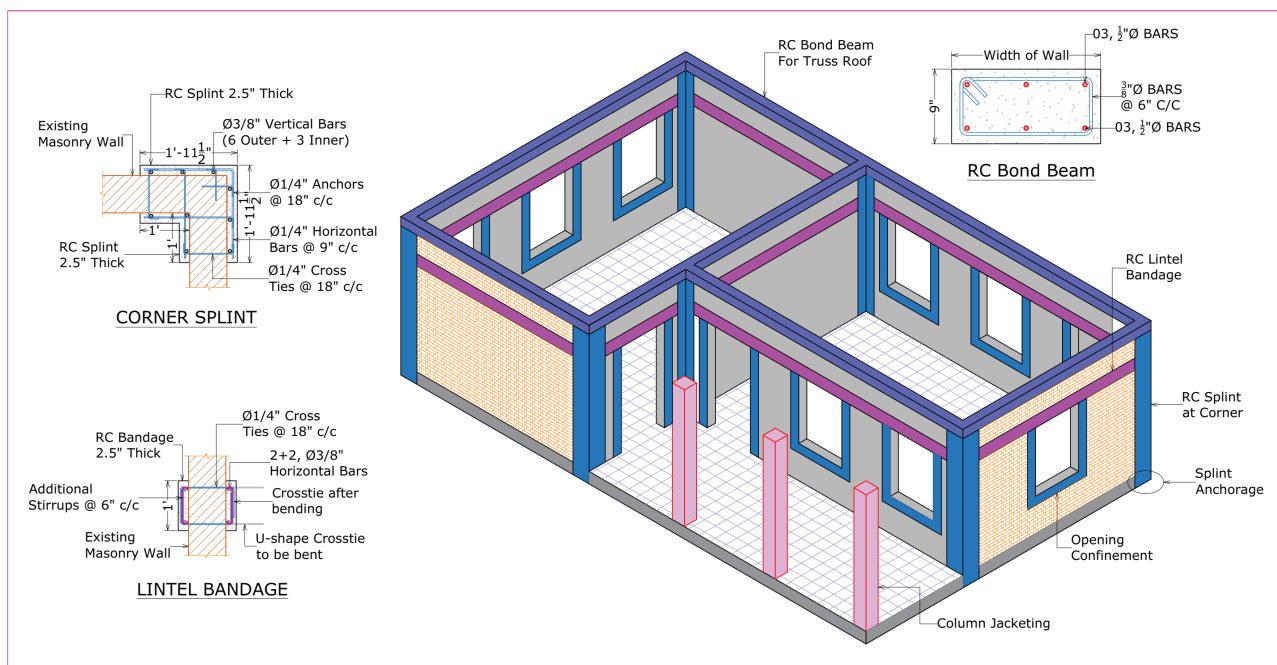


Figure 4: Image showing various retrofitting elements for a brick masonry building with light metal roof

6.2 Core retrofitting principles

The seismic retrofitting strategy for unreinforced masonry (URM) school buildings is framed around a Life Safety performance objective, consistent with observed earthquake damage patterns in low-rise masonry structures. The retrofit proposals are consistent with what can be reasonably achieved given the capacity of the existing buildings and the available technical and financial resources. The primary intent was to reduce the likelihood of global and local collapse during strong ground shaking by promoting stable, predictable structural behaviour.

Retrofitting interventions focus on establishing effective box action (Figure 5) through improved connectivity between walls, floors, and roof diaphragms [(Bothara & Brzev, 2011), (Arya, Boen, & Ishiyama, 2013)]. Past earthquake observations indicated that poor wall-to-diaphragm connections and lack of diaphragm restraint are primary contributors to out-of-plane wall failures and partial collapse in URM buildings. Strengthening these connections enables redistribution of seismic actions through multiple load paths, reducing reliance on individual walls and mitigating out-of-plane failure mechanisms.

Seismic evaluation, repair and strengthening of masonry buildings - guidelines

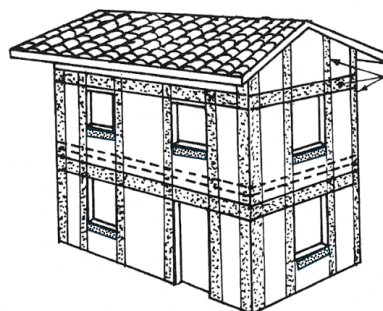


Figure 5: Developing “box effect” (source (BIS, 1993))

A holistic retrofit philosophy is adopted, guided by a ‘make no worse’ and ‘fix the most vulnerable elements first’ principles, whereby individual measures are evaluated in terms of their influence on overall structural

response. Interventions are selected to avoid introducing adverse load paths, stiffness irregularities, or brittle local mechanisms, while incrementally improving global integrity. This approach supports balanced seismic behaviour and reduces the risk of unintended performance degradation.

The retrofitting framework is based on a limited number of fundamental seismic principles: (i) provision of continuous load paths; (ii) enhancement of global integrity through seismic bands and positive connections; (iii) stabilisation of out-of-plane wall behaviour; and (iv) avoidance of brittle or poorly detailed local failure mechanisms. Consistent with these principles, the preferred retrofit measures adopt “splint-and-bandage” techniques to develop box action. The measure is supplemented by local wall strengthening, such as ferrocement overlays, where increased in-plane shear capacity is required. Typical interventions include plinth, sill, lintel, and roof bands; wall stitching; and improved wall-to-roof connections, selected based on demonstrated effectiveness, constructability, and compatibility with prevailing construction practice.

Seismic forces on the building structure and its components were estimated in accordance with the Building Code of Pakistan 2021 (PEC, 2021). For existing buildings, BCP 2021 defines the most credible earthquake (MCE) as having a 5% probability of exceedance in 50 years, corresponding to a 975-year return period. The design-level earthquake is taken as two-thirds of the MCE, which is equivalent to a 20% probability of exceedance in 50 years, or a return period of approximately 225 years.

7 LOGISTICAL CHALLENGES, ACCESS AND COORDINATION

Field experience from large-scale seismic retrofitting programmes demonstrates that logistical constraints often govern project performance to a degree equal to, and sometimes greater than, technical design considerations. In remote and socially complex settings, inadequate logistics planning frequently results in programme delays, cost escalation, compromised workmanship, and disruption to school operations. These constraints informed the structure of the guideline itself, not just its implementation, leading to logistics and coordination being treated as integral components of seismic risk reduction rather than ancillary construction management tasks.

A significant proportion of schools in Khyber Pakhtunkhwa are located in remote or semi-remote areas with limited connectivity. Access is frequently reliant on single, narrow, or unpaved routes, and in some cases, there is no motorable access. These routes are highly vulnerable to seasonal disruption from monsoon rainfall, flooding, landslides, snow, and erosion, leading to temporary or prolonged site isolation. Long haul distances from urban supply centres further increase transport time, fuel consumption, vehicle wear, and overall delivery costs. In response, the guideline emphasises advance route surveys, identification of alternative access paths, and seasonally informed logistics planning to maintain continuity of works.

Material supply chains present additional challenges, particularly for bulk construction materials and damage-sensitive items such as cement, steel reinforcement, and building services components. Extended transportation over rough terrain increases the risk of material loss and deterioration, while constrained school sites often limit secure on-site storage and increase exposure to weather damage and theft. The guideline therefore promotes phased delivery, temporary storage arrangements, local buffer depots where feasible, and selective use of locally available materials to reduce reliance on long-distance supply chains.

Logistical constraints also affect equipment mobilisation and operation. Narrow access roads, regulatory restrictions, and limited manoeuvring space can restrict the movement and deployment of construction plant. Fuel supply disruptions in remote areas pose a critical risk to generators, equipment, and site vehicles, with the potential to halt works entirely. To mitigate these risks, the guideline recommends advance permitting, staged mobilisation, use of locally sourced equipment where practicable, and provision of on-site fuel reserves with appropriate safety controls.

Workforce mobilisation and retention represent a further constraint. Remote project locations commonly face shortages of skilled labour, high mobilisation costs, and elevated turnover associated with harsh climatic conditions, limited accommodation, and social isolation. Reliance solely on externally mobilised labour unfamiliar with local conditions can reduce productivity and increase rework. The guideline therefore promotes a hybrid workforce strategy, combining trained local labour with externally mobilised skilled trades, supported by site-specific induction, safety training, and culturally informed supervision.

Socio-cultural, regulatory, and security factors further complicate coordination. Privacy requirements in girls' schools necessitate careful scheduling and segregation of work areas, while approval delays, environmental sensitivities, and occasional political or community interference can disrupt planned sequences. Early and continuous engagement with education authorities, local administrations, and communities is therefore emphasised as a risk mitigation measure.

To address these interconnected constraints, the guideline advocates a cluster-based implementation approach (Figure 6), grouping schools within defined geographic areas for coordinated execution, where feasible. Clustering enables shared mobilisation of labour, equipment, fuel, and supervision, reduces repeated transport cycles, and improves logistical efficiency. It also strengthens oversight and site security while allowing flexible sequencing in response to weather, access, and regulatory constraints. By embedding logistics planning, coordination, and community engagement within the retrofit framework, the guideline ensures that technically robust seismic interventions remain implementable, resilient to disruption, and scalable across remote and resource-constrained settings.

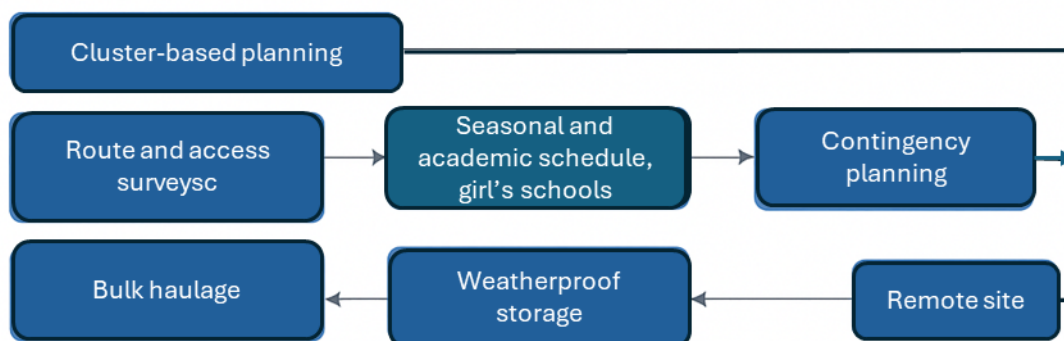


Figure 6: Cluster-based planning and establishing supply chain for construction materials

8 WORKFORCE AND TRAINING

The first-hand experience from the field indicates that a skilled and safety-aware workforce is critical for achieving consistent quality and effective seismic risk reduction in school retrofitting programmes, particularly in remote and access-constrained areas. Accordingly, the guideline treats workforce training not as a preparatory activity but as a quality assurance and risk control measure integral to retrofit programme. Training programmes for engineers, technicians, and tradespeople are therefore designed to reduce variability in workmanship, minimise construction-related errors, and ensure that critical seismic details are implemented as intended.

Recognising different learning needs and leaning methods of engineers and tradespeople, tailored role-based training has been devised. Accordingly, engineers and technicians receive short theoretical briefings combined with hands-on field exercises to strengthen practical judgement and constructability understanding. Training for tradespeople is deliberately hands-on and delivered under close supervision, with learning based on active participation in constructing and retrofitting wall mock-ups. This approach helps build confidence, consistency, and familiarity with tools, sequencing, and retrofit details.

The effectiveness of training is assessed through demonstrated competence rather than attendance alone. Tradespeople are required to complete supervised retrofit tasks to an acceptable standard before deployment on active school sites. Instruction should be delivered in local languages and should focus on correct tool use, sequencing, and safety practices, thereby reducing rework, improving consistency, and lowering the risk of workmanship-related seismic vulnerabilities during implementation.

9 DISCUSSION

This work demonstrates that large-scale seismic retrofitting of unreinforced masonry school buildings is achievable when engineering principles are translated into delivery-oriented, field-ready guidance. Although the retrofit measures adopted are intentionally simplified and focused on life safety, experience from Pakistan shows that such interventions can substantially reduce collapse risk when applied consistently at programme scale. In this context, effectiveness is defined not by full code compliance but by reliable and repeatable risk reduction.

A key insight from the programme is that seismic safety in existing school buildings is governed as much by implementation realities as by analytical design. Constraints related to access, material supply, workforce capacity, institutional processes, and socio-cultural conditions often determine whether technically sound solutions can be delivered. Treating these factors as secondary construction management issues risks undermining engineering intent. By embedding logistics, coordination, and constructability considerations within the retrofit framework, the guideline reframes seismic retrofitting as an integrated engineering and delivery problem.

The typology-based, pre-engineered approach demonstrates the value of standardisation in resource-constrained environments. Reducing reliance on building-specific design improves efficiency, supports training and supervision, and enhances quality control across dispersed sites, while allowing engineers to focus on dominant failure mechanisms. The principles presented are transferable to other seismic regions with similar constraints and offer a pragmatic pathway for meaningful seismic risk reduction.

10 CONCLUSIONS

This paper has presented the principles underpinning a field-oriented guideline for the seismic retrofitting of typical unreinforced masonry school buildings in Pakistan. By formalising practice-based knowledge into clear assessment, design, and implementation principles, the guideline supports consistent and scalable seismic risk reduction in resource- and access-constrained contexts. The approach offers a pragmatic pathway for improving school safety where technical capacity, funding, and logistical reach are limited.

Looking ahead, the institutional adoption of the guideline by education authorities and implementing agencies has the potential to embed seismic risk reduction within routine school infrastructure programmes, enabling systematic, policy-aligned improvements to school safety beyond individual donor-funded projects.

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