Expected Damage Grade Assessment of Existing Residential Buildings in the Kathmandu Valley: A Field-Based Study

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Abstract

Nepal lies in one of the most seismically active regions of the Himalayan belt, and the building stock of the Kathmandu Valley is dominated by reinforced-concrete (RC) frame and unreinforced masonry constructions of varying engineering quality. This paper presents the outcomes of a structured seismic vulnerability assessment carried out on fifty-two (52) existing residential buildings located in the Kathmandu Valley. The assessment was performed in a tiered manner, beginning with Rapid Visual Screening (RVS) and Rapid Visual Assessment (RVA), and progressing to a Detailed Assessment (DA) where the screening findings indicated significant deficiency. The methodology adopted is consistent with the Department of Urban Development and Building Construction (DUDBC) Seismic Vulnerability Evaluation Guideline [1] and the Seismic Retrofitting Guidelines of Buildings in Nepal [2], supplemented with provisions of NBC 105:2025 [3] and FEMA 310 [6]. The expected damage grade was evaluated against the maximum-credible Modified Mercalli / EMS-98 intensity of XII assumed for the Kathmandu Valley as the worst-case design scenario. For each building, construction year, number of stories, structural typology, column / wall sections, beam sections, observed damages, and dominant vulnerability factors were recorded, and an expected damage grade (DG1 - DG5, after EMS-98 [7]) was assigned. Of the 52 building units whose damage grades could be conclusively determined, 71.2 % were classified as DG4, 21.2 % as DG3, 5.7 % as DG5, and 1.9 % as DG2; no DG1 cases were identified. Non-engineered RCC frames and unreinforced / older masonry buildings concentrate the highest grades, while engineered RCC frames built after 2010 generally cluster at DG3. The findings demonstrate that the existing residential building stock of the valley still carries a significant seismic risk despite post-2015 awareness, and that strengthening of beam-column joints, columns and unreinforced masonry walls is the dominant retrofit need.

Keywords: seismic vulnerability, rapid visual assessment, detailed assessment, expected damage grade, EMS-98, Modified Mercalli intensity XII, reinforced concrete, unreinforced masonry, Kathmandu Valley, retrofitting

1. Introduction

Nepal sits at the convergence of the Indian and Eurasian tectonic plates, a setting that has historically produced severe seismic events in and around the Kathmandu Valley. The 1934 Bihar-Nepal earthquake

(M 8.0) and the more recent 2015 Gorkha earthquake (Mw 7.8) reaffirmed that the residential building stock of the valley is largely deficient in lateral-load resisting capacity [8]. Damage statistics following the 2015 event suggested that more than 600,000 residential buildings collapsed and an additional 280,000 were partially damaged across the affected districts [8], [13]. The Kathmandu Valley itself, despite being relatively distant from the rupture, exhibited concentrated damage owing to soft sediment site amplification and the presence of older, non-engineered constructions [9], [11].

In response, the Department of Urban Development and Building Construction (DUDBC) issued the Seismic Vulnerability Evaluation Guideline for Private and Public Buildings [1] and the Seismic Retrofitting Guidelines of Buildings in Nepal [2], and the Nepal National Building Code was further revised through NBC 105:2025 [3]. NBC 205:2024 [4] continues to provide the mandatory rules of thumb for low-rise reinforced-concrete residential buildings in Nepal. Despite the regulatory framework, a significant proportion of pre-code and non-engineered residential buildings remain in service, and the valley continues to grow vertically through informal additions on existing buildings without commensurate strengthening [10], [13].

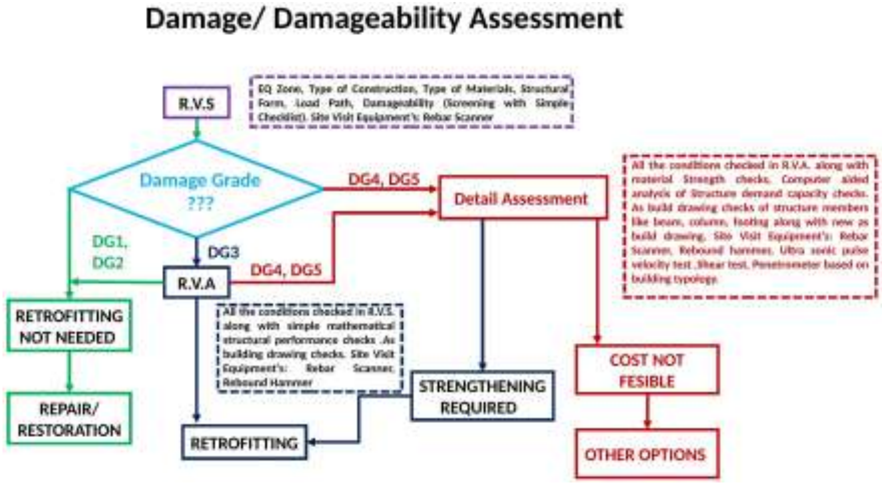
This study presents a structured field-based seismic vulnerability assessment of fifty-two (52) residential buildings distributed across the Kathmandu Valley. The work is part of a program aimed at quantifying expected seismic performance through visible vulnerability factors, geometric measurements and selected non-destructive tests, and at recommending appropriate intervention - retrofitting, repair, or detailed evaluation. The assessment was conducted using the tiered methodology of Rapid Visual Screening [5], Rapid Visual Assessment and Detailed Assessment [6], and the expected damage grade was reported in line with the European Macroseismic Scale, EMS-98 (DG1 - DG5) [7]. The expected damage grade for each building was assigned for a worst-case shaking scenario of Modified Mercalli / EMS-98 intensity XII, which represents the maximum credible intensity for the Kathmandu Valley taking into account historical Himalayan-front events [8], [13] and the strong amplification expected at soft-sediment sites within the valley.

The objective of this paper is therefore three-fold: (i) to summarize the methodology adopted for the field assessment of residential buildings in the valley; (ii) to present the consolidated findings on construction year, number of stories, structural typology, member sizes and observed damages of fifty-two (52) residential buildings; and (iii) to derive the expected damage grade distribution of these buildings and discuss its implications for retrofitting policy.

2. Methodology

A tiered seismic assessment approach was adopted, consistent with the DUDBC Seismic Vulnerability Evaluation Guideline [1] and the Seismic Retrofitting Guidelines of Buildings in Nepal [2], and supplemented by FEMA 154 [5] and FEMA 310 [6] for screening and evaluation, respectively. The flow of evaluation - Rapid Visual Screening (RVS), Rapid Visual Assessment (RVA), Detailed Assessment (DA) and recommendation - is summarized in Figure 1.

Figure 1. Tiered Damage / Damageability Assessment Workflow



2.1 Rapid Visual Screening (RVS)

Rapid Visual Screening was undertaken from the exterior to capture seismic zone, type of construction, materials, structural form, load path and damageability. The procedure follows the FEMA 154 [5] 'sidewalk' approach adapted to the Kathmandu Valley typology. A simple checklist of vulnerability indicators was filled, with a rebar scanner used to confirm reinforcement presence in selected members. Buildings classified as DG1 or DG2 at this stage were generally judged not to require structural retrofitting [1].

2.2 Rapid Visual Assessment (RVA)

Buildings flagged as DG3 at RVS, and buildings whose visible deficiencies warranted further inspection, were taken up for Rapid Visual Assessment. RVA included all the conditions checked under RVS along with simple mathematical structural performance checks (axial check on columns, span / depth check on beams, drift check based on story heights as per NBC 105:2025 [3]), as-built drawing checks, and a closer inspection of beam-column joints, infill walls and openings. Equipment included a rebar scanner and a Schmidt rebound hammer for in-situ concrete strength estimation [2], [12].

2.3 Detailed Assessment (DA)

Buildings classified as DG4 or DG5, or buildings exhibiting major damage at the RVA stage, were carried into a Detailed Assessment [6]. Detailed Assessment encompassed all conditions checked at RVA together with material strength checks, computer-aided structural analysis (linear static and pushover analyses where applicable) and demand-capacity checks of beams, columns, footings, and shear walls. As-built drawings of structural members were prepared, supplemented with new 'as-built-verified' drawings produced from site surveys. The instrumentation deployed included rebar scanner, rebound hammer, ultrasonic pulse velocity (UPV), shear test and penetrometer tests, selected based on building typology [2].

2.4 As-Built Information and Vulnerability Factors

For every building, the following descriptors were collected: construction year, number of stories (including stair-cover and basement), building typology, plinth area, plan and vertical configuration, position with respect to adjacent blocks, column / wall sections, beam sections, slab depth and foundation size where accessible, building condition (cracks, deterioration), wall on cantilever, floor / roof type and special remarks. Vulnerability factors related to building system, lateral-force-resisting system, connections and diaphragms were evaluated using checklists derived from FEMA 310 [6] and IS 13935 [12], and each non-compliant statement triggered further investigation.

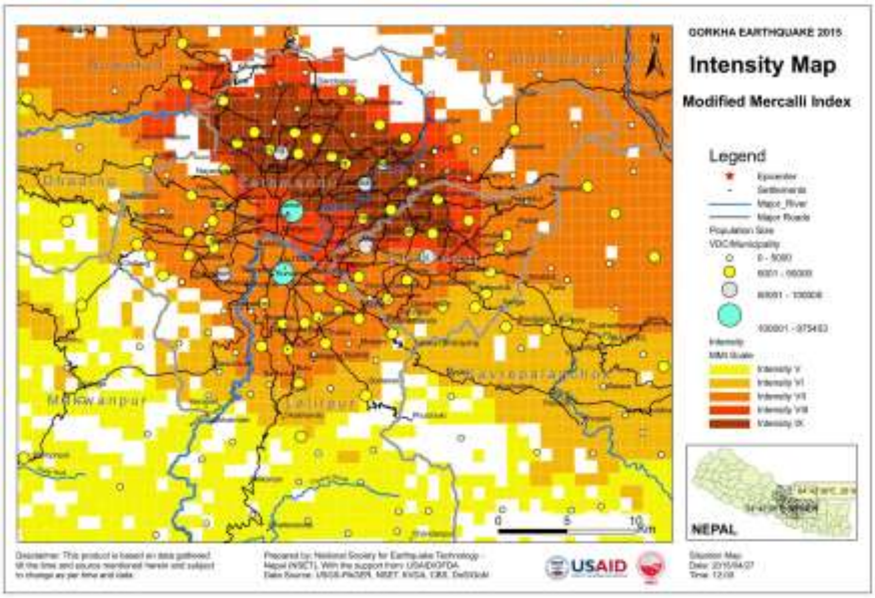
2.5 Damage Grade Assignment

The expected damage grade was assigned for each building on the EMS-98 [7] five-point scale (DG1 - DG5). The grade was assigned based on the consolidated outcome of RVS, RVA and DA: cracks, member sizes versus demand, drift estimates, capacity-demand ratios, configuration irregularities and quality of detailing. DG1 represents negligible to slight damage, DG2 moderate, DG3 substantial-to-heavy, DG4 very heavy, and DG5 destruction [7]. Recommendations of 'safe condition', 'detailed seismic evaluation' or 'not safe (retrofit)' followed the assigned damage grade in accordance with [1] and [2].

2.6 Reference Seismic Intensity

In the EMS-98 framework, the damage grade attained by a building of a given vulnerability class is a direct function of the intensity of shaking experienced at the site [7]. For the present study, the probable damage grade of each building was therefore evaluated for a reference shaking scenario representative of the worst-case credible intensity expected in the Kathmandu Valley. The Modified Mercalli (MMI) and EMS-98 scales are both 12-degree intensity scales, with intensity XII corresponding to total destruction. Historical Himalayan-front events such as the 1934 Bihar - Nepal earthquake and the 2015 Gorkha earthquake (Mw 7.8) reached MMI VIII - IX in different parts of the valley [8], [13]; however, considering the seismic gap along the central Himalayan front, the soft-sediment amplification of the valley basin, and the consequence-class of residential occupancy, the assessment was carried out for a worst-case design intensity of XII on the MMI / EMS-98 scale. Figure 2 shows, for reference, the recorded MMI distribution from the 2015 Gorkha event over the Kathmandu Valley and surrounding districts.

Figure 2. Modified Mercalli Intensity (MMI) Distribution Recorded for the 2015 Gorkha Earthquake. Source: NSET / USAID-OFDA Based on USGS-PAGER and KVDA Data



In the present assessment, the buildings were evaluated as if they were subjected to MMI / EMS-98 intensity XII, which constitutes a conservative bound on the expected damage. The damage grades reported in this paper therefore represent the upper-bound expected performance of each building under a maximum-credible-intensity scenario for the Kathmandu Valley.

3. Sample Description

A total of fifty-two (52) residential buildings were field-assessed across multiple wards of the Kathmandu Valley. The buildings are described in this paper through six non-identifying descriptors only: construction year, number of stories, structural typology, principal column / wall and beam section sizes, observed damage and assigned damage grade. Several of the surveyed sites were compound developments containing multiple structural units; in total, 52 individual structural units yielded conclusive damage-grade classifications and form the basis of the statistics reported here.

The buildings span a construction range from 1970 A.D. to 2022 A.D., with the majority constructed between 2000 and 2015. Three-story constructions were the most frequent (about 41 % of the sample), followed by two-story and basement+two configurations. A small number of mid-rise apartments (5 - 7 stories) were also included. Figure 3 summarizes the typology distribution and Figure 4 the story distribution of the sample.

Figure 3. Distribution by Structural Typology

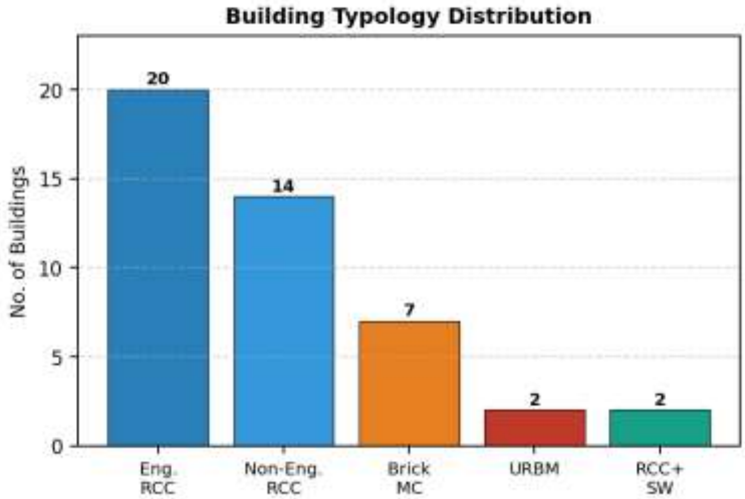
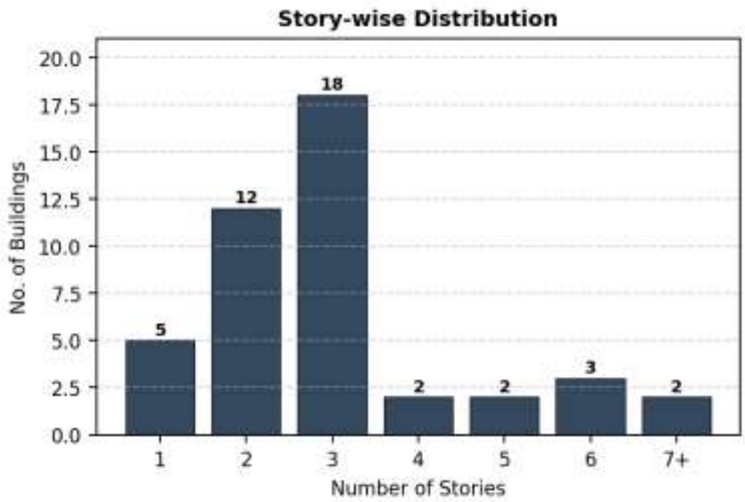


Figure 4. Storey-Wise Distribution of the Assessed Buildings



Engineered RCC frames dominate the post-2010 portion of the sample, while non-engineered RCC and unreinforced / cement-mortar brick masonry constructions are typically pre-2005 buildings. Recorded column sizes range from 230 mm x 230 mm in older non-engineered constructions to 550 mm x 550 mm in apartments, and beam depths range from 230 mm x 350 mm to 300 mm x 500 mm. Wall thicknesses for masonry constructions vary between 230 mm and 450 mm. The full set of typological descriptors was used as the basis of the structural performance evaluation discussed in the next section.

4. Results: Expected Damage Grade

The principal result of the study is the expected damage grade assigned to each building under the assumed reference intensity (MMI / EMS-98 XII). Figure 5 presents the overall distribution as a pie chart and a bar chart, while Table 1 tabulates the counts and percentages.

Figure 5. Expected Damage Grade Distribution of the Assessed Buildings

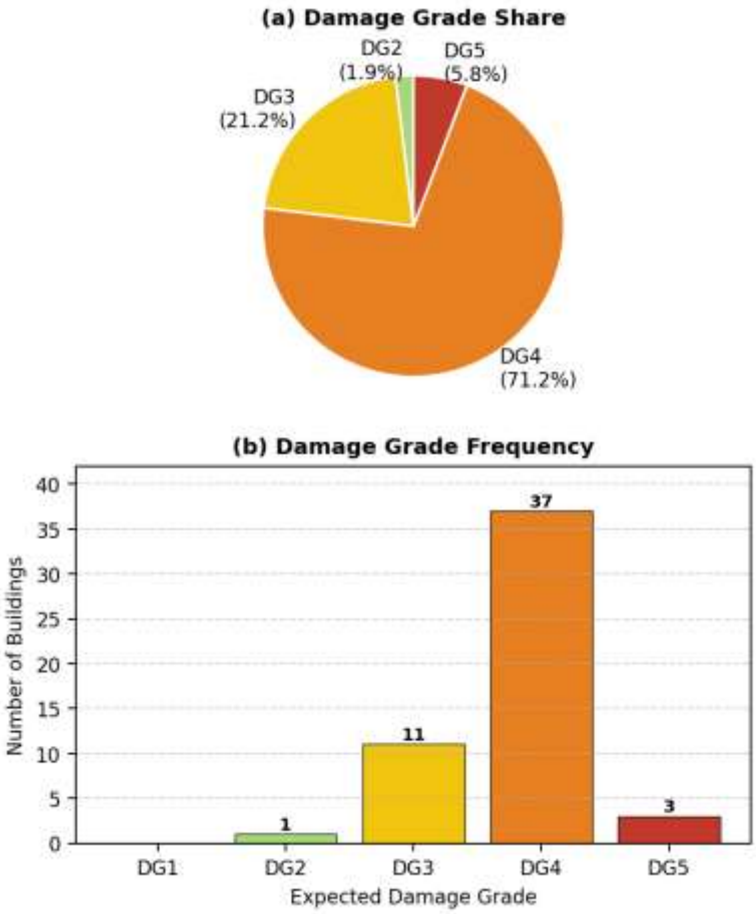


Table 1. Damage Grade Distribution

Damage Grade	Description (EMS-98)	Count	Share
DG1	Negligible / slight - hairline cracks	0	0.0 %
DG2	Moderate - cracks; partial fall of plaster	1	1.9 %
DG3	Substantial to heavy - large cracks	11	21.2 %
DG4	Very heavy - serious wall failure	37	71.2 %
DG5	Destruction - total / near-total collapse	3	5.7 %

Total		52	100 %

Out of fifty-two (52) buildings for which a conclusive damage grade could be assigned at MMI / EMS-98 intensity XII, the largest fraction - 71.2 % - falls in DG4 (very heavy structural damage). 21.2 % fall in DG3 (substantial-to-heavy damage), 5.7 % in DG5 (destruction) and only 1.9 % in DG2. No building of the sample qualified as DG1. This skewed distribution towards DG4 indicates that, even though almost all the buildings are still in service, their estimated performance under maximum-credible shaking is well below the life-safety target prescribed by NBC 105:2025 [3] and EMS-98 [7].

4.1 Influence of Structural Typology

Figure 6 disaggregates the damage grade by typology. All DG5 cases originate from un-reinforced or cement-mortar brick masonry buildings within the older compound-type construction. Non-engineered RCC frames overwhelmingly fall in DG4, whereas engineered RCC frames are roughly evenly split between DG3 and DG4, with a clear shift towards DG3 for buildings constructed after 2015 and detailed in line with NBC 105:2025 [3].

Figure 6. Damage Grade by Structural Typology (at MMI XII)

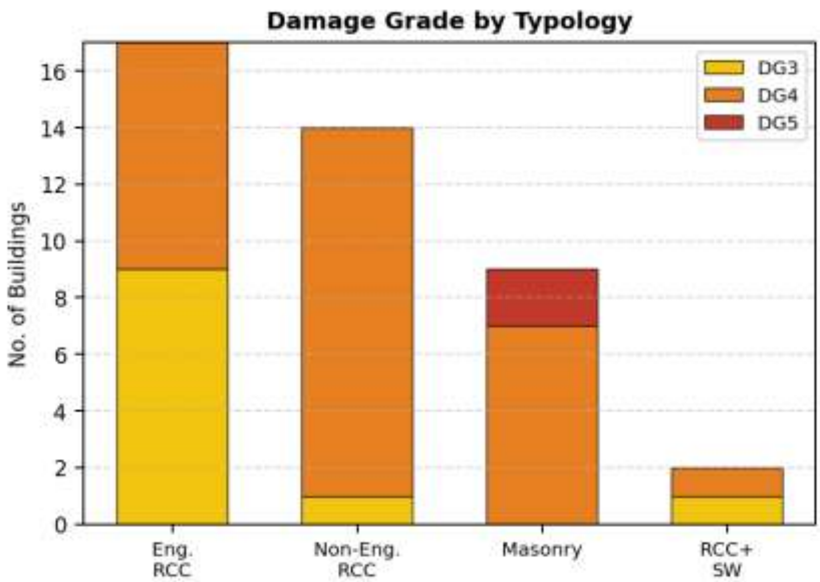


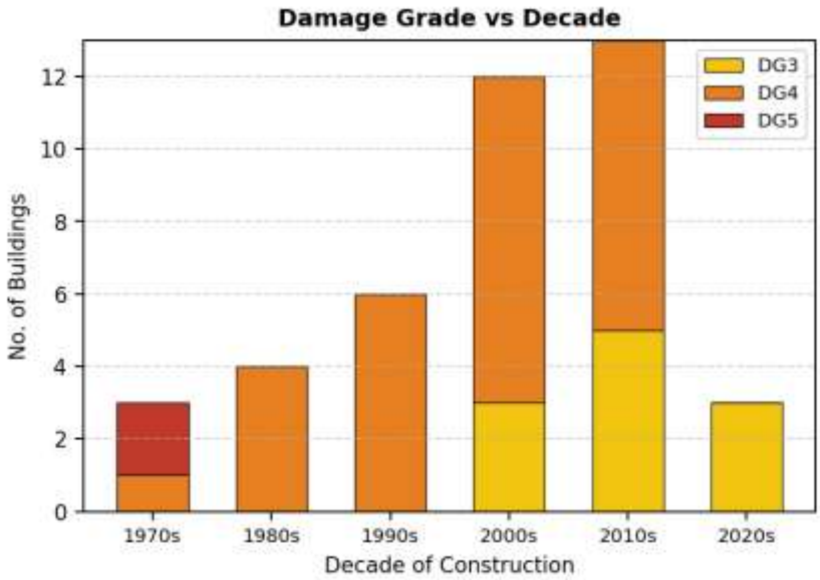
Table 2. Typology vs. Damage Grade Cross-Tabulation

Typology	DG2	DG3	DG4	DG5	Total
Engineered RCC	0	9	8	0	17
Non-Engineered RCC	0	1	13	0	14
Brick / Stone Masonry	0	0	7	2	9
RCC w/ Shear Walls	0	1	1	0	2
Compound (typ. N.A.)	1	0	8	1	10
Total	1	11	37	3	52

4.2 Influence of Construction Period

Figure 7 plots damage grade against decade of construction. DG5 outcomes are concentrated in the 1970s and earlier masonry constructions; DG4 outcomes dominate the 1980s - 2000s constructions; DG3 outcomes start to appear from the 2000s and become the dominant grade for the 2020s sub-sample (all DG3, no DG4). This trend is consistent with the progressive improvement of the Nepali building code, the adoption of NBC 205:2024 (Mandatory Rules of Thumb) for RC residential buildings [4], and improved supervision practice in the Kathmandu Valley municipalities [10].

Figure 7. Damage Grade vs. Decade of Construction (at MMI XII)



4.3 Dominant Vulnerability Factors

Across the sample, the most frequently recorded high-vulnerability factors were the following: (i) 'strong-column / weak-beam' violation in non-engineered RCC frames; (ii) flexural deficiency in columns and shear deficiency in beams arising from inadequate sectional dimensions and tie / stirrup spacing; (iii) short-column effects induced by partial-height infill walls and staircase landings; (iv) lack of vertical and horizontal seismic bands in masonry buildings; (v) plan and vertical irregularities producing torsion and soft-story behavior; and (vi) inadequate diaphragm continuity due to floor offsets and large openings [3], [6], [12]. Soil-related concerns - in particular liquefaction susceptibility and limited slope stability at boundary edges - were noted as medium-vulnerability factors in several locations across the valley [11].

4.4 Observed Physical Damages

Visible damages recorded during the survey ranged from hairline cracks at infill - frame interfaces to significant masonry fall-out, partial wall collapses and pounding marks between adjacent blocks. Settlement-induced cracks were noted in a number of ground-floor levels of older buildings. The pattern of physical damage observed closely tracked the assigned expected damage grade, supporting the consistency of the assessment.

4.5 Recommended Interventions

Following the assigned damage grade, recommendations were issued for each building. Buildings classified DG2 / DG3 with adequate detailing were marked 'Safe Condition' subject to repair of non-structural damage. Buildings classified DG4 / DG5 were marked 'Not Safe - Retrofit'; the most frequently recommended retrofit measures were column jacketing, beam FRP wrapping [14], splint-and-bandage retrofit for unreinforced masonry, addition of confined-masonry elements, and external shear-wall additions [2]. A subset of the DG4 buildings, where retrofit cost was deemed disproportionate to value, was flagged for 'other options' - relocation, dismantling and reconstruction, or change of use.

5. Discussion

The damage-grade distribution observed in this study, dominated by DG4, is broadly consistent with the post-2015 reconnaissance observations of valley residential buildings reported by Goda et al. [8] and the National Society for Earthquake Technology - Nepal (NSET) [9]. Two principal trends emerge from the present sample. First, the structural typology and the period of construction are the strongest predictors of expected performance: pre-1990 unreinforced masonry buildings concentrate the worst outcomes (DG5), while post-2015 engineered RCC frames concentrate the best outcomes (DG3 and a few DG2). Comparable trends were reported by Chaulagain et al. [11] and by Bhandari and Pradhan [13]. Second, even within the engineered RCC frame group, deficiencies in beam-column joint detailing and stirrup spacing degrade the expected performance from the design intent [3], [4].

The retrofit strategies recommended in this study are consistent with the DUDBC Seismic Retrofitting Guidelines [2]. For DG4 RCC buildings, jacketing of weak columns (RC or steel) and FRP wrapping of beams [14] remain the most widely applicable measures. For unreinforced masonry buildings, splint-and-bandage retrofit using ferro-cement strips or RC bandages, combined with corner-stitching, offers a practical and cost-effective intervention [2], [12]. Where the building is heavily damaged or geometrically irregular, the addition of new shear walls or confined-masonry retrofit elements provides the most reliable improvement of lateral capacity.

It is also important to note the limitations of the current sample: the buildings were predominantly residential, the geographic spread, while across the valley, was not stratified by ward, and the assessment relied on field measurement rather than full structural drawings. These limitations notwithstanding, the consistency of the dominant vulnerability factors observed across the sample suggests that the qualitative findings can be reasonably extrapolated to the wider stock of pre-2015 residential buildings of the valley [13].

6. Conclusions

This paper has presented the methodology and findings of a structured field-based seismic vulnerability assessment of fifty-two (52) residential buildings located in the Kathmandu Valley. The principal conclusions are summarized below.

1. A tiered RVS -> RVA -> Detailed Assessment framework, consistent with DUDBC [1], [2] and FEMA [5], [6] guidelines, is effective for screening and prioritizing existing residential buildings of the Kathmandu Valley.
2. The expected damage grade was evaluated for a worst-case shaking scenario of MMI / EMS-98 [7] intensity XII, taken as the maximum credible intensity for the Kathmandu Valley.
3. Of the buildings whose damage grade could be conclusively assigned, 71.2 % were rated DG4, 21.2 % DG3, 5.7 % DG5 and 1.9 % DG2. No DG1 case was found.
4. Structural typology and construction period are the dominant predictors of expected damage. Non-engineered RCC and unreinforced / cement-mortar masonry constructions concentrate the highest grades.

5. Recurring high-vulnerability factors include strong-column-weak-beam, beam shear deficiency, short-column effects, missing seismic bands in masonry, and plan / vertical irregularities.
6. Recommended retrofit measures are dominated by column and beam jacketing, FRP wrapping [14], splint-and-bandage of masonry, and addition of confined-masonry / shear-wall elements [2].
7. The findings reinforce the urgency of implementing systematic retrofit programs for pre-NBC-105:2025 [3] residential buildings of the Kathmandu Valley, ahead of the next major seismic event.

Further work is required to expand the sample size, stratify the survey by municipal ward, integrate the field findings into a probabilistic seismic-risk model for the valley, and to track post-retrofit performance through follow-up monitoring.

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