SEISMIC VULNERABILITY ASSESSMENT OF RESIDENTIAL BUILDINGS IN SRI LANKA

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Abstract

Although Sri Lanka is generally considered to be in a low-seismicity region, historical records and recent hazard studies indicate that potentially damaging earthquakes may occur, while non-engineered masonry housing may remain vulnerable to such loading. This study assessed typical single-storey residential buildings using ETABS-based numerical modelling and qualitative reduced-scale prototype testing. Three representative models were analysed as masonry-only and with concrete columns, beams and lintels. Equivalent static and response spectrum analyses were used to evaluate base shear, roof drift and shell-stress concentrations, while theoretical time histories were used for shaking-table testing. The masonry-only model, Model 02(A), showed the highest drift and lowest stiffness, with critical stresses around openings, corners and wall junctions. Concrete elements reduced the X- and Y-direction roof drifts of the model by 90.1 percent and 84.8 percent, respectively. Rammed earth (RE) prototype testing also showed lower wall-top displacement after improvement. The findings demonstrate that building layout, wall connectivity and opening arrangement strongly influence seismic response and that appropriate concrete elements can improve the behaviour of typical masonry houses.

Keywords: Unreinforced masonry, Numerical analysis, Rammed earth prototype testing, Shaking table testing

1. Introduction

Sri Lanka is located away from major active plate boundaries and is generally classified as a low-seismicity country. Nevertheless, historical earthquake records [1] and probabilistic hazard studies [3] indicate that potentially damaging ground shaking may occur. This is important for low-rise masonry housing, where common deficiencies include unreinforced openings, weak wall connections, poor mortar joints and missing tie elements [2]. This study evaluates the influence of building layout, wall continuity, openings and structural detailing on seismic response by comparing masonry-only and concrete-improved numerical models supported by reduced-scale prototype testing.

2. Methodology

2.1 Identification of Construction Practices and Model Selection

The methodology reviewed previous studies and field observations to identify typical Sri Lankan residential construction practices and common deficiencies [2]. Three single-storey layouts were selected as shown in Figure 1: Model 01 as a compact reference model, Model 02 as a realistic four-bedroom house, and Model 03 as a smaller two-bedroom layout suitable for prototype testing.

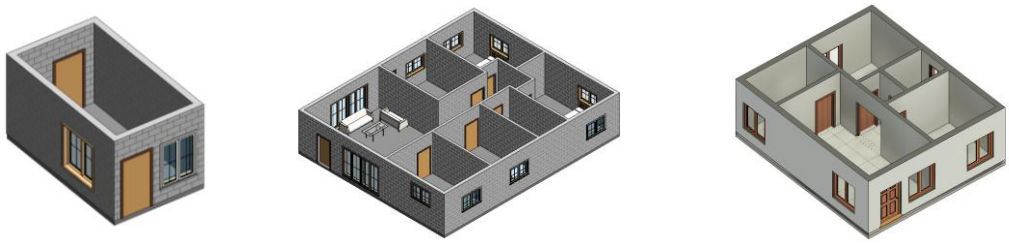


Figure 1: Representative residential building models: Model 01, Model 02, Model 03.

2.2 Numerical Analysis

Each layout was modelled in ETABS as Series A, representing masonry-only construction, and Series B, incorporating concrete elements. Load-bearing walls were idealised using shell elements. Modal, equivalent static and response spectrum analyses were performed in both principal directions using Sri Lanka's seismic conditions based on Eurocode 8, IS 1893 and previous Sri Lankan studies [3]. Fundamental period, base shear, roof drift, stiffness and shell stresses were evaluated. The roof structure was not explicitly modelled; therefore, its contributions to mass distribution, diaphragm action and lateral stiffness were not represented.

2.3 Experimental Analysis

Two 1:10 scale RE models were used to compare masonry-only and concrete-improved configurations [4]. The specimens were anchored to a shaking table and instrumented at the table base, model base, front-wall top and window region. Theoretical acceleration time histories from 0.02 g to 0.50 g were applied for 60 s in one horizontal direction. As no visible cracking occurred, the experiment was interpreted qualitatively rather than as a prediction of full-scale behaviour.



a) Model A b) Model B

Figure 2: Prepared physical models for shaking table analysis.

3. Results and Discussion

The results were interpreted using limiting stresses of 1.5 MPa in compression and 0.1 MPa in tension and shear [5]. As masonry and RE are weak in tension, shell-stress contours were used to identify critical regions around openings, corners and wall junctions. Model behaviour was compared using period, base shear, roof drift, stiffness and stress distribution.

- Compression $\sigma_c \leq 1.5\,MPa$, Tension $\sigma_t \leq 0.1\,MPa$, Shear $\tau_{allow} \leq 0.1\,MPa$ ($\approx 0.065\sigma_c = 0.0975\,MPa$)

3.1 Numerical Analysis Results

Shell-stress contours consistently identified openings, narrow wall segments, wall junctions, external corners and unsupported upper panels as critical regions. In realistic layouts, interaction between internal walls and adjacent openings altered force transfer and stress

distribution; therefore, simplified rectangular models did not fully represent the behaviour of typical houses.

Table 1: Percentage change from masonry-only model to concrete-element model.

Model	Δ Period	FZ change	EQx shear	EQy shear	Δ X drift	Δ Y drift
Model 01	-2.4%	-2.6%	+4.1%	+5.2%	+0.0%	+0.0%
Model 02	-68.5%	+81.3%	+75.1%	+127.2%	-90.1%	-84.8%
Model 03	-1.6%	+15.7%	+8.7%	+6.4%	-19.7%	-25.9%

The addition of concrete columns, beams and lintels generally increased lateral stiffness and reduced roof drift, with the magnitude of improvement depending on wall layout and opening configuration. Changes in base shear were associated with increased mass and stiffness. Overall, the improved models showed better deformation control and load-transfer behaviour.

3.2 Experimental Analysis Results

The reduced-scale investigation compared masonry-only Model 01(A) with concrete-improved Model 01(B). The highest response occurred at the front-wall top and near the window opening, while Model 01(B) showed a lower displacement response. No visible cracking occurred and dominant-frequency changes were small; therefore, the experiment provides qualitative evidence of improved deformation control rather than full-scale damage behaviour.

4. Conclusions

Typical Sri Lankan masonry houses may be vulnerable to seismic loading because of unreinforced openings, weak wall connections, poor mortar joints and missing tie elements. Numerical results showed that wall layout, opening arrangement and internal-wall connectivity strongly influence stiffness, drift, load transfer and stress concentration. Concrete columns, beams and lintels generally improved structural continuity and reduced lateral deformation. Shaking table testing also showed a lower displacement response in the improved model, although no visible cracking occurred. The findings highlight the importance of representative building layouts, strengthened openings, improved wall connections and continuous tie elements for safer residential construction in Sri Lanka.

References

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SEISMIC VULNERABILITY ASSESSMENT OF RESIDENTIAL BUILDING IN SRI LANKA

Numerical and Reduced-Scale Prototype Analysis

KEY FINDINGS

Building layout, openings and wall connectivity strongly influenced seismic response. Concrete columns, beams and lintels improved structural continuity, increased stiffness and reduced lateral deformation. Reduced-scale testing also showed lower displacement after improvement, supporting the numerical findings.

1. MOTIVATION

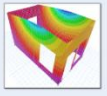


Sri Lanka low-rise masonry houses often have unreinforced openings, weak connections, poor mortar joints and missing tie elements, leading to high vulnerability.[1,2]

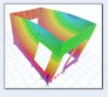
2. METHODOLOGY

Model Development in ETABS

Series A Masonary-only



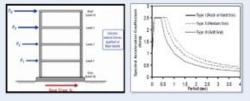
Series B With Concrete Elements



Three single-storey layouts:
Model 01 (reference). Model 02 (4-bedroom), Model 03 (2-bedroom).[3]

Numerical Analysis

Equivalent Static **Response Spectrum**



Outputs: Period, Base shear, Roof drift, Stiffness, Shell-stress distribution.[4]

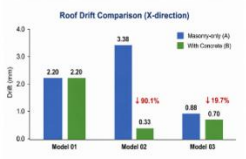
Reduced Scale Prototype (1:10 Scale)



Model 01 **Model 03**

Shaking table testing with theoretical acceleration time histories (0.02g - 0.05g).[4]

3. KEY RESULTS



Period Reduction
Model 01: -30%
Model 02: -68%
Model 03: -2%

Stiffness Reduction
Model 01: +4.1%
Model 02: +81.3%
Model 03: +15.7%

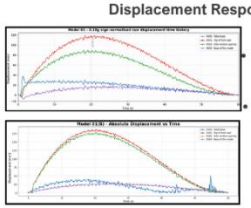
4. EXPERIMENTAL RESPONSE (SHAKING TABLE)

Shaking Table Configuration



R201 shaking table; model fixed with four bolts; excitation in one horizontal direction.[4]

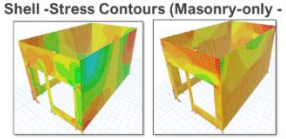
Displacement Response



- Wall-top displacement reduced.
- No visible cracking observed.[5]

4. NUMERICAL ANALYSIS

Shell -Stress Contours (Masonry-only - Model 01)



High stress concentration occur around openings, corners, wall junctions and unsupported wall regions.[4]

- Wall layout, openings and connections strongly influence seismic behavior.
- concrete columns, beams and lintels greatly improve stiffness and reduce lateral deformation.
- Prototype tests confirm lower displacement after strengthening; results are qualitative rather than full-scale.
- Findings support preliminary vulnerability assessment and practical construction guidance for safer housing in Sri Lanka

5. CONCLUSION