BTP Report

Earthquake Vulnerability Prediction for URM Buildings

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1 Introduction

India experiences frequent moderate to severe earthquakes, particularly in the Himalayan belt, Kashmir, Himachal Pradesh, Uttarakhand, and the North-East. A large proportion of the building stock consists of unreinforced masonry (URM) houses, many of which are single-storey constructions with poor connections, large openings, and no seismic detailing.

URM buildings exhibit brittle behaviour and are especially vulnerable to *out-of-plane* failure of walls. These failures occur even during moderate shaking and are responsible for a significant portion of casualties and structural collapse in Indian earthquakes.

This project develops an automated pipeline that extracts the geometry of a URM facade from an image, computes its collapse (critical) acceleration, and extends this to a full-building estimate using inter-wall and roof connectivity factors.

2 Equivalent Frame Idealisation for URM Walls

URM facades with openings are idealised using the standard **Equivalent Frame Model** (EFM), where the wall is decomposed into:

- **Piers**: vertical compression-dominated masonry strips between openings.
- **Spandrels**: horizontal masonry bands above openings.

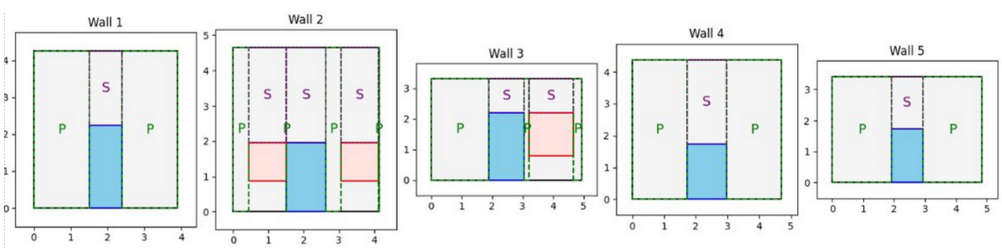

Figure 1: Equivalent Frame Representation of Piers and Spandrels

The collapse mechanism is governed by the weaker component, with failure occurring either through:

- Pier rocking,
- Spandrel rocking, or
- A coupled mechanism.

3 Critical Acceleration Formulation

The onset of rocking for a masonry unit occurs when seismic overturning moment exceeds restoring gravitational moment.

3.1 Pier Rocking Acceleration

For a pier of height h and thickness t, the critical acceleration is:

$$a_{\text{cr,pier}} = \frac{3g}{4h\sin\theta},$$

where θ is the rocking rotation given by:

$$\theta = \arctan\left(\frac{b}{h}\right),$$

and b is the effective base length.

The governing pier acceleration is:

$$a_{\text{cr,pier}} = \min\left(a_{\text{cr,pier,left}},\ a_{\text{cr,pier,right}}\right).$$

3.2 Spandrel Rocking Acceleration

For a spandrel of horizontal length L_{sp} and vertical depth h_{sp}:

$$a_{\text{cr,sp}} = \frac{h_{sp}^2}{2h^2}.$$

3.3 System-Level Acceleration

The simplified system-level collapse acceleration is:

$$a_{\text{cr,sys}} = \frac{t}{h} + \frac{L_{sp}^2}{4h^2}.$$

The final governing wall acceleration is:

$$a_{\text{cr}} = \min\left(a_{\text{cr,pier}},\ a_{\text{cr,sp}},\ a_{\text{cr,sys}}\right).$$

4 Image-Based Geometry Extraction Pipeline

Given a facade image, the goal is to extract:

- Wall height H, width W
- Number, positions and sizes of doors and windows
- Pier widths and spandrel depths

We use a classical computer vision pipeline.

4.1 Step 1: Image to Outline

- Convert image to grayscale
- Apply Gaussian blur
- Extract edges using Canny detector
- Detect external contours

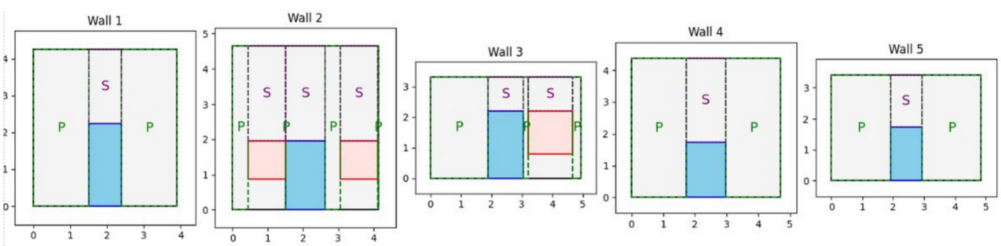

Figure 2: Extracted Outline from Input Image

4.2 Step 2: Outline to Geometric Measurements

- Thresholding + morphological closing
- Contour extraction for openings
- Classification into doors and windows by height
- Computation of:

$$b_{\text{pier}},\ h_{\text{sp}},\ \text{door width},\ \text{window width/height}$$

These measurements are passed to the analytical formulas to compute a_{cr}.

5 Dataset Generation and Typologies

To model variability in real buildings, we generate a large synthetic dataset:

- Different numbers of doors (0–20)
- Different numbers of windows (0–20)
- Randomised dimensions within realistic ranges

Each unique combination of (number of doors, number of windows) forms a **typology**. Within each typology, many configurations are generated to compute fragility curves.

6 Fragility Curve Construction

For a typology, suppose the critical accelerations from N configurations are:

$$k_1,\, k_2,\, \ldots,\, k_N.$$

The empirical probability of failure at acceleration x is:

$$F(x) = \frac{1}{N} \sum_{i=1}^{N} \mathbf{1}(k_i \leq x).$$

This produces a step function.
To obtain a smooth fragility curve, we fit a **logistic model**:

$$F(x) \approx \frac{1}{1 + e^{-a(x-b)}}.$$

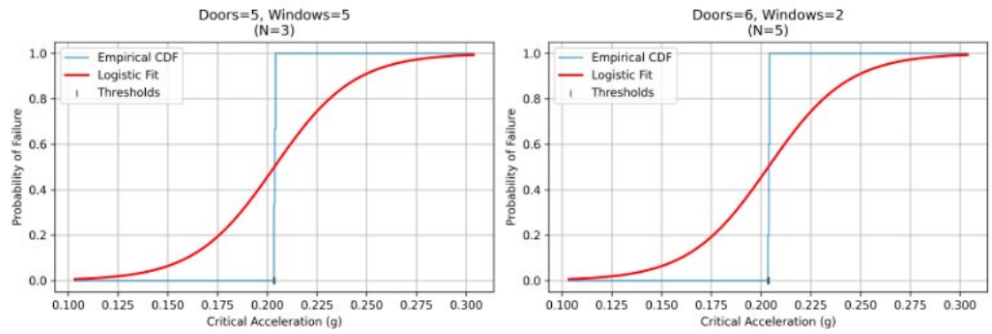

Figure 3: Example Logistic Fragility Curve

The logistic method produced stable, realistic S-shaped curves.

7 Building-Level Critical Acceleration

We extend from single facades to a full building with four walls.

7.1 Step 1: Wall-Level Acceleration

For each wall:

$$a_{\text{cr},i} = \text{AnalyticalCriticalAcceleration}(\text{Wall}_i)$$

7.2 Step 2: Wall Connection Factors

Walls connected through better junctions resist out-of-plane collapse more effectively.

$$\text{factor} = \begin{cases} 0.7 & \text{no connection} \\ 1.0 & \text{normal} \\ 1.2 & \text{interlocked} \end{cases}$$

Adjusted accelerations:

$$a'_{\text{cr},i} = a_{\text{cr},i} \times \text{factor}.$$

7.3 Step 3: Roof Aspect Ratio Factor

Let roof lengths be L_x, L_y and the ratio:

$$r = \frac{L_x}{L_y}.$$

The roof factor is:

$$\text{roof factor} = \begin{cases} 1.1 & r \leq 2 \\ 0.9 & r > 2 \end{cases}$$

7.4 Step 4: Building-Level Collapse Acceleration

The weakest (minimum) wall governs:

$$a_{\text{cr,building}} = \left(\min_i a'_{\text{cr},i} \right) \times \text{roof factor}.$$

8 Website Demonstration

The final system was deployed as a web interface where the user can:

- Upload images of the four walls
- Enter wall-connection types
- Enter roof dimensions
- Receive the final building-level critical acceleration

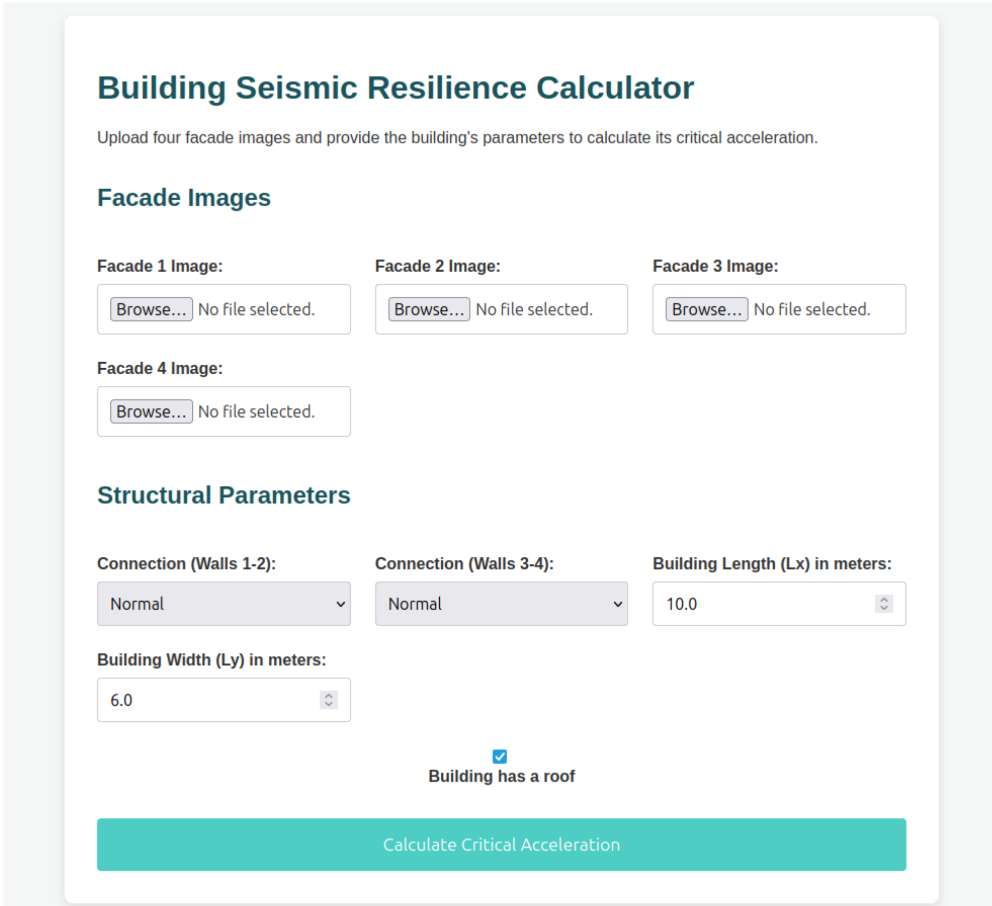

Figure 4: Website Interface

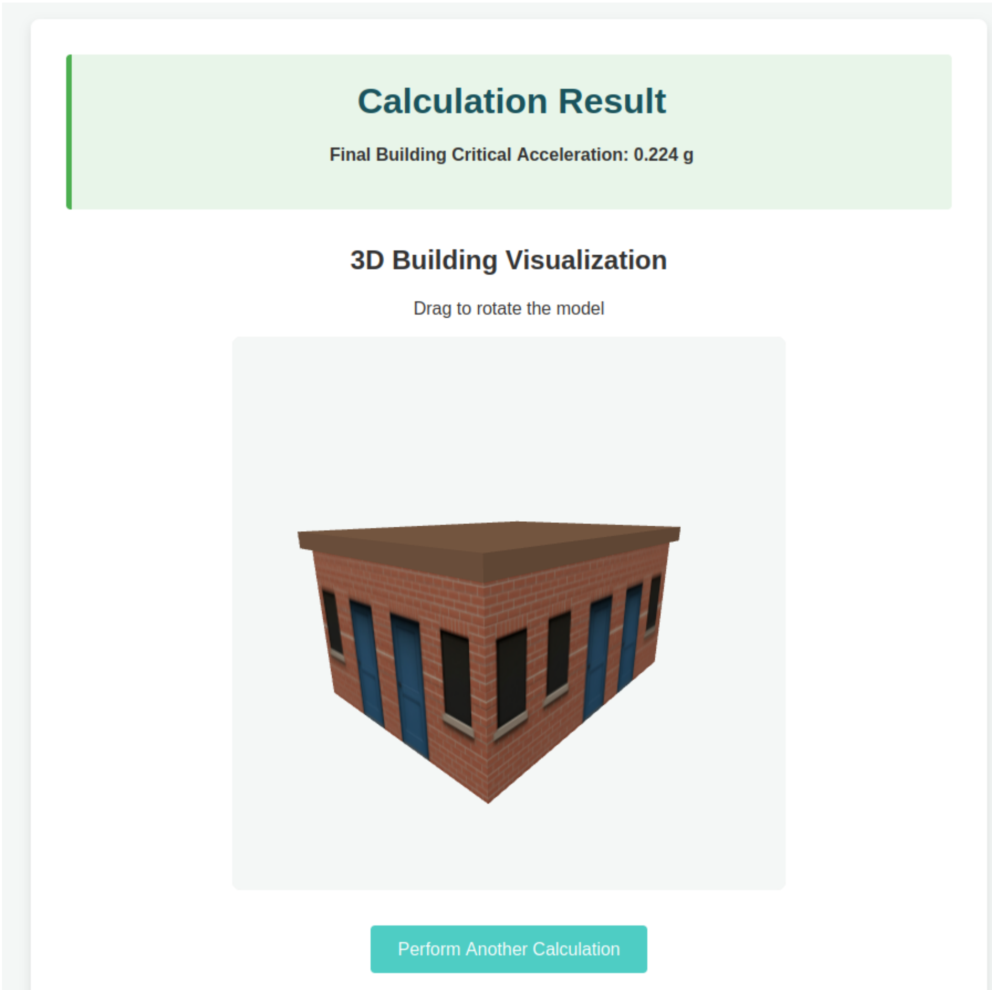

Figure 5: Building-Level Output Page

9 Novelty

- Existing literature handles only simple facades with a single door; we generalise to complex multi-opening configurations.
- Fully automated image-to-geometry pipeline using classical CV and analytical modelling.
- Logistic fragility curve fitting for arbitrary typologies.
- First end-to-end system for building-level out-of-plane collapse acceleration using only facade images.

- Robust incorporation of wall connectivity and roof effects into the final collapse estimate.

10 Future Work

- Extend the analytical model to multi-storey URM and more complex topologies.
- Include in-plane shear and bending failure mechanisms.
- Use calibrated geometric priors for better measurement extraction.
- Explore more accurate joint modelling of piers and spandrels.
- Introduce wall slenderness effects and partial diaphragm connections.

11 Conclusion

This project presents a complete automated system for estimating collapse acceleration of URM buildings using only facade images. The pipeline integrates image processing, analytical structural modelling, typology-based variation, fragility analysis, and building-level combination rules.

The methodology is fast, interpretable, and suitable for rapid seismic vulnerability assessment of Indian URM buildings.