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Rapid Seismic Capacity Evaluation Method of RC Buildings with Masonry Infill

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Seismic evaluation RC building
Masonry infill Column and Wall index

1. Introduction:

Past earthquake damages in developing countries have been exhibiting that the importance of adequate seismic evaluation and strengthening of existing buildings. These developing countries usually have masonry infilled-RC buildings, where the infill contributes to stiffness and strength of the RC frame.

This paper presents a seismic capacity evaluation method using the concept of Shiga Map (1), focusing on the cross-sectional areas of masonry infills and columns in existing RC damaged buildings, based on the past earthquake databases. The applicability of these parameters for seismic capacity evaluation is verified, and the boundary lines determining expected damage states are provided. Finally, this approach is applied to investigate the seismic vulnerability of several existing buildings in Bangladesh, according to their seismic demand.

2. Characteristics of damaged buildings:

The earthquake damage data, for existing masonry infilled-RC buildings, are collected from Turkey, Ecuador and Nepal earthquake damage databases, from the references (2), (3) and (4). Figure 1 shows the numbers of buildings and stories investigated in each country where most of the buildings are from 2 to 4 storied. Figure 2 shows the ratio of infill areas at 1st story to the total floor areas above 1st story, defined as the wall index (A_w/A_f), and the ratio of column areas at 1st story to the total floor areas above 1st story, defined as the column index (A_c/A_f). The wall and the column index are ranged from 0 to 2.0% and 0 to 1.5%, respectively. The masonry wall thickness are 100 mm and 230 mm commonly made by burnt clayed.

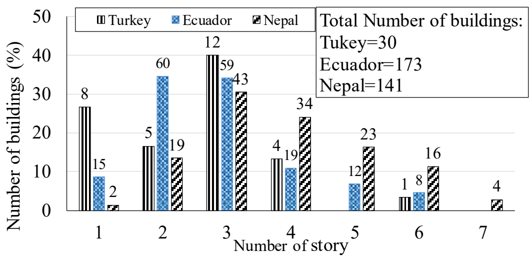
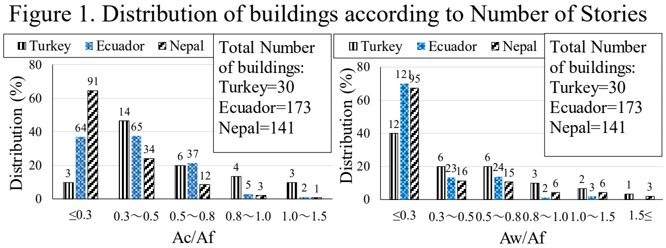


Figure 1. Distribution of buildings according to Number of Stories



(a) Column Index (A_c/A_f) (b) Wall Index (A_w/A_f)

Figure 2. Distribution (%): (a) Column Index and (b) Wall Index

The Definition of each damage state in the databases are summarized in Table 1 from the references (2), (3) and (4).

Table 1: Definition of Damages states

Damage state	Turkey	Ecuador	Nepal
Light	Fine flexural cracks	Hairline flexural cracks	Hairline flexural cracks
Moderate	Reinforcement buckled near joint	Wider cracks, concrete spalling	Wider cracks, concrete spalling
Severe	Structural failure of Individual elements	At least one element has failed.	At least one element has failed.

3. Properties of ground motions:

Acceleration response spectra of ground motions in the investigated countries are shown in Figure 3 from the references (5) and (6).

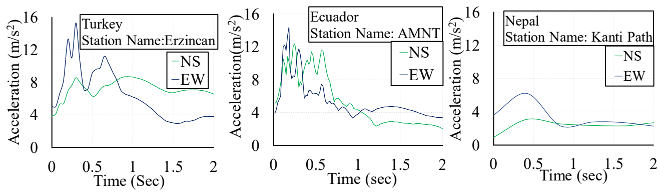


Figure 3. Acceleration Response Spectra of Different Earthquakes

4. Damage evaluation:

The seismic capacity is calculated with column and wall strength, which is product of the average shear stress and cross sectional areas of columns and walls, as shown left side in Eq. (1) which is based on Shiga Map (1). The seismic demand which is the product of the total building weight (W), the response acceleration (C_a) and the reduction factor (D_s) considering the building ductility in Eq. (1).

Seismic Capacity ≥Seismic Demand

$$\tau_c.A_c + \tau_w.A_w \geq W.C_a.D_s \qquad \text{Eq. (1)}$$

Where τ_c and τ_w are the shear strength of columns and walls.

For τ_w, ASCE seismic guideline (7) estimated 34 psi (0.24 Mpa) for good masonry condition. In this paper, therefore, τ_w is considered 0.2MPa for conservative estimation. The average shear stress for columns is roughly assumed 1.0MPa. For the calculation of seismic demand, the average weight per unit area (W/A_f) is approximately set 11kN/m^2 according to common design practice. From Figure 3, C_a is roughly estimated for buildings with short period (less than 0.5s), are 0.9g, 0.9g and 0.6g for Turkey, Ecuador and Nepal, respectively. Reduction factor (D_s) of 1.0 for elastic range and that of 0.6 for inelastic range (7) are set to provide boundaries for defining damages areas. Dividing both side of Eq. (1) by A_f, which is the area of total floor above 1st story, Eq. (2) is obtained.

$$\tau_c.A_c/A_f + \tau_w.A_w/A_f \geq W/A_f.C_a.D_s \qquad \text{Eq (2)}$$

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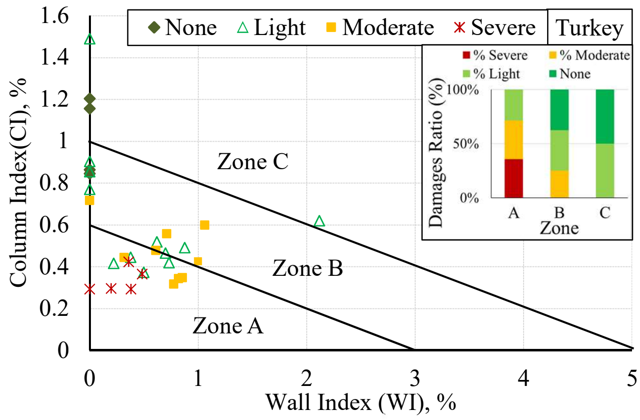
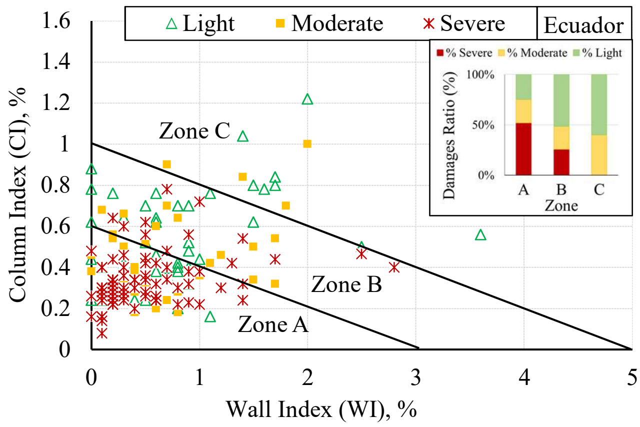
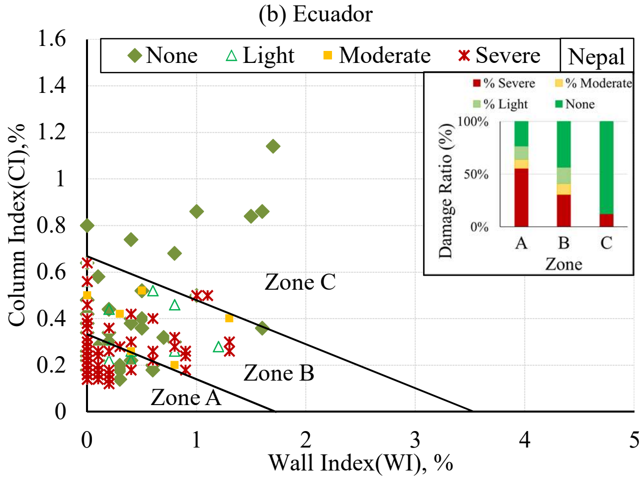
Figure 4 shows the damage ratio with capacity and different zones according to severity in different earthquake. Buildings in zone A are considered the most vulnerable and expected to have severe damage. Buildings in zone C are considered to have enough seismic capacity to avoid severe damage. The boundaries of each earthquake show good agreement with damage ratio and damage states in Turkey and Ecuador. As for Nepal, it provides fair agreement with damage states. However, the column strength $\tau_c = 1MPa$ might be not conservative enough for Nepal and need further investigation. This method is considered to be applicable for the rapid screening of vulnerability in existing building.



(a) Turkey



(b) Ecuador



(c) Nepal

Figure 4. Comparison of damaged buildings with CI and WI

5. Application to Bangladesh buildings:

In Bangladesh, the response acceleration (C_a), for typical soft soil category D, is 0.46g according to the design response spectrum of Bangladesh National Building Code (BNBC) (8) as shown in Figure 5. The corresponding seismic demand using in Eq.1, for the ground motion in BNBC (8), are 0.5 and 0.3 for the upper and lower boundaries, respectively. Figure 6 is the proposed evaluation map with boundaries for different damages zones. Several existing buildings in Bangladesh were evaluated to investigate their seismic vulnerability. Based on this approach, it seems that almost half the buildings like to have severe damage and have the higher priority for further detailed investigation.

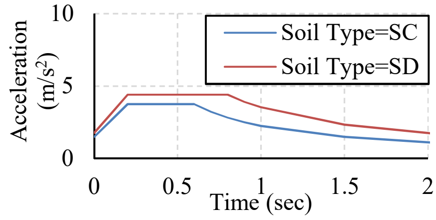


Figure 5. Design Response Spectra in BNBC 2015

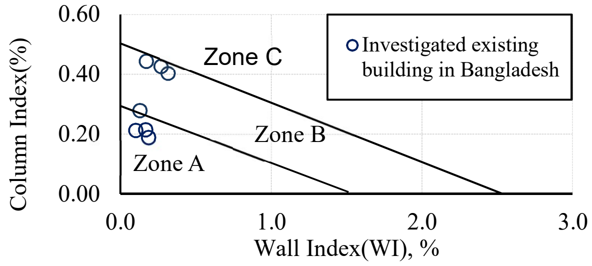


Figure 6. Proposed evaluation map for Bangladesh

6. Conclusions:

1. It is shown that Column Index (CI) and Wall Index(WI) showed good agreement with the damage state of existing building, based on past earthquake databases.
2. Column and Wall Indices were used to investigate several existing buildings in Bangladesh. This study shows about half of the building are in danger zone and likely to have severe damages based on the seismic demand of BNBC.
3. The proposed method was found to be a practical approach for screening vulnerable building with masonry infill. However, the boundaries to classify vulnerable building needs further investigations on actual materials strength.

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(8) Bangladesh National Building Code (BNBC), 2015.

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