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A Seismic Performance Evaluation Procedure of RC Frame Buildings Considering the In-plane and Out-of-Plane Performance of Masonry Infill Walls

Lateral resistance Nonlinear analysis Nonstructural element
Reinforced concrete Safety assessment Strut replacement

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1. Introduction

Masonry walls are widely used as infill in reinforced concrete (RC) frame buildings in many countries. However, they are susceptible to out-of-plane collapse, causing significant danger to life safety and altering the building performance. In contrast, there is still a lack of simple evaluation method that accounts for the out-of-plane collapse of the infills. Hence, this study proposes a simple evaluation method that estimates the out-of-plane collapse of the infill to suggest it to be strengthened and to evaluate the seismic performance considering the in-plane contribution confirming that no infill collapses. The method was applied to a typical RC frame building in Nepal with two alternative brick masonry infill wall thicknesses (full-brick thick and half-brick thick) following the common construction practices in the country. The proposed method contributes to the life safety and more accurate seismic performance evaluation of

the RC frame building with brick masonry infill walls.

2. Proposed Evaluation Method

The proposed evaluation method comprises non-simultaneous input seismic forces in two main directions of the building (longitudinal and transverse directions) to estimate the expected maximum floor acceleration to judge the out-of-plane collapse of the infills during the earthquake. **Figure 1** illustrates the overall flow of the proposed evaluation method. In Step 1 (Step 1' in the transverse direction), pushover analysis is performed in a 3D building model by applying the external force distribution proportional to the elastic fundamental mode shape of the building. In Step 2 (Step 2' in the transverse direction), based on the results obtained from the pushover analysis, a static performance curve in the form of a single degree of freedom system is obtained by using the method suggested by Kuramoto et al.^[1] on which a response point corresponding to the safety limit deformation of the building is set. The safety limit deformation is defined by the smallest drift at which one of the columns reached its deformability^[2]. Then in Step 3 (Step 3' in the transverse direction), a demand spectrum is evaluated by reducing the design spectrum by using the reduction factor (F_b)^[3]. The demand spectrum is amplified by a suitable factor (hereafter, amplification level(α)) in step 4 (Step 4' in the transverse direction) so that the resulting amplified spectrum intersects the capacity spectrum at the response point. Here, the higher the value of α , the better the seismic performance of the building. Step 5 evaluates the maximum demand acceleration ($|A_{max}|$) on each floor at the safety limit of the building that accounts for the effect of higher modes of vibrations based on the SRSS (Square Root of Sum of Squares) method^[4]. Step 6 is the key step that judges the out-of-plane collapse of the infill by comparing $|A_{max}|$ on each floor and the lateral resistance capacity (A_{cap}) of the infill which can be evaluated by using the method in the authors' past study^[5] in the focused direction. The strengthening of infills that are likely to collapse in the out-of-plane direction is suggested in Step 7 so that its capacity (A_{cap}) is higher than the demand $|A_{max}|$; thus, the reliable value of amplification level(α) can be obtained from Step 4 by considering the in-plane contribution of all the infills. The proposed evaluation method can also be used to evaluate the seismic performance of the building by removing the collapsed infills. However, the partial removal of infills during the earthquake may affect the seismic performance of the building

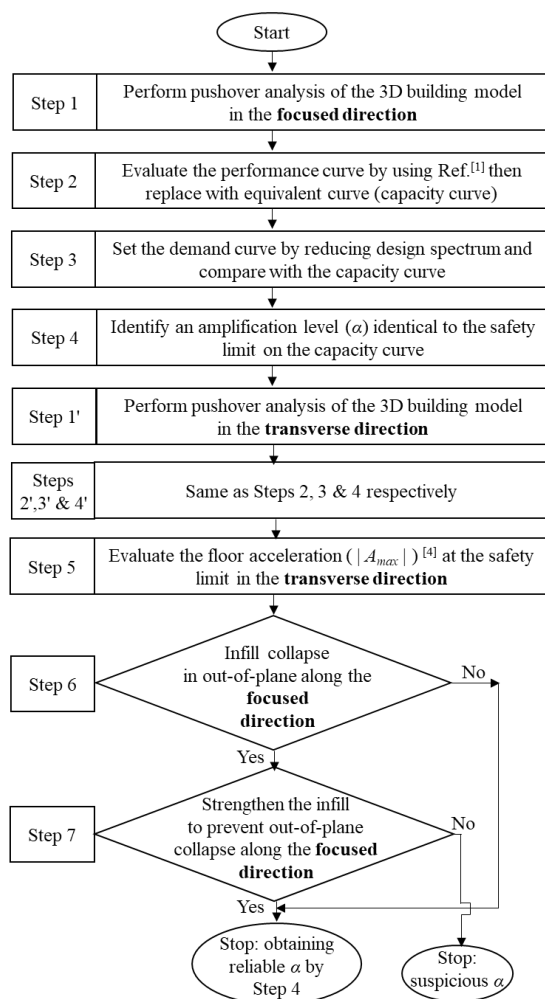


Fig. 1 Proposed seismic performance evaluation flow considering biaxial seismic forces

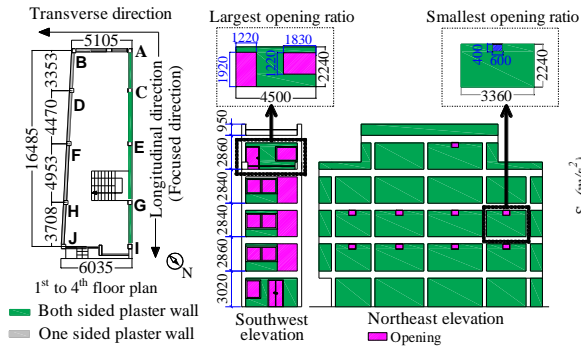


Fig. 2 Floor plans and elevations

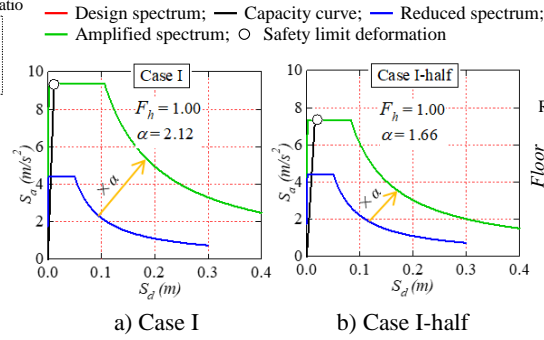


Fig. 3 Seismic performance of the building

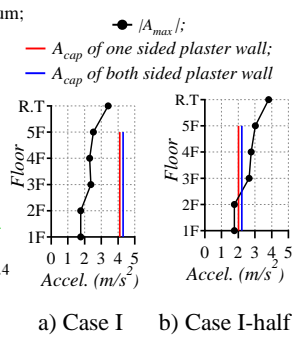


Fig. 4 $|A_{max}|$ vs A_{cap}

beyond the analytical results obtained within the current study; thus, a procedure with removing the collapsed infills is not presented herein.

3. Implementation of the Proposed Evaluation Method

The proposed evaluation method was implemented for a typical RC frame building in Nepal. Figure 2 shows the floor plans and the elevations of the building. The building has five stories superstructure and one underground structure. The detail of the building is described in the authors' past study^[2]. As shown in Fig.2, the opening ratios in the longitudinal and the transverse directions were less than 3% and more than 50%, respectively. Hence, only the infills in the longitudinal direction with limited opening were modelled based on the method suggested by Maidiawati and Sanada^[6] and the seismic performance is evaluated only in the longitudinal direction (hereafter focused direction). The infills in the transverse directions are neglected due to the higher opening ratio within this study. The proposed evaluation method in Section 2 was implemented for the building mainly to evaluate the seismic performance in the longitudinal direction. Figure 3a) represented by Case I (with full-brick thick) shows the evaluated value of α ($=2.12$) in the focused direction obtained through steps 1~4 in Fig. 1. The maximum floor acceleration of each floor was evaluated in Step 5 through steps 1' to 4' and the out-of-plane collapse of the infills in the focused direction was estimated in Step 6 by comparing $|A_{max}|$ and A_{cap} , as shown in Fig. 4a). It was judged that no infill collapsed in out-of-plane revealing that the evaluated value of α ($=2.12$) in Step 4 was reliable without any strengthening of the infills. It was due to the fact that full-brick thick infills were used in the building. However, half-brick thick masonry infills are also widely used in the country; thus, the proposed method was applied to the same building with half-brick thick infills (Case I-half). Figure 3b) shows the evaluated value of α ($=1.66$) in the focused direction obtained through steps 1~4. From the result of Step 6, it was revealed that the infills from 3rd~5th floor would collapse in the out-of-plane direction, as shown in Fig. 4b) indicating significant danger to

life safety. Since the infills collapsed in the out-of-plane direction, the evaluated value of α ($=1.66$) in Step 4 is not reliable unless measures are taken to prevent the collapse. Hence, the study suggests strengthening the infills (only for half-brick thick walls) from 3rd~5th floor for life safety, taking the reliable value of α ($=1.66$) from Step 4.

4. Summary

In this study, a simple evaluation method was proposed to estimate the out-of-plane collapse of the infills to evaluate the seismic performance of the building more accurately considering the in-plane contribution of infills that are not likely to collapse. The proposed method was applied to a typical RC frame building in Nepal. It was found that no infill collapsed in the out-of-plane direction with full-brick thick brick masonry walls. On the other hand, when a half-brick thick infill was considered, it was judged that the infills in the upper floors would collapse indicating significant danger to life safety. Hence, the study suggests strengthening the infills to prevent the out-of-plane collapse for life safety; thus, the seismic performance of the building evaluated under the proposed method considering the in-plane performance of infill walls becomes reliable.

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