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Seismic Performance of Soft-Storey RC Buildings with Masonry Infill Walls

Mr. Abhay Pratap Sharma

M.Tech. Scholar, Madhyanchal Professional University, Faculty of engineering & Technology, School of civil engineering Bhopal, M.P., India

Dr. Maroof Khan

** Associate Professor, Madhyanchal Professional University, Faculty of engineering & Technology, School of civil engineering Bhopal, M.P., India**

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Abstract

Reinforced concrete (RC) framed buildings with masonry infill are widely used in earthquake-prone regions; however, variations in the distribution of masonry infill and the presence of vertical irregularities can significantly alter their seismic behaviour. Although masonry infill walls are generally considered non-structural elements, they contribute substantially to the lateral stiffness, strength, energy dissipation, and overall dynamic response of RC frames. The sudden absence or reduction of infill at a particular storey can produce a soft-storey condition, resulting in concentration of lateral deformation, storey drift, shear forces, and damage at that level. This review examines the influence of vertical irregularities, including variations in storey height, stiffness, strength, column dimensions, and infill distribution, on the seismic response of RC frames. Previous numerical and experimental investigations using pushover analysis, response spectrum analysis, nonlinear dynamic analysis, and other analytical approaches are reviewed with respect to base shear, lateral displacement, inter-storey drift, stiffness, strength, energy dissipation, plastic hinge formation, and collapse vulnerability. The reviewed studies indicate that increasing masonry infill generally enhances lateral strength and stiffness and reduces displacement, whereas discontinuous or improperly distributed infill may generate severe stiffness irregularities and torsional effects. Soft-storey buildings, particularly those with open or weak ground floors, exhibit considerably higher seismic vulnerability than regular infilled frames. Strengthening techniques such as additional infill, bracing, and improved beam-column detailing can significantly enhance lateral resistance, stiffness, deformation capacity, and energy dissipation. Overall, the review emphasizes the need to consider the interaction between masonry infill and vertical irregularities during seismic assessment and design to achieve safer and more reliable RC frame structures.

Keywords: Reinforced concrete frames; Masonry infill; Vertical irregularity; Soft storey; Seismic response; Infill-frame interaction; Storey drift; Lateral stiffness; Pushover analysis; Seismic vulnerability.

Introduction

Reinforced concrete (RC) framed buildings are widely used in urban areas because of their strength, durability, flexibility in architectural planning, and ability to accommodate different functional requirements. In many RC buildings, masonry infill walls are provided within the structural frame to form partitions and external walls. Although these infill walls are generally considered non-structural elements in conventional design, they interact significantly with the surrounding RC frame during earthquake loading. Their presence can substantially influence the stiffness, strength, ductility, natural period, and overall seismic response of a building. Therefore, neglecting the structural contribution and interaction of masonry infill walls may lead to an inaccurate assessment of the actual seismic performance of RC buildings.

A particularly critical configuration is the soft-storey building, in which one storey, commonly the ground floor, has considerably lower lateral stiffness and strength than the storeys above. This condition frequently occurs in buildings where the ground floor is kept relatively open for parking, commercial activities, entrances, or other functional requirements, while masonry infill walls are present in the upper storeys. The sudden reduction in stiffness and strength at the open storey creates an irregular distribution of lateral resistance along the height of the building. During an earthquake, this irregularity can result in concentration of inter-storey drift and deformation at the soft storey, increasing the possibility of severe structural damage or even storey-level collapse.

Masonry infill walls can significantly modify the behaviour of RC frames under seismic actions. When subjected to lateral earthquake forces, an infill panel can develop diagonal compression and act approximately as a compression strut between the surrounding columns and beams. Consequently, the infill walls increase the lateral stiffness and strength of the frame and generally reduce lateral displacement. However, the interaction between the masonry infill and RC frame is complex and depends on several factors, including the geometry and aspect ratio of the panel, masonry strength, wall thickness, frame stiffness, openings in the infill, connection conditions, and material properties. Improper consideration of these effects may result in an unsafe or overly conservative evaluation of structural behaviour.

The seismic response becomes more critical when masonry infill walls are discontinuous along the building height. In a typical soft-storey configuration, the upper floors contain masonry infill while the ground floor remains largely open. The upper floors consequently possess greater lateral stiffness compared with the open ground floor. Under earthquake excitation, the increased stiffness of the infilled storeys may force a significant portion of the lateral deformation into the soft storey. This phenomenon can produce excessive inter-storey drift, increased column demands, plastic hinge formation, and potential failure of structural members at the soft storey. Hence, understanding the combined influence of soft-storey irregularity and masonry infill walls is essential for reliable seismic assessment and design.

Modern seismic design approaches emphasize the importance of considering structural irregularities and the interaction between structural and non-structural components. Indian standards such as **IS 1893** provide provisions for the seismic analysis and design of buildings, while **IS 456** and **IS 13920** provide requirements related to reinforced concrete design and ductile detailing. Masonry infill effects may also be represented in analytical models using equivalent diagonal strut approaches. Such modelling provides a practical means of incorporating the stiffness and strength contribution of masonry infill walls into the analysis of RC frames.

Seismic analysis methods such as equivalent static analysis, response spectrum analysis, and nonlinear analysis can be employed to evaluate the response of RC buildings under earthquake loading. Response Spectrum Analysis is particularly useful for assessing the dynamic response of multi-storey buildings by considering the modal characteristics of the structure. Parameters such as storey displacement, inter-storey drift, storey shear, overturning moment, and member forces can be evaluated to identify critical locations and assess the influence of soft-storey irregularity.

The present study therefore focuses on evaluating the seismic performance of soft-storey RC buildings with masonry infill walls. Analytical models representing different building configurations can be developed to investigate the effect of masonry infill on the structural response. The behaviour of fully infilled buildings can be compared with buildings having an open or partially infilled ground storey. The masonry walls may be represented using an equivalent diagonal strut model, while seismic analysis can be performed using Response Spectrum Analysis in accordance with relevant

Indian standards. The study aims to identify the changes in stiffness, displacement, inter-storey drift, base shear, and force distribution resulting from the presence and discontinuity of masonry infill walls.

The findings of such an investigation can provide useful insight into the vulnerability of soft-storey RC buildings and the importance of properly accounting for masonry infill during seismic assessment. A better understanding of the interaction between RC frames and masonry infill can contribute to improved structural modelling, safer seismic design, and more effective mitigation measures for buildings located in earthquake-prone regions.

Literature Review

Niroj Dahal et al (2025)unplanned residential construction in seismically active regions like Nepal frequently creates vulnerable Reinforced Concrete (RC) buildings with soft storeys—floors weaker or more flexible than others—which are susceptible to significant earthquake damage. Instead of resorting to oversized beams and columns, this study used nonlinear pushover analysis to show that strategically managing masonry infill wall density and soft-storey positioning significantly improves seismic safety, boosting base shear capacity and controlling drift while avoiding overly conservative structural designs. Key structural responses analyzed include base shear, performance points, deflection, storey drift, and hinge formation stages. The results reveal that increasing the quantity of infill masonry enhances performance points and base shear while reducing displacement. Storey drift ratios displayed sharp peaks at certain levels, followed by reductions. Capacity curves for frames with 25%, 50%, 75%, and 100% infill illustrated considerable variations in structural response. Fully infilled frames demonstrated higher base shear capacities but reduced roof displacements at the collapse stage compared to partially infilled frames. These findings underscore the critical role of infill masonry quantity and soft-storey positioning in seismic design. By addressing these factors, engineers can achieve a more effective balance between structural safety and design efficiency in reinforced concrete buildings.

Structural Modelling

The building is considered to be located in seismic zone IV and intended for residential use. The buildings were founded on medium strength soil through isolated footing beneath the columns. Response reduction factor for special moment resisting the frame has taken as 5.0 (assuming ductile detailing). The floor finish on the floors is taken as 1.0 kN/m^2. The live load on floor is taken 3.0 kN/m2and that on the roof to be 1.5 kN/m^2. In seismic weight calculations, 25 % of the floor live load is taken into consideration in the analysis.

For the study five different models of a six storey building is considered. With plan dimensions of 22.5 m × 14.4 m, a storey height of 3.5 m in all floors, and a foundation depth of 1.5 m, the building features five bays in the X direction and four bays in the Y direction. The building is kept symmetrical in both orthogonal directions in attempt to avoid torsional response under lateral force. The column is made square and size of the column is kept same throughout the height of the structure to keep the discussion focused only on the soft 1ststorey effect without distracted by the issues like orientation of column.

Result and Discussion

The seismic response of reinforced concrete (RC) buildings is significantly influenced by the distribution of masonry infill walls along the height of the structure. In the present study, RC building models with masonry infill walls and a soft-storey configuration were analysed using Response Spectrum Analysis. The objective was to evaluate the influence of masonry infill discontinuity on important seismic response parameters such as storey displacement, inter-storey drift, storey shear, and structural stiffness.
The results obtained from the analytical models demonstrate that the presence of masonry infill walls considerably modifies the lateral behaviour of the RC frame. While the infill walls generally increase the lateral stiffness and reduce

overall displacement, their absence at a particular storey can create a significant stiffness discontinuity. This effect is particularly pronounced when the ground floor is kept open while the upper floors are infilled.

Storey Displacement

Storey displacement is one of the important parameters for evaluating the seismic performance of a building. It represents the lateral movement of each floor under earthquake-induced forces.

The analysis indicates that the fully infilled building exhibits lower lateral displacement compared with the soft-storey building. The presence of masonry infill walls increases the lateral stiffness of the structure and consequently reduces the deformation caused by seismic loading. In the soft-storey configuration, the ground floor has considerably lower stiffness because of the absence or reduced number of masonry infill walls. As a result, lateral deformation becomes concentrated at the soft storey. The upper infilled storeys behave relatively rigidly, whereas the open ground floor undergoes comparatively greater lateral movement. The maximum displacement is therefore generally observed toward the upper levels of the building; however, the change in displacement between consecutive floors becomes particularly significant near the soft storey**.** This indicates that the ground storey is subjected to higher deformation demand.

The results demonstrate that masonry infill walls provide an important contribution to the lateral stiffness of the building. Their sudden removal at one storey creates an abrupt change in stiffness and modifies the distribution of seismic deformation.

Table 1- Displacement of roof nodes

Node	Model- I	Model- II
	U_x	U_x
31	-2.196	-1.675
32	-3.048	-1.692
33	-3.064	-1.694
34	-3.048	-1.693
35	-2.196	-1.677
66	-3.262	-1.721
67	-4.235	-2.44
68	-4.254	-2.454
69	-4.235	-2.44
70	-3.262	-1.722
101	-3.265	-1.74
102	-4.24	-2.445
103	-4.259	-2.46
104	-4.24	-2.445
105	-3.265	-1.741
136	-3.265	-1.741
137	-4.24	-2.445
138	-4.259	-2.46
139	-4.24	-2.445
140	-3.265	-1.74
171	-3.262	-1.722
172	-4.235	-2.44
173	-4.254	-2.454
174	-4.235	-2.439
175	-3.262	-1.72

206	-2.196	-1.678
207	-3.048	-1.692
208	-3.064	-1.692
209	-3.048	-1.69
210	-2.196	-1.674

The table presents the horizontal displacement (Ux) at selected nodes for Model-I and Model-II**.** The negative sign indicates displacement in the negative X-direction. The main observation is that Model-II consistently shows lower horizontal displacement than Model-I, indicating better lateral stiffness and improved resistance to lateral deformation.

Conclusion

Based on the Response Spectrum Analysis carried out for the six-storey reinforced concrete building models, the following conclusions can be drawn:

- ❖ The seismic response of the RC building is significantly influenced by the distribution of masonry infill walls along the height of the structure. Masonry infill contributes substantially to the lateral stiffness of the building and affects its overall deformation characteristics.
- ❖ The comparison of Model-I and Model-II shows that Model-II experiences consistently lower horizontal displacement (Ux) at the roof nodes than Model-I. The reduction in displacement indicates that Model-II possesses greater effective lateral stiffness and better resistance to earthquake-induced deformation.
- ❖ The maximum roof displacement observed in Model-I is approximately 4.259 mm, whereas for Model-II it is approximately 2.460 mm. Thus, Model-II shows a substantial reduction in lateral displacement compared with Model-I.
- ❖ The lower displacement of Model-II demonstrates the beneficial effect of masonry infill in controlling lateral deformation. The infill walls act as additional lateral load-resisting components and increase the overall stiffness of the RC frame.
- ❖ In the soft-storey configuration, the sudden absence or reduction of masonry infill at the ground floor produces a significant stiffness discontinuity. Consequently, lateral deformation tends to concentrate at the soft storey, increasing its vulnerability during seismic excitation.
- ❖ The results confirm that soft-storey buildings require careful seismic evaluation and design, particularly at the ground floor where the stiffness and strength are considerably lower than those of the upper infilled storeys.
- ❖ The symmetrical plan configuration adopted in the study helps minimize torsional effects and allows the influence of masonry infill discontinuity and soft-storey behaviour to be assessed more clearly.

Overall, the study demonstrates that the presence, distribution, and discontinuity of masonry infill walls should not be neglected in seismic analysis of RC buildings. Proper consideration of infill effects is essential for obtaining a realistic assessment of storey stiffness, displacement, inter-storey drift, and overall seismic performance.

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