Influence of opening in infill on R factor of RC infilled frame structures

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Influence of opening in infill on R factor of RC infilled frame structures

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Abstract

This paper is concerned with study of effect of opening in infills on RC framed structures. Reinforced concrete buildings with masonry infill walls have been widely constructed for commercial, industrial, buildings. In this paper presents the results of analytical program showing behavior of frames with different masonry infill i.e semi-interlocked masonry & Unreinforced masonry. The effect of infill opening on seismic response of frame buildings were evaluated. A nonlinear static analysis has been carried out on different model frames by using finite element analysis software, seismostruct. The results obtained show that calculation of response reduction factor of RC infilled frames with & without opening in infill.

Introduction

Masonry is one of the most popular and economical building material in construction system. Reinforced concrete frame buildings with masonry infill walls have been widely constructed for commercial, industrial and multistory residential uses in seismic regions all over the world. The masonry panels are generally not considered in analysis and design process and it is treated as architectural component. Nevertheless the presence of masonry infill walls has a significant impact on the seismic response of a reinforced concrete frame building, increasing structural strength and stiffness. The design of masonry with improved earthquake resistance presents a challenge for structural engineers. Semi-interlocked masonry is a new type of framed masonry built of dry stack semi-interlocking brick units (Totev 2015). This SIM units are capable of relative sliding in plane and locked relative movement out of plane. Most of the countries have been started the utilization of interlocked brick infills especially in seismically active regions. Interlocking brick system is a fast & cost effective construction system which offers good solution in construction. Hence there is a need to determine the effectiveness of interlocking brick in construction system.

Fig 1: Types of masonry infill: a) semi-interlocked masonry, b) Unreinforced masonry

2. Response Reduction factor

Response reduction factor is a force reduction factor used to reduce linear elastic response spectra to inelastic response spectra. In other words response reduction factor is the ratio of elastic to inelastic design strength. Response reduction factor is also known as response modification factor & behavior factor. The value of R factor varies from 3 to 5 in IS-1893 depending on the type of resisting frame (OMRF & SMRF). From the review of existing literature it can be seen that response reduction factor depends upon three parameters; ductility, overstrength, & redundancy.

\[ R = R_\mu \times \Omega \]

Where, R is Response reduction factor, \( R_\mu \) is ductility reduction factor and \( \Omega \) is overstrength factor.

Fig 2 Relationship between Response reduction factor, structural over-strength (\( \Omega \)) and ductility reduction factor (\( R_\mu \)) [Tarek M.Alghane27]
2.1 Ductility Reduction Factor (Rμ)

In the event of an earthquake, ductile structures have been found to perform better than brittle structures. Ductility reduction factor is a measure of the global nonlinear response of structure. It is a function of both, ductility and fundamental time period of structure. The global ductility μ or displacement ductility is represent as

\[ \mu = \frac{\Delta_{\text{max}}}{\Delta_y} \]

Where, \( \Delta_{\text{max}} \) maximum displacement and \( \Delta_y \) is yield displacement. Yield displacement is calculated by reduced stiffness method.

![Fig 3 Reduced stiffness method (By park)](image)

Different formulations have been proposed by researchers for the determination of ductility factor. The R-μ-T relationships developed by newmark & hall have been used in this study to calculate Rμ as follows;

- **Short period** \( T < 0.2 \text{ Seconds} \)
  \[ R_\mu = 1 \]
- **Intermediate period** \( 0.2 < T < 0.5 \text{ Seconds} \)
  \[ R_\mu = \frac{2(\frac{1}{1})}{1} \]
- **Long period** \( T > 0.5 \text{ Seconds} \)
  \[ R_\mu = \mu \]

2.2 Overstrength Factor

The overstrength factor is a measure of additional strength a structure has beyond its design strength. It may be expressed as

\[ \Omega = \frac{V_t}{V_d} \]

Where, \( V_t \) is the ideal yield base shear & \( V_d \) is the design base shear.

The main sources of overstrength factor are:

1. The difference between actual and design material strength
2. Load factors & multiple load cases

3. Participation of nonstructural element
4. Redundancy

2.3 Redundancy factor

Redundancy is usually defined as exceeding what is necessary or naturally excessive i.e., the gap between local yield point to global yield point of structure. Building should have high degree of redundancy for lateral resistance. In this study redundancy factor is incorporated into overstrength factor.

3. Model Description

For this study, 4 storey with 4 bays two dimensional frame (Each bay span 4m) & floor height is 3m, regular in plan is considered. This building is considered to be situated in seismic zone v & designed in compliance to Indian code of practice for earthquake resistant design of structures. The building is modeled using seismostruct software. Models are studied for comparing the response reduction factor of RC frame structure with SIM & URM infill by considering with & without opening as follows:

1) Bare frame
2) URM (open ground RC frame)
3) URM (only side bay infilled at ground of RC frame)
4) URM (Full infilled RC frame)
5) SIM (Full infilled RC frame)
6) SIM (open ground RC frame)
7) SIM (only side bay infilled at ground of RC frame)

*Inelastic Infill Panel Element (infill):*

Each infill panel element represented by four axial struts and two shear springs, as shown in Figure 3.1. This element is able to define with three groups of parameters. First group is about physical characteristics of infill panel, second group is about compression/tension struts defined by strut curve parameters, and third group is about shear spring that defined by shear curve parameters. Four node panel masonry element developed by the researcher crisafiulli (1997). It accounts separately compressive and shear behavior of masonry. It shows the adequate representation of hysteretic response. It shows the accuracy of the model to evaluate the nonlinear response of structure. Another name of this model is “Double strut nonlinear cyclic model.”

Presence of opening in infill panel will affect the stiffness and strength of frame, the effect can be incorporated by reducing the width of the diagonal strut. The stiffness
reduction factor to consider opening effect in infill in numerical modeling\(^\text{[11]}\) is given by

\[ W_{d'} = (1-2.5A_r) W_d \]

Where \( A_r \) is the opening area ratio, which is the ratio of face area of opening to the face area of infill. The above relation is valid for opening in wall greater than 5% and lesser than 40%.

In this paper opening in infill considered as 1.2 x 1.2 m = 1.44 m\(^2\)

\[ \text{Fig 3.1: Inelastic Infill Panel Element} \]

### Data Compilation and Calculation

Lumped mass is calculated and applied for each node which is due to the dead weight of the floor slab and the infill walls. Reinforcement in beam and column sections for the structure are calculated according to analytical results of frame from SAP-2000 using gravity load & seismic load condition with M30 concrete and Fe415 steel reinforcement. These sections are assigned to the simulation of the structure made in Seismostruct and lumped masses are also assigned to each node. Thus the structure is simulated in Seismostruct with 4 stories-4bays two dimensional frames with different infill conditions. This structure is loaded from x-axis to get the performance curves in respective axes.

<table>
<thead>
<tr>
<th>Floors</th>
<th>Seismic Weights in kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground floor</td>
<td>519.73</td>
</tr>
<tr>
<td>First floor</td>
<td>519.73</td>
</tr>
<tr>
<td>Second floor</td>
<td>519.73</td>
</tr>
<tr>
<td>Third floor</td>
<td>382.43</td>
</tr>
</tbody>
</table>

On the basis of this seismic weight calculation, Design Base shear = \( A_x \times \frac{W}{0.225 \times 1941.64} \)

\[ = 436.86 \text{ kN} \]

This base shear is shared amongst each floor as:

\[ \begin{align*}
1.16.95 \text{ kN (floor 1)} \\
2.67.80 \text{ kN (floor 2)} \\
3.152.55 \text{ kN (floor 3)} \\
4.199.55 \text{ kN (floor 4)} 
\end{align*} \]

### 4. Pushover Analysis

In this study, nonlinear static pushover analysis of different RC infilled frame models are carried out using finite element software seismostruct to estimate their ductility & overstrength factors which are required for computing R factor for each model. The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. A plot of total base shear versus top displacement in a structure is obtained by this analysis that would indicate a premature failure or weakness. All the beams and columns which reach yield or have experienced crushing and even fracture are identified. The analysis is performed based on displacement controlled procedure. In this study R factor is obtained with & without opening in infill by using ductility & overstrength factor from pushover curve by its bilinear idealization as per reduced stiffness criteria.
5. Results & Discussion

1. Pushover curves

![Graph showing comparison of Pushover Curves of 4storey -4bay frame with opening in infill]

Fig 5.1 Comparison of Pushover Curves of 4storey -4bay frame with opening in infill

![Graph showing comparison of Pushover Curves of 4storey -4bay frame without opening in infill]

Fig 5.2 Comparison of Pushover Curves of 4storey -4bay frame without opening in infill

2. Base shear

![Graph showing comparison of Base Shear for 4Storey -4bay frame with opening in infill]

Fig 5.3 Comparison of Base Shear for 4Storey -4bay frame with opening in infill

Base shear is minimum for bare frame as compared to all other frames. Nearly 24.44% increases for SIM full infilled frame as compared to URM full infilled frame. In case of open ground storey frames, there is a variation of 2.59%. And for SIM side bay infilled frame has maximum base shear by 18.77% as compared to URM side bay infilled frame.

![Graph showing comparison of Base Shear for 4storey -4bay frame without opening in infill]

Fig 5.4 Comparison of Base Shear for 4Storey -4bay frame without opening in infill

3. Ductility

![Graph showing comparison of Ductility for 4storey -4bay frame with opening in infill]

Fig 5.5 Comparison of Ductility for 4storey -4bay frame with opening in infill

Ductility is maximum for bare frame as compared to all other frames. Nearly 22.22% increases for SIM full infilled frame as compared to URM full infilled frame. In case of open ground storey frames, there is a variation of 12.5%. And for SIM side bay infilled frame has maximum ductility by 12.41% as compared to URM side bay infilled frame.

![Graph showing comparison of Ductility for 4storey -4bay frame without opening in infill]

Fig 5.6 Comparison of Ductility for 4storey -4bay frame without opening in infill
Ductility is maximum for bare frame as compared to all other frames. Nearly 54.76% increases for SIM full infilled frame as compared to URM full infilled frame. In case of open ground storey frames, there is a variation of 24.76%. And for SIM side bay infilled frame has maximum ductility by 18.58% as compared to URM side bay infilled frame

4. Ductility reduction factor

![Ductility Reduction Factor](image)

**Fig 5.7 Comparison of Ductility Reduction factor for 4Storey-4bay frame with opening in infill**

Ductility reduction factor is maximum for bare frame as compared to all other frames. Nearly 14.17% increases for SIM full in-filled frame as compared to URM full infilled frame. In case of open ground storey frames, there is a variation of 7.14%. And for SIM side bay infilled frame has maximum ductility reduction factor by 10.94% as compared to URM side bay infilled frame

![Ductility Reduction Factor](image)

**Fig 5.8 Comparison of Ductility Reduction factor for 4Storey-4bay frame without opening in infill**

5. Overstrength Factor

![Overstrength Factor](image)

**Fig 5.9 Comparison of Over-strength factor for 4Storey-4bay frame with opening in infill**

Over-strength factor is minimum for bare frame as compared to all other frames. Nearly 38.07% increases for SIM full in-filled frame as compared to URM full infilled frame. In case of open ground storey frames, there is a variation of 5.29%. And for SIM side bay infilled frame has maximum over-strength factor by 30.16% as compared to URM side bay infilled frame.

![Overstrength Factor](image)

**Fig 5.10 Comparison of Over-strength factor for 4Storey-4bay frame without opening in infill**

Over-strength factor is minimum for bare frame as compared to all other frames. Nearly 24.46% increases for SIM full in-filled frame as compared to URM full infilled frame. In case of open ground storey frames, there is a variation of 2.27%. And for SIM side bay infilled frame has maximum over-strength factor by 18.81% as compared to URM side bay infilled frame

6. Response reduction factor

![Response Reduction Factor](image)

**Fig 5.11 Comparison of Response Reduction Factor for 4Storey-4bay frame with opening in infill**
R factor is minimum for bare frame as compared to all other frames. Nearly 57.55% increases for SIM full infilled frame as compared to URM full infilled frame. In case of open ground storey frames, there is a variation of 1.66%. And for SIM side bay infilled frame has maximum R factor by 44.27% as compared to URM side bay infilled frame.

![Fig 5.12 Comparison of Response Reduction Factor for 4Storey-4bay frame without opening in infill](image)

6. Conclusions

This study shows that a decrease in stiffness and maximum lateral resisting strength is evident when a window opening is included in the infill. There seems to be opening area in infill increases the reduction in strength increases. Following observations are made on the basis of results:

1. Response reduction factor decreases effectively by considering opening in infill.
2. The base shear value is maximum for SIM infilled frame as compared to URM infilled frame.
3. Ductility and Ductility Reduction factor are reduces when frame is infilled with SIM and URM panel.
4. Over-strength factor increases when frame infilled with SIM and URM panel.
5. Response Reduction Factor of SIM infilled frame is higher than URM infilled frame.
6. R factor is very sensitive to both material and geometric configuration.
7. The presence of infill should be considered in the design of the frame structures in order to profit from its positive contribution to the stiffness, strength and R factor of the structure and to avoid the possible harmful effects.

References


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