Non-linear Behaviour of Infilled RC Frame

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Abstract. The reinforced concrete (RC) infilled frame is very common in exercise. In general, only infill weight is considered in the design of the RC infilled frame, and the strength of masonry is ignored. However, the prominence of masonry infill on the seismic behaviour is highlighted during past earthquakes. Nowadays, applications of different types of masonry such as fly ash, and lightweight masonry in infill, are increasing due to their superior properties over the traditional clay brick masonry. The exact behaviour of the infilled RC frame during an earthquake cannot be predicted if the strength of infill is ignored. A nonlinear static method i.e. pushover analysis for the seismic evaluation, is commonly used due to its simplicity and high accuracy. A typical four storey three bay plane infilled RC frame is considered in the present study to investigate efficacy of several formulas available in the literature for the modelling of infill employing pushover analysis method. In addition to that sensitivity analysis also conducted which revealed that the parameters, masonry wall width and masonry shear strength are significant that control the base shear at yield level. Significant decrease in the lateral stiffness is observed for a higher percentage of openings in the infilled. However, up to 5% of openings in infilled can be ignored due to its marginal change in the lateral strength of infill.

1. Introduction

Infilled masonry wall reinforced concrete framed structure, is widely spread and generally used in construction throughout the world. Normally, the strength and stiffness of the infilled masonry wall are ignored, considering it as a non-structural component. However, in the seismic prone region, avoiding the contribution of an infilled masonry is not a noble choice. Under the action of seismic load, the infilled wall stiffness enhances by diagonal compression action; it results in a possible change of the lateral demand. Masonry infilled wall can be modelled as a diagonal strut element (Figure 1).

In general, the infill used in the RC framed masonry structures is constructed of the material available in the vicinity, which results in a change in engineering properties from region to region. The variation in engineering properties might cause a difference in strength and stiffness behaviour. A non-linear static method of seismic evaluation is conducted in this study to evaluate the effect of properties of an infilled masonry wall on the seismic response of infilled RC frame.

The nonlinear static pushover (NSP) can be primarily categorised as NSPs method and N2 method. NSPs method consists of capacity spectrum method, implemented in [1], introduced by Freeman [2], and N2 method suggested by Fajfar [3] which is later included in Eurocode 8 [4]. Nonlinear analyses are essential to catch the exact behaviour of structure as it behaves inelastically when subjected to seismic loading under seismic excitation. Due to extensive proof studies that have verified the exactness and simplicity of NSP, pushover analyses are commonly adopted for the seismic assessment of existing
structures and design of new structures. Hinges, where nonlinearity will occur, can be defined manually or as default hinge, as per ATC-40 [1] and FEMA-356 [5] guidelines which are available in analysis software such as SAP2000.

The motivation of the present work is to assess the design guidelines suggested by IS 1893 [6] for infilled modelling. Different formulas are available in the literature to evaluate the diagonal strut width. In the present study efficacy of several formulas available in the literature for the modelling of infill is checked along with the various opening percentage in infilled RC frame. A sensitivity analysis to understand the significant parameters that affects the base shear response is also carried out as part of this study.

2. Modelling of infilled masonry wall

With due importance for the infilled masonry, many experimental and analytical efforts have been made to study the behaviour of the infilled RC frame. A brief literature review has revealed that the earlier version of the design code has no sufficient guideline to reflect the influence of infilled masonry on the response or design of infilled RC framed buildings.

Previous studies [7-9] has performed several experimental tests with various aspect of the infilled masonry wall. The wall is represented by the diagonal struts carrying compressive forces. Smith and Carter [10] have suggested analytical methods to ascertain the viable width of the diagonal strut. The study also concluded that cracking and crushing strength of diagonal strut depends upon the contact length, angle \( \alpha \) between infill and frame in its deformed pattern. Contact length was expressed as a function of non-dimensional factor (\( \hat{\lambda}_h \)), as presented in Eq. (1) and Eq. (2). The width of equivalent strut reduces as the loading increases, to consider the change in the stiffness of the infill due to cracking [10].

\[
\frac{\alpha}{h} = \frac{\pi}{2\hat{\lambda}_h} \tag{1}
\]

\[
\hat{\lambda}_h = h \left( \frac{E_i t \sin 2\theta}{4E_c I_c h} \right)^{0.25} \tag{2}
\]

Here, \( E_w, h_w, \) and \( t \) are modulus of elasticity, the height of the infill and thickness respectively. Also, column properties are \( E_c \) (Young’s modulus of column) and \( I_c \) (moment of inertia of column). \( \theta \), is the gradient between the horizontal and the diagonal of the infill.

Figure 1. Schematic presentation of an equivalent strut.

Modified equation is given by [11] to calculate the maximum compressive strength of infill, as shown below:

\[
F_{\text{max}} = 0.818 \frac{L_c f_{\text{cr},w}}{C_1} \tag{3}
\]

where,

\[
C_1 = 1.925 \frac{L_c}{t} \tag{4}
\]
The model is formally the same as that of the one by Panagiotakos and Fardis [12] with the major difference of no residual strength \((F_u = 0)\), shown in figure 2. Post-capping branch and elastic hardening are the three tri-linear response of single equivalent diagonal strut. Studies [13, 14] reported the change in lateral behaviour of an infilled frame in line for the openings in the masonry and [14] also suggested a reduction factor \((\rho_w)\), as presented below:

\[
\rho_w = 1 - 2.6\alpha_{co}
\]  

where \(\alpha_{co}\) is the Opening-Area-Ratio.

Different formulas are available in the literature to estimate the effective equivalent strut width \((w)\) as given in table 1.

**Table 1.** Various models for the width of the strut.

| Equivalent strut width \((w)\)                  | Reference |
|-----------------------------------------------|-----------|
| \(d/3\)                                       | [8]       |
| \(d/4\)                                       | [15]      |
| \(d(0.175\lambda_h^{-0.4})\)                  | [16]      |
| \(d(0.475\lambda_e^{-0.5}\sin 2\theta)\)     | [17]      |

**Figure 2.** Representation of the backbone curve of an infill strut model.

### 2.1. Building Geometry

A typical four storey three bay plane infilled RC frame with (230 mm wall thickness), with and without openings is considered in the present investigation for the analysis. The selected building is a residential building, having slab thickness 150 mm, located in the seismic zone II and designed as per IS 456 (2000). Live Load on the building is 3kN/m\(^2\), unit weight of Clay masonry and Fly ash brick masonry is considered 18.84 kN/m\(^3\) [19]. The lateral load profile is taken as per IS per 1893 [6].

### 3. Seismic Assessment

NSP and sensitivity analyses are carried out to evaluate the nonlinear behaviour of the infilled frame under lateral load. Parabolic lateral load pattern is used in the present study [6]. The lateral load is increased up to the failure of the structure. Schematic presentation of the pushover curve is shown in figure 3. To check the parameters of frame and masonry infill, which are sensitive to the lateral loading, sensitivity analysis is conducted by replacing one property with its percentile value and keeping all other properties as mean. The change in the response of the structure is assessed for the various input mechanical and physical properties presented in table 2. Similar properties for clay brick masonry are available in the literature [19]. Sensitivity is defined by Cеларек [20] as given below.
Figure 3. Schematic presentation of NSP.

\[
\Delta y = \frac{y(P_n) - y(P_{\text{mean}})}{y(P_{\text{mean}})} \times 100(\%)
\]

where \(y(P_n)\) and \(y(P_{\text{mean}})\) are the response at percentile and mean value of the random variables.

Table 2. Details of input variables for fly ash masonry [21].

| Property                        | Variable | Mean | COV  | Distribution |
|---------------------------------|----------|------|------|--------------|
| Masonry compressive strength    | \(f_m\) | 5.45 | 0.27 | N            |
| Masonry shear strength, (MPa)   | \(\tau\) | 0.125| 0.12 | LN           |
| Elastic modulus of masonry, (MPa)| \(E_m\) | 3275 | 0.3  | N            |
| Yield strength of steel (MPa)   | \(F_y\)  | 393  | 12   | LN           |
| Depth of column, (mm)           | \(d_{col}\) | 400  | 1.5  | LN           |
| Width of infill, (mm)           | \(w\)    | -    | 1.5  | LN           |

\(N\): Normal and LN: Lognormal

4. Results and Discussion

Different formulæ to calculate the width of the equivalent strut as per the previous literature listed in Table 1, are used to model the infill, and NSP curves are obtained as shown in Figure 4. Sensitivity analysis and pushover analysis are carried out on the selected plane RC frame. 5%, mean and 95% percentile values of random variables for the clay and fly ash infill masonry are considered to observe the change in the seismic response of infilled RC frame. Tornado diagram (TD) is used to present the result of the sensitivity analysis as shown in Figure 5. Ultimate base shear is considered as a sensitive parameter in the present study.

Figure 4. Effect of strut width.

It can be observed from the TDs that \(\tau\) (shear strength of infill) and \(w\) (width of masonry) greatly influence the response of structure for both the type of infills among all other properties considered.
Figure 5. TD masonry wall.

NSP curves are obtained for the considered plane RC frame. Figure 6 presents the NSP curves for clay and fly ash masonry infilled RC frame along with the different percentage of openings respectively. Pushover curves of a bare frame are also shown for the reference.

Figure 6. Capacity curve for a different opening percentage (a) Clay brick infilled and (b) Fly ash brick infilled.

5. Conclusions
The main findings of the present work are summarised as follows:

- Results of pushover analysis show that reduction in the value of base shear ($V_b$) increases as the percentage of opening in the infill wall increases. However, the effect of 5-10% openings in the infill can be ignored due to insignificant change in the ultimate base shear.
- Sensitivity analysis shows that the width and shear cracking strength of the infill are the most sensitive parameters in the analysis of masonry infilled RC frames.
- Among all the formulations to calculate the width of equivalent diagonal strut, Smith and Carter model [16] gives the lower bound results which is conservatively included in Indian standard IS 1893 [6].

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