

# Analytical Study on The Behavior of Partially Infilled Frames Using Finite Element Technique by Heterogeneous Model

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## Abstract

This research examines infilled frames are the structural systems that result from the composite action between frame and infilling wall. In times of earthquake it has been recently observed that such infilled frames with larger openings for windows, ventilators, etc, called as partially infilled frames, suffer from shear failure of columns. From the survey of literature on infilled frame it is found that studies in this area are limited. Hence an attempt is made to study analytically the behaviour of partially infilled frames in this work. The frame members are modelled with six degrees of freedom two noded beam elements, the infill is modelled with four noded plane stress elements so as to include the heterogeneity of the wall by modelling the brick and mortar separately. The interface is modelled as link element with particular stiffness value.

In this work an attempt is made to study the influence of i) pattern ii) height of infilling on single storey single bay and three storey two bay frames using finite element technique. The analysis is carried out for a lateral load

of 10kN at top most storey level and lateral displacement, bending moment, shear force, axial force, infill stresses are obtained.

Totally 184 cases have been studied. The infilled frame is stiffer than bare frame. The increase in stiffness for full infill is 253% and 25% for critical case of partially infilled frame than bare frame. The infilled frame to bare frame stiffness ratio is 3.5 times for full infill is 1.25 times for  $\frac{1}{4}$  infilled frame.

**Key Words:** Infilled frame, Heterogeneous model, Stiffness

## 1 INTRODUCTION

Partially infilled frame is a composite structure formed through the partial interactive behaviour of the infill with the bounding frame members under inplane lateral loads. When the infilled frame is subjected to horizontal load, the infill and the frame separate over the region where tension occurs and remain in contact where compression occurs. Slip occurs in the compression region. Considering slip and separation, infilled frame is simplified to be equivalent to that of a pin-jointed frame wherein the bounding frame acts as tie and strut members and the infill acts like an inclined diagonal strut member. The effect of this interaction reduces the lateral displacement of the frame and improves its lateral strength. The bending moment is reduced; hence the design becomes economical though the axial force is increased.

## 2 LITERATURE SURVEY

In order to assess and to critically evaluate the research works done in infilled frames, a detail review of literature has undertaken. The research on infilled frames pertaining interface characteristics and their effects are presented in the following sections, as follows:

### (i) Studies on Reinforced Concrete Partial Infilling:

Ozgur Anil and Sinan Altin (2006) [1] led to the conclusion that partially infilled RC frames exhibited significantly higher ultimate strength and higher initial stiffness than the bare frame (frame with

no infill). While the aspect ratio of the infill wall was increased, the lateral strength and the rigidity were increased significantly.

**(ii) Studies on Behaviour of Partially Infilled Frames:**

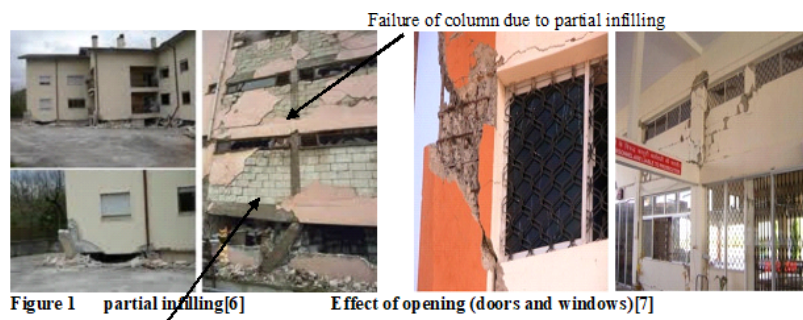
Goutam Mondala (2007) [4] has studied the Lateral Stiffness of Masonry Infilled Reinforced Concrete (RC) Frames With Central Opening. In the study, a reduction factor is proposed for effective width of diagonal strut over that of the solid infilled frame to calculate its initial stiffness when a central window opening is present. Seven specimens of infilled frame for which details of the specimens and experimental results are available in the published literature are considered. These include single-bay single-story to single-bay multi-story bare frames, infilled frames without openings, and infilled frames with central openings. These specimens are analyzed by Finite Element (FE) method using the software SAP 2000 Version. The present study is based on initial lateral stiffness corresponding to 10% of the lateral strength of the infilled frames. Based on the comparison between initial lateral stiffness using FE method and from experimental initial lateral stiffness it is found that best match with experimental results are obtained when (a) separation between the frame and the infill at the non-loaded diagonal is included, (b) end-offsets of beam-column joints in RC frames is assumed to be semi rigid wherein quarter column depth along beam from center line of column and quarter beam-depth along column from center line of beam are considered rigid, (c) the FE model is based on cracked flexural rigidity of beams and columns where the flexural rigidity of beam and column in tension is taken as  $0.5 E_c I_g$  and that of column in compression is taken as  $0.7 E_c I_g$ .

### 3 RESEARCH SIGNIFICANCE

From the literature review it is found that only limited work has been done in the area of partially infilled frame related to the influence of interface characteristics and modelling of infill element. The present investigation tries to add more information in this area by considering the effect of infill as heterogenous plane stress models.

From the studies of recent earthquakes it is found that the column adjoining infill with partial opening for ventilator or window

undergoes a severe shear failure as indicated in the Figure 1.



## 4 OBJECTIVE AND SCOPE OF THE PRESENT INVESTIGATION

The proposed investigations are mainly aimed to analytically investigate the effect of height of infill on the behaviour of reinforced concrete infilled frames.

### a) Pattern and partial infilling used for Analytical Investigation:

The pattern used for the study is a two bay (b1,b2) three storey(s1,s2,s3) frame which is shown in the Figure 2.

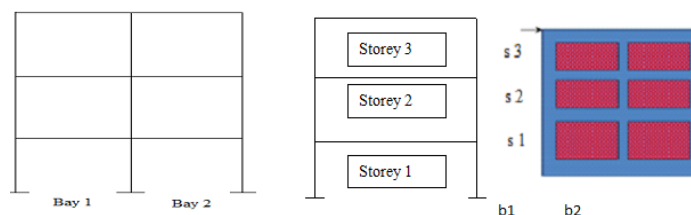


Figure 2 Pattern of frame

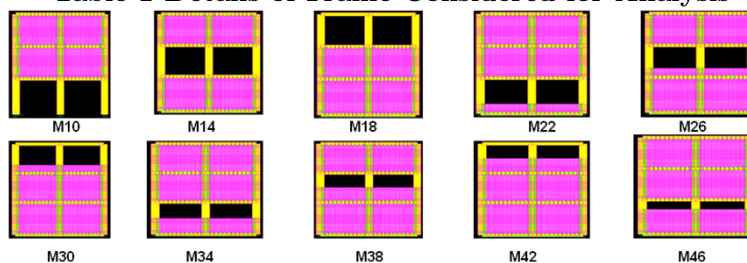
Varying partial infilling is tried on all the 3 storey and 2 bay. No of trials considered for the analysis is 184 (cases) and typical types of infilled models are shown in the Figure 3.

### b) Details of Analytical Investigation:

In this one eighty four models are considered that include M5 to M8 as bare frame,  $1/4^{th}$  infill,  $3/4^{th}$  infill and full infill. M9 to

M189 are various other combinations of varying heights of infill. A standard finite element software package SAP 2000, Version 11 is used. The frame members are modeled with two noded, six degrees of freedom beam elements. For modeling the infill, heterogeneity of the brick masonry is represented by taking four noded plane stress elements separately for brick and mortar. The interface is modeled by link elements having three degrees of freedom on frame side and two degrees of freedom on infill element. The details of frame is presented in Table 1

**Table 1 Details of Frame Considered for Analysis**



The parameters considered for study are modulus of elasticity, Poissons ratio, compressive strength and modulus of elasticity of the frame and infill material. The properties of materials considered for analysis are as follows. The properties of materials considered for analysis are given in Table 2.

**Table 2 Properties of Materials Used For Analysis**

| Particulars                               | Values (mm) |
|-------------------------------------------|-------------|
| Ground level storey height (clear height) | 2850        |
| Other floors (clear height)               | 2400        |
| Bay width (c/c)                           | 2400        |
| Beam dimension                            | 300x300     |
| Column dimension                          | 400x300     |
| Infilling dimension Thickness             | 230         |

## 5 RESULTS

### i) Convergence Study

$8 \times 8$  mesh is considered for the full infill condition. Similarly  $2 \times 2$  mesh for  $\frac{1}{4}$  h infill,  $4 \times 4$  mesh for  $\frac{1}{2}$  h infill,  $6 \times 6$  mesh for  $\frac{3}{4}$  h

infill for all the trials of analysis of partial infilled frame, from the convergence studies made.

### ii) Analytical Results

The Tables 3 represents the comparisons of results of stiffness obtained from analysis investigations.

**Table 3 Effect of Stiffness for model frame**

| Property                                   | Frame members | Infill |
|--------------------------------------------|---------------|--------|
| Compressive strength (N/mm <sup>2</sup> )  | 20            | 4.7    |
| Modulus of elasticity (N/mm <sup>2</sup> ) | 22360         | 9390   |
| Poisson's ratio                            | 0.15          | 0.15   |

### iii) Percentage Increase in Lateral Stiffness

The Percentage increase in lateral stiffness for varying infill heights for different models is shown in the Figure 4.

| S.No | Description of the frame | Lateral Stiffness (kN/mm)<br>Analytical | Ratio of Stiffness<br>IF/BF |
|------|--------------------------|-----------------------------------------|-----------------------------|
| 1    | Bare Frame               | 3.13                                    | -                           |
| 2    | Strut Model              | 10.06                                   | 3.214                       |
|      | Plane Stress Model       |                                         |                             |
| 3    | Homogenous               |                                         |                             |
|      | i) 1H                    | 10.94                                   | 3.495                       |
|      | i) 1/4H                  | 3.6                                     | 1.1504                      |
| 4    | Heterogenous             |                                         |                             |
|      | i) 1H                    | 11.06                                   | 3.533                       |
|      | i) 1/4H                  | 3.92                                    | 1.252                       |

**Figure 4 Percentage increase of lateral stiffness with varying infill heights**

### iv) Effect of Presence of Infill on Lateral Stiffness Prediction

The effect of presence of infill on lateral stiffness is predicted and shown in the Figure 5.

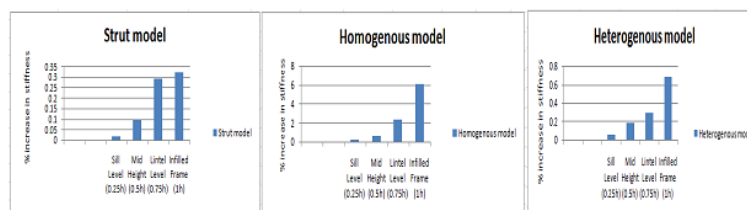


**Figure 5 Percentage increase of lateral stiffness**

### vi) Critical Values for Single Bay Single Storey and Two Bay Three Storey Frame

Based on the analytical results obtained the critical values are identified and shown in Table 4 and Table 5.

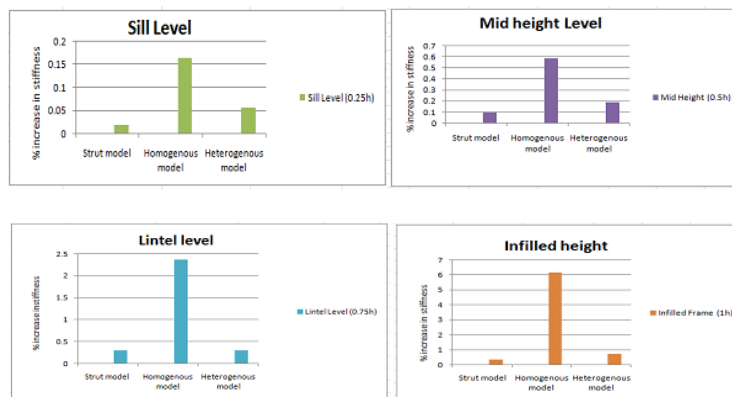


Figure 6 Effect of model on lateral stiffness

### vi) Critical Values for Single Bay Single Storey and Two Bay Three Storey Frame

Based on the analytical results obtained the critical values are identified and shown in Table 4 and Table 5.

Table 4 Critical values for single bay single storey frame

| Criteria   | Unit              | Strut model |         | Plane stress model |         | Heterogenous model |         |
|------------|-------------------|-------------|---------|--------------------|---------|--------------------|---------|
|            |                   | Model       | Values  | Model              | Values  | Model              | Values  |
| Stiffness  | kN/mm             | H           | 23.23   | H                  | 125     | H                  | 29.41   |
| AF (+ve)   | kN                | H           | 2.44    | H                  | 1.98    | H                  | 2.48    |
| AF (-ve)   | kN                | ¼H          | 16.18   | ¼H                 | 16.48   | H                  | 20.87   |
| SF (+ve)   | kN                | ¼H          | 7.93    | ¼H                 | 7.42    | H                  | 11.87   |
| SF (-ve)   | kN                | H           | 5.46    | ½H                 | 2.26    | H                  | 4.96    |
| BM (+ve)   | kN mm             | ¼H          | 9925.66 | ¼H                 | 6564.14 | ¼H                 | 8767.81 |
| BM (-ve)   | kN mm             | ¼H          | 6454.38 | ¼H                 | 6561.31 | ¼H                 | 8018.96 |
| Max stress | N/mm <sup>2</sup> | -           | -       | ½H                 | 182     | H                  | 40.88   |
| Min stress | N/mm <sup>2</sup> | -           | -       | ¼H                 | 238     | ¼H                 | 53.32   |

Table 5 Critical values for two bay three storey frame

| Frame Description<br>Details            |       |  |  |  | Remarks                   |                           |
|-----------------------------------------|-------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|---------------------------|---------------------------|
|                                         |       | Bare Frame                                                                        | Infilled Frame                                                                    | Partially Infilled Frame                                                          | Comparison of PIF with BF | Comparison of PIF with IF |
| Lateral Stiffness (kN/mm)               |       | 5.88                                                                              | 17.86                                                                             | 17.24 (M98)                                                                       | 193%                      | -3%                       |
| Max BM (kNm)                            | (+ve) | 7674.75                                                                           | 10606.60                                                                          | 15411.9 (M178)                                                                    | 101%                      | 45%                       |
|                                         | (-ve) | 7420.92                                                                           | 9356.53                                                                           | 15411.9 (M178)                                                                    | 108%                      | 65%                       |
| Max SF (kN)                             | (+ve) | 7.84                                                                              | 29.69                                                                             | 58.49 (M178)                                                                      | 646%                      | 97%                       |
|                                         | (-ve) | 0.52                                                                              | 32.97                                                                             | 53.87 (M166)                                                                      | 10260%                    | 63%                       |
| Max AF (kN)                             | (+ve) | 0.63                                                                              | 6.64                                                                              | 8.16 (M58)                                                                        | 1195%                     | 23%                       |
|                                         | (-ve) | 46.40                                                                             | 87.30                                                                             | 93.42 (M86)                                                                       | 101%                      | 7%                        |
| Principal Stresses (N/mm <sup>2</sup> ) | Smax  | 0                                                                                 | 31.49                                                                             | 36.19 (M85)                                                                       | -                         | 15%                       |
|                                         | Smin  | 0                                                                                 | 37.41                                                                             | 50.91 (M53)                                                                       | -                         | 36%                       |

M53 – B1B2bay, s20.75hremain0h      M98 – B1bayonly, s20.75hremain1h

M58B1B2bay, s11hremain0.75h      M166 – B2bayonly, s10.75hremain1h

M85 – B1bayonly, s11hremain0h      M178 – B2bayonly, s11hremain0.75h

## 6 DISCUSSIONS

### i) Effect of partial infilling

- ★ The maximum stiffness is achieved in full infill of 1.35 times in strut model, 7.12 times in plane stress model and 1.67 times in heterogenous model of bare frame
- ★ The maximum axial force (+ve) is resulted on full infill of 1.65 times in strut model, 1.34 times in plane stress model and 1.68 times in heterogenous model of bare frame.
- ★ The maximum axial force (-ve) is resulted on  $\frac{1}{4}^{th}$  model of 0.99 times in strut model, 1.02 times in plane stress model and 1.30 times in heterogenous model of bare frame.
- ★ The maximum shear force (+ve) is resulted on  $\frac{1}{4}^{th}$  model of 1.101 times in strut model,  $\frac{1}{4}^{th}$  model 1.305 times in plane

stress model and 1.648 times in heterogenous model of bare frame.

- ★ The maximum shear force (-ve) is resulted on full infill of 3.714 times in strut model,  $\frac{1}{2}^{th}$  model is 1.537 times in plane stress model and 3.374 times in heterogenous model of bare frame.
- ★ The maximum bending moment (+ve) is resulted on  $\frac{1}{4}^{th}$  model of 1 times in strut model, 0.6 times in plane stress model and 0.88 times in heterogenous model of bare frame.
- ★ The maximum bending moment (-ve) is resulted on  $\frac{1}{4}^{th}$  model of 0.996 times in strut model, 1.012 times in plane stress model and 1.23 times in heterogenous model of bare frame.
- ★ The  $\frac{1}{4}^{th}$  model is critical in -ve axial force, +ve shear force and (+) & (-) ve bending moment .so the partially is tried in  $\frac{1}{4}^{th}$  (H) model.

## ii) Pattern of Variation of Various Quantities for Critical Case Based on Less Lateral Stiffness and Maximum Shear Force

• The suggested equations for the variation of various quantities for critical case based on Less Lateral Stiffness from the graph of infill height vs the corresponding parameters are

$$\text{Stiffness} = 25.86h^3 - 44.3h^2 + 24.98h + 6.024$$

$$\text{AF (-ve)} = -78.96h^3 + 109.1h^2 - 11.53h + 55.84$$

$$\text{AF (+ve)} = -4.693h^3 + 7.44h^2 - 9.566h + 8.1$$

$$\text{Smin} = -246.3h^3 + 336.3h^2 - 67.63h + 13.6$$

$$\text{Smax} = -51.62h^3 + 81.68h^2 - 8.913h + 10.1$$

$$\text{SF (-ve)} = -306.7h^3 + 398.2h^2 - 75.52h + 0.22$$

$$\text{SF (+ve)} = -780.8h^3 + 1123h^2 - 341.1h + 8.16$$

$$\text{BM (-ve)} = -13784h^3 + 25164h^2 - 11650h + 6567$$

$$\text{BM (+ve)} = -3513h^3 + 6601h^2 - 4872h + 7278$$

• The suggested equations for the variation of various quantities for critical case based on Maximum Shear Force from the graph of infill height vs the corresponding parameters are

$$\text{Stiffness} = -6.551h^3 + 6.189h^2 + 5.679h + 8.196$$

$$\text{AF (-ve)} = -15.84h^3 + 23.16h^2 + 3.32h + 55.44$$

$$\begin{aligned}
AF (+ve) &= 3.12h^3 - 15.38h^2 + 12.57h + 1.79 \\
S_{max} &= 15.04h^3 - 11.28h^2 + 0.32h + 27.24 \\
S_{min} &= 1.546h^3 - 1.4h^2 - 3.146h + 45.42 \\
SF (+ve) &= 12.4h^3 - 42.26h^2 + 34.55h + 11.37 \\
SF (-ve) &= -24.4h^3 + 29.58h^2 + 2.25h + 46.44 \\
BM (-ve) &= -19447h^3 + 34621h^2 - 16362h + 7517 \\
BM (+ve) &= -11674h^3 + 22108h^2 - 11338h + 6417
\end{aligned}$$

## 7 CONCLUSIONS

1. The infilled frame is stiffer than bare frame. The increase in stiffness for full infill is 253% and 25% for partially infilled frame than bare frame.
2. The infilled frame to bare frame stiffness ratio is 3.5 times for full infill is 1.25 times for  $\frac{1}{4}^{th}$  infilled frame.
3. From the trials the maximum values of heterogenous model for
  - ★ stiffness is 17.24 [model 98] level H
  - ★ Axial force is 93.42 (-ve) [model 86] level  $\frac{3}{4}$  th H & 8.16 (+ve) [model 58] level  $\frac{3}{4}^{th}$  H
  - ★ Shear force values are 53.87 (-ve) [model 166] level H & 58.49 (+ve) [model 178] level  $\frac{3}{4}^{th}$  H
  - ★ Bending moment values are 15411.1 (-ve) [model 178]  $\frac{3}{4}^{th}$  H level & 15411.1 (-ve) [model 178]  $\frac{3}{4}^{th}$  H level.
  - ★ The maximum principle stress value of plane stress model is 36.19 N/mm<sup>2</sup> and minimum principal stress value is 15.91 N/mm<sup>2</sup>.

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