Statistical analysis of infilled frames

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Abstract

It is known that infill walls considerably change the behaviour of frames under horizontal loads. However, on this subject, there is not enough knowledge and experience accumulations compared with some other subjects in structural analysis. In order to contribute to the behaviour of infilled frames, a series of experiments were carried out under statical loads which were applied in the diagonal direction to the infilled samples having various conjunctions and thicknesses and framed with steel profiles. During the experimental research, the decrease in the horizontal rigidity caused by the separation and sliding between the frame and the infill should be taken into consideration. It was known from previous studies that after the frame separated and slid, the infill wall acts like a compression bar; the experiment results obtained from this study also confirmed this fact. The properties of the "equivalent compression bar" that represents the infill wall were studied and designated due to the experimental data and compared with the values suggested in the literature. Experimental studies constitute the basis of the work.

1 Introduction

The spaces of the load-carrying frames were filled with brick, concrete, briquet, etc. in the vertical plane due to the aim of usage formed from architectural concept. The walls formed by this way changed the load-carrying frame systems to the infilled frame systems. Although the weight of the infill wall was given as a load on to the frame for vertical loads in the calculations of this type of load-carrying frames, because of
the reasons of complexity and difficulty in the calculation of infilled system, not having a reliable and practical calculation method, etc., generally, the influences of the infill walls to the behaviour of the structures under vertical and horizontal loads were neglected in the calculations. This neglect can be in favour of safety or sometimes bring great mistakes and unnecessary structural arrangements and details. The experimental studies about infilled steel frames has begun with Polyakov [1] and continued with the studies of Benjamin and Williams [2,3,4], Holmes [5,12], Smith and Carter [6,7,8,9], Smolira [10], Fiorata et. al. [11], Ersoy et. al. [13]. In all of these works the infill wall was idealized as “equivalent compression bar”. But now, how the infill walls effect the behaviour of the structural system and in what degree they contribute were not explained clearly and reliable calculation models could not be developed. For this reason, generally, however the infilled frames are more strengthful and rigid than the empty frames, the completed studies are in the early stage of the development and there could not be formed a standard for the calculation of infilled frames. Because of the frames being under horizontal loads and making horizontal displacements, while it was being waited to have tensile strength through one diagonal of the infill walls, there only occurs diagonal compression because of the infill wall being seperated from the frame in the tensile region. For this reason, the representation of the effect of the infilled frame’s behaviour with an “effective” compression bar lying along the diagonal, can reflect the real behaviour so closely. Here, the important thing is to determine the mechanical properties of the compression bar in terms of the properties of the infill wall.

2 Modelling of the frame

2.1 Analytical Model

The frame model being chosen as the equivalent infilled frame was shown in Figure 1. The cross-sectional and mechanical properties of the frame were subcripted with “c”; there were shown effective width of the equivalent compression bar with “w” and its length with “d”. In the equivalent frame model, there are assumptions of the compression bar being tied to the frame with the joint and it will transfer normal force only and these should be taken into consideration.

![Figure 1: Analytical model of infilled frame system.](image-url)
2.2 The modulus of elasticity of elastic homogeneous material equivalent to infill

The equivalent modulus of elasticity of effective linear homogeneous infill material which is equivalent to the infill, was calculated as in the following and used in the model of equivalent compression bar. The cross-section of the infill wall formed from "plaster + brick" and had a unit width given as in the following.

\[
E_e = \frac{2E_J t_J - E_S t_S}{t}
\]

Figure 2: Equivalent wall material

In the explanation, modulus of elasticity is shown with "E" and the thickness with "t" and there were used "e" subscript for equivalent infill wall and "s" subscript for plaster (Figure 2); the modulus of elasticity of the wall with thickness "t" was calculated by \( E_e = \frac{2E_J t_J - E_S t_S}{t} \).

3 Experiments

3.1 Members of the experiments

The NPU120, NPU140, NPU160 profiles were chosen as frame element in the series of infilled steel frames which were prepared in plastered and non-plastered conditions with various geometries, the frame lengths (L) were changed by fixing the frame heights (h) constant. Horizontal-holed bricks were used having dimensions of 19 X 18.5 X 8.5 cm. and 19.5 X 18.5 X 13 cm and Cimentas-air holed bricks having dimensions of 60 X 25 X 10 cm. as the infill material. For wall masonry cement mortar were used in the horizontal-holed brick wall, special bond glue in the air-holed brick wall and rubble mortar for plastering. The contribution of plaster thickness to horizontal rigidity was also another parameter used by this study.

3.2 The Program of the experiments

The infilled frame samples which were formed by changing their dimensions were forced along their diagonal directions and their behaviour types were established and evaluated till the failure of the infilled frame. The angle (θ) between the applied diagonal compression force and the horizontal of the frame changes according to the (h/L) ratios; this situation agrees with the application. In the experiments, having 7 samples in each series there were tested 21 samples in 3 series including one empty frame, 3 infilled and 3 infilled+plastered frames in various dimensions.
In the experiments, in the increasing load levels, the diagonal displacements and/or shape deformations of the samples were measured according to the type of the experiment and cracking load, displacement and cracking type were determined; until the infill wall of the structure cracked and failed, the experiment continued by reading the loads and displacements at definite levels. The graphics of horizontal load-horizontal displacement for these values were drawn in Figure 3.

\[ P_H \text{ Hor. load (kN)} \]

![Graph showing horizontal load-horizontal displacement curves of test samples C128-0, C128-1, C128-4.](image)

**Figure 3: Horizontal load-horizontal displacement curves of test samples C128-0, C128-1, C128-4**

### 3.3 Equivalent Compression Bar

The "w" thickness of the equivalent compression bar can be determined by the samples used in the experiment;

1. Equating the results of the finite element model and compression bar carrying frame model;
2. Investigating what the equivalent compression bar's thickness will be in order to obtain the same displacement which was measured under the applied load in the experiment and in the frame model with compression bar under the same load.

Here, following the second way the "w" equivalent compression widths and this equivalent width's ratios to the bar length "w/d" were given in Table 1.
### Table 1. Cross-Section Properties of Equivalent Compression Bar

<table>
<thead>
<tr>
<th>Exper. Mem. No</th>
<th>Horizon. Load $P_H$ (kN)</th>
<th>Horizon. Disp. $\delta_H$ (mm)</th>
<th>X-sectional Area of Equivalent Bar $A$ (m$^2$)</th>
<th>Thickness of Infill $t$ (m)</th>
<th>Width of the Equivalent Bar $w$ (m)</th>
<th>Exper. Obtained $w/d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C128-1</td>
<td>7.07</td>
<td>0.03</td>
<td>0.07</td>
<td>0.085</td>
<td>0.82</td>
<td>0.58</td>
</tr>
<tr>
<td>C128-2</td>
<td>7.66</td>
<td>0.08</td>
<td>0.085</td>
<td>0.085</td>
<td>1.0</td>
<td>0.62</td>
</tr>
<tr>
<td>C128-3</td>
<td>8.09</td>
<td>0.042</td>
<td>0.11</td>
<td>0.085</td>
<td>1.29</td>
<td>0.75</td>
</tr>
<tr>
<td>C128-4</td>
<td>7.07</td>
<td>0.05</td>
<td>0.11</td>
<td>0.12</td>
<td>0.91</td>
<td>0.62</td>
</tr>
<tr>
<td>C128-5</td>
<td>7.66</td>
<td>0.055</td>
<td>0.10</td>
<td>0.12</td>
<td>0.83</td>
<td>0.52</td>
</tr>
<tr>
<td>C128-6</td>
<td>8.09</td>
<td>0.066</td>
<td>0.09</td>
<td>0.12</td>
<td>0.75</td>
<td>0.43</td>
</tr>
<tr>
<td>C1413-1</td>
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<td>0.26</td>
<td>0.026</td>
<td>0.135</td>
<td>0.19</td>
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<td>0.037</td>
<td>0.150</td>
<td>0.165</td>
<td>0.91</td>
<td>0.61</td>
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<tr>
<td>C1413-5</td>
<td>7.77</td>
<td>0.09</td>
<td>0.065</td>
<td>0.165</td>
<td>0.39</td>
<td>0.24</td>
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<tr>
<td>C1413-6</td>
<td>8.19</td>
<td>0.159</td>
<td>0.038</td>
<td>0.165</td>
<td>0.23</td>
<td>0.13</td>
</tr>
<tr>
<td>C1610-1</td>
<td>6.69</td>
<td>0.17</td>
<td>0.08</td>
<td>0.10</td>
<td>0.8</td>
<td>0.56</td>
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<td>1.11</td>
<td>0.77</td>
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<td>0.096</td>
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<td>0.75</td>
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<tr>
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<td>0.09</td>
<td>0.10</td>
<td>0.13</td>
<td>0.77</td>
<td>0.43</td>
</tr>
</tbody>
</table>

In the equivalent compression bar approach which is simple however giving good results and suggested by Smith [8], $w/d = 0.20 \sim 0.25$ was averagely projected. These ratios were about approximately 0.35-0.60 in the works of some researchers Smith and Carter [9] and Mainstone [14]. For calculating this ratio Smith and Carter [8] suggested the following relation,

$$w/d = 0.16 (\lambda_h \cdot h)^{-0.3} \sin 2\theta$$  \hspace{1cm} (1)

In this relation, $\lambda_h \cdot h$ which is named as "rigidity parameter" and given in the following, explains the rigidity of the frame in response to the infill.

$$\lambda_h \cdot h = \left[ \frac{E \cdot t \cdot \sin 2\theta}{4E \cdot I \cdot h'} \right]^{1/4}$$  \hspace{1cm} (2)
In the dimensionless rigidity parameter, $E_1$ represents the modulus of elasticity of the infill, "t" the thickness of the infill wall, "E" the modulus of elasticity of the frame, "I" the moment of inertia of the column and "h" the height of the infill. Mainstone [14] who used the same parameter, suggested the following relation for the previously mentioned ratio:

$$w / d = 0.175 \left( \lambda_h \cdot h \right)^{0.4}$$

(3)

In order to determine the $w/d$ ratio related with the experimental researches, there was also reached the following relation that includes the rigidity parameter by discarding some of the extreme values determined in the experiments whose program has been given previously and made on the plastered and unplastered infilled frame samples in the Selcuk University Engineering – Architectural Faculty Structure Laboratory [15].

$$w/d = 0.52 \left( \lambda_h \cdot h \right)^{0.005} \sin \theta$$

(4)

The theoretical and experimental values determined by this relation were given comparatively in Table 2 and Figure 4 with the values of Smith and Carter [9] and Mainstone [14].

<table>
<thead>
<tr>
<th>Exper. Member No</th>
<th>Rigidity Parameter $\lambda_h \cdot h = \left[ \frac{E_1 \cdot t \cdot \sin 2\theta}{4E_1 \cdot I \cdot h'} \right]^{1/4}$</th>
<th>Theoretical According to Smith &amp; Carter w/d</th>
<th>Theoretical According to Mainstone w/d</th>
<th>Experimental w/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>C128-1</td>
<td>0.049847</td>
<td>0.39</td>
<td>0.58</td>
<td>0.75</td>
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<td>0.58</td>
<td>0.62</td>
</tr>
<tr>
<td>C128-3</td>
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<td>0.37</td>
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</tr>
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<tr>
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<td>0.57</td>
<td>0.62</td>
</tr>
<tr>
<td>C1413-2</td>
<td>0.052969</td>
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<td>0.57</td>
<td>0.43</td>
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<tr>
<td>C1413-3</td>
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<td>C1413-4</td>
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<td>C1413-6</td>
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<td>0.35</td>
<td>0.55</td>
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<td>C1610-1</td>
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<td>0.42</td>
<td>0.63</td>
<td>0.56</td>
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<tr>
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<td>0.33</td>
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<td>0.40</td>
<td>0.63</td>
<td>0.55</td>
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<tr>
<td>C1610-4</td>
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<td>0.59</td>
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<td>C1610-5</td>
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<td>0.59</td>
<td>0.41</td>
</tr>
<tr>
<td>C1610-6</td>
<td>0.047120</td>
<td>0.38</td>
<td>0.59</td>
<td>0.43</td>
</tr>
</tbody>
</table>
As seen in Figure 4, the theoretical and experimental results obtained by the laboratory studies are in harmony with Smith and Carter [9].

![Figure 4: The comparison of the determined values with the literature](image)

4. Results

1. The infill walls increase the rigidity of the frames in considerable amounts. The increase in rigidity having various values could not be undervalued in each of the following three phases, (I) In the phase of the behaviour of the linear elastic material (II) After the wall cracks, and (III) The failure phase.

2. The neglect of infill walls in the structural solutions (statical calculation) is a widespread application in structural engineering. However, it is also known that the structures designed like this have sufficient performances under their design loads. The present conflict can be explained by the concept that is in application and a good index for structural dimensioning. The sufficiency of the result does not show that the modelling is adequately right. However, it is difficult to take into consideration the contribution of the infill walls to the structural strength and rigidity in adequate measures. Although the present capacities of the computers give opportunity to these like analyses, these like calculations are so difficult compared with the standard projections. In that case, it is useful to continue with the equivalent compression bar approach at least "for the time being" for taking into consideration the contribution of the walls. In this approach's literature, there exist suggestions that project to take the equivalent compression bar’s width as 0.1 to 0.4 times of the diagonal length of the compression bar (Smith and Carter. 1969; Mainstone, 1974). Due to the experiment results made here, it will be a sufficient and cautious approach to take this ratio as 0.20.

3. Plaster of good quality, increases the activity of the infill wall structurally. It is clear for the plaster to be effective that its adherence with the wall and the
frame should be well; especially at the sides plaster should not exceed the frame. In the experiments carried out here, there was seen that the plaster exceeding the frame, has been easily broken off in big parts and thrown away yet in the cracking phase.

4. In the infilled frames, it was observed that the tensile diagonal of the first cracks generally take place at the frame-wall spaces of the end zones. But, it was seen that the cracks occurred at this region did not change the rigidity of the frame nearly never and the load-displacement curve continued until there had been seen body cracks on the wall or shear or compression cracks at the end of the compression diagonal.

5. Relative increase of the frame rigidity increases the length of the frame which is in contact with the infill wall during the frame’s horizontal displacement. In order to get the expected benefit from the infill wall, the rigidity of the frame should be adequate and the failure of the frame should not occur before the failure of the infill wall.

6. All the experimental studies performed here were carried out under statical loads. However, for both seismic loads and wind loads, the infill walls would be subjected to cyclic forcings. For this reason, the effective width of the compression diagonal should be taken more cautiously than the statical load conditions. Likewise, in the literature, the suggestions related with the compression diagonal width are below the ones determined with the statical experiments.

7. Again from the literature, it is known that infill walls provide the structure from more serious damages by exhausting or decreasing the structure’s kinetic energy in a small period with the seismic energy exhausted in the cracking and failure phases. In other words, dividing walls practically contribute to the structure positively in the both elastic (small earthquakes) and plastic behaviour (big earthquakes) of the structure. The important thing is to estimate the wall contribution with a right and safe approach by not going beyond the bounds.

References


