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THE EFFECTS OF INFILL WALLS WITH DIFFERENT ASPECT RATIOS AND STRENGTHS ON THE GLOBAL PERFORMANCE OF INFILLED RC FRAMES

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Abstract: *Developing reliable numerical models for infill walls has become essential given their evident contributions to the overall performance of RC frames. For probabilistic-based analyses, the single strut approach is often used to simulate masonry infills due to their inherent simplicity and their relatively low computational cost. However, due to the variability of the material and geometric characteristics of infill walls, it is essential to consider these aspects to define the properties of strut models. In this context, this study discusses the specific effects that the aspect ratio and the strength of the masonry infill have on the global performance of infilled RC frames. To support the discussion, three frames with three aspect ratios (frame height/span length) have been analysed using a detailed finite element modelling approach with three types of infills in terms of strength (weak, moderate, and strong infills). The infill contribution to the behaviour of each case was assessed to address the influence of the aspect ratio and the strength on the global performance of the infilled RC frames. Overall, the study highlights the need for further research addressing the uncertainty associated with using predefined empirical expressions that do not adequately consider the effect of certain infill characteristics, namely its geometric and mechanical characteristics, to define the properties of strut models.*

Keywords: Reinforced concrete frames, numerical modelling, Detailed finite element modelling, strut model.

1 Introduction

Diversity is a prominent aspect of building stocks around the world, reflecting different architectural purposes and materials. Regional-scale performance-based earthquake engineering (PBEE) studies try to reflect this diversity by considering different characteristics of reinforced concrete (RC) frames taxonomy (Crowley et al., 2021; Crowley et al., 2004). These characteristics include the building age, geometric aspects, seismic design level, etc. (see (Crowley et al., 2022; Crowley et al., 2021; Martins & Silva, 2020; Villar-Vega et al., 2017) among others). In a complimentarily way, the contribution of infill walls is increasingly being identified as essential for a realistic representation of the overall behaviour of RC frames, given their significant impact on performance. In this context, single strut models are found to be an efficient modelling approach for PBEE due to their simplicity and affordable computational cost. The parameters of strut models should be mostly driven by experimental data. However, due to the scarcity of such data regarding infill walls and the manifold parameters relevant for modelling their behaviour, existing PBEE studies either use strut models whose parameters are based on empirical data that might not be relevant for the structures under analysis or discard the structural contribution of infill walls altogether (De Risi et al., 2022; Di Domenico et al., 2022). Therefore, it is essential to develop reliable numerical models for infill walls, as they have a significant impact on the overall performance of RC frames under earthquake loading.

Strut models were developed in response to the observation by (Polyakov, 1956) that infill walls act as braces for the surrounding RC frame. Since then, several studies (e.g., see (Asteris et al., 2013; Asteris et al., 2011; Basha et al., 2020; Mohamed & Romão, 2020, 2021; Mohammad Noh et al., 2017) and references therein) have been proposed to quantify the structural contribution of infills. Due to the cost and resources involved in experimental tests, existing strut model properties have typically been derived from a single test (Liberatore et al., 2017) with a single or a limited number of specimens, rather than from regression analyses based on a database of experimental results. As a result, the estimates of the strut model parameters have a significant level of uncertainty (De Risi et al., 2018; Huang et al., 2020; Mohamed & Romão, 2018b). This uncertainty can be even greater when the parameters are estimated across different types of infills with various material and geometric properties, as commonly considered in regional-scale PBEE studies (Asteris et al., 2019; Del Gaudio et al., 2018; Mohamed & Romão, 2018b).

In light of this, the proposed study investigates the effect of the geometric and material variability of infill walls, more specifically the aspect ratio and the strength of the infill, on the global performance of infilled RC frames. A validated numerical modelling strategy is used to model several RC frame specimens with several aspect ratios and mechanical properties. The study highlights the urgent need to develop models that consider these parameters, and the need to define a more comprehensive approach that can accommodate the variability of infill walls.

2 Research methodology and modelling

To study the significance of the variation of infill wall characteristics, three frames with different infill walls were modelled. Table 1 presents the main characteristics of the considered cases, and Figure 1 defines these variables. Detailed Finite Element (DFE) analysis is performed using ANSYS to accurately capture the contribution of infill walls under lateral loading. The validated finite element modelling approach proposed in (Mohamed & Romão, 2018a) is adopted in this study. Figure 2 shows the schematic finite element mesh components for a one-bay and one-story masonry-infilled RC frame to illustrate the adopted modelling strategy. As can be seen, RC and masonry components are modelled using the 3D solid finite element known as SOLID65 in ANSYS (2012).

To reduce the number of element types and the computational effort, the smeared modelling approach is used for steel rebars, in which the SOLID65 element represents both the steel and concrete of RC members. The masonry brick units are modelled according to their real geometry, and contact elements along with a cohesive zone material model are used to represent the interaction between the brick units and the RC frame (Lourenço & Rots, 1997). The proposed modelling approach is able to capture the more common failure mechanisms of masonry infills and the flexural failure modes of the RC elements but does not account for the shear failure of RC elements or the cyclic degradation of materials.

To focus on the contribution of the infill wall and to minimize the effect of the surrounding RC frame from the analysis, the authors adopted the approach proposed by (Mohamed & Romão, 2021). _More specifically, for each specimen listed in Table 1, the corresponding bare RC frame was analysed using the same numerical model as for the infilled frame. The contribution of the infill wall to overall behaviour was then extracted by subtracting the results of the bare frame analysis from the results of the infilled frame analysis.

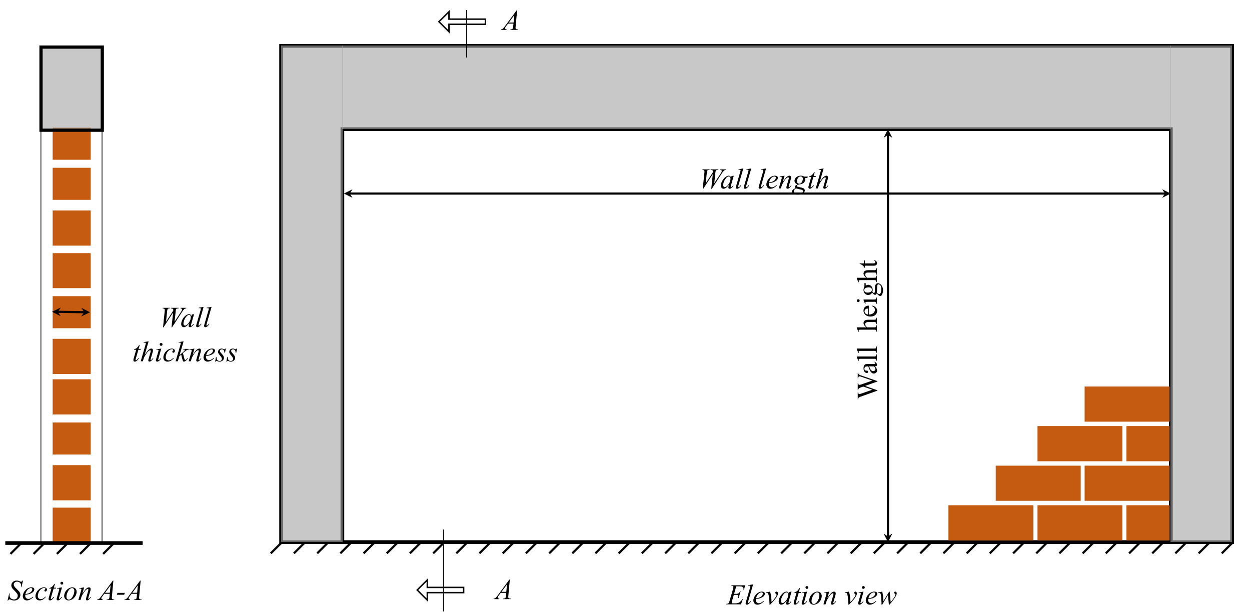


Figure 1 Definition of the considered wall variables defined in Table 1.

Table 1 The main characteristics of the considered specimens.

no	Specimen ID	Wall length L (mm)	Height H (mm)	Aspect ratio a*	Infill strength classification	Masonry compressive strength f_m MPa	Wall thickness
1	WR1	900	1150.00	0.65	Weak	1.00	110
2	WR2	1800	1150.00	1.60		1.00	110
3	WR3	2550	1150.00	2.20		1.00	110
4	MR1	900	1150.00	0.65	Moderate	3.00	110
5	MR2	1800	1150.00	1.60		3.00	110
6	MR3	2550	1150.00	2.20		3.00	110
7	SR1	900	1150.00	0.65	Strong	7.00	110
8	SR2	1800	1150.00	1.60		7.00	110
9	SR3	2550	1150.00	2.20		7.00	110

*a is the aspect ratio of the panel expressed as the wall length over its height (L/H)
The columns of RC frames were set to be 150*150 mm^2, the beam cross-sections were 150*250 mm mm^2, and the concrete compressive strength is 30 MPa

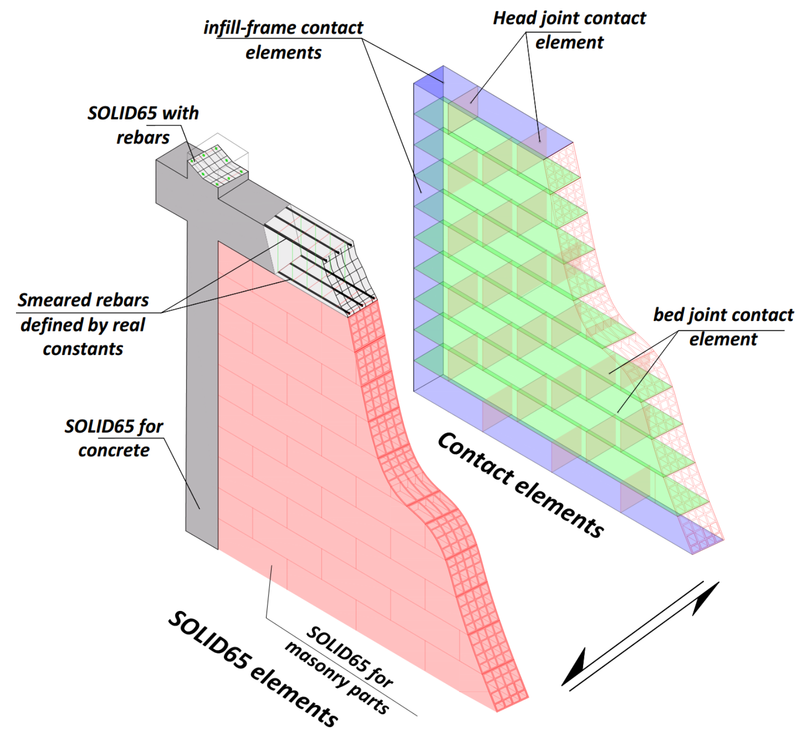


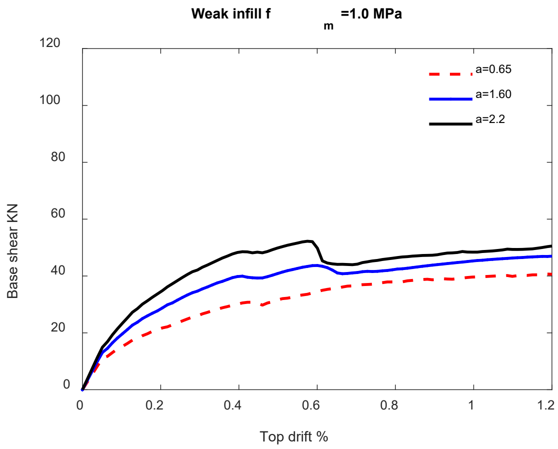
Figure 2 Adopted modelling strategy for RC element and infill walls.

3 Results and Discussion

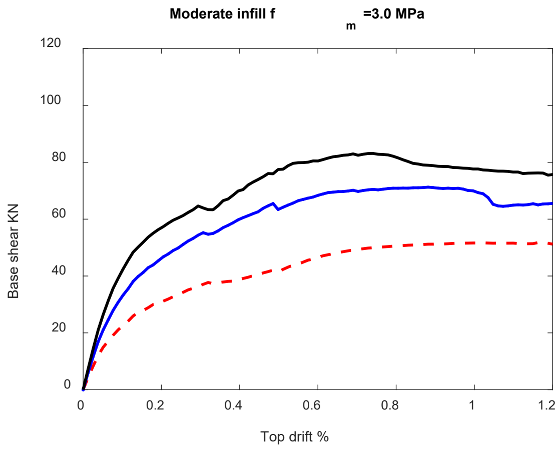
3.1 Capacity curves of the infilled frames and of the infills

The capacity curves of RC infilled frames provide comprehensive information to achieve a better understanding of their seismic behaviour. As such, capacity curves were determined numerically by applying a monotonically increasing lateral displacement at the top of each frame until reaching a lateral drift value of 1.2%. Figure 3 shows the capacity curves for three types of infills (weak, moderate, and strong) with three different aspect ratios (a=0.65, a=1.60, and a=2.20). As can be seen, infilled frames with weak infills exhibit lower lateral strength, thus highlighting the lower contribution of infills to the overall lateral strength of the structure. However, weak infilled panels in narrow infill walls show a monotonic increase in strength up to a top drift of 1.2%, which is not the case for the other two types of infills, where strength degradation is observed after a lower drift ratio. This observation can be interpreted as follows. Stronger infills are more likely to lose their integrity sooner because they exhibit higher stresses due to their higher strength and stiffness. For the moderate infills, the panels show a gradual increase in strength up to a top drift of 0.70%, followed by a gradual decrease in strength. This behaviour is attributed to the fact that moderate infills are able to sustain some damage before losing their integrity. Eventually, strong infilled panels show a sudden drop in strength after a top drift of 0.8%. This behaviour is attributed to the fact that strong infills are not able to sustain much damage before losing their integrity.

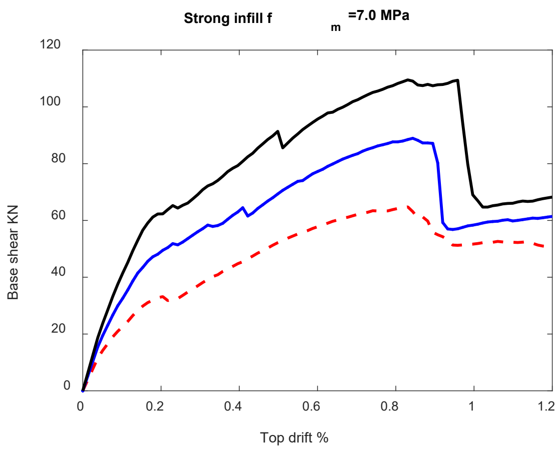
The aspect ratio of the infilled panel is seen to have a significant impact on its seismic behaviour. Narrower panels (i.e., a=0.65) show less strength capacity but have a more ductile behaviour with no sudden drop in strength, as seen in cases with strong infills (e.g., see Figure 3 c). In these cases, the overall behaviour of the infilled frame is closer to that of the corresponding bare frame. This is in contrast to the capacity curves of strong infilled panels with high aspect ratios, which typically show a sudden drop in strength at specific stage of loading (the point in which the infill starts to lose its integrity). The capacity curves of infilled panels show that the type of infill and the aspect ratio of the panel have a significant impact on their seismic behaviour.



a) Specimens WR1(a=0.65), WR2(a=1.60), WR3(a=2.2)



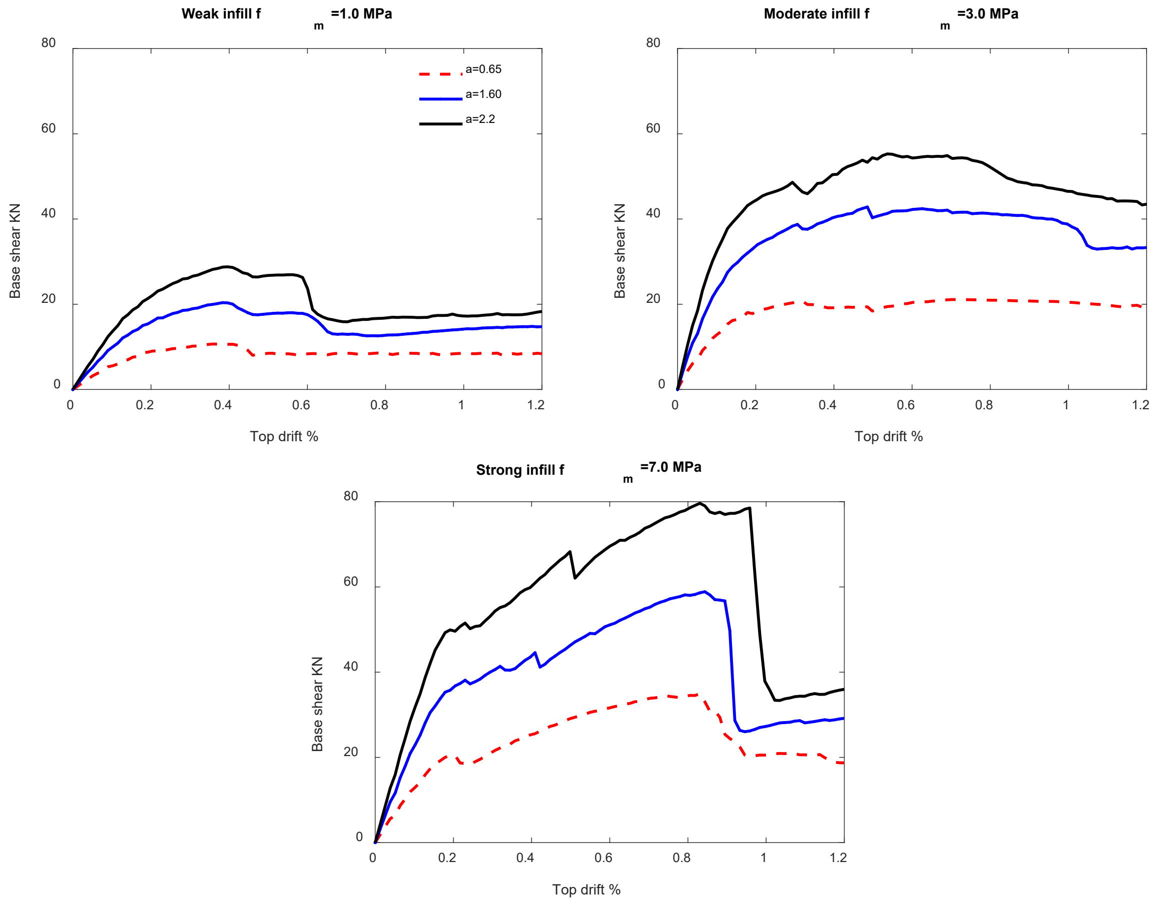
b) specimens MR1(a=0.65), MR2(a=1.60), MR3(a=2.2)



c) Specimens SR1(a=0.65), SR2(a=1.60), SR3(a=2.2)

Figure 3 Variation of RC frame with masonry infills with different aspect ratios a) weak infills b) moderate infills and c strong infills.

In order to gain a more comprehensive understanding of the contribution of the infill to the overall behaviour of the infilled frame, and to minimize the influence of the surrounding RC frame, the infill contributions were extracted from the previously shown capacity curves using the method proposed by (Mohamed & Romão, 2021). This method involves isolating the infill from the RC frame and determining its independent lateral load-carrying capacity. The infill contributions can then be used to assess the relative importance of the infill to the overall strength and stiffness of the infilled frame. Figure 4 shows the capacity curves of the infilled panels obtained by this process for the different aspect ratios and masonry compressive strengths, plotted as horizontal force against top drift ratio (in percentage). It can be seen that narrow panels with an aspect ratio of 0.65 sustain less lateral force, but do not exhibit a sudden drop in strength when compared to wider panels. This effect is more pronounced for stronger infills, which show a sudden drop of up to two-thirds of their overall lateral strength.



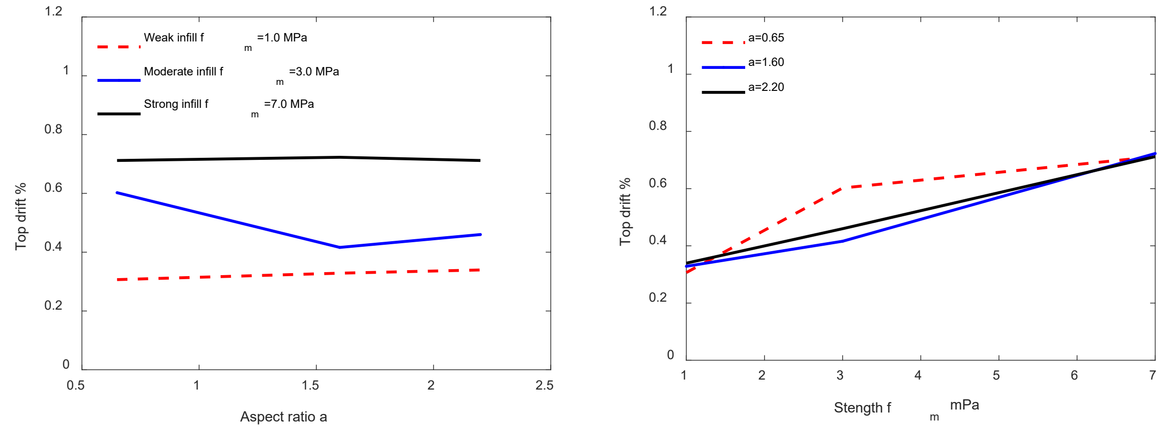
a) Specimens WR1(a=0.65), WR2(a=1.60), WR3(a=2.2)

b) specimens MR1(a=0.65), MR2(a=1.60), MR3(a=2.2)

c) Specimens SR1(a=0.65), SR2(a=1.60), SR3(a=2.2)

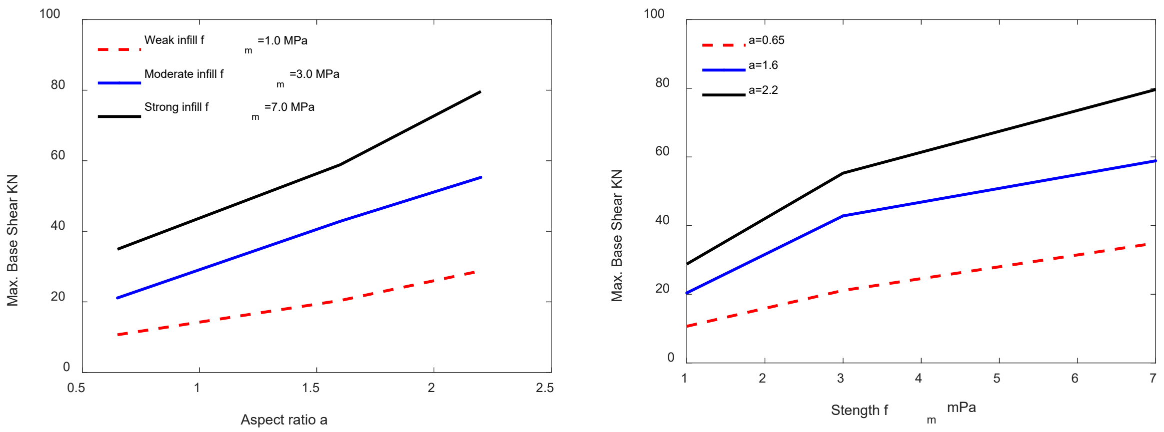
Figure 4 Contribution of infill walls with different aspect ratios a) weak infills b) moderate infills and c) strong infills.

For a more comprehensive understanding, Figure 5 and Figure 6 show the variation of the top drift ratio (corresponding to the maximum lateral force) and maximum lateral of the infilled panel, respectively, with the aspect ratio of the panel and masonry compressive strength. In these plots, it is clear that the panel aspect ratio has less effect on the top drift ratio corresponding to the maximum force than the strength of the masonry. In other words, low-strength infills will reach their damage state significantly faster than high-strength infills. This is important for PBEE analyses, since damage state limits are essential for estimating earthquake losses. In contrast, the maximum lateral force of the panel is significantly affected by both the strength of the masonry and the aspect ratio of the panel.



a) b)

Figure 5 Variation of drift corresponding to maximum strength with a) aspect ratio b) strength of masonry.



a) b)

Figure 6 Variation of drift corresponding to maximum strength with a) aspect ratio b) strength of masonry.

3.2 Reliability of existing models

As mentioned in the previous section, existing empirical models are derived from a limited number of specimens, which may limit their ability to represent a wide range of infill wall geometries and strengths. In this context, Figure 7 shows a scatter plot of the observed lateral contribution of infill walls against the empirically estimated values based on commonly used models in literature (Bertoldi et al., 1993; Durrani & Luo, 1994; Mainstone, 1971; Moghaddam & Dowling, 1988; Te-Chang & Kwok-Hung, 1984; Turgay et al., 2014). From these results, it is clear that none of these models accurately estimated the observed lateral strength for different infill panel characteristics or exhibited a uniform uncertainty around the real values. Moreover, some models overestimated or underestimated the lateral strength by a large margin. These observations suggest that the infill wall aspect ratio and strength can significantly influence the structural behaviour.

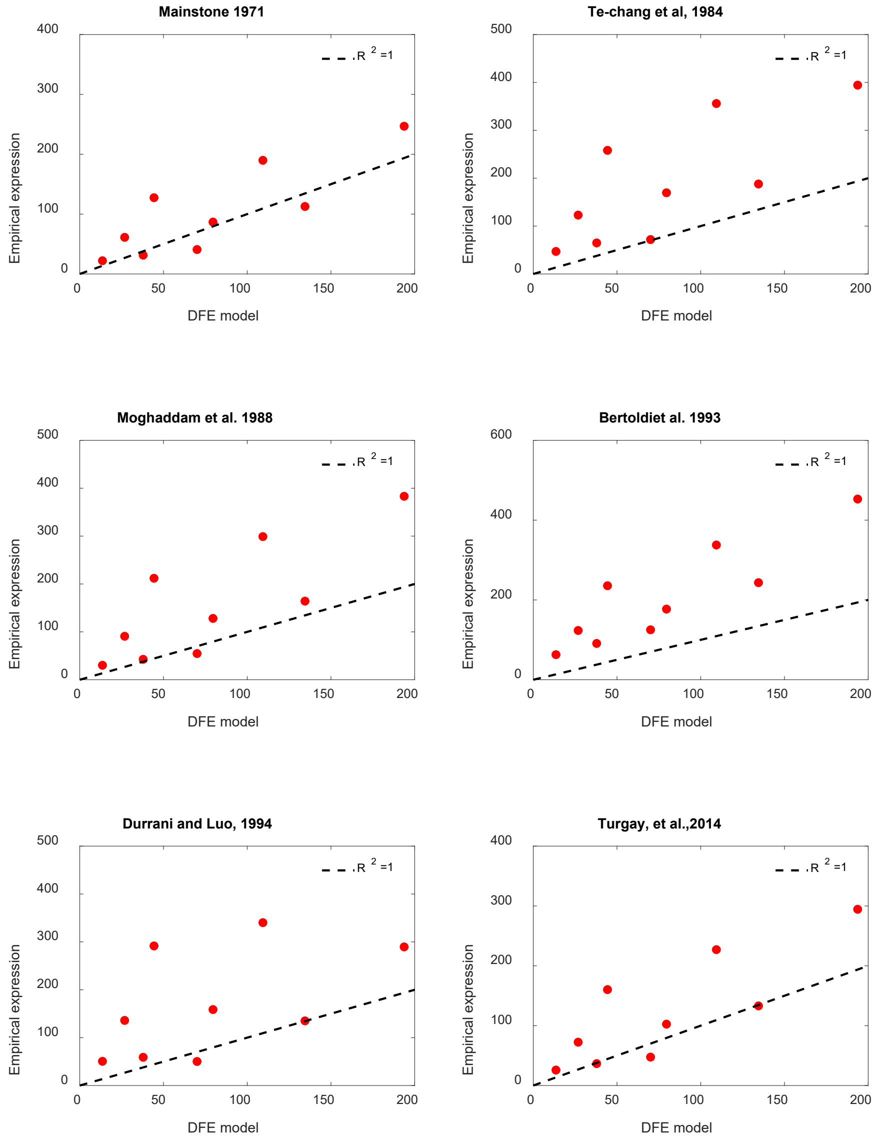


Figure 7 Scatter plots representing estimated infill contribution in terms of strength using different empirical expressions versus the strength obtained from the detailed finite element model.

4 Conclusion

Single strut models are widely used in PBEE analyses due to their advantages in terms of modelling and computational cost. However, their use for modelling the behaviour of buildings with different infill characteristics can lead to inaccurate results, as they are typically derived from a limited number of experimental tests. This results in significant uncertainties in the estimated parameters of the infill mechanical characteristics, which is even greater when the parameters are generalized across different types of infill with various material and geometric properties.

To shed light on this issue, the proposed study investigates the effect of variations in geometric and material properties of infill walls on the global performance of infilled RC frames. Results indicate that both the aspect ratio and the compressive strength of the masonry have a significant impact on the overall performance of RC frames with masonry infills. Furthermore, none of the tested empirical expressions were able to predict the expected behaviour of the infill walls modelled using a detailed finite element approach. The study highlights the need for empirical models that define the mechanical characteristics of strut models to consider these parameters, and the need to define a more comprehensive approach that can accommodate the variability of characteristics of infill walls.

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