Available online at www.eccomasproceedia.org
Eccomas Proceedia COMPDYN (2017) 3367-3379

ECCOMAS Proceedia

COMPDYN 2017
6th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Rhodes Island, Greece, 15–17 June 2017

# SIMPLIFIED MODELING OF MASONRY INFILL WALLS WITH HORIZONTAL SLIDING JOINTS

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**Keywords:** infilled frame design, deformable infill, analytical formulation, strut model, in-plane response, column shear action.

***Abstract.*** *The vulnerability of masonry infilled frame structures has been demonstrated by many recent earthquakes and research studies and it is often triggered by the in-plane interaction between the flexible frame and the masonry infill (characterized by an inherent higher stiffness). Among the different solutions studied to mitigate such issue, a deformable infill typology with horizontal sliding joints has been proposed and tested by the authors in previous studies, capable of reducing the infill-frame interaction and of limiting the damage in the masonry, so that also the out of plane infill stability is maintained.*

*This paper proposes a simplified approach to assess the seismic performance of this innovative masonry infill typology. Analytical formulations, based on geometrical and mechanical properties, are proposed to describe the in-plane response of the infill and its interaction with the bounding frame. Thanks to these formulations, a simplified numerical model for the infill, adopting an equivalent strut approach, is calibrated to be used in the non-linear analysis of infilled frame structures, accounting for their cyclic response. The reliability of the method is validated trough the comparison of the estimated infill resistance and shear demand on the column with those obtained from an extensive experimental campaign and numerical study based on refined finite element models. The results show the efficiency of the proposed simplified model in estimating the response of the infilled RC frame, in particular the shear action in the frame columns, which are the critical element of the structure.*


Peer-review under responsibility of the organizing committee of COMPDYN 2017.
doi: 10.7712/120117.5651.18605

## 1. INTRODUCTION

Over the last decades, several research studies [1]–[7] and field evidence[8], [9] stressed the seismic vulnerability of masonry infilled reinforced concrete (RC) structures. In these structures the seismic response is highly affected by the presence of stiff masonry infills, which significantly modify the RC bare frame response, triggering, in many cases, brittle and unexpected collapse. Due to the heterogeneity of the masonry infills and their scattered material properties, the infill-frame interaction modeling is still a rather challenging task for practicing engineers, so that in most cases the structural effect of the infills is ignored in the seismic design of the structures.

In the last years, several authors have focused on the masonry infill vulnerability and different innovative solutions have been proposed with the aim of reducing the infill-frame interaction, as reducing the forces transferred between the frame and the infill can reduce both the structural element vulnerability and the infill damage. The proposed solutions reached the aim with different approach: (i) partitioning of the infill wall [10]–[16]; (ii) adopting alternative joints instead of mortar (dry or plastic joints) [17]–[21]; (iii) using deformable materials for the construction of the infill [22], [23].

This paper deals with the in-plane response of masonry infill with horizontal sliding joints, subdividing the wall into sub-portions, as proposed in [12], [13]. A simplified numerical model, adopting an equivalent strut approach, is presented and validated. The model is proportioned on an analytical model first presented in [23], which is based on simple equilibrium equations. The calibration of the strut model is based on the parametric study of an infilled RC frame performed in [24], modelled with refined FEM according to [25]. In literature [26]–[28] different configurations of equivalent strut have been suggested to reproduce the effects of the infill-frame interaction. Both single or multiple diagonal struts, oriented to the frame joints or eccentric, were proposed, the latter meant to reproduce the shear action in the columns or beams.

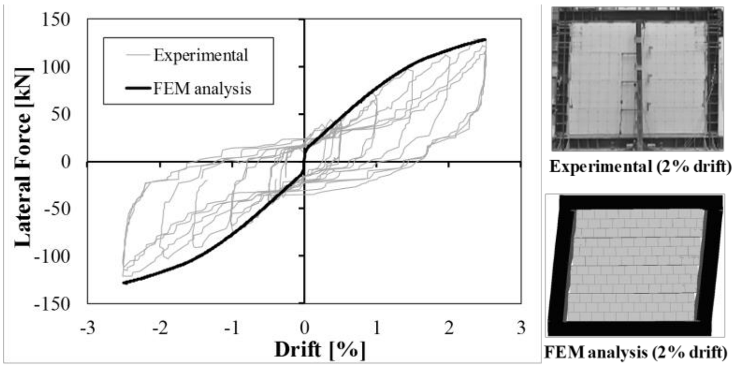
In this study two different configurations have been calibrated: (i) one with a single strut per diagonal, spanning between the frame joints, (Model A, in the following) and (ii) the other with one single strut per direction, linked with the columns at a calibrated distance (Model B, in the following), in order to reproduce the column shear action produced by the infill-frame interaction.

The comparison with the experimental and numerical results of single-bay, single-story frames [13], [24]. shows that the proposed approach can fairly reproduce both the important features of the infill response (including the initial stiffness, peak strength, and post-yielding behavior) and the effects of the infill-frame interaction, in terms of maximum column shear.

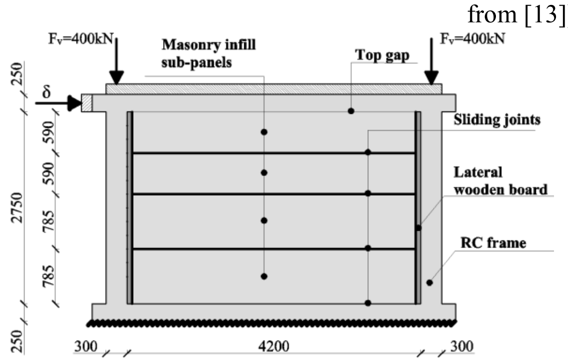
## 2. INFILL TYPOLOGY AND PERFORMANCES

The innovative construction technique proposed and experimentally assessed in [12], [13] consists in partitioning the infill wall into several sub-portions by the introduction of horizontal sliding joints at selected locations along the height (Figure 1a, b). Such solution increases the deformability of the infill, associated to the in-plane relative sliding between the infill sub-portions. To reduce the contact forces along the columns-infill interface and delay crushing of the masonry, deformable elements are placed on both the sides of the infill. In addition, a small gap is maintained between the infill and the beam above to avoid their contact and the consequent interaction.

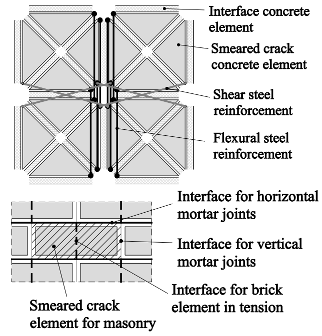
The in-plane cyclic response of an infill prototype, tested in a confining steel frame with the hinged at the column-beam joints, is reported in Figure 1a, showing a ductile response characterized by a low strength and stiffness. Moreover, the infill showed only minor damage in some masonry sub-portion, after exceeding 2% drift.



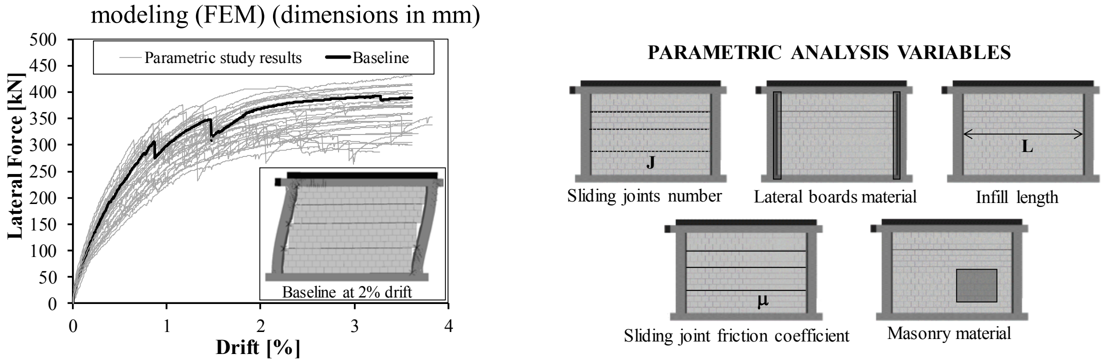

(a) steel frame infilled with a masonry wall partitioned by horizontal sliding joints: test layout and results (adapted from [13])




(b) layout of the RC infilled-frame object of the finite element modeling (FEM) (dimensions in mm)




(c) concrete and masonry FEM schematic




(d) results of the parametric analysis on the masonry infilled RC frame(adapted from [24])

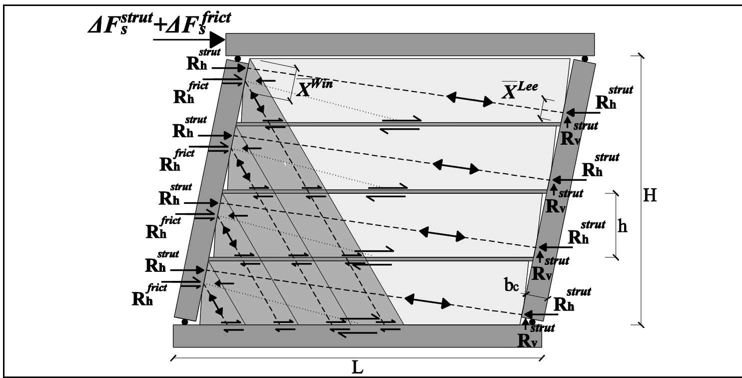
Figure 1. Synthesis of the results of previous research works on infilled frame with horizontal sliding joints and schematic of the finite element modeling (FEM) adopted.

The efficiency of such an infill typology in the application to reinforced concrete (RC) frames was extensively tested in [11] and numerically assessed in [24] by means of a refined finite element based on smeared crack and interface elements (Figure 1b, c), calibrated on the experimental mechanical properties of the different components. Such numerical model allowed to perform a parametric study investigating the role of mechanical and geometrical properties of the infill. The main results of the study are recalled in Figure 1d. Moreover, these analyses quantified the contact forces transferred by the infill to the frame columns, at the subpanel corners, which increase the shear forces acting on the RC columns compared to the bare frame response. It was observed that the shear actions on the columns increase as the imposed inter-story drift increases, and for drifts larger than 1% the shear demand on the column can have similar intensity as that in the case of traditional solid masonry infills. Therefore, despite the severe reduction of the infill stiffness and vulnerability due to the infill partitioning the design of the RC frame columns has to take this shear demand into account.

## 3. ANALYTICAL MODEL FOR THE INFILL

The analytical model here presented stems from a first analytical interpretation of the experimental response of an infilled steel frame presented in [23], then developed in [24], [29], [30], supported by the results of a refined finite element model. The proposed formulations provide an estimate of the infill net contribution ($\Delta F_s$) to the frame lateral strength, based on simple equilibrium equations, that, added to the bare frame lateral strength, provides the overall infilled frame resistance.

The contact forces to be considered in the equilibrium to rotation around the column base hinge result from the superposition of the effects of two different resisting mechanisms in the infill: the compression of the sub-portion along their diagonal ("strut mechanism",) and the friction activating by the sliding of the masonry sub-portion on the horizontal joints ("frictional mechanism"). The graphical illustration of the two mechanisms is reported in Figure 2 and the infill lateral strength can be expressed as the sum of the two contributions ($\Delta F_s = \Delta F_s^{strut} + \Delta F_s^{frict}$).




| | |
|---|---|
| $\Delta F_s$ | Infill strength contribution |
| $R_n$ | Resultant of the contact forces in the n[th] infill sub-portion |
| $R_{h,n}$ , $R_{v,n}$ | Horizontal and vertical components of the contact force $R_n$ |
| $\bar{X}_n$ | Contact length |
| h | Sub-portion heigth |
| H | Infill heigth |
| $b_c$ | Column width |
| L | Infill length |
| Apex "*Lee*" and "*Win*" refers to Windward and Leeward columns, respectively. | |

Figure 2. Static scheme adopted in the analytical model with details of the contact forces between the frame columns and the masonry infill.

Equation (1) provides the infill strength contribution due to the "strut" mechanism, obtained considering both the pertaining horizontal and vertical components of the contact forces on the columns. Such formulation is obtained under the hypothesis that, per each sub-portion, the horizontal components ($R_{h,n}^{strut} = \sigma_c \cdot \beta \cdot \overline{X}^{Lee} \cdot t$) have the same intensity on the two columns. In contrast, the vertical ones ($R_{v,n}^{strut}$) differs: on the windward column, they are proportional to the horizontal component through the contact friction coefficient ($\mu_C$), while on the leeward side the vertical contact force component is smaller as the resultant is oriented along the sub-portion diagonal (with inclination $\alpha$).

$$\Delta F_s^{strut} = \sigma_c \cdot \beta \cdot \overline{X}^{Lee} \cdot t \cdot \left[ \left( 1 - \beta \cdot \frac{\overline{X}^{Lee}}{h} \right) + \frac{b_c}{2h} \left( \mu_c + \tan\alpha \right) \right] \tag{1}$$

$$\Delta F_s^{frict} = \frac{1}{2} \cdot \left[ W + N \cdot R_{h,n}^{strut} \cdot \left( \mu_c - \tan\alpha \right) \right] \cdot \left( \frac{1}{1 - \mu_j . \mu_c} \right) \cdot \mu_j \tag{2}$$

This difference of the two vertical contact forces increases the normal stress on the horizontal sliding joints, thus affecting also the "frictional mechanism". Therefore, the analytical formulation for the contribution to the infill lateral strength due to the "frictional mechanism" results in Equation (2), where the unbalanced vertical contact force is summed to the sub-portion self-weight.

According to Equations (1) and (2), the lateral strength of the infill can be estimated once geometrical and material properties of the infill are known, except for the contact length ($\overline{X}_n$). In detail the required parameters are: the infill-column contact compression strength ($\sigma_c$), the infill thickness ($t$), the sub-portion height ($h$), the column width ($b_c$), the friction coefficient along the infill-column contact ($\mu_c$) and along the horizontal sliding joints ($\mu_j$), the sub-portion diagonal inclination ($\alpha$), the infill self-weight ($W$) and the number of sub-portions ($N$). The only parameter not a-priori defined is the contact length between the columns and the infill sub-portions ($\overline{X}_n$). The quantification of such parameter, varying the imposed lateral drift and the number of sub-portions, can be estimated with Equation (3), which was calibrated on the parametric study presented in [24]. It is worth noting that in Equation (1) a stress block approach for the estimate of the contact stress is adopted, assuming a reduction coefficient ($\beta$) for the contact length, taken equal to 0.8.

$$\begin{cases} \overline{X} = \left[ 0.3 - 0.019 \cdot (N-4) \right] \cdot Drift[\%] & Drift \le 1\% \\ \overline{X} = 0.3 \cdot \sqrt[3]{Drift[\%]} - 0.019 \cdot (N-4) & Drift > 1\% \end{cases} \tag{3}$$

### 3.1. Evaluation of the maximum column shear action in moment resisting frames

The same superposition approach adopted for the infilled frame lateral resistance allows to quantify the shear action in the columns, accounting for the infill-frame interaction, with acceptable approximation. The additional column shear due to the infill-frame interaction can be obtained after the quantification of the contact forces. The shear developing in the column due to the transfer of the bending moments at the frame joints is quantified considering the response of the bare frame, as a function of the drift.

Figure 3 shows the static scheme for the equilibrium Equations (4), proposed for the evaluation of the columns' shear located at their top or bottom end. Equation (5) specifies the calculation of the column shear action for the windward column top end, which is typically the most stressed section. $R_{h,n}$ is the horizontal components of the contact forces for the n$^{th}$ sub-portion, $h_n$ is the distance between $R_{h,n}$ and the base hinge, while $M_{col}^{top}$ and $M_{col}^{bottom}$ are the beam-column joint bending moments. Since the vertical component of the contact stresses plays a secondary role, its contribution is neglected in Equation (4).

The values of the contact forces to be adopted in the equations are those provided in the previous paragraph, considering that, on the windward column both the "strut" and "frictional" mechanism contribute to the contact force, while on the leeward column only the "strut" mechanism is involved. Equations (7) and (8) quantify the relevant contributions to the column shear actions.

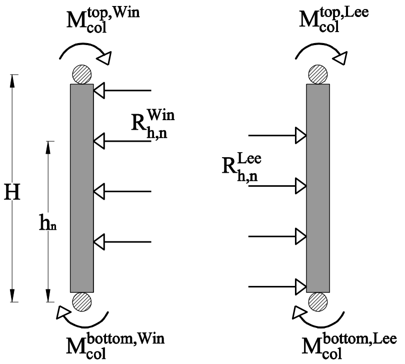



Figure 3. Static scheme for the analytical evaluation of the columns shear action for a moment resisting frame infilled with horizontal sliding panels.

$$V = V^{\inf} + V^{bare} = V^{\inf} + \frac{M_{col}^{top} + M_{col}^{bottom}}{H} \tag{4}$$

$$V_{top}^{\inf,Win} = \frac{\sum R_{h,n}^{Win} \cdot h_n}{H} = V_{top}^{strut,Win} + V_{top}^{frict,Win} \tag{5}$$

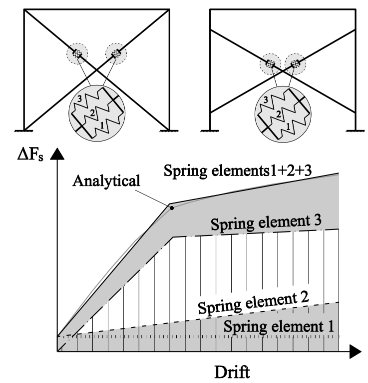
$$V_{bottom}^{\inf,Lee} = V_{top}^{strut,Win} \tag{6}$$

$$V_{top}^{strut,Win} = \frac{1}{H_{col}} \sum_{n=1}^{N} \left[ R_{h,n}^{strut} \cdot \left( n \cdot h - 0.4 \overline{X}^{Lee} \right) \right] = R_{h,n}^{strut} \cdot \left( \frac{N+1}{2} - 0.4 \frac{\overline{X}^{Lee}}{h} \right) \tag{7}$$

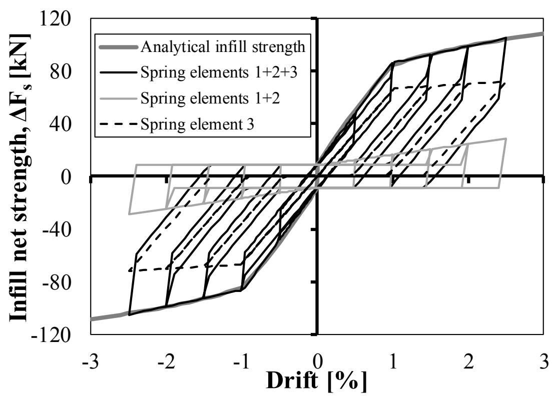
$$V_{top}^{frict,Win} = \frac{1}{H_{col}} \sum_{n=1}^{N} \left[ R_{h,n}^{frict} \cdot \left( n \cdot h - \frac{1}{2} h \right) \right] = R_{h,n}^{frict} \frac{N}{2} \tag{8}$$

## 4. SIMPLIFIED EQUIVALENT STRUT MODEL

The analytical model presented in the previous chapter allows for the calibration of a simplified strut model to be used for the analysis of multi-story buildings, for which a refined FE model would be too much time-consuming in design practice. The proposed approach models the infill by means of one compression-only truss element per infill diagonal (Figure 4a), calibrated to reproduce the previously described “strut” and “frictional” mechanisms. To this aim, each diagonal strut is equipped with three parallel non-linear spring elements with the constitutive laws reported in Figure 4a: Spring 1 has an elastic-perfectly-plastic behavior with an initial rigid branch, accounting for the “frictional” contribution provided by the sole self-weight; Spring 2 is characterized by a slip bilinear hysteretic law, calibrated to account for the hardening in the “frictional” mechanism, due to the ”strut” mechanism; Spring 3 has a slip bilinear hysteretic rule, obtained with reference to the analytical contribution of the “strut” mechanism or simply by subtraction of the response of Spring elements 1 and 2 from the analytical total infill capacity curve.




(a) monothonic response and spring elements layout



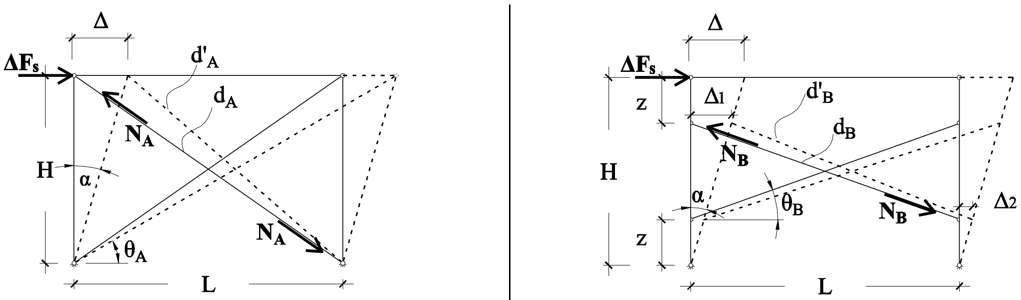

(b) cyclic response

Figure 4. Net lateral strength contribution of the infill equivalent strut model, and details of the different non-linear spring elements response.

The cyclic response provided by the selected set of springs is reported in Figure 4b, and is capable of reproducing the cyclic degradation associated to the strut mechanism.

The strut model is here proposed in two different configurations (Figure 4a): the first ("Model A") has the diagonal struts linked to the frame joints, while in the second ("Model B") the diagonals are eccentric to the joints. Both the models are suitable for reproducing the lateral strength contribution of the infill, but only Model B can capture the shear increase on the frame columns due to the infill-frame interaction.

The model parameters are assessed according to Figure 5. The spring axial behavior ($N/\Delta d$) is calibrated to reproduce the target infill lateral force-drift curve ($\Delta F_s$-$\Delta$) by means of Equations (9) to (14), where $d$ and $d'$ are the un-deformed and deformed diagonal length, $\vartheta$ is the diagonal strut inclination, $z$ is the distance of the strut from the nearest frame node, $H$ and $L$ are the bay height and length, $\Delta_1$ and $\Delta_2$ are the horizontal displacement of the two opposite strut-to-column connections. In Model B, Equation (15) quantifies the maximum shear action in the columns produced by the strut ($V_{\max}^{col}$). The choice of the $z$ value targets both the shear action ($V_{\max}^{col}$) on the columns and the net infill lateral strength ($\Delta F_s$), as obtained from the analytical model for a selected design target drift (Equation (16)).




(a)

$$N_A = \Delta F_s \cdot \sqrt{1+\left(\frac{H}{L}\right)^2} \tag{9}$$

$$\Delta d_A = \Delta \cdot \cos\theta_A \tag{10}$$

$$k_A = \frac{N_A}{\Delta d_A} \tag{11}$$

(b)

$$N_B = \frac{\Delta F_s \cdot \sqrt{1+\left(\frac{H-2z}{L}\right)^2}}{\left(1-\frac{2z}{H}\right)} \tag{12}$$

$$\Delta d_B = (\Delta_1 - \Delta_2)\cdot \cos\theta_B = \frac{\Delta}{H}(H-2z)\cdot\cos\theta_B \tag{13}$$

$$k_B = \frac{N_B}{\Delta d_B} \tag{14}$$

$$V_{\max}^{col} = N_B \cdot \cos\theta_B \cdot \left(1-\frac{z}{H}\right) \tag{15}$$

Figure 5. Static scheme for Model A (a) and Model B (b) adopted in the simplified model of the infilled frame.

$$z = h\frac{V_{\max}^{col} - \Delta F_s}{2V_{\max}^{col} - \Delta F_s} \tag{16}$$

## 4.1. Validation of the strut model

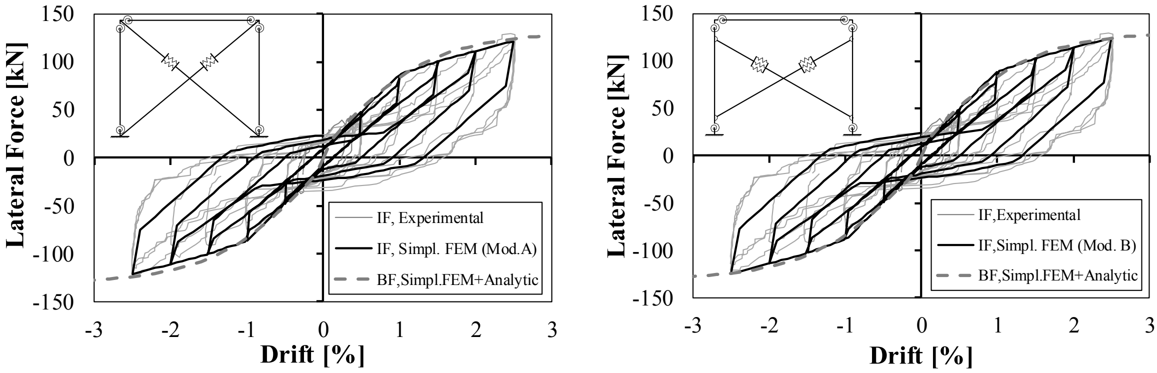
The efficiency of the proposed strut model in reproducing the infilled frame response is validated through the comparison with the results of the experimental specimen described in [13] and those obtained from the numerical study presented in [24]. For the two case studies, the adopted parameters for the springs, adopting both Model A and Model B, are summarized in Table 1. For Model B, a 2% target drift is chosen for the calibration of $z$.

Table 1. Equivalent strut parameters calibrated on the analytical model to capture the experimental response of the infilled steel frame ([13]) and the numerical results of the infilled RC frame ([24]).

| | | Horizontal component at the beam level ($\Delta F_s$) | Simplified strut model (Model A) | Simplified strut model (Model B) |
|---|---|---|---|---|
| **EXPERIMENTAL INFILLED STEEL FRAME [Preti et al.2015]** | | | | |
| **Geometry** | **Bay** | H=2.43m; L=2.93m | | |
| | **Infill** | | θ=40.5° | z=0.827m; θ=14.8° |
| **Spring Calibration** | **Spring element 1** ***(W=17.09kN, $\mu_j$=0.5)*** | $F_y$= W $\mu_j$= 8.54 kN<br>$k_{in}$=43000 kN/m<br>$k_2$=0 kN/m | $N_y$= 11.10 kN<br>$k_{in}$=1442057 kN/m<br>$k_2$=0 kN/m | $N_y$= 27.69 kN<br>$k_{in}$=8972360 kN/m<br>$k_2$=0 kN/m |
| | **Spring element 2** | $F_y$= 0.00001 kN<br>$k_{in}$=inf kN/m<br>$k_2$=341.65 kN/m | $N_y$= 0.00001 kN<br>$k_{in}$= inf<br>$k_2$=577 kN/m | $N_y$= 0.00001 kN<br>$k_{in}$= inf<br>$k_2$=3588 kN/m |
| | **Spring element 3** | $F_y$=67.66 kN (at 1% drift)<br>$k_{in}$=2784 kN/m<br>$k_2$=147 kN/m | $N_y$= 87.9 kN (at 1% drift)<br>$k_{in}$= 4699 kN/m<br>$k_2$= 249 kN/m | $N_y$= 219.26 kN (at 1% drift)<br>$k_{in}$= 29240 kN/m<br>$k_2$= 1549 kN/m |
| **NUMERICAL INFILLED RC FRAME [Bolis et al.2016]** | | | | |
| **Geometry** | **Bay** | H=2.8m; L=4.2m | | |
| | **Infill** | | θ=33.7° | z=0.901m; θ=13.4° |
| **Spring Calibration** | **Spring element 1** ***(W=28.22kN, $\mu_j$=0.5)*** | $F_y$= W $\mu_j$= 14.112 kN<br>$k_{in}$=141120 kN/m<br>$k_2$=0 kN/m | $N_y$= 16.96 kN<br>$k_{in}$= 2038400 kN/m<br>$k_2$=0 kN/m | $N_y$= 40.70 kN<br>$k_{in}$= 11737657 kN/m<br>$k_2$=0 kN/m |
| | **Spring element 2** | $F_y$= 0.00001 kN<br>$k_{in}$=inf kN/m<br>$k_2$=260.48 kN/m | $N_y$= 0.00001 kN<br>$k_{in}$= inf<br>$k_2$=376 kN/m | $N_y$= 0.00001 kN<br>$k_{in}$= inf<br>$k_2$=2167 kN/m |
| | **Spring element 3** | $F_y$=49.78 kN (at 1% drift)<br>$k_{in}$=1778 kN/m<br>$k_2$=60.9 kN/m | $N_y$= 59.83 kN (at 1% drift)<br>$k_{in}$= 2568 kN/m<br>$k_2$= 88 kN/m | $N_y$= 143.56 kN (at 1% drift)<br>$k_{in}$= 14787 kN/m<br>$k_2$= 507 kN/m |

The diagonal struts are applied into a frame modeled with beam elements and lumped plasticity, representing both flexural and shear non-linear behavior.

Figure 6 shows the comparison between the cyclic capacity curve of the simplified model and the result of the cyclic quasi-static test on the infilled steel frame ([13]). Both the proposed configurations (Model A and Model B) provide a fairly good approximation of the experimental curve, with only a slight underestimation of the dissipation capacity. In this case, no experimental data on the column shear action are available for comparison.



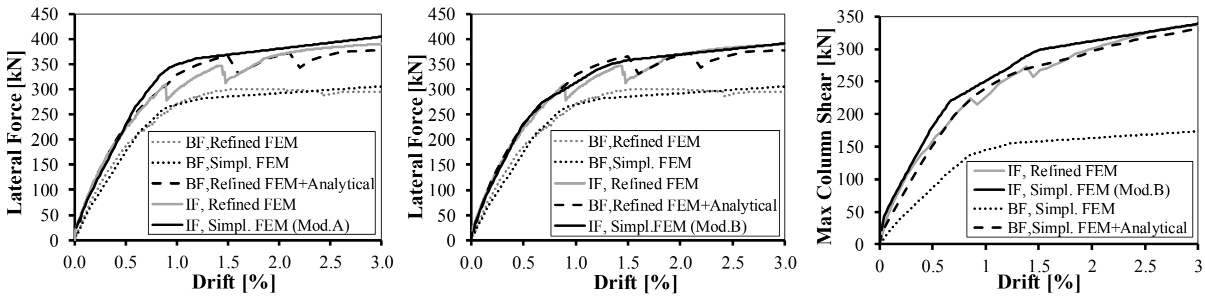

(a) Model A (b) Model B

Figure 6. Simplified model of the experimental infilled steel frame with sliding joints tested by Preti et al. (2015)

Figure 7a,b show the comparison between the capacity curves obtained with the simplified ("Simpl.FEM") and the refined ("Refined FEM") numerical model for the bare ("BF") and infilled ("IF") frame studied in [24]. Similarly to the comparison with the experimental steel frame, both the proposed configurations of the strut model (Model A and B) offer results well matching those of the refined numerical model results. As for the shear in the columns, Figure 7c highlights a safe-sided slight over-estimation obtained with the strut model (Model B). For completeness, Figures 6 and 7 report also the analytical prediction of the monothonic response, obtained from the superposition of the analytical infill contribution to the bare frame response.

Below, the validation of the simplified strut model has been extended with the comparison with some of the results of the parametric study reported in [24]. Figure 8 shows the results of the comparison for 9 different case studies, whose properties are reported in Table 2. The results of both the simplified model (Model A and Model B) are reported, normalized over the refined FEM results.

Also in these cases the result of the superposition of the analytical infill contribution to the bare frame is reported, for comparison.




(a) Force-vs.-Drift curve (Model A) (b) Force-vs.-Drift curve (Model A) (c) Max.column shear-vs.-Drift curve (Model B)

Figure 7. Comparison of the simplified and refined modeling of the reference infilled RC frame.

Table 2. Properties of the studied cases in the parametric comparison between the refined numerical model, the analytical model and the simplified models.

| **Parameters** | | **Case 1 (Baseline)** | **Case 2** | **Case 3** | **Case 4** | **Case 5** | **Case 6** | **Case 7** | **Case 8** | **Case 9** |
|---|---|---|---|---|---|---|---|---|---|---|
| N° infill sub-panel | N | 4 | 7 | 14 | 4 | 4 | 4 | 4 | 4 | 4 |
| Friction coefficient | $\mu_j$ | 0.5 | 0.5 | 0.5 | 0.05 | 1 | 0.5 | 0.5 | 0.5 | 0.5 |
| Infill length | L [m] | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 3 | 6 | 4.2 | 4.2 |
| Contact yielding stress | $\sigma_c$ [kN/m$^2$] | 2200 | 2200 | 2200 | 2200 | 2200 | 2200 | 2200 | 1040 | 3210* |

*the masonry yielding stress is adopted (2700 MPa)

On the first line of Figure 8 the comparison is reported in terms of infilled frame in-plane response for three different drift levels (0.5%, 1%, and 2%). It can be observed that at small drifts such as 0.5%, the comparison shows an approximation with an error lower than 20% except when the contact material located at the column-infill interface is stronger than masonry (Case 9). However, for larger drift, the error diminishes below 15% for all cases, with the tendency of overestimation as the drift grows to 2%. On the second line of Figure 8, the evaluation of the maximum column shear action is reported for the same three drift levels. As observed for the lateral strength, the error remains below 25% in the worst case, for 0.5% drift. The error reduces below 15% for 1% and 2% drift and shows the tendency for a safe-sided overestimation as the drift gets larger.

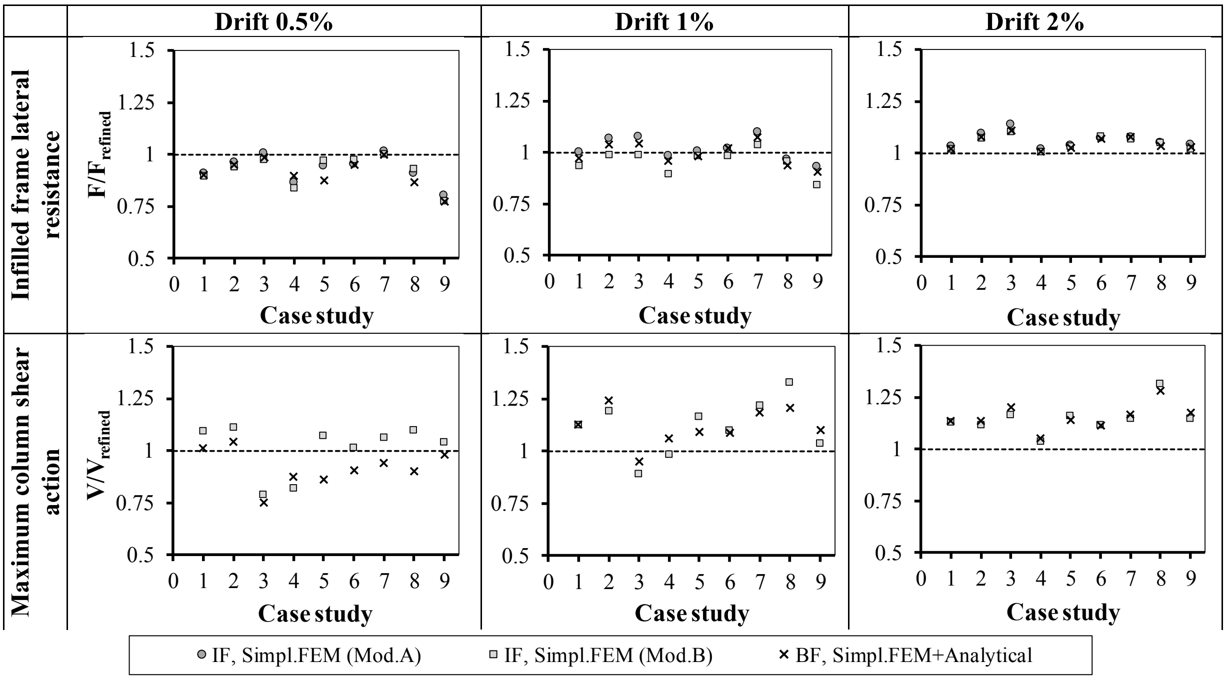



Figure 8. Results of the parametric analysis performed with the analytical and equivalent strut models, normalized on the values obtained from the refined FEM analyses, in terms of infilled frame lateral strength (F) and column shear action (V).

## 5. CONCLUSIONS

In this paper a simplified modeling approach is presented for the estimate of the infill-frame in-plane interaction when a masonry infill partitioned with horizontal joints is adopted. The approach is based on an equivalent strut numerical macro-model, calibrated on analytical formulations, capable of reproducing both the infill lateral strength contribution and the maximum column shear produced by the interaction.

The proposed analytical formulations originate from simple equilibrium equations based on few geometrical and mechanical properties of the infill, namely the infill geometry and weight, the number of sliding joints and their friction coefficient, the column-infill contact yielding stress. A basic parameter is the length of such contact, whose analytical estimate is proposed, as a function of the interstorey drift.

Based on these analytical formulations, a simplified macro-model suitable for numerical analyses of multi-story buildings is proposed and calibrated. The model reproduces the interaction of the infill with the structural frame by means of diagonal struts. Two different configurations have been proposed: the first (Model A) is only capable of reproducing the interaction in terms of contribution of the infill in the frame lateral strength; the second (Model B) allows also to reproduce the maximum shear action in the columns during the in-plane response.

The validation of the proposed models is performed by means of the comparison of their results with those obtained experimentally and numerically in previous works on infilled portal frames. The comparison of the capacity curves (monotonic and cyclic) shows a good reliability of the proposed approach, with an error that, in the worst cases, remains below 25% up to a 2% interstorey drift. As for the shear action in the column, a tendency of the simplified model to overestimate the maximum value is observed, compatible with a safe-sided design.

Moreover, the obtained results validate the adopted approach for the evaluation of the infilled frame response, based on the simple superposition of the infill contribution to the bare frame response. Such effectiveness is supported by the limited interaction with the frame ensured by the infill with sliding joints, compared to that of traditional masonry infill.

## 6. ACKNOWLEDGEMENTS

The presented study was developed in the research program financed by the "Presidenza del Consiglio dei Ministri - Dipartimento della Protezione Civile" within the Reluis research program; the present publication, however, does not necessarily reproduce the Department position and judgments.

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