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RESEARCH ARTICLE

The Contribution of the Infill Walls to the Lateral Strength of Concrete Frames

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Abstract:

Background:

Recent research studies conclude that the contribution of the infill walls to the overall lateral strength of frames is significant. The current state of the art includes two main approaches for the idealization of the behavior of the infill walls and their implementation in software. Micro modelling includes the use of the finite element method whereas the macro modelling, includes the use of one-dimensional compressive diagonal strut elements to replace the infill wall and provide the equivalent lateral stiffness.

Objective:

The aim of this study was to compare various methods for the simulation of the infill walls with the finite element method and propose an alternative approach which makes use of the rigid end offset which is a feature available in most of the finite element software.

Methods:

A reinforced concrete frame model with an infill wall was created. The model was modified to form combinations of infill wall thicknesses and values of Young's modulus. The models were analyzed using the finite element method. The results were utilized to develop equations for the calculation of the length of rigid end offsets for the beams and columns of the frame. The rigid end offsets were then used in the analysis to numerically stiffen the frame and simulate an effective lateral strength contribution from the infill wall.

Results:

The results of the implementation of the rigid end offsets to simulate the contribution of the infill walls to the lateral stiffness of the frame were compared to the results of the results from the finite element analysis. Specifically, the results for the walls normally found in construction (less or equal to 3m in height and with thickness less or equal to 25cm) showed a very good agreement while the remaining results were very close.

Conclusion:

This work proposes equations for calculation of the length for the rigid end offsets which can be used in the analysis of frames with infill walls. The results show that the utilization of this feature from the structural analysis software in the analysis of frames, results in adequate stiffening of the overall frame, thus, providing an equivalent stiffness which accounts for the presence of the infill walls.

Keywords: Infill walls, Compressive diagonal strut, Rigid end offsets, Concrete frame, Finite element, Lateral strength.

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1. INTRODUCTION

Currently, in engineering practice, it is assumed that the infill walls experience failure during an extreme event. Hence, in a structural analysis model, the contribution of the infill walls to the overall strength and stability of a frame is normally ignored. Recent research studies have come to the conclusion that the presence of infill walls affects the strength and stiffness of the infilled frame structures by increasing the stiffeness of the frame and its strength [1]. Consequently, a number of experimental and numerical attempts to simulate the contribution of the infill walls to the overall strength of the frame, are proposed in the literature. The current state of the art includes two main approaches for the idealization of the behavior of the infill walls and its implementation in structural modeling. The first approach, the micro modeling, includes the use of the finite element method [2] whereas the second approach which is referred to as macro modelling includes the use of one-dimensional compressive diagonal strut elements

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[3]. Evidently, the finite element method provides a dependable solution but it can be computationally demanding. On the other hand, the use of the compressive diagonal strut element can be confusing mainly with regard to the properties to be used. A search in the literature reveals that there is a consensus between the researchers to calculate an effective width for the compressive diagonal strut based on the properties of the infill wall and then, use the effective width for the implementation of the one-dimensional element to simulate the behavior of the infill walls in the analysis. The confusion stems from the fact that there is an inconsistency in the calculation of the effective strut's width among the various methods that are presented in the literature; moreover, as it will be presented below, they show a divergence from the finite element results. The objective of this work was to utilize the capabilities of common structural analysis software and propose an alternative approach for the simulation of the infill walls. Specifically, this work proposes the use of the Rigid End Offset sometimes called the End Length or the Frame End offset, a feature of structural analysis programs. This feature is used with the frame elements and requires the specification of a factor specifying the fraction at the end of each element which is assumed to be rigid for bending and shear deformations. This approach does not require the use of additional elements (finite element mesh or compressive diagonal struts) in the model. Considering that the Rigid End Offset (REO) stiffens the frames, the assumption made is that using an "appropriate REO" will result in an equivalent stiffening of the frame comparable to that provided by the infill walls. It is recognized that the proposed approach does not make use of the traditional REO, however, the results show a very good correlation with the results of the finite element analysis.

2. RESEARCH SIGNIFICANCE

The main target of this article is to estimate and compare the existing methods for evaluation of infill walls when they are subjected to lateral loads. This research compares those methods, examines and presents all the parameters and variables that affect the behavior of the concrete frame when the infill wall is present. Then, a simple method which utilizes the Rigid End Offset feature of structural analysis is presented, to assist the modeling of frames, accounting for the contribution of the infill wall.

3. STATE OF THE ART FOR THE MODELING OF INFILL WALLS

The studies for the analysis of infill walls can be categorized into two main approaches: micro modeling and macro modeling. Micro modeling deals with the discretization of the infill wall into a finite number of elements and the use of the finite element method to calculate the results. Macro modeling, on the other hand, replaces the infill wall with a one-dimensional element whose material and geometric properties are calculated based on the properties of the infill wall [4]. The element operates under compression and the method is referred to as the compressive diagonal strut method.

3.1. Finite Element Method (FEM) for the Modeling of Infill Walls

The finite element method is a numerical approximation used to analyze a wide variety of physical problems in solids, fluids, soil mechanics, electromagnetism and dynamics. The basic idea is to numerically calculate the solution of a continuum by discretizing it into a number of small, interconnected sub-regions. Each sub-region is referred to as a finite element and the process of subdividing a region into a finite number of elements is referred to as discretization. The finite elements are connected at specific points, called nodes, and the assembly process requires that the solution should be continuous along common boundaries of adjacent elements [5]. While the finite element method is a numerical approximation, its use by a competent structural engineer yields results with a high degree of accuracy; therefore, results obtained through the FEM normally serve as the comparison baseline for results obtained through alternative methods. Specifically, an infill wall can be analyzed using solid, shell or membrane elements.

3.2. Compressive Diagonal Strut Method (CDSM) for the Modeling of Infill Walls

The complexity in the use of the finite element method together with the increase in the computational time directed research efforts to the development of alternative methods for the simulation of the infill walls. The compression diagonal strut method attempts to replace the infill walls with one dimensional (1D) strut elements operating under compression. This is the macro modeling approach which provides the advantage of computational simplicity. The main parameter of the strut element is its equivalent width, W, which is related to the compression zone (Fig. **1**) that is formed in the infill walls under the application of horizontal forces such as the earthquakes.

Several experimental attempts to define the effective width considering the mechanical properties, the length, the width and the thickness of the infill wall, are found in the literature. The most notable of these approaches which were studied in this work are shown in Table **1**.

4. ANALYSIS AND COMPARISON OF THE FEM AND THE CDSM

In an attempt to assess the results from the equations of the previous section, a single bay reinforced concrete frame model with an infill wall was created as shown in Fig. (**1**) . This model was then modified to form combinations of three different values of thickness, t, (10cm, 20cm and 30cm) and three different values of Young's modulus, E, (4000N/mm^2, 7500N/mm^2 and 12500N/mm^2). These values were selected as they are representative of the most common infill wall types in the current practice. The models were analyzed using the FEM (Fig. **2**) to calculate the maximum horizontal displacement at point A for comparison purposes. The stress-strain relationship of the infill wall was linear up to the maximum stress which was considered a failure.

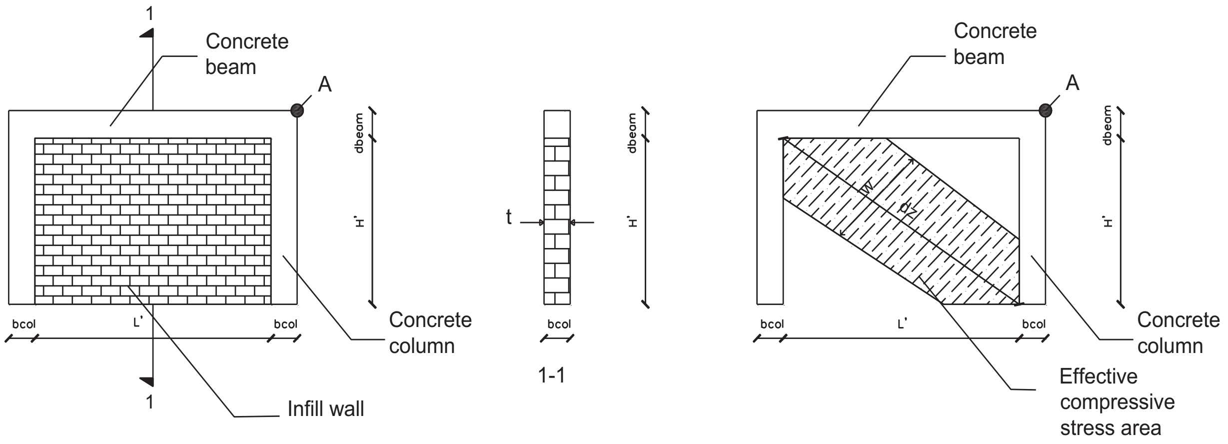

Fig. (1). Compression diagonal strut model.

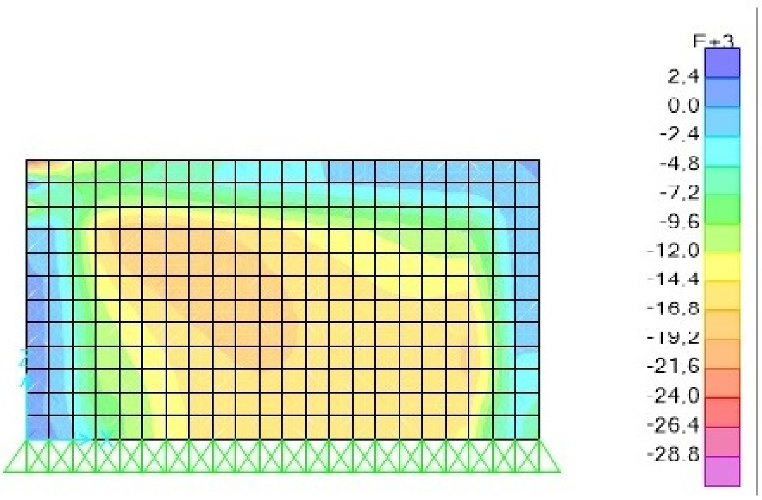

Fig. (2). Finite element model showing the compression area.

Table 1. CDSM equations for calculation of the effective width (W) of the strut.

Method	Equation
Holmes [6]	$W = \frac{1}{3} * dz$
Smith and Carter [7]	$W = 0,58 * \left(\frac{1}{H}\right)^{-0.445} * (\lambda h * H')^{0.335 * dz * \left(\frac{1}{H}\right)^{0.064}}$ $\lambda h = \left(\frac{Ez * t * sin2 * \theta}{4 * Eb * Is * H}\right)^{\frac{1}{4}}$
Mainstone [8]	$W = 0.16 * dz * (\lambda h * \mathrm{H}')^{-0.3}$ $W = 0.175 * dz * (\lambda h * \mathrm{H}')^{-0.4}$
Liaw and Kwan [9]	$W = \frac{0.95 * H * cos\Theta}{\sqrt{\lambda h * H'}}$

Method	Equation
Decanini and Fantin [10] • Uncracked masonry • Cracked masonry	$W=\left(\left(\frac{0.748}{\lambda h}\right)+0.085\right)*dz$ If $\lambda h \leq 7{,}85$ $W=\left(\left(\frac{0.393}{\lambda h}\right)+0.130\right)*dz$ If $\lambda h > 7{,}85$ $W=\left(\left(\frac{0.707}{\lambda h}\right)+0.010\right)*dz$ If $\lambda h \leq 7{,}85$ $W=\left(\left(\frac{0.470}{\lambda h}\right)+0.040\right)*dz$ If $\lambda h > 7{,}85$
Paulay and Priestley [11]	$W=\frac{dz}{4}$
Durrani and Luo [12]	$W=\gamma*\sqrt{L'^2+H'^2}*sin2\Theta$ $m=6*(1+\frac{6*Eb*Ig*H'}{\pi*Eb*Is*L'})$ $\gamma=0.32*\sqrt{sin2\Theta}*\left(\frac{H'^4*Ez*t}{m*Eb*Is*H}\right)^{-0.1}$
P100/1-2006 [13]	$W=\frac{dz}{10}$

Table **2** shows the displacement of point A for various values of thickness and the Young's modulus of the wall obtained from the FEM analysis. Observing Table **2**, as the thickness of the wall increases, the maximum displacement of the structure decreases. For example in the case of Young's modulus of 4000N/mm^2, the increase of the thickness from 10cm to the thickness of 20cm results in a reduction of the displacement by 40% and the increase to the thickness of 30cm results in a reduction of 70%. When E=7500N/mm^2, the increase of thickness from 10cm to 20cm and then to 30cm resulted in a reduction of the displacement of about 43% and 57% respectively. Similarly when E=12500N/mm^2, the reduction in the displacement for the same increase in the thickness was about 40% and 60% respectively. Further, it can also be observed that keeping the wall thickness constant and increasing the values of Young's modulus, the maximum displacement decreases. These are very interesting observations as they show that the contribution of the infill walls to the overall strength of the frame is sensitive to the thickness of the wall and the Young's modulus.

The level of the contribution of the infill walls to the response of the reinforced concrete frames justifies the large number of research initiatives to define it. In addition, the complexity in the modeling and the increase in computational time justify the attempts for simplified models such as the CDSM. The next step in this work is to compare various strut models that are found in the literature and assess their agreement with the FEM analysis. The CDSM equations shown in Table **1** were applied to calculate the equivalent width of the strut in every case. Each strut was input in the model shown in Fig. (**1**), and an analysis was performed for a total of eighty-one models. Table **3** shows the analysis results for each of the proposed models (equations) for CDSM for various combinations of wall thickness and Young's moduli. Each model is referred to as a wall type (WT). Also shown in Table **3** are the values from the FEM analysis.

The first observation from Table **3** refers to the effective width of the diagonal strut. As expected, as the effective width of the strut increases, the maximum displacement decreases. This is evident for all strut models and for all values of Young's modulus. The second observation refers to the value of Young's modulus. As expected, as the Young's modulus increases, the maximum displacement also decreases. The third observation refers to the agreement (or the lack of agreement) between the various methods of the CDSM results as compared with the FEM. The differences stem from the values of the effective width of the strut calculated based on the different equations. Table **3** shows that in some cases, the differences in the results can be great. However, of greater importance is that there is no consensus with regard to the calculation of the effective width of the strut between the various equations. Fig. (**3**) shows the computed displacements of point A (Fig. **1**) for all WTs. Table **4** shows an extract from Table **3** (high-lighted in Table **3**) and summarizes the difference in percentage between the FEM and two CDSM (Smith and Carter and the Decanini and Fantin) showing better agreement. Decanini and Fantin present two equations depending on whether the infill wall is cracked or un-cracked.

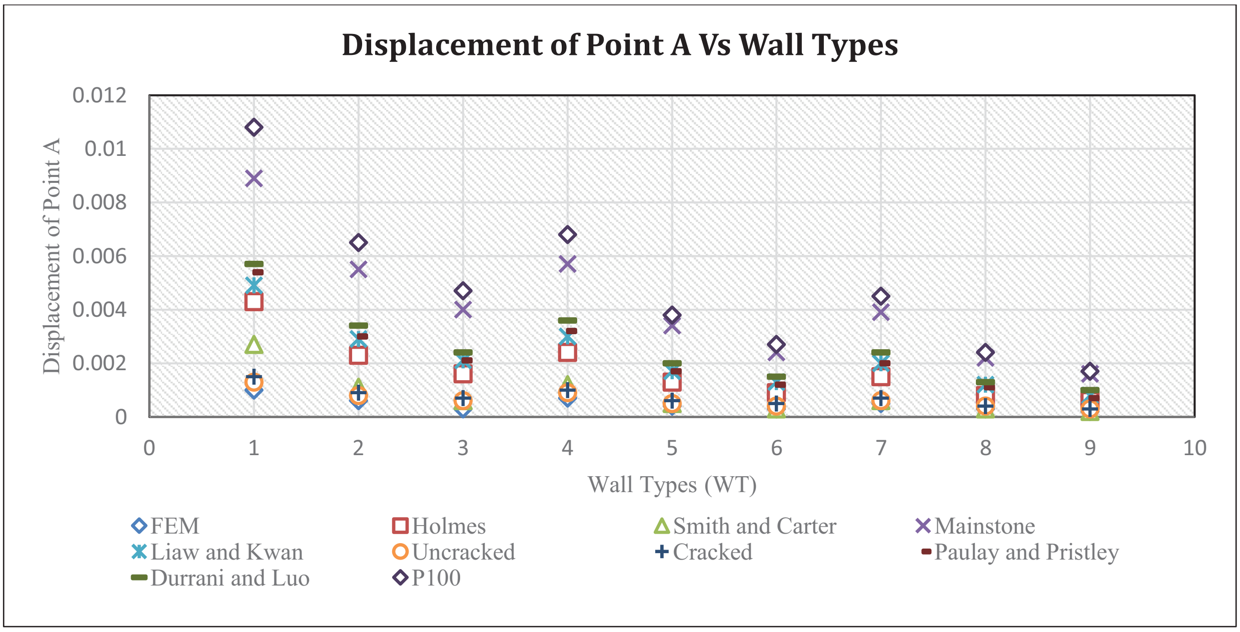

Fig. (3). Maximum displacement from CDSM (Point A) compared to the FEM.

Table 2. Maximum displacement at point A from the FEM.

Models			E = 4000 N/mm^2	E = 7500 N/mm^2	E = 12500 N/mm^2
L(m)	**H(m)**	**t(m)**	**Displacement (mm)**	**Displacement (mm)**	**Displacement (mm)**
5.0	3.0	0.1	1.0	0.7	0.5
5.0	3.0	0.2	0.6	0.4	0.3
5.0	3.0	0.3	0.3	0.4	0.2
5.0	3.5	0.1	1.3	0.9	0.6
5.0	2.0	0.1	0.3	0.2	0.2
7.0	3.0	0.1	0.7	0.4	0.3
3.0	3.0	0.1	2.4	1.8	1.4

Table 3. Maximum displacement for point A and effective width (W) from the equations in Table 1.

Formulae		E = 4000N/mm^2			E = 7500N/mm^2			E = 12500N/mm^2		
		WT1 (*1)	**WT2**	**WT3**	**WT4**	**WT5**	**WT6**	**WT7**	**WT8**	**WT9**
		10cm	**20cm**	**30cm**	**10cm**	**20cm**	**30cm**	**10cm**	**20cm**	**30cm**
Holmes	D(*2)	4.3	2.3	1.6	2.4	1.3	0.9	1.5	0.8	0.6
	W(*3)	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
Smith and Carter	D	2.7	1.1	0.6	1.2	0.5	0.3	0.6	0.3	0.2
	W	3.14	2.29	5.14	4.17	5.68	6.82	5.24	7.14	8.57
Mainstone	D	8.9	5.5	4.0	5.7	3.4	2.4	3.9	2.2	1.6
	W	0.76	0.71	0.68	0.71	0.66	0.64	0.68	0.63	0.61
Liaw and Kwan	D	4.9	2.9	2.1	3.0	1.7	1.3	2.0	1.2	0.8
	W	1.62	1.49	1.41	1.50	1.37	1.31	1.40	1.29	1.22
Decanini and Fantin Uncracked Masonry	D	1.3	0.8	0.6	0.9	0.5	0.4	0.6	0.4	0.3
	W	6.89	5.88	5.36	5.96	5.09	4.65	5.31	4.54	4.15
Decanini and Fantin Cracked Masonry	D	1.5	0.9	0.7	1.0	0.6	0.5	0.7	0.4	0.3
	W	6.12	5.15	4.66	5.23	4.41	3.99	4.16	3.89	3.52

(Table 3) contd.....

Formulae		E = 4000N/mm²			E = 7500N/mm²			E = 12500N/mm²		
		WT1 (*1)	WT2	WT3	WT4	WT5	WT6	WT7	WT8	WT9
		10cm	20cm	30cm	10cm	20cm	30cm	10cm	20cm	30cm
Paulay and Priestley	D	5.4	3.0	2.1	3.2	1.7	1.2	2.0	1.1	0.7
	W	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
Durrani and Luo	D	5.7	3.4	2.4	3.6	2.0	1.5	2.4	1.3	1.0
	W	1.33	1.24	1.19	1.25	1.17	1.12	1.19	1.11	1.06
P100/1-2006	D	10.8	6.5	4.7	6.8	3.8	2.7	4.5	2.4	1.7
	W	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Finite Element Method (*4)		1.0	0.6	0.3	0.7	0.4	0.3	0.5	0.3	0.2

(*1) Wall Type, (*2) Maximum Displacement at Point A in mm, (*3) Effective width of the strut in m, (*4) FEM results shown for reference

Table 4. Percentage divergence between FEM and select CDSM formulas.

Formulae	E = 4000N/mm²			E = 7500N/mm²			E = 12500N/mm²		
	WT1 (*1)	WT2	WT3	WT4	WT5	WT6	WT7	WT8	WT9
	10cm	20cm	30cm	10cm	20cm	30cm	10cm	20cm	30cm
	% Divergence			% Divergence			% Divergence		
Smith and Carter	62.96	45.45	50.00	41.67	20.00	0.00	16.67	0.00	0.00
Decanini and Fantin Uncracked Masonry	23.07	25.00	50.00	22.20	20.00	25.00	16.67	25.00	33.33
Decanini and Fantin Cracked Masonry	33.30	33.30	57.14	30.00	33.30	40.00	28.57	25.00	33.33

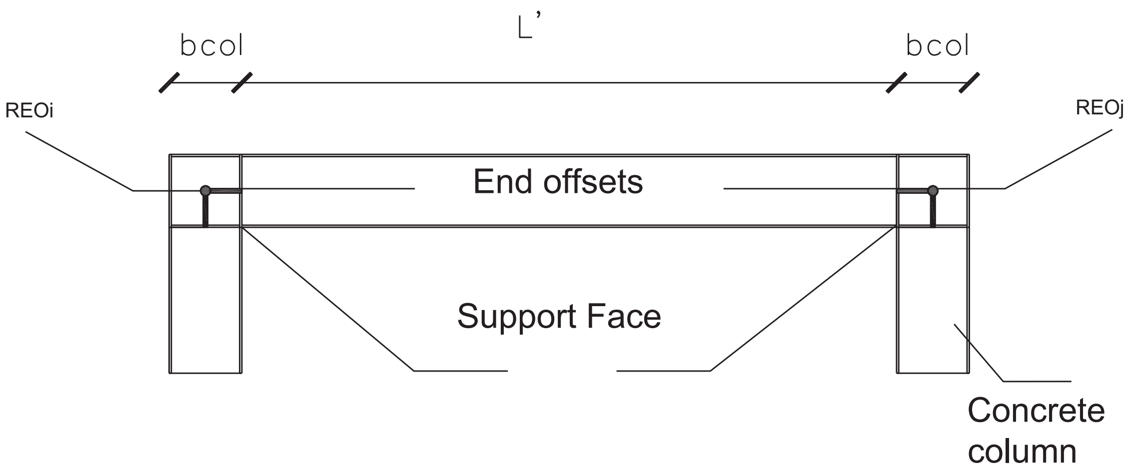

Fig. (4). Rigid end offsets.

The values of Table **4** show that the differences between the CDSM and the FEM results are greater at smaller values of Young's modulus (*i.e.* E=4000N/mm²) and smaller thickness of the wall (*i.e.* t=10cm). However, as the values of Young's modulus and the thickness of the wall increase, then the results from the CDSM models converge to those of the FEM. Furthermore, the values of Table **4** show that for E=4000N/mm² and wall thicknesses t=10cm and t=20cm, the model from the Decanini and Fantin is better to the results of the FEM as compared to those of Smith and Carter. However, this is not the case for t=30cm when the two methods provide comparative results. As the value of the Young's modulus increases, then the results from Smith and Carter improve and the two methods become similar as it is in the case of E=7500N/mm². When E=12500N/mm², the results from Smith and Carter further improve and they actually become better in the results of the FEM compared to those from Decanini and Fantin. Fig. (**3**) shows the Wall Types (WT) on the horizontal axis and the displacement of Point A for all of the wall types.

5. RIGID END OFFSET (REO) TO ESTIMATE THE CONTRIBUTION OF THE INFILL WALL

Taking into account the increase in complexity and computational time for the use of the FEM and also considering the great discrepancy for the calculation of the effective width from the various methods, the objective of this work was to investigate the possibility of using an alternative approach to calculate the contribution of the infill walls to the strength of the reinforced concrete frames. The effort to achieve a good correlation with the results of the FEM concentrated on ways to numerically increase the stiffness of the frame. The utilization of the feature Rigid End Offset (REO) provided by most structural analysis software was investigated. The REO can be used to numerically stiffen a joint when two members, such as beam and a column framing at the joint, have an "overlap" of their cross sections as shown in Fig. (**4**). This is especially important when the cross-sectional dimensions of the beams and columns are large.

The "numerical stiffening" of the joint is a function of the length of the REO, which results in the increase of the overall stiffness of the frame. Therefore, the question that arises is whether such an approach can yield dependable results. The structural analysis software SAP2000 [14] was used to:

[1] Verify that REO can be used to "numerically stiffen" the frame in such a degree that is comparable to the stiffening provided by the infill walls,
[2] Derive a formula to calculate the required REO to be used in the analysis.

5.1. Comparison of the Analysis Results with the Finite Element method and the Model with Rigid End Offsets

To meet the objectives of this work, a parametric study using the structural analysis program SAP200 was employed. A series of analyses were performed by varying the value of the REO, until the results matched those of the FEM. As with the CDSM, the target value was the displacement at Point A (Fig. **1**). The process required the definition of REO values for the columns as well as for the beams. However, the search for two parameters simultaneously increased the level of complication. In order to simplify the process, it was decided to keep the REO of the column constant at 98% of its clear height (Equation 1) while varying the value of the REO in the beam to complete a parametric study.

$$REO_c = 0.98\,H' \qquad \textbf{(1)}$$

where: REO_c = Rigid End Offset of the column

H' = Clear height of the column after subtracting the depth of the beam

Table **5** shows the results of twenty-one models of the parametric study and the required values of the REO for the beams to match the results of the FEM. Table **5** is organized in two columns for every value of the Young's modulus. On the left column for every Young's modulus, the value of the REO of the beam is presented as a percentage of the clear length. On the right column presented is the actual value of the REO at the two ends of the beam. For example, (1,7/1,7) in the table represents values of 1,7m offset at one end of the beam (REO_i) and 1,7m offset from the other end of the beam (REO_j). The leftmost column shows the parameters of the models.

The process verified that it is possible to use the REO feature to match the results of the FEM analysis. Moreover, the values of the REO were reasonable. The next step was to develop a formula that can be used to calculate the required values for the REO of the beam based on the parameters of the infill wall. It was decided to use the best fit curve through the results of the models shown in Table **5** and then verify the validity of the equation with other models. The equation is of the form:

$$REO_b = \omega_0 + \omega_1 E_w + \omega_2 t + \omega_3 \frac{H\prime}{L\prime} \qquad \textbf{(2)}$$

where: = Rigid End Offset of the beam,

E_w = Young's Modulus of the infill wall,

t = Thickness of the infill wall,

H΄ = Clear height of the infill wall by subtracting one half of the depth of the beam,

L΄ = Clear length of the wall by subtracting the half of the width of the columns (Fig. **1**),

ω_o, ω_1, ω_2, ω_3 = Constants shown on Table **6**.

The equation for the calculation of the REO for the beam elements is shown below:

$$REO_b = 662.578 + 0.0016E_w + 0.1534t - 526.131\frac{H\prime}{L\prime} \qquad \textbf{(3)}$$

Equation 2 was then used to calculate the REO of the beams for the twenty-one models used in this study. The values are shown in Table **7**

Table 5. Required REO at the ends of the beam elements to match the results of the FEM.

Models			E = 4000 N/mm^2		E = 7500 N/mm^2		E = 12500 N/mm^2	
L(m)	H(m)	t(m)	REO_b (% of L)	(REO_i/REO_j)	REO_b (% of L)	(REO_i/REO_j)	REO_b (% of L)	(REO_i/REO_j)
5.0	3.0	0.1	68.00	(1.7/1.7)	72.00	(1.8/1.8)	76.00	(1.9/1.9)
5.0	3.0	0.2	74.00	(1.85/1.85)	80.00	(2/2)	84.00	(2.1/2.1)
5.0	3.0	0.3	84.00	(2.1/2.1)	84.00	(2.1/2.1)	88.00	(2.2/2.2)
5.0	3.5	0.1	70.00	(1.75/1.75)	74.00	(1.85/1.85)	80.00	(2.0/2.0)
5.0	2.0	0.1	68.00	(1.7/1.7)	70.00	(1.75/1.75)	70.00	(1.75/1.75)
7.0	3.0	0.1	65.71	(2.3/2.3)	71.43	(2.5/2.5)	72.86	(2.55/2.55)
3.0	3.0	0.1	43.33	(0.65/0.65)	50.00	(0.75/0.75)	53.33	(0.8/0.8)

Table 6. The values of ω factors.

Constants	Values
ω_o	662.5780
ω_1	0.0016
ω_2	0.1534
ω_3	-526.1310

Table 7. Percentage of rigid end offset calculated from Equation 2.

Models			E = 4000 N/mm^2		E = 7500 N/mm^2		E = 12500 N/mm^2	
L(m)	H(m)	t(m)	REO_b (% of L)	REO divergence %	REO_b (% of L)	REO divergence %	REO_b (% of L)	REO divergence %
5.0	3.0	0.1	59.06	8.94	64.69	7.34	72.66	3.34
5.0	3.0	0.2	74.40	0.40	80.00	0.00	88.00	4.00
5.0	3.0	0.3	89.74	5.74	68.66	15.34	103.34	15.34
5.0	3.5	0.1	53.79	16.21	59.39	14.61	67.39	12.61
5.0	2.0	0.1	69.58	1.58	75.18	5.18	83.18	13.18
7.0	3.0	0.1	67.32	1.61	72.92	1.49	80.92	8.06
3.0	3.0	0.1	39.77	3.56	45.35	4.57	53.33	0.00

Table **7** shows the REO calculated by Equation 2 for every model in this study. Also the divergence of each REO is shown as compared to the corresponding REO shown in Table 5. The results show that there are 10 models with less than 5%, 5 models with less than 10%, 3 models less than 15% and three models which are over 15%. If we consider that a divergence of less than 10% is acceptable, then about 72% of the models are within the limits. About 14% has a divergence between 10-15% and the rest of the cases have divergence greater than 15%. Table **7** shows that most values with over 10% divergence correspond to models with wall thickness larger than 25cm and wall height over 3m. Considering that in most cases, the wall thickness is less than or equal to 25cm and that the clear height of a floor is normally at the range of 3m, then the proposed Equation 2 provides an acceptable proposal for the simulation of the contribution of the infill walls to the strength of frames.

CONCLUSION

This work shows that the contribution of infill walls to the overall lateral strength of frames is significant. While the use of the FEM to simulate this behavior provides the base results for comparison, the increased complexity of the numerical modeling and the increase in the computational time lead the research community to seek alternative methods for this simulation. One method that is presented in the literature is the CDSM which is based on the estimation of the compression zone in the infill wall by the means of an "effective width" of a one-dimensional element (strut) operating under compression. The strut is used in the analysis to replace the infill wall and provide the equivalent lateral resistance. One of the targets of this study was to compare the effective width of the diagonal struts calculated by several equations proposed in the literature and then compare the results of their implementation to those from the FEM. The calculation is inconsistent as the effective widths by the proposed equations results in different values. Two of the proposed equations presented by Smith and Carter and also Decannini and Fantin show the smaller difference when compared to the results from the FEM. However, the divergence is in the range of 20%-30%. This finding motivated the investigation for an alternative method which will have a better correlation with the results of the FEM. This proposal utilizes the capabilities of structural analysis software and specifically the feature of REO which is used to numerically stiffen the joints and essentially increase the overall lateral stiffness of a frame. In this paper, we present an equation which can be used to calculate an REO for the columns and the beam elements framing at a joint. This approach is very simple as it avoids the use of finite elements for the modeling of infill walls or the inclusion of additional strut elements. The results are promising as about 70% of the models show divergence less than 10% when compared to the FEM. In addition, only about 14% of the models show divergence greater than 15%. However, this divergence appears in the models where the wall thickness is greater than 25cm or has a clear floor height of greater than 3m.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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REFERENCES

[1] F.J. Crisafulli, A.J. Carr, and R. Park, "Mathematical macromodeling of infilled frames: State of the art", *J Struct Eng,* vol. 137, no. 12, pp. 1508-1517, 2000.

[2] P.G. Asteris, C.Z. Chrysostomou, I.P. Giannopoulos, and E. Smyrou, "Masonry infilled reinforced concrete frames with openings", *Proc 3rd international conference on computational methods in structural dynamics and earthquake engineering, COMPDYN2011,* 2011 Greece

[3] P.G. Asteris, L. Cavaleri, F. Di Trapani, and V. Sarhosis, "A macro-modelling approach for the analysis of infilled frame structures considering the effects of openings and vertical loads", *Struct. Infrastruct. Eng.,* vol. 12, no. 5, pp. 551-566, 2016. [http://dx.doi.org/10.1080/15732479.2015.1030761]

[4] M.I. Abdellatef, *"The Development Of A Simplified Modeling Technique For The Finite Element Analysis Of Reinforced Masonry Shear Walls"*, MSc thesis*,* Washington State University, Department of Civil and Environmental Engineering, December 2011.

[5] G. Modlen, *Introduction to Finite Element Analysis.,* The University of Manchester, 2010, p. 93.

[6] Amalia1, A., R., and Iranata1, D., "Comparative study on diagonal equivalent methods of masonry infill panel", *Green Process, Material, and Energy: A Sustainable Solution for Climate Change AIP Conf. Proc.,* pp. 030011-1-030011-11, 1855.

[7] M. Jeselia, B.R. Jayalekshmi, and K. Venkataramana, "Modeling of Masonry infills-A review", *American Journal of Engineering Research (AJER),* vol. 2, pp. 59-63, .

[8] G. Campione, L. Cavaleri, G. Macaluso, G. Amato, and F. Di Trapani, "Evaluation of infilled frames: an updated in-plane-stiffness macro-model considering the effects of vertical loads", *Bull. Earthquake Eng.,* vol. 13, no. 8, pp. 2265-2281, 2015. [http://dx.doi.org/10.1007/s10518-014-9714-x]

[9] M.D. Samoilă, "Analytical modelling of masonry infills", *Acta Technica Napocensis: Civil Engineering & Architecture,* vol. 55, no. 2, 2012.

[10] M.D. Samoilă, "Masonry infill panels - Analytical modeling and seismic behavior", *IOSR Journal of Engineering (IOSRJEN).,* vol. 3, no. 8, pp. 30-39, 2013. [http://dx.doi.org/10.9790/3021-03813039]

[11] K.H. Abdelkareem, F.K. Abdel Sayed, M.H. Ahmed, and N. Al-Mekhlafy, "Equivalent Strut Width For Modeling R.C. Infilled Frames", *J. Eng. Sci., Assiut Univ., Faculty of Engineering,* vol. 41, no. 3, 2013.

[12] C. Lima, "De Stefano1, G., and Martinelli, E., “Seismic response of masonry infilled RC frames: practice-oriented models and open issues", *Earthq. Struct.,* vol. 6, no. 4, pp. 409-436, 2014. [http://dx.doi.org/10.12989/eas.2014.6.4.409]

[13] C.N. Mohan, and M. Aslam, "Performance Evaluation of RC Frame with Brick Infill under Dynamic Loading", *International Journal of Research in Advent Technology, Special Issue International Conference on Technological Advancements in Structures and Construction “TASC- 15”,* pp. 10-11, June 2015.

[14] CSI, *SAP2000 Integrated Software for Structural Analysis and Design* Computers and Structures Inc.: Berkeley, California., .