International Journal of Technology 10(2): 394-404
ISSN 2086-9614

ANALYSIS AND DESIGN METHODS FOR INFILLED FRAMES WITH CONFINED OPENINGS

Made Sukrawa[1*], Ida Ayu Made Budiwati[1]

[1]*Faculty of Engineering, Universitas Udayana, Kampus Bukit Jimbaran - Bali 80361, Indonesia*

(Received: October 2018 / Revised: January 2019 / Accepted: January 2019)

ABSTRACT

Openings in the walls of infilled frame structural systems are very common. Reinforcement around the wall openings confines and strengthens the wall, making an infilled frame with a confined opening (IFcO) a reliable structural system for seismically active regions. To encourage the application of IFcO, an analysis method is proposed by introducing a simple equivalent diagonal strut formula with reduced width due to the wall opening. Finite element models using shell elements were used as reference to develop strut width formula for IFcO with varying opening ratios (r) and diagonal angles (θ). The formula was verified against previous test results and then applied for the design of 3 and 5-story buildings, consisting of IFcOs with r of 30, 60 and 80% to represent medium, large and very large openings. The seismic responses of the strut models were then compared to those of the shell and the bare frame models. The effect of the opening on internal forces, frame reinforcement, wall stresses and soft story mechanisms were also investigated.

Keywords: Confined opening; Diagonal strut; Infilled frame; RC frame design; Seismic load

1. INTRODUCTION

Infilled reinforced concrete frames (IFs) are one of the most common types of structure used in multi-story buildings, including in areas of high seismicity. The composite action between the brittle masonry wall and ductile RC frame produces a stiffer and stronger structure than a bare frame (BF) alone. Openings of various sizes and locations in the infill wall are very common in house windows and doors, reducing their stiffness. Surendran and Kaushik (2012) reviewed many research papers on infilled frames with opening (IFOs) and summarized the importance of considering the effect of openings in the wall in analysis and design. As most earthquake design codes do not address this issue in detail, they suggest the need for the development of a uniform method of analysis and design of IFO structures, which are constructed almost everywhere in the world. A similar study by Nicola et al. (2015) suggests the inclusion of infill walls in modelling RC frames because the seismic behavior of the structure could be affected positively or negatively by the infill distribution on the frame.

It is widely known that confinement in concrete compressive members will increase their strength and stiffness (Boonpichetvong et al., 2016). Similarly, an infill wall panel with confinement along its four edges performs better under compression. An experimental study by Sigmund & Penava (2014) on infilled frames with wall openings, with and without confinement, IFcO or IFO demonstrated that the confinement around the openings was capable of preserving the lateral strength, stiffness and ductility of the tested IFO, as in the case of a solid

*Corresponding author's email: msukrawa@unud.ac.id, Tel. +62-361-703385, Fax. +62-361-703385
Permalink/DOI: https://doi.org/10.14716/ijtech.v10i2.2467

IF. The confining element used in the experiment was in the form of a practical RC tie-column and beam with the same thickness as the wall, which would prevent early failure of the wall due to stress concentration around the opening. Provision of confinement around the wall opening is also recommended by the Euro Code (EC, 2009). The EERI (2011) also outlines the importance of confinement in the wall to improve the seismic resistance of a confined masonry structure. In addition, Sigmund and Penava (2013) propose a design method to analyze the European practice of IFO with infill employing a diagonal strut model by correcting the strut width for solid infill using complex correction factors dependent on the damage state and type of opening.

With regard to IFOs, Kakaletsis and Karayannis (2009) report IFO test results without confinement, in which the wall opening significantly reduces the lateral strength, stiffness and energy dissipation capacity of the IFO. Based on these results, Asteris et al. (2012) subsequently proposed a correction factor to reduce the strut width of solid infill using the complex strut width formula recommended by FEMA (1998). Further analytical methods have been proposed by researchers, including use of a multi-strut model with a shear spring (Crisafulli & Carr, 2007) and a micro model based on detailed modeling of the brick and mortar (Penava et al., 2014). All of these models are intended to mimic the behavior of IF up to the point of failure, instead of for use in IFO design. The lack of practical design guidance has discouraged structural engineers from considering infill walls in the design of RC frames, especially when the wall contains large openings. This lack of awareness of infill walls is one of the reasons for many soft story IF failures when subjected to strong earthquakes.

This paper proposes a simple elastic approach to the analysis and design of IF with confined openings (IFcO) based on the test results of Sigmund and Penava (2014). A new formula for diagonal strut width has been developed using finite element (FE) models for reference, with consideration of practical aspects of infill construction in Indonesia and other countries with warm climates, such as thin infill walls and low concrete strength for confinement. After validation of the formula, it was applied to the design of 3- and 5-story IFcO with varying wall opening ratios. The seismic response of the IFcOs was compared to that of the BF and FE models.

2. METHODS

To develop the new formula for IFcO diagonal strut width, finite element (FE) models were created using shell elements to represent the infill wall with various opening ratios, *r* (the ratio of the opening area to the total area of the infill wall) and the angle of the diagonal, θ (whose tangent is the wall height to width ratio). The interface between the frames and wall was modelled with a gap element with stiffness value, as suggested by Dorji and Thambiratnam (2009). The diagonal strut width was determined by trial to obtain elastic deformations equal to those of the FE models. The strut width equation was then determined using correction factors associated with opening on the wall. The equation was then validated against previous test results, and subsequently applied to the design of 3D 3- and 5-story IFcO buildings. FE and BF models were also created for comparison. A soft story model was also created by observing the inter-story drift ratio in the absence of infill walls only on the ground floor, as in the case of an open parking area below an office space. More detailed elaboration of the steps taken is given in the following sections.

2.1. Basic Form of the IFcO Strut Width Formula

In the preliminary research by Budiwati and Sukrawa (2018), the strut width equation was limited to the centric opening. The formula was essentially that suggested by Pauley and Priestley (1992), multiplied by a reduction coefficient associated with the wall opening. The formula does not explicitly include the effect of opening location, angle of the diagonal (θ) nor the strength of the frame concrete (f'_c). Referring to the strut width formulas suggested by others (FEMA, 1998; Asteris et al., 2012; Penava et al., 2014), it is important to consider these parameters explicitly. Reinforcement of the frame member, however, was not considered in the model because it does not significantly affect the reduction in stiffness (Cetisli, 2015). The base values used for the proposed formula were an f'_c of 25 MPa and θ of 45 degrees. Therefore, in this study, the proposed strut width formula is in the form shown in Equation 1. The right-hand side of the equation is basically *d/4*, divided by $tan\ \theta$, multiplied by the square root of (f'_c/25) times *C*. The factor *C* is a non-dimensional correction factor for the confined opening, which includes the effects of confinement and the opening location. The square root of f'_c was used instead of f'_c, referring to the formula suggested by FEMA (1998). The unit of $f'c$ is MPa.

$$W_{sco} = \frac{d}{4tan\theta}\left(\frac{fc'}{25}\right)^{0.5} C = \frac{d}{20\tan\theta} fc'^{0.5} C \tag{1}$$

Unlike the frame concrete, the variation in concrete strength of the tie-columns and the strength of the masonry wall were not considered as independent variables. In practice, small tie columns are usually cast by segment following the height of the wall, and hence it is not realistic to expect high strength concrete for them. Likewise, the compressive strength of the masonry wall does not vary significantly, regardless of the mortar and brick used. Masonry strength is usually much lower than that of the mortar and brick (Agarwal & Shrikhande, 2006). Therefore, for the determination of *C*, values of 15 MPa and 3 MPa were used for the tie column concrete and masonry wall respectively.

2.2. Determination of Correction Factor due to Wall Opening

Considering that under design earthquake load specified in the building codes, the IFcO is expected to behave linearly, linear analysis was performed for all the models to determine the correction factor~~s.~~ According to the test data of Sigmund and Penava (2014), the IFcO drift ratio at slight damage level was about 0.1 %. For a 1600 mm frame height, the corresponding drift would be 1.6 mm. This value was used as a reference to determine the lateral load of the FE and strut models. It was found by trial that the lateral loads associated with 1.6 mm drift for an opening ratio of 30% were 99, 70, 52 and 38 kN for θ of 33°, 39°, 45° and 51°, respectively. These load values were then used to determine the strut width of the strut models which gave a lateral displacement equal to the values of the FE models.

Centric and eccentric openings in the wall were treated separately. The frame dimensions were those of the tested specimens, apart from the wall thickness, tie column and additional horizontal beam at the bottom of window opening, as shown in Table 1. The elastic modulus for concrete was determined according to the formula given in ACI (2011). For the E_m of masonry, the value of 1000 f_m, as suggested by EC (2009), was used. The models for different types and locations of opening are shown in Figure 1. The bottom part of the window opening was also provided with confinement using a square practical RC beam as thick as the infill wall. The different diagonal angles were created by varying the height of the frame and keeping the bay width the same for all models. The bay width was 2000 mm and the story heights were 1299 mm, 1613 mm, 2000 mm and 2470 mm, which corresponded to diagonal angles of 33, 39, 45 and 51 degrees.

Table 1 Properties of IFcO models

Component	Beam	Column	Tie-column	Wall
Dim, mm	120/200	200/200	80/80	80
fc, f_m, MPa	25	25	15	3
E, MPa	25279	25279	19581	3000

80 IFcO models, 40 centric opening (IFcOc) and 40 eccentric opening (IFcOx) ones, and eight solid-IF models were made with four different diagonal angle values, 33, 39, 45 and 51 degrees, and five different opening ratio values, 10, 30, 50, 70 and 90%. 44 FE models were first made for reference, with 20 for IFcOc, 20 for IFcOx and four for solid-IF. The strut models were then created using trial strut widths to obtain displacements equal to those of the corresponding FEMs.

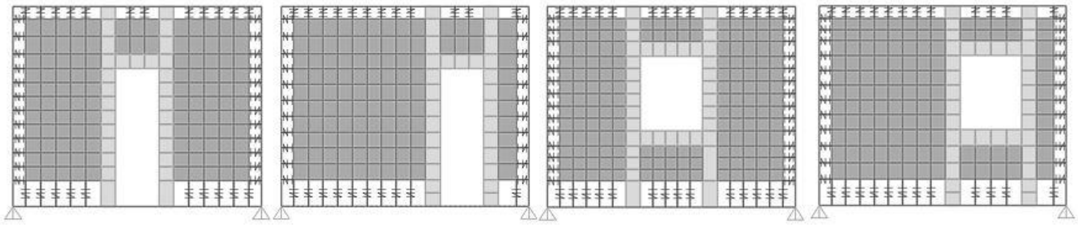

Figure 1 IFcO models with cantic and eccentric door and window openings

The strut width ratios of each IFcO model to that of the solid-IF ones with a 45° diagonal angle were then plotted together and trend lines were created, one for centric opening (*Cc*), one for eccentric opening (*Cx*) and another for all IFcOs (*C*). The trend lines are the correction factors for the strut widths corresponding to the opening ratio.

2.3. Validating the Formula

To validate the formula, non-linear static pushover analysis was performed on the strut model of the IFcWO and IFcDO of centric and eccentric opening locations referring to the previous test data (Sigmund & Penava, 2014). The steps for the pushover analysis included definition of the hinge properties using the auto hinge properties of ASCE 41-13 available in SAP 2000 (Computers and Structures, 2013). The struts were assigned as truss elements with the hinge property of axial P at the midpoint of the strut. The columns were assigned P-M2-M3 hinge properties and the beam was assigned an M3 hinge using reinforcement data on the tested specimens (Sigmund & Penava, 2014).

2.4. Application of the Formula in the Design Example

The application of the formula for the IFcO design was demonstrated in design examples of square 3-bay 3-story and 5-story building structures, using infill walls with confined openings along the perimeters of the buildings. The span length and story height were 6 and 4 meters respectively. The frame dimensions were determined by trailing using minimum sizes capable of resisting the combined vertical and lateral loads. The FE and BF models were also created using the same dimensions as those of the IF model. The diagonal angle was 33.6°. Opening ratios of 30%, 60% and 80% were used to represent medium, large and very large centric openings in the 150 mm thick wall, with compressive strength of 3 MPa. The corresponding models were named IFcO30, IFcO60 and IFcO80. The tie columns were 150×150 mm 15 MPa concrete, with 25 MPa concrete used for the frames.

The IFcO models were loaded vertically with dead load due to the weight of the structure and life load of 2.4 kN/m^2. The earthquake load was applied in accordance with IBC 2010, available in SAP 2000 (Computers and Structures, 2013), using R of 6 and Cd of 3.5 (Sukrawa & Budiwati, 2017). The values for SDs and S1 were 0.977 and 0.36 seconds, respectively. The required reinforcement for the IFcOs (IFcO30, IFcO60, and IFcO80) and BF was designed using ACI code (2011). In order to check the soft story mechanism, soft story models (IFcO30SS, IFcO60SS and IFcO80SS) were created by removing all the infill wall on the ground floor in the design example.

3. RESULTS AND DISCUSSION

3.1. Correction Factor of Strut Width Associated with Confined Opening

The displacements of the FE and strut models are shown in Table 2. It is apparent that the strut width for the centric opening is smaller than for the eccentric, and that the width decreases with increasing θ. This is in agreement with the test results of Sigmund & Penava (2014). The ratios of the strut widths of each IFcO model to the strut width of the solid-IF with a 45° diagonal angle (which is 748 mm) were then plotted together and trend lines were created, as shown in Figure 2. The plot shows that the correction factors for both types of opening have r-square values of about 0.95. From the scatter of data in relation to the trend lines, it is apparent that the lower the opening ratio, the wider the scatter, indicating lower accuracy of the approximation.

Table 2 Displacement of the FE and Strut models

Opening Ratio	θ: 33°			θ: 39°			θ: 45°			θ: 51°		
	Displacement (mm)		Strut Width (mm)	Displacement (mm)		Strut Width (mm)	Displacement (mm)		Strut Width (mm)	Displacement (mm)		Strut Width (mm)
	FE	Strut		FE	Strut		FE	Strut		FE	Strut	
0%	1.01	1.01	780	0.91	0.91	795	0.90	0.90	748	0.93	0.93	655
Centric												
10%	0.86	0.86	955	0.92	0.92	790	1.04	1.04	663	1.16	1.16	565
30%	1.31	1.31	530	1.60	1.60	405	2.03	2.03	327	2.48	2.49	277
50%	1.54	1.55	395	2.02	2.02	277	2.80	2.81	200	3.79	3.80	152
70%	2.23	2.24	149	3.08	3.09	92	4.41	4.42	61	6.11	6.13	43
90%	2.82	2.83	25	3.88	3.88	14	5.52	5.53	8	7.59	7.60	5
Eccentric												
10%	0.87	0.87	939	0.89	0.89	810	0.96	0.97	705	1.04	1.04	609
30%	1.27	1.27	558	1.48	1.48	453	1.81	1.81	378	2.15	2.15	327
50%	1.52	1.52	408	1.89	1.90	310	2.48	2.49	245	3.20	3.20	199
70%	2.23	2.23	150	3.07	3.08	93	4.40	4.41	62	6.09	6.10	44
90%	2.82	2.83	25	3.88	3.88	14	5.52	5.53	8	7.59	7.60	5

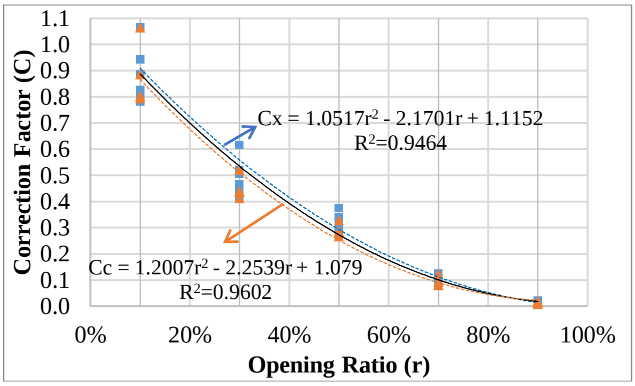

Figure 2 Correction factor associated with opening ratio

It is apparent from Figure 2 that the centric opening is slightly weaker than the eccentric one, as shown from the correction factor values. Both lines, however, are close to each other and fit the data well. For the combination of centric and eccentric openings, the line lies between the two openings, with an R-square of 0.95. From these trend lines it can also be seen that the values of the corrections factor become closer as the opening ratio increases. The correction factors for the centric (Cc) and eccentric (Cx) openings are shown in Figure 2. The single correction factor, *C*, is between Cx and Cc, as given in Equation 2.

$$C = 1.1262r^2 - 2.212r + 1.0971 \tag{2}$$

In the case of a very small opening ratio, the value for C could be greater than 1. If so, value of C should be taken not more than 1. This is possible with the contribution of the tie-columns extending from the bottom to the top of the wall, as shown in the test results of Sigmund & Penava (2014). In the case of a very large opening, the value for C is close to zero. In this case, the infill wall with tie-columns will act like a wing wall, strengthening the column and hence stiffening the frame (Yang et al., 2016). This should therefore be considered in the analysis.

3.2. Validation of the Formula

The calculated values for the correction factors or door openings with r of 13% were 0.806 and 0.851 for centric and eccentric openings respectively. The corresponding strut width values were 858 and 905 mm. For the window openings with r of 12% the correction factors were 0.826 and 0.870 for centric and eccentric opening respectively, and the corresponding strut widths were 879 and 926 mm. Likewise, using Equations 1 and 2, the strut widths were 882 mm for door openings and 902 mm for window openings, irrespective of the opening location.

Figure 3 shows the pushover curves, together with the actual test data, indicated by dashed lines. The pushover curves for the IF with door openings were slightly more flexible than the test data. For the IF with window opening, the initial stiffness of the IFcWO models matches that of the tested frames. Using a single correction factor C in equation 2 (Push-D and Push-W), the IFcO response was not very different from those using eccentric or centric values. This means that the location of the opening was not very sensitive to the performance of the IFcO. Therefore, using a single correction factor for eccentric and centric openings would not significantly change the design results.

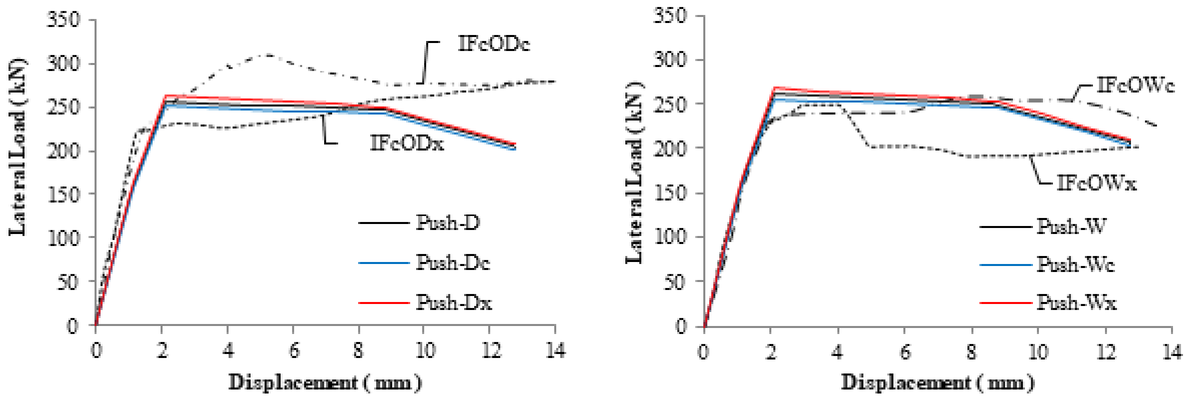

Figure 3 Pushover curve of IF with door and window (right) openings compared to previous test results

3.3. Design Application

Figure 4 shows the 3D models for the 3-story building.

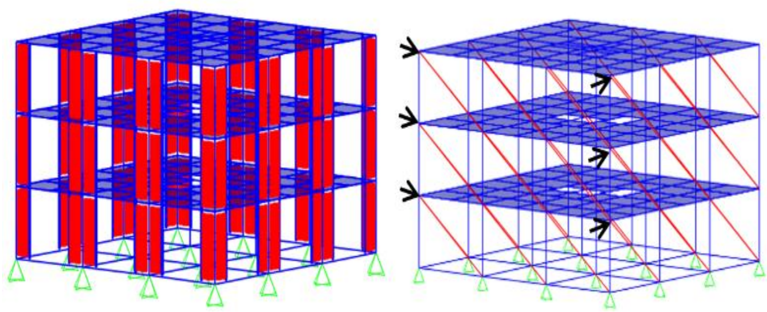

Figure 4 3D Models for the 3-story building

Shown in the figure are the FE model with an infill wall with a 60% opening ratio along the perimeter of the building, and the diagonal strut model showing lateral loads in two directions. For the 5-story building, the models are similar to those in Figure 4. The final dimensions of the frames are shown in Table 3.

Table 3 Dimensions of the frames (mm)

Story		Column			Beam	
		Ext. Corner	Ext. Middle	Interior	Exterior	Interior
3-Story	1-2	300/300	350/350	350/350	250/450	250/450
	3	250/250	250/250	300/300	250/400	250/400
5-Story	1	350/350	400/400	400/400	350/500	350/500
	2-4	350/350	350/350	400/400	350/500	350/500
	5	350/350	350/350	350/350	250/400	250/400

3.3.1. Displacement, internal forces and reinforcements of IFcO

The story displacements of all the models due to the combined vertical and lateral loads are shown in Figures 5. It can be seen that the elastic responses of the strut and shell element models are similar. The drift ratios of IFcO under the design earthquake load are significantly lower than those of BF and also much lower than the drift value associated with a moderate damage state of 0.21% (Sigmund & Penava, 2014). However, the drifts in IFcO80 of the 3- and 5-story models were higher than 0.1%. Accordingly, the IF will experience slight to moderate damage under the design earthquake specified in building codes. This means that if the openings in the wall are too large, then the wall will act like a wing wall, which requires stronger material.

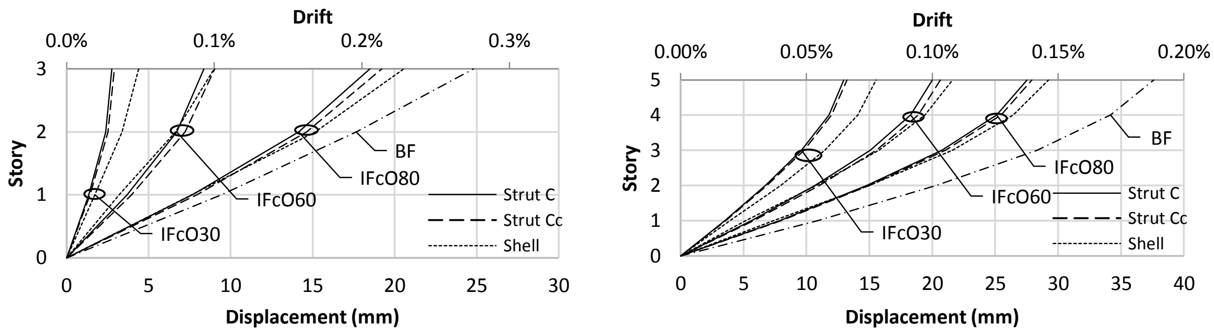

Figure 5 Story displacement of 3- and 5-story IfcO

In the strut C and Cc models, the responses are only slightly different. The bending moments in the beams and columns of the strut C and Cc models are also similar and much lower than that of the BF model (the reference). The beam shear in the strut models is also lower than that in the BF model. Interestingly, the reinforcement required in the frame is practically the same for the strut C and Cc models. This leads to the conclusion that the correction factor associated with confined openings is practically irrespective of the opening location, and therefore a single correction factor can be used for simplicity. As expected, the longitudinal steel requirement was also greatly reduced when the frame was designed as an infilled one, even for the interior frame to which no wall was attached. This was due to the increased strength and stiffness of the IFcO.

3.3.2. Wall stresses

Stresses on the walls and tie-columns in the strut models were evaluated manually using the axial force and area of the diagonal strut that produced normal compressive stress along the diagonal. The horizontal component of the axial force caused shear stress and the vertical component of the force caused normal stress perpendicular to the bed joints. For the shell element models, the stresses on the wall and tie-columns were obtained directly from the model. The maximum stress, S_{max} (MPa), under combined vertical and lateral loadings was also evaluated. It can be observed that the higher the opening ratio, the higher the stresses on the wall and lintels. The stress magnitude decreased with higher floor levels. The highest stress in the strut of IFcO80 was 2.74 MPa for the 3-story model and 2.94 MPa for the 5-story model. Both stresses were less than the compressive strength of masonry of 3 MPa. Therefore, the compressive strength of the masonry wall was not exceeded.

The stresses on the edge of the openings (the tie-columns and lintels) were much higher than that on the wall. This indicates the importance of using RC tie-columns to resist the high stresses at the edges of openings and to confine them. Steel reinforcement will enable the tie-columns and lintels to resist tensile stress and prevent the propagation of cracks once they occur. As in the case of internal forces, the Strut-C models and Strut-Cc models yielded similar stress values, although the stress in Strut-C was lower than that of Strut-Cc, with differences ranging between 1 and 6%. For design purposes, this difference was still within the tolerable range, considering a safety factor of around 1.5.

For the wall tensile stress in the shell models, the maximum values observed were 0.97 and 0.92 MPa for the IFcO80 3- and 5-story models. At this value, the wall will crack as the tensile strength of the masonry wall is 0.45 MPa, which is about 15% of its compressive strength. This is in agreement with the slight to moderate damage state category for drift ratios of between 0.1% to 0.21% (Sigmund & Penava, 2014). With the tie-column and lintels around the opening, a tensile crack in the wall will be confined.

The maximum shear stresses on the walls observed in the IFcO models were 0.45 MPa and 0.87 MPa for the 3- and 5-story IFcO30 models. Compared to the shear strength of about 0.35 MPa for 3 MPa masonry, shear cracks were expected under the design earthquake. This is also in agreement with the damage state category of slight to moderate damage.

It is interesting to note that the infill wall on the lower floor level was stressed more than those on higher ones. This means that when subjected to stronger earthquakes, the walls on the bottom floor will fail before those on the upper levels if the same quality of wall is used. In such cases, a soft story mechanism may occur, initiated by failure of the infill wall on the ground floor. To prevent this phenomenon, the walls on the lower level need to have reserved strength equal to that on the upper levels. This can be achieved by using thicker or stronger walls for the lower floor level.

In practice, the quality of the material for infill walls and confinement concrete may vary significantly according to the quality of material used and the workmanship. A lower value of f'_c was used for the confining concrete, considering the difficulty of casting small size columns and beams. The values reported for the prism compressive strength of masonry walls in Thailand range from 3.55 MPa – 10.80 MPa (Foytong et al., 2016). Different tests in Indonesia show a value of 2.97 MPa for masonry made of lightweight material and 3.71 MPa for clay brick masonry (Imran & Aryanto, 2009). The value of 3 MPa used in the models was conservative for the purposes of analysis and design.

3.3.3. Soft-story evaluation

From the inter-story drifts of the soft-story models (IFcO30SS, IFcO60SS and IfcO80SS) for the 3- and 5-story structures shown in Fig. 6, it is apparent that when the lowest part of the infill wall was removed, the inter-story drift of the bottom story was significantly greater than that of the second story. Hence, a soft story mechanism will occur for all models, including the IFcO80SS.

If the infill wall is not considered structural, and hence is excluded from the analysis, detection of soft story mechanisms will not be possible. Many building codes explicitly provide guidelines for the design of infilled frame structures. Indian standard IS 1893 (2002) is among those codes that require modelling of infill walls in the seismic analysis of framed buildings. This allows analysis of open ground story buildings without considering infill stiffness, by multiplying the base shear by a factor of 2.5 to compensate for stiffness discontinuity. This figure, however, has been argued to be too high for low rise building (Paudel, 2017).

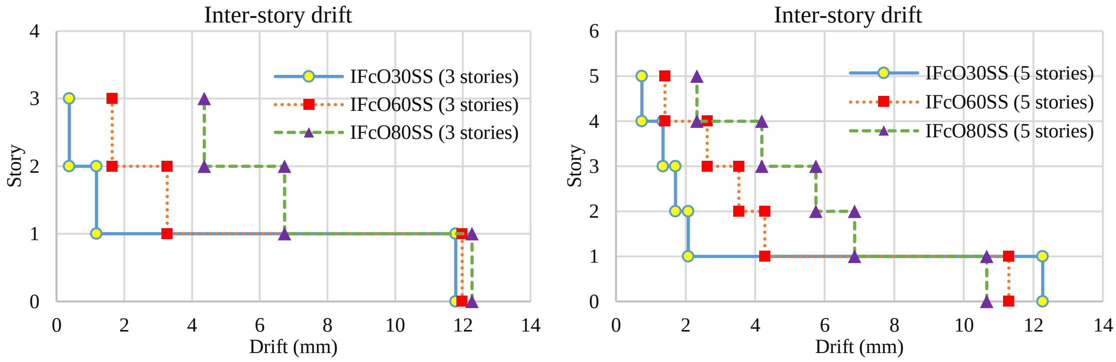

Figure 6 Inter-story drift of the soft-story model

4. CONCLUSION

A simple diagonal strut model for infilled frame with confined openings (IFcO) has been proposed using a formula of reduced strut width, *Wsco* (Eqs. 1 and 2), driven using a shell element model for reference. The proposed model includes the effect of the angle of diagonal θ, the strength of the frame concrete f'_c, and the opening ratio r.

The equation has been validated against previous test results and applied in design examples, leading to the following conclusions: (1) The type and location of openings in the wall of an infilled frame produced similar seismic responses and design results. For the purpose of designing IFcO, the proposed equation of diagonal strut width using a single correction factor (C) can be used, irrespective of the opening type or location. The confinement in the wall equalizes the response of the IFcO models; (2) The importance of including an infill wall in the analysis was justified, showing that the IFcO models were much stiffer and stronger than the bare frame (BF) models, even if the opening ratio in the wall was as high as 80%. If the opening in the wall is too large, however, the wall will act like a wing wall, which requires stronger material to prevent damage to it; (3) The maximum stress on the corners of the opening in the wall justifies the importance of a tie-column and beam around it to reinforce the opening, as well as to confine the wall; (4) Using the same wall strength and thickness along the height of the building resulted in increasing wall stresses from high to low floor levels. This may cause a soft story mechanism, initiated by failure of the infill wall on the lower floor; and (5) The soft story models, without infill walls on the ground floor, exhibited soft story mechanisms, even when the opening in the wall was very large.

The important contributions of infill walls with confined openings to the lateral stiffness and strength of frames suggests that walls with openings should be considered as part of the structural system to check for possible soft story mechanisms, as well as to obtain more accurate and efficient results. Future analytical research on IFcO should include taller structures using walls of varying thickness. Experimental research is necessary to study the actual behavior of IFcO with large confined openings in order to address the trends of large windows and doors in modern architecture.

5. ACKNOWLEDGEMENT

The research was partly funded by Udayana University of Bali through a research grant of DIPA PNBP No. 2044.2/UN 14.2.5.V.1/LT/2017. Special thanks go to Widiana Surya, Agus Putra and Prastha Bhisama, structural engineers at Vilamas, who assisted the authors in the computer modeling.

6. REFERENCES

American Concrete Institute (ACI) 318-11., 2011. Building Code Requirements for Structural Concrete and Commentary. Reported by ACI Committee 318, ACI Standard, Farmington Hills, USA

Agarwal, P., Shrikhande, M., 2006. *Earthquake Resistant Design of Structures*. PHI Learning Private Limited, Eastern Economy Edition, New Delhi, India

Asteris, P.G., Giannopoulos, I.P., Chrysostomou, C.Z., 2012. Modelling of Infilled Frames with Openings. *The Open Construction and Building Technology Journal (Suppl 1-M6)*, pp. 81–91

American Society of Civil Engineers, 2010. ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures.* Virginia, USA

Boonpichetvong, M., Pannachet, T., Pinitkarnwatkul, S., 2016. Finite Element Modeling of Concrete Specimens Confined with Metal Sheet Strips. *International Journal of Technology*, Volume 7(7), pp. 1132–1140

Budiwati, I.A.M., Sukrawa, M., 2018. A Diagonal Strut Width Formulae Application on Modeling Seismic Behavior of Reinforced Concrete Structures with Opening Wall. *In:* AIP Conference Proceeding, Volume 1977, pp. 020062-1–020062-9

Cetisli, F., 2015. Effect of Openings on Infilled Frame Stiffness. *Građevinar* Volume 67(8), pp. 787–798

Computers and Structures Inc., 2013. *Analysis Reference Manual SAP 2000*. California, USA

Crisafulli, F.J., Carr, A.J., 2007. Proposed Macro-model for the Analysis of Infilled Frame Structures. *Bulletin of New Zealand Society for Earthquake Engineering.*, Volume 40(2), pp. 69–77

Dorji, J., Thambiratnam, D.P., 2009. Modelling and Analysis of Infilled Frame Structures under Seismic Loads. *The Open Construction and Build*ing *Technology Journal*, Volume 3, pp. 119–126

EC., 2009. Euro Code 6. *Design of Masonry Structures*. Brussels, Belgium

Earthquake Engineering Research Institute (EERI), International Association for Energy Economy (IAEE), 2011. *Seismic Design Guide for Low-rise Confined Masonry Buildings*. Confined Masonry Network, Oakland, California

Federal Emergency Management Agency (FEMA) 306, 1998. *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual*. Washington, D.C., USA

Foytong, P., Boonpichetvong, M., Areemit, N., Teerawong, J., 2016. Effect of Brick Types on Compressive Strength of Masonry Prisms. *International Journal of Technology*, Volume 7(7), pp. 1171–1178

Imran, I., Aryanto, A. 2009. Behavior of Reinforced Concrete Frames In-filled with Lightweight Materials under Seismic Loads. *Civil Engineering Dimension*, Volume 11(2), pp. 69–77

Indian Standard (IS), 2002. *IS 1893-2002 (Part L) Indian Standard Criteria for Earthquake Resistant Design of Structures*. Part 1-General Provisions and Buildings. New Delhi, India

Kakaletsis, D.J., Karayannis, C.G., 2009. Experimental Investigation of Infilled Reinforced Concrete Frames with Openings. *ACI Structural Journal*, Volume 106-S14, pp. 132–141

Nicola, T., Leandro, C., Guido, C., Enrico, S., 2015. Masonry Infilled Frame Structures: State of the Art Review of Numerical Modelling. *Earthquakes and Structures*, Volume 8(3), pp. 733–759

Paudel, P., 2017. Effect of Infill Walls in Performance of Reinforced Concrete Building Structures. *International Journal of Engineering Research and General Science,* Volume 5(4), pp. 24–27

Paulay, T., Priestley, M.J.N., 1992. *Seismic Design of Reinforced Concrete and Masonry Buildings*, John Wiley & Sons, Inc. New York

Penava, D., Sigmund, V., Kožar, I., 2014. Micro-modeling of Tested Framed-wall with Openings. *In:* Second European Conference on Earthquake Engineering and Seismology. Istanbul, Turkey

Sigmund, V., Penava, D., 2013. Assessment of Masonry Infilled RC Frames with Openings. *Tehnicki vjesnik,* Volume 20(3), pp. 459–466

Sigmund, V., Penava, D., 2014. Influence of Openings, With and Without Confinement, on Cyclic Response of Infilled R-C Frames – An Experimental Study. *Journal of Earthquake Engineering,* Volume 18(1), pp. 113–146

Sukrawa, M., Budiwati, I.A.M., 2017. Analysis of Response Modification Coefficient (R) and Deflection Amplification Factor (Cd) for the Seismic Design of Infilled Frame Structure. *Research Report* submitted to LPPM Udayana University, Bali (in Indonesian)

Surendran, S., Kaushik, H.B., 2012. Masonry Infill RC Frames with Openings: Review of In-plane Lateral Load Behavior and Modeling Approaches. *The Open Construction and Building Technology Journal*, *(Suppl 1-M9)*, pp. 126–154

Yang, W., Guo, X., Xu, W., Yuan, X., 2016. Wing Walls for Enhancing the Seismic Performance of Reinforced Concrete Frame Structures. *Earthquake Engineering and Engineering Vibration*, Volume 15(2), pp. 411–423