Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-40596
www.engineeringscience.rs

publishing

Journal of Applied Engineering Science
Vol. 21, No. 2, 2023
Original Scientific Paper
Paper number: 22(2023)2, 1092, 481-490

ANALYTICAL STUDY ON BEHAVIOUR AND PERFORMANCE OF INFILLED FRAME STRUCTURE WITH REINFORCED ECCENTRIC OPENING

I Putu Agus Putra Wirawan, I Gede Gegiranang Wiryadi*, I Ketut Diartama Kubon Tubuh, Ni Luh Made Ayu Mirayani Pradnyadari

Mahasaraswati Denpasar University, Kamboja Street 11A, Denpasar, Indonesia
** gegiranangwiryadi@unmas.ac.id*

This numerical analysis has discussed the behaviour of the frame structure with eccentric infill wall opening modelled with shell and strut elements. In the beginning, validation models were created by following the laboratory tests results. Then, a simple one-storey infill frame structure with an opening was modelled with varying ratios by taking the strut angle formed to obtain an equation for the strut width that corresponds to the behaviour of shell element model with strut angles variation. The strut width equation was then applied to the 3-storey infill frame structures. The behaviour comparison between the strut and shell element model was then investigated by linear and nonlinear static analysis. The strut width equation for infill wall frame with eccentric openings (Weo) is determined by modifying the stiffness coefficient (Ce) based on the opening ratio. The application of the Weo equation to the infill frame model showed that the strut model had a comparable behaviour to the shell element model. The drift ratio comparison showed that the smaller the strut angle, the greater the structure stiffness. The pushover analysis shows the infilled frame model was able to withstand a larger base shear force than the open frame model.

Keywords: Infill wall with eccentric opening, shell element, diagonal strut width equation, diagonal strut

1 INTRODUCTION

Research on the behaviour of structures with infill walls has been widely carried out and it is proven that frames with infill walls can increase the strength and stiffness of the structure [1]. Walls in buildings have openings for doors and windows, but they still contribute to increasing the rigidity of the structure [2] to [4]. This can also be seen from the laboratory tests results by Kakaletsis and Karayannis [5] and a full-scale study by Cai and Su [6]. Infill wall frames with openings must be designed with reinforcement around the hole in the form of practical beams and columns (lintel). The presence of such reinforcement around the opening can reduce stresses and prevent cracks in the corner or on the edge of the opening.

In structural analysis using computer applications, there are two methods for modelling infill walls, namely the diagonal strut and shell element. The shell element method can describe the behaviour of structures such as stresses that occur in walls. Meanwhile, the diagonal strut method is simpler in its modelling because it is considered as a diagonal bar but can still predict the behaviour of the infilled frames [7] to [9]. Many studies have been conducted to find the equation of diagonal strut widths, but still cannot represent all variations of infill panels. This equation was only to represent the full infilled frames model, not the one with opening. Asteris [10] conducted a study on walls with openings and proposed a reduction factor for its stiffness to calculate the strut width equation. However, the proposed equation and the equation proposed by Sigmund and Penava [11] were only for unreinforced infilled frames with openings. Infill wall with a centre opening has been studied and developed for its analytical method [12] to [14], but the eccentric opening is still minimum.

For this reason, it is necessary to conduct further research to obtain a diagonal strut width equation of infilled frames with reinforced openings that corresponds to experimental tests results. The opening position is eccentric by considering the strut angle (θ) that is relevant to floor-to-floor height variations and fixed beam span. The angles are 31°, 39°, 45°, and 51°. For design purposes, the opening ratio (r) for strut width equation must be around 10%, 20%, 30%, 40%, 50%, and 60%. The opening ratio larger than 60% is not currently effective in infill wall frame structure [15]. After the strut width equation was obtained, it was then applied to the three-storey infilled frames structure. The structure was modelled with shell and diagonal strut elements with opening ratio (r) of 10%, 20%, 30%, 40%, 50%, and 60%, and was then analysed by linear analysis and nonlinear static analysis (pushover) using structural analysis software. The analysis results were presented in a comparison of behaviour and performance.

2 INFILL WALL FRAME

The addition of walls to the open frame structure (OF), significantly increases the stiffness and strength of the structure [16] to [18]. The presence of window and door openings in the infill wall is also the reason it is not considered as a structural component. Meanwhile, the test results showed that the infill wall frame structure with openings is still much stiffer and stronger than the open frame structure [1], [19] and [20].

Infilled wall-frames is a structure that consists of columns and beams made of steel or reinforced concrete with walls inside them. In the analysis, the infilled wall can be modelled with shell or diagonal strut elements. Diagonal strut models the walls which have received forces from the surrounding frame structure due to lateral forces so that the walls experience compression forces, thus, the diagonal strut is a compression member that is only capable of receiving axial forces. Equations for strut width have also been developed based on this research. One of the widely used formulas included in the FEMA-356 regulations related to infill wall analysis is the Mainstone equation as in Equation 1:

$$W_{ds} = 0.175(\lambda_1 h_{col})^{-0.4} r_{\inf} \qquad (1)$$

with λ expressed in Equation 2 as follows:

$$\lambda_1 = \left[\frac{E_{me} t_{\inf} \sin 2\theta}{4E_{fe} I_{col} h_{\inf}}\right]^{\frac{1}{4}} \qquad (2)$$

Paulay & Priestley formulate the equation for strut width which is simpler (Equation 3) and easier to calculate:

$$W_{ds} = \frac{d}{4} \qquad (3)$$

where Wds is the strut width and d is the diagonal strut length

The strut width equation for infilled wall with an opening was introduced by Asteris by reducing the wall stiffness factor based on Equation 4:

$$fr = 1 - 2\alpha_w^{0.54} + \alpha_w^{1.14} \qquad (4)$$

where aw is the opening percentage, and fr is the reduction factor. Thus, the equation becomes like Equation 5:

$$Wd = fr.W_{ds} \qquad (5)$$

In addition, Sigmund & Penava also formulated the strut width equation for infilled walls with openings by taking into account the correction factor for openings position and type based on the ratio of the basic shear force ratio of the infilled wall with openings and full infilled wall which was adjusted for the level of damage by following Equation 6:

$$W_{i,d} = \frac{K_{i,d}}{\cos^2 \phi} x \frac{d_i}{t_i E_i} \qquad (6)$$

where Wi,d is the strut width, Ki,d is the level of damage, ∅ is the diagonal strut angle, d, i is the diagonal strut length, ti is the wall thickness, and Ei is the modulus of elasticity of the wall.

The infilled wall with shell elements modelling is carried out in more detail, where the frame is modelled as a frame element, while the infill wall is modelled as a shell element. The contact area (link) of the frame and wall model is modelled as a gap element with gap stiffness proposed by Dorji & Thambiratnam [17] as in Equation 7 below:

$$K_g = 0.0378 K_i + 347 \qquad (7)$$

where Kg is the gap element stiffness (N/mm/mm), Ki is the infill wall stiffness (N/mm), Ei is the modulus of elasticity of the wall (N/mm2) and t is the wall thickness (mm).

For concrete materials, the value of the modulus of elasticity is based on SNI 2847-2019 [21]:

$$E_c = w_c^{1.5} 0.043\sqrt{f'_c} \qquad (8)$$

where Ec is the modulus of elasticity of the concrete, wc is the volume weight of the concrete, fc' is the concrete ultimate compressive strength. The value of the modulus of elasticity of the wall, based on FEMA-356:

$$E_m = 550 f'_m \qquad (9)$$

where Em is the modulus of elasticity of the brick wall, fm' is the compressive strength of the brick wall.

The stress-strain diagram is calculated based on the equation of Mander with the assumption that the maximum concrete stress occurs at the ultimate load. The wall stress-strain diagram (masonry) is calculated by the equation from Kaushik.

3 MATERIALS AND METHODS

This research began with a validation model based on the results of laboratory research that was carried out previously by Sigmund & Penava [11]. The validation models were modelled as shell and diagonal strut elements.

The load applied to the model was adjusted according to the experiment. The analysis was carried out by linear and nonlinear static analysis (pushover). In linear analysis, the elastic behaviour of the material was determined manually by changing the value of the elastic modulus (E) of the concrete, the wall according to the load level to the ultimate load, and the inertia value for the cracked cross-section was reduced [21].

The validation model was carried out by taking three specimens, namely, one full wall model 2/III (MS) and two models with eccentric door openings 3/II (MDO-Ex) and window openings 4/II (MWO-Ex). Detailed modelling and analysis results can be found in previous studies [22]. The validation results show that the structural behaviour (load-deformation) between the shell and strut element is appropriate. Based on the validation results, it is obtained that the diagonal strut width is as shown in Table 1, which for full walls still refers to Equation 3, and the width of the strut opening is obtained by trial-and-error method.

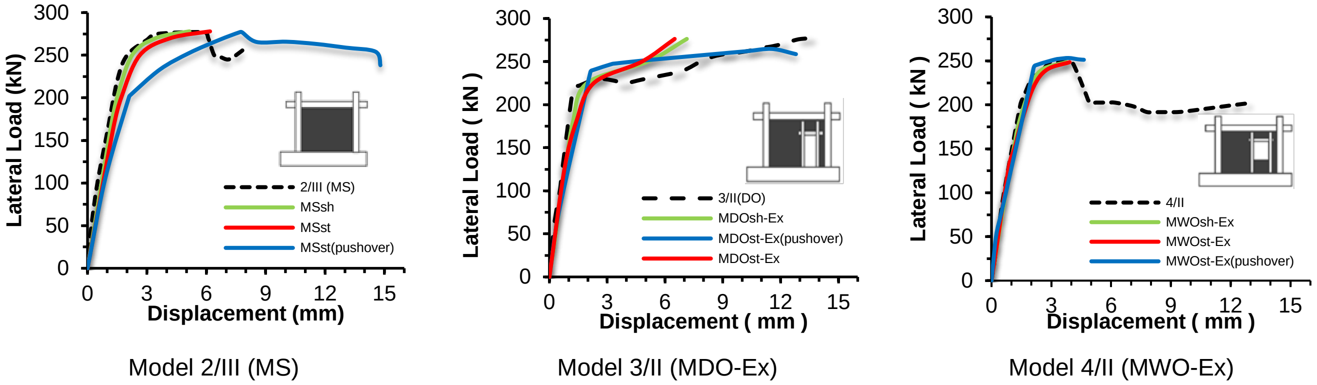


Fig. 1. Force-displacement curve of Validation Models

Table 1. Diagonal Strut Width of Validation Model

Model	Strut Width (mm)	H (mm)	L (mm)	D (mm)
MSst	642.27	1612	2000	2569
MDOst-Ex	*870			
MWOst-Ex	*890			

*done by trial and error

H = column height; L = beam length; D = diagonal length of infill wall

After the validation model result correspond with the laboratory test, a simple frame model was created. In the validation model, a strut angle of 39˚ with an opening ratio of 15% and 32% was used. This study was then continued by modelling variations in strut angles and other openings. The infilled frame model was made with one-storey by considering strut angles of 33°, 39°, 45°, and 51° and the opening ratios of 10%, 20%, 30%, 40%, 50%, 60% as shown in Figure 2. The strut angles variation is formed from a fixed span length and various floor height. Maximum and minimum floor height that was used in this research was limited to about 2.5 m and 5 m which yields strut angle of 33° and 51°. Strut angle of 39° was obtained from Sigmund and Penava experimental object. Then, a strut angle of 45° was selected as a mid-angle between 39° and 55°. All selected angles had differences of 6°. The openings variation percentage was chosen below 60% to maintain effectiveness of infill wall stiffness contribution [15].

A fixed beam length of 2000 mm was used for all models, while the columns were made with varying heights according to the strut angle needs. The column height used for strut angles of 33º, 39º, 45º, and 51º were 1299 mm, 1612.5 mm, 2000 mm, and 2470 mm, respectively. The infill walls were modelled as shell and diagonal strut elements. Similar to the validation method, the diagonal strut width was obtained by trial and error until the displacement of the strut model corresponds to the shell element model. The diagonal strut width from the analysis results of the simple frame model was then used to calculate the wall stiffness coefficient by comparing the strut width that had been obtained between the wall with opening and the full wall. To include the influence of the strut angle on the wall stiffness coefficient equation, the strut width was multiplied by the tangent of each angle under consideration.

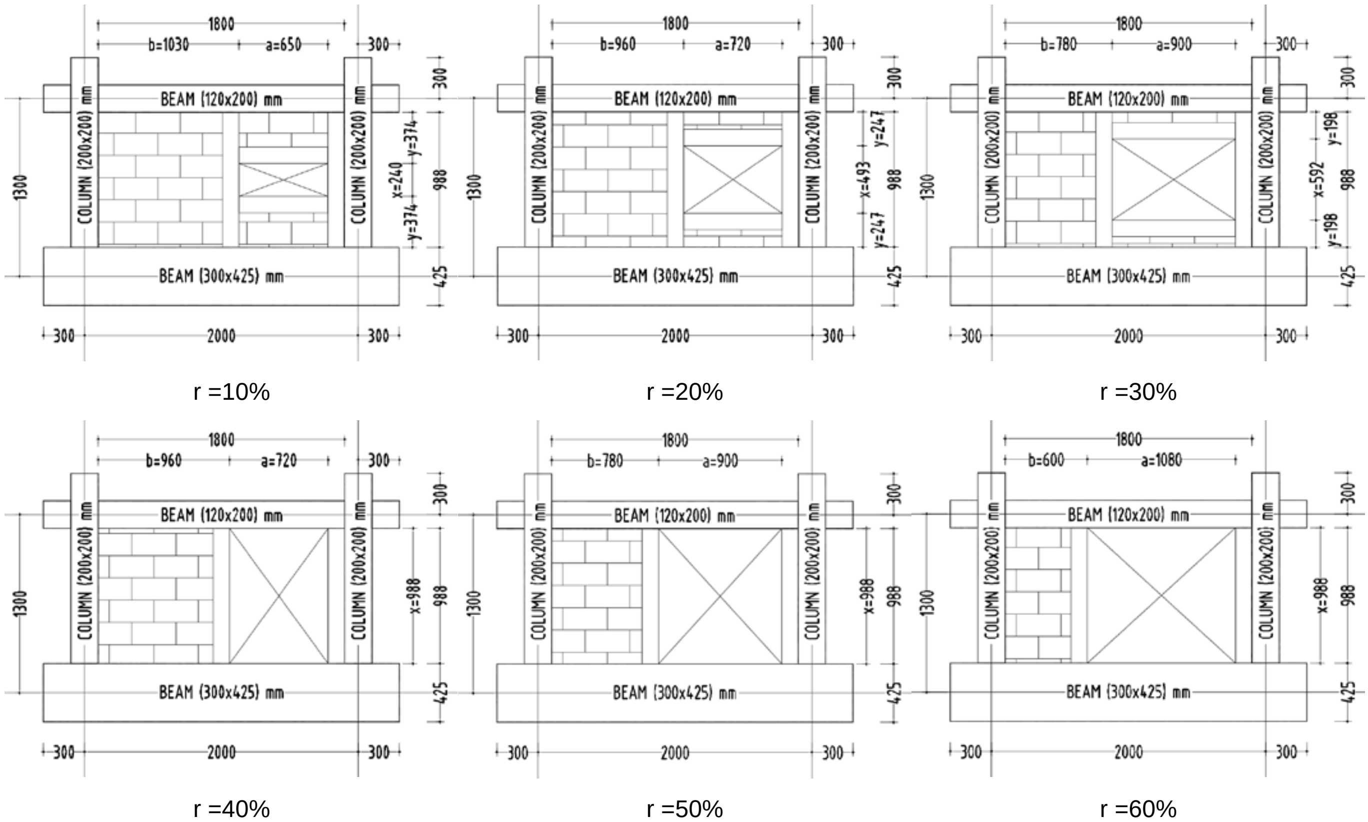


Fig. 2. Simple Frame Model Geometry with Strut Angle of 33º

The next step was to apply the strut width equation and the stiffness coefficient of the wall to the 3-storey frame structure model (M3). The frame model was made with constant beam spans and column heights that varied according to the strut angle as shown in Figure 3. Infill walls were added to the centre span of the portal with various openings of 10%, 20%, 30%, 40%, 50%, and 60%.

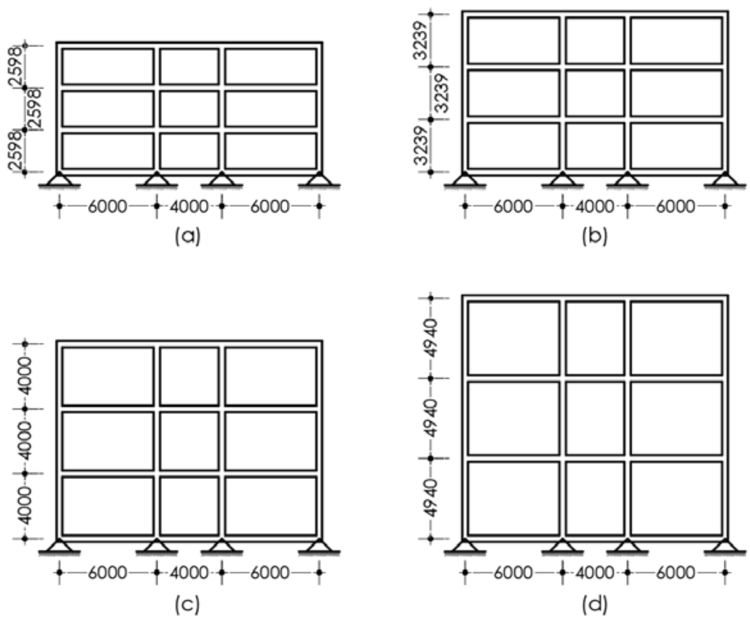


Fig. 3. Frame Structure Geometry Model with Angle of (a) 33º, (b) 39º, (c) 45º, (d) 51º

For all models, tie beam of 250/400 mm, main beam of 250/400 mm, middle column of 300/400, and edge column of 250/350 mm dimensions were used. Finally, a non-linear static pushover analysis was conducted to determine the overall structural performance, and then the structural behaviour was compared.

4 RESULTS AND DISCUSSION

4.1 Diagonal strut width analysis

The analysis results were presented in the form of a force-displacement curve as shown in Figure 4. The 10%-opening ratio model has greater strength than the full wall model for each variation of the strut angle. The displacement comparison results of the simple frame model with shell elements and diagonal strut showed that the larger the diagonal strut angle, the larger the displacement.

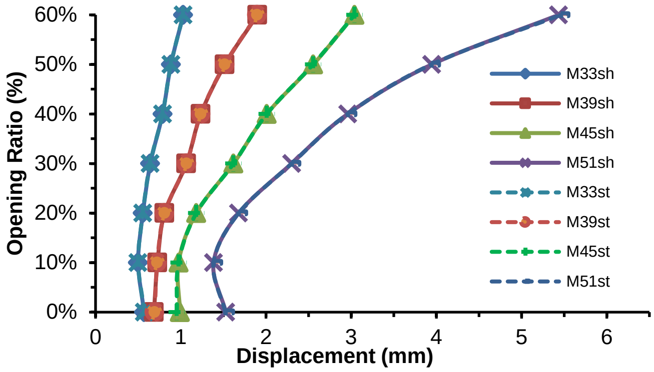


Fig. 4. Displacement Comparison of the Simple Frame Model with Shell Elements and Diagonal Strut

Strut width (W_{eo}) for opening ratios of 10% to 60% was determined by trial and error by comparing the displacement of the strut model with the shell element model. Meanwhile, Equation 3 was used for the strut width for the full wall model. To include the influence of strut angle on the wall stiffness coefficient equation (*c*), the strut width (W_{eo}) was multiplied by the tangent of each angle under consideration (θ). Strut widths for each model are shown in Table 2.

Table 2. Strut Width (mm) on the Simple Frame Model

Model		Opening percentage						
		0%	10%	20%	30%	40%	50%	60%
M 33	W_{eo}	596	677	617	535	429	373	304
	W_{eo} tan θ		440	401	347	279	242	197
M 39	W_{eo}	642	634	577	452	383	321	248
	W_{tr} tan θ		513	467	366	310	260	201
M 45	W_{eo}	707	634	546	418	341	267	219
	W_{eo} tan θ		634	546	418	341	267	219
M 51	W_{eo}	794	608	519	388	297	246	166
	W_{eo} tan θ		751	641	479	367	304	205

The strut width was then used to find the wall stiffness coefficient by performing a simple regression analysis to find the relationship between the *Ce* value and the r value so that the equation $Ce = 0.641r^2 – 1.556r + 1.005$ as shown in Figure 5 was obtained.

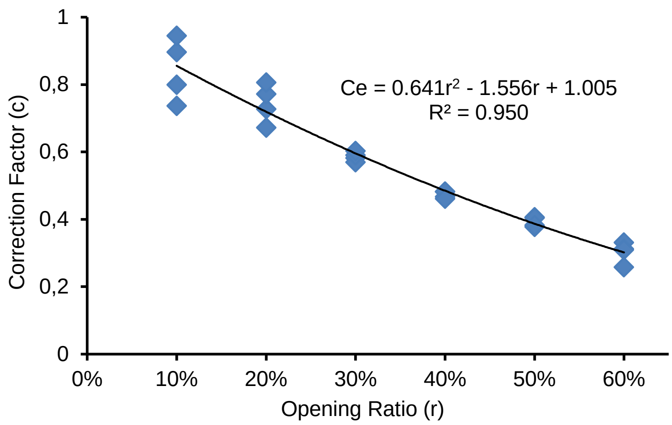


Fig. 5. Correlation between Opening Percentage (r) and Wall Stiffness Coefficient (Ce)

Based on the data shown in Figure 5, the diagonal strut width equation was determined by combining the equation for the diagonal strut width of the full wall with the equation for the coefficient of wall stiffness. The *Ce* value was returned to the initial conditions by including the divisor factor of the strut angle so that the strut width was obtained as shown in Equation 10.

$$W_{eo} = \frac{d}{4\tan\theta}Ce \tag{10}$$

$$Ce = 0.641r^2 - 1.556r + 1.005 \tag{11}$$

With W_{eo} is the strut width (mm), *d* is the wall diagonal length (mm), *θ* is the diagonal strut angle (tan-1 *H/L*), *H* is the column height (m), *L* is the beam span length, *Ce* is the wall stiffness coefficient with reinforcement around the opening, and *r* is the wall opening percentage.

4.2 Application of the Strut Width Equation in 3-Storey Frame Structure Model

In the application of this strut width equation, a comparison of the behaviour of the infilled frames with openings model was carried out by adding reinforcement around the hole with an r of 10% to 60%. The displacement comparison for each model with E_I analysis can be seen in Figure 6. The larger opening on the wall reduced the structure stiffness.

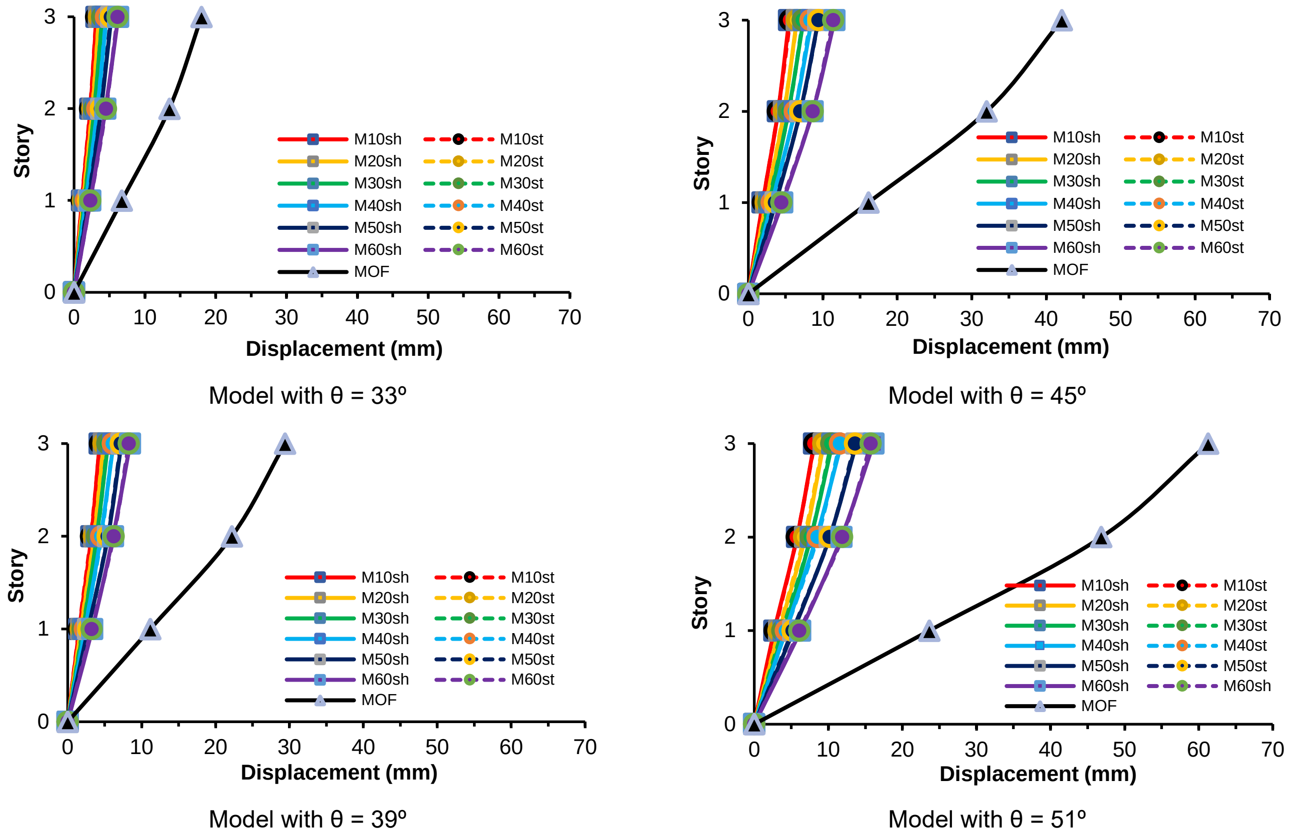
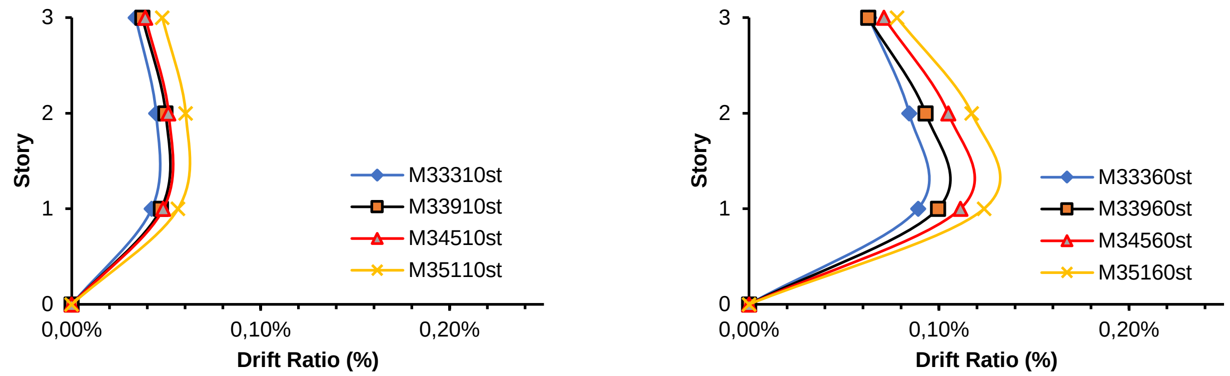


Fig. 6. Linear Elastic Displacement of the Frame

The displacement comparison results showed that the diagonal strut model has almost the same response as the shell element model. In the analysis with fixed EI values, the displacement difference between the strut model and the shell element is around 0.4% to 2.81%. Meanwhile, in the analysis with varied EI, the displacement difference between the strut and the shell element models is around 0.78% to 8%. By adding infill walls in the centre span of a 3-storey structure, the structure is stiffened by 67% to 85%.

4.3 Drift Ratio Comparison in the 3-Storey Frame Structure Application Model

Based on SNI 1726-2019 [23], the inter-storey drift should not exceed the allowable inter-storey drift (Δ_a), where the allowable inter-storey drift for the structure of risk category III is less than 0.02 (2%). Figure 7 shows the drift ratio values for the diagonal strut model with r 10% and 60%.



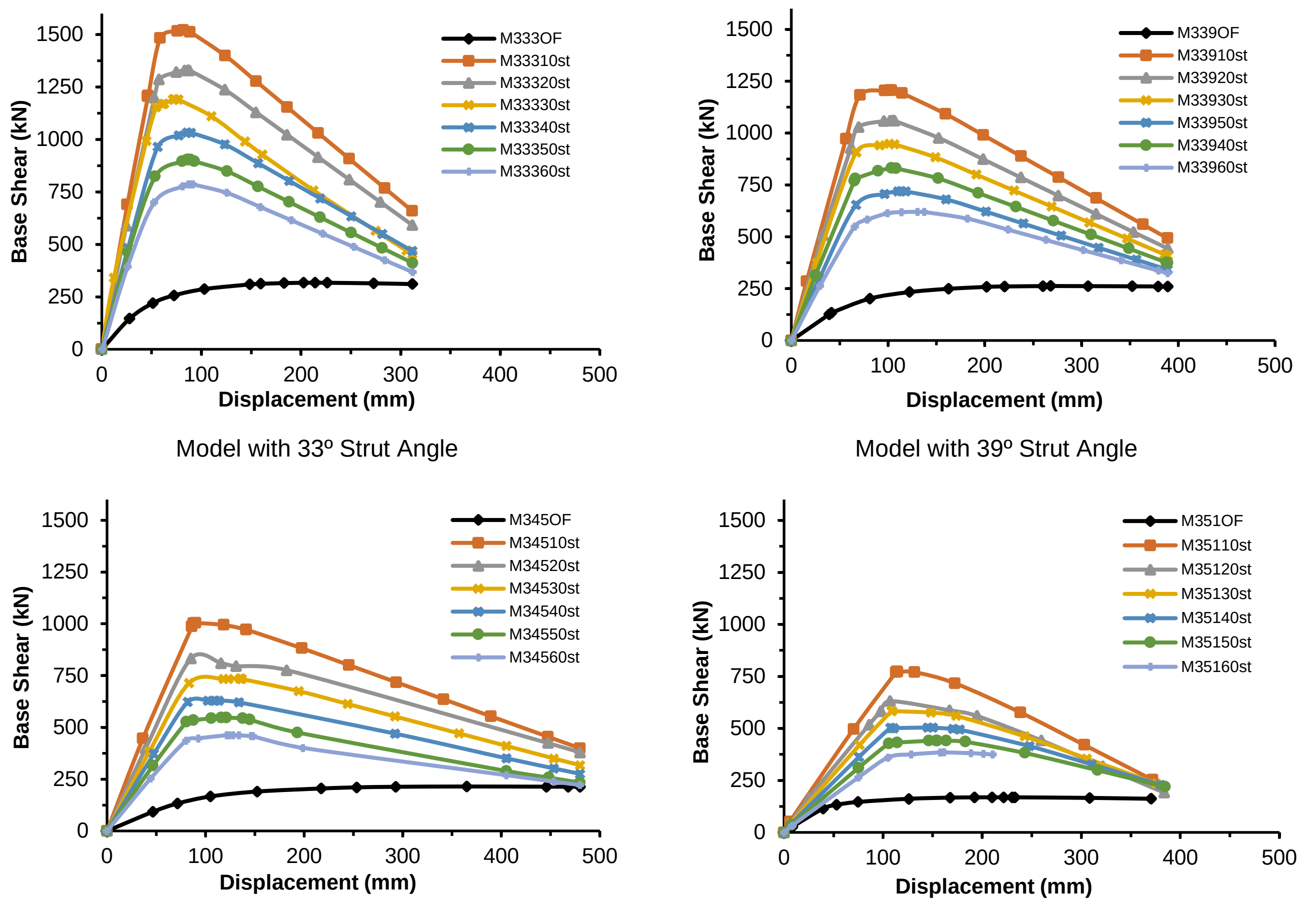
r = 10% Model r = 60% Model

Fig. 7. Drift Ratio Comparison

The drift ratio comparison results showed that the greater the strut angle and the aperture ratio, the greater the resulting drift ratio. So, it can be interpreted that the smaller the strut angle and the opening ratios, the greater the structure stiffness.

4.4 The nonlinear Static Analysis (Pushover) Results on the 3-Storey Frame Structure Application Model

The pushover analysis results are shown in Figure 8. Based on the analysis results that were shown in the capacity-displacement curve, the addition of infill walls was able to increase the structure performance up to 350% with 45% smaller displacement than the OF model. However, the increased wall opening makes the structural performance decreased by 14%. The base shear forces acting on the performance point (V_f), yielding point (V_y) and ultimate point (V_u) along with the displacement for each model are shown in Table 3 to Table 6.



Model with 33º Strut Angle Model with 39º Strut Angle

Model with 45º Strut Angle Model with 51º Strut Angle

Fig. 8. Pushover Curve of Frame Structure Application

Table 3. Base Shear Force and Effective Displacement of M333st Model

Model	Yielding Point		Performance Point		Ultimate Point	
M333	V_y (kN)	Δ_y (mm)	V_f (kN)	Δ_f (mm)	V_u (kN)	Δ_u (mm)
OF	145	27	283	99	317	214
10%	1228	45	1281	49	1521	81
20%	1124	47	1193	52	1330	86
30%	1058	50	1092	54	1191	73
40%	925	51	967	57	1032	85
50%	728	41	816	53	903	87
60%	700	52	722	60	786	89

Table 4. Base Shear Force and Effective Displacement of M339st Model

Model	Yielding Point		Performance Point		Ultimate Point	
M339	V_y (kN)	Δ_y (mm)	V_f (kN)	Δ_f (mm)	V_u (kN)	Δ_u (mm)
OF	125	38	234	125	262	267
10%	1148	66	1051	62	1205	102
20%	1002	64	969	64	1060	104
30%	907	66	908	67	948	101
40%	769	65	786	70	830	103
50%	682	67	668	75	719	113
60%	582	78	576	76	620	130

Table 5. Base Shear Force and Effective Displacement of M345st Model

Model	Yielding Point		Performance Point		Ultimate Point	
M345	V_y (kN)	Δ_y (mm)	V_f (kN)	Δ_f (mm)	V_u (kN)	Δ_u (mm)
OF	132	71	191	158	214	364
10%	979	82	871	75	1004	90
20%	825	78	819	80	832	85
30%	700	78	714	85	736	134
40%	622	82	624	87	629	113
50%	526	80	534	89	547	116
60%	435	80	447	93	462	121

Table 6. Base Shear Force and Effective Displacement of M351st Model

Model	Yielding Point		Performance Point		Ultimate Point	
M351	V_y (kN)	Δ_y (mm)	V_f (kN)	Δ_f (mm)	V_u (kN)	Δ_u (mm)
OF	114	39	164	147	168	221
10%	752	105	680	98	773	114
20%	583	97	621	104	631	106
30%	420	76	583	109	584	108
40%	362	75	501	111	504	145
50%	310	75	432	115	441	154
60%	263	74	371	121	384	161

In addition to the wall opening, the strut angle also affects the structural performance. Based on the results, the structural performance comparison on the frame structure application model with strut angles of 33º, 39º, 45º, and 51º was reviewed on the infilled frames model with an opening of 10%. The comparison results in Figure 9 shows that the model with θ = 33º is more rigid than the model with θ = 39º, 45º and 51º. From the model with θ = 33º, there is a performance decrease in the model with a strut angle of 39º until 51º. It means that the larger the strut angle, the smaller the structural stiffness and performance. This is also true for r = 20% to r = 60%.

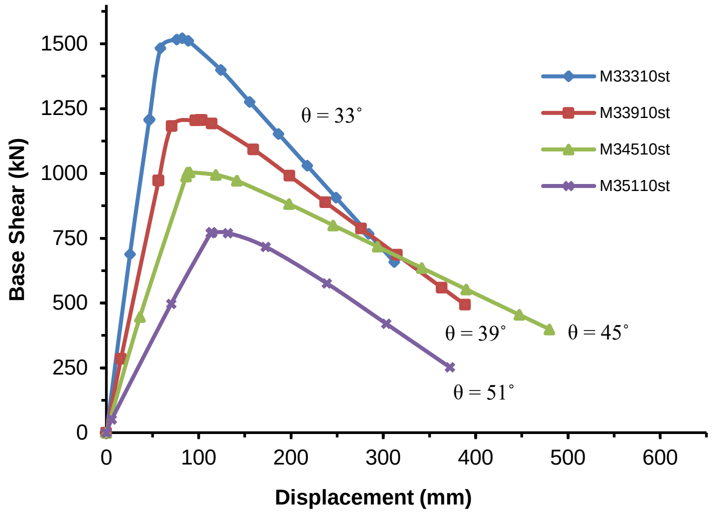


Fig. 9. Capacity Curve Comparison of Frame Structure Application Model with Strut Angle Variation for *r* = 10%

5 CONCLUSION

5.1 Conclusion

Based on the analysis results, the validation model with shell elements and diagonal strut can mimic the behaviour of the infilled frames structure with reinforced openings of the laboratory research by Sigmund and Penava [11]. The strut width equation of the infilled frames model with reinforced eccentric opening developed in this paper by modifying the stiffness coefficient (C_e) by an opening ratio (r) based on Equation 10 and 11. The application of the W_{eo} strut width equation in this study shows that the diagonal strut and the shell element models have an appropriate elastic behaviour. The drift ratio comparison shows that the smaller the strut angle, the greater the structure stiffness, and vice versa. The drift value obtained has met the minimum requirements of < 2%. Nonlinear analysis shows the infilled frames model can withstand a larger base shear force than the OF model. The larger the wall opening and the strut angle, the smaller the structure stiffness.

5.2 Suggestion

For design purposes, the strut width equation for infill wall frames with eccentric openings is recommended to be used in nonlinear analysis. The strut element model gives comparable results to the shell element model, but the shell element model is more conservative because it is easier to observe the stress values in the wall directly.

6 ACKNOWLEDGEMENT

This research was funded by Mahasaraswati Denpasar University research grants in the “Hibah Internal Penelitian Universitas Mahasaraswati Denpasar Tahun 2021 No. 585/C.13.02/Unmas/V/2021”.

7 REFERENCES

[1] Zine, A., Kadid, A., and Zatar, A. (2021). Effect of masonry infill panels on the seismic response of reinforced concrete frame structures. Civil Engineering Journal (Iran), vol. 7, no. 11, doi: 10.28991/cej-2021-03091764.

[2] Ahani, E., Mousavi, M. N., Rafezy, B., and Osmanzadeh, F. (2019). Effects of central opening in masonry infill on lateral behavior of intermediate RC frames. Advances in Civil Engineering Materials, vol. 8, no. 1, doi: 10.1520/ACEM20180040.

[3] Akid, A. S. M., Rashid, M. H., and Rahman Sobuz, M. H. (2021). Effect of masonry infill wall with opening on reinforced concrete frame due to seismic loading: Parametric study. International Journal of Structural Engineering, vol. 11, no. 1, doi: 10.1504/IJSTRUCTE.2021.112103.

[4] Tabeshpour, M. R. and Noorifard, A. (2020). A new procedure to determine equivalent strut of infill walls with openings for engineering applications. Proceedings of the Institution of Civil Engineers: Structures and Buildings, vol. 173, no. 8, doi: 10.1680/jstbu.18.00113.

[5] Kakaletsis, D. J. and Karayannis, C. G. (2009). Experimental investigation of infilled reinforced concrete frames with openings. ACI Structural Journal, vol. 106, no. 2, 132–141, doi: 10.14359/56351.

[6] Cai, G. and Su, Q. (2019). Effect of Infills on Seismic Performance of Reinforced Concrete Frame structures—A Full-Scale Experimental Study. Journal of Earthquake Engineering, vol. 23, no. 9, doi: 10.1080/13632469.2017.1387194.

[7] Lee, S. J., Eom, T. S., and Yu, E. (2021). Investigation of Diagonal Strut Actions in Masonry-Infilled Reinforced Concrete Frames. International Journal of Concrete Structures and Materials, vol. 15, no. 6, doi: 10.1186/s40069-020-00440-x.

[8] Roosta, S. and Liu, Y. (2021). Development of A Finite Element Model for All-Masonry Infilled., in Canadian Masonry Symposium.

[9] Timuragaoglu, M. O., Dogangun, A., and Livaoglu, R. (2019). Comparison and assessment of material models for simulation of infilled RC frames under lateral loads. Gtedevinar, vol. 71, no. 1, 45–56, doi: 10.14256/JCE.2307.2017.

[10] G. Asteris, P., Giannopoulus, I. P., and Chrysostomou, C. Z. (2012). Modeling of Infilled Frames With Openings. The Open Construction and Building Technology Journal, vol. 6 (Suppl 1 pp 81--91, doi: 10.2174/1874836801206010081.

[11] Sigmund, V. and 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, vol. 18, no. 1, 113–146, doi: 10.1080/13632469.2013.817362.

[12] Messaoudi, A., Chebili, R., Mohamed, H., and Rodrigues, H. (2022). Influence of Masonry Infill Wall Position and Openings in the Seismic Response of Reinforced Concrete Frames. Applied Sciences, vol. 12, no. 19, 9477, doi: 10.3390/app12199477.

[13] Medriosa, H., Maidiawati, M., Tanjung, J., and Zaidir, Z. (2022). Analytical study on effect of central opening of masonry infill to the lateral strength of RC Frame structure. Journal of Applied Engineering Science, vol. 20, no. 3, 745–753, doi: 10.5937/jaes0-35912.

[14] Sukrawa, M. and Budiwati, I. A. M. (2019). Analysis and design methods for infilled frames with confined openings. International Journal of Technology, 126–136, doi: 10.14716/ijtech.v10i2.2467.

[15] Sukrawa, M. (2015). Earthquake response of RC infilled frame with wall openings in low-rise hotel buildings. Procedia Engineering, 125 933--939, doi: 10.1016/j.proeng.2015.11.118.

[16] Wirawan, I. P. A. P., Tubuh, I. K. D. K., and Wiryadi, I. G. G. Studi Analitikal Perilaku dan Kinerja Struktur Rangka Dining Pengisi dengan Bukaan Sentris., Denpasar. doi: 10.22146/jcef.XXXXX.

[17] Brodsky, A., Rabinovitch, O., and Yankelevsky, D. Z. (2018). Effect of masonry joints on the behavior of infilled frames. Construction and Building Materials, vol. 189, doi: 10.1016/j.conbuildmat.2018.08.209.

[18] Zhao, J. and Qiu, H. (2022). Seismic Performance and Reliability Evaluation of Ductile RC Frame Structures with Infills. Periodica Polytechnica Civil Engineering, vol. 66, no. 2, doi: 10.3311/PPci.19777.

[19] Wang, F., Zhao, K., Zhang, J., and Yan, K. (2021). Influence of different types of infill walls on the hysteretic performance of reinforced concrete frames. Buildings, vol. 11, no. 7, doi: 10.3390/buildings11070310.

[20] Bose, S., Martin, J., and Stavridis, A. (2019). Simulation Framework for Infilled RC Frames Subjected to Seismic Loads. Earthquake Spectra, vol. 35, no. 4, 1739–1762, doi: 10.1193/042218EQS100M.

[21] Badan Standarisasi Nasional (2019). SNI 2847:2019 Persyaratan beton struktural untuk bangunan gedung dan penjelasan. Jakarta, 695.

[22] Tubuh, I. K. D. K., Wiryadi, I. G. G., Wirawan, I. P. A. P., and Pradnyadari, N. L. M. A. M. Modeling and Validation of Experimental Test Results on Infilled Frame with Eccentric Reinforced Opening., in 5th International Conference on Sustainable Development, 2021, 189–198.

[23] Badan Standardisasi Nasional (2019). SNI 1726:2019 Tata Cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan non gedung. Jakarta, 238.

Paper submitted: 11.10.2022.

Paper accepted: 22.01.2023.