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ASSESSMENT OF MASONRY INFILLED REINFORCED-CONCRETE FRAMES WITH OPENINGS

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Original scientific paper

Reinforced-concrete (R/C) frames infilled with masonry wall, especially with the presence of an opening, are insufficiently explored structural elements. We have experimentally investigated influence of the opening's type and position to the lateral response of reinforced-concrete frames with masonry infill. Correction factors, that take into account influence of the opening's type and position in the masonry infill in relation to frame without infill, are defined as an improvement of the equivalent diagonal compression strut model. This improvement enables use of R/C frames with masonry infill, with or without openings, as structural element. Its use would result in better seismic assessment of the masonry infilled R/C frames.

Keywords: *reinforced-concrete frame with infill, infill with openings, seismic response, assessment*

Proračun armirano-betonskih okvira ispunjenih ziđem s otvorima

Izvorni znanstveni rad

Armirano-betonski okviri sa zidanim ispunom, naročito uz prisustvo otvora, nedovoljno su istraženi konstruktivni elementi. Eksperimentalno smo istražili utjecaj vrste i položaja otvora na seizmički odgovor armirano-betonskih okvira sa zidanim ispunom. Uvedeni su korekcijski faktori kojima se u obzir uzima utjecaj vrste i položaja otvora u zidanom ispunu u odnosu na okvir bez ispuna, u svrhu poboljšanja modela zamjenske tlačne dijagonale. Poboljšanje omogućava uporabu a-b okvira sa zidanim ispunom, s i bez otvora, kao konstruktivnog elementa. Primjena će omogućiti kvalitetniji seizmički proračun a-b okvira sa zidanim ispunom.

Ključne riječi: *armirano-betonski okvir sa ispunom, ispuna s otvorima, potresni odgovor, proračun*

1 Introduction

Reinforced-concrete frames infilled with masonry wall behave differently than bare frames under lateral loading. Presence of openings in masonry infill influence the behaviour [1 ÷ 3], which has not been sufficiently explored. As many uncertainties in the framed-wall model exist, their combined behaviour is usually neglected. The existing design models are commonly calibrated on individual experiments with materials uncommon in the Republic of Croatia [4, 5]. An improved numerical model that takes into account composite frame-wall behaviour, with or without openings, is required [6 ÷ 8] and is presented in this paper.

Current design models either use some type of an equivalent diagonal compressive strut [9 ÷ 11] or method of sub-components described in [1, 7]. This method assumes that the components' behaviour could be predicted and that the total infill's strength is the sum of components' individual strengths, as in [1]. Calculated are the capacities that have no relation to drift. Although experiments showed that division of the infill into sub-components exists, its failure occurred when critical component failed e.g. masonry pier [8].

In this paper we are proposing a design model suitable for design of R/C frames infilled with masonry, as a system, with- or without opening. On the basis of the results of original experiments performed on the specimens of R/C frames infilled with masonry, we derived parameters important for the lateral response of the system. They take into account opening size, type and position in the infill and relate them to the capacities at different drift levels. The proposed method could be used as an improvement of the diagonal strut model that takes into account presence and position of an opening.

2 Diagonal strut model

Suggested calculation model is based upon defined correction factors and the application of equivalent diagonal strut method (Fig. 1). Similar was done in [11], but we took additional infill and opening parameters into consideration and connected the capacities with damage states of the whole "framed-wall" system by changing the strut width.

Size of the opening and its position is an important parameter. The openings could be classified into small, medium and large in compliance with [12]. Symbol γ is taken for size criteria (see Tab. 1).

In order to evaluate the width of the compression diagonal strut, we used the expression for the stiffness of the axial structural element

$$K_{i,\theta}=\frac{E_i\cdot A_{i,\theta}}{d_i}, \tag{1}$$

where index i designates infill without frame, index θ diagonal direction, E_i modulus of elasticity of masonry infill perpendicular to the bed-joints, $A_{i,\theta}$ area of the strut cross-section and d_i strut length which is equal to the length of the infill's diagonal.

The modulus of elasticity of masonry is considered constant at all storey drifts for the sake of simplification.

Table 1 Classification of an opening according to its size

Parameter	Small opening	Medium opening	Large opening
$\gamma = A_o/A_i$	$A_o/A_i \leq 0{,}075$	$0{,}075 < A_o/A_i \leq 0{,}15$	$A_o/A_i > 0{,}15$

Where: A_o = area of the opening; $A_i = h_i \cdot l_i$ = area of the masonry infill panel

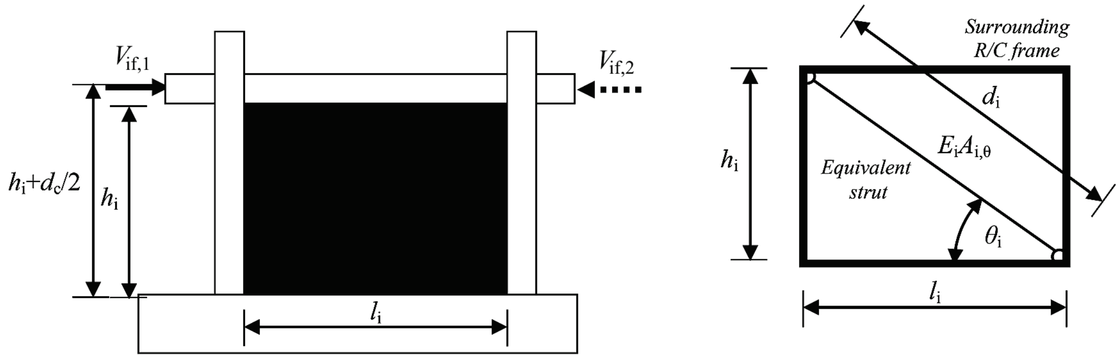


Figure 1 R/C frame with full infill (left) and equivalent single diagonal strut model with its basic properties (right)

The strut area from the Eq. (1) is

$$A_{\mathrm{i},\theta}=\frac{K_{\mathrm{i},\theta}\cdot d_\mathrm{i}}{E_\mathrm{i}}, \tag{2}$$

and the strut width is

$$w_\mathrm{i}=\frac{K_{\mathrm{i},\theta}.d_\mathrm{i}}{t_\mathrm{i}\cdot E_\mathrm{i}}, \tag{3}$$

where: t_i is thickness equivalent to the thickness of the infill. A single equivalent diagonal strut model is given in Fig.1. Stiffness of the diagonal structural element changes in regard to the four damage states of the infilled-frames (Tab. 2). The set of the secant stiffness values $K_{\mathrm{i},\theta,d}$ in diagonal direction is obtained by the expression

$$K_{\mathrm{i},\theta,d}=\frac{K_{\mathrm{if},d}\text{-}K_{f,d}}{\cos^2\theta}=\frac{K_{\mathrm{f},d}\cdot(\beta_d\text{-}1)}{\cos^2\theta}, \tag{4}$$

where K_f represents the secant stiffness of the R/C frame without infill, K_if the stiffness of the R/C frame with complete infill, index d corresponds to the selected damage state and θ is the angle of the diagonal.

Factors α and β represent ratios of the strength/stiffness and are defined by the expression

$$\alpha_d=\beta_d=\frac{V_{\mathrm{if},d}}{V_{\mathrm{f},d}}=\frac{K_{\mathrm{if},d}}{K_{\mathrm{f},d}}. \tag{5}$$

For each of the four damage states $\alpha_d=\beta_d$ the stiffness values are the ratio of the base shears and corresponding storey drifts d_r (see Tab. 5), i.e.

$$K_{\mathrm{if},d}=\frac{V_{\mathrm{if},d}}{d_{\mathrm{r},d}}. \tag{6}$$

By combining the Eq. (3) and (4) we obtain

$$w_{\mathrm{i},d}=\frac{K_{\mathrm{f},d}\cdot(\beta_d\text{-}1)}{\cos^2\theta}\cdot\frac{d_i}{t_\mathrm{i}\cdot E_\mathrm{i}} \tag{7}$$

and

$$K_{\mathrm{i},d}=K_{\mathrm{f},d}\cdot(\beta_d\text{-}1) \tag{8}$$

in which the stiffness of the R/C frame is removed from result and the Eq. (7) becomes

$$w_{\mathrm{i},d}=\frac{K_{\mathrm{i},d}}{\cos^2\theta}\cdot\frac{d_\mathrm{i}}{t_\mathrm{i}\cdot E_\mathrm{i}}. \tag{9}$$

Contribution of the masonry infill to the overall stiffness decreases with increasing drifts and is negligible at Pre-collapse damage levels, so the strut width at these levels is close to zero.

The strut width is evaluated for the damage states and additionally expressed as a ratio towards horizontal area of the infill (Tab. 2). As a result, the four values of the strut width depending on the storey drift represent the strut behaviour law for the complete infill case (see Fig. 6a).

Table 2 Area and width of diagonal strut for selected damage states

Specimen	Damage state of the infill							
	Slight (s) d_r=0,05÷0,1 %		Moderate (m) d_r=0,2÷0,3 %		Heavy (h) d_r=0,5 %		Collapse (c) d_r=0,75÷1 %	
	$A_{\mathrm{i},\theta}/A_{\mathrm{i,h}}$	$\lambda_\mathrm{s}=w_\mathrm{i}/w_\mathrm{i,s}$	$A_{\mathrm{i},\theta}/A_{\mathrm{i,h}}$	$\lambda_\mathrm{m}=w_\mathrm{i}/w_\mathrm{i,s}$	$A_{\mathrm{i},\theta}/A_{\mathrm{i,h}}$	$\lambda_\mathrm{h}=w_\mathrm{i}/w_\mathrm{i,s}$	$A_{\mathrm{i},\theta}/A_{\mathrm{i,h}}$	$\lambda_\mathrm{c}=w_\mathrm{i}/w_\mathrm{i,s}$
III/2	0,36	1,0	0,20	0,60	0,02	0,06	0,01	0,03

Where: $A_{\mathrm{i},\theta}=w_\mathrm{i}\cdot t_\mathrm{i}$ = cross-section area of the strut; $A_\mathrm{i,h}=l_\mathrm{i}\cdot t_\mathrm{i}$ = horizontal area of the masonry infill panel (without frame)

Due to symmetry this applies for both loading directions. It is demonstrated that the strut width decays due to stiffness parameter till it reaches the point where it is close to zero (see also Tab. 2 and Tab. 7). At that point only R/C frame exists and the infill is not able to carry any load.

2.1 Strut area for different damage states

Symbol λ is used as the ratio of the strut width at the actual damage state in regard to the Slight damage state (see Tab. 2) and is expressed as

$$\lambda_\mathrm{s}=\frac{w_{\mathrm{i},d}}{w_\mathrm{i,s}}. \tag{12}$$

The strut width is expressed as a function of the width at Slight damage state and becomes

$$w_{\mathrm{i,s}}=\lambda_{\mathrm{s}}\cdot w_{\mathrm{i,s}}. \tag{13}$$

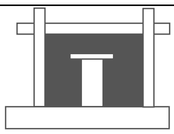
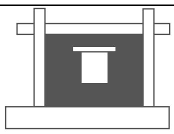
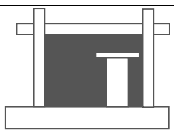
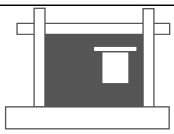
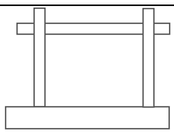
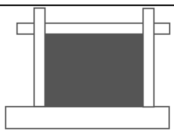
The initial strut width at zero drift is extrapolated (dashed part in Fig. 6a). It is evaluated by the value at slight damage state by a factor of two, based on the experimental results

$$w_{\mathrm{i},\theta}=2w_{\mathrm{i,s}}\approx h_{\mathrm{i}}. \tag{14}$$

The initial strut width can be adopted to be equal to the infill's height, in accordance with Eq. (14) and the data from Tabs. 4 and 7.

So, if the base shear values at characteristic storey drifts of the frame without infill are known, by using the stiffness factors we could obtain the same for the R/C frame with complete infill. We also calibrated the strut properties with respect to completely infilled frame response, as described above and in [12, 13].

Table 3 Classification and description of the specimens

Specimen	Display	Opening type, area and dimensions	Opening position
I/1		Door l_o/h_o=0,35/0,90 m A_o=0,32 m^2	Centric e_1=e_2=0,90 m
I/2		Window l_o/h_o=50,0/60,0 cm A_o=0,30 m^2	Centric e_1=e_2=0,90 m P=0,40 m
I/3		Door l_o/h_o=0,35/0,90 m A_o=0,32 m^2	Eccentric e_1=0,44 m e_2=1,36 m
I/4		Window l_o/h_o=50,0/60,0 cm A_o=0,30 m^2	Eccentric e_1=0,51 m e_2=1,29 m P=0,40 m
III/1		–	–
III/2		–	–

Where: l_o = length of an opening; h_o = height of an opening; P = window parapet wall; $e_{1,2}$ = distance between symmetry axis of an opening to closer or distant inner column face respectively

3 Test specimens

Diagonal parameters were determined by the experimental research carried out on the specimens in 1:2,5 scale. Six one-bay, one–storey planar R/C frames infilled with masonry and one bare R/C frame were built and tested at the Faculty of Civil Engineering, Josip Juraj Strossmayer University of Osijek. They were tested under series of quasi-static stepwise increasing loading cycles up to the moment of infill's and/or frame's failure, in accordance with [14]. Tests were performed under the same conditions enabling the comparison of results. All frames were identical with rigid frame joints and dimensions as shown in Fig. 2. The specimens were divided into three groups according to the opening type and position [8, 12, 14] and are presented in Tab. 3.

The masonry infill wall was produced with hollow clay blocks of Group IIb, in compliance with [2] and with cement-lime mortar of class M5. The hollow clay blocks are commonly used for infill in Croatia. They have high vertical and low horizontal strength and comply with the requirements of [2, 3]. Openings in the masonry infill were centrically (Group I) or eccentrically positioned (Group II). Two specimens (Group III) were boundary cases, one bare R/C frame and one R/C frame with full infill. Infill was connected to the frame by adhesion only.

3.1 Geometry

All specimens were one-story, one-bay reinforced concrete frame specimens, as shown in Fig. 2. They were designed as medium-ductility frames (DC-M) according to [3, 15].

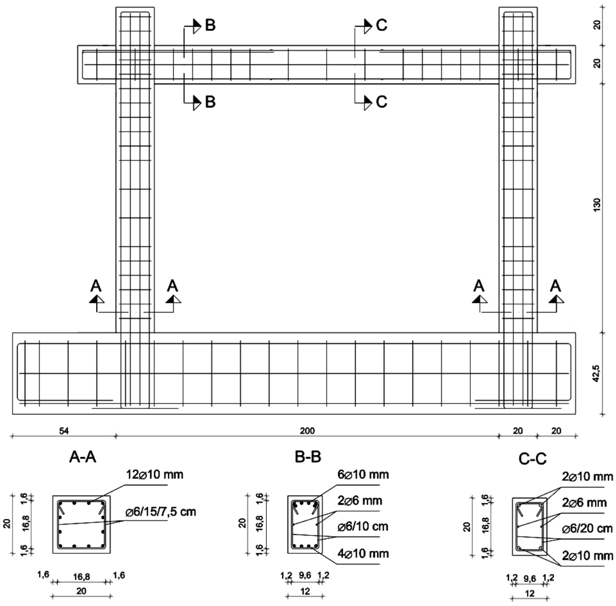


Figure 2 Reinforcement details and specimen's dimensions (cm)

Table 4 Mechanical properties of the materials used in test

Material	Norm	Properties	Value	Units
Hollow-clay-tile	[16, 17]	f_b	15,9	MPa
		f_{bh}	2,6	MPa
General purpose mortar	[18]	f_m	5,15	MPa
		f_{mt}	1,27	MPa
Masonry	[19, 20]	f_k	2,7	MPa
		E	3900	MPa
		ε_u	0,57	‰
		f_{vk0}	0,7	MPa
		$\tan\alpha_k$	0,8	MPa
Frame concrete	[21]	$f_{ck,cube}$	45	MPa
Longitudinal and transverse reinforcement	[22]	f_{yk}	600	MPa
		f_{uk}	700	MPa
		E_s	210 000	MPa

Where: f_b and f_{bh} − normalized compressive strength in vertical and horizontal direction; f_m and f_{mt} − compressive and bending-tensile strength; f_k, f_{vk} − characteristic compressive and initial shear strength, E = modulus of elasticity; ε_u= ultimate normal strain; $f_{ck,cube}$ = characteristic compressive strength of a concrete cube; f_{yk} and f_{uk} − characteristic yield and ultimate tensile strength.

3.2 Materials

The material characteristics were determined by tests in accordance with the relevant EN norms, and are briefly given in Tab. 4 and in details in [4, 5].

3.3 Test results

The general test results of all specimens are presented in Tab. 5 and in Figs. 3 and 4. They describe the failure mechanism, observed damage to masonry infill and specimen's behaviour expressed with the hysteresis loops and resistance envelope curves (Figs. 3 and 4).

The masonry infill's contribution to the behaviour of the bare frame is given as the ratio of strength and stiffness of infilled and bare frames at corresponding drifts, as given in Tabs. 6 and 7. In the case of eccentric opening the values for both loading directions were given and in the case of symmetric infill adopted is the average value of both loading directions. It could be observed that among the specimens with infill no significant difference in strength and stiffness exists.

The experimental results were validated and behavioural correction factors were introduced. They represent base shear and secant stiffness ratio of the frame with complete infill to that of the bare frame and the ratio between cases of full infill and infill with opening. Opening's type and position were taken into account. The values of the correction factor are given for storey drifts that correspond to slight, moderate, heavy and pre-collapse damage state.

Table 5 Overview of damage intensities with corresponding shear and drift

Specimen	Slight damage d_r = 0,05 ÷ 0,1 %		Moderate damage d_r = 0,2 ÷ 0,3 %		Heavy damage d_r = 0,5 %		Collapse d_r = 1 %		Failure mechanism
	d_r / %	V / kN	d_r / %	V / kN	d_r / %	V / kN	d_r / %	V / kN	
I/1	0,10	200	0,20	260	0,50	260	–	–	Two piers and one spandrel were formed due to bed-joint sliding in the plane bellow lintel. The pier had dominant diagonal shear failure.
	−0,10	−201	−0,26	−260	–	–	–	–	
I/2	0,09	201	0,26	300	0,52	310	–	–	Two piers and two spandrels were formed due to the bed-joint sliding in the plane above and below opening. The pier had dominant diagonal shear failure.
	−0,11	−201	−0,23	−280	−0,52	−289	−1,01	−261	
I/3	0,09	199	0,17	258	0,53	275	0,94	265	Two piers and one spandrel were formed due to the bed-joint sliding in the plane bellow lintel. The pier had dominant diagonal shear failure.
	−0,10	−201	−0,17	−261	–	–	–	–	
I/4	0,10	201	0,22	261	0,50	278	1,00	286	Two piers and two spandrels were formed due to bed-joint sliding in the plane above and below opening. The pier had dominant horizontal shear failure.
	−0,10	−202	−0,28	−220	–	–	–	–	
III/1	0,10	73	0,24	119	0,47	180	1,00	209	The r/c frame yielded at lateral load of 209 kN and drift of 1,0 %.
	−0,10	−96	−0,22	−167	−0,49	−192	–	–	
III/2	0,11	227	0,20	267	0,57	260	1,09	258	The diagonal shear and horizontal shear failure occurred in the infill.
	−0,09	−200	−0,21	−282	–	–	–	–	

Table 6 Lateral load capacity at certain drift/damage levels

Specimen	Slight damage d_r = 0,05 ÷ 0,1 %			Moderate damage d_r = 0,20 ÷ 0,30 %			Heavy damage d_r = 0,50 %			Collapse d_r = 1,0 %		
	d_r / %	V / kN	V_{if}/V_f	d_r / %	V / kN	V_{if}/V_f	d_r / %	V / kN	V_{if}/V_f	d_r (%)	V / kN	V_{if}/V_f
I/1	0,10	201	2,37	0,23	260	1,82	0,50	260	1,40	–	–	–
I/2	0,10	201	2,38	0,24	290	2,02	0,52	299	1,61	1,01	261	1,25
I/3	0,09	199	2,35	0,17	258	1,81	0,53	275	1,48	0,94	265	1,27
	−0,10	−201	2,38	−0,17	−261	1,82	–	–	–	–	–	–
I/4	0,10	201	2,38	0,22	261	1,82	0,50	278	1,49	1,00	286	1,37
	−0,10	−202	2,39	−0,28	−220	1,54	–	–	–	–	–	–
III/1	0,10	85	1,00	0,23	143	1,00	0,48	186	1,00	1,00	209	1,00
III/2	0,10	213	2,52	0,21	274	1,92	0,57	260	1,40	1,09	258	1,23

Table 7 Specimens' secant stiffness at various damage levels

Specimen	Slight damage d_r = 0,05 ÷ 0,1 %			Moderate damage d_r = 0,20 ÷ 0,30 %			Heavy damage d_r = 0,50 %			Collapse d_r = 1,0 %		
	d_r / %	K_{if} / kN/mm	$K_{if}/K_{if,s}$	d_r / %	K_{if} / kN/mm	$K_{if}/K_{if,m}$	d_r / %	K_{if} / kN/mm	$K_{if}/K_{if,h}$	d_r / %	K_{if} / kN/mm	$K_{if}/K_{if,c}$
I/1	0,10	143	1,00	0,23	81	0,57	0,50	37	0,26	–	–	–
I/2	0,10	145	1,00	0,24	85	0,59	0,52	41	0,28	1,01	18	0,13
I/3	0,09	160	1,00	0,17	108	0,68	0,53	37	0,23	0,94	20	0,13
	−0,10	150	1,00	−0,17	108	0,72	–	–	–	–	–	–
I/4	0,10	142	1,00	0,22	86	0,60	0,50	40	0,28	1,00	20	0,14
	−0,10	145	1,00	−0,28	56	0,39	–	–	–	–	–	–
III/1	0,10	63	1,00	0,23	45	0,71	0,48	27	0,44	1,00	15	0,24
III/2	0,10	151	1,00	0,21	94	0,62	0,57	32	0,22	1,09	18	0,12

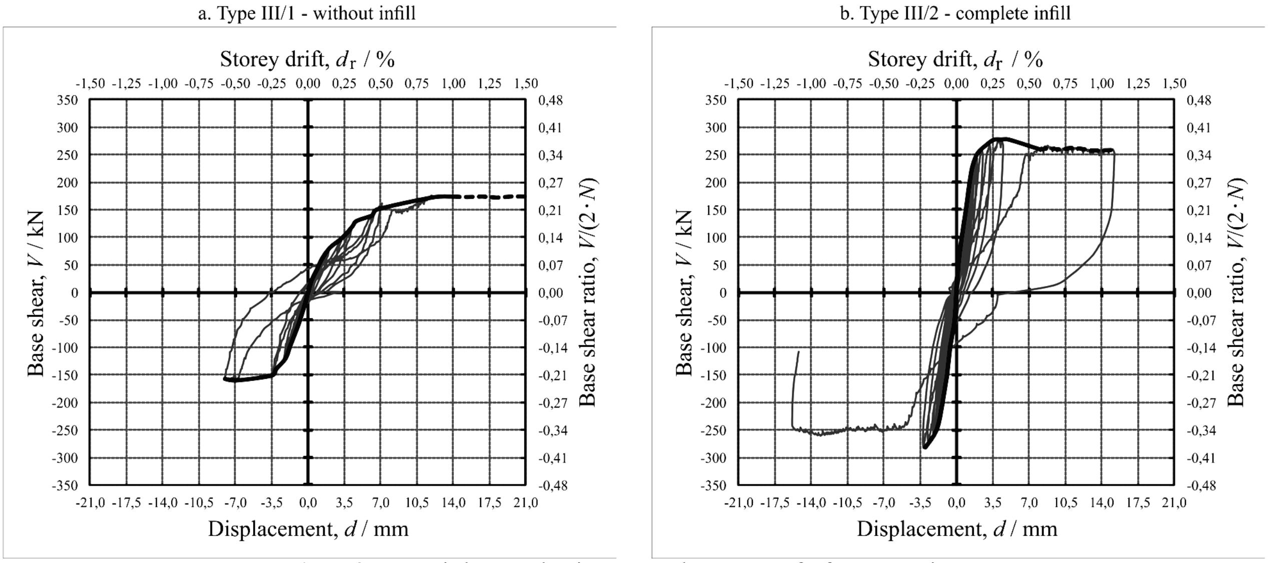


Figure 3 Hysteretic loops and resistance envelope curves of reference specimens

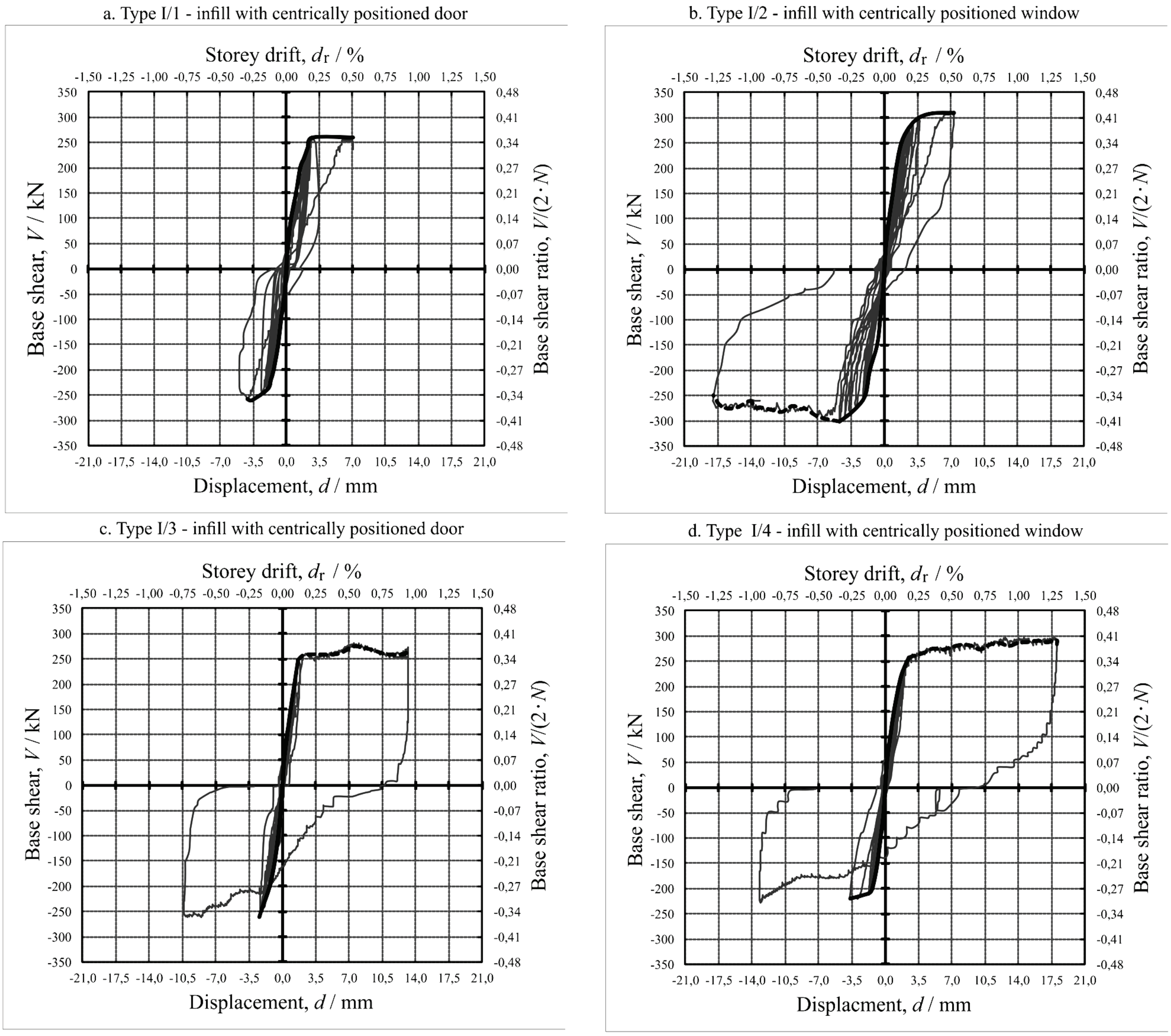


Figure 4 Hysteretic loops and resistance envelope curves of specimens' with opening

4 Diagonal strut model of the infill with opening

The strut width expression given by Eq. (11) is modified to take into account the opening's type and position. Corresponding factors (Tabs. 6 and 7) were used to form the expressions, and are in detail explained in the following paragraphs.

$$w_{i,d}=\vartheta_d \cdot \iota_d \cdot \frac{K_{i,s}}{\cos^2\theta} \cdot \frac{d_i}{t_i \cdot E_i} \tag{13}$$

and

$$w_{i,d} = \vartheta_d \cdot \kappa_d \cdot \frac{K_{i,s}}{\cos^2\theta} \cdot \frac{d_i}{t_i \cdot E_i}, \quad (14)$$

where Theta variant ϑ is used for correction factor for the opening type and Iota ι which is used to mark the factor related to e_1, and Kappa κ to mark the factor related to e_2 are introduced to account the opening position (see Fig. 5).

For centrically placed opening i.e. $e_1 = e_2$, both expressions give the same result. In the case of eccentrically positioned opening, the Eq. (13) is used for the infill's side marked with e_1, and the Eq. (14) for another (e_2). So, the eccentric opening in the infill is modelled by the overcrossing compression diagonals with different widths at the same damage state.

The strut areas in the specimens for the infill with centric and eccentric opening are given in Tab. 8, along with the results for full infill, in relation to the infill horizontal gross area.

Table 8 Area ratio of the diagonal strut for different damage states

Specimen	Damage state of the infill			
	Slight (s) d_r = 0,05 ÷ 0,1 %	Moderate (m) d_r = 0,2 ÷ 0,3 %	Heavy (h) d_r = 0,5 %	Collapse (c) d_r = 0,75 ÷1 %
	$A_{i,\theta}/A_{i,s}$	$A_{i,\theta}/A_{i,m}$	$A_{i,\theta}/A_{i,h}$	$A_{i,\theta}/A_{i,c}$
III/2	0,35	0,20	0,02	0,01
I/1	0,33	0,19	0,02	-
I/2	0,33	0,21	0,02	0,01
I/3-1	0,35	0,19	0,02	0,01
I/3-2	0,35	0,18	0,02	0,01
I/4-1	0,35	0,18	0,02	0,01
I/4-2	0,35	0,15	0,02	0,01

Strut area ratio and storey drift relation are shown in Fig. 6b for the cases with centrically positioned opening.

These represent the width of overcrossing diagonals regardless of the horizontal loading direction. The opening position's sensitive parameters are shown in Figs. 6b and 6c.

4.1 Influence of the opening's type

The door and window openings (as given in Tab. 3) were considered as opening types. Correction factor, that takes into account the opening's type, is obtained as the ratio of the base shear for the case of infill with opening to the full infill (see Tab. 6).

Influence of the opening's type is obtained by considering the response of different centrically placed openings. This is described by the equations:

$$\vartheta_d = \frac{K_{ifoc,d}}{K_{if,d}}, \quad (15)$$

or

$$\vartheta_d = \frac{V_{ifoc,d}}{V_{if,d}}, \quad (16)$$

where indices d, if and oc designate selected damage state, frame with infill and presence of centrically positioned opening, respectively. K designates secant stiffness. As damage states of the infill occurred at similar drifts in all specimens, both Eq. (15) and Eq. (16) could be used. In further elaboration we used the Eq. (16).

For each of the centrally placed opening types four factors have been determined based on adopted average values from Tab. 6 and/or 7. That is, the base shear value at storey slight damage drift of d_r = 0,05 ÷ 0,1 % for window opening is $V_{ifwoc,s}$ = 201 kN. Here the indicie o is replaced with wo to indicate the opening's type. For the same drift measured base shear was $V_{if,s}$ = 213 kN. So we got the dimensionless coefficient value of

$$\vartheta_s = \frac{V_{ifwoc,s}}{V_{if,s}} = \frac{201}{213} = 0{,}94. \quad (17)$$

Accordingly, letters m, h and c in the indices for selected damage state, refer to the damage state, namely: Moderate, Heavy and Pre-collapse infill damage state, respectively.

Remaining correction factors were calculated and summarized in Tab. 8.

The correction coefficients for the door opening were obtained for the available damage states that corresponded to the measured drift capacity of the specimens, according to Tab. 6. In Tab. 6, Moderate damage corresponds to the Pre-collapse state and the coefficient could be applied to infill alone.

4.2 Influence of the opening's position

The influence of the opening's position is calculated as the ratio of the measured base shear for eccentrically and centrically placed opening. Correction factors are evaluated at the four defined damage states in Tab. 6.

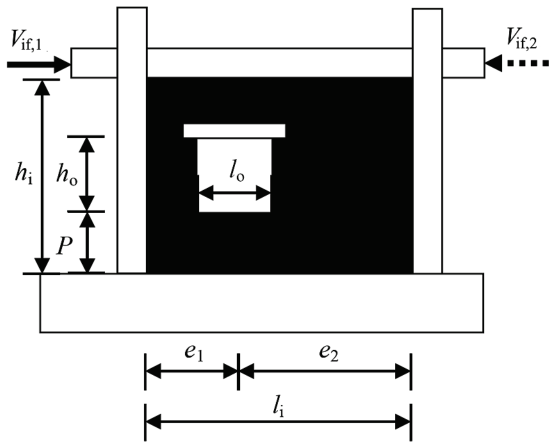


Figure 5 Geometry parameters for eccentrically positioned opening

The first eccentricity parameter, e_1, is distance from the opening's symmetry line to the closer column face, and the second, e_2, is the distance to the face of the other column. It is to be noted that states $e_1 \le e_2$. Two different equations were formed to take into account the opening's position. They are:

$$\iota_d = \frac{V_{ifoe1,d}}{V_{ifoc,d}} \quad (18)$$

and

$$\kappa_d = \frac{V_{\text{ifoe2},d}}{V_{\text{ifoc},d}}. \qquad (19)$$

Symbols related to other indices are the same as for the opening's type factor given in Eq. (16). For the case of centric opening, $e_1 = e_2$ and factors ι and κ should be taken as 1,0 at all damage states.

Using data from Tab. 6, for the case with eccentrically positioned window opening and for the horizontal force acting from the side close to the opening, we calculated the correction factor that takes into account the opening's position, at slight damage state by using Eq. (18) to be

$$\iota_\text{s} = \frac{V_{\text{ifwoe1,s}}}{V_{\text{ifoc,s}}} = \frac{201}{201} = 1,0. \qquad (20)$$

On the other hand, for the case with distant opening, the correction factor was calculated by the Eq. (19) as:

$$\kappa_\text{s} = \frac{V_{\text{ifwoe2,s}}}{V_{\text{ifoc,s}}} = \frac{202}{201} = 1,0. \qquad (21)$$

The missing values, such as for κ_h and κ_c, were compensated with the ones from the other i.e. weaker direction (see Figs. 3 and 4).

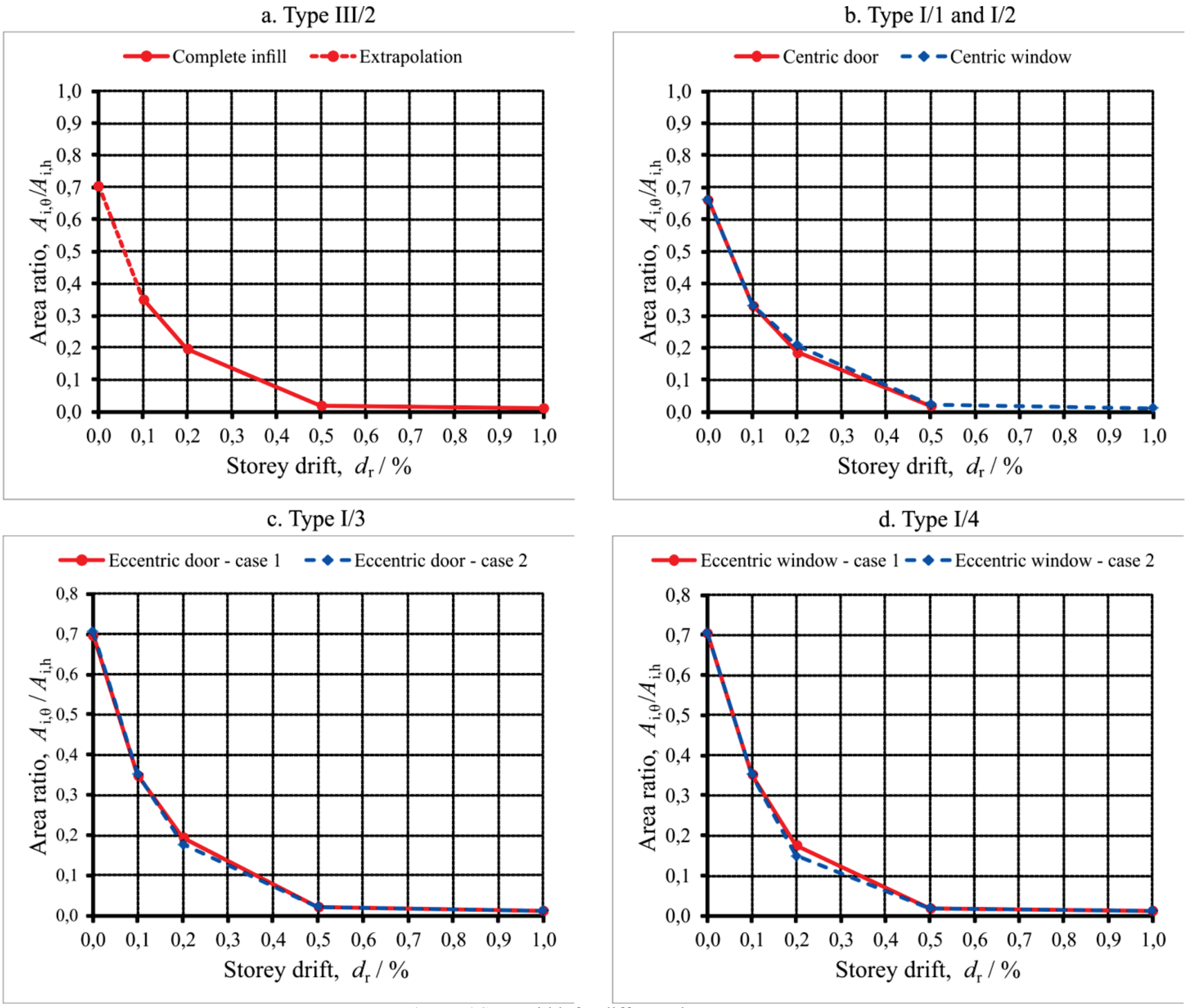


Figure 6 Strut width for different damage states

This gave an approximate solution on the safe side. Remaining correction factors were calculated and summarized in Tab. 8. Due to similarity in behaviour of all specimens in experiments, the factors that came out as result are close or equal to unity.

In the next step width of the diagonal strut is calculated according to the Eqs. (13) and (14) in which the influence of the opening type and position is included, as shown in Fig 6. and in Tab. 8.

5 Conclusions and remarks

Diagonal strut model could be used for the modelling of the infill placed within the reinforced-concrete frame. It fails to describe the behaviour of infill with opening that occurs often. We classified the openings in three sizes small, medium and large based on the ratio of the opening's and infill area (γ). Additional factors that needed to be considered were opening type and its position and damage state correlated with expected drifts.

The values of these correction factors were obtained from the experimental results measured on the specimens of r/c frames infilled with masonry that had various opening types and positions. For eccentrically placed opening, proposed are strut properties that are sensitive to loading direction and opening's position with respect to it. Another possibility is to take the weaker properties as common for the overcrossing diagonals, as approximate approach.

Proposed corrected diagonal strut model could be used as the realistic estimation tool. It is based on the experimental results and correlates diagonal widths with infill's damage states, opening size, type and position.

In the future numerical studies, calibrated on the experimental research, the correction factors for other opening's sizes and geometry would be determined.

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