16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 821

Registration Code: S-F1462956121

CONFINED MASONRY BEHAVIOUR WITH VARIOUS CONNECTION DETAILS

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Abstract

Test of confined wall panels under in-plane cyclic shear loading were performed to provide some insight into the effect of alternating the details of connection between tie-columns and masonry. Three different types of wall specimens (without any connection between masonry and tie-columns, tooth-linked and connecting by U-shaped stirrups in bed joints) built at a scale 1:1,5 were subjected to in-plane quasi-static tests. Mixed displacement-force control was used. Based on experimental test data we obtained: the interstory drift associated to damage grade according to EMS-98 [1], ductility, energy dissipation and failure mechanism. The average resistance envelope curves were obtained for three specimen groups and then simplified by bilinear curves. The behaviour factor q was evaluated for each investigated wall group.

Keywords: confined masonry, quasi-static test, connecting detail, behaviour factor

1. Introduction

Eurocode 6 [2] prescribed the technical design details for confined masonry of the connections between vertical tie-columns and masonry. Application provided details complicates and slows down the process of construction. In Croatia it is common to build up the confined masonry apartment buildings with technological process respects: masonry walls are constructed first, then tie-columns are casting in-place with flat edges, and finally horizontal beams are constructed simultaneously with the floor slab construction. The connecting of masonry and vertical ties remain without additional connection as required by regulations. This type of masonry structure is not covered by the current norms [2 and 3]. Therefore, we carried out research in-plane behaviour of confined masonry walls with different connection details between masonry and reinforced concrete tie-columns subjected to a horizontal cyclic loading. Our goal was to determine whether the masonry buildings with details made as described can be categorized as confined masonry constructions and if so, what are the restrictions of such type of constructions.

2. Experimental work

The wall prototype represented a middle ground-floor wall in a residential low-rise confined masonry building. It was 216 cm long, 249 cm high and 29 cm thick. The specimens were built by standard Croatian materials: hollow clay masonry units of Group 2, the general purpose mortar M5, C30/37 concrete and reinforcement B500B. The material properties were obtained according to standard test procedures. A thorough description of the relevant material properties and of the experiments can be found in [4].

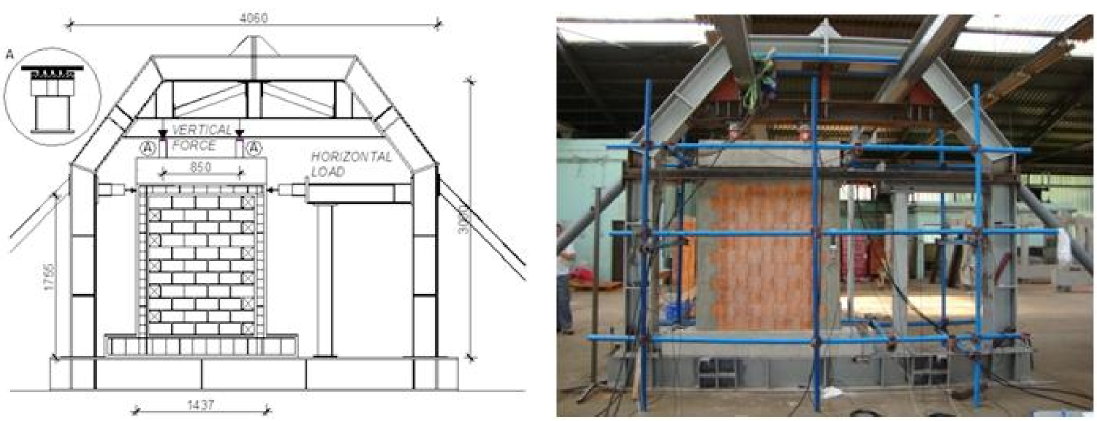


Fig. 1 – Test setup

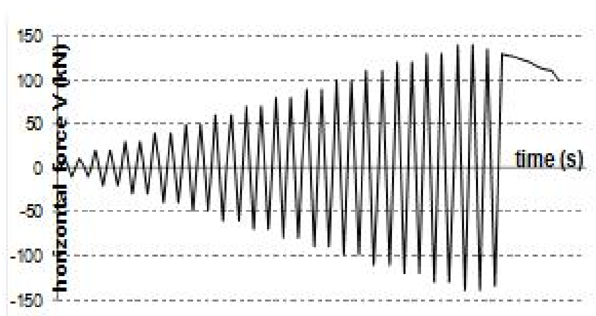


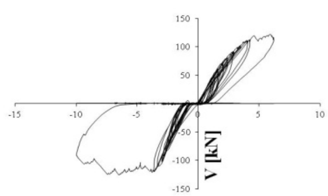
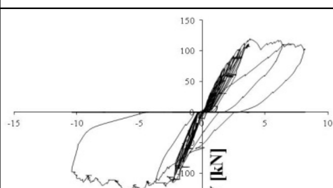
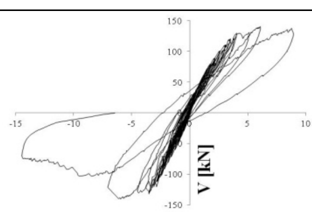
Fig. 2 –Pattern of cyclic loading

Three different types of wall specimens (without any connection between masonry and tie-columns, tooth-linked and connected by U-shaped dowels in bed-joints) built at a scale 1:1,5 were subjected to quasi-static tests. Each type of the wall was presented with three specimens. Specimens were fixed in a rigid frame and cyclic lateral loading was imposed at the upper horizontal beam as shown in Figs.1 and. 2. During testing vertical stress was attempted keeping constant. Mixed displacement-force control was used. Applied forces at each of four loading points, vertical and horizontal displacement of the specimen upper edges and the elongation of diagonals were continually recorded during testing. Length, width and location of occurrenced cracks were observed. Relations between the observed damage grade (according to classification for a residential building from EMS-98) and interstory drift were explored.

2.1. Failure mechanisms

General, the failure mechanism walls is estimated based on several important indicators: the hysteresis loop shape, ways of genesis and final cracks pattern, and maximum horizontal resistance force. Sliding shear failure mechanism was not expected. The walls exhibited good energy dissipation with fat hysteretic loops in the post softening stages. The peak load of 195,76 kN for flexural failure mechanism was evaluated as defined in the report [5]. All the values of maximum horizontal resistance forces were less than that (Table 1), so it can be concluded that the specimens have collapsed in the mode of shear failure or hybrid shear-flexural mechanism. This conclusion is confirmed by observed crack patterns (Fig.3). Significant out-of-plane deflections were not observed.

Table 1 – Test results

Specimen	Type of connection	Hysteresis loop shape	Peak load [kN]	Mean value of peak load [kN]	Drift at peak load [mm]	Interstory drift at failure [%]	Failure mechanism
1	Without additional connection		161,1	155,5	4,8	0,29	hybrid shear-flexural failure
2			125,7		6,52	0,39	hybrid shear-flexural failure
3			179,6		5,5	0,33	brittle shear failure
4	“Tooth”-shaped connection		167,4	142,2	6,04	0,37	shear failure
5			130,7		10,21	0,62	shear failure
6			128,6		6,21	0,38	shear failure
7	Dowel connection		148,7	138,8	10,19	0,62	shear failure
8			136,4		5,07	0,31	shear failure
9			138,8		6,28	0,38	shear failure

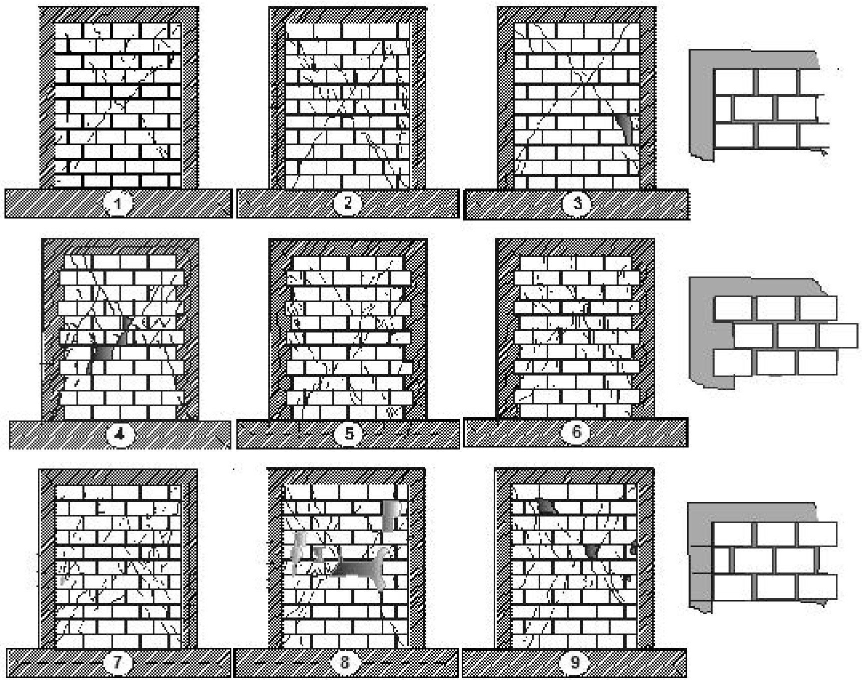


Fig. 3 – Crack patterns

Table 2 – Dependence of damage grade on interstory drift

2.2 Damage grade associated to interstory drift

The typical damage for all the specimens were manifested as a group of inclined cracks through mortar and masonry units. During testing the cracks progressively formed some X shape similar to diagonal struts pattern. With increased displacement, spalling of the brick face and grout cracking became more significant. Propagation of diagonal cracking into the tie-columns was preceding the collapse. The wall panels could not be tested until total collapse because of equipment safety. The level of damage was classified according to EMS-98 [1] criteria for a residential masonry building. Dependence of damage grade on interstory drift ratio has been established (Table 2).

Table 2 – Dependence of damage grade on interstory drift

Grade of damage		Connection type		
		without additional connection	tooth-shaped connection	dowel connection
G1	Interstory drift [%]	0,16	0,13	0,13
G2		0,35	0,47	0,45
G3,G4		0,48	0,63	0,86

Obviously wall panels without additional connecting between masonry and tie-columns reached the heavy damage domain at smaller interstory drift than those properly designed.

2.3 Dissipated energy

The hysteretic low was used to estimate dissipated energy and equivalent viscous damping ratio. The cumulative dissipated energy in the experiments is presented in Figure 4. A least squares approximation was conducted using exponential function. The lowest energy dissipation is characteristic for the wall panels with "tooth" connection details.

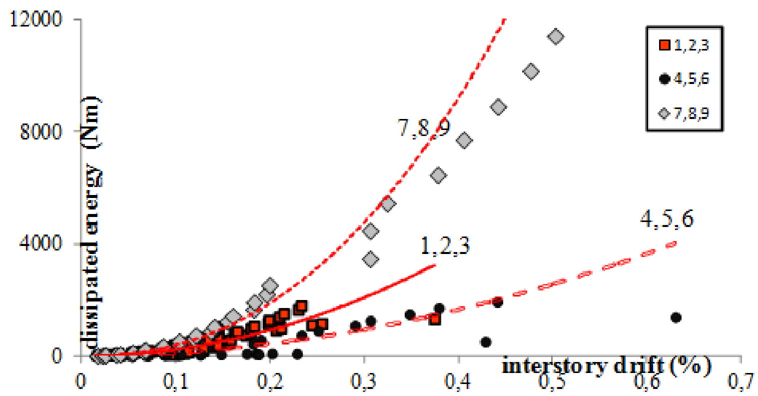


Fig. 4 – Cumulative dissipated energy in terms of interstory drift

The equivalent viscous damping ratio ξ was derived based on wall hysteretic response and hysteretic energy dissipated during testing (Fig. 5). This study indicates that damping ratio ξ is somewhat higher than others in case of dowel connection type walls.

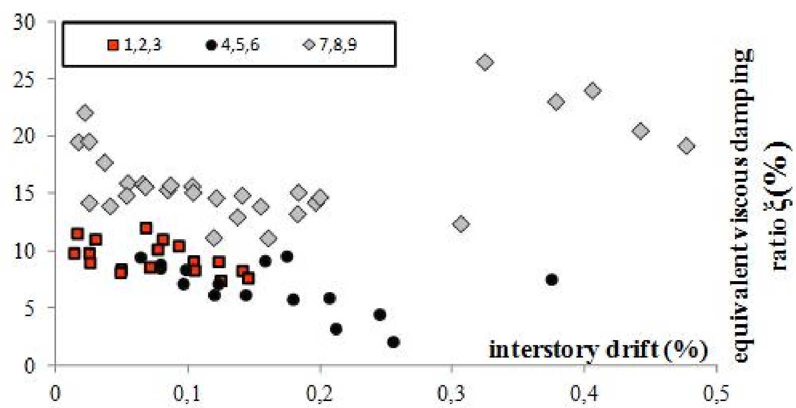


Fig. 5 –The equivalent viscous damping ratio in terms of interstory drift

2.4 Structural behaviour factor

Average resistance curve for the particular group of tested specimens were obtained using Nedler-Mead simplex algorithm [6]. Afterwards, experimentally evaluated representative primary curves were transformed to bilinear as recommended by Tomažević [7] and shown in Figure 6. Evaluated parameters of the average resistance curves and its bilinear idealization graphs are presented in Table 3. It is especially interesting that the provision of additional connection between the masonry wall and reinforced concrete vertical ties resulted with about 20% smaller value of initial stiffness. Ductility μ is defined herein as ratio between the ultimate displacement and the displacement at the onset of yielding. Ductility values ranged from 3,49 (for the wall panels without additional connection) to 3,7 (for the wall panels with "tooth" shaped connection).

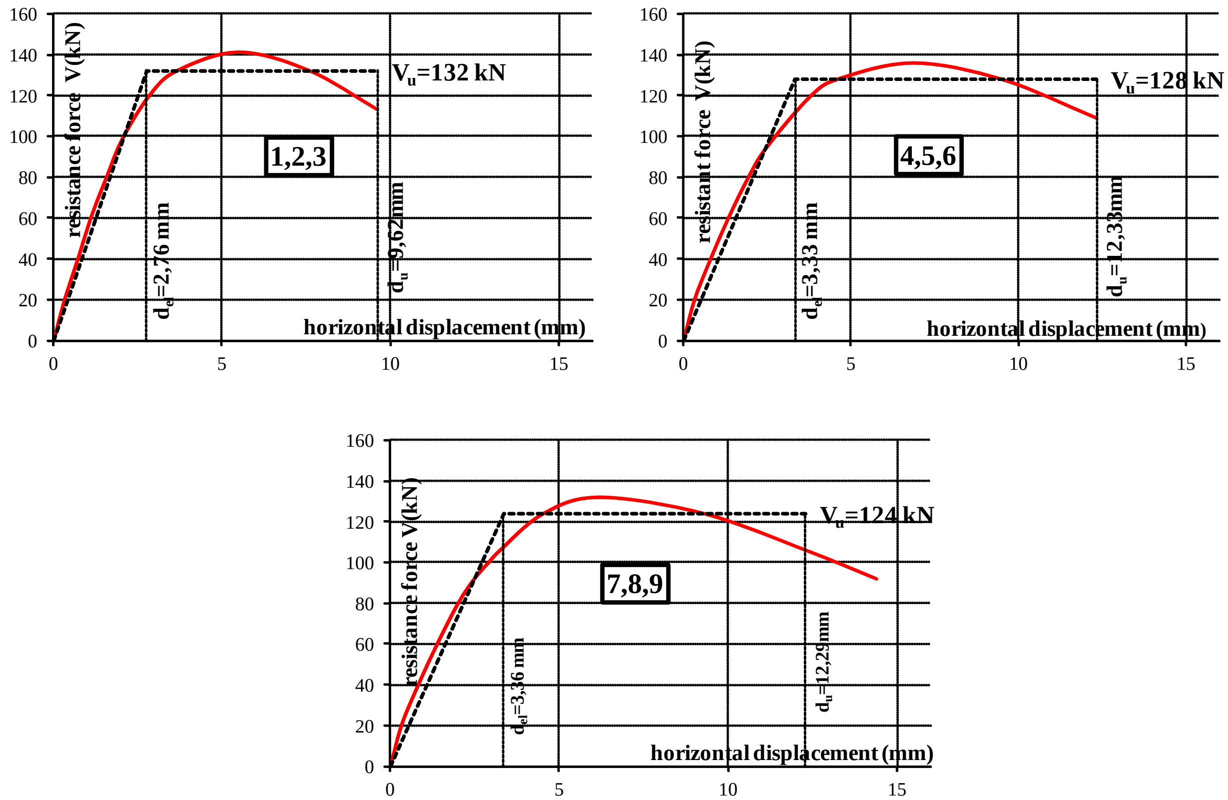


Fig. 6 –Bilinear idealization for average resistant envelope curves

The structural behaviour factor, q, for three different wall panel types, was estimated by the approximate Eq. (1) and afterwards corrected through the overstrength ratio Vu/Ve [8].

$$q^{+} = \sqrt{(2\mu_u - 1)} \qquad (1)$$

Table 3 – Parameters evaluated from bilinear idealization of primary curves

Specimen	K_{el}[kN/mm]	V_u [kN]	d_y [mm]	d_u [mm]	$\mu=d_u/d_y$ [%]	V_u/V_e	**q***	**q**
1,2,3	48,3	132	2,76	9,62	3,49	1,33	**2,44**	**3,26**
4,5,6	38,2	128	3,33	12,33	3,70	1,35	**2,53**	**3,41**
7,8,9	37,2	124	3,36	12,29	3,66	1,35	**2,51**	**3,39**

The lack of additional connection between the masonry and column-ties did not caused a significant reduction in the value of the behavior factor. The structural behaviour factors obtained for all three types of panel walls exceeded the upper limits recommended by [9].

3. Conclusions

The paper presents the data of nine quasi-static cyclic tests of confined masonry wall panels with three different connection types between masonry and reinforced concrete tie-columns: without any additional connection, “tooth” shaped connection and linked by stirrups in bed joints. Collapse mechanisms of wall specimens without additional connection between the masonry and confining elements showed a separation of reinforced concrete and masonry parts with few horizontal hairline cracks in vertical confining elements. Typical shear failure mechanisms were identified for all other wall-panels. In comparison with the others, specimens without interlocking between tie-columns and masonry suffered serious damage (heavy and very heavy) at considerably smaller interstory drift. It was observed that connection detail did not influence the cumulative dissipated energy, equivalent viscous damping ratio and the maximum lateral force significantly. Ductility for all types of wall panels was rather even. And finally, evaluated behavior factors for all walls and connection details, were greater than those prescribed in EC8 [9]. So, it can be concluded that construction of reinforced concrete confining elements, even without the prescribed connection details, ensures improved in-plane behavior of the wall and meets the requirements of the current regulations.

ACKNOWLEDGEMENTS

The work is done within the scope of the research programme nr. 3013 named “FRame-MAsonry composites for modelling and standardization” supported by the Croatian Science Foundation.

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