Investigation of the bed joint reinforcement effect on the drift capacity of modern unreinforced masonry walls

Ernesto Inzunza[1*], *Savvas* Saloustros[2], and *Katrin* Beyer[1]

[1] EESD, École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne Switzerland

Abstract. Bed joint reinforcement significantly affects the shear capacity of masonry walls due to its effective ability to transfer shear forces through a diagonal crack, but how does this phenomenon impact its drift capacity? This paper presents an experimental study containing a series of four quasi-static cyclic tests conducted on masonry walls of same size. Two of them incorporated truss-type bed joint reinforcement, while the other two were completely unreinforced. All specimens were subjected to double bending boundary conditions to observe shear-controlled behaviour and were tested under two levels of compression load. The primary objective of this research is to determine the role of horizontal reinforcement in the seismic properties of unreinforced masonry walls focusing on the displacement capacity. The findings from this experimental study are expected to provide empirical evidence for subsequent numerical simulations and contribute to the development of analytical formulations. The results aim to enhance our understanding of the seismic response of masonry walls, ultimately informing design practices and seismic retrofitting strategies.

1 Introduction

The influence of bed joint reinforcement (BJR) on the seismic behaviour of masonry walls have been extensively investigated in previous works. In fact, only the experimental campaign described in Jasiński [1] contains a total number of 76 walls using three types of units and four bed joint solutions. Although this experimental investigation reports that the incorporation of bed joint reinforcement resulted in an increase in shear deformation capacity, there are challenges regarding comparison with other shear-compression wall tests due to the singular testing characteristics (cyclic loading in only one direction).

Additionally, most of the studies have been carried out in walls built with concrete blocks [2-6]. For the case of walls made with hollow clay bricks (HCB) including only horizontal reinforcement, very limited research provides information about its impact on the deformation capacity. Among the experimental campaigns compiled by Penna et al. [8], the tests conducted by Technical University of Bucharest [7] reported that walls with horizontal

* Corresponding author: ernesto.inzunza@epfl.ch

These proceedings are published with the support of EuLA.

rebars increased their drift capacity between 130-215% compared to the walls without reinforcement.

With the aim of extending the research on this subject, this study intends to contribute with additional experimental evidence to analyse the effect of BJR on the drift capacity of HCB masonry walls identifying the mechanical phenomena behind the impact on its seismic behaviour.

2 Methodology

Four masonry walls of dimensions 1.54 m long, 2.00 m high and 0.25 m thick were constructed and tested in shear-compression under double-bending boundary conditions (equivalent to a shear span equal to mid-height of the wall, $H_0 = 0.5 \cdot H_{wall}$) in the Laboratory of Structures of EPFL. The aspect ratio of the walls was selected in order to observe a shear-controlled behaviour for the applied boundary. The specimens were built with full scale hollow clay bricks (HCB) of 300 mm long, 250 mm wide and 190 mm high (nominal strength of 28 MPa and Group 2 according to Eurocode 6 [9]), and standard cement-based mortar (M15) fully filling head and bed joints (constituent materials can be seen in the Figure 1b). The walls were subjected to axial load ratios ($ALR = \sigma/f_{masonry}$) of 0.1 and 0.2, while keeping the compression force constant until reaching the axial load collapse.

Two out of the four walls incorporated a truss-type BJR in hot galvanized steel of 180 mm width with a diameter of 5 mm (Figure 1a). The amount of reinforcement in both specimens was the same, being included every two rows which means a total number of five bed joints with reinforcement in each wall. The quantity of reinforcement corresponds to 0.04%, magnitude similar to the minimum amount specified in Eurocode 6 [9] ($\rho_{min} = 0.03\%$). The notation for each specimen corresponds to MW0.1 and MW0.2 for the walls without BJR, subjected to 0.1 and 0.2 ALRs respectively; while LRTW0.1 and LRTW0.2 for the walls including BJR, under 0.1 and 0.2 ALRs.

(a) (b)

Fig. 1. Masonry typology with and without bed joint reinforcement.

The loading protocol was displacement-control which was increased progressively after completing two cycles per drift level (Figure 1b). The instrumentation plan consisted of thirteen wired sensors for measuring deformations at specific points in real time during the test, fiber optics attached to bed joint reinforcement measuring strains in real time, and a stereo-camera system for conducting Digital Image Correlation (DIC) analysis (Figure 2a and Figure 2c).

The LVDT wired sensors were located: at the top of the wall (Figure 2a) to measure the drift and follow the displacement-controlled protocol; at the concrete base (Figure 2a) to determine if the wall needed to be corrected by rocking or sliding; and on the lateral face of bricks at the extreme of the wall (Figure 2c) to obtain the expansion-compression of the units during the loading cycles. Regarding the DIC system, it consisted in a set of 2 digital cameras of 28.8 MPx capturing gray-scale images every 5 seconds.

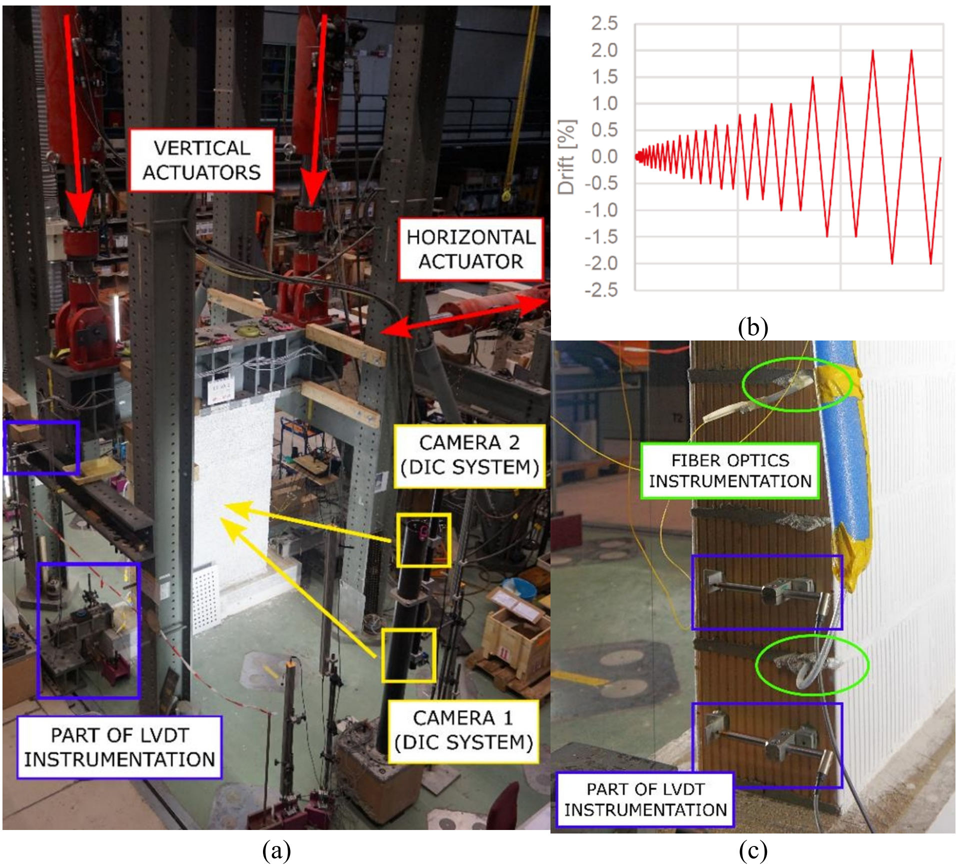


Fig. 2. Test setup and protocol

3 Results

Figure 3 displays the in-plane response of the four walls using the data obtained from DIC. The hysteretic curve in black is obtained in terms of the horizontal stress (horizontal force at the top of the wall normalised by its cross-sectional area) and the drift (top displacement normalised by the height of the wall). The envelope in positive and negative direction are highlighted in blue, where the respective ultimate drifts (δ_u) have been identified with a red dot. The ultimate drift has been defined as the drift at which the horizontal load has drop in 20% the shear strength (τ_{max}). The bilinearisation is also visible in green defined by the effective stiffness (k_{eff}) determined as the secant stiffness intersecting the envelope curve at 70% of the shear strength in the pre-peak regime, and the ultimate stress calculated as the magnitude of the shear stress for which the area under the envelope curve is equals the area under the bilinear curve within the drift range [0,δ_u].

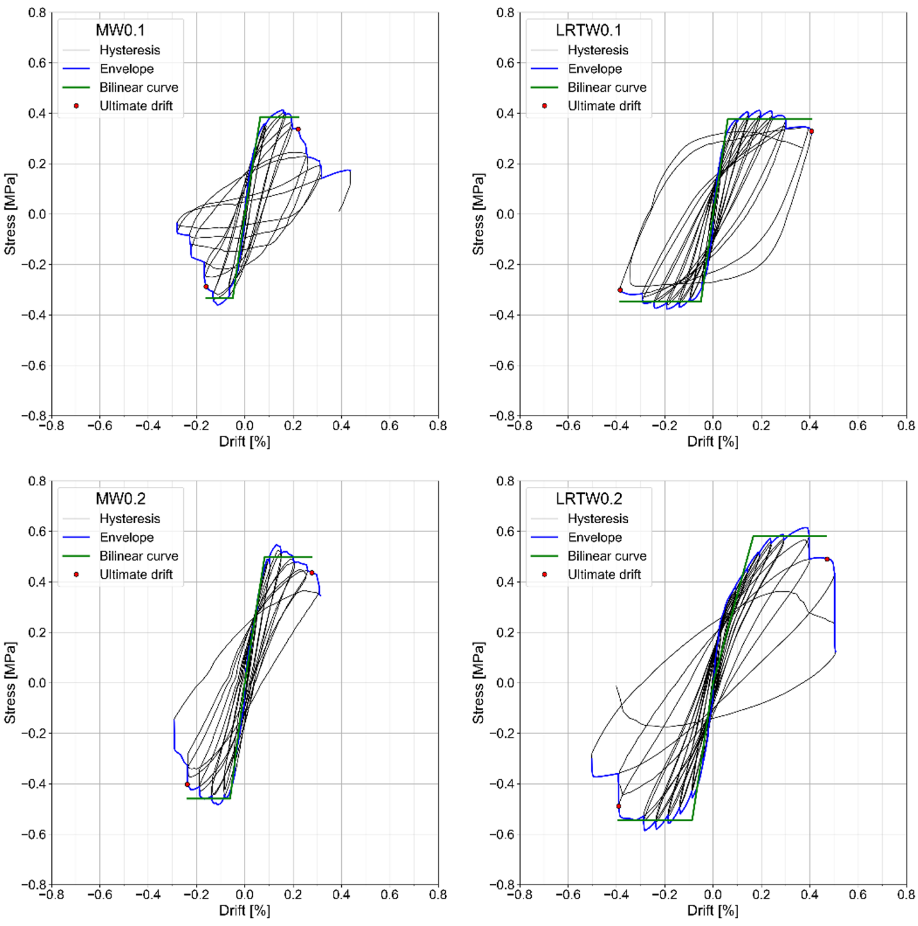


Fig. 3. Hysteretic curve including envelope and bilinearisation.

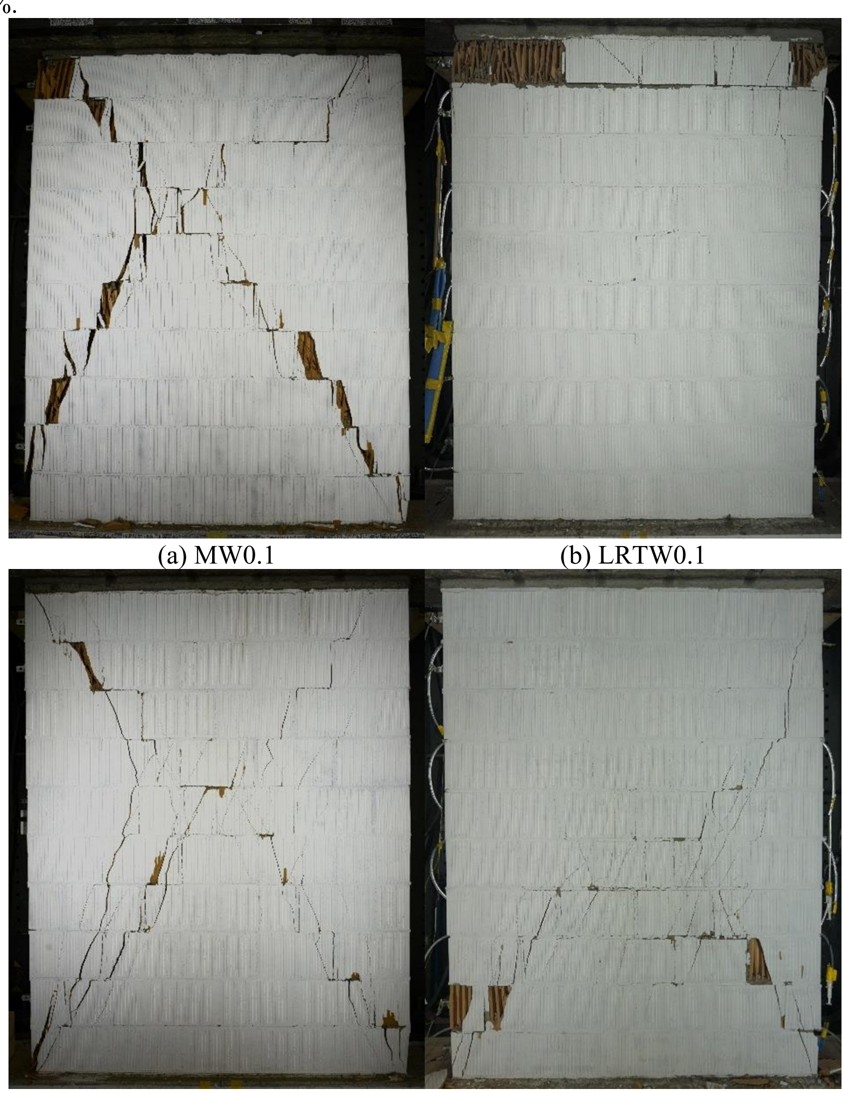
Table 1 shows some seismic parameters obtained from the shear-compression tests. The average effective stiffness (k_{eff}^{AVG}) has been calculated as the average of the effective stiffness in both directions; the shear strength (τ_{max}) corresponds to the maximum of the peak shear stress in both directions; and the ultimate drift (δ_u) has been calculated as the maximum ultimate drift between the two directions.

Table 1. Seismic parameters extracted from hysteresis.

Wall	k_{eff}^{AVG} [Mpa/%]	τ^{max} [MPa]	δ_u [%]
MW0.1	6.35	0.41	0.22
LRTW0.1	6.55	0.41	0.41
MW0.2	6.82	0.55	0.28
LRTW0.2	4.89	0.61	0.47

 https://doi.org/10.1051/matecconf/202440305008

There is no correlation between the effective stiffness and the inclusion of BJR or the increase in axial load. For ALR = 0.1 the inclusion of BJR resulted in an increase of effective stiffness of 3.2%, while for ALR = 0.2 the behaviour was the opposite, with a reduction in effective stiffness of 28.3%. This latter phenomenon requires further investigation, but one aspect to consider is the asymmetric behaviour exhibited in the LRTW0.2 wall. Figure 3 indicates that in the positive direction of loading, the hysteresis displays significantly less stiff behaviour than in the negative direction. Since the values in Table 1 provide the average effective stiffness, the magnitude difference in both directions have an influence on the final value presented. Similarly, the increase in ALR caused an increase of 7.4% in the effective stiffness for walls without reinforcement, while for the walls incorporating BJR a decrease of 34%.



(a) MW0.1 (b) LRTW0.1

(c) MW0.2 (d) LRTW0.2

Fig. 4. Damage pattern before axial load collapse.

The shear strength increased 49.4% when increasing the ALR for reinforced walls and increased 32.2% when increasing the ALR for unreinforced walls. However, the effect of

BJR in the strength capacity has only been observed for ALR = 0.2, resulting in an increase in 12.5%. Finally, the ultimate drift has been influenced by both, the ALR and the incorporation of BJR. The inclusion of BJR increased the ultimate drift in 85% for ALR = 0.1 and 70.4% for ALR = 0.2. The increase in the axial load brought an increment in the ultimate drift of 25.9% for unreinforced walls and 16% for reinforced walls.

Figure 4 depicts the condition of the walls in the last drift level before the axial load collapse. The failure mechanism in walls without reinforcement corresponds two major diagonal cracks going from corner to corner. On the other hand, the walls including BJR show different damage patterns compared to the unreinforced walls and for the distinct ALRs. The specimen subjected to ALR = 0.1, although developing a less visible diagonal crack from top right corner to bottom down corner, concentrated the damage at the top row with evidence of a horizontal crack at the bed joint in addition to bricks crushing and deforming laterally. Besides, the case under higher compression load (ALR = 0.2) presents diagonal cracks in both directions, but the damage is mainly concentrated at the lower part of the wall. When comparing cracks by naked eye, although the walls with BJR reached considerable larger drift levels the cracks on the unreinforced walls seem to be wider.

4 Conclusions

From the global representation of the seismic behaviour described by the hysteretic curve and the local phenomena observed in the damage pattern, it is possible to remark the following:

- The drift capacity represented by the ultimate drift has shown to be influenced by the axial load and by the incorporation of BJR. In this regard, the presence of horizontal reinforcement brought a considerable increase of the drift capacity between 70-85%.
- There is not a clear influence of ALR nor the presence of BJR on the effective stiffness of the walls.
- The increase in compression load has led to an increase in the shear capacity of masonry walls.
- Given that the addition of BJR had no effect on the shear strength for the walls tested with ALR = 0.1, it cannot be concluded from the examined cases that the inclusion of BJR increased the shear capacity of masonry walls.
- For the cases analysed, the inclusion of BJR can be related to a change in the damage pattern. Specifically, it has been observed that the walls with horizontal reinforcement have concentrated the damage more locally. Additionally, the walls with BJR seem to develop thinner cracks. However, this latter observation still needs to be supported by a more detailed crack width analysis based on DIC data. In this regard, it is expected to conduct analyses not only before the collapse, but also at different moments of the post-peak regime to evaluate the damage progression.

Acknowledgements: The work presented here has been financed through the research grant BAFU-D-828B3401/337 by the Swiss Federal Office for the Environment (OFEV). The authors would like to thank the team of the Structural Engineering Laboratory at EPFL for their technical support.

References

1. R. Jasiński, Research on the influence of bed joint reinforcement on strength and deformability of masonry shear walls. Materials, **12** (16): 2543 (2019).

2. A. Costa, A. Penna, G. Magenes, Seismic performance of autoclaved aerated concrete (AAC) masonry: From experimental testing of the in-plane capacity of walls to building response simulation. Journal of Earthquake Engineering, **15** (1), 1-31 (2011). https://doi.org/10.1080/13632461003642413
3. P. B. Lourenço, G. Vasconcelos, J. Gouveia, V. G. Haach, J. F. de Freitas, Validation of masonry systems for in-plane lateral loading using truss reinforcement (2008)
4. A. Penna, M. Mandirola, M. Rota, G. Magenes, Experimental assessment of the in-plane lateral capacity of autoclaved aerated concrete (AAC) masonry walls with flat-truss bed joint reinforcement. Construction and Building Materials, **82**, 155-166 (2015). https://doi.org/10.1016/j.conbuildmat.2015.02.057
5. H. Sadek, S. Lissel, Seismic performance of masonry walls with GFRP and geogrid bed joint reinforcement. Construction and Building Materials, **41**, 977-989 (2013). https://doi.org/10.1016/j.conbuildmat.2012.07.005
6. M. Tomaževič, R. Žarnić, The effect of horizontal reinforcement on the strength and ductility of masonry walls at shear failure (Tech. Rep.). Dimiceva 12, Ljubljana, Yugoslavia: University of Zurich, Department of Informatics (1985)
7. CNRRS-UTC, Structural testing programme for masonry elements made out of hollow bricks produced by Wienerberger (Tech. Rep.). Bucharest, Romania: Ministry of Transport, Construction and Tourism, Romania and Technical University of Civil Engineering (2005)
8. A. Penna, A. Menon, G. Magenes, Improving the seismic performance of masonry buildings by flat-truss bed-joint reinforcement, in Proceedings of 8th International Masonry Conference, Dresden, Germany (2010)
9. CEN, Eurocode 6- Design of masonry structures - Part 1-1: General rules for reinforced and unreinforced masonry structures. Brussels, Belgium (2005)