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Masonry elements with multi-layer bed joints: Behaviour under monotonic and static-cyclic shear

Nebojša Mojsilović *, Miloš Petrović, Xavier Riba Anglada

Institute of Structural Engineering, Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, 8093, Switzerland

HIGHLIGHTS

- Monotonic and static-cyclic shear tests on masonry with multi-layer bed joints are presented.
- Five different types of core layer, protected by two thin elastomer layers, were considered.
- The shear strength was highly influenced by the pre-compression level and loading speed.
- The Mohr–Coulomb criterion is recommended for predicting of the shear strength.
- Large deformation capacity can be expected in URM walls with multi-layer bed joints.

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ABSTRACT

The goal of the research project presented here is to investigate the effect of multi-layer bed joints on the shear behaviour of unreinforced masonry elements subjected to cyclic actions, and to assess the shear mechanical characteristics of multi-layer bed joints. Such joints consist of a core soft layer protected with two thin extruded elastomer membranes, which in turn are placed in a bed mortar joint. The extruded elastomer membranes are employed to prevent and/or limit the deterioration of the core soft layer during the cycling action, which has been observed in previous investigations. Five different core soft layer materials, namely rubber granulate, cork-rubber granulate, cork, bitumen and polyvinylchloride were employed. A total of 57 clay block masonry triplets were subjected to both monotonic and static-cyclic loading under varying levels of pre-compression.

The shear behaviour of the specimens was greatly influenced by the applied pre-compression level and by the loading speed. Increasing the level of pre-compression leads to the higher values of shear strength. The same is true for increasing loading speed. Further, for the prediction of the failure shear force a Mohr–Coulomb failure criterion with zero cohesion can be applied. Finally, experimental findings showed that extruded elastomer layers largely fulfilled the intended protective role.

The results indicate that multi-layer bed joints with adequate material properties have the potential to change the typical brittle shear response of unreinforced masonry walls to a more desirable quasi-ductile behaviour. Moreover, based on the observed hysteretic behaviour, considerable energy dissipation could be expected in masonry structures with multi-layer bed joints. Such behaviour would be desirable for enhanced seismic performance.

1. Introduction

In today's construction practice various types of soft layer membrane are used in unreinforced masonry structures. Depending on their purpose, soft layers are often placed at the bottom and/or the top of masonry walls, being incorporated in a bed joint, either placed between two mortar layers or laid directly on the masonry units or underlying concrete slab with the mortar placed atop. In some applications soft layers are placed in the bed joint without mortar. Bed joints with built-in soft layers are designed to meet serviceability design criteria such as providing a moisture barrier in the form of a damp-proof course (DPC) membrane or ensuring sound insulation at the base and/or the top of the masonry walls, as well as accommodation of short-term or long-term differential movements between the masonry walls and the floor construction. Due to the presence of a soft layer in the bed joint, the shear and tensile characteristics of the joint can be significantly altered. Since

* Corresponding author.
E-mail address: mojsilovic@ibk.baug.ethz.ch (N. Mojsilović).

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these material parameters could be governing for the masonry behaviour, especially under seismic, i.e. cyclic loading it is of the utmost importance to investigate and understand the influence of such layers incorporated in a bed joint of a masonry wall. It could also be useful to take advantage of such weakened bed joints in order to modify the response of shear walls, i.e. redistribute the shear force within the masonry structure. It has been observed that during cycling loading the soft layer material is subject to certain degree of deterioration. This additionally influences the mechanical characteristics, namely the friction coefficient of the bed joint. In order to protect the soft layer, the present research investigates multi-layer bed joints in which the core soft layer membrane is protected by two adjacent thin extruded elastomer membranes.

A relatively modest amount of research data is available on the shear behaviour of unreinforced masonry walls containing soft layer membranes. The majority of the previous research has been focused on the investigation of the behaviour of various types of soft layer at different pre-compression levels. Attention has been paid to the assessment of the shear parameters and the overall performance of joints containing soft layers by conducting static, static-cyclic and dynamic tests on small masonry elements (mostly triplets), see [1–8]. The behaviour of larger elements (wallettes) with soft layers has been also investigated, see [9–12]. The research findings indicate, that a shear force can be transmitted through the joints containing soft layer membranes and that due to sliding failure along the soft layer a considerable amount of energy dissipation and quasi ductile behaviour could be expected for masonry with soft-layers. A summary of the material parameters that characterise the bed joint resistance, namely the friction coefficient and cohesion, obtained from reviewed experimental work, is presented in Table 1. This table also provides information on materials used for bed joint construction as well as on the position of the soft layer within the bed joint.

Suter and Ibrahim [1] performed monotonic tests on masonry triplets. Three different types of DPC material, i.e. polyethylene, polycrepe and copperfibreen were applied. Zhuge and Mills [2] performed two sets of experiments aimed at determining the in-plane shear strength of masonry containing a DPC membrane. A total of eighteen typical masonry triplets were tested. As soft layer materials different types of DPC membrane were considered (embossed polyethylene, bitumen-coated fabric and aluminium-cored polyethylene). In order to evaluate the performance of masonry joints containing soft layers under dynamic loading, as well as to assess their seismic integrity and establish their friction capacity, Griffith and Page [3] performed monotonic, static-cyclic and dynamic shear tests on masonry triplets with different types of DPC membranes (bitumen-coated aluminium; polythene/bitumen-coated aluminium and embossed polythene) and reported the corresponding friction coefficients, see Table 1. The DPC membranes were placed in both mortar joints of the brick triplet; in one series, the middle brick was made of concrete in order to simulate the concrete floor slab. Test specimens were initially subjected to a given level of pre-compression, which was kept constant during the test. The shear load was applied in the out-of-plane direction. In order to expand the abovementioned findings Simundic et al. [4] investigated the long-term shear behaviour of the masonry triplets subjected to monotonic loading. Their results indicated that all tested slip joints, besides a proven potential to transmit short-term transient seismic loads, had the potential to accommodate long-term moisture and thermal movements. Trajkovski and Totoev [5] reported the results of an experimental investigation on the shear capacity of masonry elements with reinforced polyvinylchloride as a damp-proof course. The DPC membrane was placed in the bed joint mortar. The research aimed to clarify the correlation between the sliding rate and value of the friction coefficient. Two different displacement rates were considered. The obtained average values of the maximum and residual shear strength, as well as dynamic and static friction coefficients were reported (Table 1). Totoev and Simundic [6] carried out monotonic tests on DPC membrane slip joints placed at the interface between concrete and masonry. As DPC materials, bitumen-coated aluminium and embossed polythene were used. This research addressed the pseudo viscosity of the joints containing DPC, i.e. dependence of the joint response on different strain rates. Mojsilović [7] performed monotonic tests on ten series of masonry triplet specimens with three different soft layers (elastomer-, bitumen- and polythene-based membranes). The friction coefficients found for bed joints with soft layer membranes are presented in Table 1. Shear behaviour of the specimens was highly influenced by the applied pre-compression level, while the influence of the location of the DPC membrane was much smaller. Recently, monotonic and static-cyclic tests were performed on masonry triplets with an incorporated embossed polythene DPC membrane, placed either in the middle of the bed joints or between the bed joint mortar and the brick, see Mojsilović et al. [8]. Test results on the mechanical characteristics, energy dissipation and the overall behaviour of the masonry elements with a DPC subjected to static-cyclic loading were reported (see Table 1 for the mechanical characteristics obtained).

At the same time, static-cyclic tests were performed on 21 masonry wallettes subjected to static-cyclic shear loading with an embossed polythene DPC placed either in a mortar joint or at the masonry–concrete slab interface [9,10]. Masonry materials used were characteristic for Australia (extruded clay bricks and cement–lime mortar). Three levels of pre-compression (0.7, 1.4 and 2.8 MPa) were considered. Results from this investigation also confirmed the good performance of the DPC soft layers subjected to cyclic loading. The behaviour of the wallettes was highly influenced by the pre-compression level. Furthermore, the presence and position of the DPC had a considerable influence on the behaviour of the wallettes, especially on the failure mode. Two types of failure were observed, namely sliding along the bed joint containing the DPC for low and moderate pre-compression and compression failure, i.e. toe crushing, for higher levels of pre-compression. Wallettes that failed in compression exhibited limited energy dissipation. Those that failed by sliding displayed considerable energy dissipation and behaved in a quasi-ductile manner. The mechanical characteristics relevant for the present work are shown in Table 1. More recently 16 static-cyclic shear tests on clay block masonry wallettes with two different soft layers (extruded elastomer and rubber granulate) were performed, [11,12]. A soft layer was placed either in a mortar joint or at the masonry–concrete slab interface. Rubber granulate soft layers placed in a masonry wall bed joint have the potential to enhance the seismic performance of unreinforced masonry walls producing a more desirable, quasi-ductile behaviour with higher deformation capacity compared to conventional unreinforced masonry walls. Extruded elastomer layers have a higher friction coefficient that precludes the occurrence of sliding. The friction coefficient for the rubber granulate layer is damage-dependent. With an increasing number of cycles, the degradation of the soft-layer increases and the friction coefficient decreases. The mechanical shear properties relevant to the present work are shown in Table 1.

A research project on the seismic behaviour of masonry shear walls with a soft layer membrane placed in the bed joint is underway at ETH Zurich. The main goals of this research project are to investigate the influence of the soft layer on the behaviour of masonry under static-cyclic shear, to assess the mechanical shear properties of bed joints with different soft layers, and to establish if and how the soft layer modifies the lateral load resistance mechanism of the wall. The present research findings will be used to analyse/model the behaviour of the full-scale masonry shear walls