Engineering Structures 86 (2015) 16–32

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Masonry wallettes with a soft layer bed joint: Behaviour under static-cyclic loading

Christian Vögeli, Nebojša Mojsilović *, Božidar Stojadinović

Institute of Structural Engineering, Department of Structural, Environmental and Geomatic Engineering, ETH Zurich, 8039, Switzerland

ARTICLE INFO

Article history:
Received 25 September 2014
Revised 19 December 2014
Accepted 22 December 2014
Available online 8 January 2015

Keywords:
Cyclic shear
Damp-proof course
Extruded elastomer
Load tests
Rubber granulate
Shear behaviour
Soft layer
Unreinforced masonry

ABSTRACT

The main goal of the research project presented herein is to investigate the effect of damp proof courses and soft layer wall bearings on the seismic shear behaviour of unreinforced masonry walls subjected to cyclic actions, in particular how the lateral load resisting mechanism of the wall is influenced thereby. Unreinforced clay block masonry wallettes with soft layers of three different thicknesses (3, 5 and 10 mm), and two different materials (rubber granulate and extruded elastomer) were subjected to static-cyclic shear under varying levels of pre-compression. The soft layer was placed either in the first bed joint of the wallette or in the interface joint between the wallette and the underlying concrete slab.

Soft layers were beneficial when the tested wallettes failed in sliding. Such sliding failure was observed for wallettes with rubber granulate soft layers placed in the first bed joint. This resulted in quasi-ductile behaviour of the wallettes, with a displacement and energy dissipation capacities significantly larger than those of the conventional unreinforced masonry control specimens. Furthermore, wallettes failing by sliding along the joint containing the soft-layer showed considerably less damage compared to wallettes that exhibited other failure modes at the same displacements levels. The progressive deterioration of the rubber granulate layers lead to a decreasing shear strength at larger horizontal displacements. Wallettes with extruded elastomer layers and wallettes with layers placed in the interface joint did not fail in sliding. Apart from slightly increased energy dissipation, no beneficial effect on the shear force–deformation behaviour of the wallettes could be observed in these tests.

The results indicate that soft-layers with adequate material properties placed in the first bed joint have the potential to change the typical brittle shear response of unreinforced masonry walls to a more desirable quasi-ductile behaviour.

1. Introduction

Quasi-brittle structures, such as the unreinforced masonry ones, pose a significant seismic risk. Designing such structures with enough strength is the principal, albeit costly, method to mitigate this risk. Response modification strategies such as rocking [1] and sliding [2] are viable options. In fact, sliding was document as the primary mechanism that significantly reduced building damage to unreinforced masonry structures in earthquakes that occurred between 1897 and 1950 in Assam, India [3]. Subsequently, sliding was proposed as an effective way to mitigate the seismic damage in unreinforced masonry structures by Arya et al. [4]. In this work, they introduce a sliding surface between the foundation beams and bond beams that support the masonry walls on a membrane made of polyethylene or used motor oil. Different materials, such as sand and graphite, were explored in subsequent work [5,6].

Unrelated to seismic actions, a damp proof course is often incorporated into the base of unreinforced masonry walls to prevent moisture from rising into the wall and/or to act as a slip joint to allow for differential movements in the building. Lately, soft layer membranes have also been used to improve the sound insulation of masonry walls. Such soft layer membranes placed in the bed joints have the potential to act as planes of weakness due to the lower shear and tensile strength of the joint with the membrane. Thus, it is important to understand the influence of such soft layers on the seismic shear behaviour of unreinforced masonry walls.

In previous investigations, a series of static, static-cyclic and dynamic tests on masonry specimens with different types of soft layers, in this case damp-proof courses (DPCs), were performed. The results indicated that shear load could be transmitted through a joint containing a DPC. The bed joint shear mechanical properties, i.e. cohesion and friction coefficient, obtained in these tests lie below the corresponding characteristic for masonry without soft layers. The cohesion showed a vanishing value and the friction coefficient values found in tests were generally smaller than those

* Corresponding author. Tel.: +41 446333763; fax: +41 446331064.
E-mail address: mojsilovic@ibk.baug.ethz.ch (N. Mojsilović).

http://dx.doi.org/10.1016/j.engstruct.2014.12.038
0141-0296/

typical for standard mortar (usually between 0.8 and 0.9). Griffith and Page [7] performed monotonic, static-cyclic and dynamic shear tests on small masonry elements (triplets) with different types of DPC membranes (bitumen coated aluminium; polythene/bitumen coated aluminium and embossed polythene) and reported the corresponding friction coefficients (0.53, 0.31 and 0.59, respectively). 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. The masonry materials used in these tests were typical extruded clay bricks with standard mortar. Similar results were reported by Zhuge and Mills [8] and Simundic et al. [9]. Recently, within the framework of a research project on the shear behaviour of masonry elements (triplets) with DPC membrane placed in the bed joints, load tests on ten series of masonry triplets with three different DPC membranes (elastomer-, bitumen- and polythene-based membranes) were done, see Mojsilović [10]. The friction coefficients found for bed joints with soft layer membranes were 0.71 (elastomer), 0.06 (bitumen) and 0.75 (polythene), while the friction coefficient for the control specimen with conventional mortar bed joints was 0.87. The 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. Simultaneously, static-cyclic tests were performed on masonry wallettes subjected to static-cyclic shear loading with embossed polythene DPC placed either in a mortar joint or at the masonry-concrete slab interface, see Mojsilović et al. [11]. Masonry materials used were characteristic for Australia (extruded clay bricks and cement-lime mortar). Three levels of the pre-compression (0.7, 1.4 and 2.8 MPa) were considered. Results from this investigation also confirmed 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. Similar interaction between sliding, shear and compression (rocking) response mechanisms was observed during conventional unreinforced masonry wall tests, e.g. Magenes and Calvi [12], Tomaževič [13].

A research project on the seismic behaviour of masonry wallettes with soft layer membrane placed in the bed joints is under way 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 different bearing layers, and to establish if and how the soft layer modifies the lateral load resistance mechanism of the wall. This paper presents the results of two test series on a total of 16 masonry wallettes made using Swiss masonry materials (hollow clay blocks and cement mortar) and having commercial rubber-based built-in soft layers. The effects of soft layer material and thickness, pre-compression level, and soft layer position are investigated, which in general distinguishes this research from previously reported work. Recommendations for further research and for use of soft layers in bed joints in practice are made.

The presented test series were preliminary studies for the larger research project, which has been started recently. The squat (aspect ratio of 1) wallettes were chosen to investigate the influence of the soft layer material in one of the lower bed joints. It has been expected that this layers would change the failure mode from shear and/or compression (toe crushing) failure to the sliding. Applied levels of the pre-compression were characteristic for the Swiss two to three stories residential homes. The size of specimen was determined by the need to conduct a relatively large number of tests in a limited time.

2. Test programme and masonry materials

Static-cyclic load tests on two series of masonry wallettes with soft layers incorporated in the bed joints have been performed at the Institute of Structural Engineering of ETH Zurich. For comprehensive overview, see Barandun [14], Mojsilović et al. [15] and Vögeli [16]. The summary of this test programme is shown in Table 1.

The first test series consisted of seven specimens, with nominal dimensions of $1200 \times 1200 \times 150$ mm, that contained soft layer in the bed joint between the first and the second course of bricks. Two different soft layer materials, i.e. rubber granulate (G) and extruded elastomer (E), with thicknesses of 3, 5 and 10 mm were used. All test specimens were constructed by professional masons in the testing laboratory and were air cured at the testing site for at least 28 days. The wallettes were built in running bond. Both the bed and the head joints were nominally 10 mm thick and fully filled. During the wallette construction, the soft layer strip was placed directly on the first block course. The membrane was then covered with a layer of mortar, before the next course of bricks was laid on top. Note that for the specimens with 3 and 5 mm thick soft layers the total bed joint thickness was kept at 10 mm. For the two wallettes with 10 mm thick membranes, the thickness of the joint containing the soft layer was increased to 15 mm to have a minimum mortar layer thickness of 5 mm. In addition to the specimens with built-in soft layer, a control specimen with the same nominal dimensions but without a soft layer was tested.

After being placed in the test set-up, the specimens were first subjected to a gravity load to induce a pre-compression stress of 0.60 MPa. This level of pre-compression corresponds to approximately 10% of the nominal gravity load capacity of the wallets. While the gravity (axial) load was kept constant during the test, the specimens were subjected to the cyclic shear load, applied in an incrementally increasing displacement-controlled sequence. Note that the first three tests (W0, WE3 and WE5) had to be repeated due to the various problems with the test set-up, which caused unacceptably high variation of the pre-compression load during the test. The results presented here are obtained from repeated tests (performed on new specimens).

Table 1
Test programme and specimen designation.

Specimen	t_{sl} (mm)	Layer material	Pre-compression (MPa)
First test series			
W0	–	None	0.6
WE3	3	Extruded elastomer	0.6
WE5	5	Extruded elastomer	0.6
WE10	10	Extruded elastomer	0.6
WG3	3	Rubber granulate	0.6
WG5	5	Rubber granulate	0.6
WG10	10	Rubber granulate	0.6
Second test series			
W0.10	–	None	0.6
WE3.10	3	extruded Elastomer	0.6
WE10.10	10	Extruded elastomer	0.6
WG3.5	3	Rubber granulate	0.3
WG3.10	3	Rubber granulate	0.6
WG3.15	3	Rubber granulate	0.9
WG10.5	10	Rubber granulate	0.3
WG10.10	10	Rubber granulate	0.6
WG10.15	10	Rubber granulate	0.9