Component-level Testing

Wallets and walls with block size and notch design that is described in the file *Specimens_Setup_LoadingProtocol.pdf*, which are similar to the houses tested in the shaking table tests, were tested under vertical compression and shear-compression tests, respectively. This file describes these two tests.

1. Vertical compression test

The vertical compression test is a typical test to determine masonry characteristics at full-scale. The specimen design and test procedure are adapted from the norm DIN EN 1052-1 (1998) for small-scale testing. The wallet specimen consists of two bricks in the horizontal direction and five bricks in the vertical direction. Additionally, bearings at the top and bottom were printed with the wallets to ensure uniform loading of the specimen (Figure 1).

The masonry wallet had a height of h = 70.2mm, a length of l = 39.6mm, and a width (thickness) of t = 15mm. A total of 8 specimens are tested. The geometry of the wallet is shown in Figure 1.

Setup and Instrumentation

The test was conducted using a universal testing machine (UTM). A 100kN capacity load cell above the specimen measured the induced force, while a three-dimensional Digital Image Correlation system (3D-DIC) system captured displacements and strains.

Loading Protocols

Three loading protocols are used (two specimens are tested per protocol):

• Loading Protocol 1: The load was monotonically applied in a displacement-controlled fashion with a rate of 0.1mm/minute until failure. Stiffness parameters are calculated as the secant modulus between 15% and 33% of the compressive strength.

• Loading Protocol 2: Using the compressive strength from the first loading protocol, this protocol included a force-controlled phase with three cycles between lower stress of 15% of the expected strength and upper stress of 33% of the expected strength. The specimen was then unloaded to a minimal load of 100N, marking the end of the force-controlled phase. The load was then monotonically increased in displacement-control until failure. The loading rate was 0.1MPa/s and 0.1mm/min in the force-controlled and displacement-controlled phases, respectively. Stiffness properties are evaluated from the secant modulus of the third cycle.

• Loading Protocol 3: Identical to Protocol 2, except that the displacement-controlled phase was cyclic, with incrementally increasing target displacements. Stiffness properties are evaluated from the secant modulus of the third cycle.

Figure 2 illustrates the three loading protocols. The parts highlighted in red show where the elastic properties are assessed.

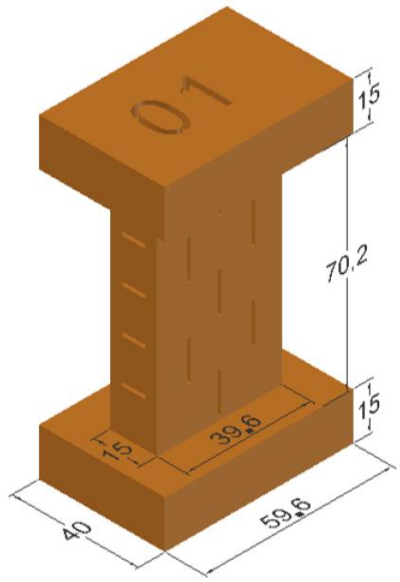

Figure 1. Geometry of the tested wallets – vertical compression test (dimensions are in mm).

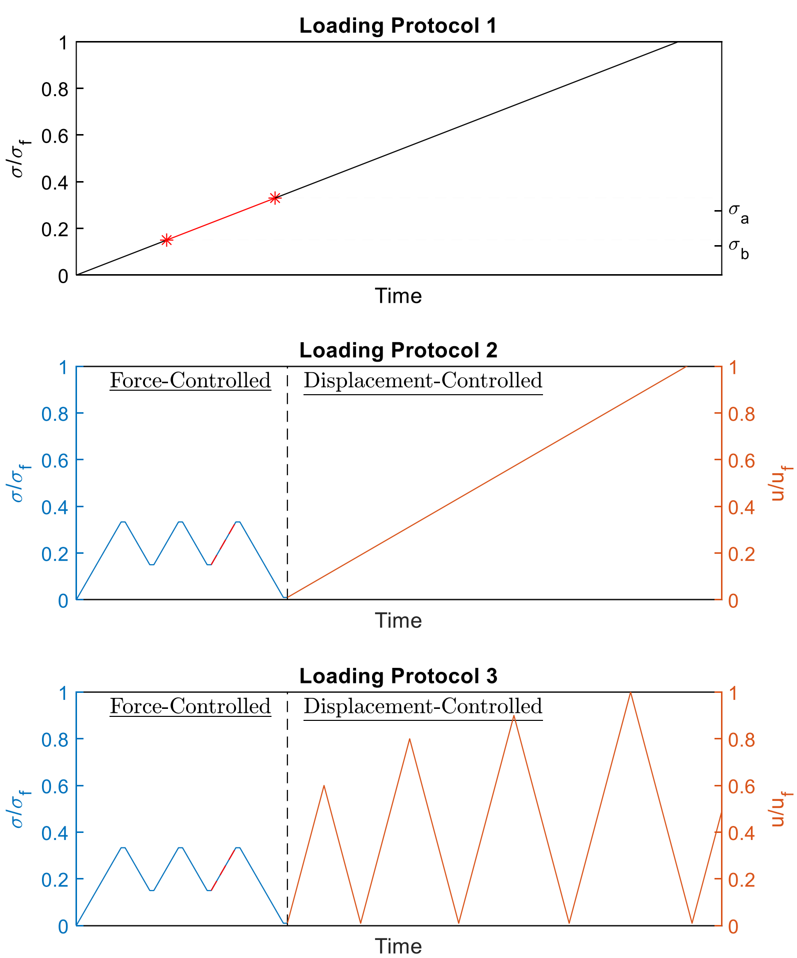

Figure 2. Adopted loading protocols – vertical compression test.

The failure mode of the masonry wallets is illustrated in Figure 3. In all the specimens a horizontal crack in the lowest notch area was observed. The only exception is given by specimen VComp_3, where a diagonal staircase failure can be observed.

The stress-strain curves for the tested specimens are presented in Figure 4. The stress-strain curves plot horizontal and vertical strains in the negative and positive directions, respectively. The mean and the coefficient of variation (CoV) of compressive strength, elastic and shear moduli, and Poisson's ratio, obtained from these tests, are summarized in Table 1.

The stress, vertical strain (in the direction of loading), and horizontal strain for the six specimens are provided in *ComponentTestingData.zip* under Input Data. The Naming of the files is "SpecimenName.txt," where "SpecimenName" is according to the first column in Table 1. Each text file contains three columns as follows:

Column1: stress in MPa

Column 2: vertical strain (in the direction of loading)

Column 3: horizontal strain

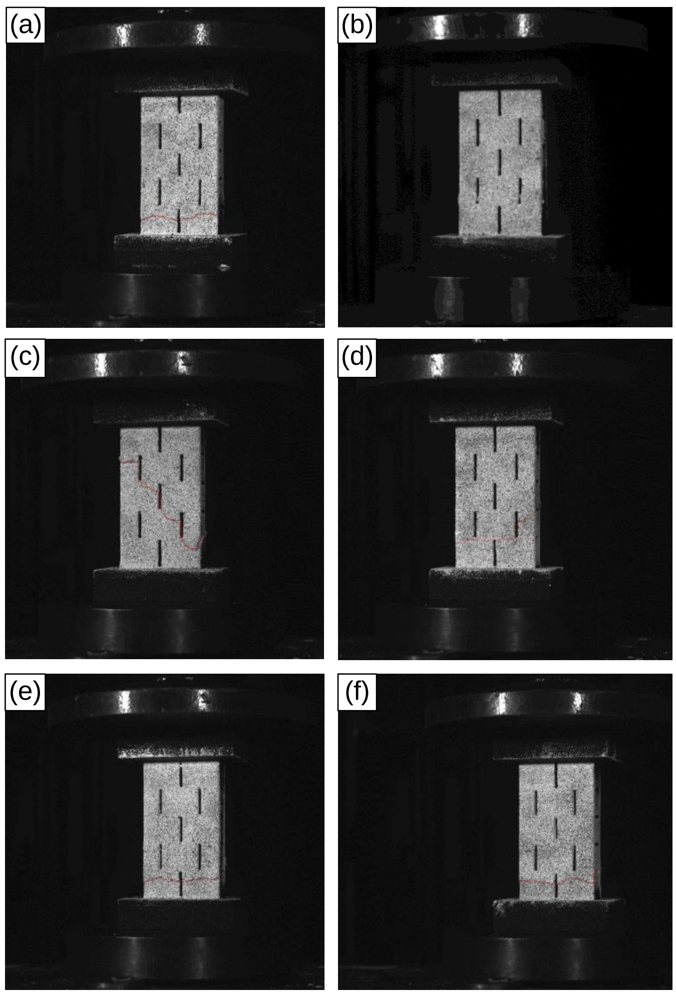

Figure 3. The failure mode of the six tested specimens in vertical compression tests: (a) specimen VComp_1, (b) specimen VComp_2, (c) specimen VComp_3, (d) specimen VComp_4, (e) specimen VComp_5, and (f) specimen VComp_6.

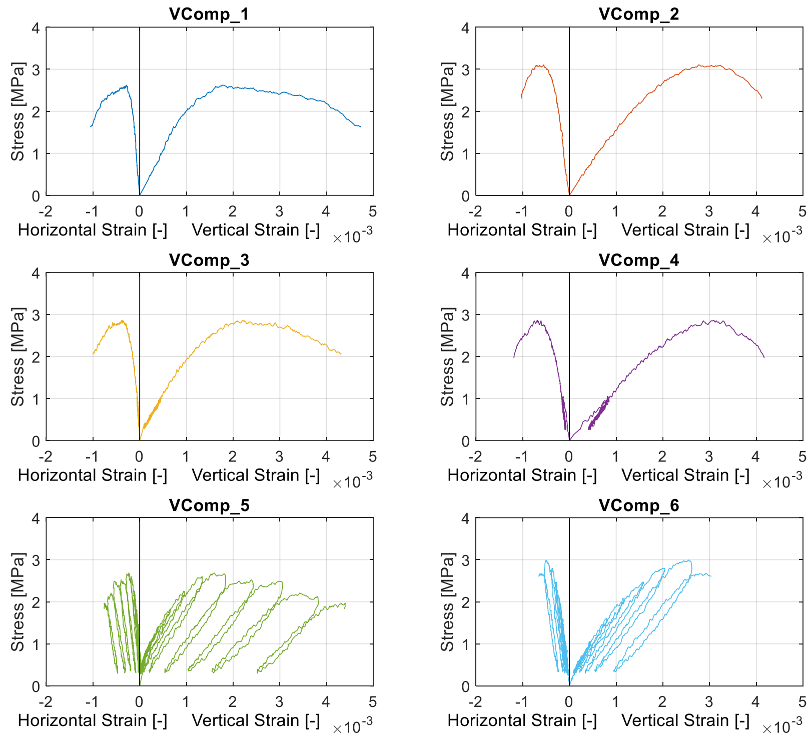

Figure 4. Stress-strain relationships for the tested wallets – vertical compression test.

Table 1. Summary of the vertical compression test results.

Specimen	Loading protocol	Elastic modulus [MPa]	Poisson's ratio [-]	Shear modulus [MPa]	Compressive strength [MPa]
VComp_1	1	2137.3	0.16	922.9	2.62
VComp_2	1	1532.2	0.19	644.4	3.11
VComp_3	2	2124.8	0.15	921.2	2.86
VComp_4	2	1820.1	0.16	783.1	2.86
VComp_5	3	3619.5	0.12	1614.1	2.68
VComp_6	3	2299.4	0.14	1006.9	2.99
Mean		**2255.5**	**0.15**	**982.1**	**2.85**
CoV		**0.32**	**0.15**	**0.34**	**0.06**

2. Shear-compression test

Specimen Design

Two walls with the same geometry were tested under constant compressive and cyclic horizontal loading. The geometry of the two walls is identical to the East wall of the houses tested on the shaking table, (*Specimens_Setup_LoadingProtocol.pdf*). The walls had a length of l = 161.4mm, height h = 150.4mm, and thickness t = 15mm. Bearings were attached to the top and bottom of the walls, similar to the vertical compression test. Figure 5 illustrates the geometry of the tested walls. Tests were conducted at two different axial stress levels: 0.06 MPa, and 0.3 MPa.

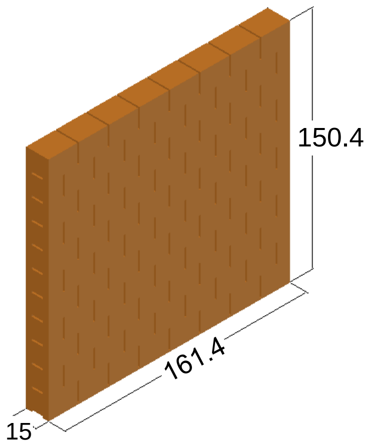

Figure 5. Geometry of the tested walls (dimensions are in mm).

Setup and Instrumentation

The in-plane cyclic shear-compression test setup is shown in Figure 6. The test setup includes two vertical and one horizontal actuators. The lower plate was attached to two triaxial loadcells, which are able to measure forces in three directions and bending moments in two directions. A 3D Digital Image Correlation (3D-DIC) system was used for precise measurement of displacements and strains.

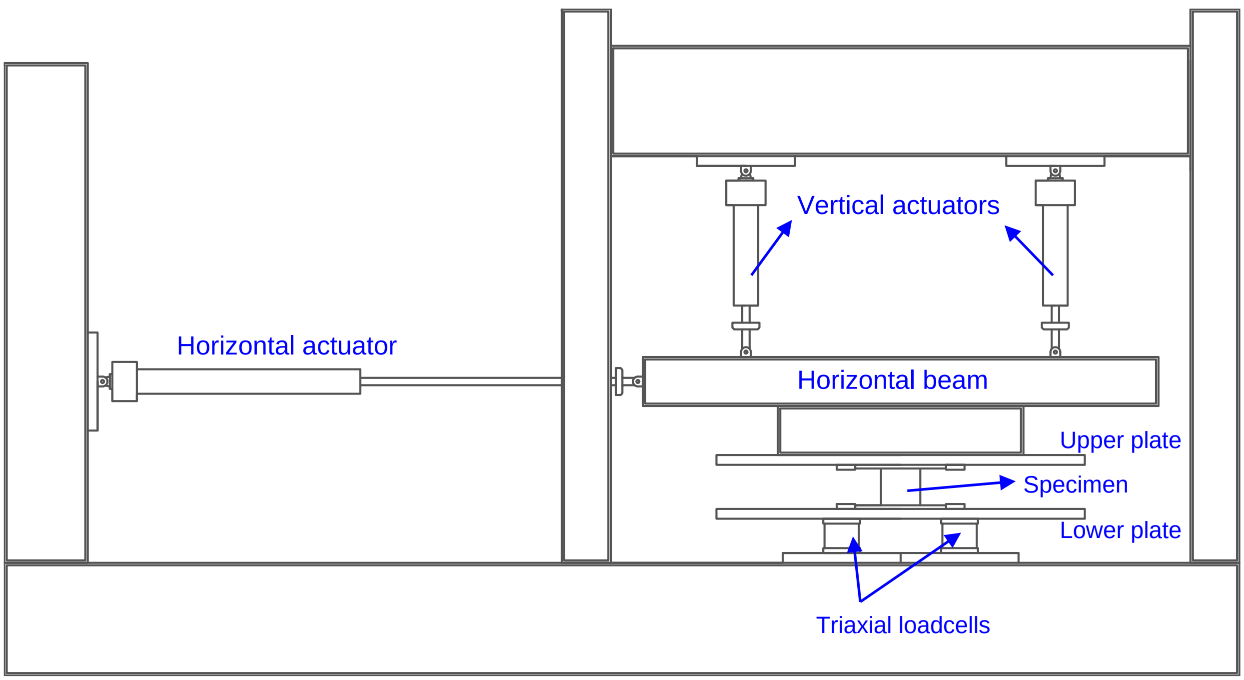

Figure 6. Test setup – Shear compression test.

Loading Protocol

The specimens were subjected to constant vertical compression and cyclic horizontal displacement. Two cycles are conducted for each horizontal displacement amplitude. Each cycle was applied over a duration of 120.48 s, with a displacement rate that varied based on the amplitude.

Bilinearization

The backbone curve of the hysteresis is idealized as an elastic-perfectly plastic bilinear curve. Effective stiffness K_{eff} is defined as the secant modulus to the load $0.7V_{max}$, where V_{max} is the peak force. The ultimate displacement d_u corresponds to the point where the force drops to 80% of the peak force. Yield displacement d_e is determined based on equal areas under the backbone and bilinear curves. The bilinearization process is illustrated in Figure 7. As discussed later, the entire recorded force displacement data is provided, therefore the contestants are welcome to use this data in any way that they would like for their modeling purposes. The bilinearization discussed in this section is only used for characterizing the effective stiffness, yield force and the displacement values provided in Table 2.

Results

Figure 8 depicts the recorded shear force-drift ratio relationships, the backbone curves, and the idealized elastic-perfectly plastic relationships for the two walls. The backbone curve is derived from the hysteresis by identifying the maximum horizontal force during the first cycle to each amplitude, in both positive and negative directions. The top left corner of these figures shows the average axial stress (σ) applied. The axial stress is calculated dividing the average axial force measured by the loadcells by the wall area (161.4mm by 15mm). The top left corner of Figure 8 also shows the ratio of the axial stress normalized by the compressive strength of the masonry (denoted as α) obtained as the mean value from the vertical compression test (σ_f = 2.85 MPa in Table 1).

Idealized bilinear force deformation relationships are determined from the backbone curves with the previously described method (Figure 7). Table 2 summarizes the parameters of the shear-compression test and the bilinearization. It includes the axial stress on the wall specified with σ and α. K_{eff}, V_u, d_e, and d_u are effective stiffness, yield force, yield displacement, and ultimate displacement, respectively, resulting from the bilinearization process.

Failure Mode

Figure 9 depicts the failure mode of the tested walls. Wall 1 (axial stress of 0.06 MPa) failed in a sliding shear mode, concentrated in the lowest notch area. In Wall 2, a diagonal crack extended over half the wall height, and additional horizontal cracks developed in the lowest notch regions.

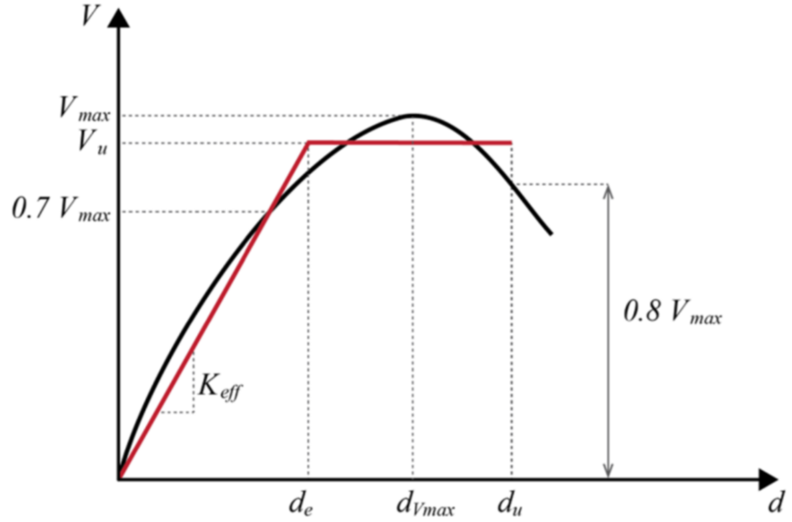

Figure 7. Bilinearization method (Del Giudice et al. (2024))

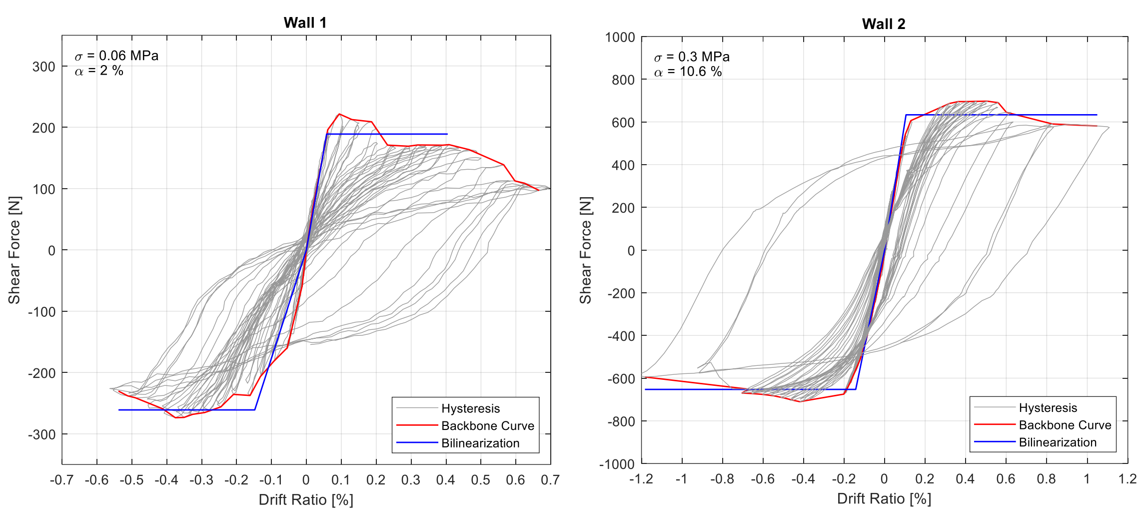

Figure 8. Hysteretic behavior, backbone curve, and bilinearization of (left) Wall 1, 0.06 MPa axial compressive stress, and (right) Wall 2, 0.3 MPa axial compressive stress.

Table 2. Summary – shear compression test.

Specimen	σ [MPa]	α [%]	Direction	K_{eff} [N/mm]	V_u [N]	d_e [mm]	d_u [mm]
Wall 1	0.06	2	+	2092.2	184.8	0.088	0.615
			-	1198.6	264.8	0.221	0.817
Wall 2	0.3	10.6	+	3953.5	633.1	0.16	1.593
			-	3013.9	652.9	0.217	1.796

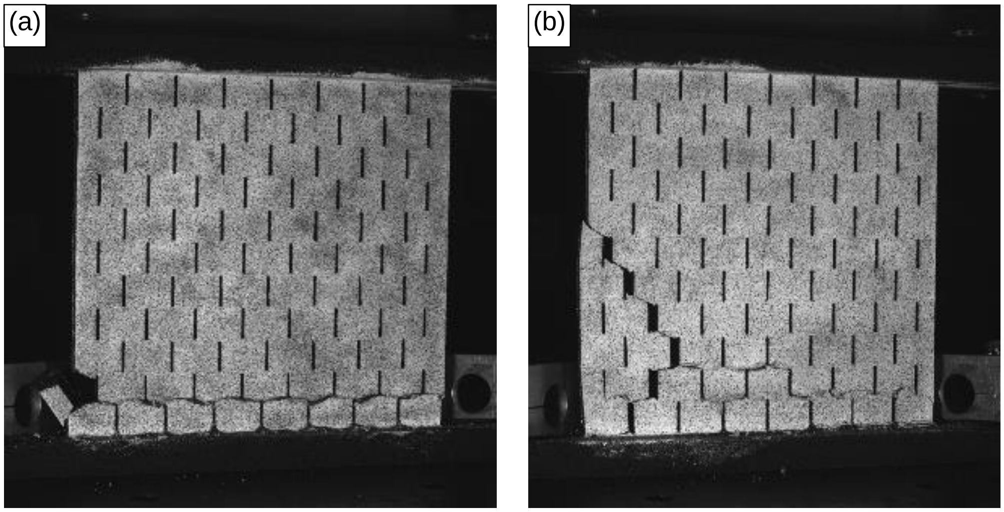

Figure 9. Failure mode of the tested walls – shear compression test: (a) Wall 1 (0.06 MPa axial compressive stress) and (b) Wall 2 (0.3 MPa axial compressive stress).

The shear force and drift ratio for the two specimens are provided in *ComponentTestingData.zip* under Input Data. Naming of the files is “SpecimenName.txt” where “SpecimenName” is according to the first column in Table 2. Each text file contains two columns as follows:

Column1: shear force in Newtons

Column 2: drift ratio (displacement/height) in %

References

Del Giudice, L., Katsamakas, A., Liu, B., Sarhosis, V. and Vassiliou, M.F., 2024. Physical modelling of unreinforced masonry walls using a sand-based 3D printer. *Engineering Structures*, 305, p.117665.

EN DIN EN 1052-1. Prüfverfahren für mauerwerk–teil 1: Bestimmung der druckfestigkeit. 1998.