SHEAR TESTS ON CLAY UNIT MASONRY WALLS UNDER STATIC-CYCLIC HORIZONTAL LOADING

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SUMMARY

At Kassel University 15 walls made of clay units and seven further walls made of calcium silicate units and Lightweight Aggregate Concrete (LAC) units were tested under static-cyclic loading. These tests on various types of clay bricks and different kinds of mortar with different levels of vertical stress and different wall lengths were carried out using a new test method, which is described in another paper "Shear test method for masonry walls with realistic boundary conditions".
The results are going to be used for a comparison with shaking table tests and pseudo-dynamic large scale earthquake tests within the ESECMaSE project. Furthermore, the test data are suited to support the development and validation of improved models for the shear strength and the deformation capacity of masonry walls.

INTRODUCTION

Within the European research project ESECMaSE – i. e. "Enhanced Safety and Efficient Constructions of Masonry Structures in Europe" – static-cyclic shear wall tests were carried out at Kassel University (Germany), at Pavia University (Italy) and at the Technical University of Munich (Germany). These tests were executed to extend the knowledge of the shear bearing capacity and the deformation capacity of masonry walls made of different kinds of units and mortar. The results of the 15 wall tests of clay units will be displayed here and compared with each other. The comparison of the results covers the different boundary conditions such as wall length, different types of bricks, different types of mortar, different kinds of vertical loading.

MATERIALS USED

Clay units

Three different kinds of vertically perforated clay bricks were used. Each of them had a width of 175 mm and a length of 363 mm. The height of the bricks depended on the type of mortar used and was 238 mm for general purpose mortar and 249 mm for thin layer mortar. The conventional clay brick were a HLZ-Plan–12–0.9–9DF. The optimised ones had different hole patterns but the same density.

Because the first range of the optimised clay bricks had a smaller vertical compressive strength as the conventional bricks, a second range of optimised clay bricks with smaller holes was fabricated.

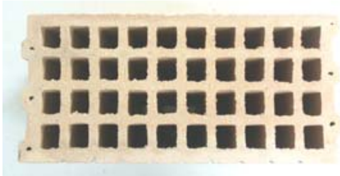
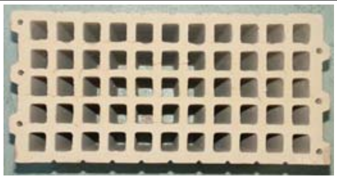
conventional	optimised	optimised 2
		

Figure 1. Different hole patterns of the clay units

Mortar

The first and the last layer of mortar of all tested walls were fabricated with a general purpose mortar Sakret ZM M10 according to DIN EN 998-2. The other kinds of mortar were specific to each kind of bricks.

- General purpose mortar
  ready-mixed mortar M5 according to DIN EN 998-2

- Thin layer mortar
  Bellenberger Planziegel thin layer mortar
  Generally approved by the building authorities (DIBT Zul.-Nr. Z.17.1-261)

DESCRIPTION OF THE SHEAR-TEST

Within the research project ESECMaSE 15 walls made of clay units (see table 1) were tested by a test method which is described in the paper "Shear test method for masonry walls with realistic boundary conditions". All these walls were tested with a fixed support of the top of the wall, so that the point of zero moment is at mid height of the wall ($\psi = 0.5$). The point of zero moment can be calculated by equation (1), see figure 1.

$$N_1 \cdot e_1 - N_2 \cdot e_2 = H \cdot (h_w \cdot (1-\psi) + h_a) \qquad (1)$$

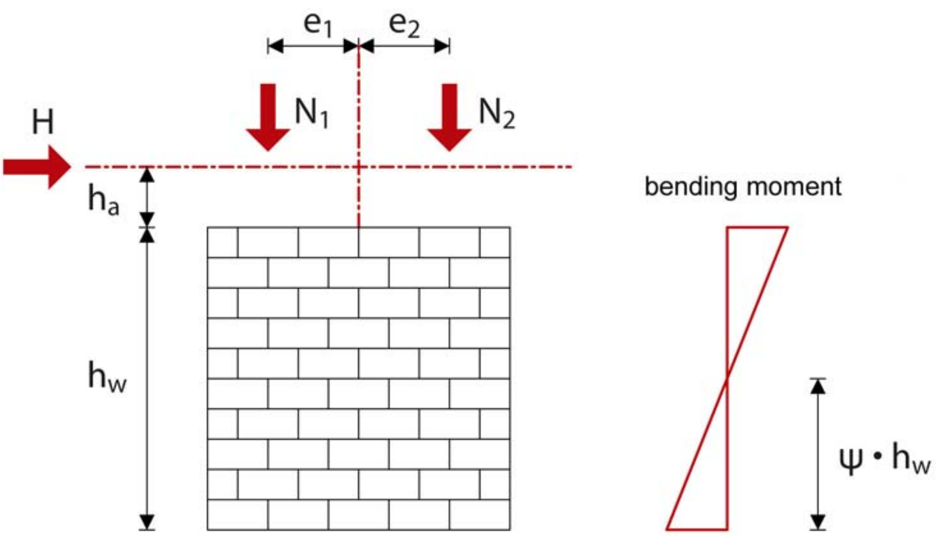


Figure 2. Idealised load state of the shear wall

For all combinations of units and mortar investigations on different wall lengths and different levels of vertical loading were performed. Table 1 represents all tests with their special boundary conditions.

Table 1. Overview of the wall tests on clay bricks

No.	specimen	kind of brick	Length of the wall [m]	mortar	vertical stress [N/mm²]	M/Q/h
1	Hlz-nm-220-380-1	conventional	2,2	general purpose	1,00	0,5
2	Hlz-dm-220-380-1	conventional	2,2	thin layer	1,00	0,5
3	Hlz-nm-220-380-2	conventional	2,2	general purpose	1,00	0,5
4	Hlz-dm-220-380-2	conventional	2,2	thin layer	1,00	0,5
5	Hlz-opti-dm-220-380-1	optimized	2,2	thin layer	1,00	0,5
6	Hlz-opti-nm-220-380-1	optimised	2,2	general purpose	1,00	0,5
7	Hlz-opti-dm-110-190-1	optimised	1,1	thin layer	1,00	0,5
8	Hlz-opti-nm-110-190-1	optimised	1,1	general purpose	1,00	0,5
9	Hlz-opti-dm-220-95-1	optimised	2,2	thin layer	0,25	0,5
10	Hlz-opti2-dm-220-380-1	optimised 2	2,2	thin layer	1,00	0,5
11	Hlz-opti2-nm-220-380-1	optimised 2	2,2	general purpose	1,00	0,5
12	Hlz-opti2-dm-110-190-1	optimised 2	1,1	thin layer	1,00	0,5
13	Hlz-opti2-dm-110-95-1	optimised 2	1,1	thin layer	0,50	0,5
14	Hlz-opti2-dm-110-48-1	optimised 2	1,1	thin layer	0,25	0,5
15	Hlz-opti2-dm-220-95-1	optimised 2	2,2	thin layer	0,25	0,5

TEST RESULTS

Table 2 shows the results of the 15 wall tests on clay units. Herein the horizontal force of the first visible crack on the wall and the maximum force are displayed. Furthermore, the maximum deformations [d_{u1} and d_{u2}] at both sides on top of the wall are given.

Table 2. Overview of the test results

No.	specimen	first crack H_C [kN]	maximum force H_F [kN]	H_C / H_F [-]	H_F / V [-]	d_{u1} [mm]	d_{u2} [mm]
1	Hlz-nm-220-380-1	90	160	0.56	0.42	3.1	2.7
2	Hlz-dm-220-380-1	100	140	0.57	0.37	3.3	4.5
3	Hlz-nm-220-380-2	102	118	0.86	0.31	7.0	5.6
4	Hlz-dm-220-380-2	130	147	0.88	0.39	7.0	5.7
5	Hlz-opti-dm-220-380-1	90	120	0.75	0.32	6.7	6.5
6	Hlz-opti-nm-220-380-1	149	149	1.00	0.39	6.9	7.8
7	Hlz-opti-dm-110-190-1	50	60	0.83	0.32	12.1	11.1
8	Hlz-opti-nm-110-190-1	55	56	0.98	0.29	15.9	10.8
9	Hlz-opti-dm-220-95-1	63	72	0.88	0.76	13.6	9.9
10	Hlz-opti2-dm-220-380-1	127	150	0.85	0.39	7.9	4.9
11	Hlz-opti2-nm-220-380-1	140	162	0.86	0.43	9.3	6.9
12	Hlz-opti2-dm-110-190-1	70	70	1.00	0.37	5.8	7.8
13	Hlz-opti2-dm-110-95-1	41	43	0.95	0.45	15.4	15.6
14	Hlz-opti2-dm-110-48-1	25	25	1.00	0.53	> 25	> 30
15	Hlz-opti2-dm-220-95-1	70	75	0.93	0.74	13.5	11.5

To compare the load bearing capacity of all walls tested with a restraint due to the floor slabs and a width of 175 mm, the values l' and τ' may be adopted.

$$l' = \alpha \cdot l_w / h_w \tag{2}$$

$$\alpha = \frac{\sigma_v}{f_k} \tag{3}$$

$$\tau' = \frac{H_F}{f_k \cdot A_w} \tag{4}$$

with: σ_v = normal stress due to vertical loading of the wall
f_k = compressive strength of masonry
l_w = length of the wall
h_w = height of the wall
H_F = maximum horizontal force
A_w = base area of the wall

In figure 3 τ' is displayed against l' for ψ = 0.5. Here it can be seen, that the load bearing capacity of the wall is increasing with l'. As expected, a higher vertical loading and a larger wall length lead to a higher load bearing capacity of the wall.

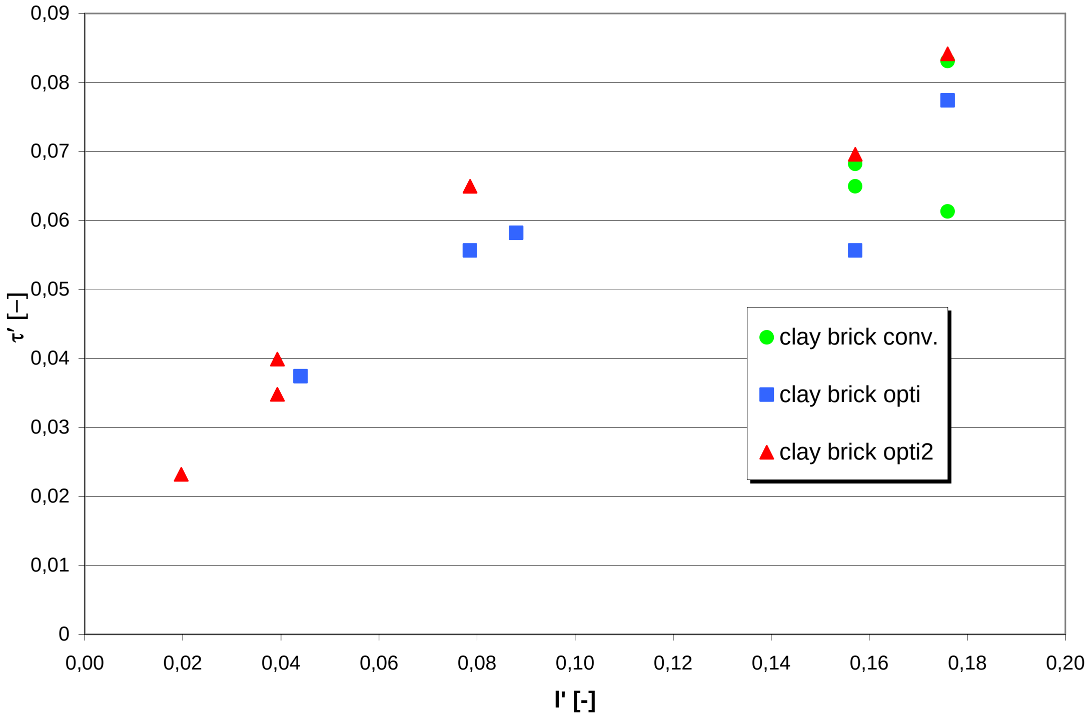


Figure 3. Load bearing capacity

Comparison of the different kinds of mortar

Clay units of two different unit heights were used with thin layer mortar and general purpose mortar M5, respectively. To compare the influence of the two different kinds of mortar on the shear bearing capacity of masonry walls, the enveloping curves of the hysteresis curves of walls with the same boundary conditions but different kinds of mortar, are displayed in figure 4.

Figure 4 indicates that on the one hand the wall with general purpose mortar and clay bricks opti2 has a higher shear bearing capacity as the wall with thin layer mortar and clay bricks opti2. On the other hand the wall with general purpose mortar and conventional clay bricks has a lower shear bearing capacity as the wall with thin layer mortar and conventional clay bricks.

The scattering of the test results can be estimated between 10 % and 20 %. Hence a significant influence of the two different kinds of mortars could not be observed.

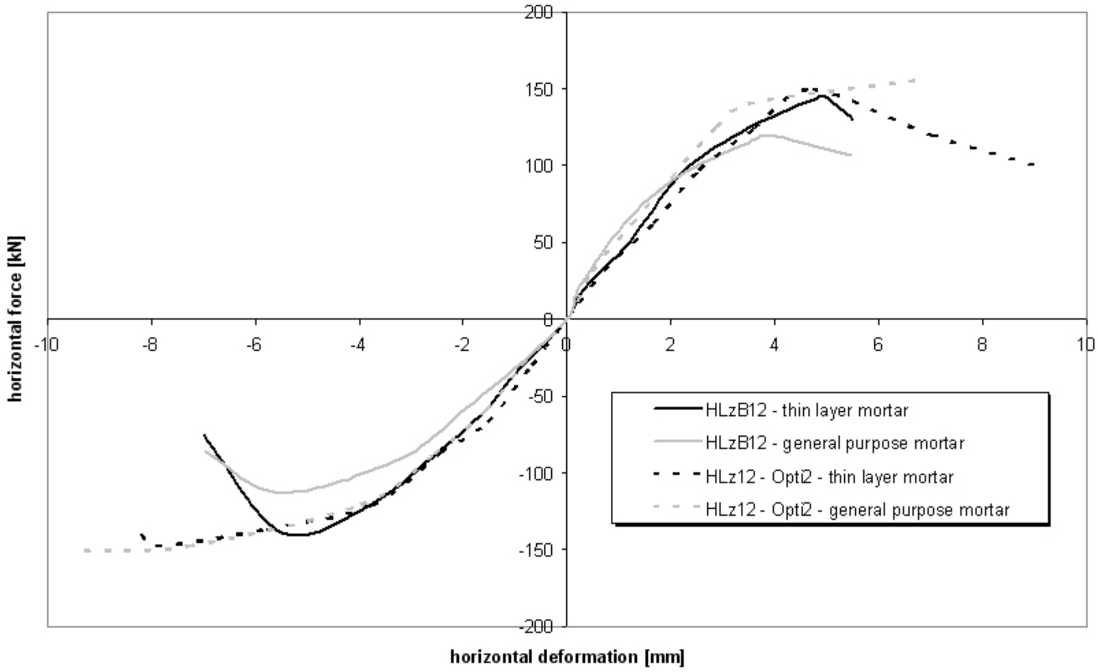


Figure 4. Comparison of different kinds of mortar with clay bricks

Comparison of the different kinds of vertical loading

The walls were tested at three different stress states of vertical loading. Each wall type was tested at a vertical stress of 0.25 N/mm^2, 0.5 N/mm^2 or 1.0 N/mm^2 (see table 1). Figure 5 displays the comparison of two 2.20 m long walls of clay bricks opti2 at a vertical loading of 0.25 N/mm^2 and 1.0 N/mm^2. It can be pointed out, that the wall with a fourth of the vertical loading of the other wall has about half of the maximum horizontal force, whereas the wall with the lower vertical loading has a higher deformation capacity.

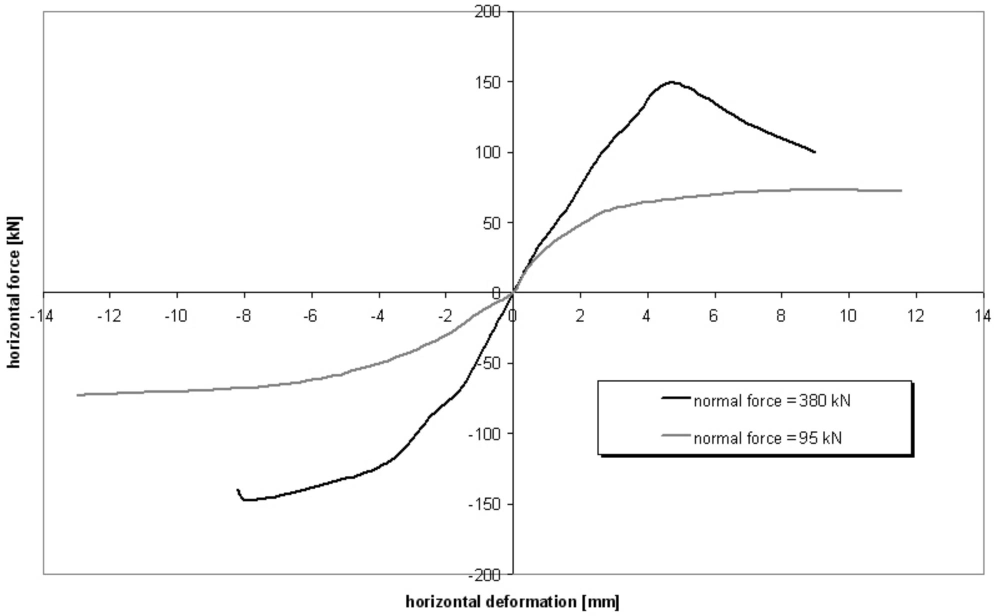


Figure 5. Comparison of different kinds of vertical loading (wall length 2.20 m)

Figure 6 displays three walls with a length of 1.10 m made of clay bricks opti2. The three kinds of vertical loading show three different kinds of hysteresis curves. With decreasing vertical loading the maximum horizontal force is decreasing, too, whilst the deformation capacity of the wall is enlarging.

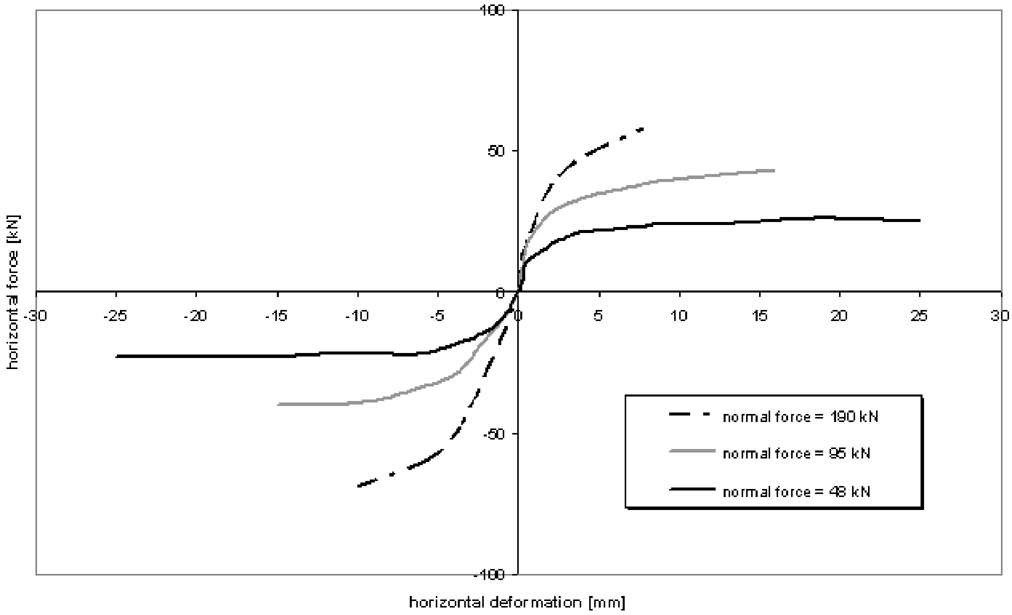


Figure 6. Comparison of different kinds of vertical loading (wall length 1,10 m)

Validation of the optimising of units

The two optimising steps of clay units (see [Grabowski 2005 and Schermer 2005]) are displayed in figure 7 for a wall with a length of 2.20 m and a vertical loading of 1.0 N/mm^2. In this case it can be shown, that the first optimising step (grey hysteresis curve) led to a lower shear bearing capacity of the wall. Therefore a second optimising step was needed and resulted in the dashed envelope curve. These results of the wall with clay bricks opti2 show at least in the third quadrant the highest horizontal force.

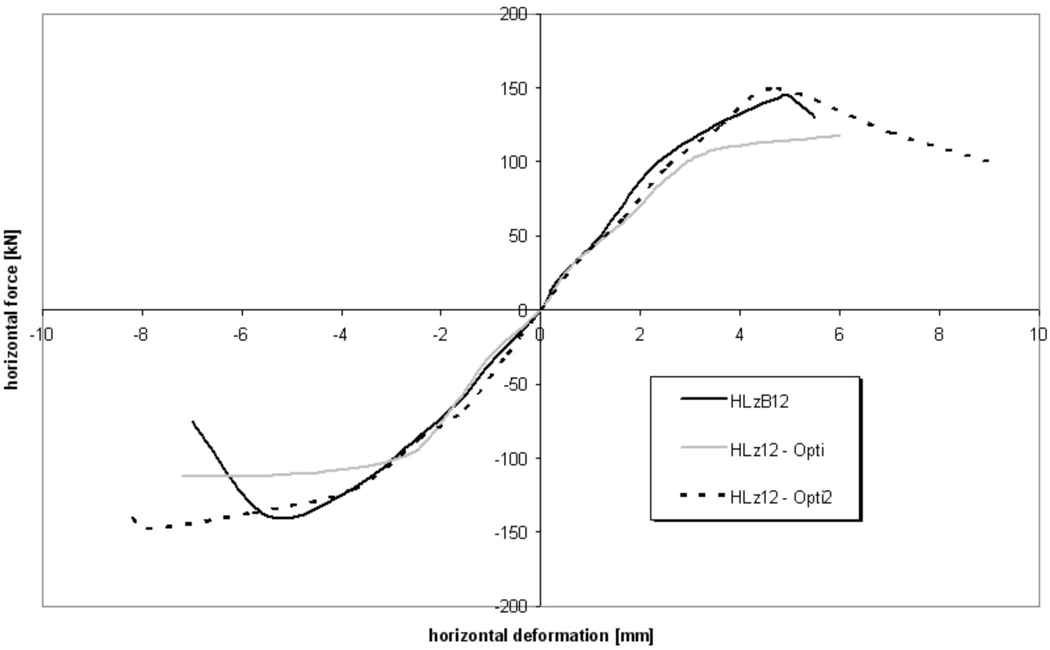


Figure 7. Comparison of different kind of vertically perforated bricks

CONCLUSION

The wall tests on clay units carried out at Kassel University represent the whole range of masonry failure types under shear loads.

Walls with different boundary conditions are compared to each other. The comparison of the bearing capacity of the walls is given by the comparison of l'. It can be noted, that a higher vertical loading and a larger wall length lead to a higher load bearing capacity of the wall.

The comparison of the different kinds of mortar shows, that a significant influence of the two different kinds of mortar could not be observed. The scattering of the wall test results can be estimated from 10 % up to 20 %, possible distinctions are in the range of the scattering as usual for masonry.

The comparison of the different kinds of loading shows, that at decreasing vertical loading the maximum horizontal force is decreasing and the deformation capacity of the wall is increasing.

The validation of the optimised units shows that neither an increase of the bearing capacity nor of the ductility of the walls could be observed.

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