ESECMaSE

Enhanced Safety and Efficient Construction of Masonry Structures in Europe

Project No. Coll – Ct - 2003 - 500291

ESECMaSE

Enhanced Safety and Efficient Construction of Masonry Structures in Europe

Horizontal Research Activities Involving SMEs

Collective Research

Work Package N°: 6

D 6.4 Series of shear tests for validation

Due date of deliverable: 10.07.2005
Actual submission date: 10.02.2006

Start date of project: 10.04.2004 Duration: 36 months

University of Kassel
Institute of Structural Engineering
Chair of Structural Concrete
Kurt-Wolters-Straße 3
34109 Kassel [draft 1]

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents:

1. Introduction

In work-package 6.3 the different test setups of the Technical University of Munich (TUM) and the University of Kassel (UNIK) for shear tests on masonry walls have been built and documented. For each of these two installations, verification tests have been performed in order to validate the shear test method described in deliverable D6.2 as well as the test setups described in D6.3.

Deliverable D6.4 deals with the description of the verification tests, which have been performed at the two different universities. The verification tests described here include two tests at UNIK and TUM using AAC (Autoclaved Aerated Concrete) masonry and one additional test on clay brick masonry (at UNIK).

Within ESECMaSE, tests of this kind will be carried out also in a third laboratory, mainly with calcium silicate units. In order to obtain comparable results for the setups in all three laboratories, three more verification test at the

⇒ Technical University of Munich (TUM)

⇒ University of Kassel (UNIK)

⇒ University of Pavia (UPavia)

will be performed. The results of these further tests (using calcium silicate units) will be given in an appendix to this deliverable.

2. Construction of the masonry specimens

Both AAC masonry walls, the wall at UNIK as well as the specimen of TUM, were built up by the same person (qualified brick layer, provided by the manufacturer of the AAC units) and have the same geometry.

2.1. Materials used

Units as well as mortar have been taken from the same production charge to ensure that comparable results can be obtained. The units had been extracted from the regular production and were provided by the manufacturer:

units: PP 4/0,55 with flat head joints and a size of 499*249*175 mm

mortar: thin layer mortar "REDI Typ 10"

mortar of the screed: NM MG III

For testing the compressive strength of the mortar, prisms according to DIN 18555 were produced and tested at the same time as the masonry wall. The average compressive strength of the mortar prisms, fulfilling the requirement of the building authority approval of 10.0 N/mm^2, is given in table 1.

table 1: compression strength of the tested mortar prisms

compression strength [N/mm^2]		**period of storage [days]**
normal mortar	**thin layer mortar**	
11.15	14.38	28

Furthermore, after the test on the wall at TU Munich, some test specimens (unit + mortar-layer + unit) have been cut out from the uncracked region of the wall and tested according to DIN 18 555-5. The age of the specimens was 35 days.

table 2: Adhesion strength between mortar an units (without the correction factor 1.2)

Adhesion strength [N/mm^2]	**Distribution of the failure surface**
0.98	60% in the unit / 40% in the mortar joint
0.96	95% in the unit / 5% in the mortar joint
0.90	100% in the unit
Mean value: 0.95	

Also the compression strength of the units has been determined experimentally. The mean value was 4.9 N/mm^2. The density of the units reached 0.56 kg/dm^3.

2.2. Test specimens

The two masonry walls were built using thin layer mortar. For the application of the mortar a notched trowel was used. Both walls had the same dimensions of 2.50 m * 2.50 m and a thickness of 175 mm, as shown in figure 1.

figure 1: test specimen of the University of Kassel

The masonry wall of the University of Kassel was tested after 28 days. The specimen of the Technical University of Munich was tested five days later, at an age of 33 days. Since the mortar strength does not change significantly during the 5 additional days, the vertical strength of both wall specimens was expected to be very similar.

2.3. Test setup and measuring equipment

The test facility as well as the measuring equipment of both laboratories are described in deliverable D6.3. Both walls are loaded by a vertical force of 240 kN, leading to a level of normal stress of σ= 0,55 MPa which corresponds to 0.5*σ_0 according to DIN 1053-1.

3. Verification test executed at the University of Kassel

3.1. Load-history

Figure 2 shows the loading of the masonry wall versus time. The horizontal force and the two vertical forces are depicted. The black line shows the normal force in the wall (sum of the two vertical forces). It can be seen that the normal force could be kept practically constant during the loading. However, between the different loading cycles, the first version of the control software required an unloading of the normal force in order to enable the input of new values for the target forces /deformations of the next cycle.

For the first loading cycle, the horizontal force is increasing up to a compression force of 50 kN and reverses up to a tension of 50 kN. In the second cycle, the horizontal force increases up to 108 kN and reverses up to a tension of 89 kN. For the third cycle, the horizontal force is brought up on the cracked masonry wall by a compression of 72 kN and a tension of 85 kN.

The achieved deformations are shown in figure 4.

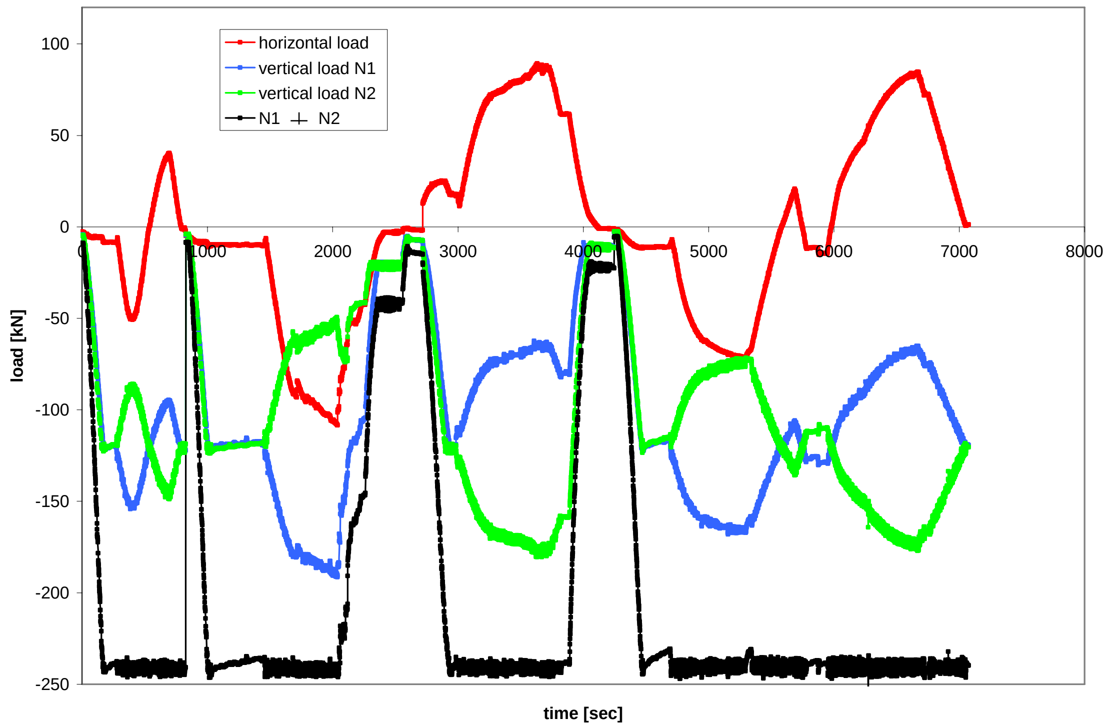

figure 2: loading versus time (UNIK)

3.2. Structural behaviour of the masonry wall

The first visible cracks in the masonry wall occurred at a horizontal load of about 70 kN. Two parallel cracks were developing along a diagonal line from top left (see figure 3) to the bottom right corner of the wall. The complete crack pattern of the masonry wall after loading is shown in figure 3. The cracks of the wall which are coloured black follow from load step 2 and the red coloured cracks result from load step 3.

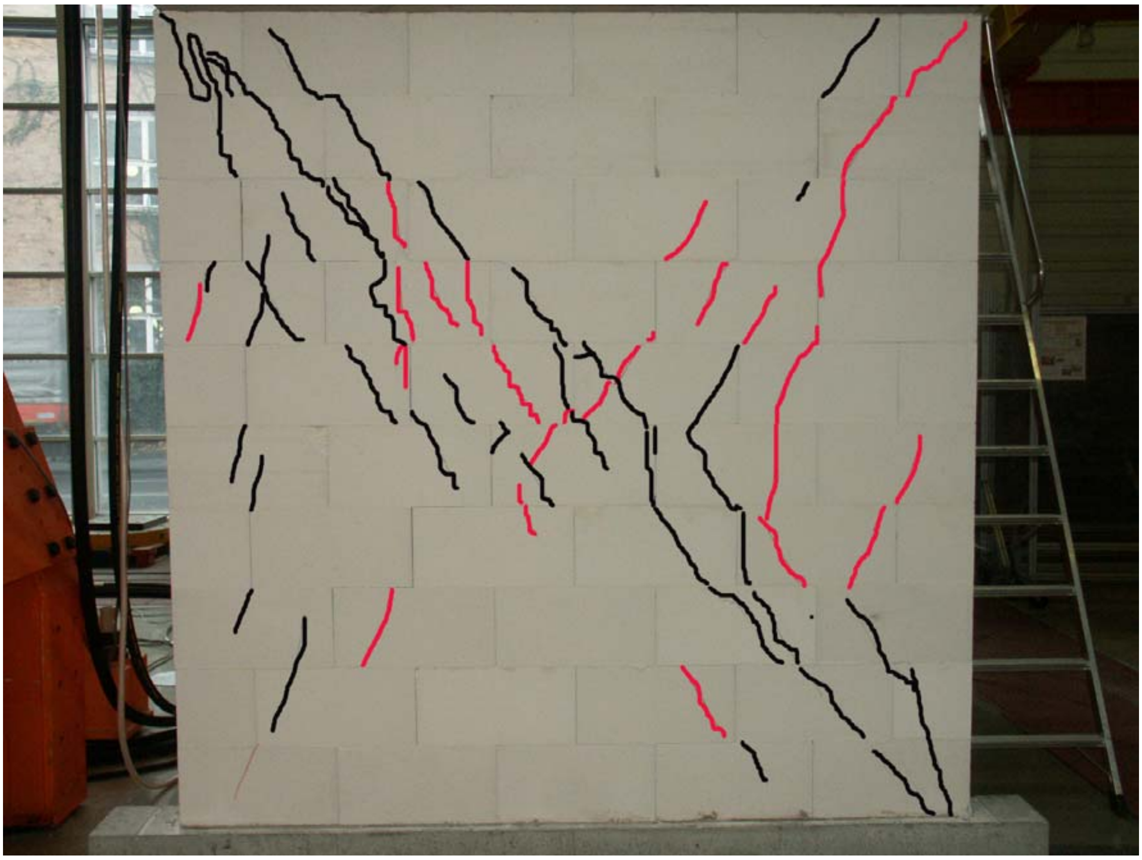

figure 3: crack pattern of the wall (UNIK)

3.3. Load-deformation-behaviour

The hysteresis – given in figure 4 – shows the three loading cycles within the verification test. Since erroneously, the deformation measurements were set to zero at the beginning of each loading cycle, the complete hysteresis had to be reconstructed from the data of each single cycle. This procedure was made even more difficult due to the fact that the normal force was released two times during the whole test duration.

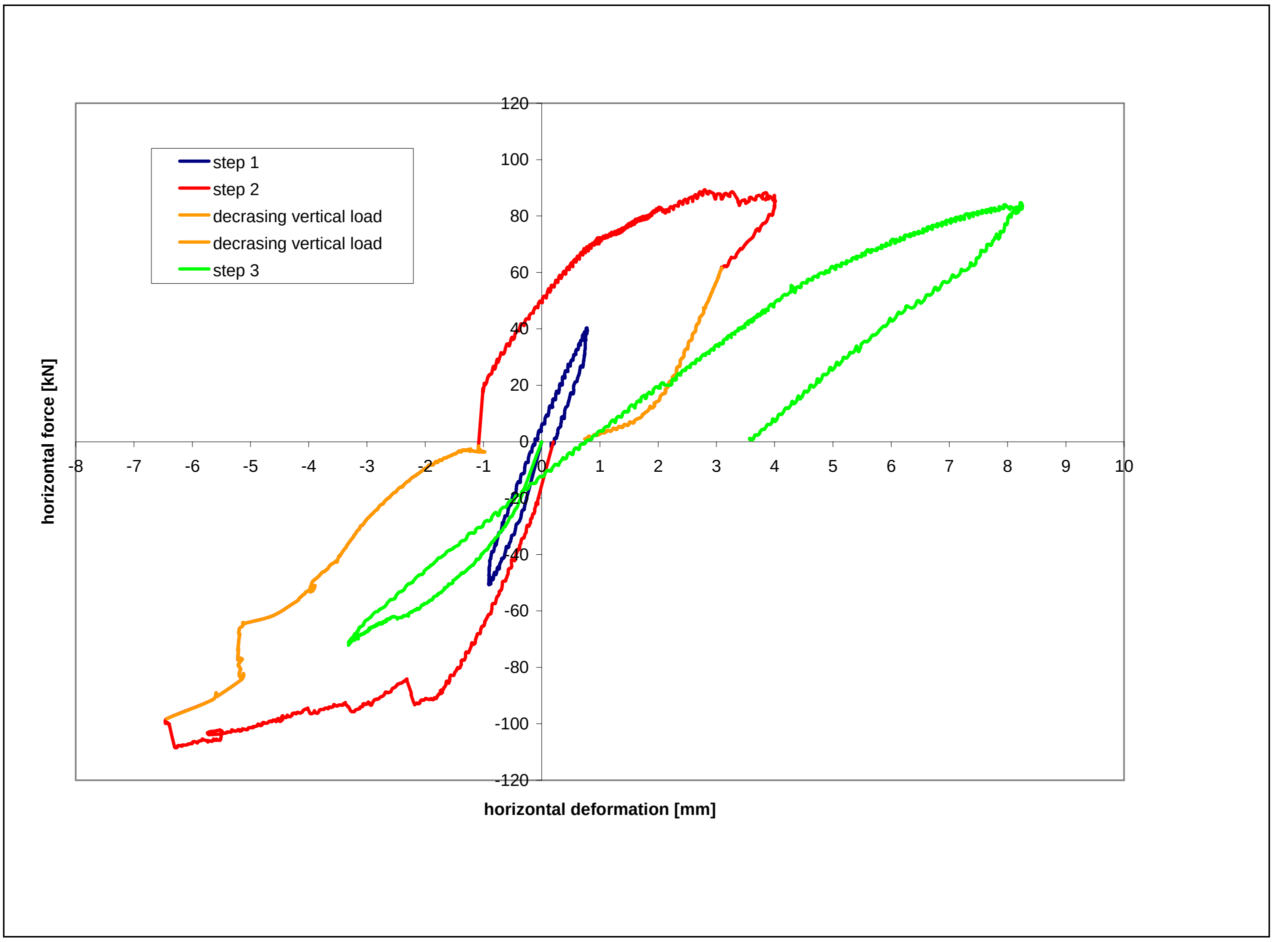

figure 4: hysteresis of the validation test (UNIK)

As the hysteresis curve of the test of the University of Kassel shows a reconstruction of the data of the three single curves, the data of the curve can be verified with the data of the test at TU Munich, but for a validation of the test setup of the University of Kassel a second verification test became necessary.

Figure 5 presents the hysteresis curve of a second validation test. Within this test a wall built of vertical perforated clay bricks with a height of 2.50 m a length of 2.20 m and a thickness of 175 mm was tested. The test facility as well as the measuring equipment was equal to the first test.

The wall was loaded by a vertical force of 380 kN, leading to a normal stress of σ= 1,0 MPa which corresponds to 0.4*σ_0 according to DIN 1053-1.

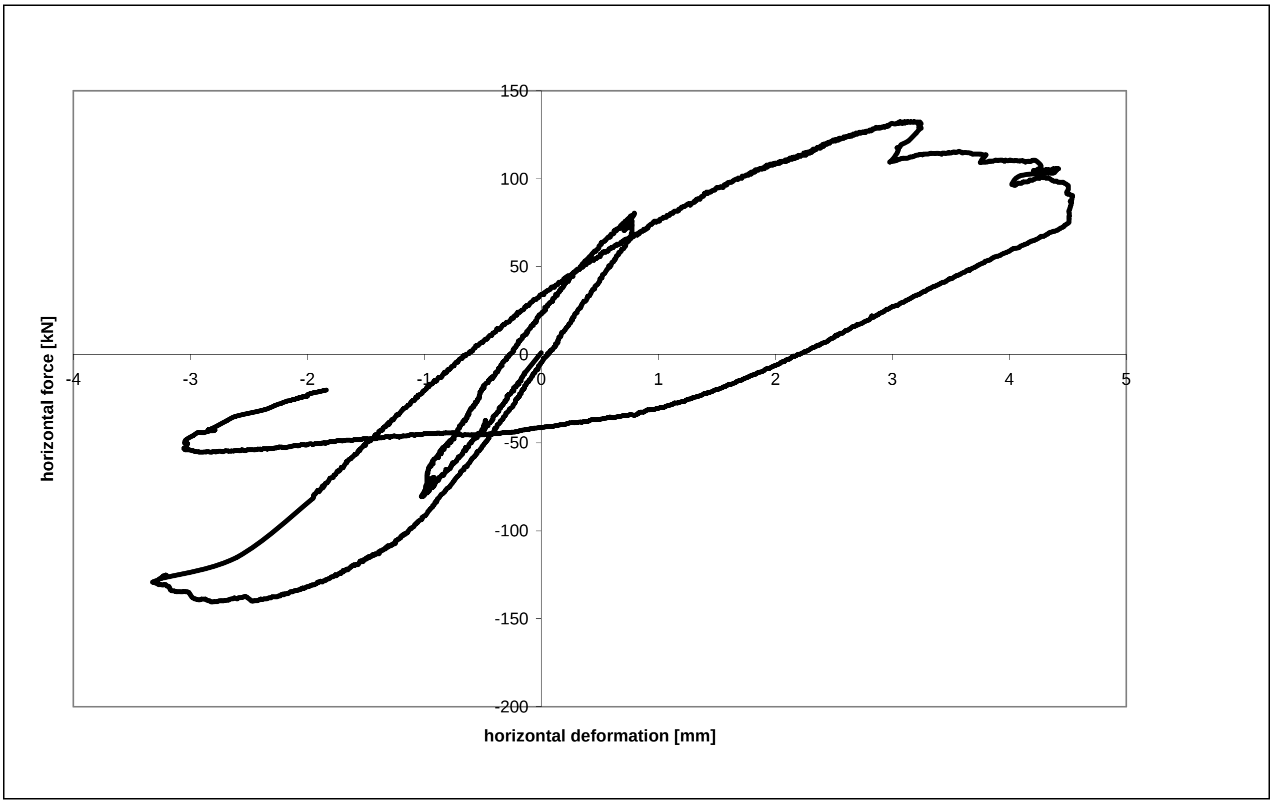

figure 5: hysteresis of the second verification test (UNIK)

4. Verification test executed at the Technical University of Munich

4.1. Load-history

Figure 7 shows the load history of the tested wall at the TU Munich. The loads, i.e. the vertical load (force controlled) and also the horizontal load (displacement controlled) were applied in several discrete load steps, ensuring the boundary conditions as given below:

- Constant (vertical) normal force, i. e. N1 + N2 = 240 kN = const.
  (At the beginning of the tests the vertical load was increased linearly from 0 kN to 2 x 120 = 240kN.)
- Bending moment at the cap of the wall determined to ensure the bending moment in the mid height of the wall to be zero (see figure 6).

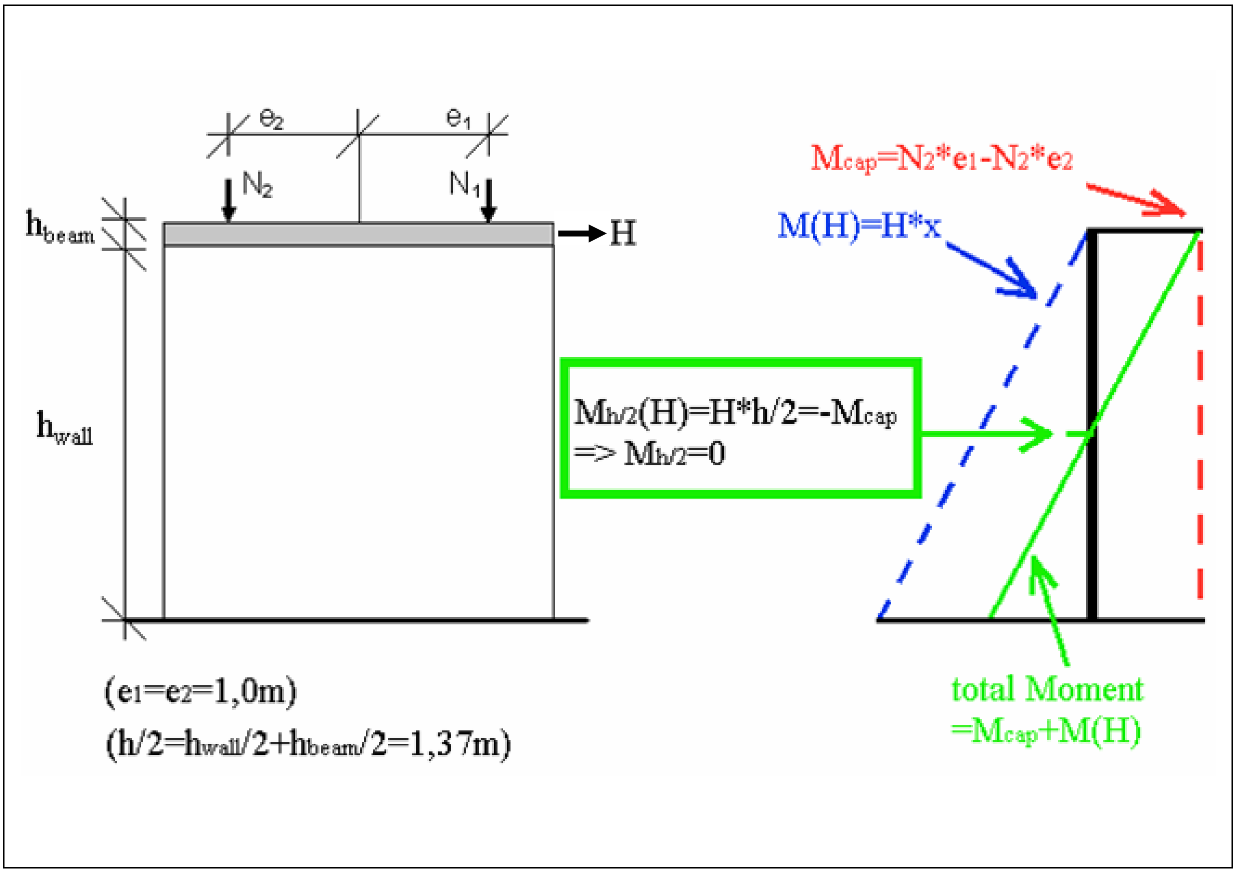

figure 6: Mechanical system and relation of the external and internal loads.

In Figure 7 the time history of the measured forces, normal forces N_1 and N_2 and also H are shown together with the target values. A high degree of congruency is found.

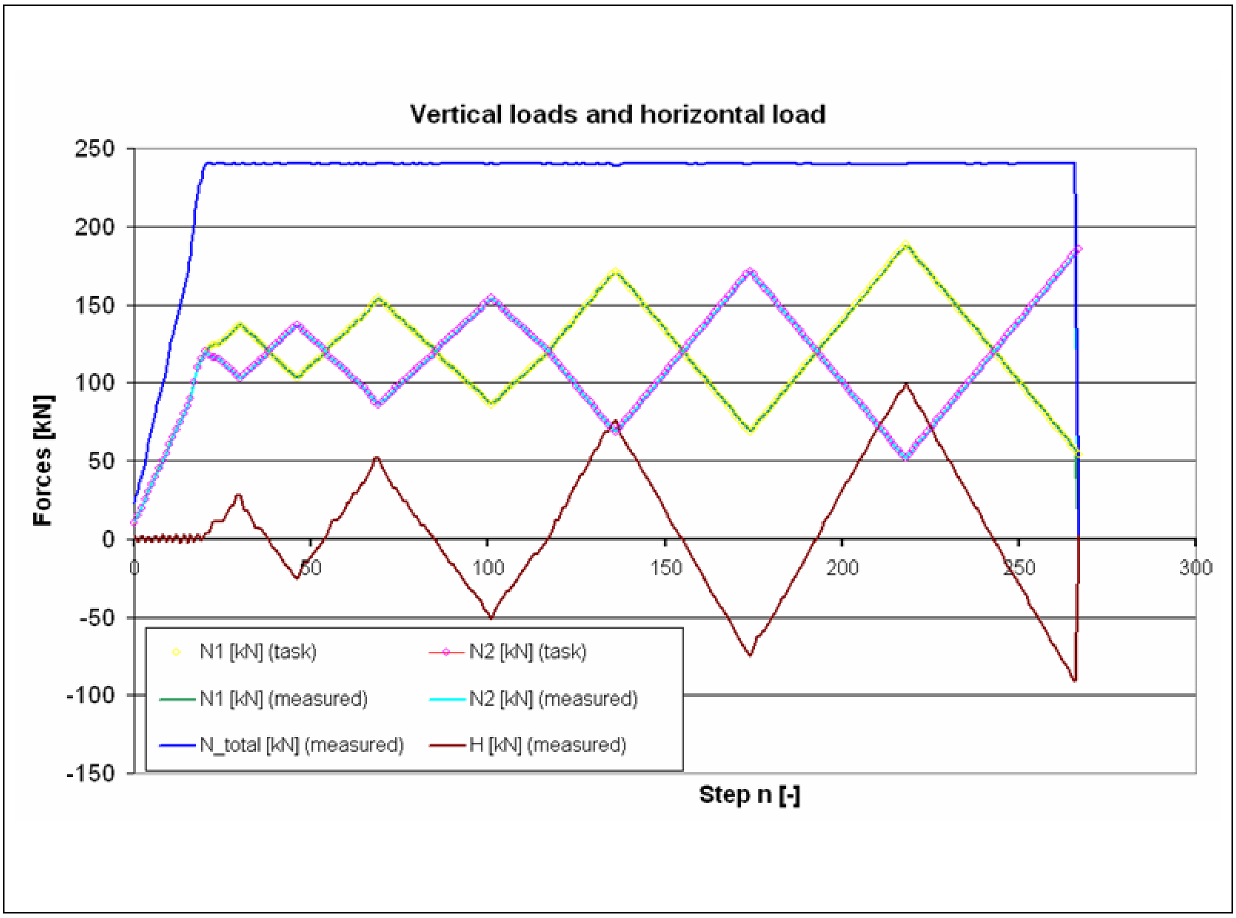

figure 7: load-history (TUM)

The vertical load N, i. e. the sum of N1 and N2 remained constantly during the test.

The horizontal load was applied in several levels of +-25 kN, +-50 kN, +-75 kN and 100kN. The distribution of the vertical forces N_1 and N_2 followed the time history of the horizontal force to ensure the demands stated before.

4.2. Structural behaviour of the masonry wall

In the first loading cycle, the horizontal load was increased up to 25 kN in the compression range and then reduced to 25 kN tension force. The next load level was +50 kN / -50 kN and the following one +75 kN / -75 kN. The first cracks, marked as no. 2, were observed at a horizontal force of -63 kN (tension).

They can be characterized as a tension failure in the units. (The crack marked with no. 1 was assumed to be a tension failure perpendicular to the bed joint in the bottom layer, before loading.)

Then the load was increased to 100 kN in the compression range. Cracks no. 3 appeared already at a horizontal load of 95 kN (diagonal cracks in the units). In order to reach the target value, relatively high displacements of 7.4 mm at the cap of the wall had to be applied.

After unloading the top displacement was switched to the tension range. Cracks (no. 4) appeared at a horizontal load of -87 kN. Increasing the displacement, cracks no.5 were observed at a horizontal load of -91 kN. After this, the opening of the cracks increased significantly and no higher load level could be reached.

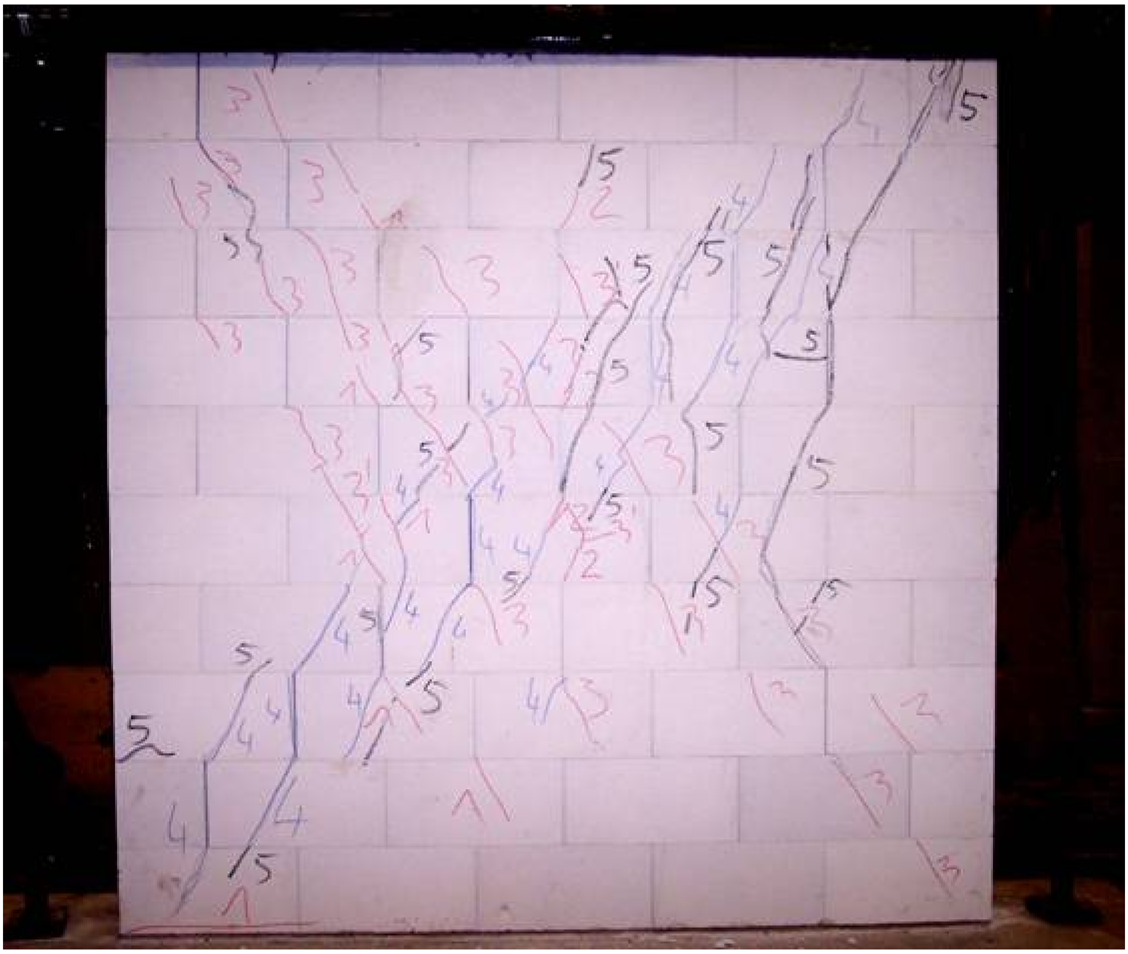

figure 8: Final crack pattern of the tested wall at TU Munich

4.3. Load-deformation-behaviour

The hysteretic load-top-displacement behaviour is shown below. Here the measured horizontal force as well as the top displacement relationship is depicted for the discrete load steps. A significant non-linear behaviour is found after the appearance of cracks in the wall.

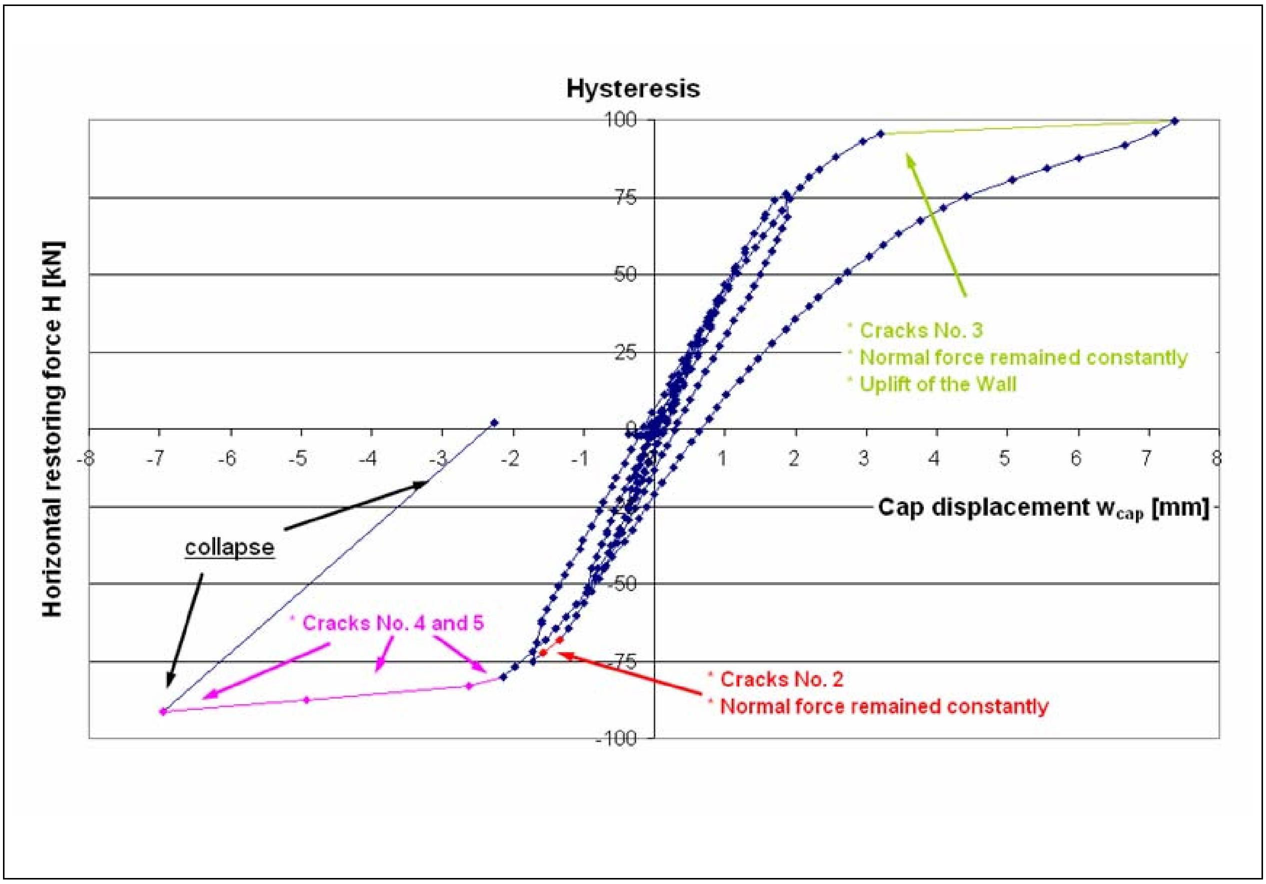

figure 9: Hysteresis of the validation test (TUM) in the discrete load steps

The measurement procedure has also recorded the values in between the discrete load steps resulting in a more detailed hysteresis as shown in figure 10. By this graph also the behaviour of the wall exceeding the last load step (top displacement -7 mm and horizontal load -91 kN) is covered. The top displacement was increased up to the maximum value of 13 mm where a significant drop down of the resulting horizontal force observed. This was caused by the appearance of additional cracks and the increasing opening of existing cracks. The test had to be aborted as no sufficient load bearing capacity was assumed and the wall collapsed.

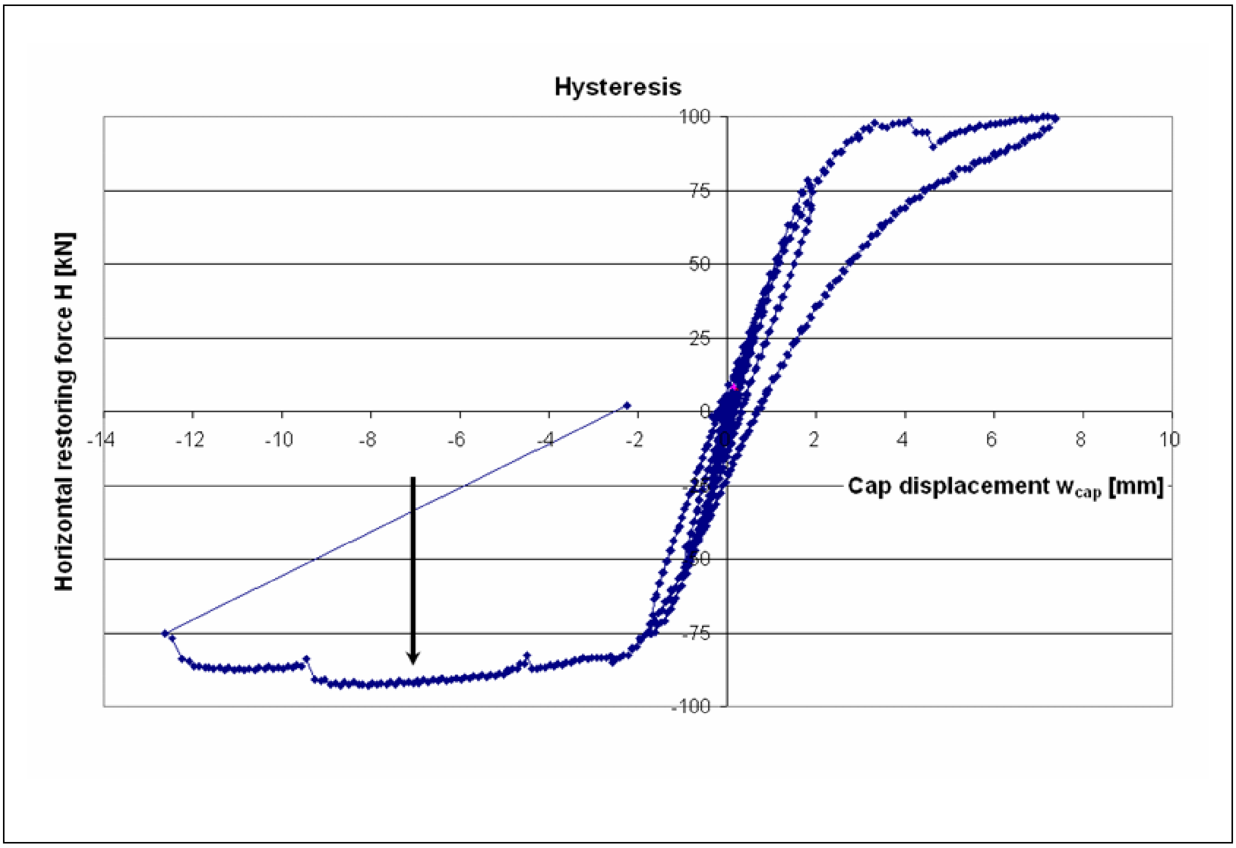

figure 10: Hysteresis of the validation test (TUM)

5. Comparison of the two verification tests

Both verification tests - the test of the University of Kassel as well as the test of the Technical University of Munich - show nearly the same maximum horizontal load. While the specimen at the University of Kassel could carry a horizontal force of 108 kN, the wall at TU Munich reached a horizontal force of 100 kN. These results show a dispersion of about 4 % from the average horizontal force, which is quite low for masonry structures. It has to be mentioned, that the maximum horizontal load level for the test at TU Munich has been limited by the target load level of 100 kN. If the top displacement had been increased further, also higher loads could have been reached.

The stiffness of the two masonry walls is nearly the same as well. Regarding both hysteresis curves (figure 4 and figure 10), the deformation at a horizontal force of 50 kN is about 1 mm. At a higher horizontal load it is difficult to compare the deformation of two curves. When the maximum force was reached, the deformation was increasing until it was decided to stop, because of safety reasons. So the maximum deformation is not comparable but anyway with a maximum deformation of about 7 mm to 8 mm in tension nearly the same.

6. Conclusions

The estimated behaviour of the two masonry walls within these verification tests could be fulfilled, because in both tests a shear-failure of the specimens could be achieved.

The two verification tests showed a high correlation, so it is not necessary to have more than these two validation tests at the University of Kassel and at the Technical University of Munich. On the other hand at the University of Pavia another validation test has to be done. Therefore three more verification tests using calcium–ciliate-units will be done at the mentioned universities. These results will be given in an appendix to this deliverable.

Because of the satisfying results of the first three tests, no more verification tests are deemed to be necessary in Kassel and Munich. Since the tests in total had been allocated for deliverable D6.4, it has been decided to perform additional experiments in work package 7 at the University of Kassel and TU Munich.