ESECMaSE

Enhanced **S**afety and **E**fficient **C**onstruction of **Ma**sonry **S**tructures in **E**urope

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°: 3

D 3.0.2 Stress-strain-relation of perforated bricks (4-brick-specimen)

Due date of deliverable:
Actual submission date:

Start date of project: 10.06.2004 Duration: 36 months

University of Kassel
Institute of Constructive 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	
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 order to perform numerical analyses of the structural behaviour of masonry under earthquake loading within the research project „Enhanced Safety and Efficient Construction of Masonry Structures in Europe", it is necessary to acquire the basic characteristic data of the masonry materials on the basis of small tests. This report describes the experiments performed on clay brick specimens at the Institute of Structural Engineering of the University of Kassel.

Three specimens were to be tested. Since two of the masonry specimens did not fail inside the range of the displacement transducers but in the region of the screed at the bottom, three more specimens have been built up and tested.

2. Experimental setup and realisation of the test

2.1. Materials used

The masonry units under investigation were hollow core clay bricks with vertical holes. They had been extracted of the regular production and were delivered by the manufacturer.

bricks:	Poroton HLZ-Plan – 12 – 0.9 – 9 DF
mortar:	Quic-Mix thin bed mortar with building authority approval

For testing the compressive strength of the mortar, prisms according to DIN 18555 have been produced and testes after seven days. The average compressive strength of the mortar prisms amounted to 10.24 N/mm^2 fulfilling the requirement of the building authority approval of 10.0 N/mm^2.

2.2. Test Specimens

A four – unit specimen has been selected for the tests. It enables to measure deformations across the bed joints as well as deformations (strains) of the units themselves. Moreover, the two middle units (bricks) and the middle joint are much less affected by stress disturbances due to the introduction of loads than the upper and the lower unit.
To build up the specimens, a mortar roll has been used. In order to facilitate the use of the mortar roll and to reflect the situation at a real building site, all four bricks were laid down one behind the other into one line, so that the mortar could be applied in one working step on all units. Afterwards the bricks were laid on top of each other.

figure 1: masonry specimens

figure 2: testing machine (lateral view)

The masonry specimens were built up on steel-plates in order to enable transport into the testing machine (see figure 1 and figure 2).

For the load application, a gypsum bed was applied on top of each specimen and the load introducing beam was let down on the gypsum in order to obtain two coplanar planes. In order to maintain symmetry, the joint below the bottom brick was also made of gypsum.
After hardening, the masonry specimens were painted with white colour in order to be able to identify cracks during testing.
The three specimens of the first series had been tested after 28 days, the second series already after seven days. Hence, after seven days the mortar strength has been tested to check if the required minimum strength was given.

2.3. Test facility and measuring equipment

The specimens have been tested in a 6.3 MN hydraulic testing machine. In order to obtain sufficient accuracy of the load measurement, two 500 kN load cells have been used in addition to the load cell of the machine. The load cells have been positioned between the upper loading plate of the testing machine and the load inducing beam.

For the second series a hinge between the load inducing beam and the two load cells (see figure 3) has been used in order to ensure centric loading.

For measuring deformations 20 inductive displacement transducers (LVDTs) have been installed. They were arranged in an symmetric pattern on the two middle bricks. The arrangement allows to measure longitudinal deformations both of the bricks and in the joint region as well as transverse strains (see figure 4).

figure 3: load application

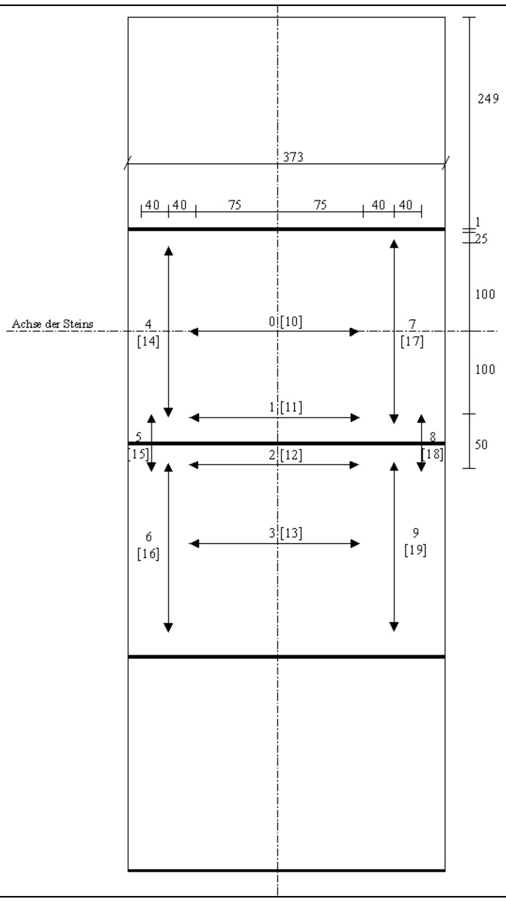

figure 4: arrangement of the displacement transducers

2.4. Load Application

The masonry specimens were loaded displacement controlled. A speed of $2.5 \cdot 10^{-3}$ [m/s] had been chosen. Thus, the loading rate amounted to about 0.5 kN/sec. Therewith, the duration of the test was about 15 minutes.

3. Structural behaviour of the specimens

Two of the three specimens of the first series failed outside the range where the LVDTs had been installed. The failure took place in the bottom region of the lower brick. It turned out that the lower screed was incomplete. This may have produced stress concentrations in some regions.

Because the failure in the screed area was attributed to an incorrect screed of these specimens, three new masonry specimens were brought up. Special attention was paid now to the evenness of the screed.

The three masonry specimens of the second series began to show cracks at a stress between 2.0 N/mm^2 up to 2.5 N/mm^2 . Further cracks developed until a stress of about 3.5 N/mm^2 had been reached. From this stress on, which is about the half of the ultimate stress, only a few small cracks appeared almost up to the ultimate stress.
The failure of the specimens happened by breaking out of pieces of the perforated bricks, which broke suddenly. By this the load could not be raised further.

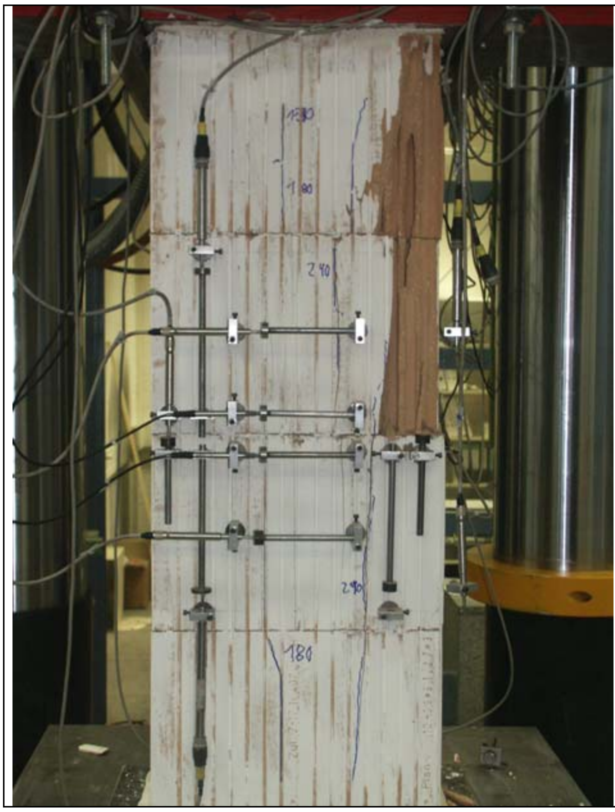

figure 5: destructed specimen

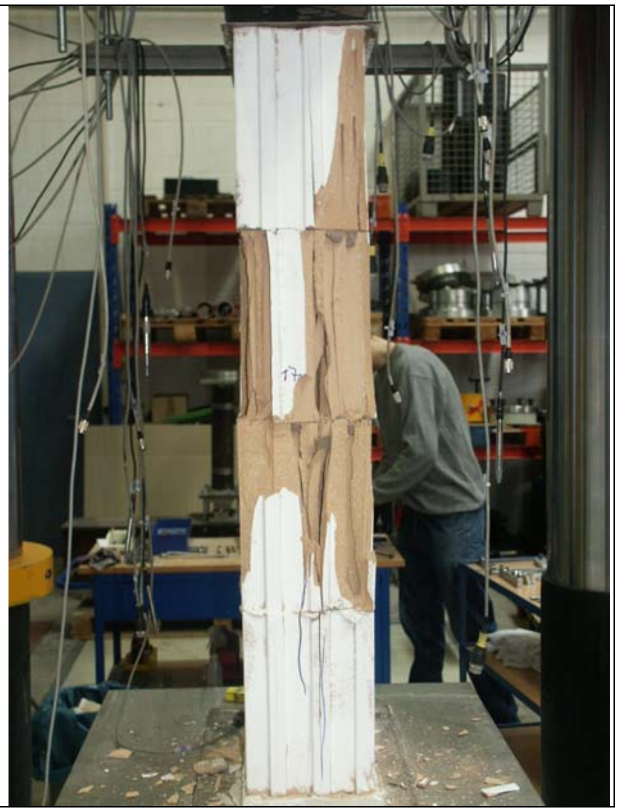

figure 6: face side of MWK 5

3.1. Compressive strength of the specimen

The compressive strength of the masonry specimens is calculated by $f_c = \frac{\max .F}{A}$ and composed in table 1.

Specimen No.	Ultimate Load [kN]	Area [mm^2]	Strength [N/mm^2]
1	366.0	65275	5.6
2	621.5	65272	9.5
3	474.0	65275	7.3
4	315.0	65275	4.8
5	392.0	65272	6.0
6	418.5	65275	6.4

Table 1: bearing capacity of the masonry specimens

Considering all specimens, there is an average value of the ultimate strength of 6.6 N/mm^2. At this there is a variance from the average up to 27 % for the specimen with the lowest ultimate strength (MWK 4) and up to 44 % for the specimen with the highest ultimate strength (MWK 2).

3.2. Stress – strain – behaviour

In the following, the stress-strain-behaviour is presented for both the blocks and the combination of block and joint. The longitudinal strains have been obtained by averaging the displacements from the four transducers. When a transducer reached or exceeded its measurement range, this transducer as well as the transducer in the diagonally opposite position have been neglected in order to avoid misinterpretation of the data.

The three specimens of the first series show an approximately linear elastic behaviour up to the ultimate stress.

For specimens 2 and 3, the failure of the masonry column occurred outside of the measurement range. No information on the post peak behaviour is available so far for these specimens.

For specimen MWK 1, ductile behaviour after reaching the strength is obvious from Figure 7.

At about half of the ultimate strength, a certain drop of the axial force (and thus: average stress) can be observed from the stress-strain-diagrams of the specimens of the second series can be observed. This can be explained by the appearance of cracks leading to a stress redistribution inside the specimens. However, the overall deformation of the specimens did not decrease. This has been checked by comparison with the path of the measured machine displacements.

All specimens of the second series show a relatively ductile behaviour after reaching the ultimate strength. They are able to keep the ultimate load during increasing deformation although existing cracks enlarge and parts of the blocks break away in a brittle manner. However, no significant increase of load is possible any more in this phase. Whereas the overall behaviour may be called ductile, locally the failure is of brittle nature.

Since local failures occured, the fixation of some of the LVDTs has been lost. For this reason, the measurements in the post peak region could not be evaluated for all specimens.

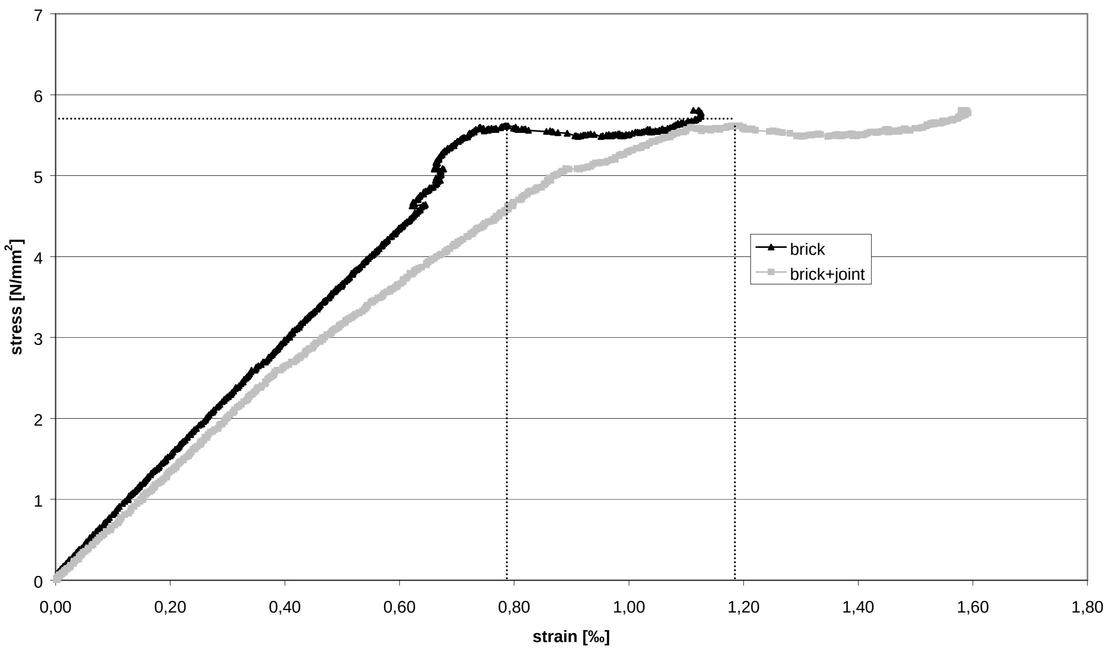

figure 7: stress-strain-behaviour (vertical elongation) of specimen MWK_1

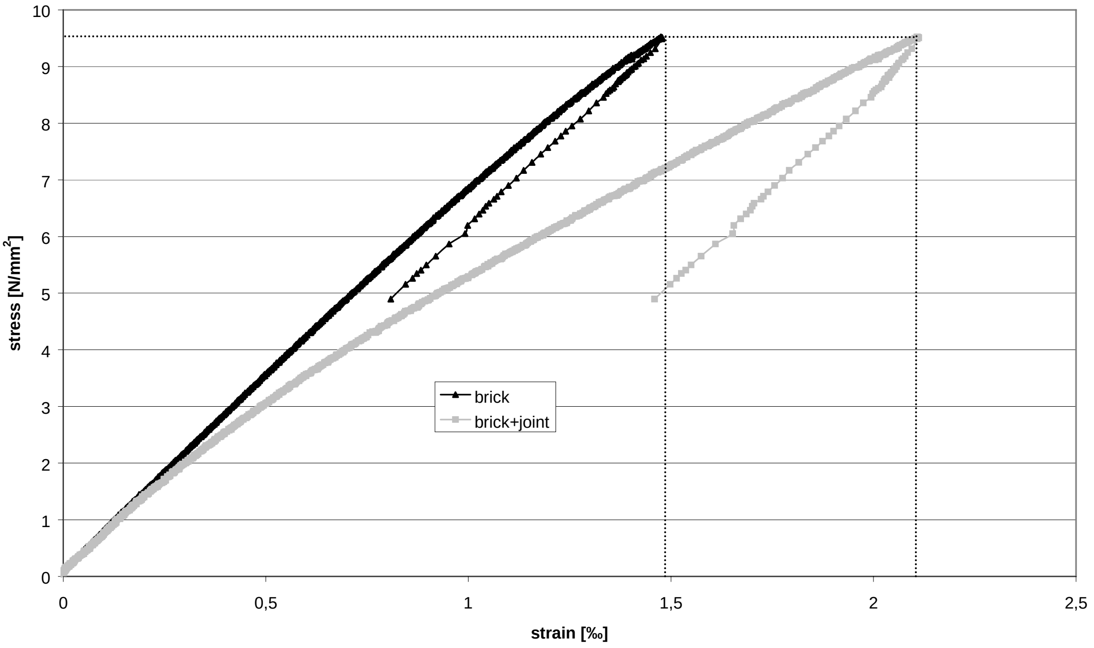

figure 8: stress-strain-behaviour (vertical elongation) of specimen MWK_2

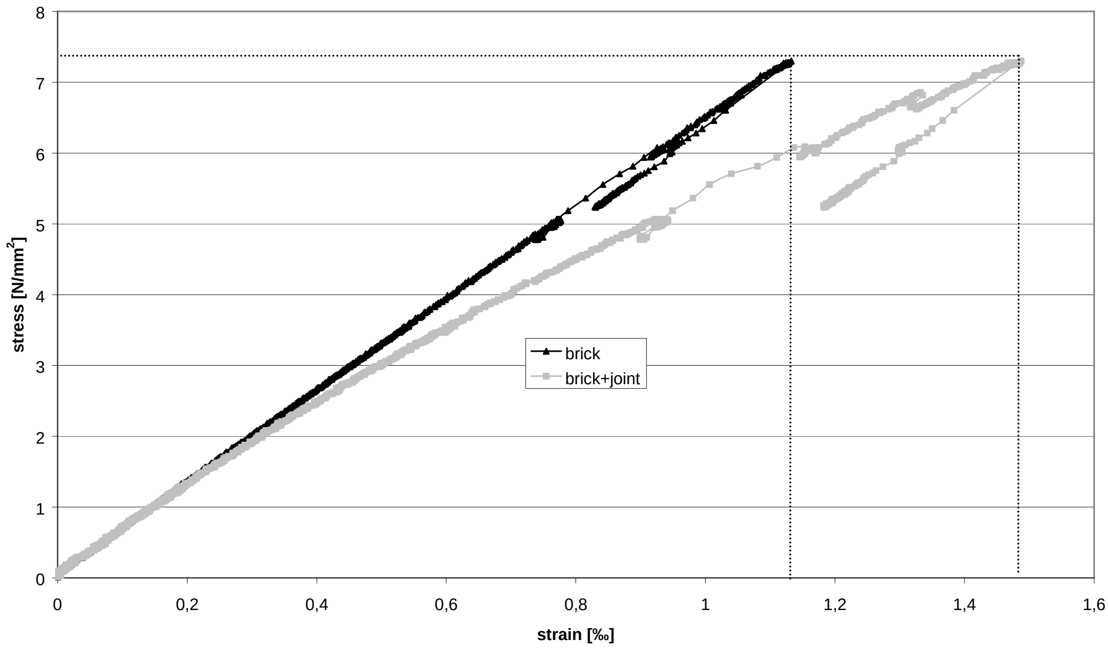

figure 9: stress-strain-behaviour (vertical elongation) of specimen MWK_3

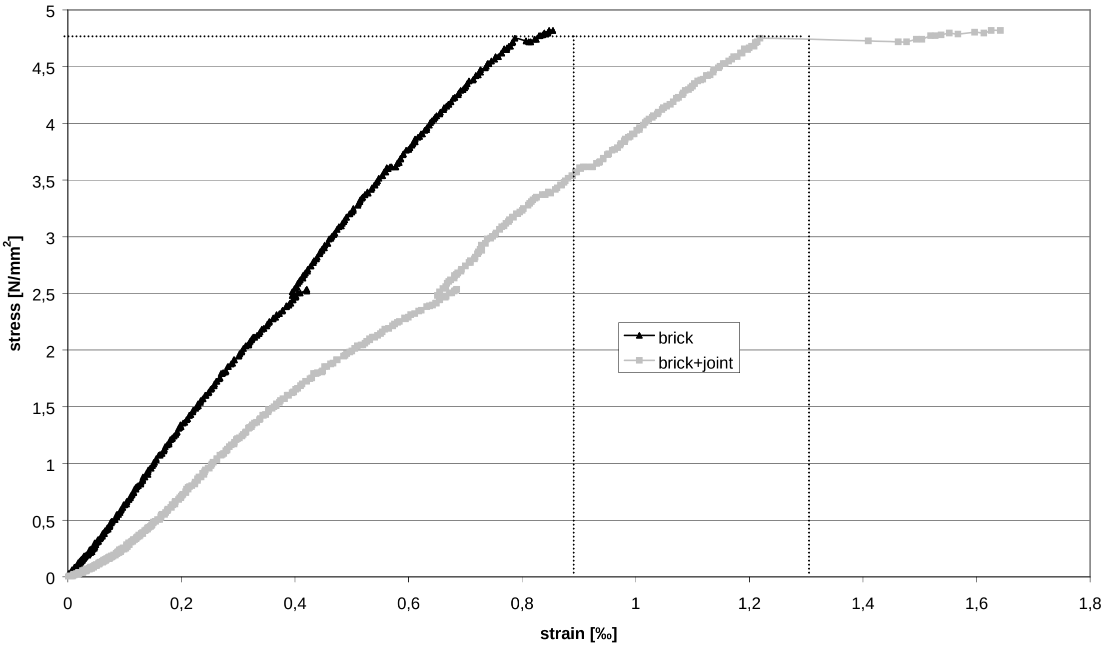

figure 10: stress-strain-behaviour (vertical elongation) of specimen MWK_4

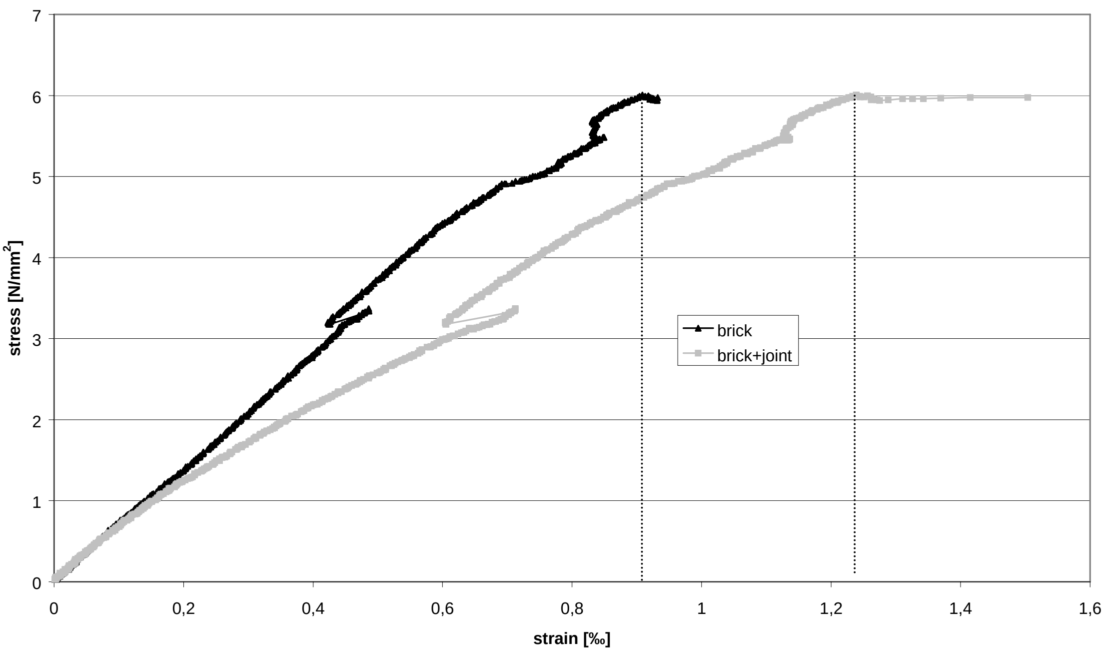

figure 11: stress-strain-behaviour (vertical elongation) of specimen MWK_5

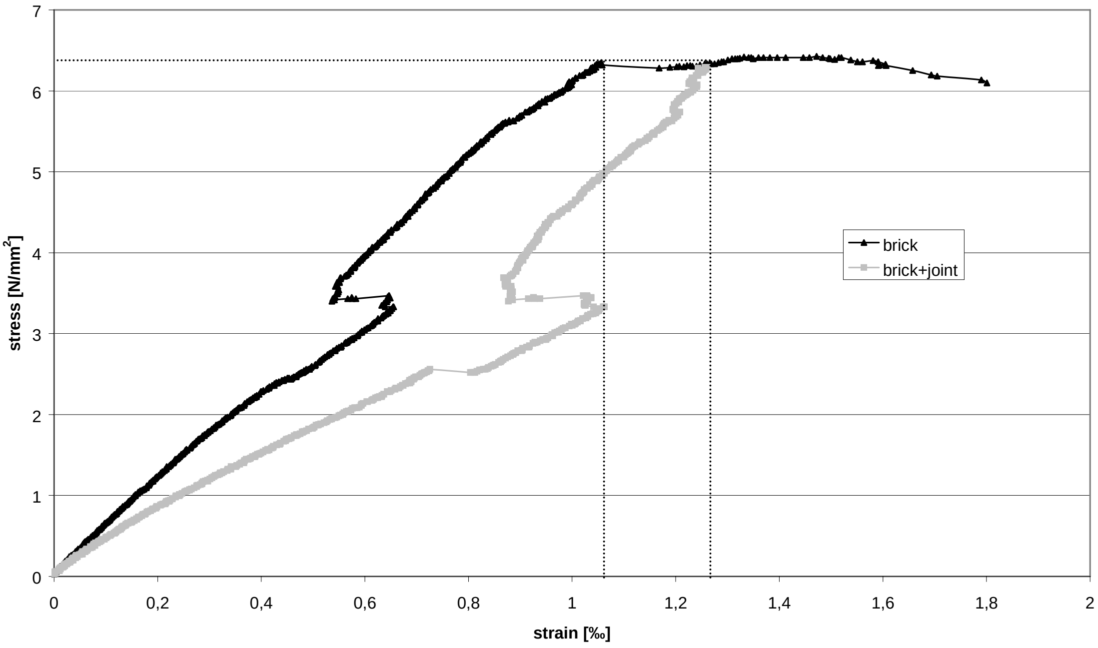

figure 12: stress-strain-behaviour (vertical elongation) of specimen MWK_6

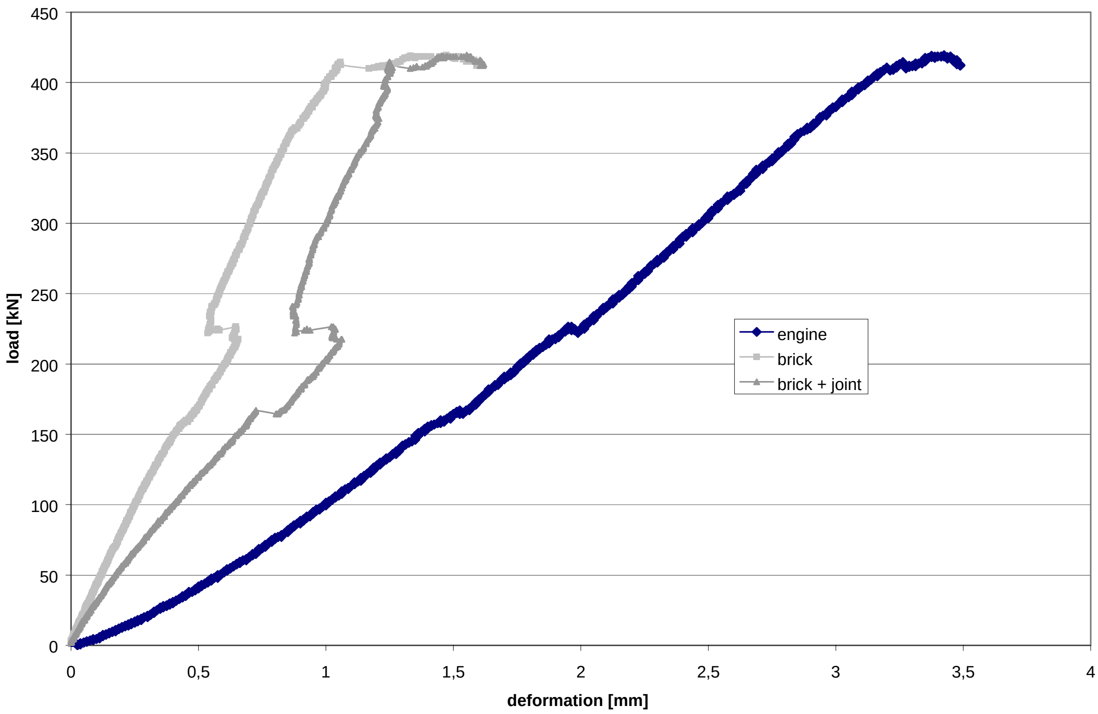

figure 13: load-deformation-behaviour of specimen MWK_6

3.3. Young's modulus of the bricks and the masonry columns

The Young's modulus E has been determined according to DIN 18554-1 as a secant-modulus of the stress at a third of the compressive strength and the corresponding strain $\bar{\varepsilon}$ (from the average of the vertically measured deformations) as follows:

$$E = \frac{\beta_{D,mw}}{3 \cdot \bar{\varepsilon}}$$

The values as obtained form this basis are shown in table 2.

	specimen No.	**$\beta_{D,mw}$ [N/mm^2]**	**$\bar{\varepsilon}$ [‰]**	**E [N/mm^2]**	**average [N/mm^2]**
brick	1	5.6	0.24	7778	6892
	2	9.5	0.44	7197	
	3	7.3	0.36	6759	
	4	4.7	0.22	7121	
	5	6.0	0.30	6667	
	6	6.3	0.36	5833	
brick and joint	1	5.6	0.30	6222	5344
	2	9.5	0.52	6090	
	3	7.3	0.38	6404	
	4	4.7	0.37	4234	
	5	6.0	0.36	5556	
	6	6.3	0.59	3559	

table 2: combination of the young's modulus

3.4. Lateral strain of the bricks

The horizontal deformations of the bricks have been recorded by four inductive displacement transducers in the centre of the two blocks (at half the height of the middle blocks) and by four other ones in a distance of 25 mm above and below the middle joint as shown in figure 4.

The strains, as obtained from these measurements, versus the stresses are shown in figure 14 and figure 15 for two selected specimens of the first and the second series. They depict the different behaviour of the specimens through the experimental setup (with and without a hinge).

In table 3 the strain coefficients (poisson ratio) of the six tests are given and an average is calculated, for the measurement at the centre of the bricks as well as for the measurement near the joint.

Table 3 shows a wide scatter of the measured lateral strains. A possible explanation could be, that some of the transducers may have measured deformation across a burning crack, which can lead to totally different strains in comparison to an area without cracks

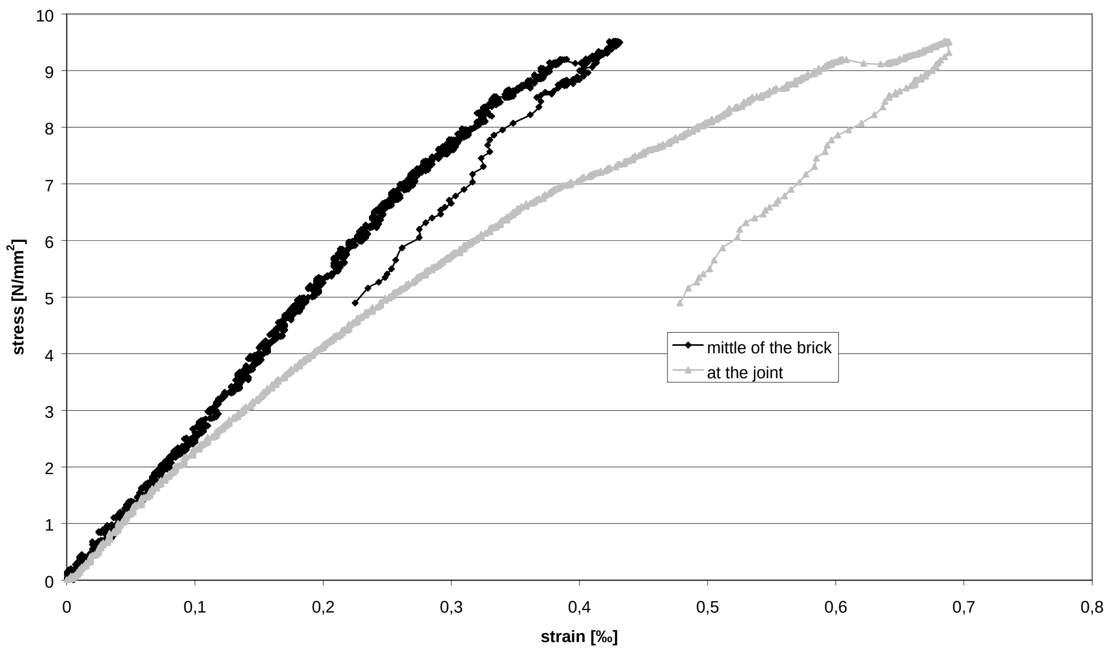

figure 14: horizontal strains of specimen MWK_2

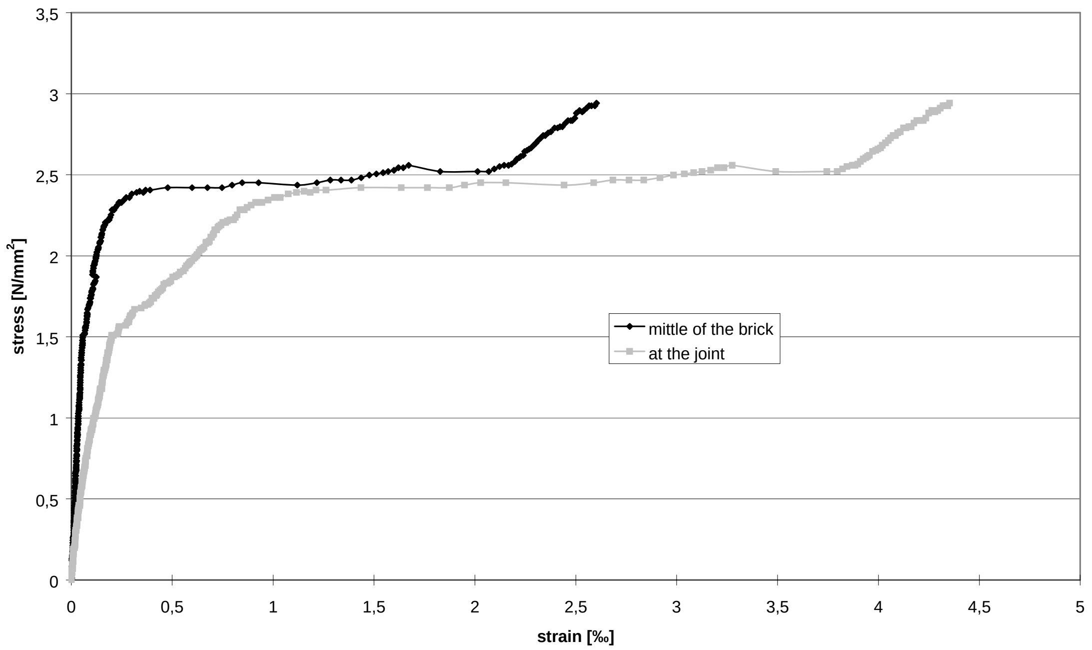

figure 15: horizontal strains of specimen MWK_6

	specimen No.	strain [N/mm^2]	vert. strain [‰]	lateral strain [‰]	strain coefficient ν [-]	average [-]
centre of the unit	1	3.0	0.40	0.11	0.28	0.17
	2	3.0	0.41	0.12	0.29	
	3	3.0	0.45	0.05	0.11	
	4	1.5	0.21	0.01	0.05	
	5	1.5	0.90	0.06	0.07	
	6	1.5	0.25	0.06	0.24	
near the joint	1	3.0	0.45	0.10	0.22	0.21
	2	3.0	0.50	0.15	0.30	
	3	3.0	0.49	0.07	0.14	
	4	1.5	0.35	0.04	0.11	
	5	1.5	1.22	0.04	0.03	
	6	1.5	0.39	0.18	0.46	

table 3: summary of the strain coefficients

4. Examination and abstract

The measured strength shows a significant scatter. However, average values for strength, E-Modulus and Poisson ratio may be established on the basis of this experimental investigation.

The highest strength values had been obtained from specimens without hinges in the load introduction. However, for these cases, the failure occurred near the gypsum screed and thus outside the measuring length for the determination of strains. In those cases where the load introduction had used a hinge, the specimens had to realign themselves in order to maintain the concentric transfer of the normal force. This which may have caused a reduction of overall bearing capacity. It is interesting to note, that the second test series, which had used a hinge, showed a significant ductility, however, occurring at a lower level of the ultimate load in average.

The majority of the stress-strain diagrams show a significant ductility. However, it should be noted that a less ductile behaviour can be observed when looking at the overall deformation behaviour of the entire specimen.

5. Literature

[1] DIN 105 Mauerziegel; Vollziegel und Hochlochziegel
[2] DIN 1048-5 Prüfverfahren für Beton; Festbeton, gesonderte Probekörper
[3] DIN 1053-1 Mauerwerk; Berechnung und Ausführung
[4] DIN 1053-100 Mauerwerk; Berechnung auf der Grundlage des semiprobalistischen Sicherheitskonzepts
[5] DIN 18554-1 Prüfung von Mauerwerk; Ermittlung der Druckfestigkeit und des Elastizitätsmoduls
[6] DIN 18555-3 Prüfung von Mörteln mit mineralischen Bindemitteln; Bestimmung der Biegezugfestigkeit, Druckfestigkeit und Rohdichte
[7] DIN 18555-9 Prüfung von Mörteln mit mineralischen Bindemitteln; Bestimmung der Fugendruckfestigkeit
[8] Eurocode 6 Unbewehrtes Mauerwerk