ESECMaSE

Enhanced Safety and Efficient Construction of Masonry Structures in Europe

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Enhanced Safety and Efficient Construction of Masonry Structures in Europe

Horizontal Research Activities Involving SMEs

Collective Research

Work Package N°: 3

D 3.0.3 Stress-strain-relation of perforated bricks (Rilem-specimen)

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[draft 1]

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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)	

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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.

Since the test of deliverable 3.0.2 showed a large scatter in the behaviour of the masonry, three more specimens were built up and tested. Within the first six tests the bricks were placed in such a way, that the webs of the perforated bricks lie on top of each other. For the tests described in this report, the bricks were laid displaced.

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 from 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 were produced and tested after 15 days. The average compressive strength of the mortar prisms amounted to 10.4 N/mm^2 fulfilling the requirement of the building authority approval of 10.0 N/mm^2.

2.2. Test Specimens

The Rilem-specimen (see figure 1) was selected for the tests. To build up the specimens, a mortar roll was used. 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 first of the three specimens were tested after 15 days, the two other ones after 16 days. Hence, after 15 days the mortar strength was tested to check if the required minimum strength was given.

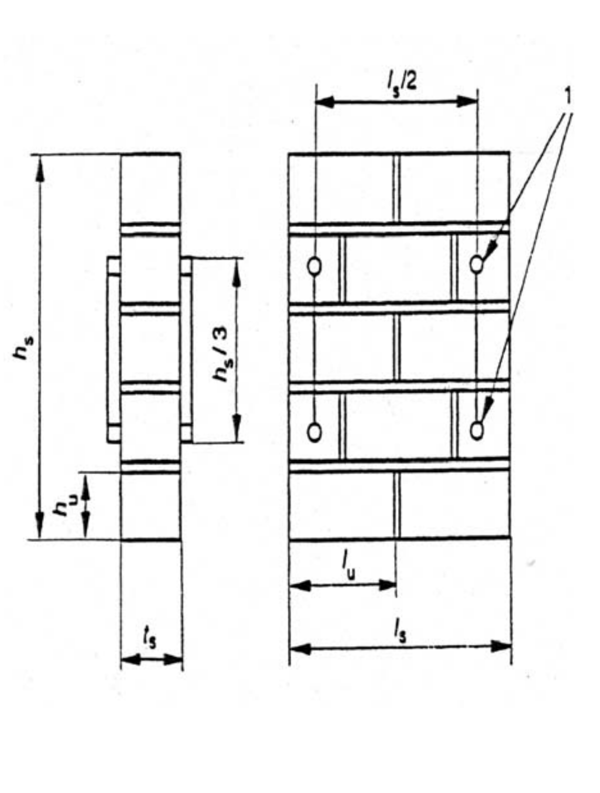

figure 1: Rilem-specimen [8]

figure 2: testing machine (lateral view)

2.3. Test facility and measuring equipment

The specimens were tested in a 6.3 MN hydraulic testing machine. To induce the loads evenly distributed into the masonry wall, a steel beam was used.

For measuring deformations ten inductive displacement transducers (LVDTs) were installed. They were arranged in an symmetric pattern on the three middle brick layers. The arrangement allowed to measure longitudinal deformations both of brick and joint region (see figure 3). As it can be seen, the inductive displacement transducers WA_0, WA_1, WA_2, WA_5, WA_6 and WA_7 were arranged at the masonry wall. The LVDTs WA_3, WA_4, WA_8 and WA_9 have been installed to measure the overall deformation between the upper and the lower loading plate. They are used to control the deformation applied by the hydraulic testing machine. The LVDTs at the masonry specimen were arranged centric and had a measuring length of 500 mm.

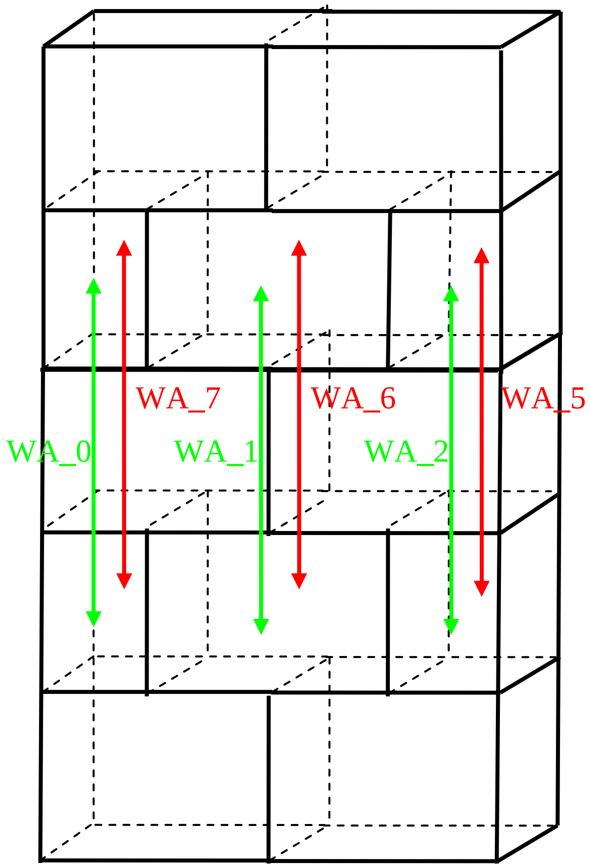

figure 3: arrangement of the displacement transducers

2.4. Load Application

The masonry specimens were loaded displacement controlled. A speed of $3.75 \cdot 10^{-3}$ [m/s] was chosen. Thus, the loading rate amounted to about 1.0 kN/sec. Therewith, the duration of the test was about 15 minutes.

3. Structural behaviour of the specimens

The masonry specimens Rilem_1 and Rilem_2 began to show cracks at a stress from 4.0 N/mm^2 up to 4.5 N/mm^2. From this stress on some more cracks appeared almost up to the ultimate stress. The specimen Rilem_3 already began to show cracks at a stress of 1.5 N/mm^2. The failure of the specimens happened by breaking out of big pieces of the perforated bricks, which broke suddenly. So the load could not be raised further.

figure 4: destructed specimen (Rilem_2)

figure 5: face side of Rilem_2

3.1. Compressive strength of the specimen

The compressive strength of the masonry specimens is calculated by $f_i = \frac{F_{i,\max}}{A_i}$ and composed in table 1.

Specimen No.	Ultimate Load [kN]	Area [mm^2]	Strength [N/mm^2]
1	914.5	127050	7.2
2	893.8	127050	7.0
3	752.5	127050	5.9

Table 1: bearing capacity of the masonry specimens

Considering all specimens, there is an average value of the ultimate strength of 6.7 N/mm². Hereby there is a variance from the average up to 7 % for the specimen with the highest ultimate strength and up to 12 % for the specimen with the lowest ultimate strength. The average value of the ultimate strength of the specimens tested in deliverable D 3.0.2 was 6.6 N/mm². So the average value of the ultimate strength of the Rilem-specimens is about the same as the one of the 4-brick-specimen. The variance however is clearly lower.

3.2. Stress – strain – behaviour

In the following, the stress-strain-behaviour is presented for the average of the six displacement transducers (WA_0, WA_1, WA_2, WA_5, WA_6 and WA_7) and the averaged strain of the whole specimen including the two gypsum beds (WA_3, WA_4, WA_8 and WA_9).
All three specimens show an approximately linear elastic behaviour up to the ultimate stress. The behaviour of all specimens after reaching the ultimate stress could be named as quasi-brittle. All the specimens of this series could not resist the full any more load in the post peak range. The stress decreases to half the ultimate stress at a strain increase of about 0.2 ‰ to 0.5 ‰. So after the ultimate stress the masonry specimens are not in the position to continue stress.
Since local failures occured, the fixation of some of the LVDTs was lost. For this reason, the measurements in the post peak region could not be evaluated for all specimens.

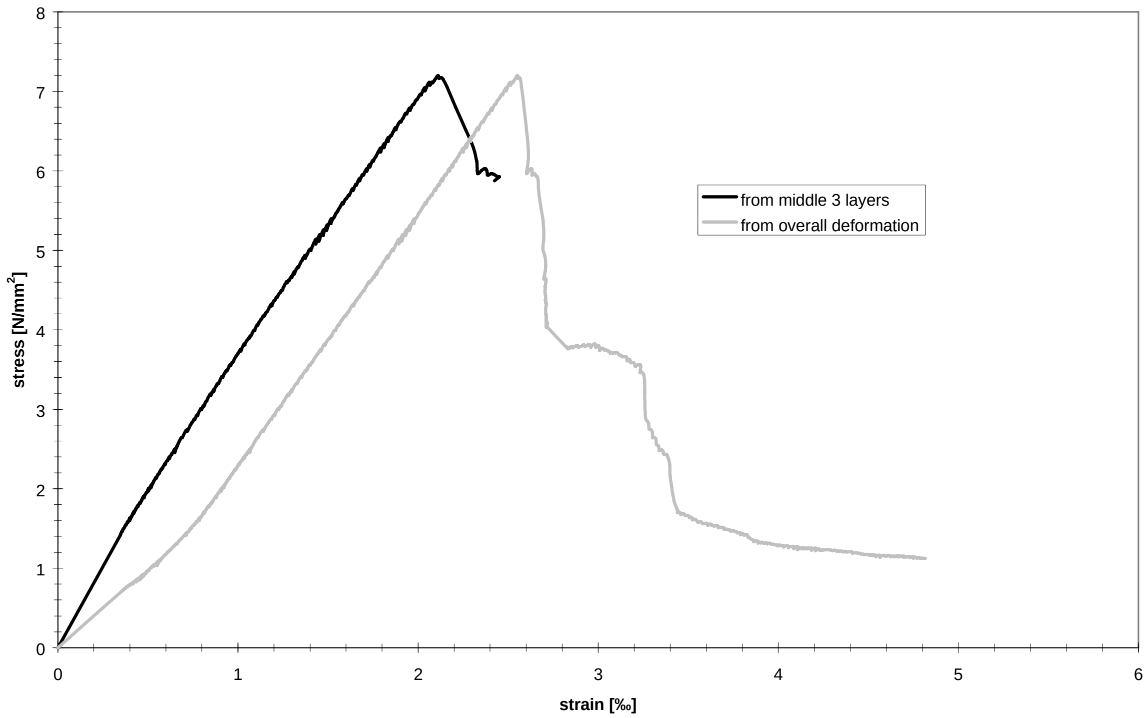

figure 6: stress-strain-behaviour of specimen Rilem_1

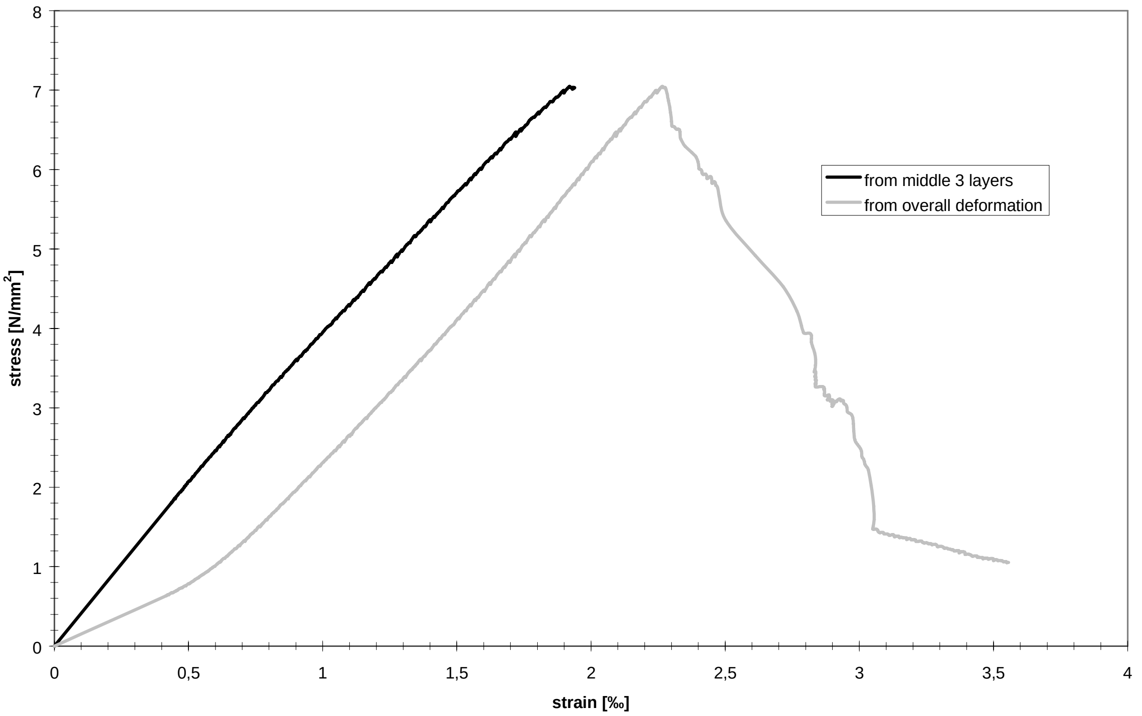

figure 7: stress-strain-behaviour of specimen Rilem_2

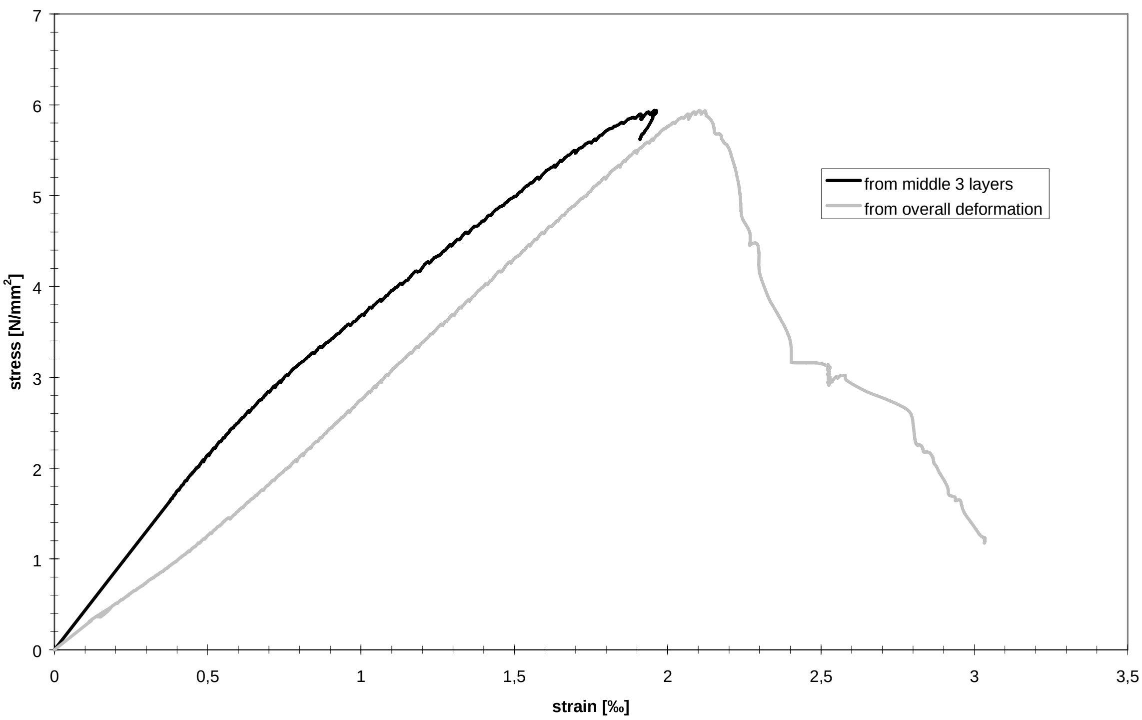

figure 8: stress-strain-behaviour of specimen Rilem_3

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

The Young's modulus E is determined according to DIN EN 1052 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:

$$E_i = \frac{F_{i,\max}}{3 \cdot \varepsilon_i \cdot A_i}$$

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

	specimen No.	**f_i [N/mm^2]**	**ε_i [‰]**	**E_i [N/mm^2]**	**average [N/mm^2]**
brick and joint	1	7.2	0.62	3871	4080
	2	7.0	0.57	4094	
	3	5.9	0.46	4275	

table 2: combination of the young's modulus

The young's modulus shown in table 2 is clearly lower than the young's modulus of the 4-brick-specimens. This may arise from the fact, that the webs of the perforated bricks in this tests did not lie on top of each other.

4. Examination and abstract

The measured strength does not show such a significant scatter as the test of D 3.0.2. However, the average strength obtained from these three tests is almost identical with the results of the six tests in D 3.0.2. So the average value of strength of about 6.7 N/mm^2 may be established on the basis of this experimental investigation.
The young's modulus is lower than the young's modulus of the 4-brick-specimens, because the webs of the perforated bricks did not lie on top of each other. Even in walls of a house the webs of the bricks will not be laid on top of each other, a young's modulus of about 4000 N/mm^2 could be established on the basis of this experimental investigation.
All for this deliverable tested specimens show a quasi-brittle stress-strain-behaviour. After reaching the peak load, a softening branch could be observed in the stress-strain path.

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] Din EN 1052 Prüfverfahren für Mauerwerk

[9] Eurocode 6 Unbewehrtes Mauerwerk