ESECMaSE
Enhanced Safety and Efficient Construction of Masonry Structures in Europe

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ESECMaSE

Enhanced Safety and Efficient Construction of Masonry Structures in Europe

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D 3.0.1 Stress-strain-relation of calcium silicate bricks

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1. Introduction

A substantial precondition for numeric investigations is generally the knowledge of the necessary initial parameters. In the context of the research project "Enhanced Safety and Efficient Construction of Masonry Structures in Europe" bearing capacity and deformation behaviour of shear-loaded masonry were measured by using the method of finite elements. For this kind of theoretical investigations a smeared material model was used. Therefore it is necessary to determine the stress-strain-relation of the actually regarded masonry by test results.

The stress-strain-relations of masonry-specimens have been identified in order to calibrate and verify the calculations within this additional inserted subproject regarding the choice of reference units. This report, written at the Technical University of Munich, describes the results of investigations on specimens built with calcium-silicate units. The appropriate investigations of reference clay bricks took place at the University of Kassel.

1.1 Used units

In the context of these investigations only reference units of calcium silicate, selected in Work package 2.1, were considered. Both units are solid bricks, taken from the regular production. The following calcium silicate bricks were used:

Calcium silicate unit	DIN V 106	-	KS-R	20 – 1,8 - 6 DF (175)
Calcium silicate unit	DIN V 106	-	KS XL-PE	20 – 1,8 (998 x 175 x 623)

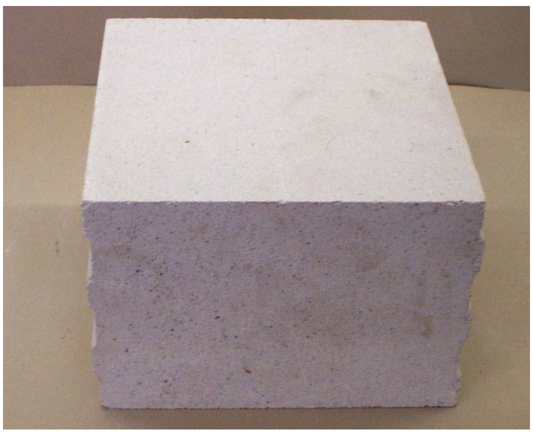

figure 1: KS R

figure 2: KS-XL-PE

In a first step the material parameters were carried out by experimental test. The units are classified by the national standard (DIN V 106-1 (02/03) [12]) of the producing country. Thus, all tests were realized according to German/European standards, especially DIN EN 771-2 (08/03) [7], DIN EN 772-1 (09/00) [8], DIN EN 772-13 (09/00) [9].

1.2 Used Mortar

The Forschungsvereinigung Kalk-Sand e.V. delivered a mortar for the construction of test specimens of masonry to the Technical University of Munich. The used mortar is a thin layer mortar – calcium silicate thin layer mortar ("KSK grob") - and can be assigned to a mortar class of M15 (DIN EN 998-2 (09/03) [10]) with an average strength of 15 N/mm². The Forschungsvereinigung Kalk-Sand e.V. accomplished examinations of the mortar characteristics according to DIN 18555 part 1 [3], 2 [4], 3 [5] and 5 [6]. The test results of these characteristic examinations were placed at the disposal of the technical University of Munich by the delivery of the units.

An apparent density of green mortar was determined to 1.68 kg/dm³, air void contents to 7,0 volume % and a rate of dispersion to 18.3 cm with these material testing.

An apparent density of harden mortar is determined to 1.46 kg/dm³, the compressive strength to 19.3 N/mm², the flexural capacity to 5.4 N/mm² as well as an adhesive shear strength to 0.55 N/mm² on further investigations on the mortar prism.

2. Test setup and carrying out the test

2.1 Description of the test specimens

Four-stone specimens were manufactured for the determination of the stress-strain curves. These test specimens were made out of the reference units and a thin layer mortar. The mortar was applied on the units, which laid one behind the other, by using a mortar sledge. Subsequently, each with mortar provided unit was set on the top of the other.

It was not necessary to equalize the calcium silicate units because these are plane units and elements. Setting the test items into a gypsum bed wasn't necessary because of parallel and plane top- and bottom-surfaces. So the test specimens were installed with pure unit surface into test facility.

22 inductive sensors were placed on the test specimens according to figure 3 and figure 4, because of the not directly measurable strain behaviour of joints and the different deformation behaviour over unit height. For this reason the horizontal strain was measured both in the middle of the unit (H1, H4, H5 and H8) as well as in the boundary region of the unit (H2, H3, H6, and H7). Also the vertical deformations were measured exclusively over the height of a single unit (Va1 to Va8) and over the joint range (Vb1 to Vb4). Additionally, strain behaviour of composite material examined on the test specimens of masonry by measuring from the centre of one unit to the centre of the next one (Vc1 and Vc2). In order to be able to exclude possible effects on the deformation behaviour of the test specimen resulting in the initiation of load (lateral extension within the introduction range), only the middle units were provided with probes.

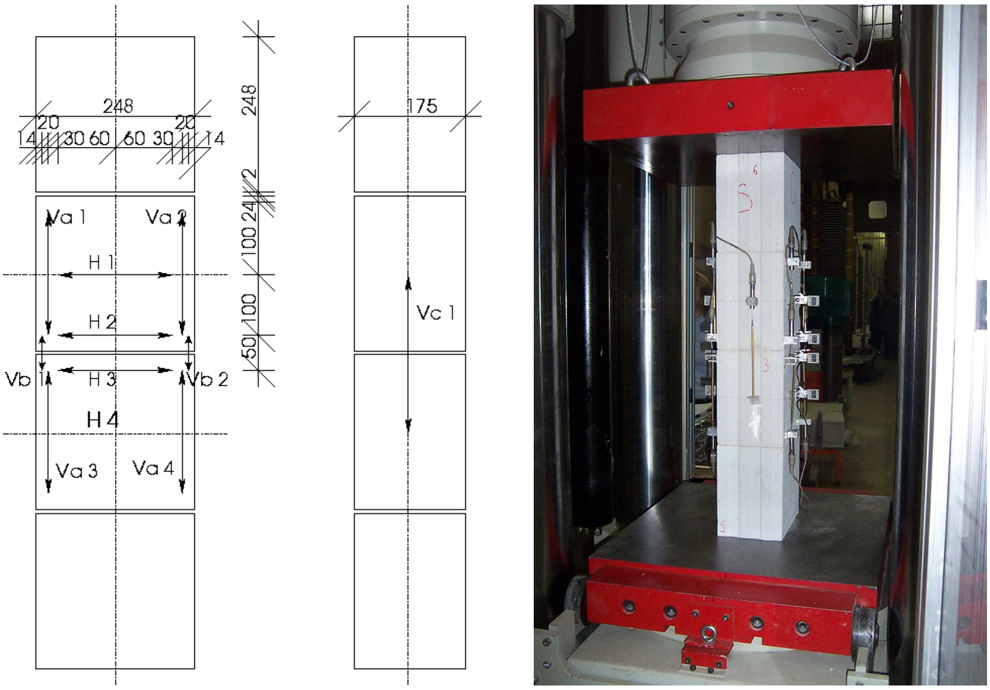

figure 3: Arrangement of probes on test specimens out of KS R

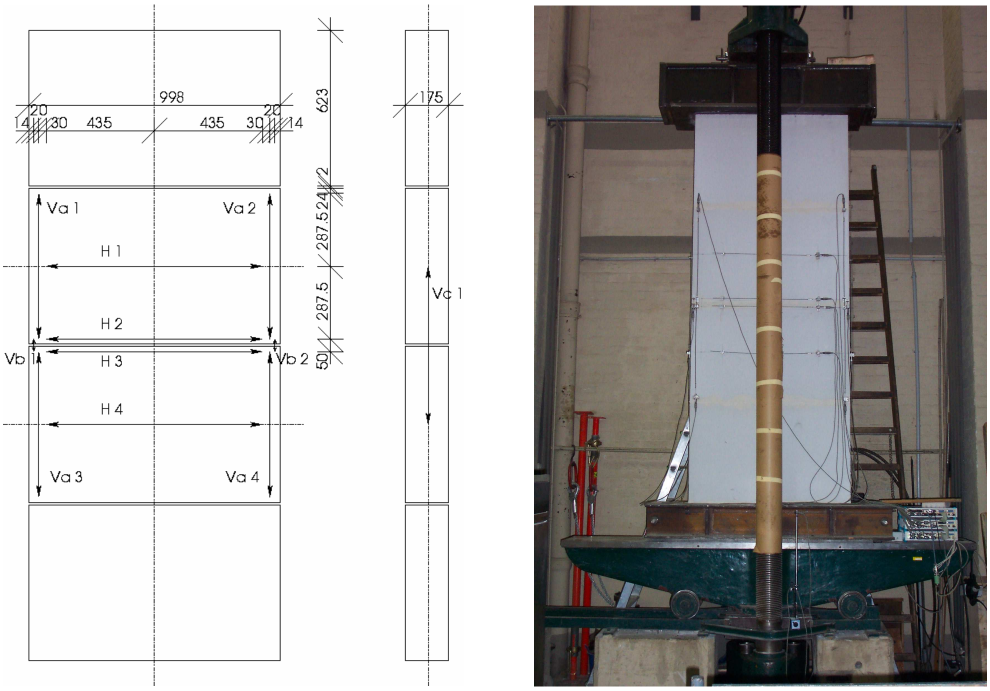

figure 4: Arrangement of probes on test specimens out of KS-XL-PE

Additionally to the stress-strain behaviour of masonry also the jacking load and way of the jack were registered.

2.2 Execution of test (KS R 20-1.8)

The experiments were carried out displacement controlled. The rate of load application amounted in the first two experiments to about 0.1 mm/min and in the following two attempts to about 0.2 mm/min. The rate of load application has been increased, because the test took too much time. Another important point was to exclude possible influences of the loading duration. The test specimens were loaded continuously. In two of four experimental tests (specimen number 1 and 3) load was kept under equal level of approximately 80% of the ultimate load of the test specimens in order to take down the sensors, would not be damaged by the very brittle failure of masonry. The other two test specimens (test item number 2 and 4) failed unexpected, so the probes could not removed in time.

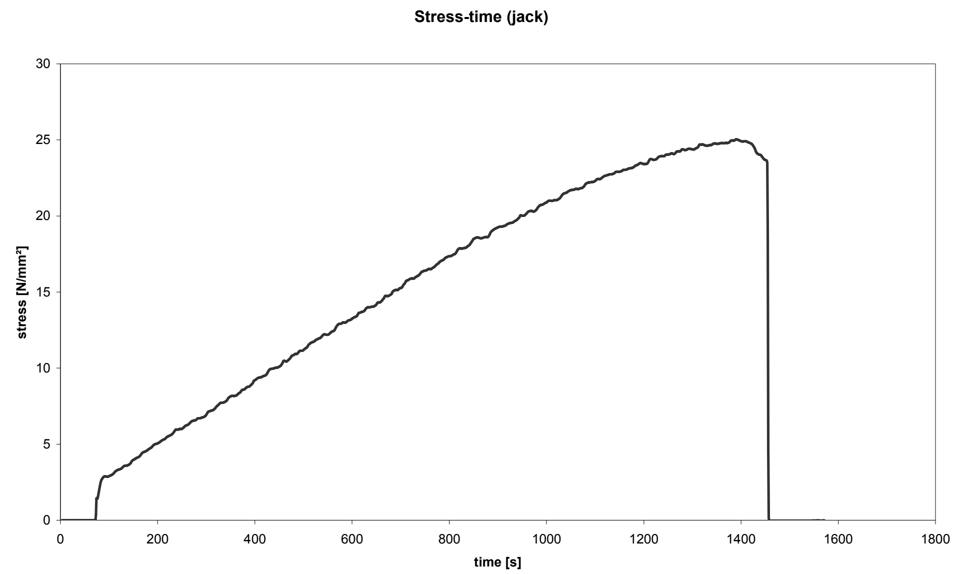

figure 5: loading dependent on time

2.3 Execution of test (KS XL-PE 20-1.8)

These attempts could not be examined in the same testing machine as experiments with 4-unit-specimens made out of KS R, which are described above, due to the dimensions of test specimens.

For the execution of the first test the load was increased continuously to 1 MN within 10 min. After unloading the probes were removed. Subsequently the load increased continuously within 10 min up to the failure.

The following test specimens were loaded and unloaded continuously three times to 1.5 MN. The execution of the test took approximately 15 min. After removing the probes the load increased within about 5 min up to the fracture of the sample.

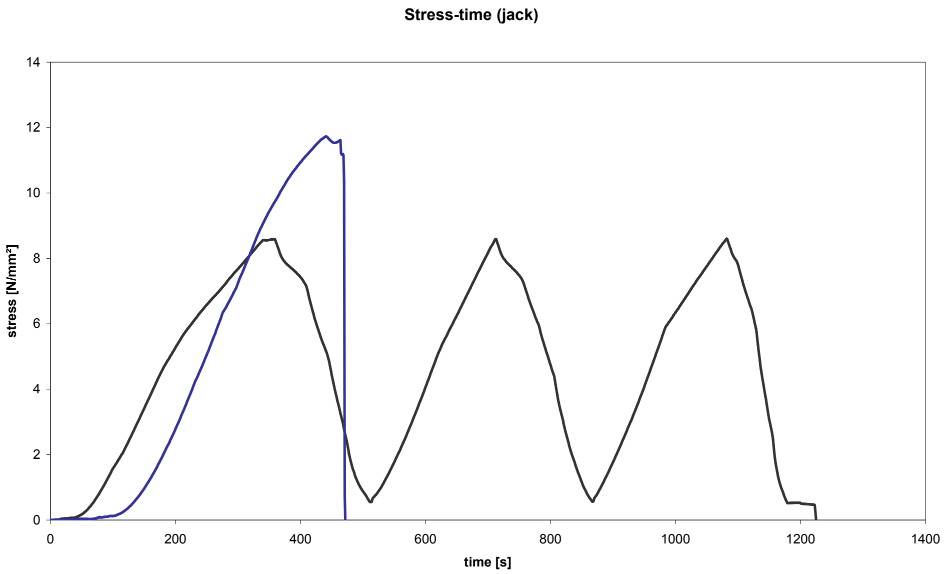

figure 6: loading dependent on time

During execution of the third attempt the calotte of the testing machine placed itself inclined. So load was introduced eccentrically into the specimen. The misalignment of the wedged calotte became visible after the failure of the test specimen. This was obviously because of eccentric crack formation after the collapse. Therefore a further test was carried out.

3. Evaluation of carried out tests

3.1 Fracture behaviour

During all executions of the attempts the specimens failed abruptly without any advance notice.

In the test with four-unit-specimens made out of KS R the failure occurred by cracking of the units in the middle. While the test specimens were broken out of the testing facility it became obviously that the joint of three of the four test items were pulverized or destructed. Only after the first attempt the joints were kept complete.

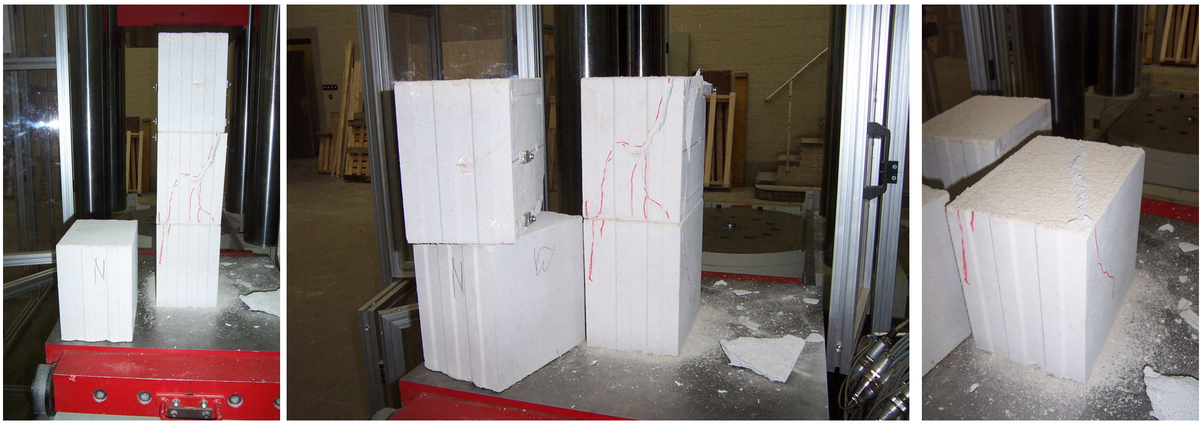

figure 7: Destructed joint of a test item (KS R)

In each test specimens of large sized units the elements within the load introduction range failed, either the first or the last unit. Also at these experimental tests a nearly complete failure of the horizontal joints and consequently the adhesive bond could be observed.

figure 8: Destructed test specimen (KS-XL-PE)

3.2 Compressive strength of specimens

The pressure strength of the samples is calculated according to equation (1) of DIN EN 1052-1 [11] or rather equation (2) of DIN 18554 [2] by using

$$f_i = \frac{F_{i,max}}{A_i} .$$

The influence of the slenderness of the test specimens was not considered.

table 1: Bearing capacity of masonry specimens (KSR)

sample No.	ultimate load [kN]	area [mm²]	compressive strength [N/mm²]	char. compressive strength [N/mm²]	loading rate [N/mm²]
1	947,0	43400	21,8	18,2	0,1
2	926,7	43400	21,4	17,8	0,1
3	1130,5	43400	26,0	21,8	0,2
4	1086,7	43400	25,0	20,9	0,2

The average value of this random sample on test specimens out of KS R determines to 23.6 N/mm². The quality of this test series can be allocated by means of the standard deviation. This amounts to 2.3 N/mm². The single results scatter with a variation coefficient of about 10 % around the mean value.

Hence, the mean value of the characteristic compressive strength of masonry out of KS R averages to about 17.8 (19.6) N/mm² according to equation (3) of DIN EN 1052-1 [11].

$$f_k = \frac{f}{1.2} \qquad \text{or} \qquad f_k = f_{i,min}$$

In a first step the ultimate strength of single units and mortar was determined on the basis of compression tests. The compressive strength of KS R units amounts itself on the average of 34.5 N/mm² with a standard deviation of 1.2 N/mm² and a variation coefficient of 4 %. The sample size represents 6 attempts. The ultimate compressive strength of mortar amounted to an average of 18.1 N/mm² up to the time of the examination of the test specimens out of KS R (sample size: 6 test specimens). The standard deviation is identified to 0.7 N/mm² and the variation coefficient to 4 %.

According to DIN EN 1052-1 the characteristic compressive strength is expressed also by the terms of equation (4):

$$f_k = \frac{f}{1.2} \qquad \text{or} \qquad f_k = f_{id,min}\,.$$

For masonry units made with thin layer mortar, of thickness 0.5 to 3 mm, and calcium silicate units the characteristic compressive strength of masonry determines according to equation (3.3) of Eurocode 6 [13] theoretically to

$$f_k = 0{,}80\, f_b^{0{,}85}\,.$$

Inserting the given values for the compressive strength of single units into the equation specified above, the compressive strength of masonry achieves to about 16.2 N/mm². This corresponds approximately to the actual compressive strength of masonry determined in the attempt. It was determined to 17.8 N/mm² as represented above. This matches to a deviation of 9 %.

table 2: Bearing capacity of masonry specimens (KS-XL-PE)

sample No.	ultimate load [kN]	area [mm²]	compressive strength [N/mm²]	char. compressive strength [N/mm²]	comment
1	2251,3	174650	12,9	10,8	
2	2048,2	174650	11,7	9,8	
3	1777,7	174650	10,2	8,5	eccentric load introduction
4	2128,8	174650	12,2	10,2	

The average value of this random sample on test specimens out of KS-XL-PE determines itself to 12.3 N/mm² (Due to the evaluation of the mean value the experimental results of test three was disregarded because of incorrect load initiation). The quality of this series can be allocated by means of the standard deviation. It amounts to about 1.1 N/mm². The single results scatter with a variation coefficient of about 10 % around the average value. Hence, the mean value of the characteristic compressive strength of masonry of KS-XL-PE averages to about 9.8 (10.2) N/mm² according to equation (3) of DIN 1052-1 [11] (Due to the evaluation of the mean value the experimental results of test three was disregarded because of incorrect load introduction).

In preliminary tests first the ultimate strength of single units and mortar was determined on the basis compression tests. The compressive strength of the KS-XL-PE units determines itself on the average of 19.4 N/mm² (determined at specimens cut out of the element according to DIN 771-2 [7]) with a standard deviation of 5.3 N/mm² and a variation coefficient of 27 %. The sample size represents 12 attempts. The ultimate compressive strength of mortar amounted to 18.8 N/mm² at the time of the examination of the first three test specimens out of KS-XL-PE (sample size: 6 mortar prism). The standard deviation is identified to 1.0 N/mm² and the variation coefficient to 5 %. Also for the last four-unit-specimen mortar samples were manufactured again. At the time of the examination of this last test specimen the mortar reached a compressive strength of 15.1 N/mm². The standard deviation of this series amounted to 0.6 N/mm². Thus the variation coefficient corresponds to 4 %.

The compressive strength of masonry which can be expected determines to about 9.9 N/mm² by using equation (3.3) of Eurocode 6 [13]. The compressive strength of a single unit determined by attempts was set in this equation. Also in this case the normative determined compressive strength of the masonry and the ultimate strength determined by experimental tests (9.8 N/mm²) obtains a good agreement. The proportional deviation amounts to 1%.

3.3 Stress-strain-behaviour

In the following, the stress-strain-behaviour of masonry specimens is represented for the example on specimen number 2 (masonry item of KS R). Because of the arrangement of measurements it is possible to differentiate the kind and the range of elongation. All displayed stress-strain-relations are averaged of the respective sensors.

First of all the tendency of the general stress-strain-behaviour of calcium silicate masonry is characterized by the curves in figure 9 and also in the figures of the appendix. Every graph of stress-strain-relation of masonry shows an approximately linear elastic behaviour with a small strain hardening range. The graphs of the unit-behaviour look very similar to the masonry-behaviour. The units show also a linear elastic behaviour up to the ultimate strength with a very brittle failure. Only the graphs of the joint range show a different – non-linear elastic – behaviour. It is obviously that the modulus of elasticity of joints is much smaller than that one of the units of the masonry. In addition the joints fail not so brittle like the units.

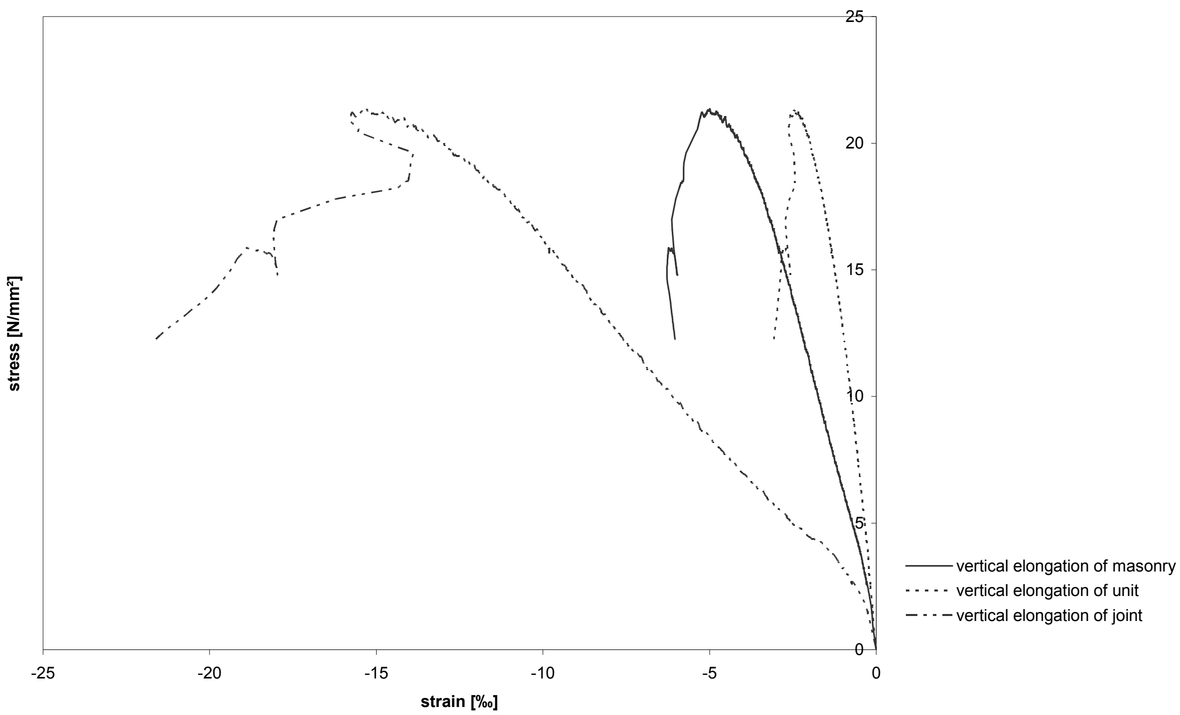

figure 9: stress-strain-behaviour (vertical elongation) of specimen 2 (KS R)

The stress-strain-diagrams of specimens out of KS-XL-PE (shown in the appendix) are not as significant as that one of KS R. At this kind of experimental tests the sensors were removed before the load increased up to the ultimate load. Therefore the diagram of KS-XL-PE shows only an approximately stress-strain-behaviour but no failure. The fracture behaviour can only be shown in a load-displacement-diagram of the jack (figure 10). Masonry specimens made of large-sized element failed more brittle than specimens made of normal-sized units in consideration of the load-displacement-relation of the jack.

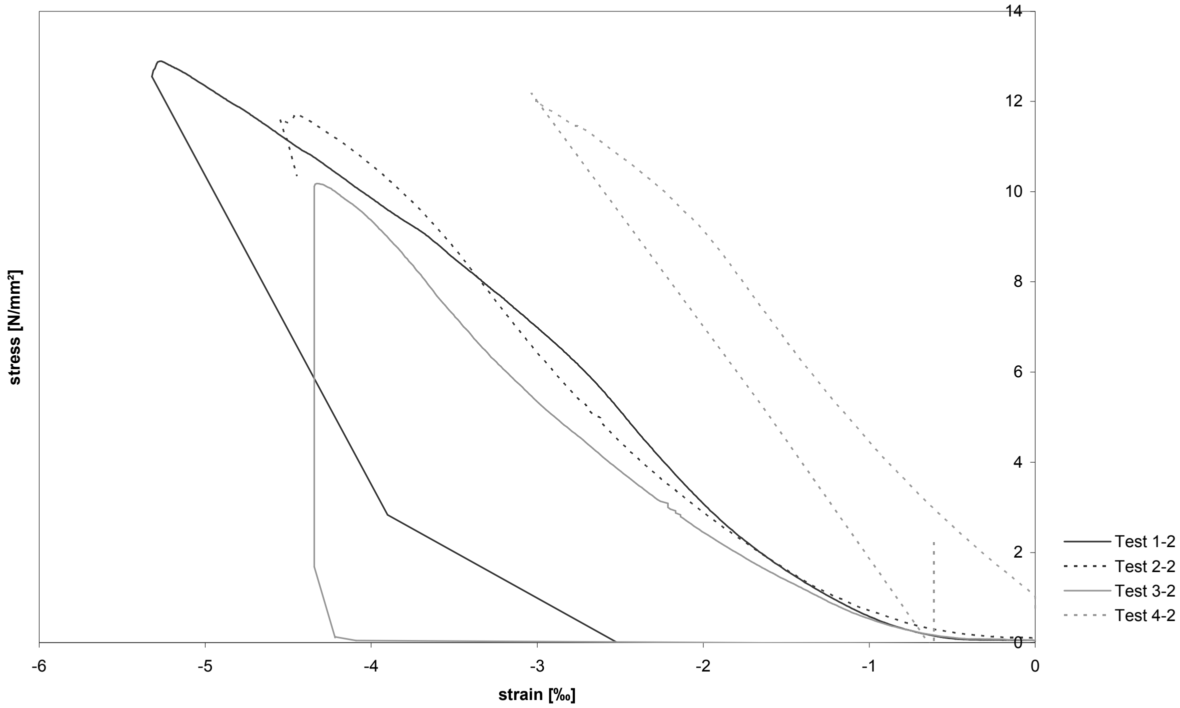

figure 10: load-displacement-curve of the jack (vertical elongation) of specimens out of KS-XL-PE

The lateral strain behaviour was registered by respectively 4 probes in the unit centre and four probes within the joint range in a distance of 24 mm above/below from the border of the brick. The stress-strain behaviour, displayed in figure 11, of the equivalent sensors on the opposite sides of the test specimen is averaged in each case. In this diagram the transverse elongation of masonry specimens is represented on the example of test item number 4 made of KS R. The graphs of the transverse strain show an approximately linear elastic behaviour with a strain hardening range. After reaching the ultimate strength the lateral strain shows a ductile behaviour (figure 23 and figure 25).

However, the lateral strain behaviour of masonry specimens of KS-XL-PE could only be observed in the range of elasticity. The probes had to be removed of the test items in time because of the very brittle failure of the specimens with large-size elements. Therefore, it was not possible to observe the behaviour of the transverse elongation in the post peak region.

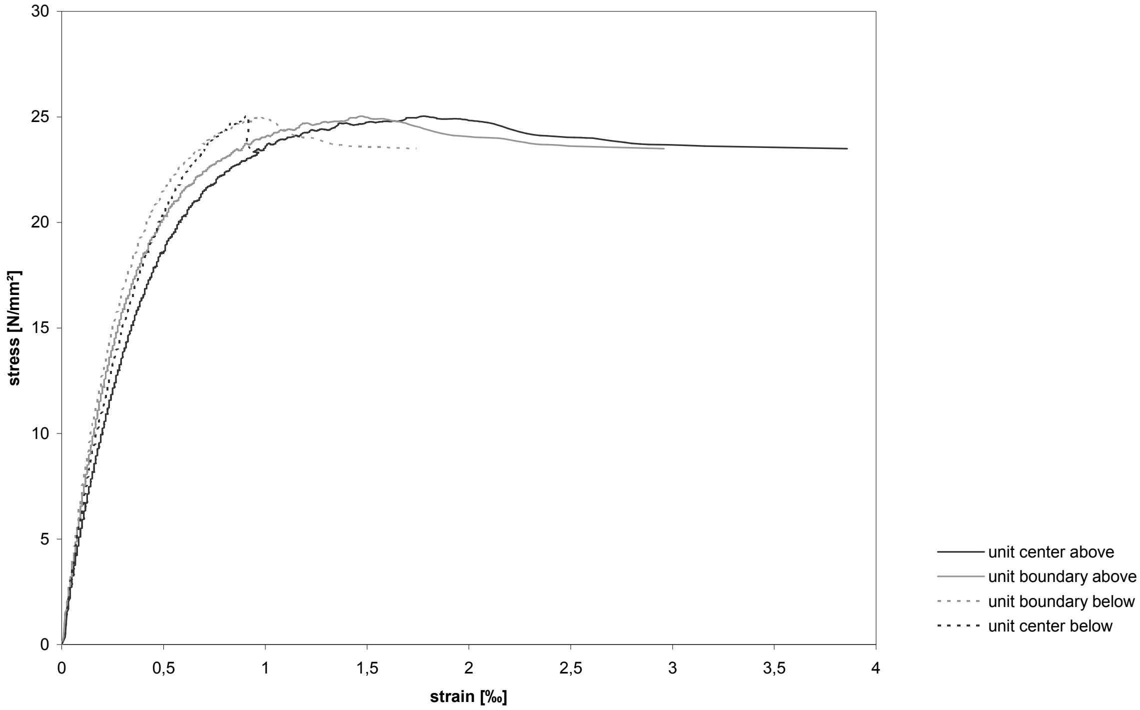

figure 11: stress-strain-behaviour (horizontal elongation) of specimen 4 (KS R)

3.4 Modulus of elasticity

The modulus of elasticity of the test item was determined as a secant modulus considering the strain ε at a defined stress state of a third of the compressive strength $\sigma_i = F_i / A_i$ according to equation (2) of DIN EN 1052-1 [11] alternatively to equation (4) of DIN 18554 [2] as follows

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

It is pointed out that the modulus of elasticity was determined only at a four-unit-test item and not at a masonry specimen mentioned in the standards. Possible structural influences were not considered.

table 3: Evaluation of the modulus of elasticity at test items of KS R

	sample no	$f_{i,max}$ [N/mm²]	$f_{i,}$ [N/mm²]	$\bar{\varepsilon}$ [mm²]	E [N/mm²]	mean value [N/mm²]
masonry	1	21,8	7,27	0,75	9693	7562
	2	21,4	7,12	1,17	6085	
	3	26,1	8,70	1,32	6591	
	4	25,0	8,35	1,06	7877	
unit	1	21,8	7,27	0,58	12534	13620
	2	21,4	7,12	0,52	13692	
	3	26,1	8,70	0,58	15000	
	4	25,0	8,35	0,63	13254	
joint	1	21,8	7,27	1,64	4433	2849
	2	21,4	7,12	4,09	1741	
	3	26,1	8,70	4,00	2175	
	4	25,0	8,35	2,74	3047	

table 4: Evaluation of the modulus of elasticity at test items of KS-XL-PE

	sample no	$f_{i,max}$ [N/mm²]	$f_{i,}$ [N/mm²]	$\bar{\varepsilon}$ [mm²]	E [N/mm²]	mean value [N/mm²]	comment
masonry	1	12,9	4,30	0,67	6418	6356* (6366)	
	2	11,7	3,91	0,63	6206		
	3	10,2	3,39	0,53	6396		eccentric load introduction
	4	12,2	4,06	0,63	6444		
unit	1	12,9	4,30	0,53	8113	7794* (8200)	
	2	11,7	3,91	0,48	8146		
	3	10,2	3,39	0,36	9417		eccentric load introduction
	4	12,2	4,06	0,57	7123		
joint	1	12,9	4,30	2,51	1713	2386* (2098)	
	2	11,7	3,91	2,23	1753		
	3	10,2	3,39	2,75	1233		eccentric load introduction
	4	12,2	4,06	1,10	3691		

* without consideration of attempt 3 - eccentric load introduction; () provision for all values

Contrary to the attempts at the test items of small size bricks the test specimen of calcium silicate plan elements were not loaded by a linear load path, but examined according to DIN 1048 part 5 [1]. The load was increased three times in each case on a defined loading level and relieved afterwards. Thereby the loading level was chosen free. In the first attempt the load increased to 1 MN (5.72 N/mm²) before the test specimen was unloaded. In the further three attempts the load was increased three times on a loading level of 1,5 MN (8.6 N/mm²) and unloaded again to 0,1 MN (0.9 N/mm²) immediately. In the opposite to the standard of concrete tests the upper and/or the lower loading level was not kept a defined time interval on that level. The modulus of elasticity determined by the difference of an upper and lower testing level according to DIN 1048 part 5 [1]. The lower testing load level is determined by DIN 1048 part 5 to 0.5 N/mm², the upper testing load level corresponds to a third of the ultimate strength / bearing capacity of the specimens. In that case the strains on the third load path are to be considered in each case. The modulus of elasticity was determined according to equation (7) of the DIN 1048 part 5.

$$E = \frac{\sigma_o - \sigma_u}{\varepsilon_o - \varepsilon_u}$$

If the secant modulus of masonry of small sized units is intended in accordance with this standard, the modulus of elasticity will determine to 6659 N/mm². The secant modulus of masonry of large sized elements is identified to 6377 N/mm² in that way.

3.5 Evaluation of the lateral strain

The modulus of elasticity of test items was determined as a secant modulus in accordance with equation (2) of DIN EN 1052-1 [11] alternatively equation (4) of DIN 18554 part 1 [2].

The values of the modulus of elastic are investigated for masonry specimens respective the brick dimensions according to the following tables.

table 5: Evaluation of the transverse modulus of elasticity on test items of KS R

sample no.	$f_{i,max}$ [N/mm²]	f_i [N/mm²]	$\bar{\varepsilon}_q$ [mm²]	E_q [N/mm²]	mean value [N/mm²]
1	21,8	7,27	0,10	72700	64656
2	21,4	7,12	0,13	54769	
3	26,1	8,70	0,13	66923	
4	25,0	8,35	0,13	64231	

table 6: Evaluation of the transverse modulus of elasticity on test items of KS-XL-PE

sample no.	$f_{i,max}$ [N/mm²]	f_i [N/mm²]	$\bar{\varepsilon}_q$ [mm²]	E_q [N/mm²]	mean value [N/mm²]	comment
1	12,9	4,31	0,06	71833	65055* (60899)	
2	11,7	3,90	0,05	78000		
3	10,2	3,39	0,07	48429		eccentric load introduction
4	12,2	4,08	0,09	45333		

* without consideration of attempt 3 - eccentric load introduction; () provision for all values

The Poisson ratio of the carried out tests are given in table 7, differentiated to the location of the strain behaviour. Here the modulus of elasticity and the transverse modulus of elasticity are calculated in accordance to DIN 1048 part 5.

table 7: Evaluation of Poisson ratio

Unit	*location*	*sample no.*	*E* [N/mm²]	E_q [N/mm²]	Poisson ratio	average
KS R	unit	1	12340	64230	0,208	0,253
		2	13950	49384	0,282	
		3	14887	48705	0,306	
		4	12352	57246	0,216	
	joint	1	2676	71367	0,031	0,028
		2	1572	70549	0,022	
		3	1928	90105	0,021	
		4	2720	69090	0,039	
KS-XL-PE	unit	1	7492	63201	0,119	0,121*
		2	8319	60219	0,132	
		3	10446	54363	0,165	
		4	7059	66638	0,112	
	joint	1	1806	64453	0,028	0,048*
		2	2011	47467	0,031	
		3	988	135909	0,015	
		4	5469	62558	0,085	

* without consideration of attempt 3 - eccentric load introduction; () provision for all values

If the secant modulus of masonry of small sized units (KS R) is intended in accordance with this standard, lateral extension modulus results to 63502 N/mm². The lateral strain behaviour can be describe in this case by a Poisson ratio of ν = 0,112. For large size elements (KS-XL-PE) the transverse modulus of elasticity is calculated to 62726 N/mm² and the Poisson ratio to ν = 0,102.

4. Abstract

Altogether a brittle failure could be observed on the basis these attempts at four-unit-specimens. The stress-strain curves generally show linear-elastic behaviour of the test specimens. By the use of small size units an unimportant strain hardening range is observed under ultimate load. This behaviour does not arise at attempts on large sized elements.

The compressive strength determined on attempts corresponds approximately to that one calculated by the theoretical equations after EC 6 determined. Thus, the averaged compressive strength of test items of KS R identifies to 16.2 N/mm² contrary to 17.8 N/mm² after Eurocode 6 [13]. The mean value of the compressive strength of four-unit specimens of KS-XL-PE is investigated to 9.9 N/mm² by experimental test contrary to 9.8 N/mm² after Eurocode 6.

The deformation behaviour is described by the modulus of elasticity. figure 12 represents the deformation behaviour and the modulus of elasticity as well as the modulus of lateral extension of specimens of KS R.

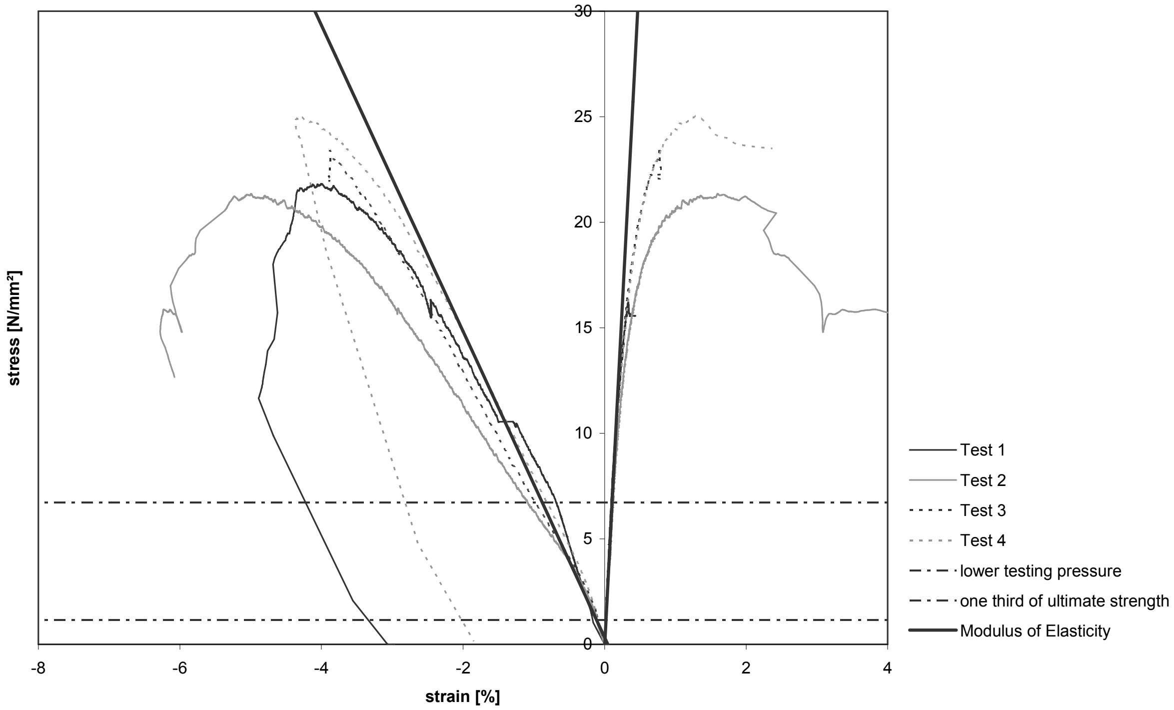

figure 12: deformation behaviour of all specimens of KS R

The modulus of elasticity at four-unit-specimens determines itself to 6659 N/mm² and the modulus of transverse elongation to 64656 N/mm². Hence, the Poisson ratio results to 0.112.

figure 13 shows the appropriate diagram for KS-XL-PE. In this case the deformation behaviour was determined by loading and relieving strength.

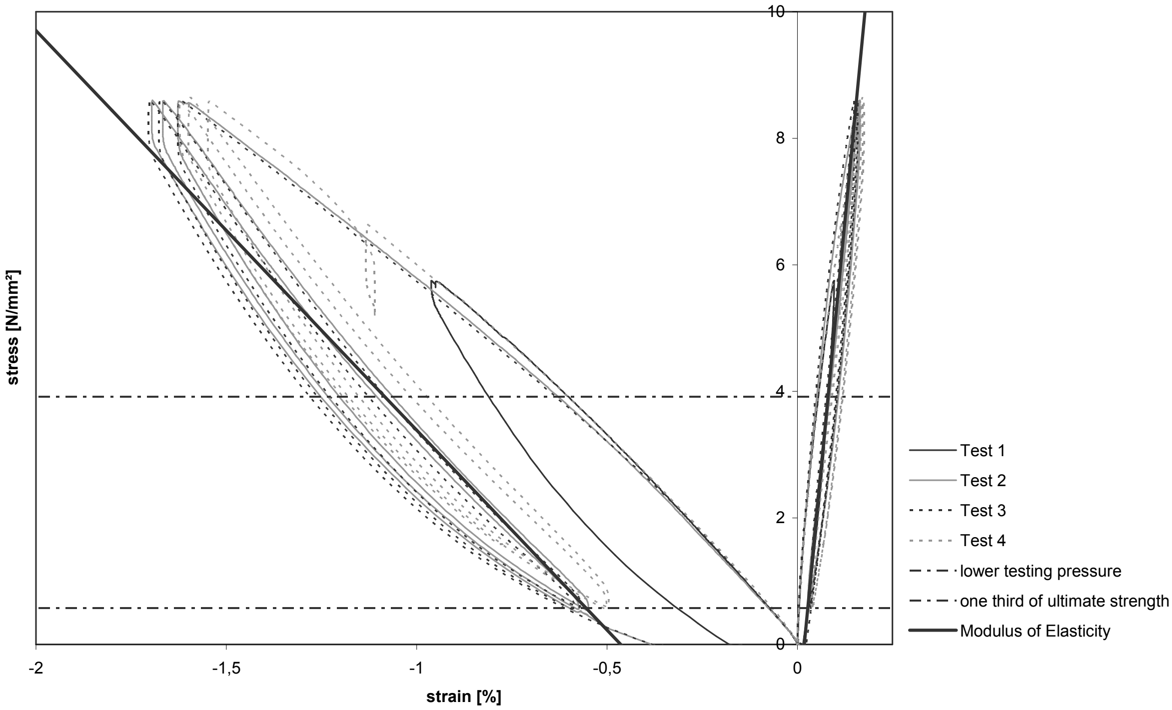

figure 13: deformation behaviour of all specimens of KS-XL-PE

The modulus of elasticity at four-unit-specimens of KS-XL-PE determines itself to 6377 N/mm², the modulus of transverse elongation to 65055 N/mm². Hence, the Poisson ratio results to 0.102.

In principle an expecting influence of the kind of federation and the overlapping length on the deformation behaviour cannot be quantified due to missing attempts.

References

[1] DIN 1048, Teil 5: Prüfverfahren für Beton. Teil 5: Festbeton, gesondert hergestellte Prüfkörper; Juni 1991.

[2] DIN 18 554, Teil 1: Prüfung von Mauerwerk. Teil 1: Ermittlung der Druckfestigkeit und des Elastizitätsmoduls; Dezember 1985.

[3] DIN 18 555, Teil 1: Prüfung von Mörtel und mineralischen Bindemitteln. Teil 1: Allgemeines, Probenahme, Prüfmörtel; September 1982.

[4] DIN 18 555, Teil 2: Prüfung von Mörtel und mineralischen Bindemitteln. Teil 2: Frischmörtel mit dichten Zuschlägen - Bestimmung der Konsistenz, der Rohdichte und des Luftgehalts; September 1982.

[5] DIN 18 555, Teil 3: Prüfung von Mörtel und mineralischen Bindemitteln. Teil 3: Festmörtel - Bestimmung der Biegezugfestigkeit, Druckfestigkeit und Rohdichte; September 1982.

[6] DIN 18 555, Teil 5: Prüfung von Mörtel und mineralischen Bindemitteln. Teil 5: Festmörtel - Bestimmung der Haftscherfestigkeit; März 1986.

[7] DIN EN 771-2: Festlegung für Mauersteine. Teil 2: Kalksandsteine; August 2003.

[8] DIN EN 772-1: Prüfverfahren für Mauersteine. Teil 1: Bestimmung der Druckfestigkeit; September 2000.

[9] DIN EN 772-13: Prüfverfahren für Mauerwerk. Teil 13: Bestimmung der Netto- und Brutto-Trockenrohdichte von Mauersteinen (außer Natursteinen)

[10] DIN EN 998-2: Festlegung für Mörtel im Mauerwerksbau. Teil 2: Mauermörtel; September 2003.

[11] DIN EN 1052-1: Prüfverfahren für Mauerwerk. Teil 1: Bestimmung der Druckfestigkeit; Dezember 1998.

[12] DIN V 106-1: Kalksandsteine. Teil 1: Voll-, Loch-, Block-, Hohlblock-, Plansteine, Planelemente, Fasensteine, Bauplatten, Formsteine; Februar 2003.

[13] prEN 1996-1-1: Eurocode 6: Design of Masonry Structures – Part 1-1: Common rules for reinforced and unreinforced masonry structures; March 2003.

Appendix

Stress-strain-behaviour – vertical elongation

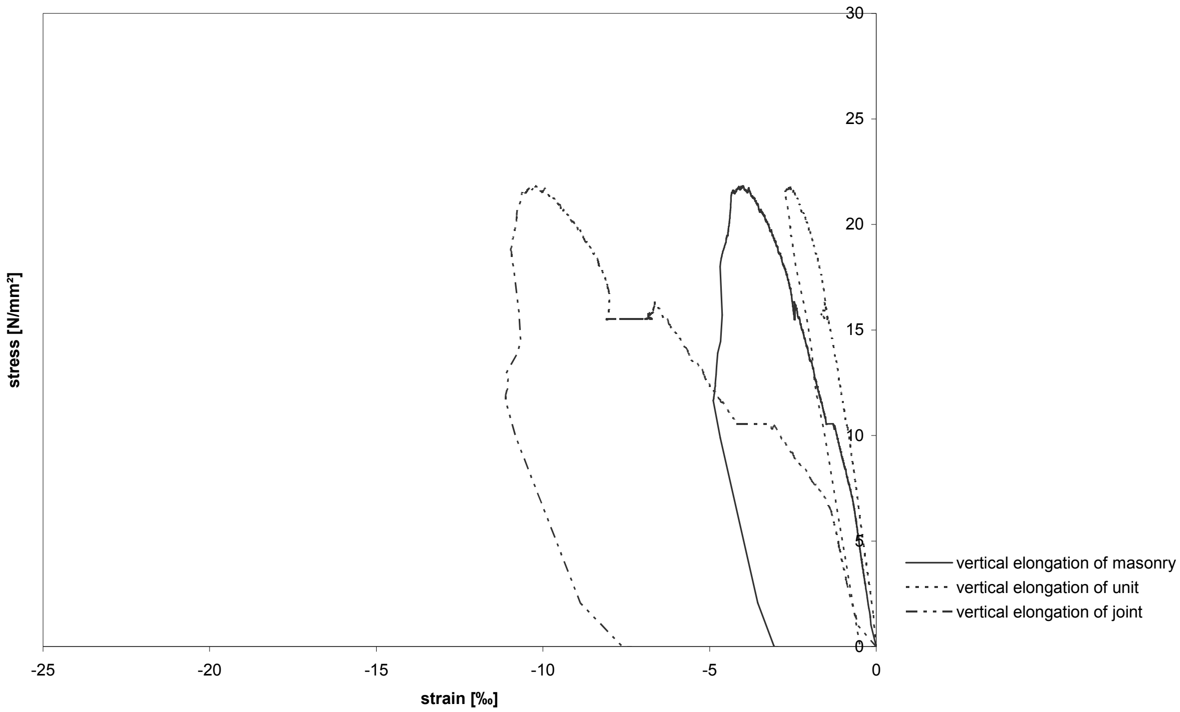

figure 14: stress-strain-behaviour (vertical elongation) of specimen 1 (KS R)

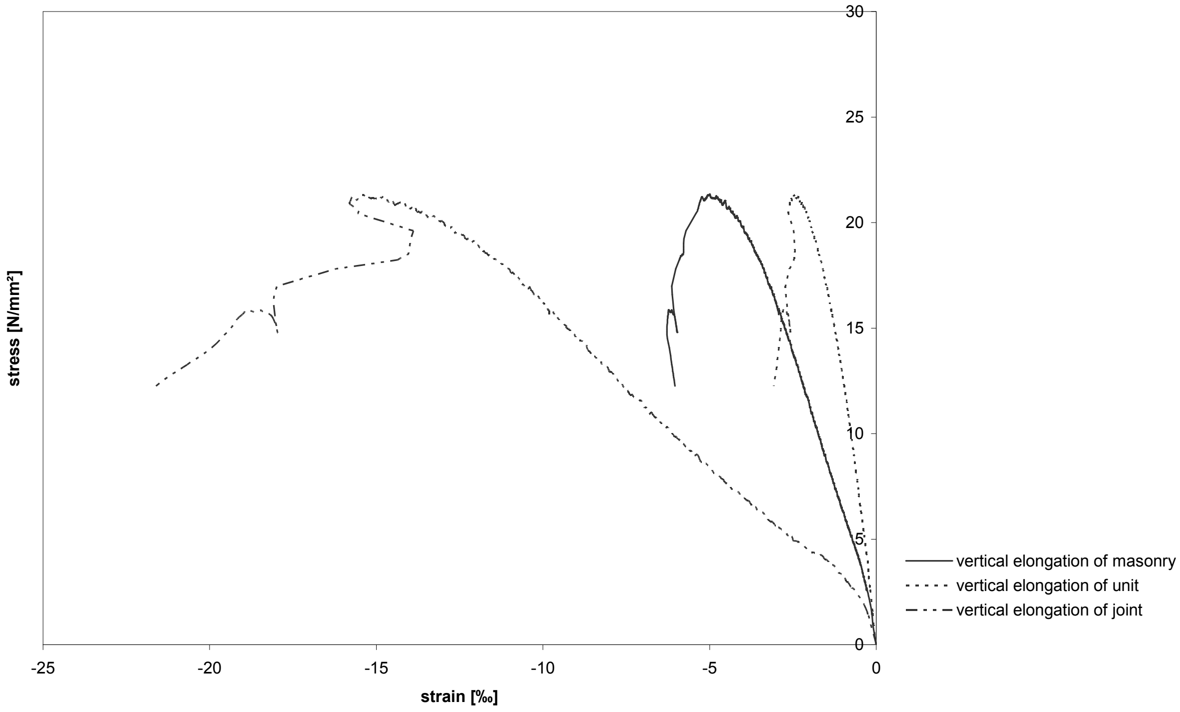

figure 15: stress-strain-behaviour (vertical elongation) of specimen 2 (KS R)

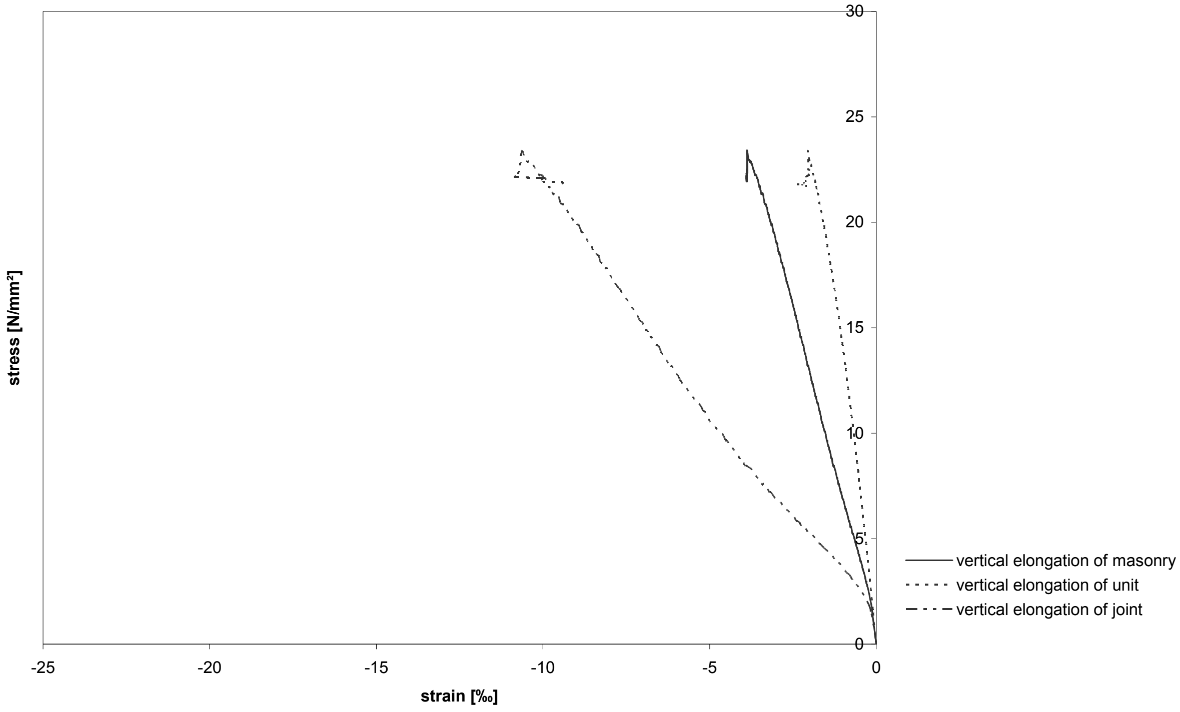

figure 16: stress-strain-behaviour (vertical elongation) of specimen 3 (KS R)

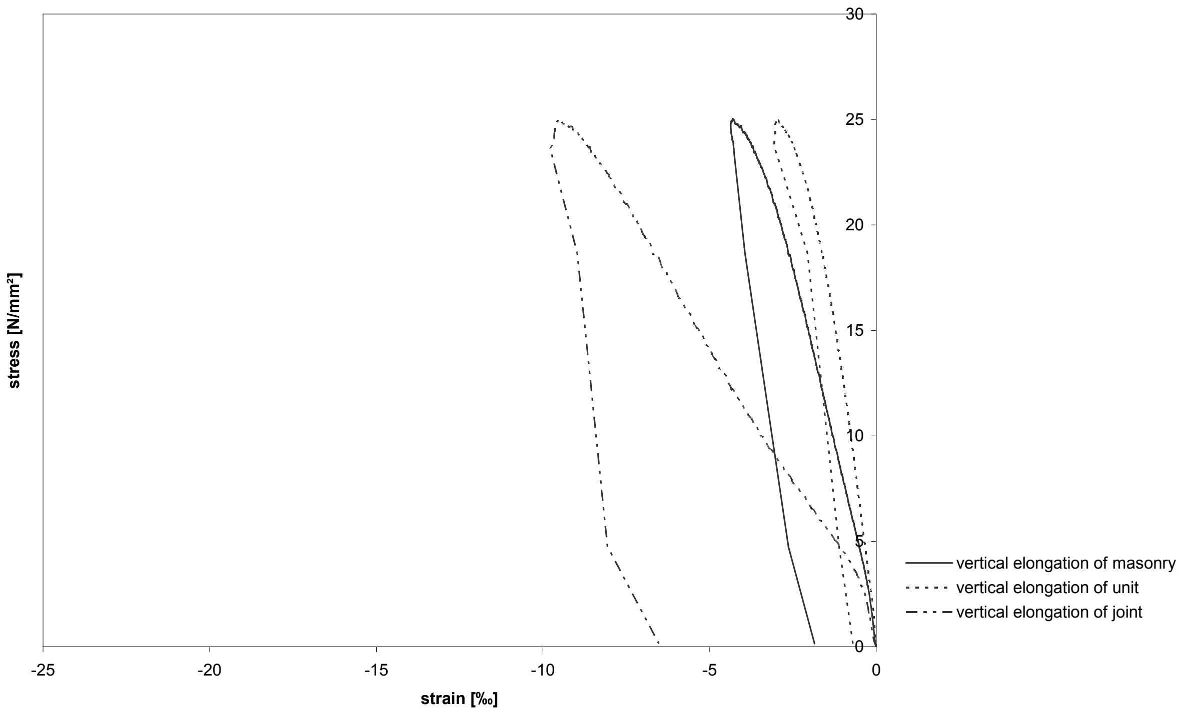

figure 17: stress-strain-behaviour (vertical elongation) of specimen 4 (KS R)

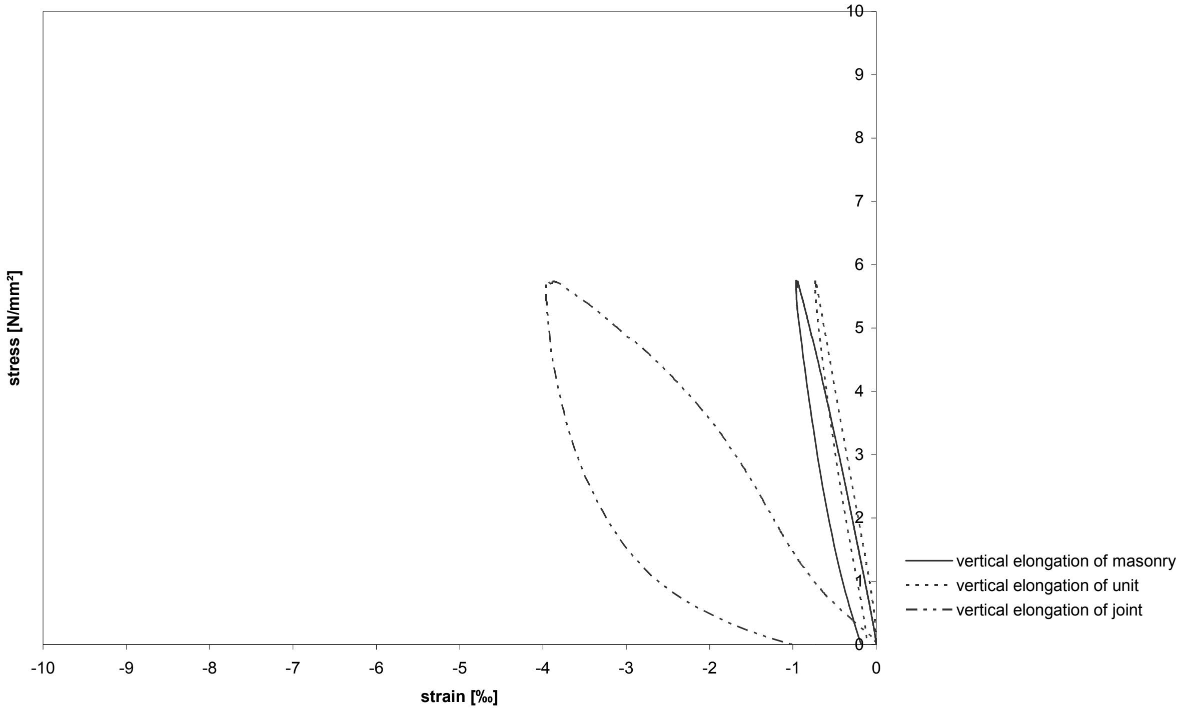

figure 18: stress-strain-behaviour (vertical elongation) of specimen 1 (KS-XL-PE)

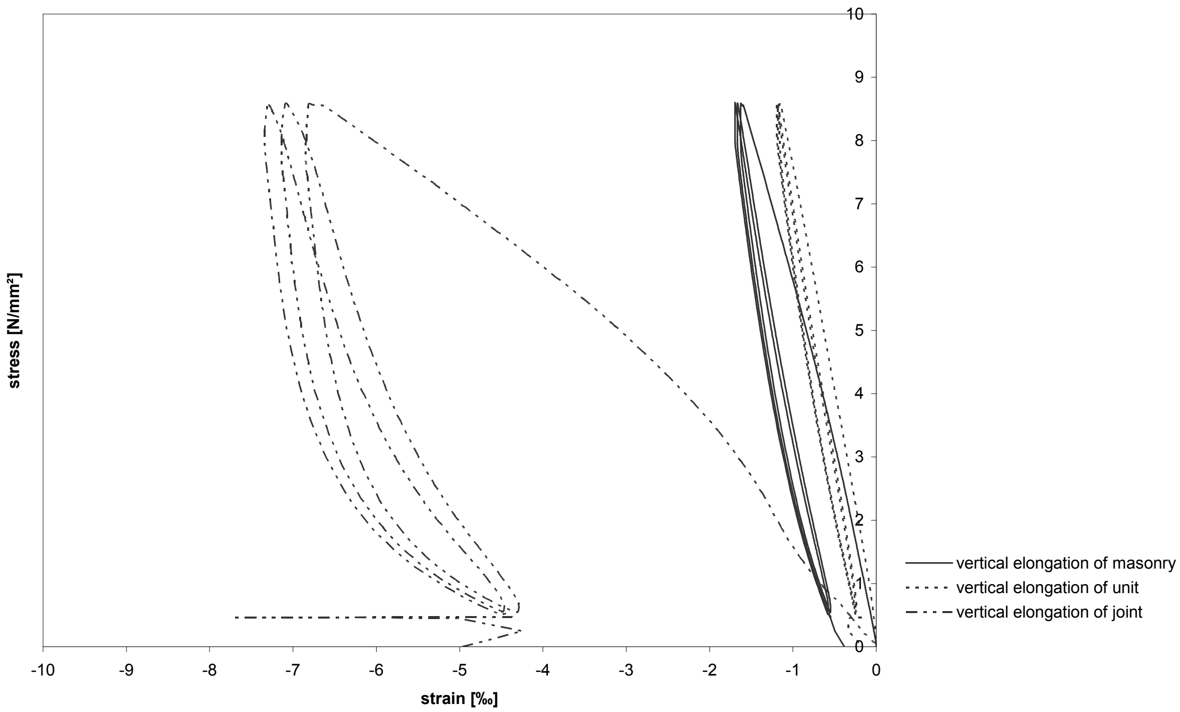

figure 19: stress-strain-behaviour (vertical elongation) of specimen 2 (KS-XL-PE)

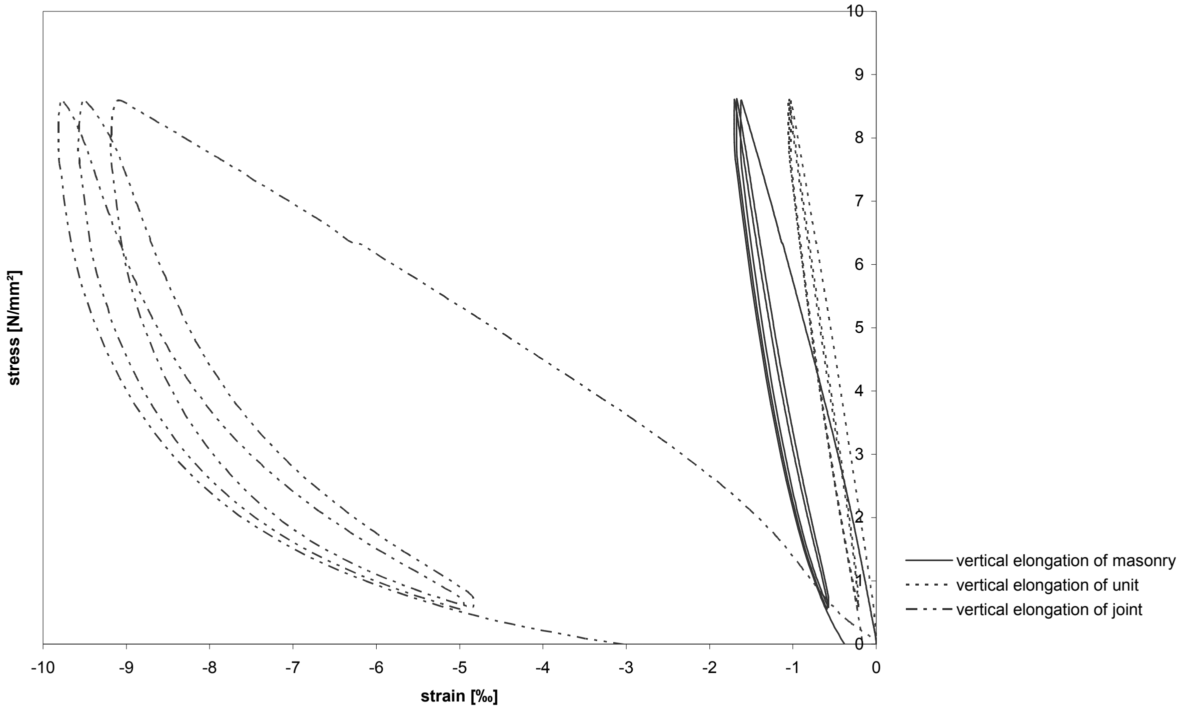

figure 20: stress-strain-behaviour (vertical elongation) of specimen 3 (KS-XL-PE)

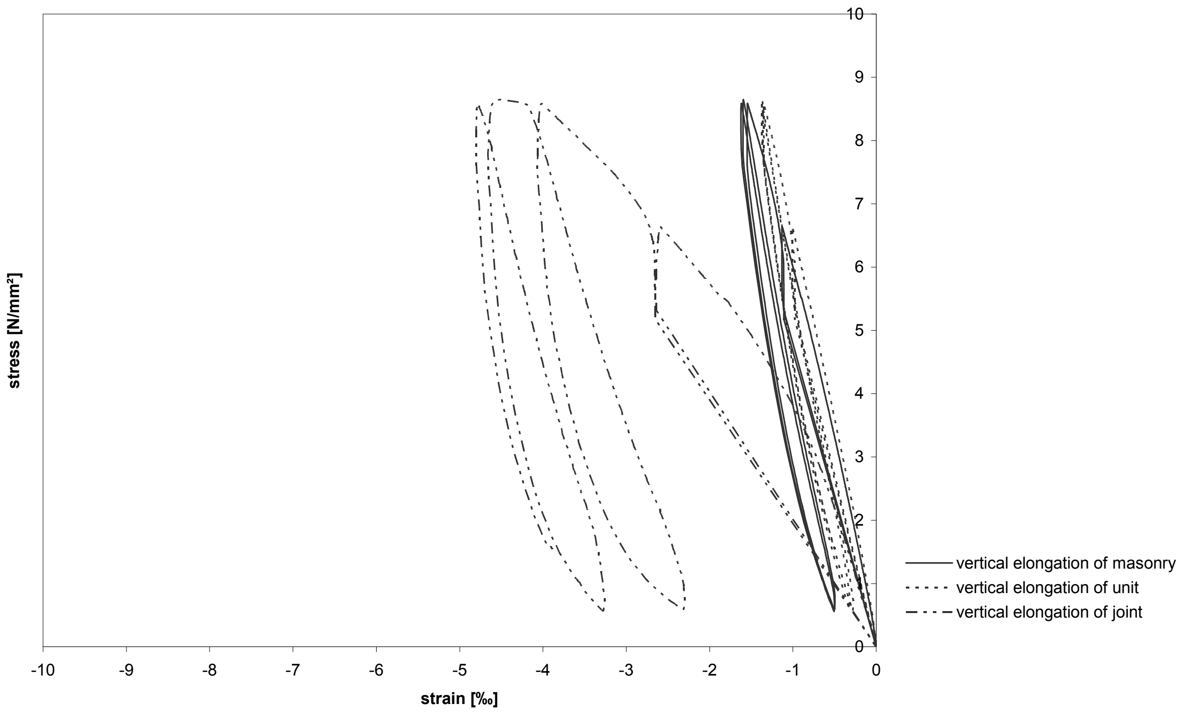

figure 21: stress-strain-behaviour (vertical elongation) of specimen 4 (KS-XL-PE)

Stress-strain-behaviour – horizontal elongation

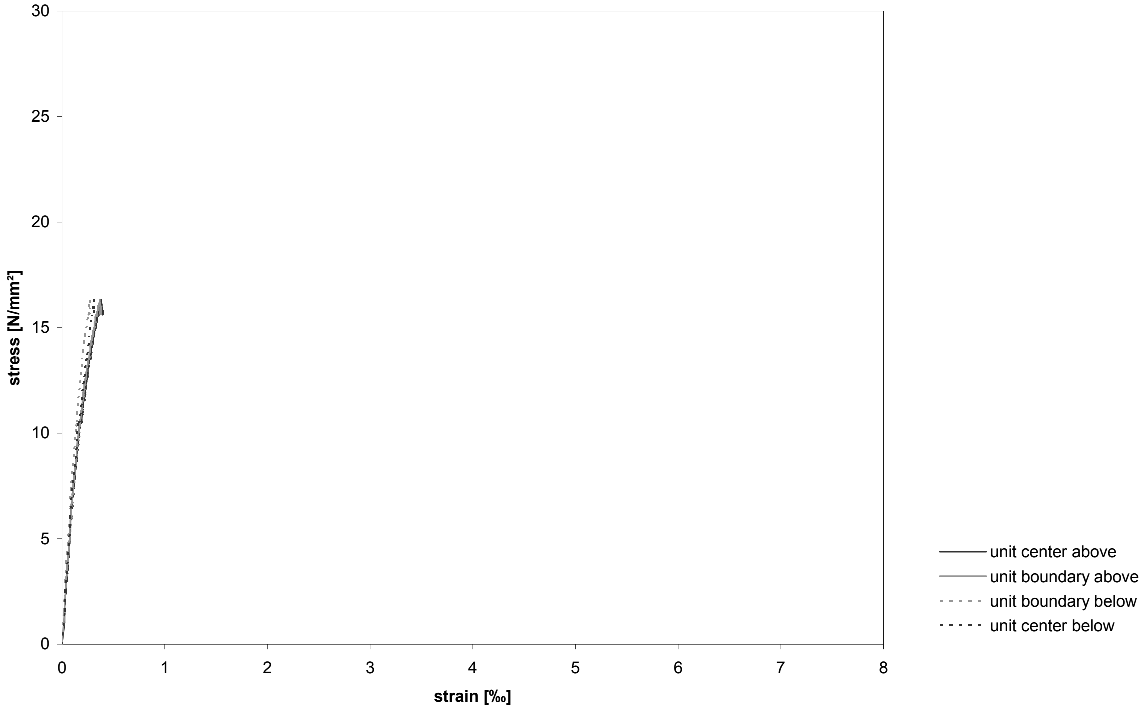

figure 22: stress-strain-behaviour (horizontal elongation) of specimen 1 (KS R)

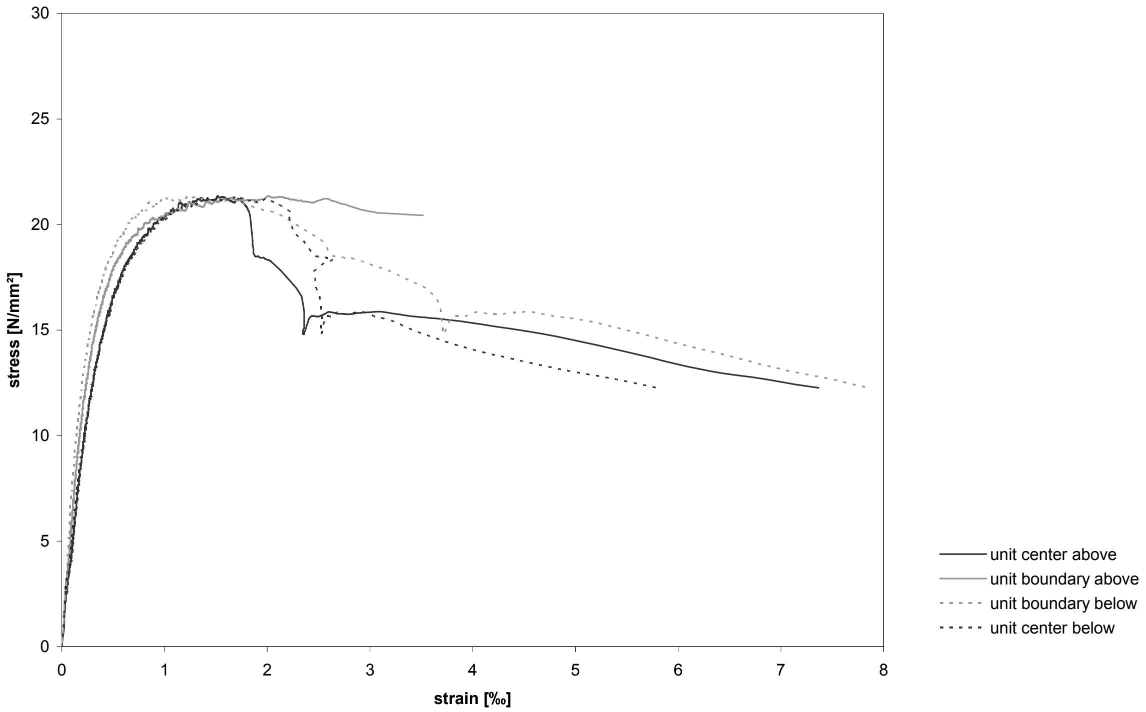

figure 23: stress-strain-behaviour (horizontal elongation) of specimen 2 (KS R)

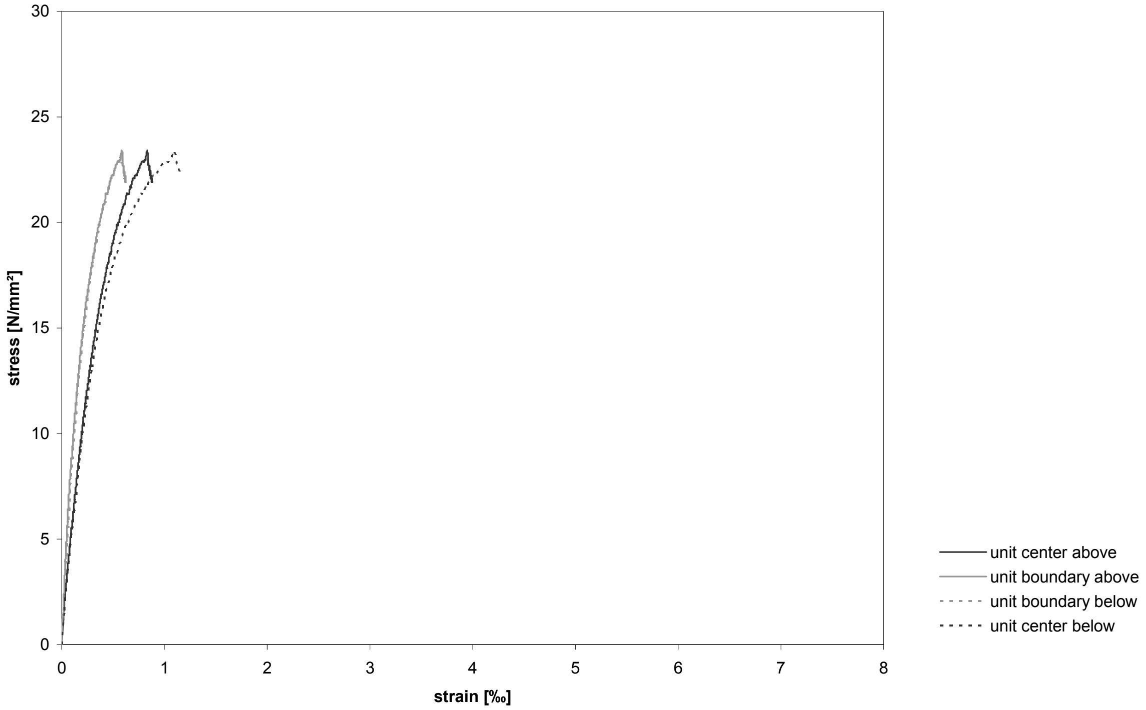

figure 24: stress-strain-behaviour (horizontal elongation) of specimen 3 (KS R)

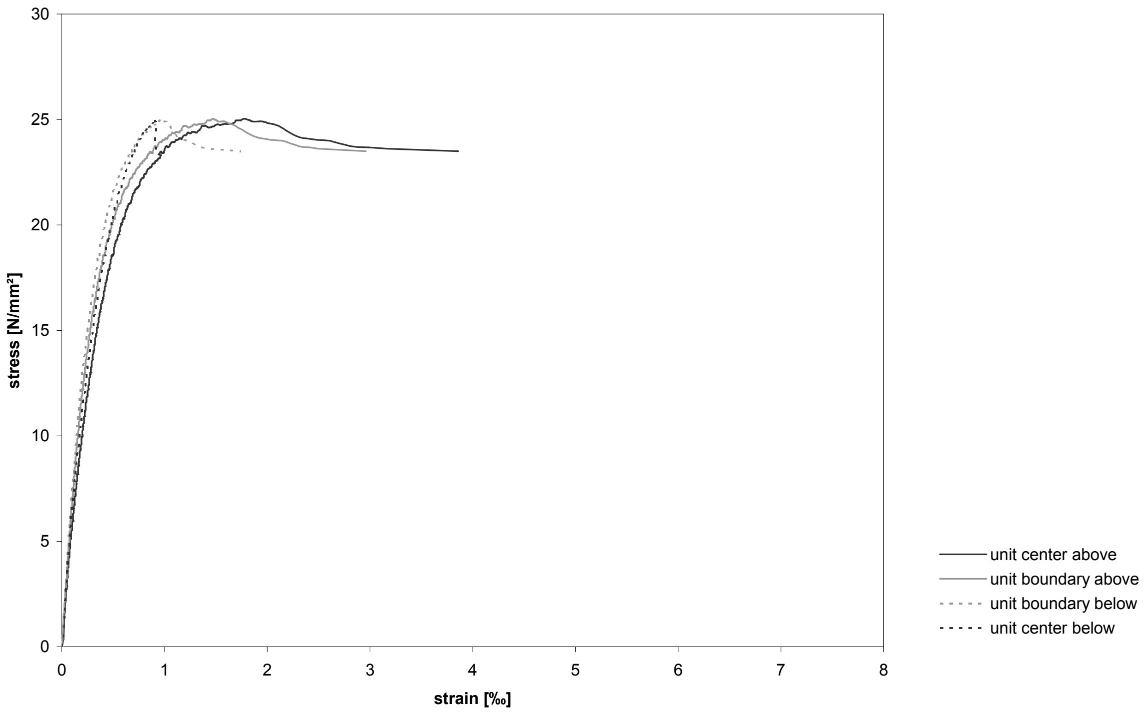

figure 25: stress-strain-behaviour (horizontal elongation) of specimen 4 (KS R)

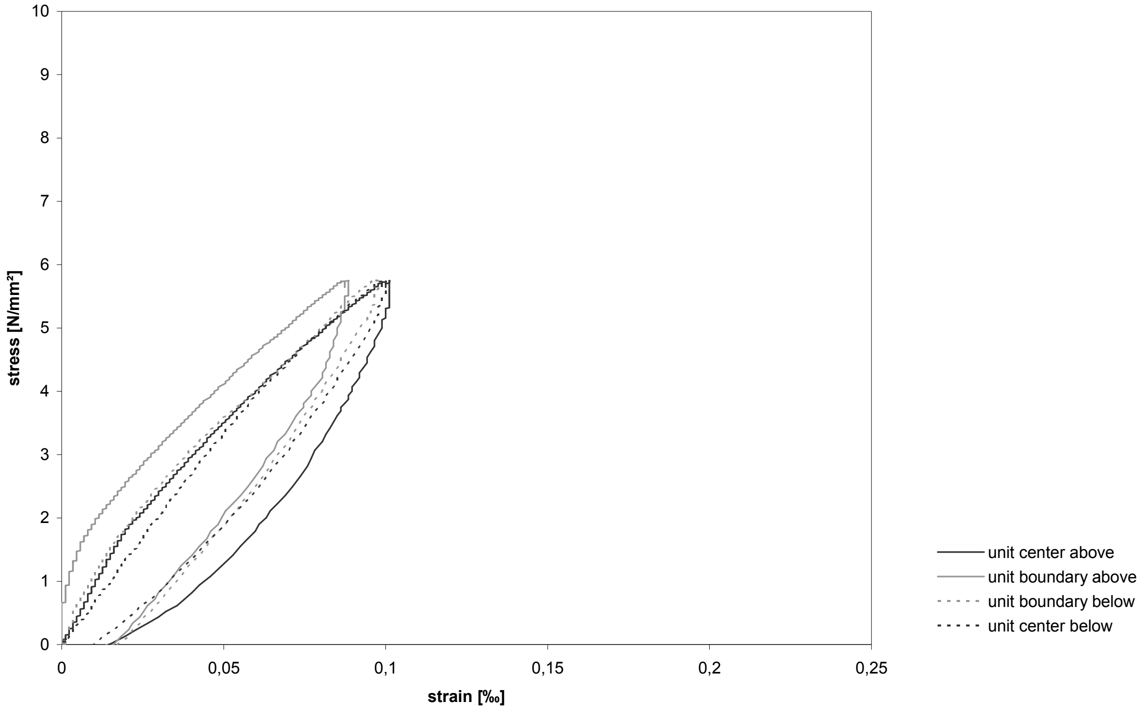

figure 26: stress-strain-behaviour (horizontal elongation) of specimen 1 (KS-XL-PE)

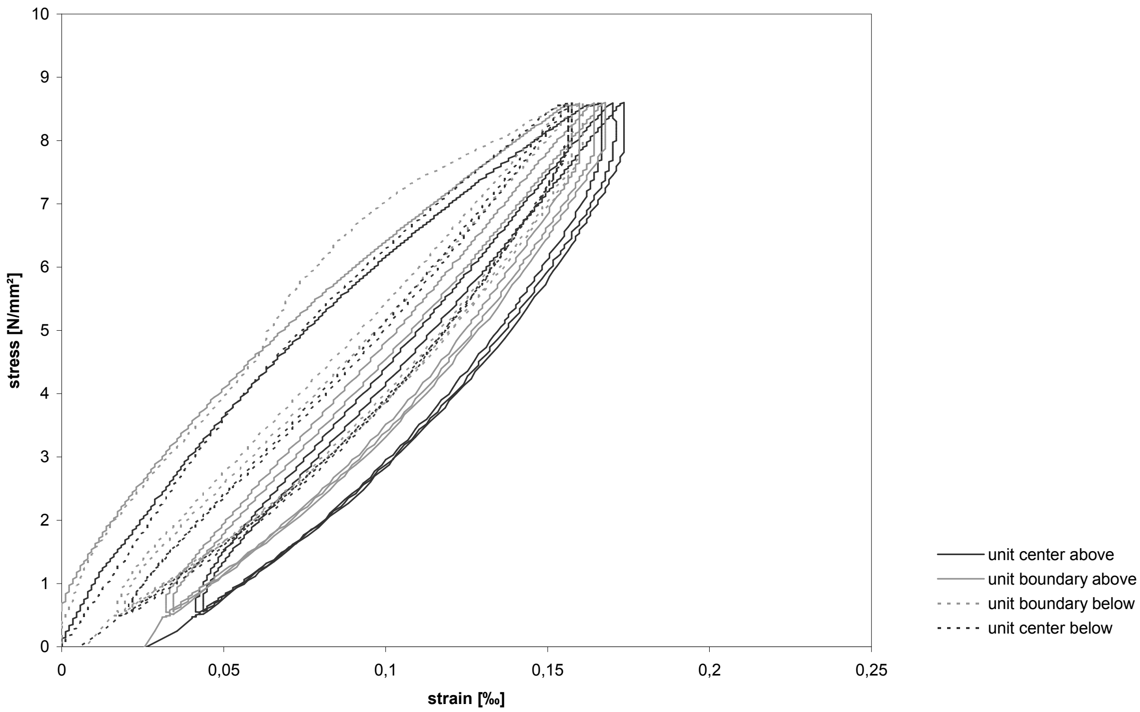

figure 27: stress-strain-behaviour (horizontal elongation) of specimen 2 (KS-XL-PE)

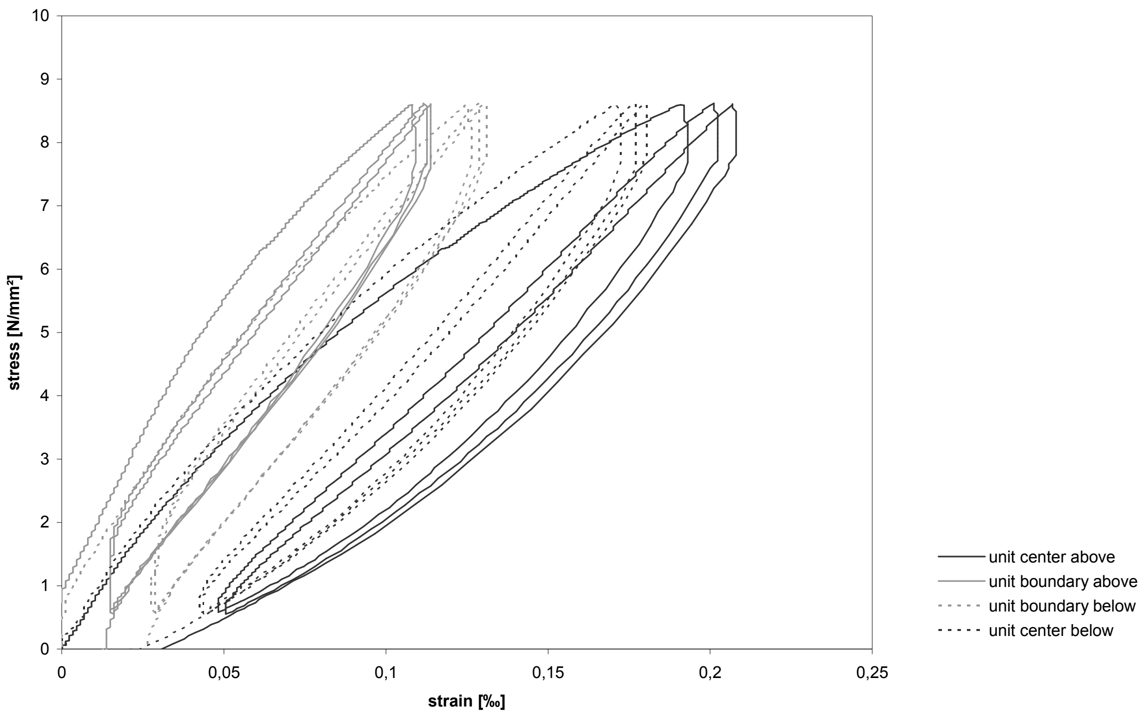

figure 28: stress-strain-behaviour (horizontal elongation) of specimen 3 (KS-XL-PE)

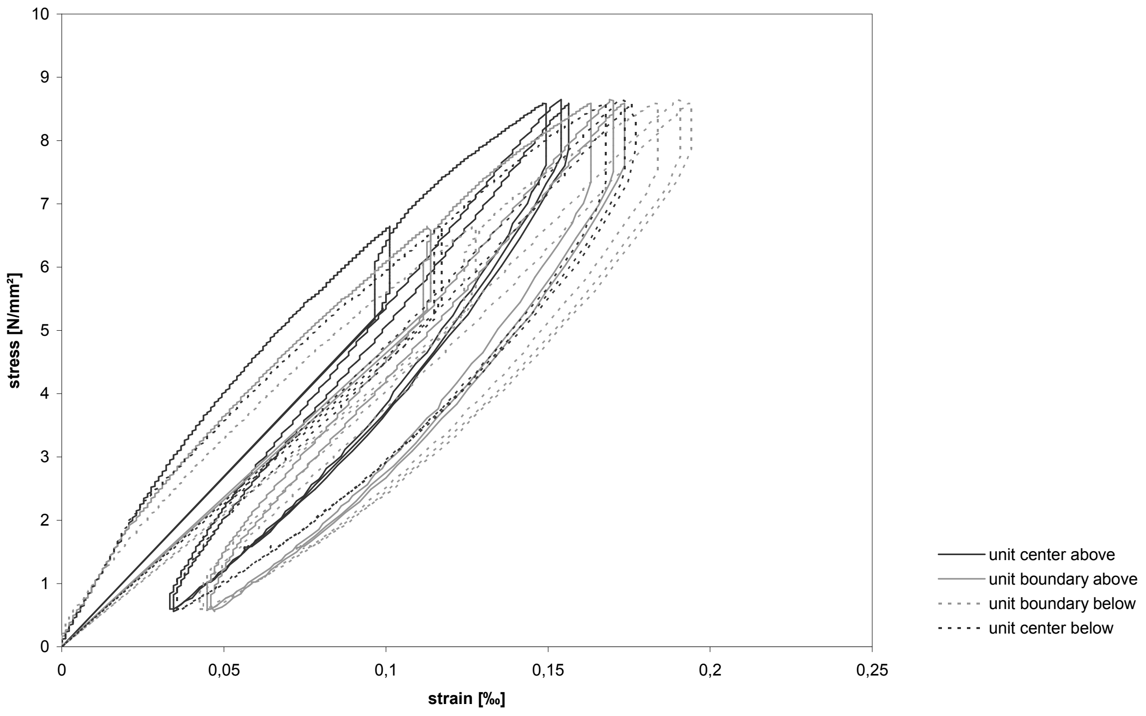

figure 29: stress-strain-behaviour (horizontal elongation) of specimen 4 (KS-XL-PE)