The Effect of Lateral Joint Reinforcement on the Strength and Deformation of Brickwork Piers

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ABSTRACT

The paper reports on test results of reinforced and unreinforced brick masonry piers subjected to axial compression. All possible combinations of 2 types of mortar, 2 types of bricks as well as 3 different types of lateral joint reinforcement were taken into account. Lateral and longitudinal strains, failure strengths, plastic deformations within the working stress and stresses of the reinforcing rods were evaluated. Results obtained are failure patterns, bearing strengths and stress-strain relationships. Significant differences were recorded among the reinforced piers as well as when compared to the unreinforced specimens. Results are shown as a function of brick and mortar strengths and the shape of reinforcement, respectively.

1. INTRODUCTION

The bearing strength of brickwork subjected to axial compression is mainly dependent on the strength and deformation behaviour of its components, the mortar and the masonry unit.

Latest investigations into the failure mechanism of brick masonry yielded the conclusion that the differences in lateral strains of both materials cause a triaxial stress state - longitudinal compression and tension in perpendicular directions -, so failure of piers is due to exceeding the tensile strength of the bricks which at ultimate load do not reach their compresive strength.

Considering this failure mechanism it can be assumed that restraint of the lateral strain of the mortar joint reduces the tensile stresses in the bricks, thus approaching the compressive strength of the bricks to a greater extent. Such a restraint is attained by reinforcing the mortar with steel rods.

The tests reported herein are parts of an ample investigation on the effect of reinforcement embedded in the mortar of axially loaded masonry piers. The piers vary in strengths of mortar and brick. Different shapes of reinforcement were used while the slenderness was kept constant. The tests aimed to determine the effect of lateral reinforcement upon the strength and deformation behaviour of brickwork piers.

2. MATERIALS

Masonry units

Light-weight concrete solid blocks 2 DF (German abbreviation B, length/width/height = 240/115/113 mm) and sand-lime perforated bricks 2 DF (same dimensions, abbreviation KS) were used. Compression tests according to the

pertinent standards [1] showed the following strengths:

light-weight concrete solid blocks (B): $\beta_D = 4{,}58 \frac{N}{mm^2}$

sand-lime bricks (KS): $\beta_D = 16{,}07 \frac{N}{mm^2}$

The dry volume weights were 1,02 kg/dm³ for solid blocks (B) and 1,52 kg/dm³ for bricks (KS), respectively.

M o r t a r

Two types of mortar were used which corresponded to the types IIa und III of the German Standard DIN 1053:

mortar type IIa : hydraulic-lime-cement mortar

" " III : portland-cement mortar.

The sand was common masonry sand of the grading 0,08 ... 2,0 mm. Water was added für good workability of the mortar. Mortar prisms conforming [2] were tested. The results are listed in Tab. 1.

Tab. 1: Eigenschaften und Festigkeiten der verwendeten Mörtel.
Characteristics and strengths of mortars.

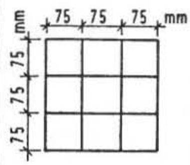
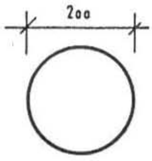
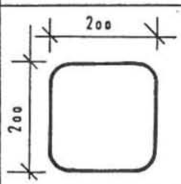
Mörtel-gruppe Type of mortar	Mischungsverhältnisse nach Gew.-Teilen Zement: P-M-Binder-Sand mortar mix by weight cement: masonry cement:sand	Wasser/Zement-Fakt. water/cement-ratio	Abmessungen der Prismen dimensions of prisms cm	Alter Tage age days	Druckfestigkeit compressive strength N/mm²	Biegezugfestigkeit flexural tensile strength N/mm²
IIa	1 : 2 : 8	0,41	4 / 4 / 16	28	10,1	2,69
III	1 : 0 : 4	0,50	4 / 4 / 16	28	20,8	2,83

R e i n f o r c e m e n t

Reinforcement of each pier consisted of either quadratic or round hoops or a steel wire mesh laid in every horizontal joint. Types of steel included types I und IV which are commonly used in Germany.
For more details see Tab. 2.

Tab. 2: Horizontale Fugenbewehrung

Reinforcement of horizontal joints

Bewehrung Reinforcement		Durchmesser diameter mm	Stahlsorte nach DIN 488 type of steel acc.to DIN 488	Streckgrenze yield point N/mm²	Zugfestigkeit tensile strength N/mm²	DMS-Meßstellen pro Pfeiler strain gauges measuring points per pier
Netz mesh		3	IV G	500	550	-
Bügel hoop		6	I G	220	340	4
Bügel hoop		6	I G	220	340	4

3. SPECIMENS AND TEST PROGRAMME

The test specimens (Fig. 1) were 240/240/1750 mm (width/length/height) i.e. 14 layers with an average brick height of 113 mm and a mortar thickness of 12 mm. After the columns were completed they were capped with a thin layer of gypsum. The storing conditions consisted of a temperature of 10° to 17° Celsius and a relative humidity of 50 to 70%. Testing of all specimens took place after 28 to 29 days. Strains were measured vertically spanning over 1 or 4 joints, horizontally spanning over one vertical joint or just transversing the brick.

The testing programme comprised all possible combinations of the mentioned materials with the three types of reinforcement including the plain piers. The expected ultimate load was applied in increments of 10 steps. Prior to final loading specimens were tested cyclically five times up to about 40% of the ultimate load, so as to determine the plastic deformations of the piers under working stress conditions. The 6th loading was then extended until failure occurred. Loads were applied axially; exact inducing of the load was furnished by hinged calottes which topped both ends of the piers.

4. TEST RESULTS

M o d e o f f a i l u r e

Two distinct types of failure, one for the unreinforced and one for the reinforced piers, could be observed whilst only insignificant differences in failure were recorded among groups of different types of bricks and different types of mortars. All unreinforced piers splitted vertically along the joints and straight through the brick extending over nearly the complete height of the column. The reinforced piers however, showed local spalling of the bricks which was distributed unregularily over the complete specimen and, in some cases occurred at the same time at different locations on the column.

The perforation of the sand-lime bricks caused larger portions to be spalled off than in the case of the light-weight-concrete blocks. In general, the failure modes in both characteristical shapes observed were not dependent on types of bricks or mortars. A special occurance was recorded in the case of the sand-lime bricks reinforced with round hoops: portions of bricks spalled outside the ring zone leaving the inner core unharmed. Other investigators [3,4] report that this core could sustain a certain amount of re-loading which however was not carried out here because of the inclined position of the pier after failure.

The wire mesh was the only reinforcement to show distinct visible deformations. The expanding mortar produced an outward bending of the steel rods between the welded knots of the mesh; this in some cases yielded the rupture of the welded knots at the outer part of the mesh.
The hoops did not show visible deformations.

Effect of the lateral joint reinforcement

Lateral reinforcing of the piers resulted in different increases of ultimate load considering the test groups listed in Tab. 3. In combination with type IIa mortar mesh reinforcement and hoops enhance the ultimate load by about 15%, regardless of the type of brick. In case of the type-III-mortar specimens the sand-lime brick piers reach values of 20 and 24%. The quadratic hoops reinforcing the light-weight-concrete block piers reduced the failure load whereas a slight increase was noted for the sand-lime brick piers. The strength increase of the mortar-III-piers compared to the corresponding mortar-IIa-piers lay between 4 to 12% for both types of bricks and did not depend on the reinforcement. No dependence on any reinforcement could be stated comparing the sand-lime brick piers with the corresponding concrete block piers; this increase is represented by a constant factor of 3,5 on an average.

These results confirm the well-known fact that masonry strength is far more affected by the strength of the brick than by the mortar strength. This is not altered by the use of lateral joint reinforcement.

Prior to final loading the specimens were cyclically loaded five times up to 40% of their expected failure load in order to determine the plastic deformations occurring within the working stress. After 3 to 4 cycles a constant deformation was established which did not change during the following cycles. These pre-deformations were neither dependent upon the type of mortar nor upon the type of reinforcement but were 0,05‰ for concrete block piers and 0,1‰ for sand-lime brick piers, respectively.

Referring to the stress-strain-relationship a distinct influence could be recorded for the test groups sand-lime brick-mortar-III and concrete-blocks-mortar-IIa (Fig. 2..5). The graphs show - and again not dependent on the type of reinforcement - in their lower part a much steeper inclination for the reinforced columns than for their unreinforced counterparts; thus for longitudinal strains up to half the ultimate load and for lateral strains up to 0,6 ... 0,7 the ultimate load a linear stress-strain relationship can be adopted with good approximation. The graph also makes plain the strangling effect of the round hoops and the mesh reinforcement which reduces the lateral strains to 50% of the corresponding value of the unreinforced pier. For the test groups concrete-blocks-mortar-III as well as sand-lime-bricks-mortar-IIa no significant changes in the stress-strain relationship caused by reinforcement were obtained.

The author of [5] reports that the testing procedure - application of the load in equal increments of forces or strains, load increase continously or in steps - affects considerably the exact determination of the ultimate load. This was confirmed herein when some specimens suffered complete damage while the load was stopped for strain reading. It has been concluded therefore that on establishing a qualifying design criterion for a column the longitudinal and lateral deformation behaviour evaluated in the lower range of loading should be considered en lieu of the failure load.

Stresses of the lateral hoops were measured by strain gauges. Fig. 6 shows the idealised stress-strain-curve for the type of steel used according to the German standard DIN 1045 and the highest stress attained in test. It indicates that at failure load the steel had reached one third of its yield strength whereas the tensile strength of the bricks was already exploited.

This may be due to the fact that the grade of lateral restraint is limited because the mortar tends to flow over the steel rod which is not as thick as the mortar joint or, in the case of the quadratic hoops, the rods do not promote a high strangling effect by lack of sufficient bending stiffness.

5. CONCLUSIONS

1. Comparing the reinforced to the unreinforced masonry piers a completely different failure pattern is to be noted. The unreinforced piers splitted vertically along the joints and straight through the brick whereas failure of the reinforced columns was led off by local crushing without collapsing. A characteristic of all tests was the abrupt failure without any preliminary warning; earliest visible cracks occurred at about 80% of the ultimate load.

2. The assumption based on theoretical findings that horizontal joint reinforcement would increase the bearing capacity of axially loaded masonry piers was confirmed by the tests. To provide this increase the reinforcement has to be capable of restraining the horizontal expansion of the mortar thus reducing the tensile stress of the bricks perpendicular to the direction of loading.

3. Mesh wires and round hoops proved to be the most efficient shapes for reinforcement. The greatest increase of 24% of the plain column strength was obtained at pier N° 16 (sand-lime brick, mortar III, mesh). The quadratic hoops used had little if any effiency due to their low bending stiffness between corners. Enhancement of strength which is valid for all types of mortars and bricks tested was observed only for mesh wire reinforcement. Nevertheless the test results permit the assumption that not only mesh reinforcement but also round hoops in combination with cement mortar and bricks having some higher strengths will give strength increases of distinctly more than 20%.

4. Different brick and mortar strengths used in piers with the same type of reinforcement had different effects. Comparing the strength increases among the reinforced piers to those among the plain piers for concrete-block columns no influence of the type of mortar is to be stated but for the sand-lime brick piers mortar III had a more considerable effect than did mortar IIa.
   The brick strength itself affected the pier strength in the same way for all reinforced and unreinforced piers.

5. Plastic deformations obtained after several loading cycles within the working stress were 0,05 ‰ for concrete-block piers and 0,1‰ for sand-lime brick piers. This was the case for both reinforced and unreinforced types of specimens.

6. Some of the reinforced piers exhibited stress-strain-curves which were considerably steeper than those of the corresponding plain piers.

   The lateral deformation of those unreinforced columns could be reduced by 50% reinforcing the horizontal mortar joint.

7. The test results indicate that longitudinal and lateral strains obtained in the lower range of the stress-strain diagrammes are more suitable for clasifying a masonry pier than the failure load which depends to a great extent on the testing procedure.

8. Tests are being continued. Topics of further investigations will be the influence of other kinds of bricks, types of reinforcement, percentages of hooping and slenderness ratios upon the strength and deformation behaviour of masonry piers.

REFERENCES

[1]	DIN 106 DIN 18152	Kalksandsteine Vollsteine und Vollblöcke aus Leichtbeton
[2]	DIN 1164	Teil 7 Portland-, Eisenportland-, Hochofen- und Traßzement Bestimmung der Festigkeit
[3]	Withey, M.O.	Tests on Reinforced Brick Masonry Columns ASTM Proceedings 1934
[4]	Hilsdorf, H.	Bewehrtes Ziegelmauerwerk Bericht Nr. 33, MPA für das Bauwesen der TH München 1962
[5]	Schneider, H.	Tragfähigkeit und Verformungsmodul von Mauerwerk mit neuen Mörtelgruppen Forschungsbericht Nr. F 1531 IRB, Stuttgart

Tab. 3 Versuchsergebnisse
Test results

Nummer Number	Mörtelgruppe Bewehrung type of mortar reinforcement	Bruchlast ultimate load KN	Bruchspannung ultimate strength N/mm²	Steigerung gg.über unbew.Pfeiler Increase compared to unreinf.piers %	Steigerung gg.über MG IIa Increase compared to mortar IIa piers %	Bruchlast KS / Bruchlast B Failure load KS / Failure load B
B 1	IIa o.Bew. no reinf.	192,5	3,34	0		
B 3	IIa Netz mesh	220,5	3,83	15		
B 5	IIa o	212,9	3,70	11		
B 6	IIa □	174,8	3,03	- 9		
B 7	III o.Bew. no reinf.	207,8	3,61	0	8	
B 8	III Netz mesh	235,5	4,09	13	7	
B 9	III o	213,3	3,70	3	0	
B 10	III □	169,1	2,94	-19	-3	
KS 11	IIa o.Bew. no reinf.	620,2	10,77	0		3,2
KS 12	IIa Netz mesh	711,7	12,36	15		3,2
KS 13	IIa o	722,0	12,53	16		3,4
KS 14	IIa □	643,9	11,18	4		3,7
KS 15	III o.Bew. no reinf.	643,8	11,18	0	4	3,1
KS 16	III Netz mesh	798,1	13,86	24	12	3,4
KS 17	III o	773,4	13,43	20	7	3,6
KS 18	III □	671,6	11,66	4	4	3,9

Bild 1:
MESSANORDNUNG

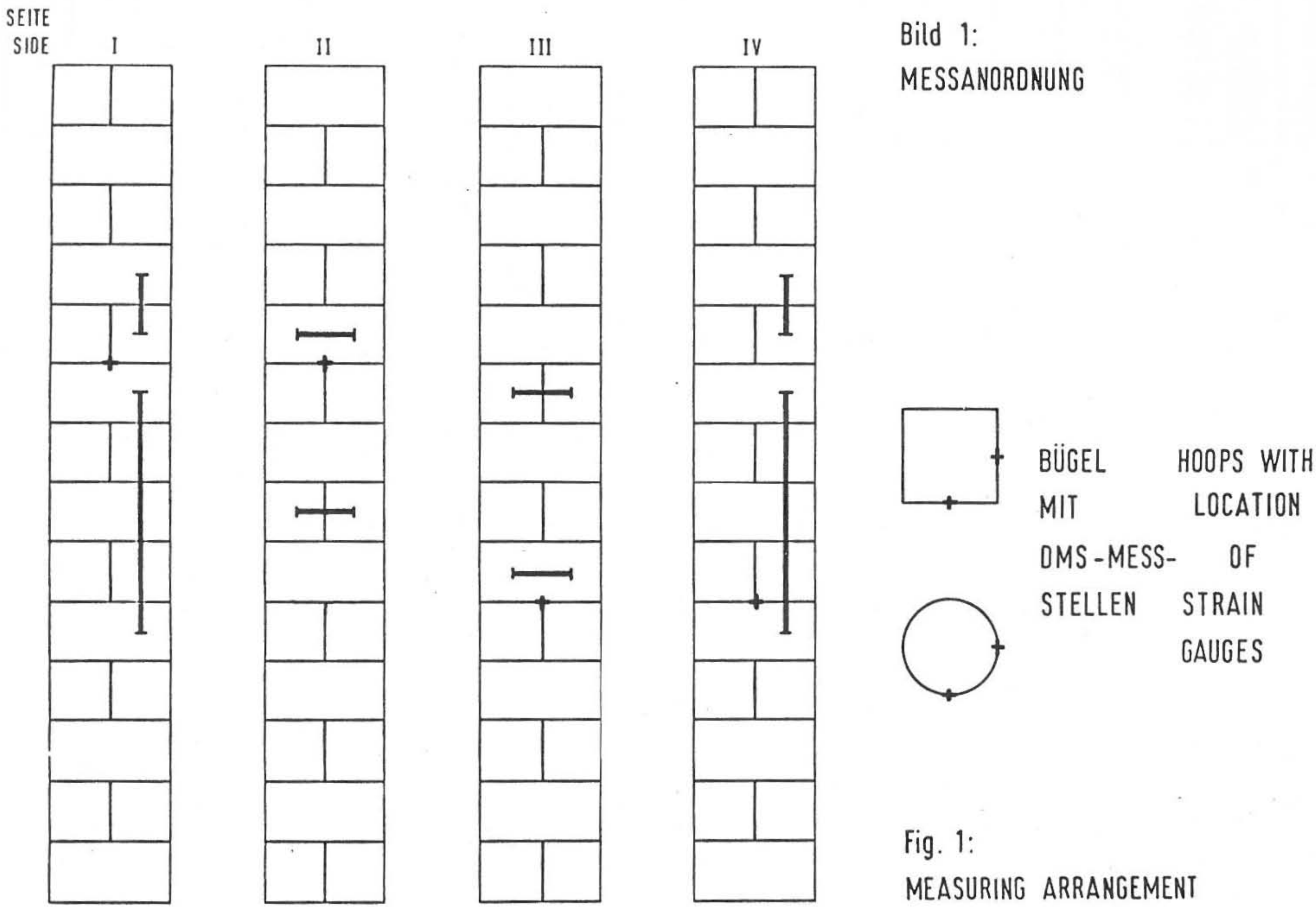


Fig. 1:
MEASURING ARRANGEMENT

Bild 2:

SPANNUNGS - DEHNUNGS - DIAGRAMM

BIMS MG IIa

Fig. 2:

Stress-strain-diagram

Lightweight-concrete blocks mortar IIa

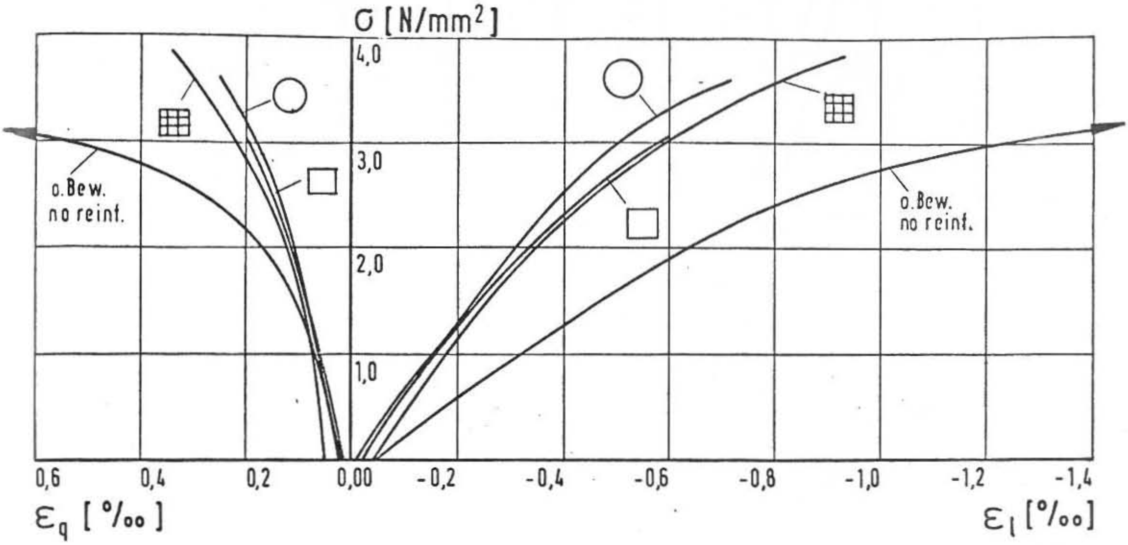


Bild 3:

SPANNUNGS-DEHNUNGS-DIAGRAMM

BIMS MG III

Fig. 3:

Stress-strain-diagram

Lightweight-concrete blocks mortar III

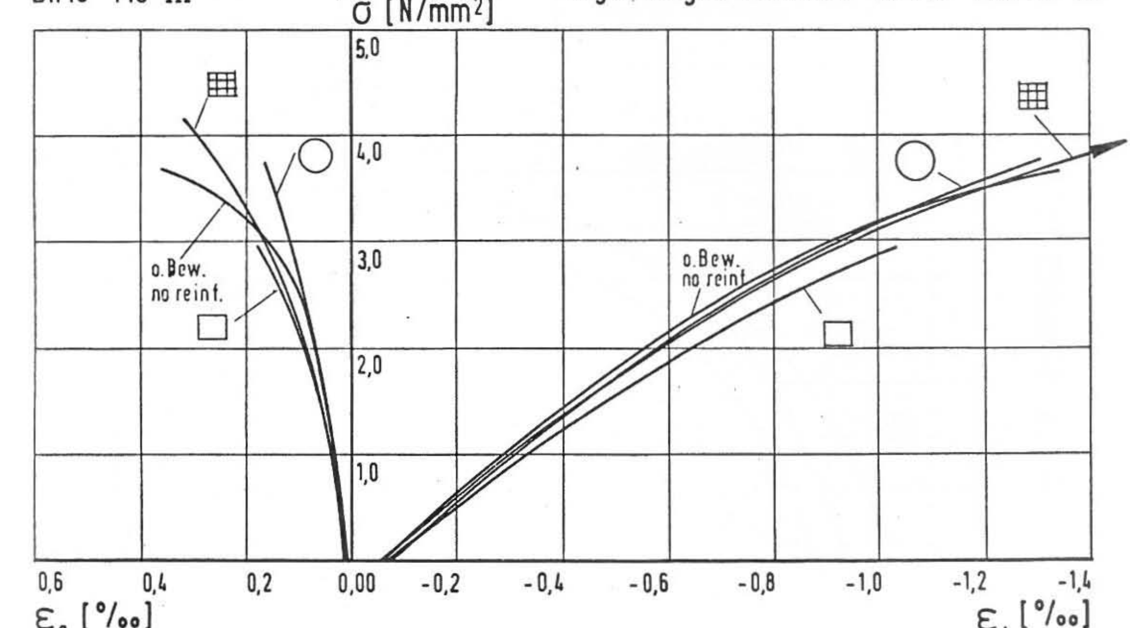


Bild 4: SPANNUNGS-DEHNUNGS-DIAGRAMM KALKSANDSTEINE MG II a

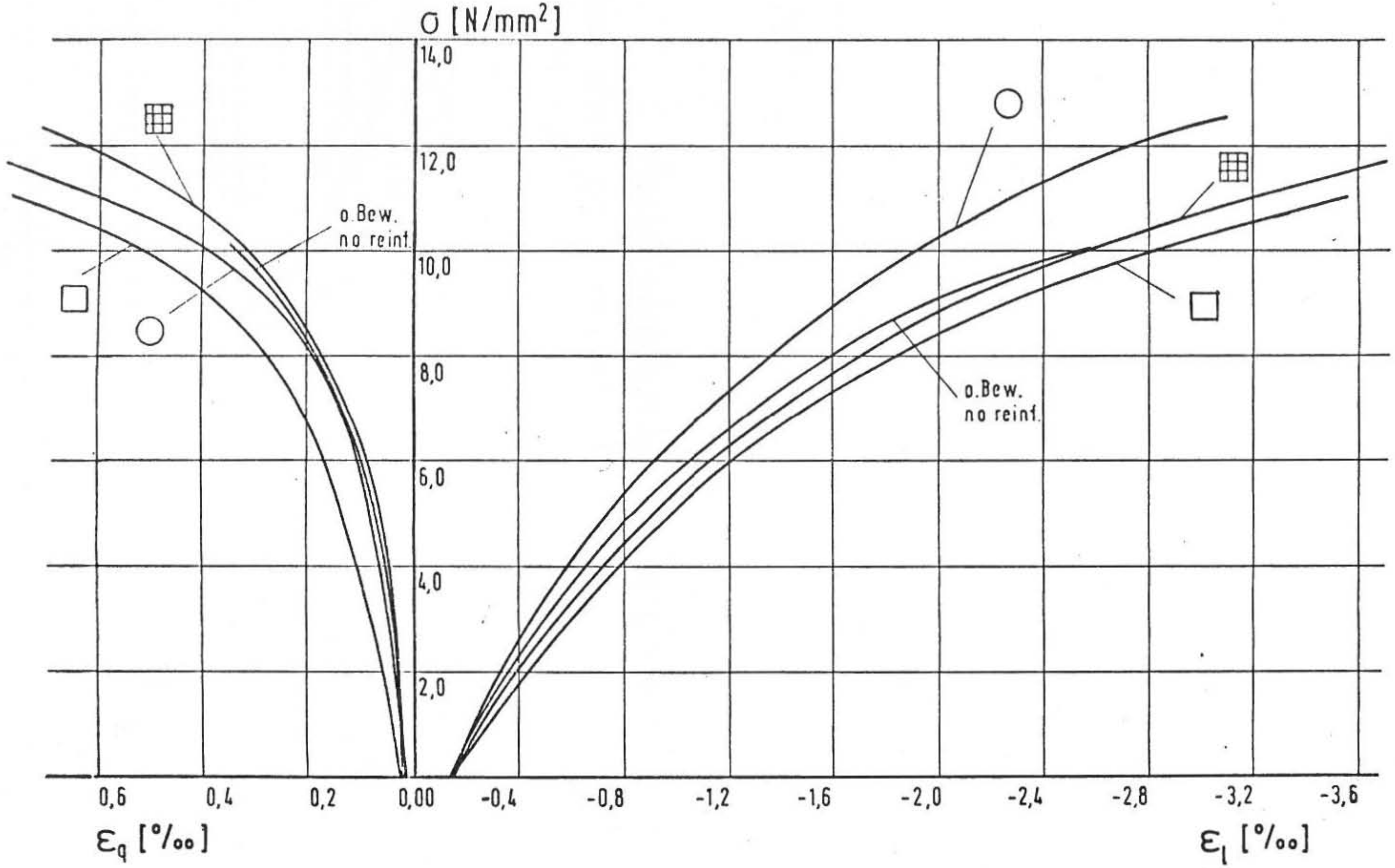


Fig. 4: Stress-strain-diagram

Sandlime bricks mortar II a

Bild 5: SPANNUNGS - DEHNUNGS - DIAGRAMM KALKSANDSTEINE MG III

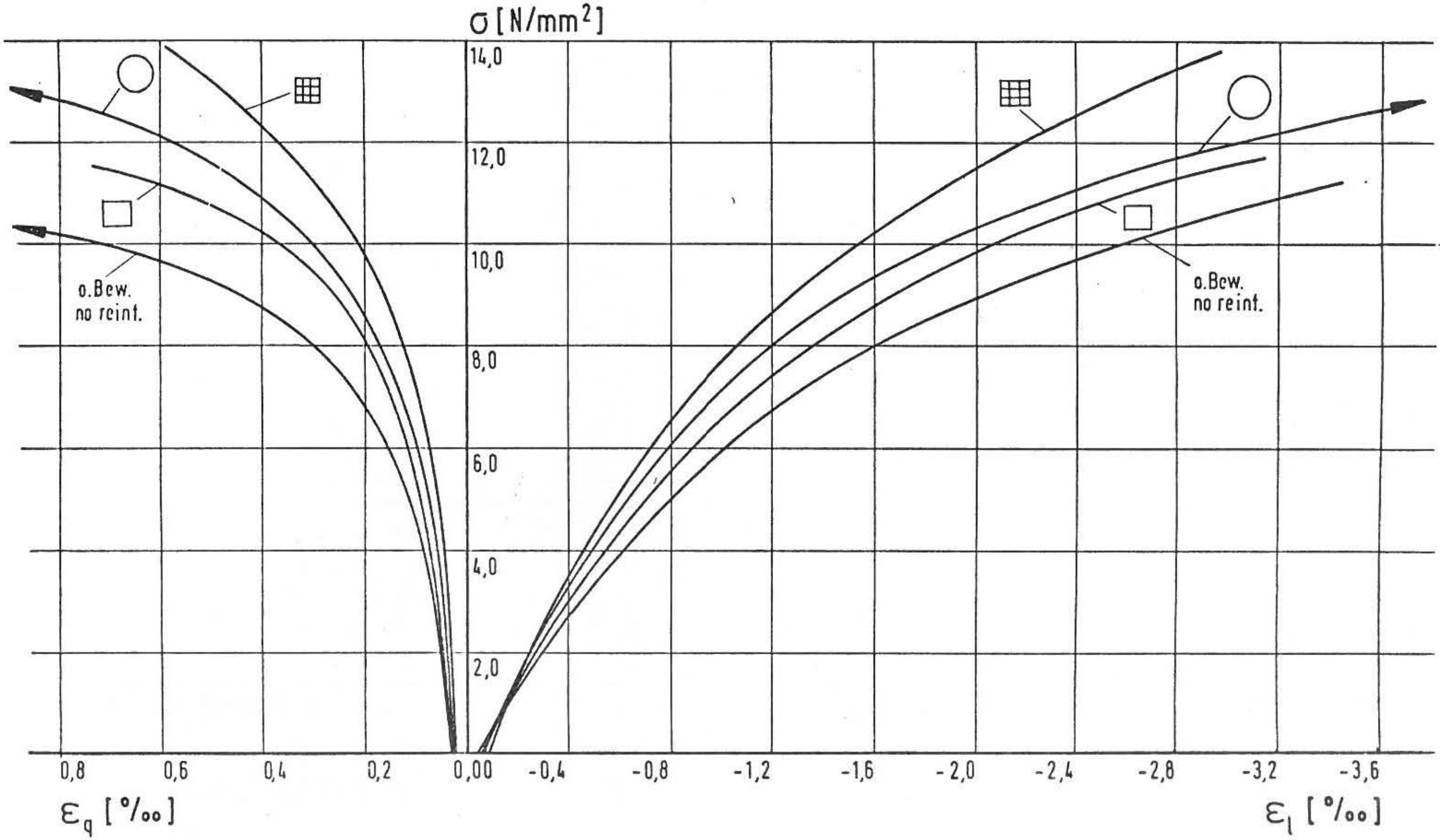


Fig. 5: Stress-strain-diagram Sandlime bricks mortar III

Bild 6:

AUSNUTZUNG DER HORIZONTALEN BÜGEL

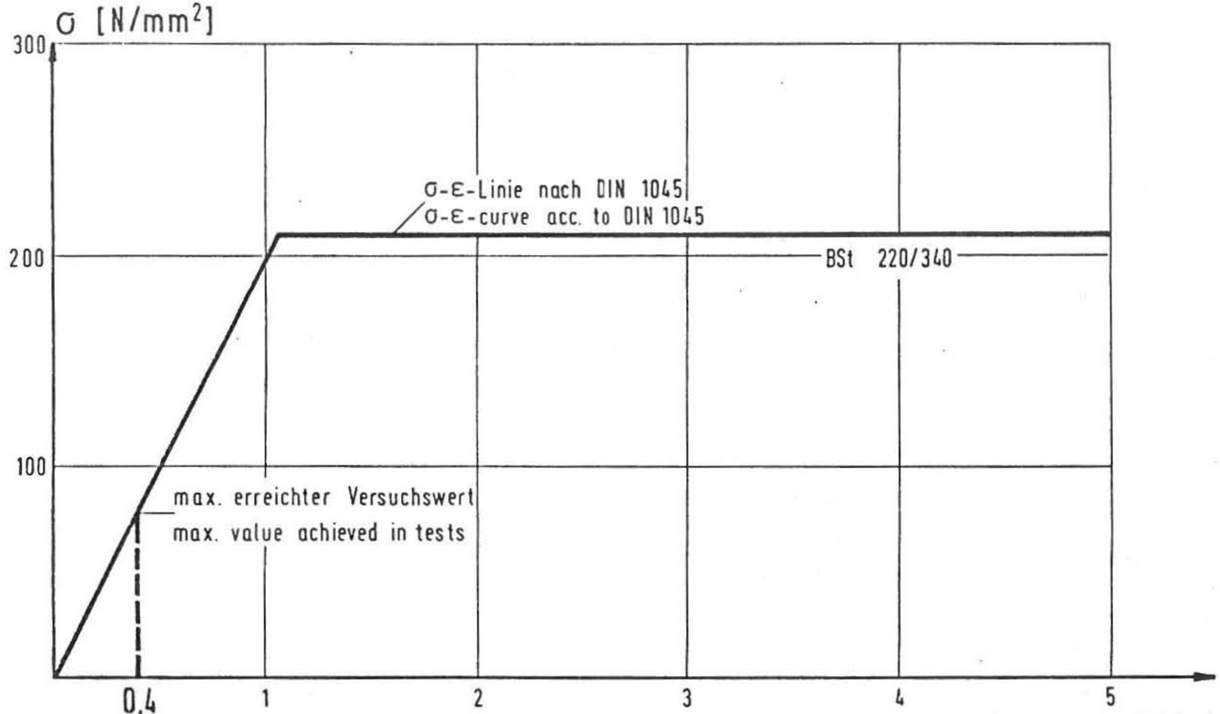


Fig. 6:

Stress-strain relationship of hoops