Enhanced Ductility of Masonry loaded in Compression

C. Flohrer, H.K. Hilsdorf, Institut für Baustofftechnologie,
University of Karlsruhe (Deutschland)

1. Introduction

Compared to reinforced concrete, masonry may have a number of advantages, the most significant among them being its thermal insolation properties. However, for engineering type structures masonry may be less suitable.

Presently, in Germany various efforts are being made to widen the scope of applicability of masonry particularly for highly stressed engineering structures. Specifications required for engineering design have been developed (1).

For such structures high strenth masonry is required which may be achieved by the use of high strength masonry units and high strength mortar as well as by particular care in quality control und supervision of construction. However, a decisive disadvantage of high strength masonry compared to reinforced concrete is its lack of ductility and an almost explosive type of failure when loaded in compression. When brittle materials are used in construction higher safety factors or required compared to those necessary for ductile materials. This in turn leads to higher over all costs. Therefore, efforts are being made to improve the ductility of high strength masonry. Possibilities of accomplishing this are discussed in this paper.

2. Theoretical considerations

The failure mechanism of masonry has been delt with in various studies (2,3). From this it follows that in a masonry unit loaded in compression lateral tensile stresses occur. These tensile stresses are counteracted by lateral compressive stresses in the joints. Furthermore, the stresses in the direction of the external load frequently are not distributed uniformly resulting in local stress concentration and premature cracking and crack propagation in the masonry units. Reinforcement of the bed joints restrain the lateral strains of the mortar and thus reduce the lateral tensile stresses in the masonry units. Furthermore, local stress concentrations may be reduced. Very closely spaced

reinforcement such as thin fibres or wire mesh may inhibit propagation of cracks in the masonry units. Inhibited crack propagation and reduced crack width results in a more uniform stress distribution and leads to the formation of many closely spaced and narrow cracks rather than a few wide cracks. Such crack behavior may lead to an increased compressive strength but more important to an improved ductility. At the same time explosive failures may be avoided. This mechanism, however, can become effective only if there is sufficient bond between the reinforcement and the joint material as well as between the joint material and the masonry units.

3. Types of joint reinforcement

It has been pointed out already that evenly distributed and closely spaced reinforcement should be particularly effective in enhancing the load carrying properties of masonry. Such reinforcement material may be fibers or closely spaced wire mesh. Furthermore, it may be of advantage to have a higher percentage of reinforcement in the direction of the smaller dimension of the cross-section of the masonry, because according to (3) lateral tensile stresses in the masonry units are larger in this direction. Apparently, uniform distribution of stresses and inhibition of crack propagation may be accomplished only if the percentage of reinforcement is sufficient. This has to be studied by theory and by experiments.

4. Experimental studies

In (6) experiments on masonry made of glass fiber reinforced mortar joints are presented. The studies described in the following are an extension of this work. In the first part suitable materials for plain or fiber reinforced mortars have been tested. Then studies on masonry units have been carried out in order to determine the strength and deformation characteristics of reinforced masonry loaded in compression. In the first series masonry units have been made of sand-lime bricks and fiber reinforced mortars. In the second series sand-lime bricks as well as clay bricks have been used together with mortars reinforced with metallic reinforcement.

4.1. Tests on mortars

In preliminary experiments three types of mortars (IIa, III, III a) of various strengths have been studied. The mix proportions as well as the compressive and flexural strength are given in the following table.

The fiber reinforced mortars which are described in section 4.3 have the same composition. However, in order to take into account the increased water requirement of fiber reinforced mortars, water reducers have been added to the mortar. The gradation of the sand is given in Fig. 3.

Mortar	mix proportions by volume lime - portland-cement-sand	water/ cement	flexural strength MN/m^2	compressive strength MN/m^2
II a	1 : 1 : 6,5	1,82	1,26	5,34
III	0 : 1 : 4,5 : 0,2 flyash	1,25	3,43	11,83
III a	0 : 1 : 3,2	0,92	4,24	20,43

4.2. Tests on masonry units

Two types of sand-lime bricks and two types of cored clay bricks have been studied so far. Their designation according to the German specifications (4,5), dimensions, compressive strength, unit weight and water absorption are given in the following table.

Type of masonry unit	Dimension lxbxh mm	Compressive strength MN/m^2	Unit weight kg/dm^3	Water absorption $g x min/dm^2$
clay bricks:				
HLz 20	237x115x 111	55,4	1,12	12.34
HLz 36	245x115x 115	41,5	1,26	11,27
sand-lime bricks				
KSL 20 (cored)	239x114x 112	21,2	1,51	15,01
KSV 60 (solid)	240x114x 112	62,7	2,0	4,35

4.3. Reinforcement

The various types of reinforcement, their diameter as well as the percentages of reinforcement are related to the volume of mortar summarized in the following table. In addition to CEM-FIL glass fibers and galvanized wire mesh, also conventional prefabricated masonry reinforcement has been used which consists of 2 reinforcing bars, diameter 5 mm and of diagonals, diameter 3 mm connecting both bars.

Type of reinforcement	Notation	Wire diameter mm	Mesh size mm	Number of layers	Percentage of reinforcement percent by volume
CEM FIL-Fibers 12 mm	KF	-	-		1.5
CEM FIL-Fibers 24 mm	LF	-	-		1.5
Hexagonal wire mesh	H-2	0,7	-	2	1.36
Square wire mesh	5-2	0,55	5	2	1.44
Square wire mesh	8-1	0,8	8	1	0,97
Square wire mesh	8-2	0,8	8	2	1.94
Masonry reinforcement	M	5		-	3.35

4.4. Masonry

The strength and deformation characteristics of reinforced masonry loaded in compression have been studied on specimens shown in Fig. 4 The thickness of the joints was 12 mm. Longitudinal strains have been observed with two inductive strain gages over a gage length of 250 mm on opposite sides of the specimens. Lateral strains have been measured over a length of 150 mm in the center of the specimen. In order to observe the poste failure behavior of the specimens also the displacement of the load bearing platens of the testing machine have been measured. The specimens have been subjected to a constant strain rate of 0.5×10^{-3} mm/m$\cdot$min.

The specimens were stored for 7 days at 20°C and 95 percent RH. Subsequently they have been kept in a constant environment of 20°C and 65 percent RH. They were tested at an age of 28 days.

The experimental program on masonry carried out so far is summarized in the following table:

Series	Masonry unit/ mortar	Metallic reinforcement						Fibers	
		-	8-1	8-2	5-2	H-2	M	12 mm	24 mm
Series1	KSL 20/IIa	x						x	x
	KSV 60/IIIa	x						x	x
Series2	HLz 20/IIa	x	x	x	x	x	x		
	HLz 20/III	x	x	x	x	x	x		
	HLz 36/III	x	x	x	x	x	x		
	KSL 20/III	x	x	x	x	x	x		

Three specimens have been tested for each combination of parameters. So far 3 x 30 specimens have been studied.

4.5. Experimental results

4.5.1 Series 1: Fibers reinforced sand-lime brick masonry

The results of series 1 are summarized in Table 1. Stress-strain diagrams as observed on the specimens are given in Figs.1 and 2. From the figures as well as from column 2 in Table 1 it follows that the use of fiber mortar rather than conventional mortar did not lead to an increase of strength of the specimens. In column 3 the strains at meximum stress measured between the bearing platens are given. Column 4 and 5 give the strains of the descending part of the stress-strain diagramm at stresses of two thirds and of one third of the maximum stress. From these results it follows that no substantial improvement of ductility could be obtained through the use of fiber reinforcement.

4.5.2 Series 2: masonry with metallic reinforcement

The results of series 2 are summarized in Table 2: The data of Column 2 indicate that joint reinforcement of masonry made of sand-lime bricks did not result in an improvement of strength,

whereas a substantial increase of strength has been observed for masonry made of clay bricks and reinforced with wire mesh. With one exception no strength increase was obtained for the conventional type of joint reinforcement. No clear trend regarding the effect of percentage of reinforcement and wire spacing for the wire mesh reinforcement is apparent so far.

The stress-strain diagrams of series 2 are given in Figs. 5 through 8. The strains given therein are those obtained from measurment of the displacement of the bearing platens of the testing machine. Fig. 5 shows the stress strain diagrams of the masonry made of clay bricks HLz 20, combined with a cement-lime mortar IIa. From this diagram as well as from Table 2 column 3 it follows that the strains at maximum stress are slightly larger for reinforced specimens than for plane specimens. However, the strains in the descending part of the stress-strain diagram at two third (column 4) and at one third (column 5) of the maximum stress are substantially increased by the reinforcement. Similar observations have been made for the combination of HLz 20 and a cement mortar (Fig. 6) and for HLz 36 and a cement mortar (Fig. 7). Thus the ductility of the specimens has been substantially enhanced by the wire reinforcement. There is a general trend that the ductility increases as the percentage of reinforcement increases. An exception to this is the conventional masonry reinforcement which did not result in a significant improvement of ductility.

As hypothesized in section 2 the wire-reinforced masonry made of clay bricks showed substantially more cracks with smaller crack width than those observed on the plane specimens. In the wire-reinforced masonry made of sand-lime bricks only a few cracks with a large crack width developed. These studies are being continued. They are supplemented by theoretical studies. At this stage it appears that in materials used so far the bond strength between mortar and sand-lime bricks is not sufficient to ascertain closer crack spacing in the masonry units.

5. Summary

5.1 In contrast to experiments on clay brick masonry (6) fiber reinforcement of masonry made of sand-lime bricks did not result in a significant improvement of compressive strength and ductility.

5.2 The use of conventional prefabricated masonry reinforcement with large bar diameters led to an increase of compressive strength only in one of three cases. There was no substantial difference between the stress-strain diagrams for plane and conventionally reinforced masonry loaded in compression.

5.3 Wire mesh reinforcement of masonry made of clay bricks resulted in a strength increase up to 28 percent. The ductility expressed by the strains in the descending portion of the stress-strain diagrams has been improved substantially particularly for specimen with a high percentage of wire-reinforcement.

5.4 In all cases in which the ductility had been improved by wire-reinforcement an explosive type failure normally observed on plane specimens has been avoided. The crack propagation has been inhibited and failure developed only gradually.

6. References

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Table 1: Results of Series 1 : Fiber reinforced sand-lime brick masonry

1	2	3	4	5
masonry/mortar/ Fibers	Compressive stress MN/m²	strain at ultinate (platens) ‰	strain at 2/3 of ultinate ‰	strain at 1/3 of ultinate ‰
KSL 20/III/ -	12,99	4,13	4,68	4,96
KSL 20/III/KF	12,67	3,86	4,69	4,95
KSL 20/III/LF	12,13	3,86	4,62	5,16
KSV 60/III/ -	34,73	7,53	8,59	8,65
KSV 60/III/KF	35,11	7,79	8,53	8,93
KSV 60/III/LF	34,35	7,38	8,11	8,65

Table 2: Results of Series 2: masonry with metallic-reinforcement

1	2	3	4	5
masonry/mortar/ reinforcement	Compressive stress MN/m²	strain at ultinate (platens)	strain at 2/3 of ultinate	strain at 1/3 of ultinate
KSL 20/III/ -	13,81	4,38	4,98	5,38
KSL 20/III/8-1	12,57	4,20	5,03	5,49
KSL 20/III/8-2	12,21	4,35	5,25	6,16
KSL 20/III/5-2	12,92	4,13	4,95	5,90
KSL 20/III/H-2	13,49	4,41	5,45	5,97
KSL 20/III/Mue	12,74	4,46	4,73	5,18
HLz 20/IIa/ -	10,87	3,60	4,60	5,73
HLz 20/IIa/8-1	12,94	3,77	6,10	7,99
HLz 20/IIa/8-2	13,86	3,99	6,70	8,15
HLz 20/IIa/5-2	11,57	3,52	5,84	7,55
HLz 20/IIa/H-2	12,55	3,89	5,58	7,92
HLz 20/IIa/Mue	10,36	3,48	4,40	4,70
HLz 20/III/ -	15,17	2,94	3,45	3,86
HLz 20/III/8-1	18,52	3,29	4,50	5,58
HLz 20/III/8-2	16,10	3,43	5,25	6,68
HLz 20/III/5-2	18,45	3,19	4,10	5,11
HLz 20/III/H-2	16,71	2,98	5,19	6,90
HLz 20/III/Mue	17,78	2,94	3,60	4,36
HLz 36/III/ -	15,81	3,07	3,60	4,18
HLz 36/III/8-1	16,67	3,46	4,78	6,40
HLz 36/III/8-2	17,03	3,82	6,63	8,65
HLz 36/III/5-2	16,49	3,56	5,28	6,80
HLz 36/III/H-2	16,24	3,58	5,35	7,40
HLz 36/III/Mue	16,20	3,34	3,90	4,26

FIG. 1-RESULTS OF SERIES 1 :

FIBER REINFORCED SAND-LIME BRICK MASONRY KSL20/III.

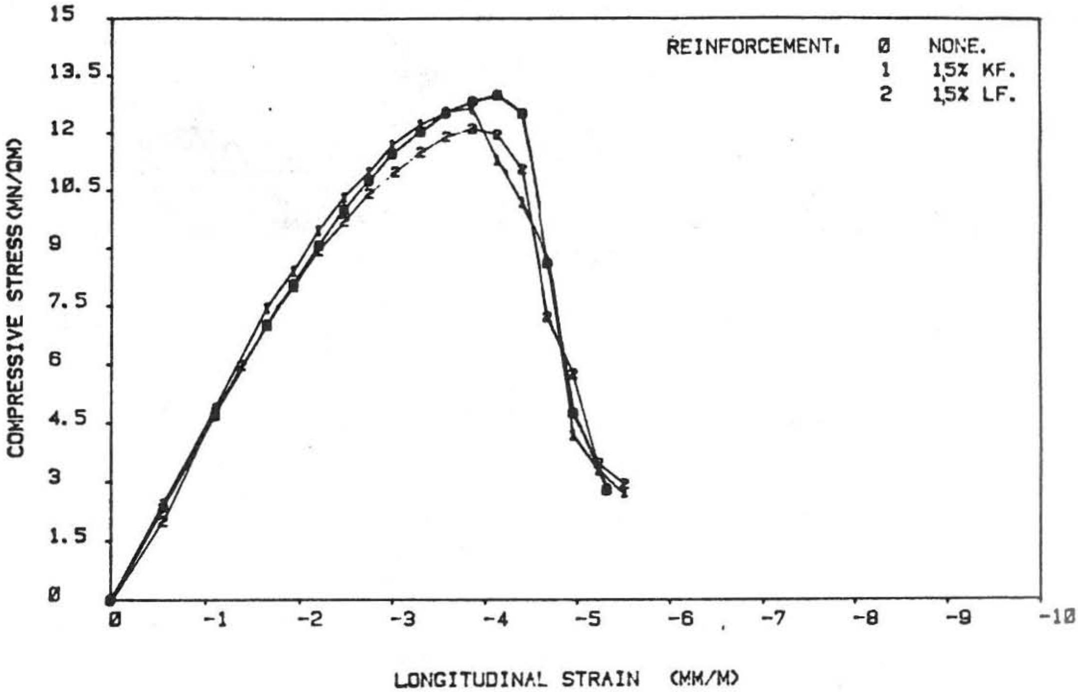


FIG. 2-RESULTS OF SERIES 1 :

FIBER REINFORCED SAND-LIME BRICK MASONRY KSV60/IIIA.

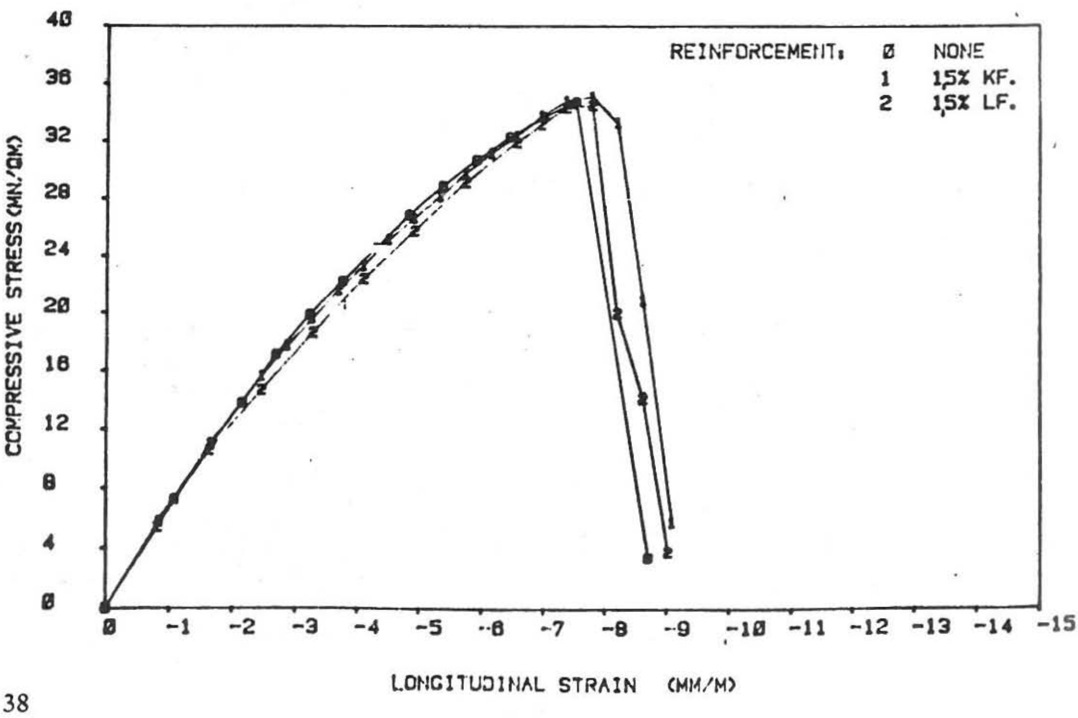
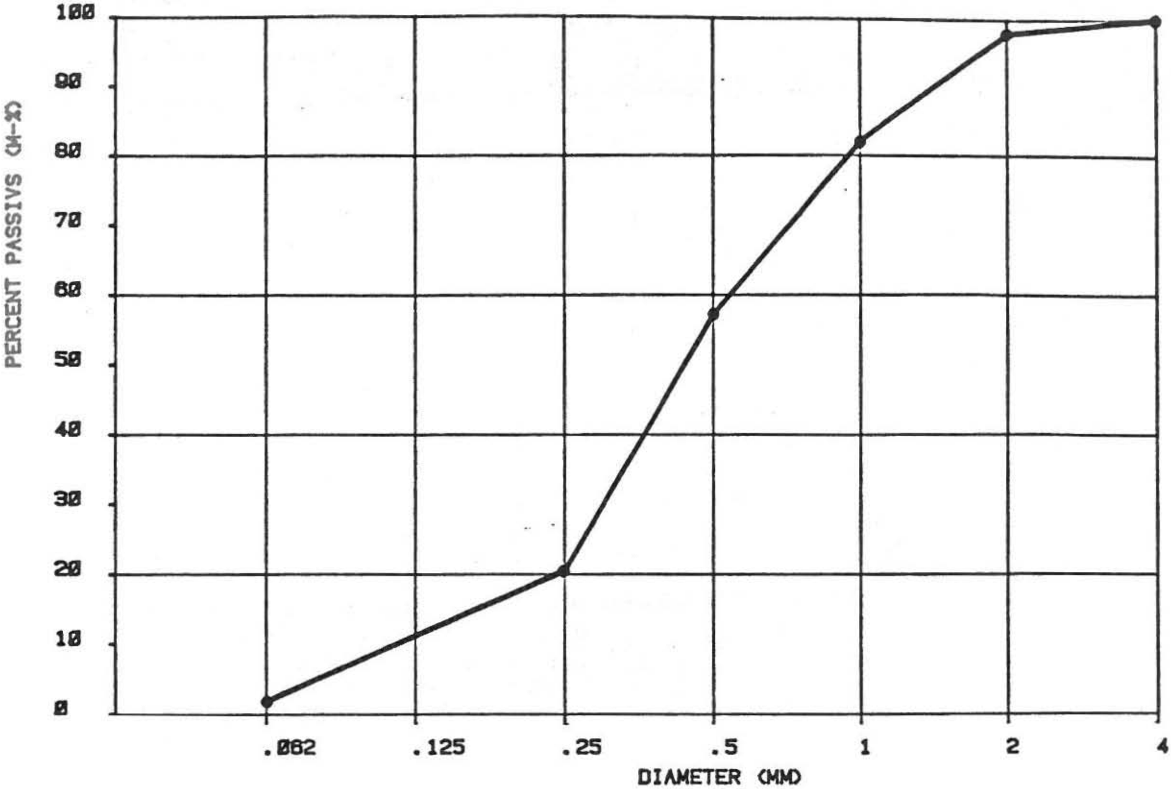


FIG. 3 - GRADATION OF SAND:



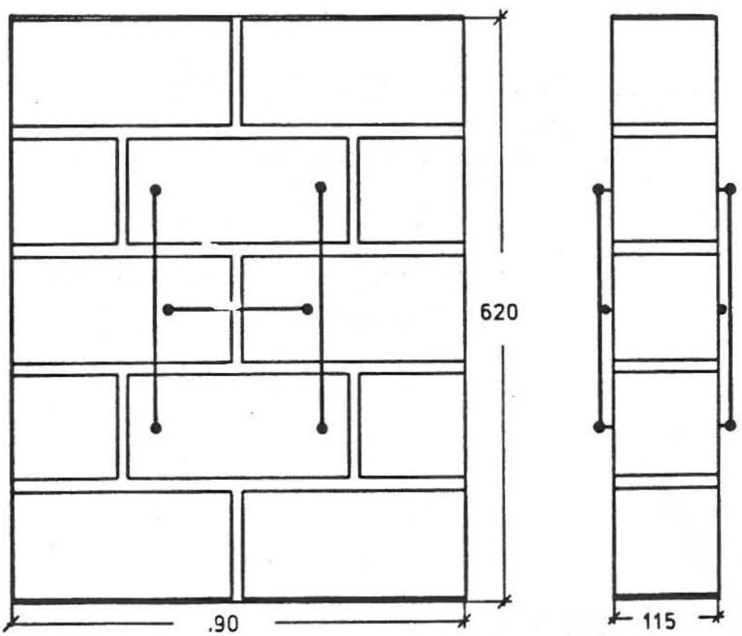


Fig. 4 : Type of specimen and location of strain measurements

FIG. 5- RESULTS OF SERIES 2 :

MASONRY WITH METALLIC REINFORCEMENT HLZ20/IIA.

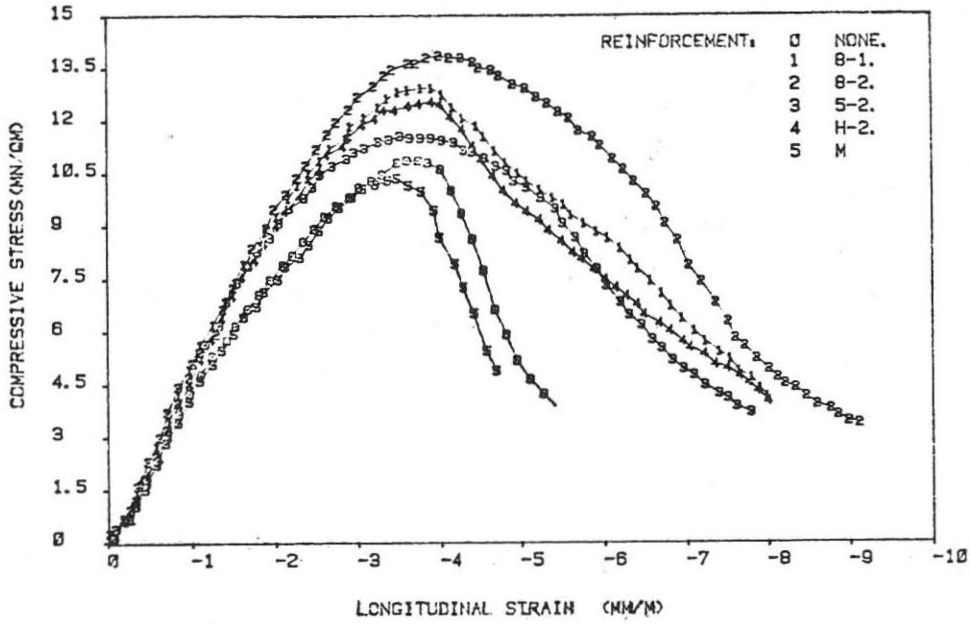


FIG. 6-RESULTS OF SERIES 2 :

MASONRY WITH METALLIC REINFORCEMENT HLZ20/III.

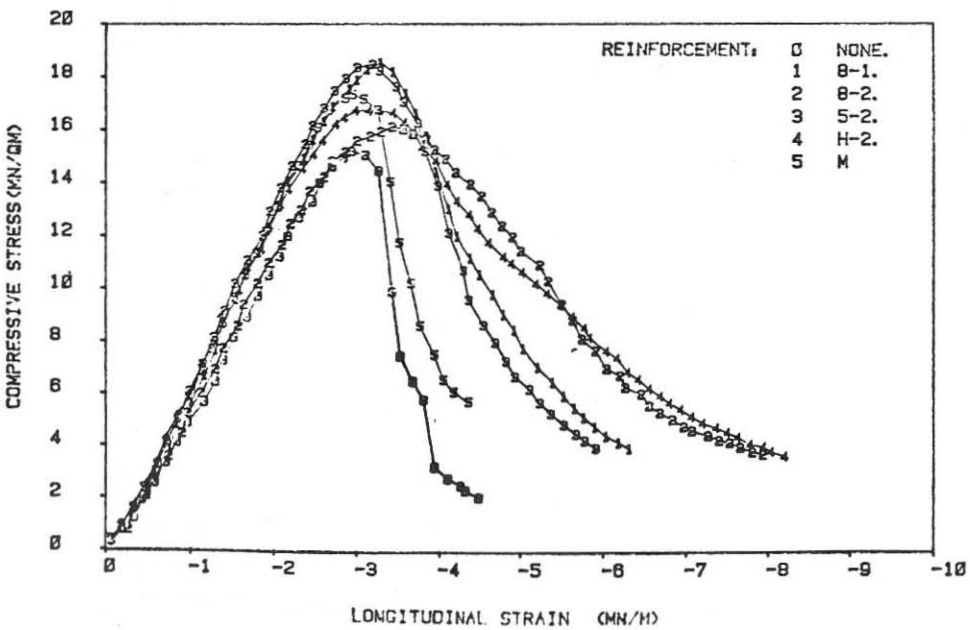


FIG. 7-RESULTS OF SERIES 2 :

MASONRY WITH METALLIC REINFORCEMENT HLZ36/III.

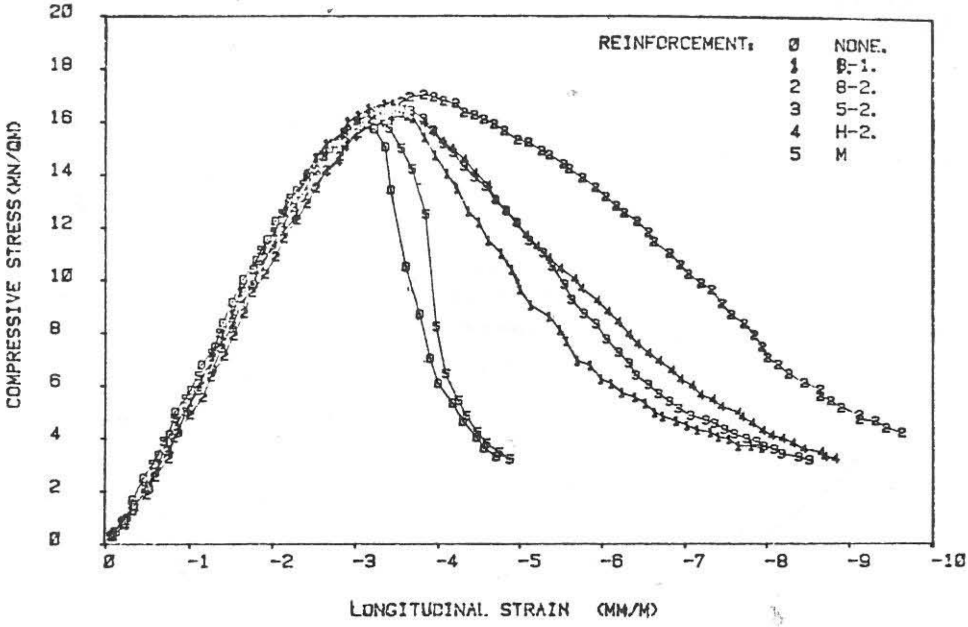


FIG. 8-RESULTS OF SERIES 2 :

MASONRY WITH METALLIC REINFORCEMENT KSL20/III.