POST-STRENGTHENING OF MASONRY COLUMNS BY USE OF FIBER-REINFORCED POLYMERS (FRP)

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Abstract

Within the scope of this paper the test results of post-strengthened masonry columns are presented. Two different types of bricks and two different types of mortars are used to produce the test specimens: vertical coring bricks and solid bricks, calcium cement and calcium mortar. The test specimens are wrapped with two types of fabrics: unidirectional carbon and unidirectional glass tapes with varying numbers of layers. In all cases a thixotropic epoxy system is used as matrix. The paper documents the first results of the load bearing behaviour of the masonry columns. For direct comparison of the load bearing capacity reference columns with the same dimensions and the same brick mortar combinations are tested. The adhesion strength of the carbon sheet on the brick surface was determined by preliminary anchorage tests.

Keywords: post-strengthening, masonry, columns, fiber-reinforced-polymers

Introduction

Reorganisation, change of use or replanning of industrial buildings might cause changes of structural systems as well as higher life loads. Preservation instead of replacement saves ecological as well as economical resources and even construction time. But in many cases preservation of load bearing structures needs strengthening due to higher stresses.

One possibility to strengthen load bearing structures is to apply fiber-reinforced polymers (FRP). For the application on masonry carbon, aramid or alkali-resistant glass fibers can be used as fabric. They are added on the load bearing walls as laminates or sheets. Often epoxy-based resins are used as adhesive.

Within the building industry the method of strengthening using FRP was mainly given in concrete construction first. Investigations by using the method of strengthening masonry walls with fiber-reinforced polymers were first realized by Schwegler [1]: based on his results, the load bearing walls of a six story building were strengthened with carbon FRP laminates [2]. Further studies about the strengthening of masonry walls in seismic endangered zones were reported by Ehsani [3,4], Saadatmanesh [5] and Velazquez-Dimas[6]. Different types of carbon fiber and glass fiber sheets were combined with different types of matrices and the position of the sheets on the walls was varied. Laursen [7] tested carbon overlays as retrofit and repair technique to mitigate seismic strength and ductility deficiencies of masonry walls. In-plane and out of-plane tests on one story walls were carried out. The shear and flexural strength of repaired, retrofitted and original masonry walls were analyzed. Triantafillou [8] studied the strength of externally bonded laminates under out-of-plane and in-plane bending and in-plane shear, all combined with axial load.

Experimental investigations on post-strengthening of reinforced concrete columns with FRP are reported by Saadatmanesh and Seible [5, 9].

It can be assumed that wrapping techniques should be even more efficient in the case of masonry columns. Therefore, 18 masonry specimens were tested under compression: 10 unstrengthened specimens to study the influence of the specimen geometry on the compression strength and 8 specimens strengthened by wrapping with various amounts of carbon fiber and glass fiber sheets for comparison.

Materials

Masonry

Two types of masonry were obtained using two different types of bricks. The solid bricks (Mz 20), had dimensions of 7,1 cm * 11,5 cm * 24,0 cm. The nominal compression strength was 20 MN/m^2 with a density of 2,0 kg/dm^3. The vertical coring bricks (HLz 12) had dimensions of 11,3 cm * 11,5 cm * 24,0 cm. The compression strength was 12 MN/m^2 with a density of 0,9 kg/dm^3.

Two different types of mortar were used: type MG I was a calcium mortar. The compression strength was found to be 1,0 MN/m^2 after 35 - 45 days. Type MG II was a calcium - cement mortar with a compression strength of 5,1 MN/m^2 after 28 days.

Brick and mortar materials were selected in order to get a good representation of existing masonry structures in Germany.

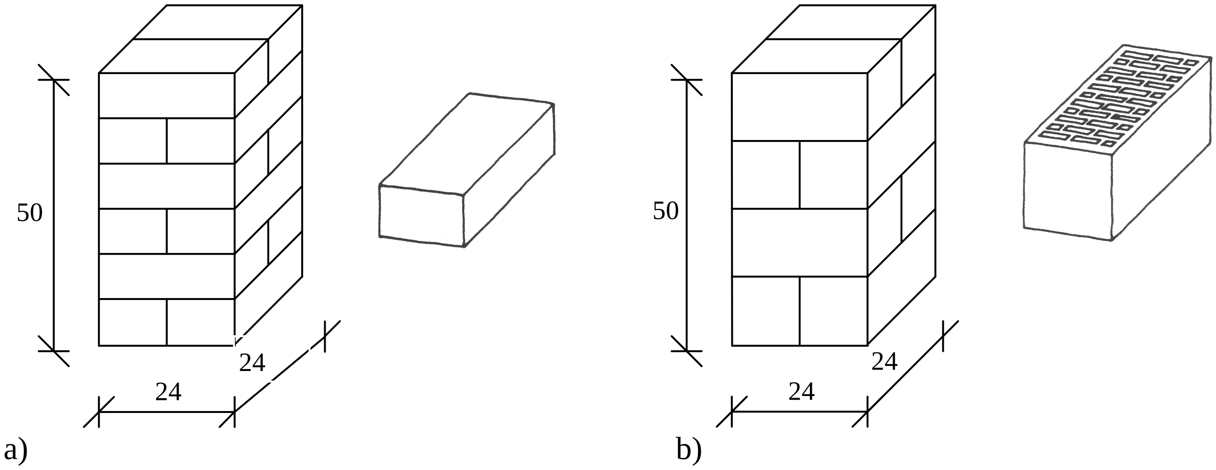

Figure 1. a) Masonry specimen type A, b) Masonry specimen type B, dimensions in cm

Fiber-reinforced polymers

For strengthening two types of carbon fiber and glass fiber sheets were used in combination with an epoxy-based resin, Figure 2.
Table 3 shows the main material parameters as given by the supplier.

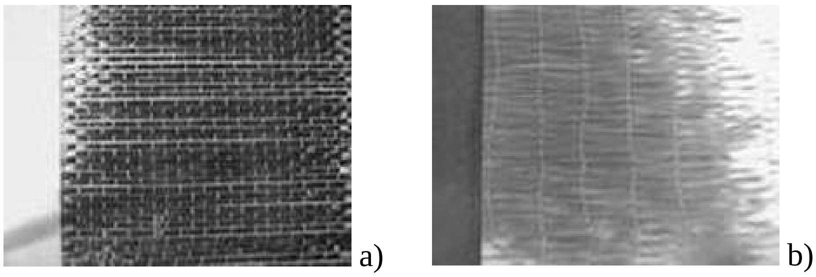

Figure 2. a) Unidirectional carbon fiber sheet, b) Unidirectional glass fiber sheet

Table 1. Material parameters of sheets and resin [12]

Material	Tensile strength	Failure strain	Young's modulus
	[N/mm^2]	[%]	[N/mm^2]
Carbon fiber sheet *Sika Wrap -230C*	3 500	1,5	230 000
Glass fiber sheet *Sika Wrap -430G*	2 250	3,1	70 000
Resin *Sikadur -330*	30	-	3 800

Masonry specimens and strengthening

Reference specimens

In order to form the experimental basis 10 specimens without reinforcement or strengthening were tested as reference. Materials, dimensions and ultimate loads are documented in Table 2 and Figure 3. The compression strength was determined under monotonic loading.

The results obtained from Rilem-specimens (Figure 3 and Table 2, geometry 1) were compared with compression strengths of square specimens with the same and the double height. The differences in compression strengths can be interpreted as scattering due to local imperfections of the bricks or the mortar layer.

Kirtschig [10] evaluated tests with Rilem-specimens under standardized conditions: dry bricks with the same dimensions, the same mortar strength and the same masonry strength. But even in this case a considerable scatter of test results was reported.

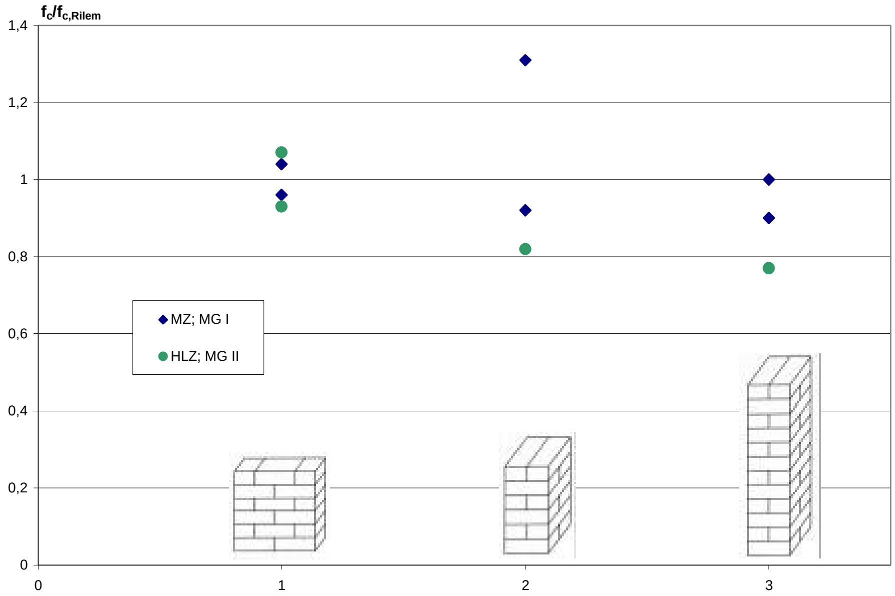

Figure 3. Influence of the geometry of the specimens on the compression strength [11], dimensions of the specimens are given in table 2

Table 2. Materials, geometries and ultimate loads of the reference specimens

	Mortar		Brick		Geometry of test specimens h * w * d [cm] (compared Figure 3)			Ultimate load
No.	MG I	MG II	Mz 20	HLz 12	1 50*49*11,5	2 50*24*24	3 100*24*24	[kN]
1	x		x		x			250
2	x		x		x			260
3	x		x			x		250
4	x		x			x		360
5	x		x				x	280
6	x		x				x	240
7		x		x	x			210
8		x		x	x			230
9		x		x		x		190
10		x		x			x	200

Post-strengthening of specimens

In total 8 masonry specimens were strengthened by wrapping around up to three layers of carbon fiber or glass fiber sheets.

Each specimen is identified by a combination of the following characters: the first letter, A or B, refers to the type of masonry. Specimens of type A were made out of solid bricks and a mortar MG I, Type B specimens were made out of vertical coring bricks and a MG II. The last letters and numbers designate the numbers of layers and the fabric which was used, e.g. 1-L C ≙ one layer carbon fiber sheet.

Table 3. Nomenclature of the post-strengthened specimens

Test specimen	1 layer carbon fiber sheet	2 layers carbon fiber sheet	2 layers glass fiber sheet	3 layers glass fiber sheet
Type A (Mz 20/MG I)	A/ 1-L C	A/ 2-L C	A/ 2-L G	A/ 3-L G
Type B (HLz 20/MG II)	B/ 1-L C	B/ 2-L C	B/ 2-L G	B/ 3-L G

The edges of the columns were rounded with a radius of 3 cm to prevent any stress concentrations within the reinforcing layers. Before bonding the sheets mortar was applied to fill and to smoothen the edges. The sheets were applied to the specimen after wetting the brick faces and the sheets with the epoxy. The fabric was wrapped around the column horizontally. The epoxy was forced through the fabric with a roller before the next layer was applied (Figure 4). The pressing increases the adhesion because entrapped air is pressed out and the wetting of the fibers is improved.

The overlap of the sheet in circumferential direction is 10 cm, and there is no lengthwise overlap.

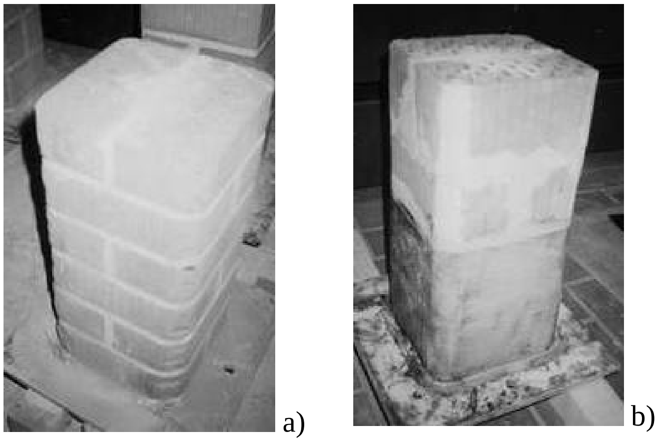

Figure 4. Specimens a) type A, b) type B

Test setup

Figure 5 presents the test setup used for the compression test. The load was applied by means of a 40 mm steel plate witch was laid in mortar on the column. In order to assure the force acting centrically on the test specimen a hinge was placed between the steel plate and the vertical actuator.

The instrumentation for the specimens consists of 4 displacement transducers measuring the compressive deformation on each side of the column. Additionally a strain gauge was attached onto each middle section of the column to record the local strain in circumferential direction.

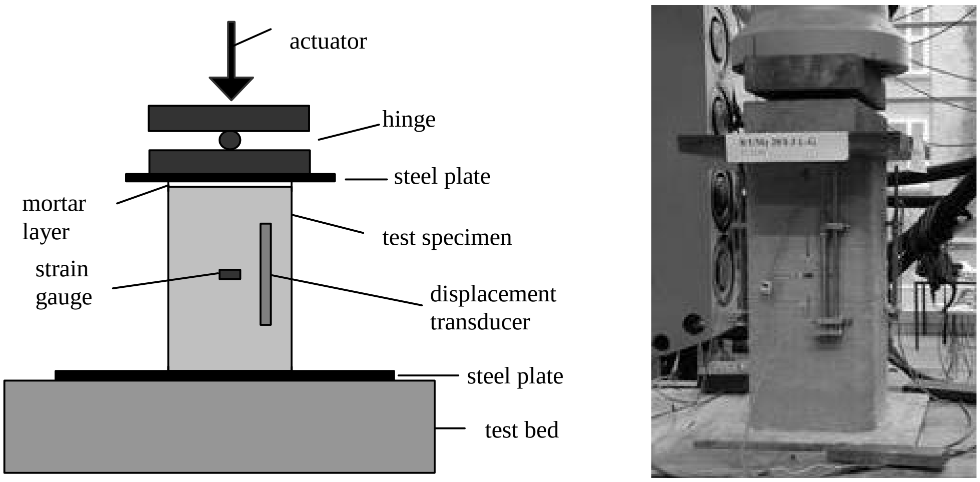

Figure 5. Test setup

According to strength predictions of the reference tests the columns were loaded in 5 steps up to 150 kN in displacement control. The first level was at 30 kN. After reaching each level the force was held for 90 seconds. Beyond reaching 150 kN the force was increased to the maximum load level.

Experimental Results

Table 4 presents the ultimate loads of the post-strengthened columns compared to the unstrengthened specimens. For type B masonry ultimate loads of the strengthened specimens were found to be 30 % to 60 % higher compared to unstrengthened specimens. For masonry type a strengthening was even more successful: the compression strength was improved up to 250 % to 300 % through the post-strengthening of the masonry.

Table 4. Test results

Specimens	Ultimate load of the post-strengthened specimens	Ultimate load of the reference specimen
	[kN]	[kN]
A/ 1-L C	760	250 360
A/ 2-L C	848	
A/ 2-L G	690	
A/ 3-L G	751	
B/ 1-L C	270	190 230
B/ 2-L C	300	
B/ 2-L G	337	
B/ 3-L G	338	

Solid - brick masonry – type A

Figure 6 shows the load-strain diagram of the specimen A/ 3-L G. The characteristics of these curves are representative for the behavior of all type A specimens. As to be expected the increase of load results in a linear increase of strain up to a load level of about 250 kN. This point, referred to as "internal failure" level, is reached when failure of the unstrengthened columns occurs (Table 4). Increasing the load above this level leads to a clearly non-linear behavior of the load-strain relationship. A small increase of load leads to a large increase of strain. Obviously the specimen is in a state of transition caused by subsequent failure. The mechanisms governing this process are not clearly elucidated so far. But it is important to notice that throughout this state and beyond the load can be increased by a factor of three until the structure fails.

Final collapse of the specimen occurs at 760 kN initiated by local fiber fracture of the reinforcement (Figure 8). With increasing deformation the load even drops.

Figure 7 presents the results of all type A specimens. These results are compared to an unstrengthened reference specimen and show an obvious increase of ultimate load. The overall strain was calculated from the displacement of the machine transducer and the overall height of the specimen; so the values differ from those in figure 6 which were measured over the length of the displacement transducers which were fixed on the composite's surface and therefore represent local values.

The stiffness of the specimen A/ 2-L G is higher than that one of the specimen A/ 3-L G due to the age of the specimens at the time they were tested (A/ 2-LG;144 days, A/ 3-L G: 41 days).

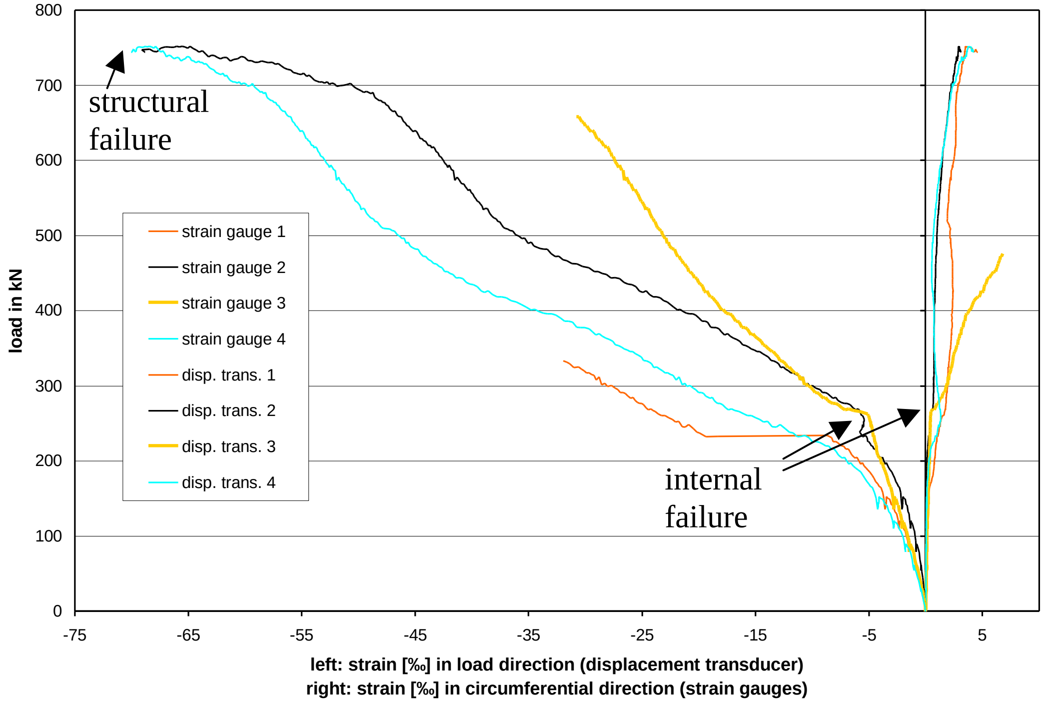

Figure 6. Load-strain diagram of the specimen A/ 3-L G

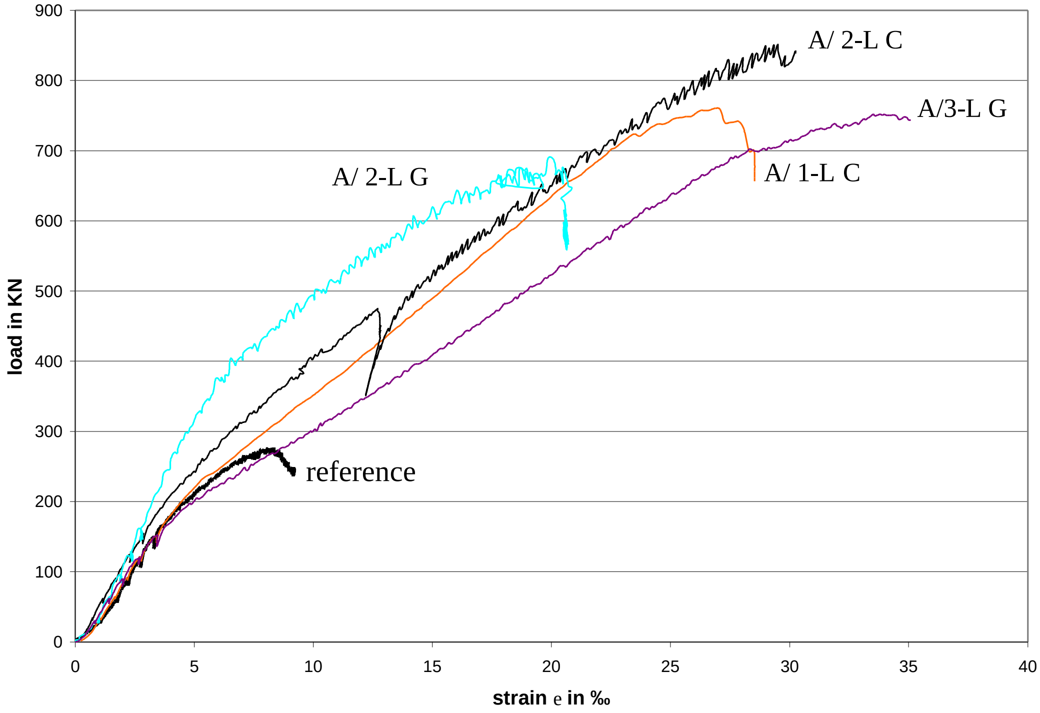

Figure 7. Load-strain curves of the strengthened specimens type A compared to an unstrengthened reference specimen

a)

b)

Figure 8. a) Specimen A/ 1-LC after failure; b) specimen A/ 3-L G after failure

Cored brick masonry – type B

Figure 9 shows a characteristic which is typical for all type B fiber-wrapped specimens. As expected the increase of load leads to a linear increase of strain in circumferential direction. When the load level reaches 210 kN the internal failure of the masonry is indicated by the flattening of the load-strain curves. The test was stopped at a load level of 270 kN because an increase of load was no longer possible. The vertical coring brick failed far before the tensile capacity of the laminate was reached.

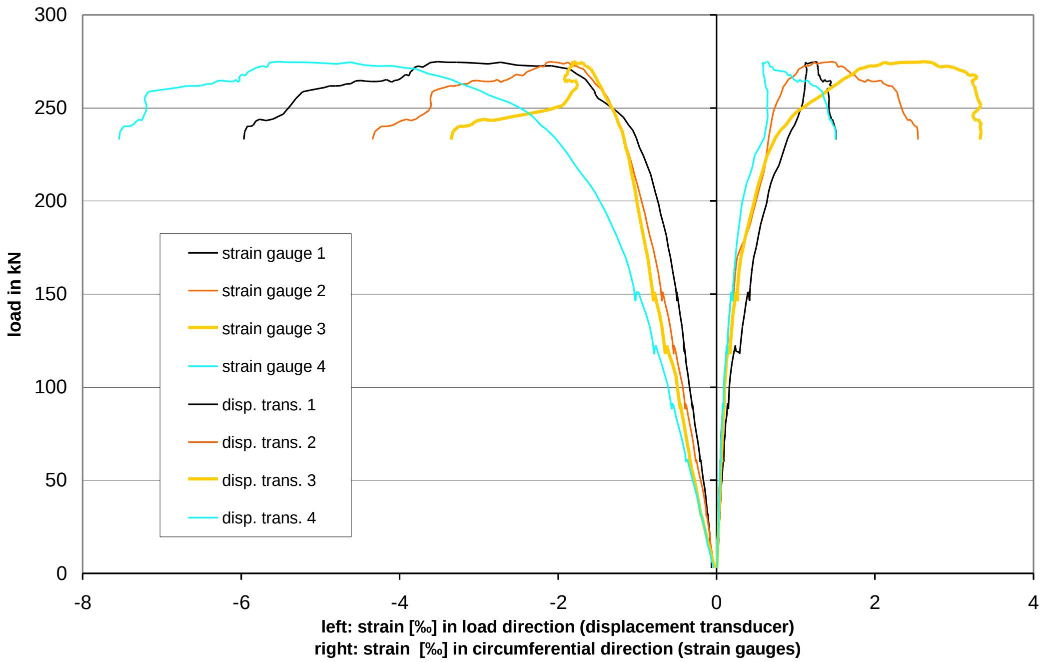

Figure 9. Load-strain diagram of the specimen B/ 1-L C

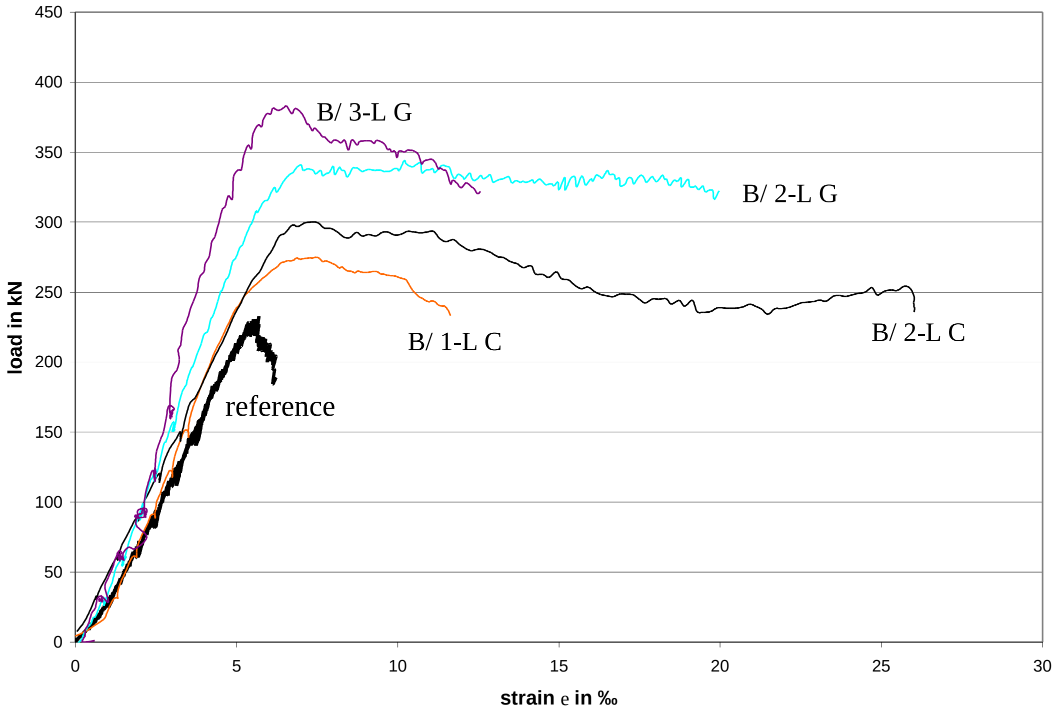

Figure 10. Load-strain curves of the post - strengthened specimens type B compared to a reference specimen

Figure 10 shows the increase of load bearing capacity compared to the unstrengthened reference specimen.

Again strains were calculated from the displacement of the machine transducer and the overall height of the specimen. Even if the level of strengthening – ultimate load of a post-strengthened specimen compared to the unstrengthened specimen – was not as high as it was in the case of solid-brick masonry the ductility was improved considerably.

Summary

The results show that the post-strengthening of masonry columns leads to an essential increase of ultimate load and ductility. For vertical coring bricks an increase of 30 % - 60 % can be achieved depending on the stiffness of the reinforcement. Due to the internal geometry of cored bricks the characteristic of failure is substantially different to that of solid bricks, where the load could be increased up to 300 %.

More studies are necessary to analyze and complete these first results. Further experimental studies will be complemented by numerical investigations.

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