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INVESTIGATION OF EFFICIENCY STITCH BOSS ON CAPACITY OF CRACKED MASONRY WALLETS

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ABSTRACT

The results of the investigations of four kinds of strengthening cracked masonry are presented in this paper. Strengthening was realized by so-called cracks stitching with bars of two types. Then the value of the compressive strength of the reinforced masonry was compared with the compressive strength of the masonry both un-cracked and cracked, but not strengthened. The investigations made it possible to determine the effectiveness of strengthening cracked masonry.

Key words: *Masonry, clay bricks masonry, strengthening of masonry, compressive masonry, reinforced masonry, bed joint reinforcement.*

1. INTRODUCTION

Hairline cracks and significant cracks are the most common faults to be found in masonry construction. In practice, the repair and strengthening of the masonry is carried out in several different ways. In general practice it is normal for individual cracked bricks to be removed and replaced (1); reinforce the masonry by using bowstrings or anchors (1); stitch with bars (1, 2, 3) or bond the brick by means of chemical injection (4). As only limited information and recommendations are generally available for strengthening cracked masonry, the method selected for a particular application is usually based upon experience and instinct.

The purpose of our investigations was to check the effectiveness of strengthening vertically cracked compressed masonry with stitching bars of two different types.

The results of these investigations allow us to assess four ways of strengthening in respect of the values obtained of the compressive strengths and the modulus of elasticity of the masonry after repair.

2. DESCRIPTION OF INVESTIGATIONS

Investigations were made on elements as illustrated in fig. 1, which were made using clay brick and cement-lime mortar in the ratio of cement: lime: sand of 1:1:6.

Within the main investigations four series, (three elements in each series), were examined of strengthened samples and two series of un-strengthened elements. All samples were loaded continuously until their complete destruction. Readings of load and displacement were made every 100 kN by means of a dynamometer and inductive sensors (see fig. 1) with an accuracy of 0,002mm.

As part of the programme, material investigations included the measurement of the compressive strength and modulus of elasticity of the mortar using cylindrical samples according to Polish standard PN-71/B-04500 (5) as well as compressive and flexural strength using cuboid samples as recommended in European Standard EN 1015 (6). Also measurements were made of the compressive strength and modulus of elasticity of the brick used in all samples according to European Standard PrEN 772-1: 1995 (7) as well as on the two joint halves of bricks according to Polish Standard PN-70/B-12016 (8).

Additionally, in accordance with standard EN 1052-1 (9) measurements of the compressive strength and modulus of elasticity of the masonry specimen shown in fig. 2 were carried out. This masonry specimen was subjected to compression in two directions: parallel to the plane of the bed joints (series AH - 5 elements) and perpendicular to the plane of the bed joints (series AV – 5 elements).

Figure 1. Investigation element.

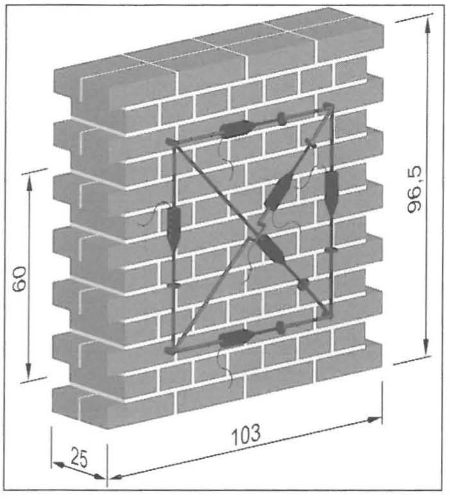
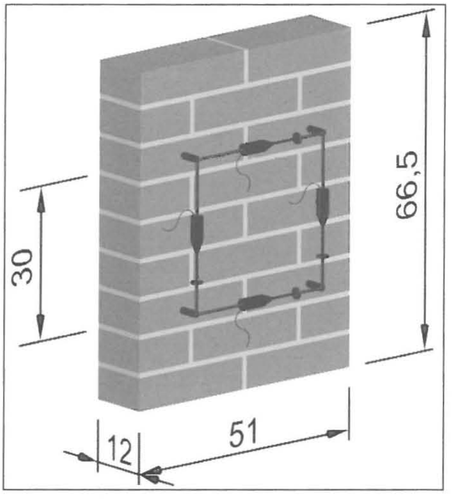


Figure 2. Standard masonry specimen.



3. DESCRIPTION OF STRENGTHENING METHODS

In the first stage we examined samples un-cracked and un-strengthened. The series of these samples was marked with a symbol B and included 5 samples. The next stage of the investigation was cracking the remaining elements. Cracks were generated by means of a 16 mm diameter rod made from smooth steel through which the force F was delivered from the head of the press onto the element. The rod was placed in the centre of the length of the specimen. This way we obtained single crack in the centre of the specimen. It was assumed that the crack should reach about 3/4 height of the element, along the centre line and with a width of about 1 mm (see fig 3.).

In order to be able to quantify exactly the effect of the methods of strengthening employed, three specimens were used from the C series which were cracked but un-strengthened, to provide a datum.

The following series included samples already strengthened. Stitching of the cracks in all samples was carried out on one side of the element only (fig 4). Bars were arranged in slots at a depth of about 40 mm. For the F series (double bars), and to maintain the standard conditions of mortar cover, rods were embedded in the slot with a depth of about 60 mm.

The first method of strengthening was to stitch the cracks using a copper rod 6 mm in diameter embedded in cement-lime mortar (series of type D three elements). This mortar had approximately the same characteristics as the mortar used to make the test samples.

For the next three methods of strengthening a repair technique was used, which was developed in Great Britain and is widely used for strengthening masonry construction including vaults, arches and brick-bridges (10). Strengthening crac-

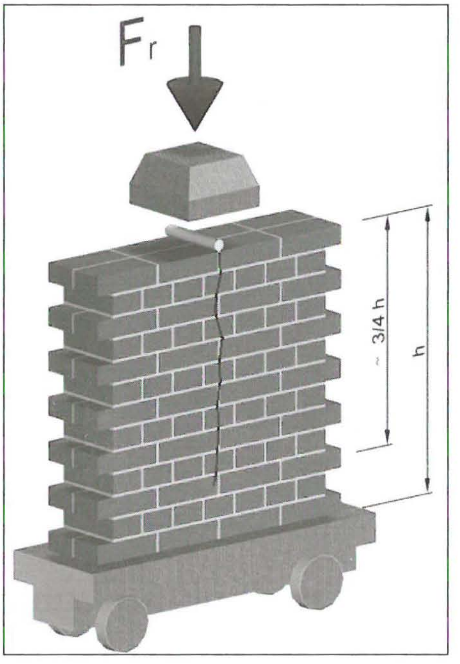


Figure 3.
Meaner of cracking
the elements.

Figure 4. Place of strengthening.

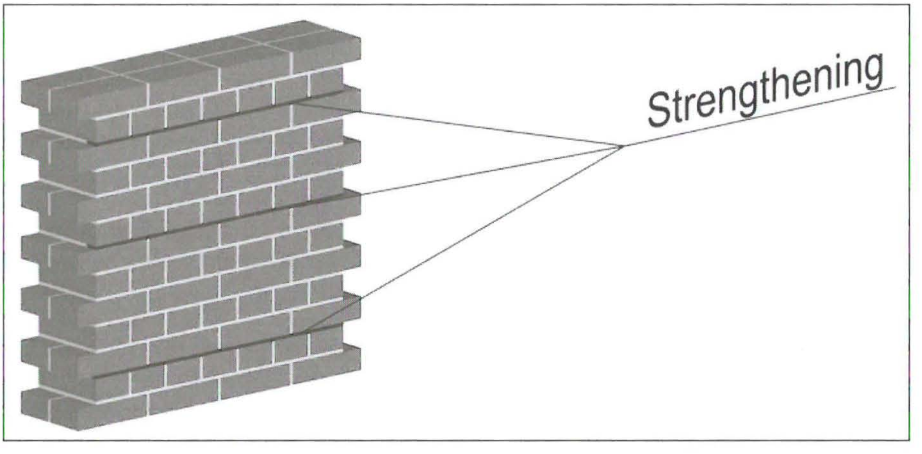
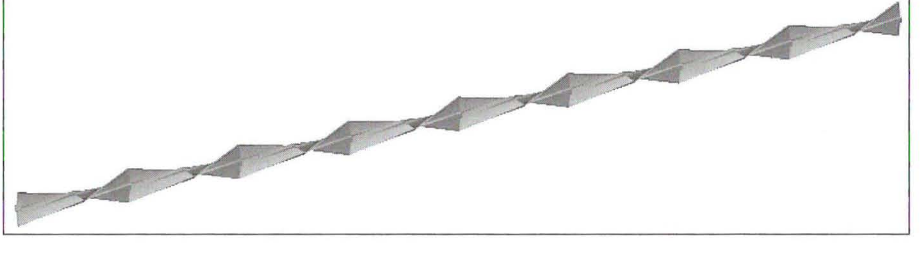


Figure 5. HB spiral bar.



ked elements of D, E and F series was carried out by crack stitching with special HB spiral bars (see fig. 5) of about 6 mm diameter. The bars were made from austenitic stainless steel and embedded in cementitious, thixotropic, injectable, non-shrink HB MM2 grout. The strengthening of the E samples (3 specimens) was achieved using three HB bars embedded in the mortar HB MM2 as shown in fig 4.

The methods of strengthening the samples in the F series, which include three elements, were close to the method used in the E series tests. The difference being that two rods in a single bed joint only were used.

The last method of crack repair (only one model marked as G) was also similar to the method used in the samples of the E series. However, in addition to the stitching rods 9 special DF ties were used fixed perpendicular to the surface of the masonry (see fig 6). Details of the strengthening of all the series are illustrated in fig 7.

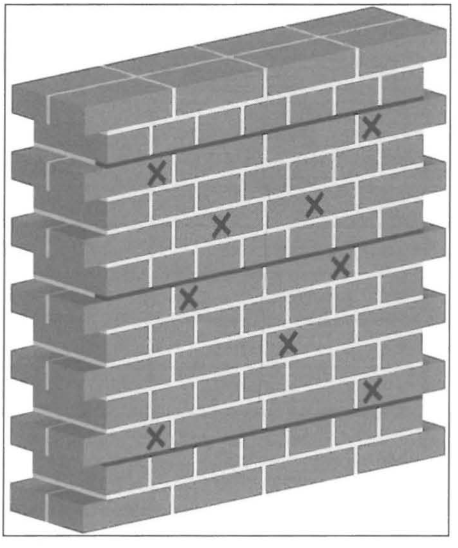


Figure 6. Location of DF ties.

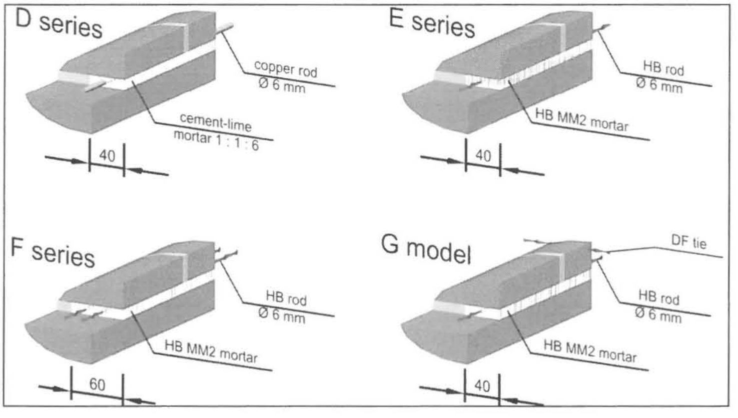


Figure 7. Details of the strengthening.

4. RESULTS OF INVESTIGATIONS

4.1. Material properties

The average values of compressive and flexural strength and modulus of elasticity obtained from investigations of the mortar are shown in table 1, and the results of the brick investigations are to found in table 2.

Graphs of average values of s-e relationships for AV and AH series are shown in fig. 8.

The average values of compressive strengths obtained for the AV and AH series are very similar but the deformation of the samples loaded in parallel to the plane of the bed joints is about double. In Table 3 below, the average values of com-

Table 1. Material properties of cement-lime mortar.

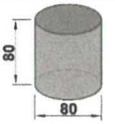
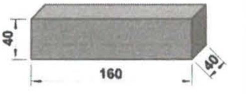
Determined value	Acc. PN-71/B-04500 [5]	Acc. EN 1015 [6]
		
Compressive strength f_m [N/mm²]	5,7	4,3
Coefficient of variation [%]	9,6	9,5
Bending strength f_{mt} [N/mm²]	-	1,5
Coefficient of variation [%]	-	10,2
Modulus of elasticity E_m [N/mm²]	5480	-
Coefficient of variation [%]	8,9	-

Table 2. Compressive strength and modulus of elasticity of brick.

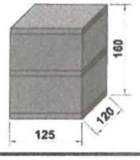
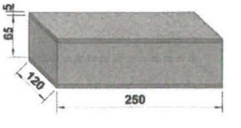
Determined value	Acc. PN-70/B-12016 [8]	Acc. PrEN 772-1:1995 [7]
		
Compressive strength f_b [N/mm²]	9,2	19,2
Coefficient of variation [%]	14,7	7,8
Modulus of elasticity E_b [N/mm²]	-	4620
Coefficient of variation [%]	-	15,1

Figure 8. s-e relationships for AV and AH series.

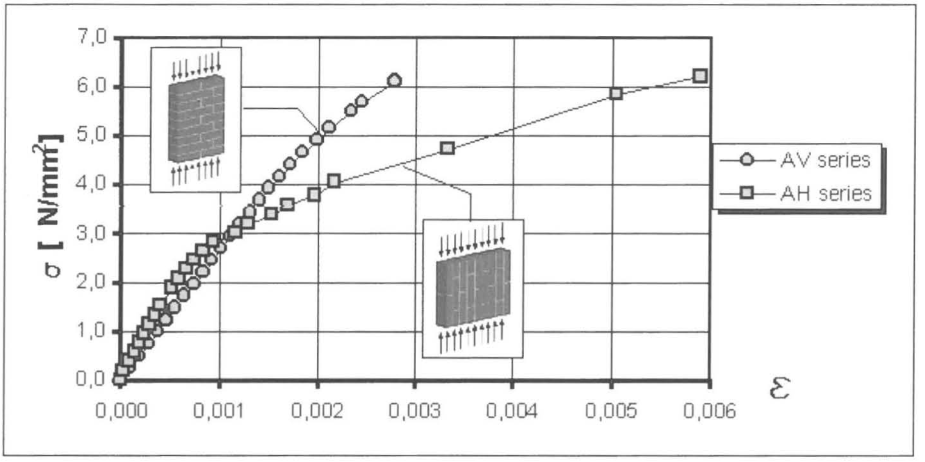
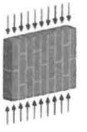


Table 3. Compressive strength and modulus of elasticity of masonry.

Determined value	AV series 	AH series 
Compressive strength f_{AV} [N/mm²]	6,1	6,2
Coefficient of variation [%]	6,3	7,3
Modulus of elasticity E_{AV} [N/mm²]	2620	3130
Coefficient of variation [%]	14,7	9,1

pressive strengths and modulus of elasticity from the tests on the samples of Type AV and AH are shown.

4.2 Main investigations

All the samples in the B series cracked and deteriorated in a similar way. When 40 ÷ 50 % of the maximum compressive stress was reached the first cracks in the samples started to appear. The cracks developed and combined under the influence of the increasing load until the sample separated into three or four individual posts.

In table 4 the average values of compressive strength and of the modulus of elasticity obtained from the investigations of the samples in the B series are shown,

while in fig 9 there is a comparison of σ-ε relationships for un-strengthened and un-cracked samples of the AV and B series.

The stress-strain relationships for the samples of the series B and AV test specimens are almost identical. The greater carrying capacity of the samples of the B series can be explained due to the reduced influence of the slenderness ratio of these elements.

The manner of failure of the samples in the C range (cracked but un-strengthened) was similar to the samples in the B series. In table 4 the values of compressive strength and of the modulus of elasticity are shown which were obtained from investigations of the samples in the C series. Graphs of σ-ε relationships for the series of samples not cracked in series B, and cracked but un-strengthened in series C are shown in fig 10.

A considerable difference can be noted between the compressive strength and modulus of elasticity for samples cracked and uncracked. The values for the cracked samples are about half the uncracked samples.

The pattern of fine cracks in the reinforced samples of the D, E and F series was similar but completely different from the pattern of cracking in the samples of the B and C series. In the strengthened samples the failure always occurred in the internal joint across the brick headers. All the samples split into two separate panels. Small perpendicular cracks occurred on the surface, which did not contain reinforcement while on the strengthened face there was no sign of cracking.
In order to eliminate the adverse crack down the internal joint across the headers, it was decided to include 9 transverse ties in the last sample (model G). In this single sample, the failure also occurred along the internal joint in spite of including the ties. However the incorporation of the ties made it possible to obtain the

Figure 9. Comparison of s-e relationships for un-strengthened and un-cracked samples.

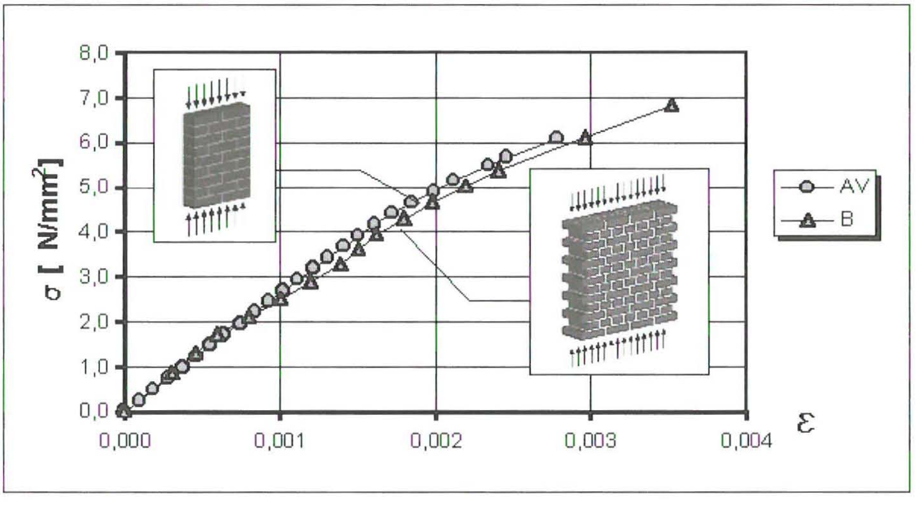
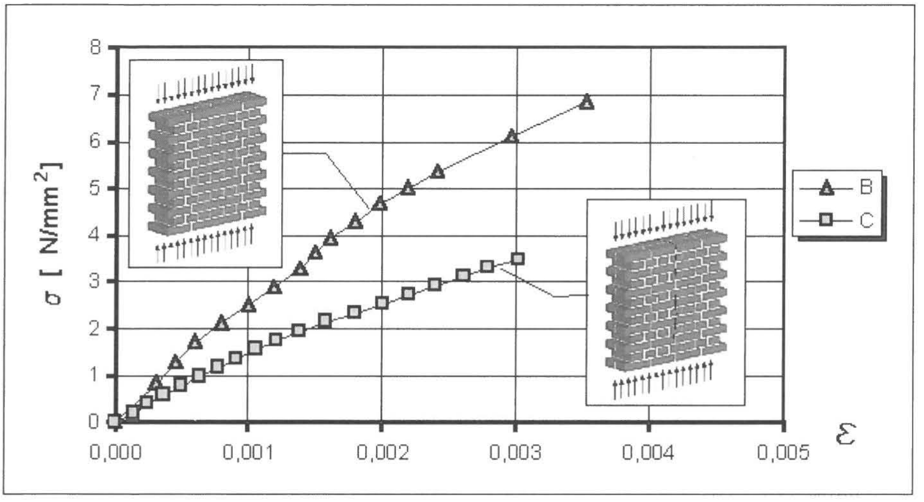


Figure 10. s-e relationships for the B and C series.



greatest compressive strength of all the test samples. It was noticed that the surfaces contained a greater number of hairline cracks than elsewhere.

Below, in table 4, the average values of compressive strength and of modulus of elasticity obtained from investigations of strengthened elements are shown.

Table 4. Compressive strength and modulus of elasticity of models B, C, D, E, F and G.

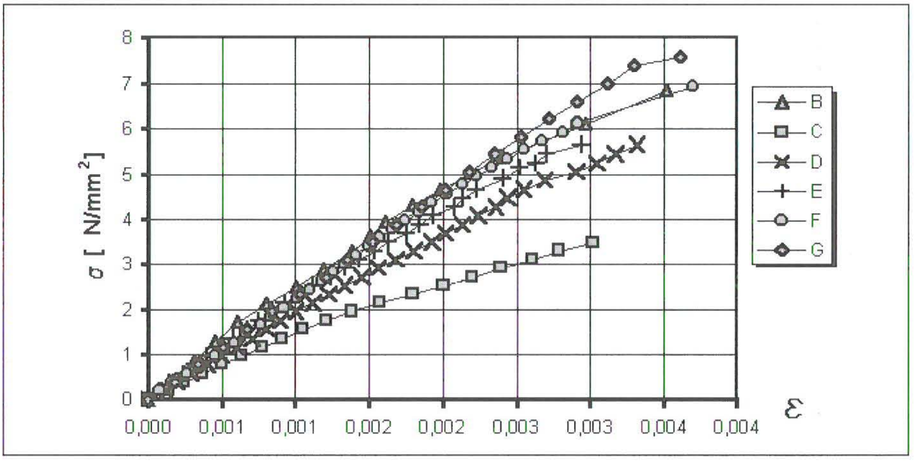
Series number	Compressive Strength f_B (N/mm²)	Modulus of elasticity E_B (N/mm²)
B	6,8	2710
C	3,5	1520
D	5,7	1940
E	5,7	2320
F	6,9	2180
Model G	7,6	2250

5. RESULTS ANALYSIS

In fig 11 the average graphs of the σ-ε relationships for models of all series are shown. From the comparison presented in fig 11 it can be seen, that the stress-strain relationship obtained for samples in the D series, strengthened with copper rods places oneself exactly among similar relationship to that obtained from the measurement of the un-cracked samples in the B series and the cracked samples in the C series.

Samples strengthened using the British technique produced evidence of similar properties to samples that were un-cracked. The stress-strain relationships obtai-

Figure 11. s-e relationships for models of all series.



ned from the investigations of E, F and G models approximate to the graph for the samples in the B series.

In table 5 the comparison of compressive strength and the modulus of elasticity for all samples in the entire programme are shown.

The most effect method of strengthening proved to be the use of stitching bars together with the transverse ties. The value of the compressive strength measured was about 10% greater than the compressive strength of the un-cracked elements and more than twice the compressive strength of un-reinforced, cracked masonry.

The results of the investigations of the samples of the F series do not look as good as the results of the G sample. A 100% increase of compressive strength was obtained in relation to the cracked masonry, which compares to the compressive strength of the un-cracked masonry.

The average values of performance of the samples of the D and E series are identical. Strengthening using three single rods gave a 60% increase of compressive strength in comparison with cracked masonry, which compares to 80% of the

Table 5. Comparison compressive strength and modulus of elasticity for all models.

Series number	Not strengthened elements		Stregthened elements			
Parameter	B	C	D	E	F	G
f_i / f_B	1	0,51	0,83	0,83	1,08	1,11
F_i / f_C	1,96	1	1,63	1,63	2,00	2,18
E_i / E_B	1	0,56	0,71	0,86	0,80	0,83
E_i / E_C	1,79	1	1,28	1,53	1,43	1,48

compressive strength of un-cracked masonry. In spite of the identical values of compressive strength under compression, the method of strengthening used in the models of the E series appears to be better providing a modulus of elasticity closer to the value of un-cracked masonry.

6. CONCLUSIONS

Due to the limited scope of the test, the investigations of the effectiveness of strengthening cracked masonry can only be indicative. However, on the basis of the test it can be stated that:

- Repair of cracks by stitching bars is an effective solution and, as presented, the investigations showed an increase of 60 to 100% of carrying capacity compared to the cracked masonry;
- The biggest increase of carrying capacity was obtained for specimens strengthened with HB stitching bars in the bed joints and with DF transverse ties across the bricks;
- The average values of the modulus of elasticity of reinforced masonry was 15 to 30% less then the modulus for un-cracked masonry;
- The use of stitching bars reduces crack formation in the masonry under increasing load;
- For masonry one brick thick, stitched on one side only, the characteristic failure of the element was changed so that it split into two separate panels at failure.

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