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THE STRENGHTENING OF THE DAMAGED HISTORIC MASONRIES BY USING SPECIALS MORTARS

BY

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Abstract. Rehabilitation of the historical built heritage over the last decades has recorded a massive awareness, the importance of structural rehabilitation of historical buildings, to preserve the cultural heritage, becoming a constant preoccupation of researchers and practitioners in the field. It is well known that most of the historic structures (given their age) are structures of masonry with low strength mortars. Low strength mortars or weak mortars are defined as those in which the binder can be hydrated lime, clay or combinations between them. It is obvious that there are major differences between the mechanical characteristics of the pieces of masonry (stone, brick) and the used binder (mortar). Because of this, the cracks in brickwork often appear in the joints, at the interface mortar–brick. The studied method in this paper represents the increase of the strength of damaged masonry by consolidating the joints with different types of mortars with addition. In the research program carried out at the Faculty of Civil Engineering and Building Services were analysed the physico-mechanical characteristics of the materials component and of the results obtained by joints rehabilitation using special mortars having in their components different addition (cement with rubber powder type FlexCement, reinforced cement with polypropylenic fiber type EdiFiber3, additives for increasing the adhesion type Ceresit CM11, superior class eco cement based mortar), by testing the consolidated specimens at centric compression. Results of

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the experimental tests revealed significant increase of compressive strength and improved failure modes, depending on the type of mortar used.

Key words: structural rehabilitation; weak mortars; joints strengthening; structural response.

1. Introduction

Rehabilitation of the hystorical built heritage over the last decades has recorded a massive awareness, the importance of structural rehabilitation of hystorical buildings, to preserve the cultural heritage, becoming a constant preoccupation of researchers and practitioners in the field. It is well known that most of the historic structures (given their age) are structures of masonry with low strength mortars. Low strength mortars or weak mortars are defined as those in which the binder can be hydrated lime, clay or combinations between them since the cement, as a building material in the form that we know today, was patented by Joseph Aspdin from Leeds, England not until 1824 (Portland cement). These types of mortars for masonry were used before the "cement age". It is obvious that there are major differences between the strength characteristics of the piece of masonry (stone, brick) and the used binder

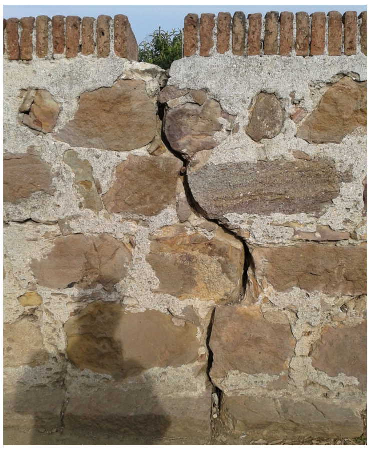

Fig. 1 – Damaged masonry joints caused by water infiltration, XVIIth century masonry.

Fig. 2 – Mortar without continuity caused by aggressive environment's agents, XVth century masonry.

(mortar) (Covatariu *et al.*, 2011a). At these types of masonry, cracks will often occurs in the vulnerable areas (in the joints), at the interface mortar–brick from various reasons: premature aging of the materials, water infiltration by capillarity (Fig. 1), exposure to an aggressive environment (Fig. 2.), land movements caused by geological phenomenon or seismic, foundation soil degradation, etc.

The damage of the joints occurs by partial or total removal of mortar due to physico-mechanical characteristics degradation (Covatariu *et al.*, 2011b). Mortar porosity allows interior–exterior changes of natural vapours and elimination of excessive moisture absorbed in the structure (during construction and exploitation). However, porosity constitutes in a unfavourable characteristic of the mortars because it allows water absorption, favouring the rise of water throw joints capillarity (for compact stone masonry and solid burnt bricks), constituting a favourisant factor of mortars degradation throw the frost and dissolution/transport of the water-soluble salts (minerals) that are in the composition of the soils, stones from the masonry, marine air (calcium sulfate, sodium sulfate, magnesium sulfate, potassium sulfate and sodium chloride).

National and international commonly used techniques for consolidating damaged masonry works are defined on two major directions (Covatariu / Budescu, 2012):

a) Rehabilitation using traditional materials by coating, woving and injecting the cracks, through joints strengthening rigid steel bars, by replacing the total compromised portions and by grouting with compatible mortar (on constant depth) to degraded joints.

b) Rehabilitation through surface treatments by introducing in the structure some adjacent elements of metal, wood, concrete or composite materials, by jacketing with various materials (steel wire mesh, bar reinforcements) and covering with cement and ferocement based shotcrete.

However, these techniques, even they reestablish the structure stability by restoring the structure to an insured seismic degree required for a safety future exploitation, can cause damage to the masonry structures from the built historical heritage, affecting their unique architecture or even causing damage (partial or total) of the frescoes, wall paintings (ENV-1-1, Eurocode 6; ASTM C1357-09, 2009). Therefore, it is necessary to use special technologies for rehabilitation that in the end to reunite the exigencies of structural safety but also the aesthetic, architectural, durability and even of technological reversibility (the Venice Charter).

2. Objectives

The main goal in the research program conducted at the Faculty of Civil Engineering and Building Services of Iaşi constituted the analysis method to rehabilitate the damaged masonry by strenghtening the mortar joints through grouting with special mortars, having as main objectives

a) increase the strength in the joints using sustenable materials, different types of special mortars with additions;

b) increase the bearing capacity of the masonry wall at horizontal and vertical actions;

c) increase the capacity of energy dissipation accumulated in the moment of seismic action using mortars with elastic additions;

d) enhance the consolidated masonry durability using materials that assure protection for joints against environmental agents (rain, freeze, atmospheric pollutants) or that are inside the masonry (sulfide salts, moisture);

e) increase the adherence between the pieces of masonry (it is known that clay/lime mortars are brittle).

3. Experimental Procedure

3.1. Joints Consolidation Technique

For testing the structural response on consolidated samples, 15 samples of solid brick masonry with clay mortar (560 × 460 × 140 mm) and 3 samples for each method of joints reinforcement (4 methods) were prepared. After the

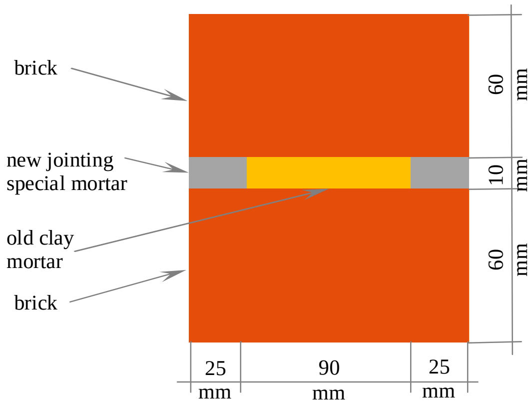

Fig. 3 – Masonry Jointing pattern.

Fig. 4 – Control sample.

Fig. 5 – Strengthened joints sample.

maturing period of the samples, they were consolidated by horizontal grouting and re-filling with special mortars in order to test before the rehabilitation

(Fig. 3) and 3 samples were kept as control samples (Fig. 4) in order to compare with the consolidated samples.

4. Used Materials for Specimens

4.1. Bricks

The bricks were obtained from the demolition of a historical building with approximately 80 years age, full burnt clay bricks. The bricks were chosen for a more accurate simulation of existing materials in the structure of historical masonry. After the tests carried out on the brick samples were obtained the following strength characteristics: compression strength 42 daN/cm^2; tensile strength 5.2 daN/cm^2.

4.2. Special Mortars Mixtures

The optimal dosages for the admixtures used in mortars were obtained by laboratory series tests. Were established 4 mortar's mixtures using a cementitious binder ECO-CEMENT (SR-EN 197-1:2002) type CEM II/B-M (S-LL) 42.5N manufactured at Heidelberg Cement România, like follows:

a) Mix 1: Eco-cement mortar with FlexCement admixture (20% proportion from binder quantity).

b) Mix 2: Disperse reinforced eco-cement mortar with polypropylene fibres (5% proportion).

c) Mix 3: Ceresit CM11 type, special adhesive used in order to increase the adherence at the interface of the mortar-brick.

d) Mix 4: M10 Superior class mortar with cement type CEM II/B-M 42.5N.

FlexCement is cement having natural and recycled rubber powder admixture, which can be used in the joints to obtain certain advantages) (*Fişa tehnică*: http://www.compaktuna.be...):

a) increased adherence compared to an ordinary mortar, which could increase the bonding between masonry's bricks layers;

b) increased elasticity of the mortar;

c) much increased strength to the environmental aggressive agents attack and, by default, an in-time increased durability of the masonry.

EdiFiber3 Polypropylenic Fibers can be used as an addition to mortars, with a lenticular and fine fibrillated aspect (12...19 mm) that can effectively prevent cracking due to plastic shrinkage (*Fişa tehnică*: http://www.edilcom.ro/...). It is used as addition in mortars for joints consolidation in masonries that are subjected to dynamic loads and also increase the capacity of taking over and amortization. The advantages of using these polypropylene fibres as disperse reinforcement are

a) provide a three-dimensional reinforcement throughout the mass of the mixture;

b) eliminate cracks and fissures due to contractions and tensions;

c) significantly increase the wear resistance and to the freeze–thaw cycles;

d) greatly reduces the permeability of mortars being practically neutral chemical corrosive agents;

e) increases the workability and plasticity of mortars by eliminating the segregation, compaction;

f) increases the fire resistance of mortars.

Cement type CM11 is an additioned binder that inhance the adherence to the interface between bricks and mortar with the following advantages (*Fişa tehnică*: http://www.ceresit.ro/...):

a) increase strength to freeze–thaw cycles;

b) has excellent workability;

c) is characterized by limited sliding, having a high adhesion coefficient.

For each type of mortar used to strengthen the joints, in order to determine the tensile strength in bending (on 40 × 40 × 120 mm prisms) (Fig. 6) and the compressive strength (on 40 × 40 × 40 mm cubes) (Fig. 7) have been performed tests (ASTM C780-10, 2010; ASTM C270-10, 2010).

Fig. 6 – Reinforced mortar prism samples tested for tensile strength in bending.

Fig. 7 – Determination of compressive strength of hardened mortar prisms.

The tests revealed a superior strength at cement additioned with EdiFiber 3 samples, while CM11 mortar samples showed a brittle behaviour (a very good adherence, low mechanical characteristics, long setting time for thickness of material above 5 mm).

4.3. Samples Testing

Masonry samples (3 for each group) were tested in the laboratory of the Faculty of Civil Engineering and Building Services of Jassy in order to determine the centric compressive strength, using a Universal Testing Machine having a load capacity of 3,000 kN, supplementary equiped with a 1,000 kN load cell, 4 displacement LVDT traducers and numerical analogical conversion system (Figs. 8 and 9).

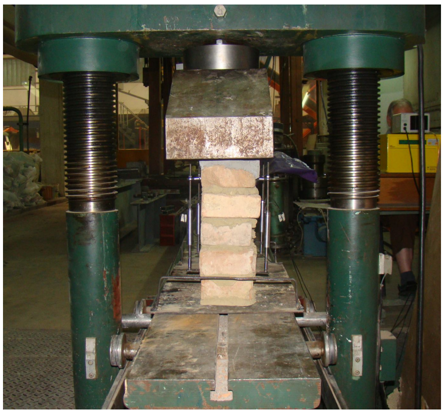
Fig. 8 – Handling of samples for testing at centric compression.


Fig. 9 – Control sample equiped with displacement traductors (on both sides).

4.4. Tests Results for Centric Compression

After the interpretation of the numerical results of the centric compression tests on the samples of masonry and the failure modes were observed the following:

a) the best behaviour have those that have been reinforced with disperse polypropylene EdiFiber3 (Fig. 10 *c*), obtaining the highest values of the breaking forces (Table 1, col IV);

b) the largest displacements have been determined at the samples with the joints rehabilitated with mortars additioned with Flexcement, addition of rubber from the cement composition allowing the structure to have bigger displacements with respect to CM11 or those reinforced with disperse polypropylenic fibers (Fig. 10 *b*);

c) regarding the failure mode it is noted that the samples rehabilitated with addition of CM11, that in spite of a good adherence at the support layer, it show a brittle failure character (the material expulsion is observed by removal of big pieces of brick and adhesive) (Fig. 10 *e*), as well as the samples of superior class cement, where minor cracks are observed on both sides, without large displacements, before failure (Fig. 10 *d*).

Fig. 10 – Aspects of the failure modes of masonry samples rehabilitated with:
a – control samples (clay mortar); *b* – FlexCement additioned mortar;
c – cement mortar disperse reinforced with polypropylene fibers EdiFiber3;
d – M10 cement based mortar; *e* – CM11 type adhesive.

Table 1
Results Obtained for Samples Subjected to Centric Compression

Material used in joints rehabilitation	Probe no.	Sample dimensions mm	Maximum fracture force, [kN]	Observations: Force at which the first cracks appeared and the place were they occur (on the principal or lateral faces)
Control samples	1	550/360/140	198	110 kN / both faces
	2	570/370/140	204	95 kN / both faces 115 kN / lateral
	3	560/380/140	205	120 kN / both faces
FlexCement additioned mortar	1	570/390/140	224	170 kN / both faces 190 kN / lateral
	2	560/460/130	210	120 kN / both faces 130 kN / lateral
	3	560/450/130	220	110 kN / both faces
Cement mortar disperse reinforced with olypropylene fibers EdiFiber3	1	600/420/140	270	170 kN / both faces
	2	580/320/150	265	157 kN / both faces
	3	570/490/130	277	162 kN / both faces
CM11 type adhesive	1	570/440/140	228	110 kN / both faces
	2	580/320/150	219	110 kN / both faces
	3	570/490/130	259	160 kN / both faces
M10 cement based mortar	1	580/420/140	250	150 kN / both faces
	2	580/380/130	225	180 kN / both faces
	3	570/440/130	210	170 kN / both faces

5. Final Remarks

1. Proposed rehabilitation methods have proved the efficiency (through tests on materials and on masonry samples) revealing higher ultimate displacements of the samples with joints rehabilitation than those of the control, decreasing the risk of the structure's collapse.

2. Maximum centric compressive forces revealed that in all cases it was observed a significant increase of the mechanical strength on rehabilitated samples.

3. Using addition mortars with elastic binders significantly increases the deformability of the structures, noticing greater displacements at the same forces, as compared to control samples.

4. Physical characteristics of the additions used in mortars for grouting also presume a protection/insulation of the joints against the environmental agents.

5. The grouting technology of additioned mortars requires an easy manufacture, without specialized equipment.

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CONSOLIDAREA ZIDĂRIEI ISTORICE FOLOSIND MORTARE SPECIALE ADITIVATE

(Rezumat)

Reabilitarea patrimoniului istoric construit a înregistrat în ultimele decenii o conştientizare masivă, importanţa reabilitării structurale a clădirilor istorice, pentru a prezerva moştenirea culturală, devenind o preocupare constantă a cercetătorilor şi practicienilor în domeniu. Este bine ştiut faptul că majoritatea structurilor istorice (având în vedere vechimea acestora) sunt structuri din zidărie cu mortare de rezistenţă scăzută. Mortarele de rezistenţă scăzută sau mortarele slabe se definesc ca fiind acele mortare în care liantul poate fi varul hidratat, argila sau combinaţii ale acestora. Este evident că există diferenţe majore între caracteristicile mecanice ale bucăţii de zidărie (cărămida, piatra) şi liantul folosit (mortarul). Din această cauză, fisurile în zidărie vor apare de cele mai multe ori în rosturile acesteia, la interfaţa mortar–cărămidă. Metoda studiată în prezentul articol se bazează pe creşterea rezistenţei zidăriilor avariate prin consolidarea rosturilor cu diferite tipuri de mortare cu adaosuri. În cadrul programului de cercetare realizat în laboratoarele Facultăţii de Construcţii şi Instalaţii au fost

analizate caracteristicile fizico-mecanice ale materialelor componente şi ale rezultatelor obținute prin reabilitarea rosturilor utilizând mortare speciale având în componență diferite adaosuri (ciment cu adaos de cauciuc tip FlexCement, ciment armat dispers cu fibră polipropilenică tip EdiFiber3, adaosuri pentru creşterea aderenței tip Ceresit CM11, ciment eco de clasă superioară), prin testarea specimenelor consolidate la compresiune centrică.

Rezultatele testelor experimentale au evidențiat creşteri semnificative ale rezistenței la compresiune şi moduri de cedare îmbunătățite, în funcție de tipul de mortar utilizat.