SEISMIC RETROFIT OF MASONRY WALLS USING REPOINTING

Festim Ademi
MSc in Civil Engineering
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia
festim.ademi@hotmail.com

Sergey Churilov
PhD, Professor
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia

Elena Dumova Jovanoska
PhD, Professor
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia

Seismic strengthening of masonry structures through repointing has been recognized as an efficient and low-cost technique for increasing structural stability, particularly in regions of high seismic activity. This paper shows the results from the research program that involved laboratory tests of the mechanical properties of masonry. The objective of the research was to evaluate the effectiveness of repointing as a method of strengthening existing structures, providing greater resistance to compression and dynamic loads.

The results show that repointing, particularly when advanced materials are used, considerably increases the compressive strength of masonry structures as well as their ability to sustain seismic forces. Additionally, the method contributes to the improvement of their long-term stability, which makes it applicable to a wide spectrum of structures. The economic analysis of the application of repointing shows that this approach is not only effective but also financially viable which makes it a practical choice in civil engineering, being able to provide a considerable contribution to the seismic safety of structures.

Keywords: seismic strengthening, masonry structures, polypropylene strips, repointing.

1. INTRODUCTION

Unreinforced masonry buildings were of interest to be built centuries ago. Most of these buildings that still exist in our country were built at the beginning of the twentieth century. These types of buildings include individual houses, religious buildings, residential buildings, but also larger buildings that house public institutions (hospitals, schools, sports halls, museums, etc.).

Masonry has withstood the test of time as a durable and reliable construction technique, but with the evolving challenges posed by seismic activity and aging infrastructure, it is imperative that we develop effective retrofitting methods to improve the resilience of these structures.

In contemporary practice, scientists and engineers are actively exploring the potential of repointing as a seismic retrofitting technique for existing structures. Research indicates that proper repointing with advanced materials, such as fiber-reinforced polymer (FRP) systems, can enhance the capacity of walls to withstand dynamic forces induced by earthquakes. Both laboratory and field investigations have demonstrated this method's efficacy as a critical component in seismic strengthening strategies, enabling improved risk assessment and mitigation of catastrophic damage [1].

2. EXPERIMENTAL PROGRAMME FOR TESTING THE EFFECTS OF REPOINTING

To define the effects of repointing on behavior of bearing walls, it was proposed to carry out an experimental program involving laboratory testing of the bearing capacity of masonry in which repointing was applied in the following three different ways:

- Strengthened masonry repointed with lime mortar and with horizontally placed polypropylene strips (Figure 1 and Figure 3).
- Strengthened masonry repointed with lime mortar and with diagonally placed polypropylene strips Figure 2 and Figure 4).
- Strengthened masonry repointed with repair mortar FS4 and with horizontally placed polypropylene strips.

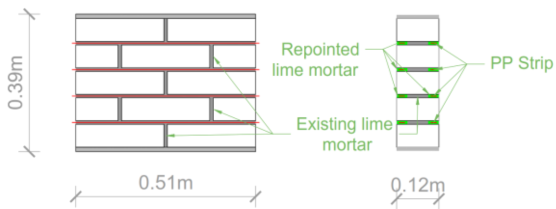

Figure 1. Horizontal application of PP strip and repointing.

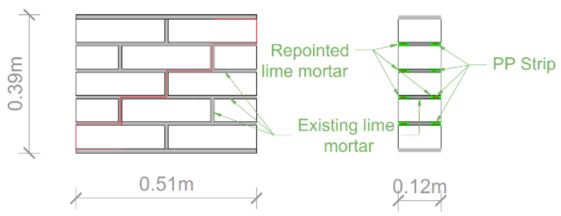

Figure 2. Diagonal application of PP strip and repointing

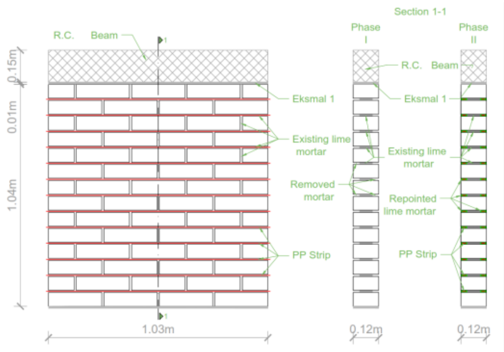

Figure 3. Horizontal application of PP strip and repointing.

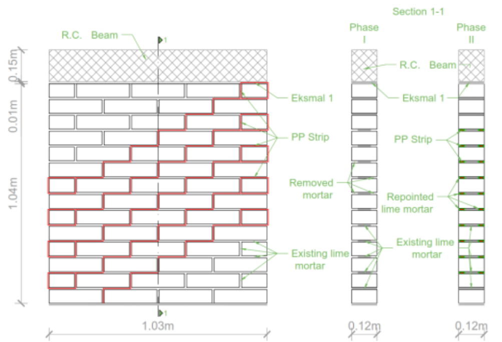

Figure 4. Diagonal application of PP strip and repointing.

Taking into account that masonry is a composite material, the experimental program consisted of three parts: testing of the mechanical characteristics of the constituent materials, bricks and mortar, testing of the compressive strength and testing of the shear strength of masonry. To quantify the proposed repointing procedures, the results from testing of unreinforced masonry were used as referent values. Further in the text, a brief description of the performed tests, the obtained results and the corresponding conclusions is given.

2.1 TESTS ON CONSTITUENT MATERIALS

Tests on constituent materials represent a key step in assessing their durability and suitability for use in engineering structures. The mechanical and physical properties of the materials are defined through different tests, enabling analysis of their behavior under different loads [2]. The presented research involved tests on solid clayey bricks, mortars and polypropylene strips for the purpose of obtaining data on their strength, density, water absorption and other characteristics that are important for optimization of structural systems and improvement of safety of structures. Table 1 shows the obtained mechanical characteristics of the constituent materials.

Table 1. Mechanical characteristics of constituent materials.

Material	Density γ_d	Compres. strength $f_{m,comp}$	Flexural tensile strength $f_{m,flex}$
	(kg/m^3)	(MPa)	(MPa)
Clay brick	1750.50	9.54	2.05
Lime mortar		0.73	0.42
Repair mortar		50.40	11.97

2.2 TESTS ON MASONRY AS CONSTITUENT MATERIAL

For the needs of the investigation, two special setups were developed. They were designed to test the compressive strength and the shear strength of masonry. These setups enabled a precise and controlled analysis of different types of walls, including unreinforced and strengthened structures for the purpose of defining their mechanical properties and behavior under different loads. This provided the basis for comparison of the results and optimization of the strengthening methods in engineering practice [3].

2.2.1 Setup for Testing Compressive Strength of Masonry

Testing of compressive strength was carried out by a special setup consisting of two metal columns (steel columns) fixed to a reinforced concrete floor by steel anchors, connected to an upper steel beam (steel beam "I 160") that served to provide stability and support to the hydraulic actuator. The testing wall was placed between the columns of the steel beam ("I 300") through a rubber layer with a thickness of 10 mm for better contact. Placed on the top of the wall was an additional rubber layer and a steel beam ("I 160") for transfer of the force to the load cell connected to the hydraulic actuator. This setup enabled precise measurements of compressive strength under strictly controlled laboratory conditions.

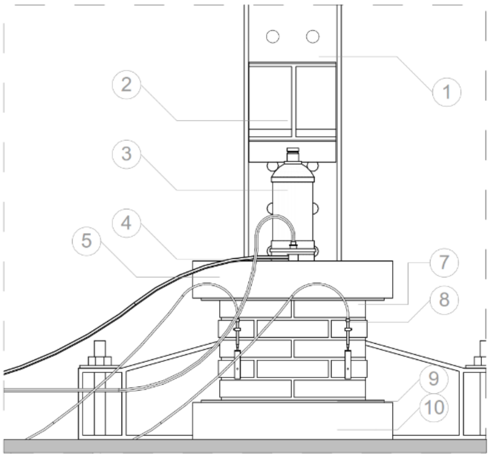

Figure 5. Setup for testing the compressive strength of masonry.

2.2.2 Setup for Testing Shear Strength of Masonry

The setup for testing of shear strength consisted of four metal columns fixed to the reinforced-concrete floor, connected with steel beams. The walls were placed upon a steel beam ("I 200") and were stabilized with a reinforced concrete beam, whereas rubber layers with a thickness of 10 mm were used for better contact between the materials. Horizontal force was generated by the hydraulic actuator that transferred the force to the walls through roller bearings. A deflection meter (strain gauge) was placed for precise measurement of strains caused by horizontal loads.

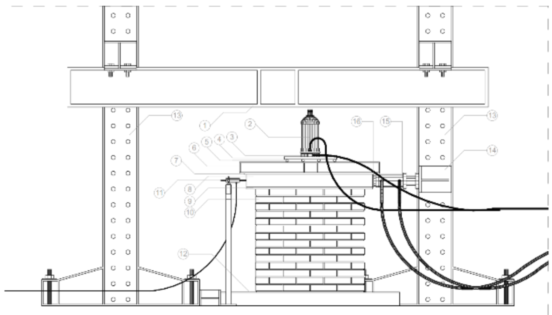

Figure 6. Setup for testing of shear strength of masonry.

These two setups enabled precise and controlled assessment of the performances of different types of walls, including unreinforced and strengthened structures. The results obtained provided important data on the mechanical properties of masonry to be applied in the design and optimization of engineering structures.

2.3 TESTS FOR DEFINITION OF COMPRESSIVE STRENGTH OF MASONRY

Within the frames of the investigation of the mechanical properties of masonry, several wall specimens were tested to define their compressive strength. The specimens were composed of 10 clayey bricks and mortar (lime mortar and repair mortar) that functioned as a composite material. The proportions of the bricks were 250 x 120 x 60 mm, whereas those of the walls were 510 x 390 x 120 mm. Tested were eight walls, distributed into four categories with two specimens each: unreinforced walls, walls strengthened with lime mortar and PP strip in horizontal joints, walls strengthened diagonally with a PP strip and walls strengthened with repair mortar FS 4 and PP strip in horizontal joints.

Figure 7. Testing the compressive strength of masonry.

Figure 8. Compressive strength - a wall after testing (under the effect of compressive force).

2.4 TESTS FOR DEFINITION OF SHEAR STRENGTH OF MASONRY

Within the frames of the investigation of the mechanical properties of masonry, in addition to the tests of compressive strength, tests of shear strength were also carried out. Each wall was composed of 56 clayey bricks and mortar (lime mortar or repair mortar) as a composite material. The proportions of the bricks were 250 x 120 x 60 mm, while those of the test specimens were 1030 x 1040 x 120 mm. Tested were a total of eight walls divided into four categories, with two specimens each: unreinforced walls, walls strengthened with lime mortar and PP strip in horizontal joints, walls strengthened diagonally with PP strip and walls strengthened with repair mortar FS4 and PP strip in horizontal joints.

Figure 9. Testing of shear strength of masonry.

Figure 10. Shear strength - wall after testing.

3. RESULTS FROM TESTS

The results from the performed tests of compressive and shear strength of masonry structures provided a detailed insight into the mechanical properties of different types of walls. Through graphic analysis, the force - deformation relationships and the response of the walls to different types of loads are presented. These results are of primer importance for the assessment of the effectiveness of the applied strengthening techniques and their ability to provide structural stability under static and dynamic forces for improvement of safety and durability of structures [4].

3.1. COMPRESSIVE STRENGTH OF MASONRY

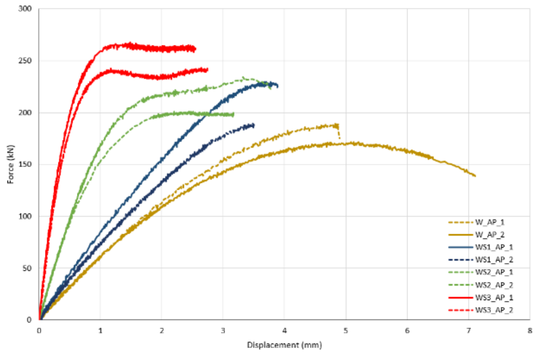

Figure 11. Force-deformation diagram for testing compressive strength of walls.

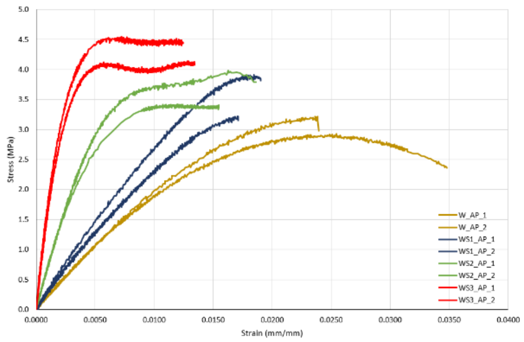

Figure 12. Stress-deformation diagram for testing compressive strength of walls.

The tests showed important improvements in the strength of masonry structures by the application of different strengthening techniques [5]. WS1_AP: Strengthening with lime mortar and PP strip in horizontal joints resulted in an increase of maximum strength of 16.1% and final strength of 31.9%, with a decrease of deformation of 27.6% and 38.5%. WS2_AP: The diagonal position of the PP strip led to an increase of maximum strength of 20.6% and final strength of 34.1%, with a decrease of deformations of 42.5% and 41.9%. WS3_AP: Strengthening with repair mortar and PP strip in horizontal joints showed the highest level of improvement, with an increase of maximum strength of 41.5% and final strength of 60.1%, whereas deformations were reduced for 58.9% and 55.9% The data are presented in tabular form in Table 2.

Table 2. Values obtained for compressive strength of walls.

Types of Examined Walls (Names)	Peak compressive stress, $f_{mas,test}$	Peak stress inc-rease (%)	Ultimate compressive stress, $f_{mas,ult}$	Ultimate stress inc-rease (%)
W_AP	3.07	0.0%	2.67	0.0%
WS1_AP	3.56	16.1%	3.52	31.9%
WS2_AP	3.70	20.6%	3.58	34.1%
WS3_AP	4.34	41.5%	4.27	60.1%

Types of Examined Walls (Names)	Peak strain, ε_{max}	Peak strain decrease (%)	Ultimate strain, ε_{ult}	Ultimate strain dec-rease (%)
W_AP	0.0246	0.0%	0.0294	0.0%
WS1_AP	0.0178	-27.6%	0.0181	-38.5%
WS2_AP	0.0141	-42.5%	0.0171	-41.9%
WS3_AP	0.0101	-58.9%	0.0130	-55.9%

3.2. SHEAR STRENGTH OF MASONRY

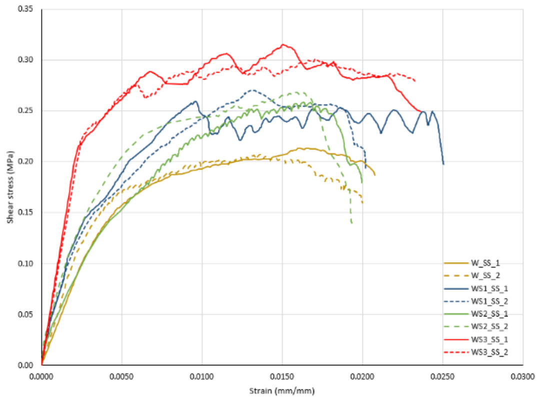

Figure 13. Shear stress - deformation diagram for different types of walls.

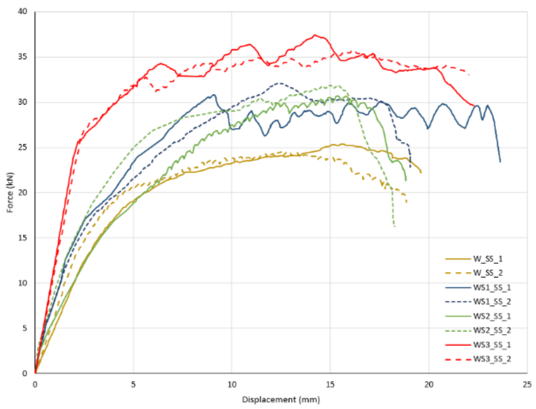

Figure 14. Force - displacement diagram for unreinforced walls and walls strengthened with different methodologies.

W_SS_1 and W_SS_2 unreinforced walls served as the basic line for comparison. They showed the lowest shear strength and the greatest deformation under loads. WS1_SS_1 and WS1_SS_2 were strengthened with lime mortar and a horizontally placed PP strip, which resulted in an increase of shear strength of about 25.9% and a decrease of deformation of 24.5% compared to unreinforced walls. WS2_SS_1 and WS2_SS_2 with a diagonally placed PP strip and lime mortar showed an increase of shear strength of 25.3% and a decrease of deformation of 6.3% compared to the basic specimens. WS3_SS_1 and WS3_SS_2, strengthened with repair mortar FS4 and horizontally placed PP strips showed the best results, with an increase of shear strength of 46.6% and a decrease of deformation of 6.1%.

Table 3: Values of maximum strength and deformation at shear for different types of walls.

Types of Examined Walls (Names)	Peak shear stress, $f_{mas,test}$	Peak shear stress inc-rease (%)	Peak shear strain, ε_{max}	Peak shear strain dec-rease (%)
W_SS	0.210	0.0%	0.0151	0.0%
WS1_SS	0.265	25.9%	0.0114	-24.5%
WS2_SS	0.263	25.3%	0.0161	6.3%
WS3_SS	0.308	46.6%	0.0161	6.1%

4. CONCLUSION

The experimental investigations confirmed that the application of different techniques for strengthening with repointing considerably improved the mechanical characteristics of masonry, particularly from the aspect of its compressive and shear strength. The results showed that unreinforced walls were characterized by the weakest mechanical properties, with limited bearing capacity and considerable susceptibility to deformations under loads.

These walls were identified as a referent point for the assessment of the effectiveness of different strengthening techniques.

As to the compressive strength, strengthening with lime mortar and horizontally placed PP strips led to an increase of maximum strength of 16.1% and an increase of final strength of 31.9%, with a considerable decrease of deformations. Diagonal placement of PP strips showed additional improvement, but the greatest progress was achieved by use of repair mortar and horizontal PP strips, resulting in an increase of maximum strength of 41.5% and an increase of final strength of 60.1%, whereat the deformations were considerably decreased.

Regarding the shear strength, unreinforced walls again showed the lowest bearing capacity and the highest susceptibility to deformations. Strengthening with horizontal PP strips resulted in an increase of strength of 25.9%, whereas diagonal placement of PP strips added an increase of 25.3%. The greatest improvements were achieved with repair mortar and horizontally placed PP strips, whereat shear strength was increased for 46.6%, while deformations were reduced for 6.1%.

These results pointed out that proper choice and application of strengthening techniques could considerably increase bearing capacity, stability and resistance of masonry structures, particularly in seismically active regions. The use of repair mortar in combination with horizontally placed PP strips was shown as the most optimal solution, providing maximum bearing capacity, minimal deformations and increased safety of structures. This methodology represents an important contribution to engineering practice, with direct application in design and advancement of engineering structures in zones of high seismic risk.

REFERENCES

[1] Sergey Churilov – ''Experimental and Analytical Research of Strengthened Masonry'' – Doctoral dissertation

[2] Sergey Churilov, Elena Dumova-Jovanoska, ''In-plane Shear Behaviour of Unreinforced and Jacketed Brick Masonry Walls'', Elsevier Ltd, 2013.

[3] Bojan Damchevski, Sergey Churilov, Elena Dumova-Jovanoska, ''Mechanical Characterization of Polymer Fibre-reinforced Cement-based Mortar for Masonry Joint Repointing'', Thessaloniki, 2018.

[4] MEASURES OF REHABILITATION OF UNREINFORCED MASONRY SPORTS FACILITY WITH IRREGULARITIES. - Festim Ademi, Enis Jakupi, Rezona Fetahu , Journal of Applied Sciences-SUT (JAS-SUT), Volume 9.

[5] Calderini, C., Cattari, S., & Lagomarsino, S. (2009). In-plane Strength of Unreinforced Masonry Piers. Earthquake Engineering and Structural Dynamics, 38(2), 243–67.