Second Conference on Smart Monitoring,
Assessment and Rehabilitation of Civil Structures

SMAR 2013

Clean masonry strengthening for inside application

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ABSTRACT: There are different solutions available which can strengthen masonry as a very vulnerable construction material in seismic regions. The efficiency of the most systems is verified by many scientists, but only rare the practical issues are solved. In this paper a clean strengthening system with many benefits is presented. The concept provides an application of thin wallpaper like glass fibre textile glued directly on an existing plaster in a building with special high ductile water based polyurethane adhesive. The practical benefits are: No plaster has to be removed, very fast and clean application like wallpaper hanging, health friendly material, and high deformable connection plaster to textile. In the paper different experimental work on static cyclic loaded masonry walls in in-plane direction and dynamic wall tests in out-of-plane direction are presented. The results have confirmed the effectiveness of the proposed retrofit scheme.

1 INTRODUCTION

Masonry buildings while earthquake shaking are vulnerable for in-plane as well as out-of-plane lateral forces. Fibre reinforced plastics are therefore a good and light strengthening solution which were tested and approved by several studies of scientists. For the out of-plane direction Ehsani et al (1994) were one of the first which tested masonry walls with b/h ratio of 14 and 28 and reinforced with glass fibre stripes and epoxy glue. The maximum possible increase in the load bearing capacity was 650% compared to the unreinforced walls. Tumialan et al. (2000) conducted out of plane tests with hollow bricks and concrete block masonry which were reinforced with glass and aramid fibre reinforcement. He additionally determined the bonding with special putty. Further work was done by Hamilton and Dolan (2001), Reinhorn and Madan (1995), and Hamoush (2002). All of them used a static loading and stiff glues like epoxy resign. Also for in-plane loading different authors made several tests on walls. Schwegler (1994) one of the first researchers in this field tested 1994 masonry walls with different fibre materials and different reinforcement strategies. Wallner (2008) and Münich (2010) used also cement based plasters instead of epoxy resign in static cyclic tests. Only ElGawady (2004) and Turek (2004) tested their walls under dynamic conditions on a shaking table. ElGawady chose hollow bricks, carbon stripes, glass- and aramid fibre textiles. The possible increase in the load bearing capacity was between 30% and 150%. While all of them used stiff epoxy and cement based matrices, a soft bonding with polyurethane glue was not considered. In this paper water based non-burning polyurethane glue as bonding material is used for applying a thin impregnated wallpaper textile directly on existing plaster. The system is called in the following chapters MapeWrap EQ System. The practical benefits are the fast and cheap indoor application. No plaster under dust development, no tenancy changeover and clean solution are the result. Of course all positive effects are bought with an additional failure zone between brick and the existing plaster.

2 STRENGTHENING MATEIAL PROPERTIES

To evaluate the quality of the bonding between stone and plaster, at various junctures tensile pull tests were performed. The tensile bond strength of the bonding between adhesive-plaster, lime plaster and brick-wall was determined. After help of a diamond cutter an circular groove with a diameter of 50 mm was compounded under load measurement the pull test was deducted according to DIN EN1015-12. The range of values was between 0.31N/mm² and 0.64N/mm². The quality of the adhesive plaster connection was in middle of the strength values of the bonding interface from plaster to brick and lime stone. The table of the test values are shown below.

Table 1.Results of the pull tests

Nr.	Bonding interface	Tensile force [kN]	Tensile stress [N/mm²]
1	Adhesive – plaster	0,79	0,40
2	Adhesive – plaster	0,75	0,38
3	Adhesive – plaster	1,09	0,56
4	Adhesive – plaster	0,97	0,49
5	Adhesive – plaster	0,86	0,44
6	Lime sand brick -plaster	0,61	0,31
7	Lime sand brick - plaster	0,78	0,40
8	Clay brick – plaster	1,15	0,59
9	Clay brick – plaster	1,25	0,64

As adhesive Curvalin D 3682 HV was used for the textile application each time by full covering both masonry surfaces. The glass fibre wallpaper had following material properties which are divided in the weft and warp direction in following table.

Table 2. Properties of the fabric

Direction	Tensile strength N/mm²]	Strain	Equivalent cross section [mm²/m]	Roving
weft	1787	3,85 %	46,15	300 tex
warp	1623	4,25 %	57,69	300 tex

3 IN-PLANE WALL TESTS

Scaled in-plane wall tests were conducted with three different test specimens with lime sand bricks and lime plaster. While the first wall was unreinforced and only covered with plaster, the second was additionally strengthend with the glass fibre textile. The third specimen was comparable with the second, but on each corner fixed with glass fibre anchors like visible in figure 1 (right). They should transfer the tensile forces from the fabric directly into the masonry and should avoid local tensile stress in the out-of-plane direction. The shear loading in-plane was in the strong inertia force direction with a vertical stress of 0.2 MPa. For the horizontal cyclic displaced head beam the displacement and the horizontal force were measured. Representative results of the envelops of the hysteresis curves from the unreinforced masonry (URM) and the two reinforced masonry (RM) tests (1.25 m x 1.25 m) are shown below in figure 2. The maximum resistance force of the URM wall was 177.28 kN, for the RM wall 212.16 kN and for the wall with additional anchors 214.16 kN. The increase of horizontal shear force capacity in comparison to the URM wall was 20 %, but much more important was the increase in ductility of factor 2. The anchors were especially for the after cracking behaviour very useful and lead to a maximum deformation of 24 mm before anchor pull out resulted torsion in the wall.

Figure 1. Cross cracking at the unreinforced masonry wall (left), horizontal shear cracking at the wall with anchors at the corners (right)

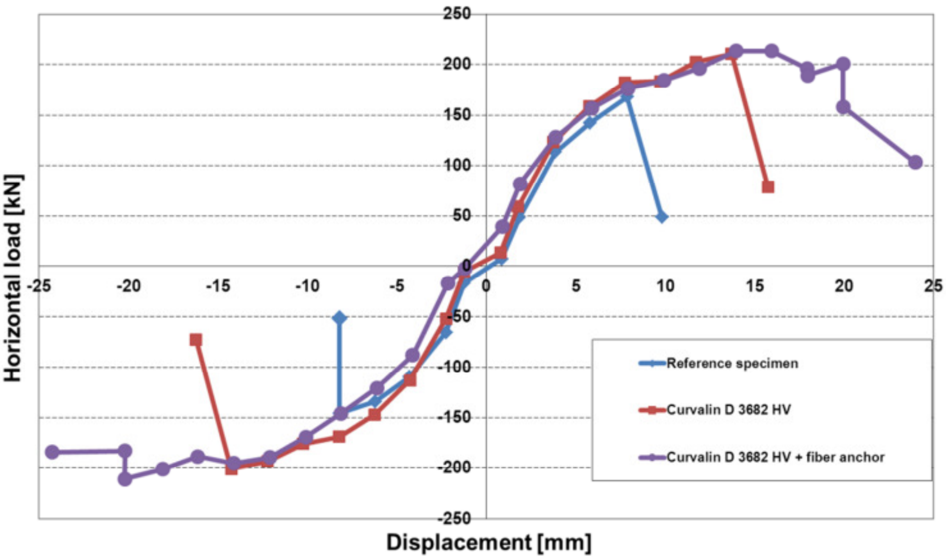

Figure 2. Envelops of the hysterese curves of three masonry walls

4 OUT-OF-PLANE WALL TESTS WITHOUT OPENING

The dynamic out-of-plane testing was conducted on a uniaxial shaking table with the size 3 m x 3 m in a special constructed steel frame. Two tests (WO1) and (WO2) were conducted in each case one 2.4 m x 2.6 m wall with only plaster and a second wall with plaster and the MapeWrap EQ System reinforcement. The difference in the second test was the inserted door opening and the two diagonal steel crosses for frame stiffening. The stones were hollow bricks with tube orientation in the horizontal direction. To the stone surface was applied a typical in Istanbul used cement based plaster with a compressive strength of 8.87 N/mm² according to ASTM C 109 Standard. All walls were hold at three sides, while the top side could move freely.

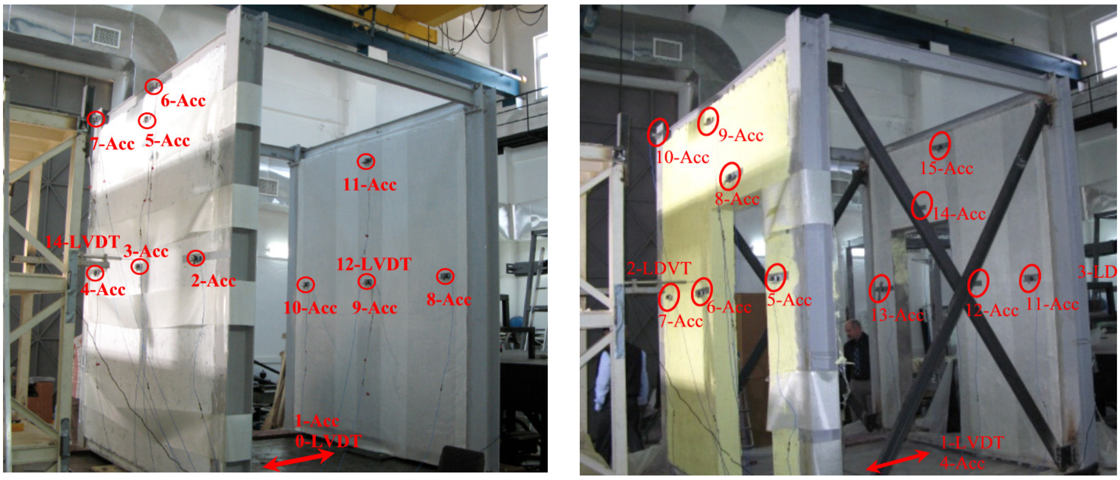

Figure 3. Sensor definition for the test (WO1) (left), Sensor definition for the test (WO2) (right); in both tests a URM wall and a RM wall were synchronously in the frame

Before testing the walls the natural frequencies were determined. The Fourier analysis showed for both walls a bending frequency of about 15 Hz. First stress tests were carried out with the time history of the earthquake Gölcük (Kocaeli). While the tests by scaling the maximum PGA at 50%, 100% and 200% of the original measured values no damage to both walls occurred. After 300% scaling local fine vertical cracks on the unreinforced wall were visible. The natural frequency of the wall decreased after the damage to 13.2 Hz. The maximum PGA in this case was 1.89 g and for the time history excitation the maximum achievable value, while maintaining the duration of 22 seconds.

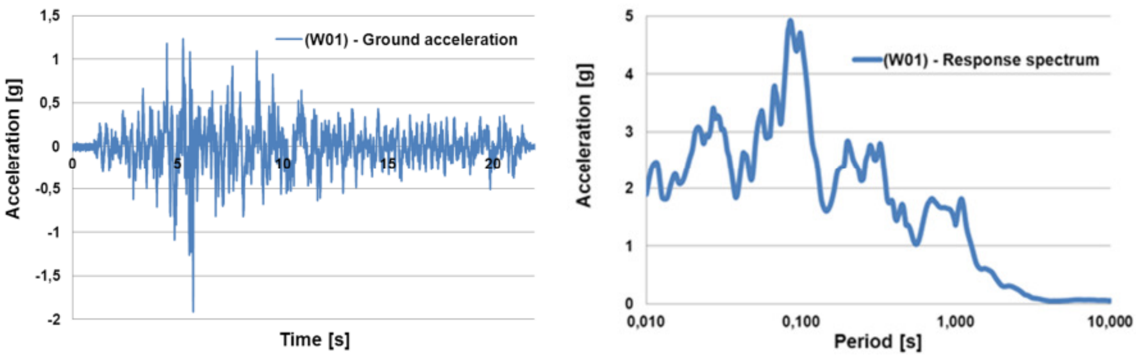

Figure 4. Time history of 300% Gölcük earthquake (left), response spectrum (right)

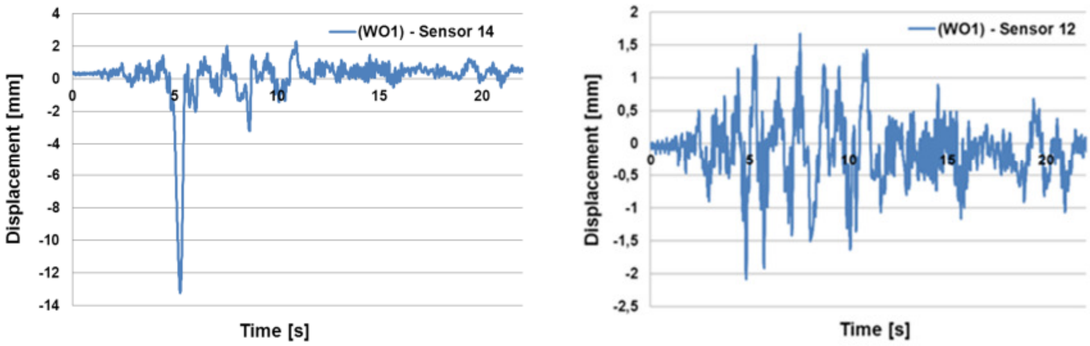

Figure 5. Displacement data sensor 14 while 300% Gölcük (URM) (left), Data sensor 12 (RM) (right)

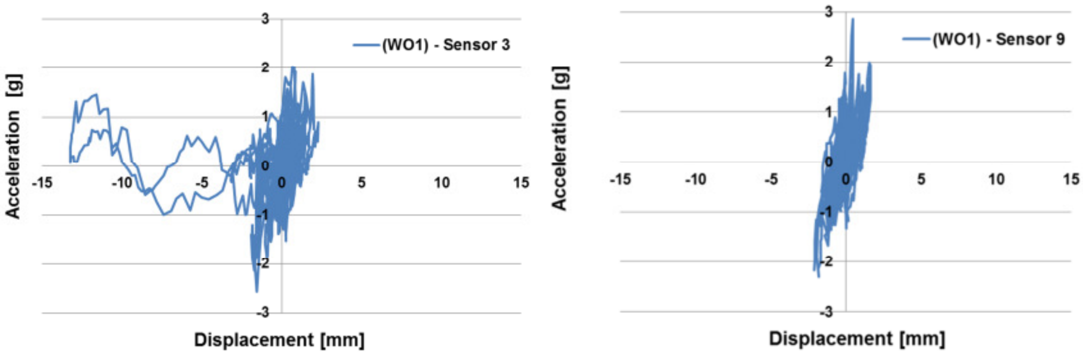

Figure 6. Hysterese curve in middle of the unreinforced wall while 300 % Gölcük (left), reinforced (right)

In Figure 6 the time of the first crack development is clear when it suddenly came after 5 seconds through the damage to large deflections (13mm) of the wall at center point of the unreinforced wall. In contrast the reinforced wall at maximum deflection of 2.1 mm in the linear elastic range showed no damage. The hysteresis loops measured from the deflection and acceleration respectively in central wall position clearly indicating the effect of damage to one side first.

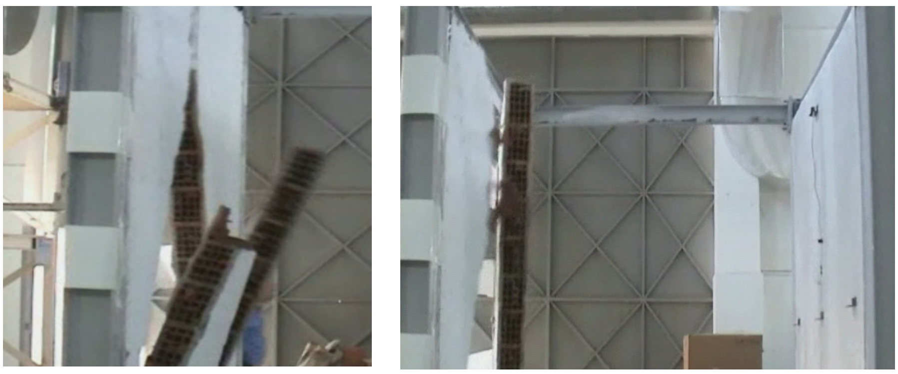

Figure 7. Collapse of the middle wall part (left), total collapse of the unreinforced wall and failure free reinforced wall (right)

For further damaging the walls sine sweep with the natural frequency was chosen as load conditioning. The failure of the unreinforced wall developed in several stages. After the load under the 300% Gölcük time history a fine hairline crack was starting from the central wall and the upper side in the vertical direction to extend downwardly. After first sinusoidal oscillation in the range from 1 to 25 Hz, a plan view image of an inverted Y-crack developed (analogous to the break line theory) with strong stone failures. Further crack mechanism was a collapse of a triangle section like shown in figure 8. In the end the two remaining trapezoids collapse. In contrast, the wall with MapeWrap EQ System could not be damaged under maximum sinusoidal load of 3 g

5 OUT-OF-PLANE WALL TESTS WITH OPENING

The construction of the second experiment (WO2) was analogous to the first examination (WO1) in the previous chapter, except the doors were added. The opposite doors were arranged according to staggered. Technical relevance was a better distribution of the masses, not to cause torsion forces by imbalances. Also more mass has been moved into the middle of the field, whereby the bending moments have been increased in comparison to the central arrangement by a factor of 1.71. Again both walls were dynamically stimulated under the Gölcük time history and sine vibration in the natural frequencies of the walls. The time history load caused no visible damage on both walls. Therefore the damage to the walls was feasible only through specific sinusoidal oscillations at the natural frequency of the walls. Four steps were conducted.

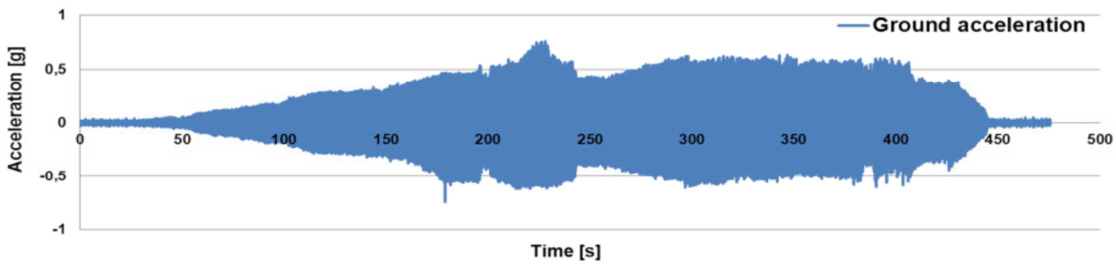

Figure 8. Shaking table acceleration from the first step

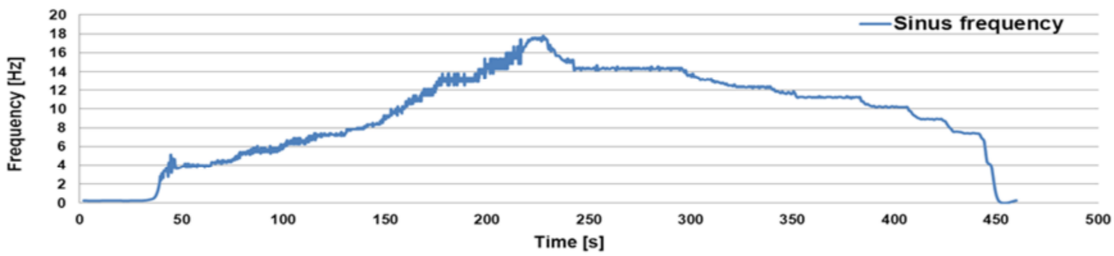

Figure 9. Sine frequency of the first load step

For the characterization of both walls with opening the natural frequencies of the Fourier spectra were calculated using targeted impulse excitations. Both walls had a natural frequency of approximately18.4 Hz. Higher natural frequency in comparison to the first test (WO1) was the result from the reduction in mass by 27%. After the first sine excitation with a PGA of 0.76 g of a crack on the wall was unreinforced wall starting at the central area and extending door upwards. It first broke out of the stone of the inner corner, which subsequently led to a vertical, continuous bending crack of the wall segment on the door. The second load step (0.83 PGA) lead to further cracking and stiffness degradation. As result the hysterese curve of the unreinforced wall showed plastic acceleration-deflection behaviour, like shown in figure 10. Maximum deflections at this point were 42.5 mm.

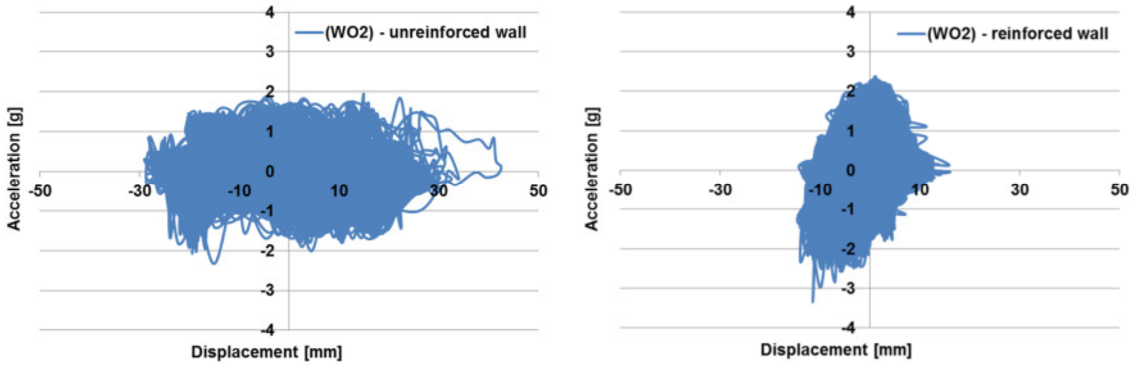

Figure 10. Hysterese curve of the unreinforced wall (left), reinforced wall (right)

The further loading resulted in a total collapse of the unreinforced wall at a PGA of 1.28 g. Synchronous first fibre cracks were locally at the corner position determined. The fourth and final sine excitation led a PGA of 1.97 g to a failure of the fabric, so that similar to the unreinforced wall developed a similar fracture pattern of the masonry. The comparison of the maximum PGA's under similar level of claims therefore had a reinforcing effect of 1.97 g / 0.76 g = 2.6.

Figure 11. Collapse of the unreinforced wall (left), tension failure in the fabric (right)

Table 3. Summary of the load steps and measured test results

Loading	PGA [g]	max. 2-LDVT [mm]	f_{def} 2-LDVT [%]	max. 3-LDVT [mm]	f_{def} 3-LDVT [%]	max. 9-ACC [g]	max. 15-ACC [g]
Sinus 1	0,76	9,84	0,41	10,12	0,42		
Sinus 2	0,83	42,56	5,64	16,03	0,67	2,02	3,72
Sinus 3	1,28	-	-	-	-	-	-
Sinus 4	1,97	-	-	-	-	-	-

6 CONCULIONS

A comprehensive test program with three in-plane walls with a size of 1.25 m x 1.25 m and four out-of-plane walls of size 2.4 m x 2.8 m were conducted. The in-plane test results indicate that the ductility of the walls reinforced with the proposed wall paper increased by two times and their lateral load carrying capacity increased by 20% in comparison with unreinforced walls. The out-of-plane dynamic tests were performed on walls made of Turkish bricks with cement base plaster. The first experiment (WO1) consisted of two walls with no door openings and second walls with doorways. The two dynamic vibrating table tests were carried out both under earthquake excitation and under sinusoidal oscillations. Comparing the damage pattern was noted that the unreinforced wall after the rectilinear pattern of the fracture line theory failed. In the first experiment, it was not possible to destroy the reinforced wall, so there is no quantitative assessment of the increase in the load resistor can be made. In the second case, a fibre failure, and can be observed according to the assessment of the degree of damage based on the similar reason, maximum acceleration, a load resistance of about 2.6-fold increase was observed.

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