# INCERCĂRI EXPERIMENTALE ALE PEREȚILOR DE ZIDĂRIE DE CĂRĂMIDĂ CONSOLIDAȚI PRIN CĂMĂȘUIREA CU BETON TORCRETAT, LA INCERCĂRI CICLICE PERPENDICULAR PE PLANUL PERETELUI
# TESTING SHOTCRETE REINFORCED MASONRY WALLS UNDER OUT OF PLANE CYCLIC LOAD

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***The importance of capillary imbibition and evaporation processes in the alteration of building stones under the action of salt crystallization can be estimated by various experimental techniques. The aim of this study is to understand the direct relationships between salt weathering, petrophysical and structural properties. We chose to work on calcarenite stone which was commonly used as building material in* historical monuments in Morocco*. Laboratory wetting-drying cycles were tested on calcarenite specimens with sodium chloride solutions of different concentrations. Results show that the permeability and specific mass of precipitated salt depend on the material porosity and solution concentration. Moreover, variations of thermal conductivity and permeability during applied cycles are less important for samples taken parallel to the sediment bedding than for those taken perpendicularly. The material anisotropy will also be discussed.***

***Keywords:*** Masonry Structure, Out of plane loading, Steel reinforced shotcrete.

**Terminology**

| | | | |
|---|---|---|---|
| $\Delta_i$ | rigidity | $m_e$ | effective mass |
| $a_1$ | on the first floor acceleration | $m_i$ | th floor mass |
| $a_2$ | on the second floor acceleration | $y(t)$ | building release |
| $a_{ort}$ | average acceleration | $S_{(T)}$ | spectral coefficient |
| $f_e$ | effect of out of plane earthquake load on the wall | $A$ | unit area of the wall |
| $W$ | unit weight of the wall | $F_{CR}$ | bending crack |
| $F_e$ | the total load to the wall effect | $F_{FR}$ | bending fracture |
| $h_e$ | effective mass, height | $\mu$ | ductility |
| $h_i$ | th floor height | | |

## 1. Introduction

Turkey, located in the Alp-Himalayan earthquake zone is an earthquake country. 95% of the population live in earthquake zones, 45% of our existing building stock most of which are in the rural areas are composed of the masonry structures [1].

In rural areas of Turkey the stock piling of goods overloads the structure of masonry structures and these results in a greater propensity for collapse during an earthquake. For example, during 2002 the Afyon-Cay and 2007 the Ankara-Bala earthquakes there were loss of life and damage to buildings because of the stockpiling of goods in various buildings[2]. Since the latter earthquake there has been a call for buildings to be strengthened.

During an earthquake the seismic energy produces ground motion that causes a lateral displacement of the structure. Thus, the maximum momentum is created on the top floor of the building into the plane of the wall, as well as out of-plane loads. In masonry structures, the collapse mechanism of the resistance of the walls out of the plane is assumed to dominate. The stockpiling behaviour of walls under the impact of earthquakes has been investigated by Kanıt [3]. When strengthening masonry against the effects of earthquakes the structure of the load bearing walls should be taken into account.

The ongoing work in Turkey in strengthening masonry buildings against earthquake forces uses a variety of methods and the development of these methods continues. Using reinforced shotcrete is one of the methods and in this method has been used to create building facades Turkey in recent years. In 2007 the Turkish Ministry of Education initiated a programme of shotcrete reinforcement of school buildings in rural areas in order that they can continue to be used.

The number of studies investigating the strengthening of masonry structures with shotcrete has been relatively low and no scaled experimental study has been carried out, however, the following

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research has been undertaken.

Tong; investigated masonry walls reinforced by FRP fiber blanket with plastic rods and sheets with the finite element method and show that this method improves the seismic behaviour of reinforced wall [4].

Galati, Tumialan and Nanni; studied facade of masonry walls with FRP reinforcement applied to the epoxy and at the end of the experiments they showed that the ductility of walls increased [5].

Jin; examined masonry walls strengthened with CFRP and showed that there were significant increases in the lateral load capacity and ductility of the reinforced walls under the plane of and increased out of plane load [6].

Milao; studied experimentally masonry walls reinforced by CFRP. The plane of inner loads and vertical loads applied on the reinforced walls samples. Investigated lateral shift in load, crack pattern and CFRP \ 's effect of the wall. As a result of the experiments, the ability of the walls of load and displacement at considerable improvements have been observed. Significant improvements determined trait features under the lateral loads [7].

Yasser; studied experimentally masonry walls reinforced by FRP and showed that significant increases in load capacity, energy consumption and endurance capacity of the reinforced walls under the static and dynamic loads [8].

Dakhakhni and Wagih; investigated masonry walls reinforced with steel framing. They observerd an increase in the carrying capacity and decrease in deformation on reinforced walls which are under out of plane cyclic load [9].

Sallio; analysed a chest hospital building with SAP 2000 program and determined the wall needs to be strengthened by this method. He assumed that when the walls were strengthened with reinforced concrete, comparing unreinforced walls with reinforced walls, he concluded that there was a numerically increase on the seismic resistance on the reinforced walls [10].

Kanit and Donduren; modelled similar geometric properties of masonry walls with ANSYS program and compared with experimental data results and program data results. They showed that, program data results and the experimental data results were largely match [11].

Erdal; studied similar geometry of masonry walls reinforced by FRP and showed that breaking load increased 2 times and ductility increased 4,25 times on reinforced wall [12].

Most of the buildings are built as a masonry structure in rural areas in Turkey. Strengthening of masonry buildings with reinforced shotcrete on facades biggest advantage of the application is made with traditional materials and craftsmanship.

In this experimental study, an unreinforced masonry wall out of plane cyclic loading test results compared with its strengthened test results were investigated.

According to the experimental findings, the selected method of strengthening increased the resistance, ductility, rigidity and the energy consumption capacity of the masonry wall, thus improved the performance of the wall in relation to seismic activity.

## 2. Research Method

This study used the results of work previously performed by Kanit. [3] The SMW was created with the same geometric and material properties as the URM and the mechanical behaviour were examined.

### *2.1. Unreinforced Masonry Wall (URM)*

A URM of 190 x 190 x 50 mm size was built from clay bricks filled blends according to Turkish Standards TS EN 771-1. The dimensions of the wall are given in Table 1. [13]

A cement mortar was prepared according to Turkish Standards TS EN 998-2. On the front and back surfaces of the URM was applied 30 mm of plaster (20 mm rough and 10 mm thin plaster). C16 concrete was used on the floor beams and floor [14].

For the application of the cyclic load, a 30 mm thick, 100 x 100 mm steel plate was used and the load is applied such a way that it is spread equally on four points. The moment of the out of plane cyclic load was created to be similar to a seismic moment.

The loading in the experiment was applied in incremental steps by a hydraulic pump. At the end of the experiment, the values obtained from the load cell and with the help of LVDT, transferred to a data logger system and the results were assessed according to these values. The experimental results and detailed discussion of URM is given by Kanit [3].

### *2.2 Strengthened Masonry Wall (SMW)*

Strengthening of URM example phases are described below in order of:

Table 1

Geometric properties of the test walls

| Width of wall (mm) | Length of side wall (mm) | Height of wall (mm) | Beams height (at the bottom and top) (mm) | Reinforced concrete floor thickness (mm) |
|---|---|---|---|---|
| 2600 | 1100 | 2700 | 200 | 100 |

- In order to provide the adherence of sprayed concrete with wall, joints of the wall that is ready to be strengthened is opened through an iron hook.
- The wall exterior was covered with steel wire mesh Φ6 188/188 according to TS 4559 / T3 with overlapping joints (Figure 1) [15].

Fig. 1 - Wall coating with steel wire mesh.

- Beams and floor beams were linked to the steel bar of Φ8.
- In order to brick wall and layer of shotcrete work together, steel bar was anchored to the wall with epoxy resin at 500 mm intervals (Figure 2).
- The wall surface was cleaned with a compressed air.
- A wet concrete mixture was prepared according to TS 11747, ASE 500 VP machine was used to apply 50 mm thickness of shotcrete (Figure 3) [16]. The properties of shotcrete are given in Table 2.
- The wall was left to cure for 7 days. Then the internal and external surfaces of the wall were plastered in the same way as the URM.
- 7 days was allowed for the plaster to harden, the test mechanism and loading mechanism was the same as used in the URM experiment.
- The SMW load and displacement measurements applied to the URM were the same as those used in the experiment performed on the URM.

Fig. 2 - a) Mesh of steel beams anchored to the floor anchor with epoxy resin.

**Fig. 2.** b) Steel mesh anchor on the wall

**Fig. 3-** Spraying concrete on the surface of the wall

**Table 2**

Properties of wet mix shotcrete material [16]

| The amount of cement (kg/m$^3$) | Gravel within the total aggregate rate (%) | Slump value (cm) | Water/cement ratio |
|---|---|---|---|
| 300 – 400 | 20 - 40 | 4 – 10 | 0,35 – 0,55 |

### *2.3. Application of Experiment*

#### *2.3.1. Experiment mechanism*

The experiment was applied by the aid of reaction wall in order to determine the behaviour and fracture figure of the masonry wall under the out of plane load. The load was applied with a jack that is able to compress and tensile in two way action. The jack pump had the capacity of 60 t consisting of 30 t of tensile, 60 t of compression abilities. Reversible seismic effect was created on the experiment wall with the help of jack. In experiment mechanism, a rigid steel bar was placed to pass through the center of the steel plates with same properties on both surfaces of the wall. Thus, it was deducted that the forces which were applied to the center of the wall with load plate creates a similar moment distribution to uniformly distributed loads. Loading mechanism, experiment wall and reaction wall can be seen in Figure 4.

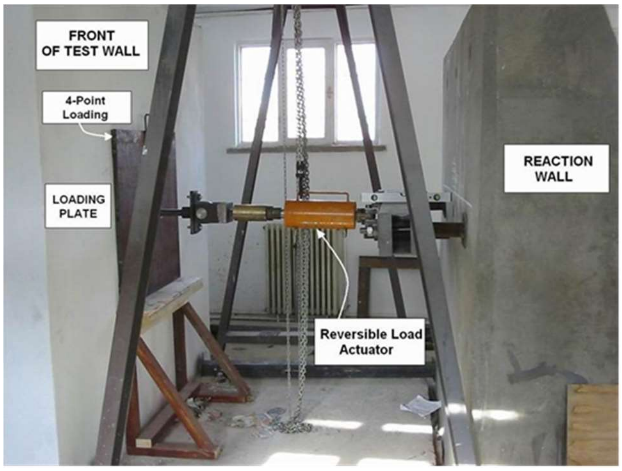


Fig. 4 - Loading mechanism.

#### *2.3.2. Measurement techniques and load measurement*

In both experiments, load measurements were done by load cell and displacements were indicated by the aid of LVDTs. In consequence of loading, the data and values that were obtained by load cell and LVDTs were transferred and recorded to computer immediately with the help of datalogger system and the results were evaluated according to these results.

#### *2.3.3 Measurement of displacement*

LVDTs were used in order to measure the displacements and shortening and elongation which occured on the wall during the experiment. The LDVTs that were used on experiment were capable of reading 0.01mm precision. To determine the rotation on lower and upper chords of the horizontal displacements of the lower and upper ends of the steel frame system, four displacement measurers were placed on four edges of both faces of the wall each, two displacement measurers were placed on left upper and right upper edges of front and rear walls each. See Figure 5. It was deducted that porosity, compression, unit weight, time required for hardening are identical compared to spraying and using hand shovel to lay concrete. However, adhesion strength value for the surface and shotcrete (spraying concrete) is higher. This increases average performance of concrete layer and brick wall under loading [17].

Fig. 5 – Placement of measuring devices on the wall.

#### *2.3.4. Computer transfer of load/displacement measurements and assessment*

Dataloggers were used to transfer and log the stress and tension values that were obtained from data cell and displacement measurers. The data transfer were performed via channels on dataloggers. The data on computers were created by using PCLab software. By using Microsoft EXCEL the graphics were drawn for the given parameters, horizontal load-displacement graphics were created and compared for URM and SMW.

### 3. Experimental Results/Findings

The findings related to URM and SMW experiments are examined in terms of the crack pattern, strength, ductility, rigidity and energy consumption capacity.

### *3.1. Crack pattern*

The crack pattern that is observed under the out of plane load is shown at Figure 6. The first crack on the wall occurred at a loading of +45 kN. When the load reached to +60 kN, length and thickness of cracks that were occured on the wall increased. The power consumption of the wall occurred loading of +60 kN. The crack pattern in the wall plane looks similar to flow lines that are seen in concrete plate. The crack patterns in the SMW are shown in Figure 7. The first crack in the wall within the elastic limits, occurred at a loading of -70 kN. This crack began to flow from the steel

**Fig. 6 -** Crack pattern of the URM.

**Fig. 7 -** Crack pattern of the SMW.

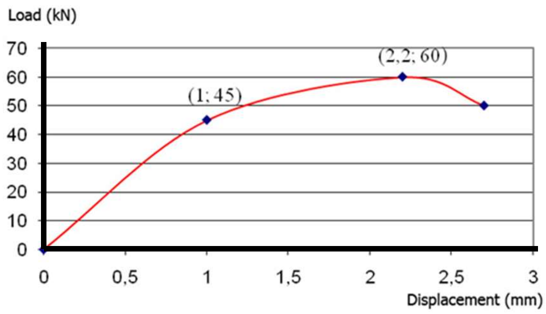


Fig. 8 - First cracking and fracture displacement of the corresponding values of the URM.

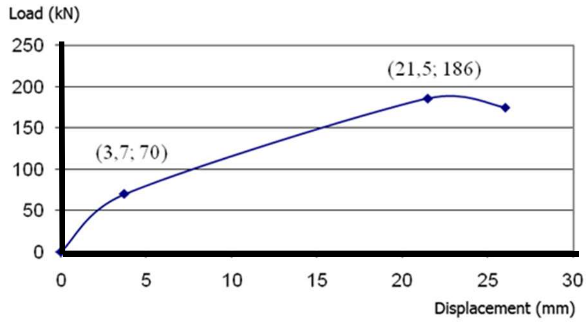


**Fig. 9 -** First cracking and fracture displacement of the corresponding values of the SMW.

reinforcements on the wall. The first flexural cracks from the pull force occurred in the wall corners. After cracking, on the inner wall on the left towards the central region crack growth was observed. Bending cracks over the whole wall were also observed. The lack of occurrence of cutting cracks showed that the wall was resistant to cutting. The wall broke under a load of +186 kN with cracks occurring at the wall corners and parallel to the floor and consists in the case of the pressure force is applied the wall.

### *3.2. Strength*

The first bending crack was $F_{CR}$ = +45 kN, breaking was FFR= +60 kN on URM; first bending crack was $F_{CR}$ = -70kN, breaking was $F_{FR}$ = +186 kN on SMW.

When the first crack values are compared, it is seen that SMW is 70kN/45kN=1.56 times more resistant than URM.

When the break values are compared, it is observed that SMW, 186kN/60kN = 3.1 times more resistant than URM.

### *3.3. Ductility*

The displacement value of URM at +45kN, which is the first crack load of it, is measured 1mm and the ductility value at fracture load of +60kN is measured as 2.2mm (Fig.8).

In this case the ductility for URM is:

$$\mu_{RW} = \frac{2.2mm}{1.0mm} = 2.2$$

The first crack load of displacement value 3.7 mm occurred at -70 kN and the fracture load value was +186 kN displacement measured at 21.5 mm on the SMW (Fig. 9).

Accordingly, the ductility of the SMW is:

$$\mu_{SRW} = \frac{21.5mm}{3.7mm} = 5.81$$

In this case by strengthening of URM:

$$\frac{5.81}{2.2} = 2.64$$

times increase on its ductility was observed.

### *3.4. Rigidity*

The rigidity of the experimental wall was calculated as;

$$\Delta i = \frac{F}{\delta} \quad (1)$$

Where:

$\Delta i$ = rigidity (kN/mm);

F= load (kN), δ = displacement (mm)

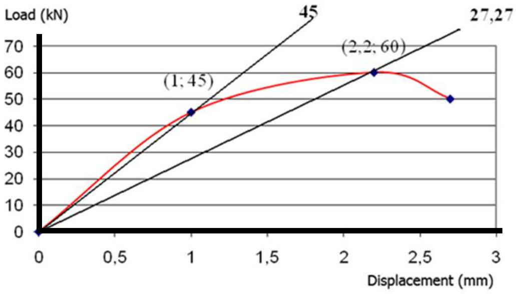


Fig. 10 - Rigidity values of the URM

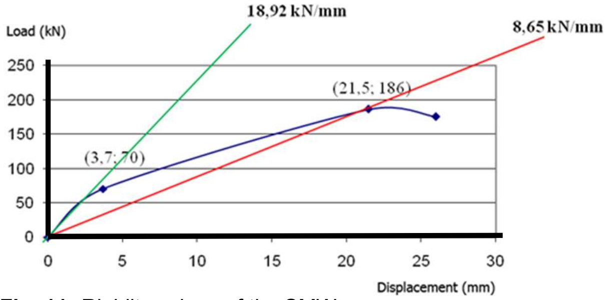


Fig. 11- Rigidity values of the SMW

According to the first cracking load on URM rigidity:

$$\Delta i_{RW_{CL}} = \frac{45kN}{1mm} = 45 \text{ kN/mm}$$

and according to the fracture load rigidity:

$$\Delta i_{RW_{FL}} = \frac{60kN}{2.2mm} = 27.27 \text{ kN/mm}$$

was found.

According to the value of the first cracking on SMW rigidity:

$$\Delta i_{SRW_{CL}} = \frac{70kN}{3.7mm} = 18.92 \text{ kN/mm}$$

and according to the fracture load rigidity:

$$\Delta i_{SRW_{FL}} = \frac{186kN}{21.5mm} = 8.65 \text{ kN/mm}$$

was found.

According to the first crack load and the fracture load of rigidity values of the URM and SMW are shown graphically in Figures 10 and 11.

A comparison of the rigidity of the URM and SMW of the first cracking load showed:

$$\frac{\Delta i_{RW_{CL}}}{\Delta i_{SRW_{CL}}} = \frac{18.92}{45} = 0.42 \text{ rate of decrease}$$

rigidity of fracture load;

$$\frac{\Delta i_{RW_{FL}}}{\Delta i_{SRWD_{FL}}} = \frac{8.65}{27.27} = 0.32 \text{ rate of decrease}$$

was observed.

***3.5. Energy consumption capacity***

The load / displacement graphs of the test walls are given in Figures 12 and 13. The energy consumption capacities calculated from the area between the displacement curve and the horizontal axis were found to be 320 kNmm for the URM and 4461kNmm for the SMW.

Comparing the energy consumptions of the walls, it was concluded that

$$\frac{4461}{320} = 13.94$$

times more energy was consumed by the SMW.

## 4. Analytical studies

According to Turkish Earthquake Regulations on the Response Spectrum Method [18], when a damping rate of 0.05, it is assumed that in order the mass to be affected the ground acceleration is enlarged 2.5 times. When second derivative of shift equation is taken, it is accepted that the distribution to height of building of relative response acceleration converges to linearity. Accordingly, the response acceleration that is occurred in any height of the building can be calculated by Equation 2, multi-storey buildings mean momentum can be calculated by equation 3, the masonry wall plane off vibrations to forced acceleration magnitude can be calculated by Equation 4 and the effective acceleration height can be calculated by Equation 5.

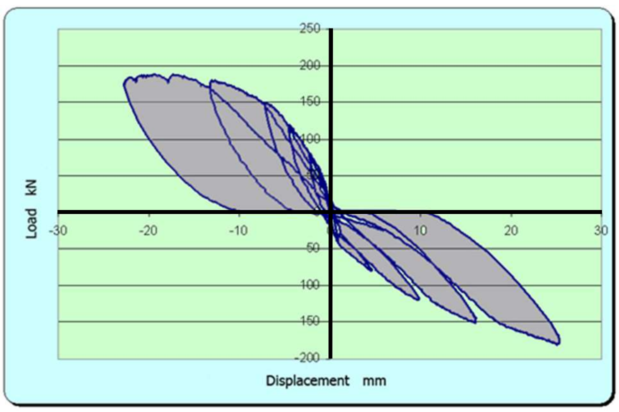


Fig. 12 - Load/displacement graph and energy consumption capacity of the URM (area 320kNmm).

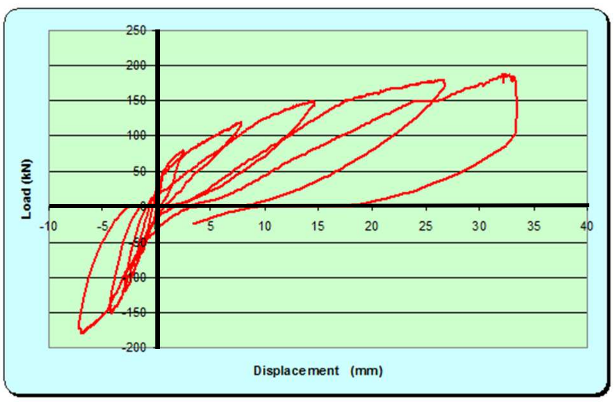


Fig. 13 - Load/displacement graph and energy consumption capacity of the SMW (area 4461kNmm).

(2) $a = 2,5 \times a_g \times \frac{h}{h_e}$

(3) $a_{AVG} = \frac{1}{2} \times (a_1 + a_2 + ....a_n)$

(4) $a_{max} = S_{(T)} \times a_{(ort)}$

(5) $he = \frac{\varepsilon(m_1 \times h_1) \times h_1}{\varepsilon(m_1 \times h_1)}$

According to Turkish Earthquake Regulations [18], for 1st degree earthquake zone the max acceleration of ground g = 0.4 was used, for 2-storey masonry masses were m1 = m2 = m, 1st floor height h1 = 3.0 m. and 2nd floor height h2 = 3.0 + 3.0 = 6.0 m. The effective acceleration height is derived from equation 4:

$$he = \frac{(3.0^2) + (6.0^2)}{3.0 + 6.0} = \frac{45}{9} = 5.0 \text{ m}$$

The acceleration of 1st. floor is derived from equation 1;

$$a_1 = 2.5 \times (0.4g) \times \frac{5.0}{3.0} + (0.4g) \times \frac{6.0}{5.0} = 1.08g$$

The maximum acceleration is given in equation 2,

$$a_{max} = 2.5 \times a_g \times \left(\frac{h_2}{h_e}\right) = (2.5 \times 0.4g) \times \left(\frac{6}{5}\right) = 1.20g$$

In the literature, theoretical model studies gave $a_{max}$ = 1.20g instead of;

$$\left(\frac{4}{3}g\right) = 1.33 \text{ g}$$

found in this study.

In this case the average acceleration from equation 3,

$$a_{AVG} = \frac{1}{2} \times (a_1 + a_2 + ....a_n)$$

$$a_{AVG} = \frac{1}{2} \times (1.08 + 1.33) = 1.21g$$

The acceleration which forces SMW to create out of plane vibration is $a_{SRW\max}$

This acceleration increases by interacting with the floor slab. The enlarged out of plane acceleration on the SMW can be calculated by using equation 4. According to the Turkish Earthquake Regulations [18], an acceleration magnification factor of 2.5 is required, as shown in equation 3,

$$a_{SRW\max} = 1.21g \times ((2.5)) = 3.03g$$

using equation 4. According to the Turkish Earthquake Regulations [18], an acceleration magnification factor of 2.5 is required, as shown in equation 3,

$$a_{SRW\max} = 1.21g \times ((2.5)) = 3.03g$$

A 0.4g of ground acceleration increases with the impact of earthquake forces and forcing out of plane on the SMW and acceleration is converted to 3.03 g.

The acceleration of the wall plane can be assumed to be uniformly distributed over the walls. Uniformly distributed out of plane seismic forces are effective on the wall,

$$f_e = \frac{W_{SRW}}{g} \times (a_{SRW\max}) \text{ kN/m}^2 \qquad (6)$$

The weight per unit area of the wall on SMW is,

$$W = (0.30 \times 1.0 \times 1.0) \times 20 = 6 \text{ kN/m}^2$$

is the replacement on equation 6,

$$f_e = \frac{6}{g} \times (3.03g) \text{ kN/m}^2 \qquad f_e$$

and = 18.18 kN/m² is.

The total load affecting the wall is calculated by

$$F_e = f_e \times A \qquad (7)$$

Wall sizes are 2.70 x 1.0 m. The total load affecting the wall is

$$F_e = 18.18 \times 2.70 \times 1.0 = 103.08 \text{ kN}$$

The equivalent fracture load is given by,

$$f_e = \frac{F}{A} \qquad (8)$$

According to breaking load of 60 kN is URM,

$$f_e = \frac{60}{2.1 \times 2.7} = 10.58 \text{ kN/m}^2 \text{ as is.}$$

The accepted maximum acceleration is $a = 0,4g$; the theoretically calculated out of plane seismic strength is $f_e = 18,18$ kN/m², and experimental seismic strength is $f_e = 10,58$ kN/m² on the URM.

According to these results of acceleration on the URM is,

$$a_{RW} = 0.4g \times \left( \frac{10.58}{18.18} \right) = 0.232g$$

In this case, the URM is assumed to be fractured under an acceleration of 0.232 g.

Fracture load of the SMW is 186 kN,

$$f_e = \frac{186}{2.1 \times 2.7} = 32.8 \text{ kN/m}^2.$$

The accepted maximum acceleration of SMW is $a = 0,4g$; the theoretically calculated out of plane seismic strength is $f_e = 18,18$ kN/m$^2$, and experimental seismic strength is $f_e = 32,8$ kN/m$^2$ on the SMW.

According to these results of acceleration on the SMW,

$$a_{SRW} = 0.4g \times \left( \frac{32.8}{18.18} \right) = 0.722g \cdot$$

In this case, the SMW is expected to be fractured under an acceleration of 0.722 g.

When the fact that the acceleration of the URM and the acceleration of SMW is fractured with accelerations of $a_{RD} = 0,232g$ and $a_{GD} = 0,722g$ respectively is taken into account, it can be said that the strengthening of URM with reinforced shotcrete increases the seismic performance against fracture resistance as follows,

$$\frac{a_{SRW}}{a_{RW}} = \frac{0.722g}{0.232g} = 3.11 \text{ times increase.}$$

## 5. Conclusions

In this study, the URM that is examined under the reversible out of plane load is compared to mechanical behaviours of the SMW and the results are listed below:

- The walls that are loaded out of plane there can occur such cracks that are similar to the cracks which occurs in the 2-way reinforced concrete slab and those cracks can be transformed into flow lines and does not result in a large amount of damage.
- The wall that strengthened externally with reinforced shotcrete can be resistant to more than a rate of 3.1 fracture load.
- For the externally strengthened SMW a 2.64 times increase in the ductility values was observed. Strengthening the inner surface of the wall will produce a higher ductility.
- The out of plane breakage of the reinforced experiment wall is similar to bending fracture but it has been ductiled shear effect. In terms of the earthquake energy consumption capacity, a 13.94 times increase was achieved in the SMW.
- In the external wall strengthened with reinforced shotcrete a 3.11 times increase in seismic resistance performance was observed.
- In the SMW the first cracks appeared on the inner side so it can be said that the wall would collapse inwards. Therefore, it is recommended that the inside of the wall should be strengthened.
- The SMW was strengthened with Φ6 of 188/188 steel wire mesh it would be useful to carry out further tests on different classes of steel wire mesh.
- Because of the fact that the breakage of the wall that is externally strengthened with reinforced shotcrete has occurred in a way that creates cutting impact, it is beneficial to examine seismic behaviour under in plane loading [19].

According to these results; it is concluded that the wall which is loaded reversible out of plane, reinforced out of surface with shotcrete, strengthening both surfaces of the wall with same method and making further tests on different classes of steel wire mesh to strengthen the wall will be useful to examine.

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Capitelul unei coloane interioare (pg. 13 - Nicolae St.Noica - ATENEUL ROMÂN ŞI CONSTRUCTORII SĂI)

Detaliul coloanelor de susținere a peretelui ce desparte scena de noua construcție (pg. 119 - Nicolae St.Noica - ATENEUL ROMÂN ŞI CONSTRUCTORII SĂI)