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Research Article

THE EFFECT OF THE BRICKS USED IN MASONRY WALLS ON CHARACTERISTIC PROPERTIES

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ABSTRACT

Conventional masonry walls serve as partition element or main load-bearer of masonry buildings and reinforced concrete components. Examination of the damages occurring in the walls has revealed the effect of the material used, laying technique and bond between the masonry unit and joint. This study examines the norm feature (hollow directions) of the fabricated brick and masonry brick preferred in conventional walls on laying of the wall. To do this, lime mortar and cement mortar, which are commonly used for joints, were used in laying wall with the two different types of bricks. The data obtained by applying lateral+vertical loading to four different walls manufactured were analyzed through data collection device to ensure that load-displacement diagram are obtained. The study has revealed the effect of the material used and placement direction of the brick on strength of the wall.
Keywords: Masonry wall, fabricated and masonry brick, mortar, load-displacement chart.

1. INTRODUCTION

In terms of building stock, masonry walls are widely used both in our country and in the world. Ease of laying such walls and preference of materials varying by region increase the rate of preferring masonry wall in buildings. Stone, adobe, brick and concrete blocks are preferred in manufacture of such buildings. In particular, hollow fabricated bricks, which are conveniently available and which are easy to lay, are being preferred recently.

Raw material of the bricks is clay, feldspar, quarts, and if necessary, additives. Bricks are manufactured by mixing these materials together, shaping and kiln-drying the mortar prepared. While preferring clay inside the brick paste provides further plasticity to the material, kiln-drying enhances strength of the material. Changes take place in mineralogical, chemical and physical properties of the main substance during kiln-drying [1]. These fabricated bricks are manufactured in various dimensions and norms. They are manufactured with hollows to make them lighter. Shape and area of the gaps on the bricks will affect the amount of self-weight as well as the way it transmits the self-weight. Another factor affecting the gap ratio of the bricks as much as the mineralogical composition and baking tempera tures is the shaping methods. Such factors as

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baking temperature and baking speed should be considered in determining the effect of capillary spaces in the bricks. Total gap ratio and gap dimensions significantly affect the water holding capacity of the material and circulation of the water inside the material and these values constitute the parameters affecting determination of the problems that may arise in connection with the characteristics of the material. Moreover, the changes in the void structure of affect the mechanical properties of the material [1-4]. Singh and Munjal (2017) used concrete and clay bricks with different surfaces in their study. The concrete brick with a big hollow surface showed a lower strength compared to that with gaps filled [5].

Masonry walls laid with such bricks show more brittle character. Not only masonry units are used in laying wall. Mortar is used to ensure that masonry units are held together. The studies show how the composite panel formed by these two components work together. It was demonstrated in these studies that behavior of a masonry wall formed by the combination of components with different properties from each other is difficult to determine. Since the materials used in production of the walls will affect the behavior of the wall, properties of the materials used are determined by experiments. As the load or impact acting on the wall is borne by the brick or mortar composite component, characteristic feature of the material used affects the behavior of the wall. The behavior of a masonry construction is affected by the chemical and mechanical properties of materials constituting the construction and of the mortar used as binder. Although the characteristic strength of the materials constituting the masonry wall is high, the wall does not bear exactly the same character with the material. Hence, it is not reasonable to arrive to an overall conclusion about the wall [6]. Various experiments were performed for behavior of the walls in the literature [7-11]. Gumaste, et al., (2007) examined in their study the young module and compressive strengths of the masonry walls under compression effect. It was detected that masonry compressive strength value can be 25% to 50% of the brick compressive strength. They also stated that one of the reasons of collapse of the masonry walls with low-strength mortars is the weakening that takes place on the brick/mortar surfaces [12]. The uncertainty between the brick/mortar surfaces can lead to uncertainty in masonry, as well. If shearing collapse occurs due to the loss of interaction between brick and mortar, the lateral compression value in the bricks drops and tensile rupture can occur. If even one of the bricks in the wall is weak, this brick can be crushed due to the tensile rupture in other bricks. In the walls made with a mortar having high compressive strength, the stresses occurring in vertical mortar joints can lead to shear collapses in the brick below. Kaushik, et al., (2007), examined the effect of compressive strength of the brick and mortar in calibrating the young module of the brick and mortar in masonry walls by examining the stress-strain values of the brick units produced from clay. The reason why the tensile strength of masonry wall is low is the fact that the masonry consists of two materials with different properties and the weak interaction between brick and mortar [13]. Considering that masonry is the combination of brick and mortar units, we also see in their study the idea that strength and rigidity value of the masonry may be between the strength and rigidity values of the brick and mortar. They associated the accuracy of this with the strong brick-weak mortar or strong mortar-weak brick principle when looked at the mechanical properties of the brick and mortar materials constituting the masonry. Moreover, in masonry prisms produced with strong mortar, mortar acts homogenously and damage attributable to stress occurs along the joint [14]. When examined, collapse mechanisms produced with weak mortars, they concluded that it exhibited nonlinear behavior and had a tendency to damage the walls earlier, and affected axial stress of the wall [15-16]. Characteristic properties of the mortar especially in the bed joints affects deformability of the wall [17-18]. Mechanical properties of the components constituting the walls and the joining points were determined in laboratory environments through experimental studies. Wall models were set up, wall behavior was identified, and the parameters attained were used in modelling to make comparisons [19-22]. Behavior of the masonry walls under compressive stresses is brittle. A ductile behavior at a certain rate is observed under shear stresses. From the studies conducted for load-displacement behavior of the masonry wall under axial load, a result was attained to the effect that co mpressive strength of masonry can usually be calculated using single-axis compressive strength values of the masonry unit, that contribution of the mortar to compressive strength is too little. In studying the regional fracture of the walls show that the energy level of the wall is at a lowest level, the ductility is reduced, the wall space ratio has to be designed and the use of brittle materials should be considered. Accordingly, earthquake reliability and ductility will be maintained with proper production [23].

In studies show that masonry infill walls affect the strength and stiffness of infilled frame structures. In previous studies, infill walls have been neglected during the design of the buildings because of the fact that the brittle behavior of the walls is unknown. Experimental tests and analytical investigations are recommended in order to determine the behavior of frame and composite infill walls [24, 25, and 26]. The extensive analysis should be completed in order to determine the crushes on the corner of the walls during the damage mechanisms. Under lateral loads an infill wall acts as a diagonal strut connecting the two corners. The behavior of the macro-modeled infill walls have been studied by asterisk and the parameters have been defined to use in the analytical model [27, 28, 29, 30, and 31].

The behavior of masonry structures under compression is brittle. Besides, the masonry structure show limited ductile behavior under shear stresses. The experimental studies for load-displacement behavior under axial load for masonry structures show that uniaxial strength of the masonry structures can be calculated only by the uniaxial strength of the masonry elements and the mortar effect is limited. Tomazevic (1999) points out that inelastic and elastic performance of the walls can be used to demonstrate the durability effect of the walls, using the concept of excellent plastic curve. This shows an approach depends the equal energy dissipation of real and idealized stress-strain curves [32]. In a study by Essa et al. (2014), the effect of the behavior of high strength reinforced concrete beams on the ductility of the infill walls was investigated. Therefore, for the purposes of this study, different types of materials in different thicknesses filled with filled and non-filled beams were produced [33]. Different parameters were obtained on this count. It was found that the scrape type affects the ductility. Thus, behavior of the load-bearing walls may be identified and it may be possible to develop methods to rehabilitate the damages [25-34].

This study investigated the effect of fabricated bricks with different properties on behavior of masonry walls. To do this, bricks with different pores and dimensions were selected. Production was performed by changing the mortar type with these bricks. Strengths, displacements and material effects of those walls produced were analyzed.

2. THE EXPERIMENTAL WORK

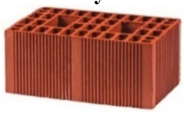
2.1. Test Work of Masonry Elements

Fabricated brick and masonry brick used in conventional masonry unit production were used in the study. NHL 3.5 lime mortar and CEM 32.5 cement mortar were used to ensure the interconnection in brick laying. CEN was used for mortar. The bricks used to be able to form the walls were the load-bearers of conventional masonry buildings, fabricated brick, which are more widely used in rural areas and known as red brick, and masonry brick. Brick properties are given in table 1.

Compression, flexion and young modulus experiments were conducted in order to test mechanical properties of the preferred brick [36-37]. According to experiment results, strengths of the bricks are similar (6.38-6.11 MPa). The compressive strength of CEM 32.5 mortar is twice as the masonry units. Determination of fresh and hardened properties of the mortar affects its role in the wall. Fresh and hardened behavior of the mortar is affected by water/cement ratio and aggregate properties. Mortar strength is required to be attained through mechanical experiment.

For that purpose, compressive strength, elasticity modulus and tensile experiments are performed [38]. The experiments applied to the materials in the study are given in Figure 1.

Table 1. Properties of Masonry Units

Masonry Unit	**Masonry Brick**	**Fabricated Brick**
		
Hollow Direction in Wall Laying	Vertical	Horizontal
Dimensions	290 x 190 x 135 mm^3	190 x 190 x 135 mm^3

Compression Experiment **Young Modulus Experiment** **Flexion Experiment**

Figure 1. Experiment Images

Mechanical experiments were applied to the mixture prepared so as to determine the properties of the mortars. Mechanical experiments were applied to the mortars and masonry units (Table 2).

Table 2. Test results of masonry unit materials

	Compressive Strength (MPa)	**Flexural Strength (MPa)**	**Young Modulus N/mm^2**
Masonry Brick	6.38	0.3	1427
Fabricated Brick	6.11	0.4	1322
CEM 32. 5	12.5	2.12	16723
NHL 3.5	4.59	2.59	5586.1

2.2. Masonry Wall Experimental Setup and Wall Experiment Analysis

This study was conducted in the Material Laboratory of Yıldız Technical University. First, four different walls were produced and the walls were allowed to gain strength for 28 days. Wall laying was performed in single row, by preferring fabricated brick, using NHL 3.5 and CEM 32.5 such that joint thickness is 2 cm. Then, the setup in figure 3 was used to determine displacement of the walls against vertical and horizontal loading. In order to obtain the displacement distances of the wall against the load, four LVDTs that can be fitted in and removed from the experiment setup were placed. A data collection point (box) where data can be read is available on the device.

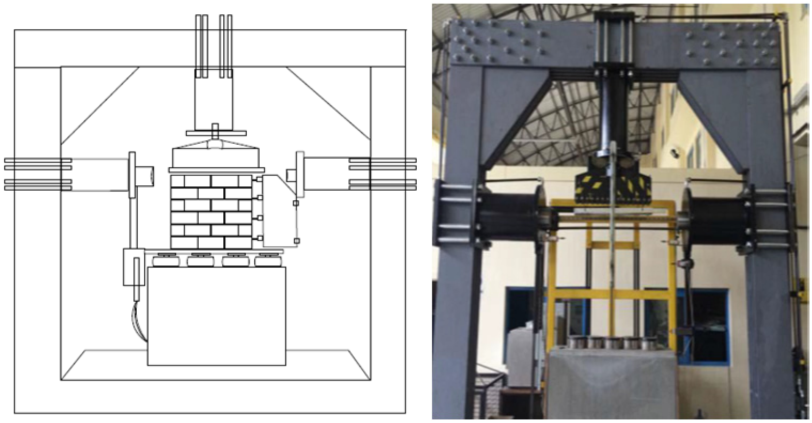


Figure 3. Experimental setup

2.3. Walls produced with Masonry Brick (C2Yand N2Y)

To be able to perform production similar to conventional masonry walls, production was performed in laboratory environment in one row in an eccentric arrangement. Masonry bricks and mortar prepared with CEM 32.5 cement and/or NHL 3.5 were used in wall bonding. Production was performed such that horizontal joint thicknesses are 20 mm and vertical joint thickness is 10 mm. Due to porous structure of the brick, filling should be performed in the hollows at a certain rate during bonding for the joint bed to be flat. In vertical direction, loading was applied under 50 kN to the walls with CEM and under 25 kN to the walls with NHL. In horizontal direction, incremental direction was applied and the experiment was ended once the wall was deformed. Image of the damage after the experiment is given in Figure 4.

C2Y N2Y

Figure 4. Damage of the Walls produced with Masonry Brick

With also the effect of friction in bed joints, the bricks are bonded to each other and their shifting is prevented in the walls. However, notable damages occurred in the horizontal joints due to shifting. There were tensile stresses in the beds, notable disintegrations occurred in the vertical joints against the vertical load. Diagonal cracking occurred in general. Brick damages occurred in the blocks close to vertical joints. Tensile damages occurred in the bricks in the bottom left row. Surface break out was observed in the brick due to fact that strength of the cement is higher than strength of the brick. In terms of strength capacity of the walls, C2Y is higher by 118% compared to N2Y. In terms of displacement ratios, C2Y displaced 20% more compared to N2Y. Load-displacement diagram is given in Figure 5.

C2Y N2Y

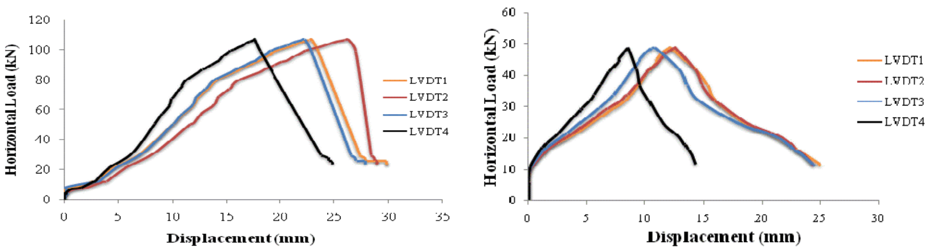


Figure 5. Damage of the Walls produced with Masonry Brick

2.3. Wall produced with Fabricated Brick (C2F and N2F)

In fabricated brick walls produced with similar properties to the walls produced with masonry brick, production was performed so that only hollow direction of the brick is horizontal. When the hollows were in vertical direction, there was no need for filling the hollows. There is no additional load to the walls. Damage during the experiment is given in figure 6.

C2F N2F

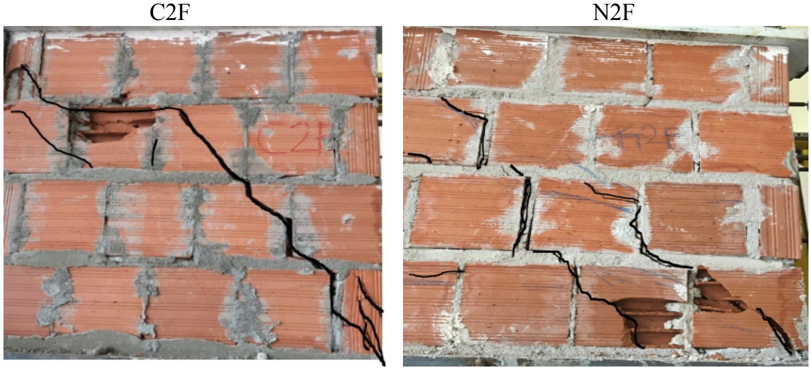


Figure 6. Damage of the Walls produced with Fabricated Brick

Nearly diagonal damage occurred in the walls produced with CEM 32.5 mortar. Surface break out occurred on the brick where horizontal loading was applied. Crushing was observed at the support point at the base of the walls. Cracks were also observed on brick surface due to the fact that mortar strength is high. More damage was observed both on brick surface and in joints in the walls produced with NHL 3.5. Surface break outs occurred on the bricks especially in the lower zones. Bricks and joints worked together since strengths of NHL 3.5 mortar and brick were similar linear parameters. In terms of strength capacity of the walls, C2F is higher by 29% compared to N2F. In terms of displacement ratios, N2F displaced 65% more compared to C2F. Load-displacement diagrams is given in Figure 7.

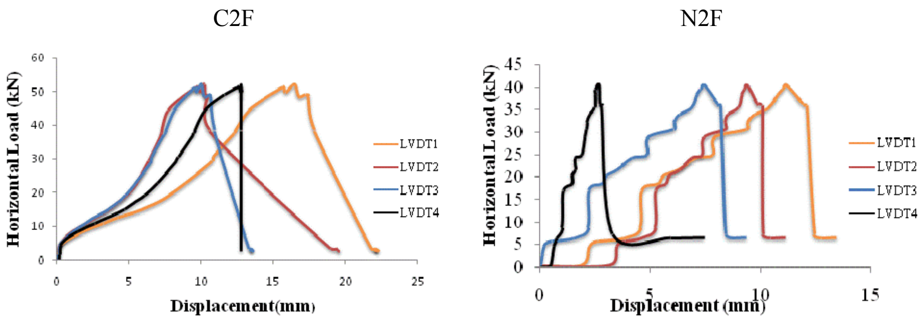


Figure 7. Damage of the Walls produced with Fabricated Brick

3. COMPARISON MASONRY WALL

In the experimental study, the ductility of the structure was determined by empirical analysis to examine the responses of the walls. Ductility is defined as the ratio of maximum and yield deformation [39]. The level of ductility describes the energy absorption capacity of the structure and its ability to deform on lateral loads. Therefore, the selection of ductile materials is an important safety feature in earthquake zones. The ductility limit is obtained from the load displacement graphs. If the structure is not designed based on the seismic code, cracks and damage occurs under seismic loads. If the loads cannot consume enough energy, large lateral forces occur. The area under the Lateral-Force displacement graph shows the energy consumption of the structure.

$$\mu = \frac{\Delta u}{\Delta y} \quad (1)$$

In formula 1.Δu and$\Delta y$are the deflections at ultimate and yield load. According to the experimental results using the durability formula, the test results are given in Table 5. The ductility rate of the N2Y wall is about twice that of the other walls. The ductility rates of other walls are closer to some.

Table 5. Testing result of walls

Wall Name	Δu (mm)	Δy (mm)	μ	Energy Dissipation Capacity(kNmm)	Horizontal Load(kN)	Vertical Load(kN)
C2Y	29.81	26.2	1.14	1722.03	107.16	50
N2Y	24.99	12.08	2.07	703.11	49.07	25
C2F	22.18	17.85	1.24	565.14	52.51	50
N2F	13.41	11.88	1.29	244.89	40.57	25

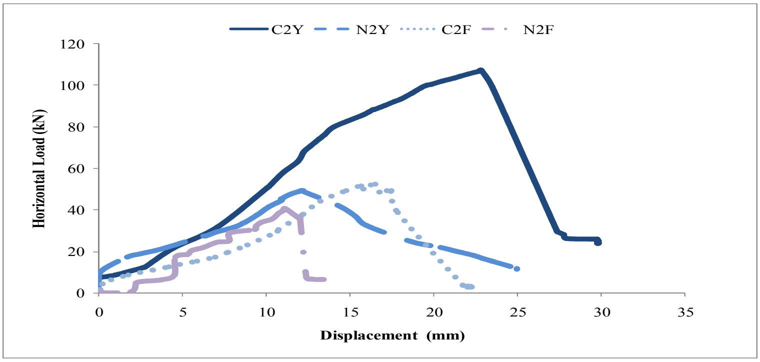


Figure 8. Load-displacement diagram of the walls

Damage analysis and displacements under load were obtained and compared for four different (C2Y, C2F, N2Y, and N2F) walls produced using different bricks and mortars. Depending on the horizontal loading - load displacement diagram, comparison result of the four walls is given in figure 8. Accordingly, the walls produced with CEM 32.5 joint exhibited 78% higher strength under horizontal load in average compared to NHL 3.5. Moreover, displacement ratio of the walls produced with masonry brick is 35% higher. Although strength of the wall produced with masonry brick is higher than strength of the wall produced with fabricated brick, with the effect of the mortar used in the joint, C2F and C2Y strength and displacement amounts came up with similar results. The material strength affects the enery consumption levels on the structure. C2Y walls have the largest energy consumption levels (1722.03 KNmm). As walls produced with CEM32.5 has three times higher energy consumption levels than walls produced with NHL3.5.

4. CONCLUSION

In this study, 4 different prototype walls were produced using two different kinds of bricks and two different kinds of mortar (CEM 32.5/ NHL 3.5). The gap direction of the bricks are different for the walls that have been produced.

The experimental study shows the conclusion.

- It demonstrates that properties of the materials used in wall laying affect the damage status of the wall.
- CEM 32.5 mortar is 2.72 times higher than NHL 3.5 mortar. As a result, the vertical loads applied to the walls with cement mortar are twice as much as the walls with NHL mortar.
- The walls produced with CEM 32.5 mortar have more strength to lateral loads. The damage on the brick-mortar joints are more significant because of the higher mortar strength. The damage on the brick surfaces appear on these walls.
- Surface break outs occur on the surface of the bricks with the gaps in horizontal direction.
- As a result of stronger mortar and stronger brick, the lateral load strength of the wall is 107.16Kn. On the other hand, the lateral load capacity of the other three walls is similar to each other.
- The fabricated bricks and masonry bricks have similar compressive strengths.
- The comparison between walls produced with masonry bricks and walls produced with fabricated bricks show that there are differences between wall strengths and wall ductilities as a result of hole directions on the bricks is the walls produced with masonry bricks are more rigid because of vertical hole direction of the brick structure.
- The durable material used in the joint fully changes behavior of the wall. The walls can

work together thanks to the fact that strength of the joint is close to or lower than that of the masonry unit. In addition, since the bricks are laid according to the hollow feature, it leads to different damages along with the extra load it will bring to the wall.

- The walls produced with CEM 32.5 mortar have three times more energy consumption level than walls produced with NHL 3.5 mortar. On the other hand, the walls produced with masonry bricks have 2.5 times higher energy consumption level than walls produced with fabricated bricks. It has been the wall produced with masonry bricks have higher stiffness.
- The choice of different materials changes the ductility of the walls. The greatest ductility is on the bricks with vertical gaps. The ductility of wall N2F is twice as much as other walls while ductility of the other walls is similar to each other.

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