

ÇİFT CİDARLI YIĞMA DUVARLARDA KENET TAŞININ ÖNEMİ**Erhun AÇAR**

Van Yuzuncu Yıl University, Faculty of Engineering, Department of Civil Engineering, Van, Turkey

Barış ERDİL

Van Yuzuncu Yıl University, Faculty of Engineering, Department of Civil Engineering, Van, Turkey

ORCID ID: 0000-0001-5282-3568**Fırat KIPÇAK**

Van Yuzuncu Yıl University, Van Vocational School, Department of Construction, Van, Turkey

ORCID ID: 0000-0003-3849-7545**ÖZET**

Türkiye'nin kırsal kesimlerinde ve tarihi yapıların büyük bir bölümünde yığma malzemeler kullanıldığı bilinmektedir. Yığma yapılar malzeme kalitesi ve yapısal sistem düzeninden doğrudan etkilendiğinden bu yapıların deprem performanslarının belirlenmesi güçleşmektedir. Fakat deprem sırasında belirli göçme tiplerinin baskın geldiği görüldüğünden ilgili göçme tiplerinin özel olarak çalışılması davranışı anlama noktasında önemli fikirler verebilecektir. Yığma yapılarda yoğun olarak düzlem dışı yığma duvar göçmesi gözlemlendiğinden bu çalışmada çift cidarlı yığma duvarların düzlem dışı göçme profillerine ve kapasitelerine kenet taşının ne kadar etkisi araştırılmıştır. Harman tuğlası kullanılacak duvarlar en olumsuz durumu temsil etmek ve kenet taşının etkisini görebilmek için harçsız olarak inşa edilmiştir. Deneylerde planda U şeklinde yığma duvarlar ½ ölçekli olarak imal edilmiştir. Üç farklı duvar deneyi özel olarak imal edilen bir sarsma masasında yapılmıştır: ilk duvarda kenet taşı kullanılmamış, ikinci duvarın açıklığının ortasında duvar yüksekliği boyunca tek sıra halinde kenet taşları kullanılmış, son duvarda ise kenet taşları iki sıra halinde yerleştirilmiştir. Düzlem dışı deplasman profillerinin ve yatay yük kapasitelerinin belirlenebilmesi amacı ile deneylerde doğrudan deplasman ölçümleri alınmıştır. Kenet taşı kullanılan bütün duvarlarının kapasitelerinde, kenet taşı kullanılmayan duvarın itme kapasitesine oranla önemli ölçüde artış meydana gelmiştir. Tek sıra kenet taşı ile kapasite %100 artarken, iki sıra kenet taşı kapasiteyi %120 artırmıştır.

Anahtar Kelimeler: Yığma duvar, Harçsız duvar, Harman tuğlası, Düzlem dışı kapasite**ACKNOWLEDGEMENT**

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THE IMPORTANCE OF HEADER STONES IN DOUBLE-WYTHER MASONRY WALLS

ABSTRACT

It is known that masonry materials are used in rural areas of Turkey and in most of the historical buildings. Since masonry structures are directly affected by material quality and structural system layout, it is difficult to determine the earthquake performance of these structures. However, since it is observed that certain types of failure are dominant during earthquakes, special study of the relevant failure types can provide important insights into the behavior. Since out-of-plane masonry wall failure is commonly observed in masonry structures, this study investigates the effect of header stones on the out-of-plane failure profiles and capacities of double-wyther masonry walls. The walls to be used with solid bricks were constructed without mortar in order to represent the most unfavorable case and to see the effect of the header stones. In the experiments, U-shaped masonry walls were constructed in $\frac{1}{2}$ scale. Three different wall tests were carried out on a specially constructed tilting table: the first wall was constructed without header stones, the second wall had header stones used in the center of the wall span, and in the last wall header stones were placed in two rows. In order to determine the out-of-plane displacement profiles and horizontal load capacities, direct displacement measurements were taken in the experiments. The capacities of all the walls with header stones increased significantly compared to the pushover capacity of the wall without header stones. While the capacity increased by 100% with a single row of header stones, two rows of increased the capacity by 120%.

Keywords: Masonry wall, Dry-stack wall, Solid brick, Out-of-plane capacity

1. INTRODUCTION

Masonry structures are usually constructed with thick walls (double skin, complex, etc.) to ensure a certain stability. The frictional force between mortar and masonry units has a significant effect on the strength of the walls. In the absence of mortar connection, the connection between the units in the wall will only be provided by the friction force between the masonry units (Casapulla and Argiento 2016). It is known that in-plane loaded walls have higher strengths than out-of-plane loaded walls. This is because in-plane loaded walls resist the horizontal forces as a whole due to the continuous friction of the wall and the overturning and sliding movements of the masonry units on each other. In out-of-plane loaded walls, on the other hand, due to the low frictional forces and insufficient resistance to overturning moments, the masonry units will both slide easily on each other and overturn under low loads.

Giuffrè (1996) experimentally and analytically investigated the effect of the density of the header stones used in masonry walls (stone material) on the out-of-plane capacity of the wall. Double-wythe "opus quadratum" walls were used in the study. It was concluded that the out-of-plane capacity of the wall decreases with a decrease in the amount of header stones. Giuffrè (1996), and De Felice (2011) stated that strong bonds formed by binding mortars and fasteners in masonry structures increase the stiffness of the wall and increase its out-of-plane capacity. El Sayed et al. (2001) found that when multi-wythe masonry structures are subjected to out-of-plane motions, the walls with weak connections are easily separated from each other and this reduces the stiffness of the wall and accelerates collapse. Considering that the out-of-plane capacity can be improved by strengthening the connection between the wall units with a cement-based binder material, they determined that the out-of-plane capacity of the wall increased by 30% in some experiments. Bayülke N. (2011) stated that the wall strength of masonry structures depends on the compressive strength of the masonry units and the strength of the binding materials that connect these units. Besides the inadequate thickness of the mortars or the thickness of the joints, increase in the void ratio in vertically perforated bricks reduce the shear and compressive strengths. De Felice (2011), referring to the work of Giuffrè (1996) and using existing wall sections in Italy, concluded in his analytical study that header stones make a positive contribution to the out-of-plane displacement capacity of the wall.

Akansel et al. (2014) analyzed several strong motion records to investigate the characteristics of ground motions in Van and Erciş district after the October 23, 2011 earthquake with magnitude $M_w = 7.0$. Post-earthquake field observations revealed the amount of out-of-plane collapse of the masonry walls. Bayülke, N. (2018) stated that the thicker or thinner joints and the larger or smaller ratio of brick thickness to joint thickness, and the use of thicker or thinner bricks will affect the strength of the brick wall. He determined through a series of experiments that the ratio between the depth of the brick and the thickness of the joints has a significant effect on the vertical load carrying capacity of the wall.

Erdil B. (2020), based on the reports and articles written on out-of-plane collapse in masonry structures after the earthquakes that occurred in recent years, experimentally investigated the effect of the side wall and the gaps in the side wall (door and window) on the out-of-plane moving wall in single-walled masonry structures. Seven different masonry building models with U and L geometries constructed with solid mortar bricks were tested with a bending table setup. Unlike standard brick wall tests, no binding material was used between the masonry units and the specimens were constructed in ($\frac{1}{2}$) scale. It was stated that the out-of-plane capacity of

the walls would decrease with the increase in the voids and decrease in the amount of the side walls.

Erdil et al. (2022) drew attention to the following deficiencies in their article written after the earthquakes that occurred in the villages of Özalp and Saray districts of Van in 2020: It was emphasized in the field surveys conducted after the earthquakes that none of the buildings were in compliance with the existing regulations, the foundations and walls were damaged due to environmental exposures, and these damages either increased due to seismic loading or the structure collapsed completely. The constructions were built by local craftsmen using local materials, non-standard construction techniques and the connection elements between the masonry units did not have sufficient strength. In general, it was determined that out-of-plane collapse is common and heavy roofs negatively affect the out-of-plane collapse capacity.

The seismic behavior of masonry buildings is complex compared to reinforced concrete and steel structures. Although they have advantages in terms of economy, material availability and workmanship, masonry buildings are generally not considered as earthquake resistant structures due to their low resistance to dynamic and horizontal loads such as earthquakes because they are made of very heavy and brittle materials (Bayülke, 1992). It is known that the mechanical behavior of masonry material depends on many factors such as the compressive or shear strength of the components (mortar and blocks), block shape, volumetric ratio between components and wall texture. This is the result of the application of a set of construction tools that constitute the "rule of art". Given the complexity of the problem due to the large number of variables, a fair assessment of the load-bearing capacity of walls can only be made by in-situ testing (Borri et al. 2020).

After the recent earthquakes, it is understood that the behavior of masonry structures under lateral loads is not well known. Current studies are required to analyze the out-of-plane behavior profile well, to better design masonry structures and to determine and evaluate the behavior of masonry structures under lateral loads. In the present study, double-wythe masonry walls without binding materials were built using only the header stones placed at different locations and at different densities. Walls were in U-shape and tested in out-of-plane direction via a specially designed tilting table. The header stones were placed perpendicular to the two wythes to determine the effect on the out-of-plane capacity of the wall.

2. MATERIAL AND METHODS

In the experiments, dry-stack brick masonry U-shaped walls were designed in a scale close to the real building walls ($\frac{1}{2}$ scale) depending on the laboratory conditions. It is thought that this

study will contribute to the literature for a better understanding of earthquake induced out-of-plane behavior of masonry structures. In the experiments, 15 LVDTs were placed on the walls to determine the out-of-plane profiles of masonry walls constructed with double-wythe and header stones (Figure 1). Header stones were placed close to the midspan of the wall. Three different wall configurations were tested: TD-N is the wall without header stones, TD-I is the wall with a single line of header stones and TD-II is the one with header stones placed in two lines (Figure 2). All wall dimensions were the same: height 1.40 m, side wall lengths 2.00 m, and the length of the wall whose out-of-plane behavior profile was to be determined was taken as 2.80 m. Solid bricks having 5x10x20 cm were used as the masonry units.

Two LVDTs were placed at the bottom of the table to record the upward displacement of the table (Figure 3). The upward displacements were correlated with the lateral load using Eqn. 1.

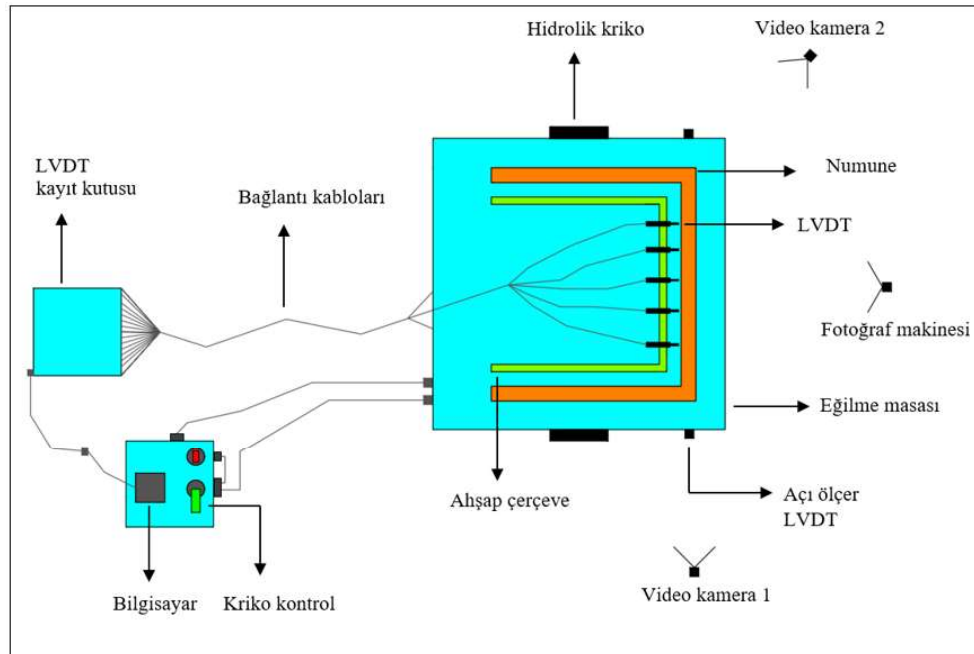


Fig. 1. Schematic view of the test setup.

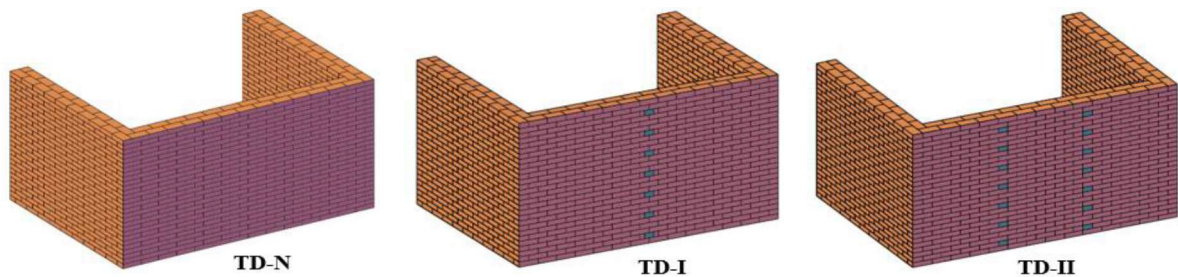


Fig. 2. Wall configurations

$$V = mgsin\alpha \quad (1)$$

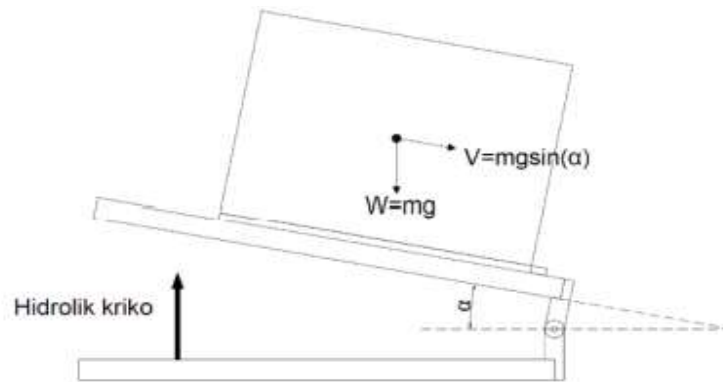
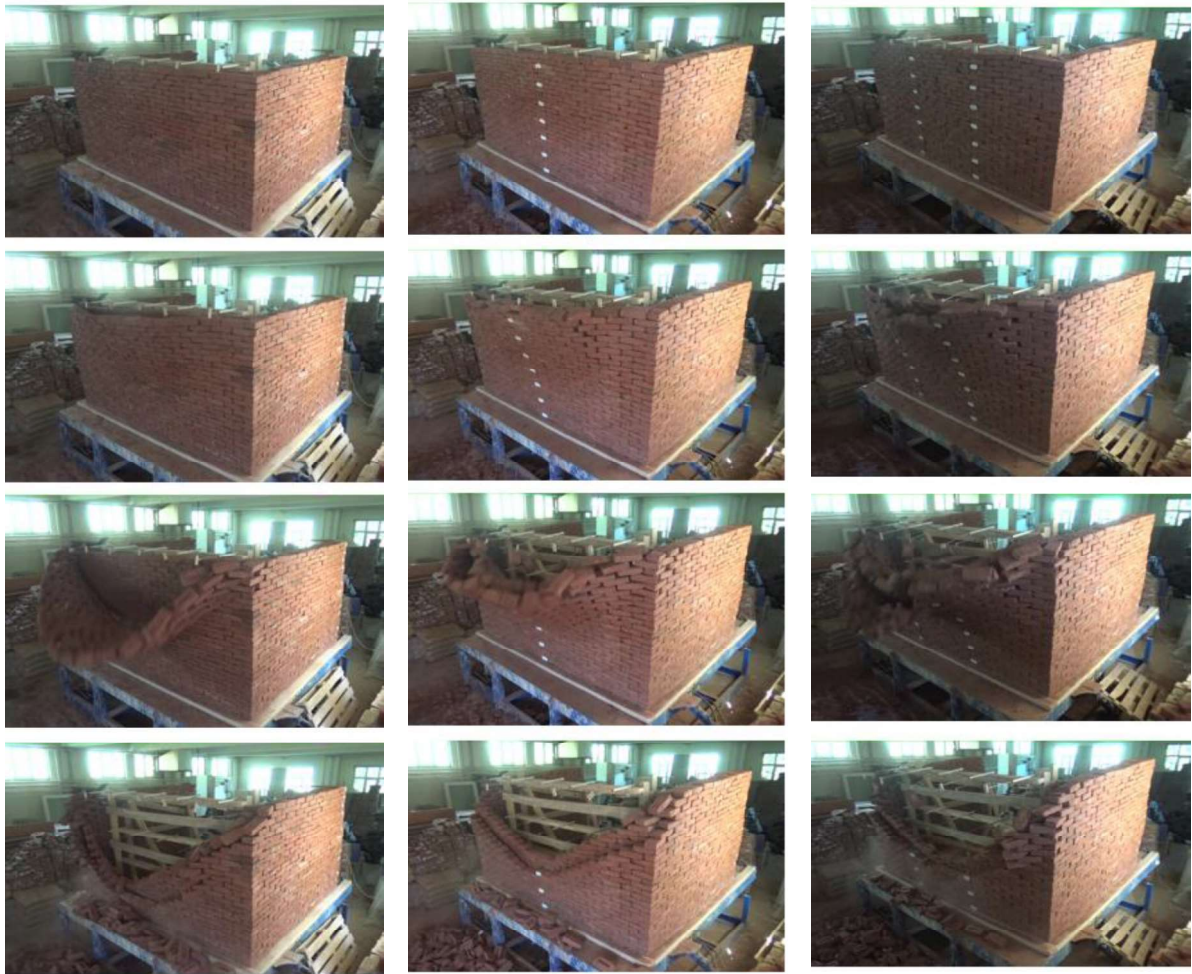


Fig.3. Recording the lateral load

3. RESULTS AND DISCUSSION

3.1. Out-of-plane collapse behavior

Figure 4 shows the pictures taken before the test, during the test and after test. It is seen that all the walls failed due to the out-of-plane collapse occurred at the front wall. An arch shape was seen after the collapse indicating the importance of the supports at the bottom from the base and from the side walls. In the TD-N wall which had no header stones, inner and outer wythes behaved differently and outer wythe started to fail early. After the collapse of the outer wythe, inner wythe started to fail due to the large out-of-plane displacements. This behavior was not visible in the ones with header stones. In TD-I wall single line of header stones seems to increase the bond between both wythes and made both wythe displaced together until the collapse. Bond between the both wythes seems to be increased in case of the two lines of headers stones (TD-II). Both wythes had almost equal displacements in out-of-plane direction. Out-of-plane displacement profiles were comparatively shown in Figure 5. From the figure the difference in the out-of-plane displacement profiles can be clearly seen. Since no connection existed between the wythes of TD-N, the inner and outer wythes behaved differently. A single line of header stones in TD-I seem to increase the connection at the midspan of the wall and the out-of-plane displacement profile turned from a smooth arch to a pointed arch. Using two lines of header stones in TD-II changed the shape to a smooth arch again. The displacements recorded at the header stone locations were almost the same revealing a constant displacement region at the midspan.

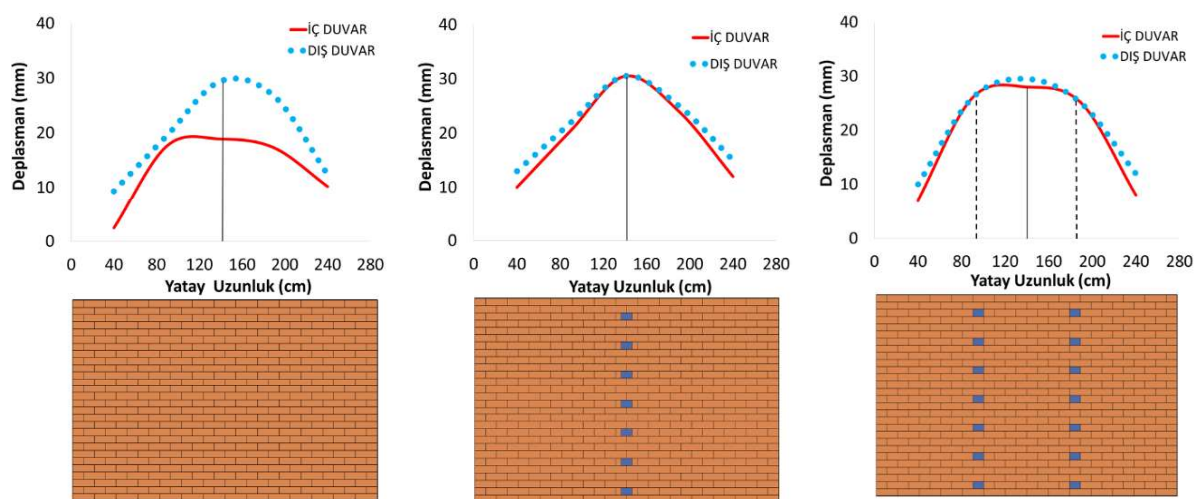


TD-N

TD-I

TD-II

Fig.4. Collapse behavior of the walls



TD-N

TD-I

TD-II

Fig.5. Out-of-plane displacement profiles

3.2. Out-of-plane capacity

Pushover curves were comparatively given in Figure 6. Although lateral load capacity of TD-N was recorded as 6% of the wall weight, it was 10 % in TD-I wall indicating a 66.7% increase, and it was 12 % in TD-II revealing a 100% increase in load-carrying capacity. No smooth pushover curve was obtained for TD-N due to the different out-of-plane behaviors of the wythes. Behavior started to get smoother with the introduction of a single header stone line which resulted in significant increase in the capacity. Since double lines of the header stones increased the connection between the wythes, inner and outer wythes behaved almost the same indicating the same pushover behavior resulted in further increase in the capacity.

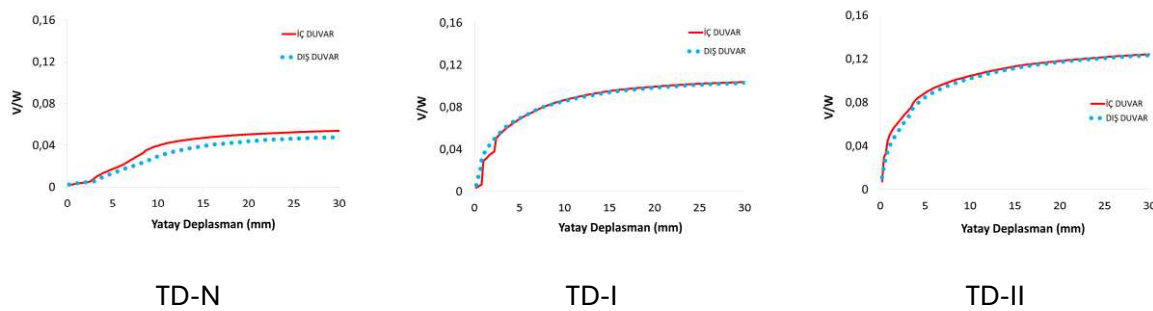


Fig.6. Pushover curves

CONCLUSIONS

In this study 3 different U-shaped double-wythe brick masonry walls were constructed without mortar and having different header stone configuration. Out-of-plane behaviors were recorded using a specially designed tilting table and following conclusions were drawn:

- Collapse behavior changed significantly due to the use of header stones. Without header stones two wythes of the wall behave differently and show different collapse profile. Introducing single line of header stones at midspan increases the connection at this location and force the wythes to behave together. Two lines of headers stones increases the connection significantly and almost all the parts of the wall started to behave the same.
- Collapse profile was like a smooth arch in the wall without header stones and it turned to be a pointed arch in the case of single header stone line indicating the increased

connection at this location. However, the profile turned to be a smooth arch when two lines of header stones used.

- Even a single line of header stones increases the lateral load capacity by 66.7%. When two lines of header stones used, lateral load capacity increased by 100 % when compared to the one without header stones.

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