Shear Stiffness of Solid Clay Brick Wallets Sheared Perpendicularly to the Masonry Bed Joints

Adam Piekarczyk

Abstract

The article presents some results of experimental tests on solid clay brick masonry wallets ca. 130 × 140 cm subjected to simultaneously shearing perpendicular to the bed joints and vertical compression. Angular distortions and shear stiffness were calculated based on measured strains of masonry and applied shear forces. The purpose of the study was to examine how the angular distortion depends on the shear stress and how the masonry shear stiffness changes with load increasing. The impact of the value of compressive stress perpendicular to the bed joints on shear stiffness was also tested. The results of investigations showed that relationship between the shear stresses and the angles of distortion were quite linear for shear stresses from 0 to \( \tau_{cr} \) (\( \tau_{cr} \) – shear stress accompanying first diagonal cracking). The \( r-\theta \) relationship was nonlinear after diagonal cracking. Distinctive hardening (increase of shear stresses) of cracked masonry was evident for the specimens simultaneously sheared and compressed. The hardening was stronger when the specimens were strongly compressed.

The biggest values of the shear stress \( \tau_{cr} \) accompanying the first cracking, the distortional angle \( \theta_{cr} \) in common with the ultimate shear stress \( \tau_u \) were reached when the compression was stronger. When the higher values of compressive stresses accompanied shearing then the shear stiffness was bigger in whole range of the shear stresses.

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1. Introduction

Vertical shear forces (perpendicular to the bed joint) and in-plane bending acting on the building masonry walls may result from uneven dislocations of the elements of the structure which is adjacent to them, most often from deflection of ceilings and flooring which the walls were made on and also their foundations. The dislocations of the elements which are adjacent to the non-structural walls and which support them may result from improper preparation of the base under the flooring. Uneven movement of the subsoil may be result of inadequate or uneven soil compaction, change of water regimes connected with land quality improvement or additional drainage, subsoil dewatering as a result of deep excavations made in the building vicinity, soil swelling or shrinkage caused by greenery, dislocations of expansive soils, soil leaching as a result of water and sewerage or storm water installations damage or the loss of the subsoil stability. It should be taken into account displacements of the subsoil due to additional land subsidence caused by erection of new objects near the present building or soil compaction and increase of loads as a consequence of vehicle traffic as well as base deformations caused by the mining extraction.

The very frequent reason of cracks in the masonry walls, including partition and infill walls are the deflections of the ceilings on which the partitions have been built.

Discussed walls have the limited possibility of horizontal deformations. That’s why the vertically sheared walls could be treated as some kind of the confined masonry. Therefore, the horizontal normal stresses are produced.

Investigations of sheared masonry have been conducted in The Department of Building Structures of Silesian University of Technology from more than 20 years. Results of the sheared masonry walls investigations were published in [1, 2, 3, 4, 5, 6, 7, 8].

2. Specimens and Test Setup

2.1. Materials and specimens

All specimens were made of the solid clay brick with mean compressive strength of 20.0 N/mm² and the cement-lime mortar strength class M5 with proportions of the ingredients 1:1:6 (cement:lime:sand). The shape and overall dimensions of all specimens were the same, i.e. length ca. 129 cm, height ca. 142 cm and thickness 25 cm (Fig. 1).

Two series of the unreinforced specimens were investigated. Each series consisted of five specimens, one sheared without the accompanying vertical compressive stress and the other four were simultaneously sheared and compressed. Mean values of the accompanying compressive stresses \( \sigma_c \) were 0.3, 0.6, 0.9 and 1.5 N/mm². Specimens were marked as follows N-XX/Y, where N represents the unreinforced masonry, XX indicate the value of compressive stress \( \sigma_c \) (XX = 03, 06, 09 and 15) and Y stands for the individual number of specimen (Y = 1 or 2).

2.2. Materials and specimens

The steel test setup shown in Fig. 2 was especially designed and constructed to enable the tests of simultaneously vertically sheared and compressed masonry specimens. The specimen was joined with outer and inner column of the test setup using concrete made of early setting cement.

The vertical shear force \( F \) was realized and measured with the use of hydraulic jack and load cell with the range up to 3000 kN. The vertical shear force was transmitted to the masonry specimen directly by inner column. The vertical reaction \( R \) was transferred to the outer column of the test setup and then to the laboratory floor. The horizontal reactions \( S \) were transmitted through the ties to the resisting members and the laboratory floor, as well. The compressive stress \( \sigma_c \) generated by the \( N_c \) forces (see Fig. 2) were realized with four pairs of the tension member’s diameter 45 mm with the steel springs for compensation of the masonry displacements.
The diagram of stress configuration in the vertically sheared and compressed specimen is shown in Fig. 3. Beyond the external area of the specimen (close the edge of specimen) where the distribution of stresses is highly non-uniform the stresses configuration similar to presented below (Fig. 3) could be accepted.

Deformations of the vertically sheared masonry were represented by the mean angle of distortion $\theta$. The values of $\theta$ angles were calculated on the basis of length changes of the square measuring frames shown in Fig. 4. The measuring frames were placed on both sides of specimens. The lengthening and shortening of measuring frames sides and diagonals induced by the specimen deformations were registered by 12 displacement transducers (6 transducers in each measuring frame) with 0.002 mm accuracy.
3. Results and Discussions

Table 1 contains partial results of tests, i.e. the mean values of shear stress, angle of distortion and shear stiffness accompanying first diagonal cracking – $\tau_{cr,mv}$, $\theta_{cr,mv}$, $G_{vcr,mv}$ and the mean ultimate values of shear stress and angle of distortion – $\tau_{u,mv}$ and $\theta_{u,mv}$. The shear stress $\tau_i$ was calculated using the formulae (1) and the shear stiffness $G_{vi}$ was obtained from the equation (2), where $F_{vi}$ is the shear force, $A_i$ is the vertical cross section area of the specimen, $\tau_i$ and $\theta_i$ are the shear stress and corresponding angle of distortion.

![Fig. 4. Arrangement of measuring frame and displacement transducers.](image)

Table 1. Partial results of investigations

<table>
<thead>
<tr>
<th>Specimens</th>
<th>$\sigma_{cr}$</th>
<th>$\tau_{cr,mv}$</th>
<th>$\tau_{umv}$</th>
<th>$\theta_{cr,mv}$</th>
<th>$\theta_{umv}$</th>
<th>$G_{vcr,mv}$</th>
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</thead>
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<tr>
<td>N-00</td>
<td>0</td>
<td>0.58</td>
<td>0.66</td>
<td>0.361</td>
<td>3.60</td>
<td>1620</td>
</tr>
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<td>0.80</td>
<td>0.94</td>
<td>0.480</td>
<td>1.06</td>
<td>1670</td>
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<tr>
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<td>0.92</td>
<td>1.21</td>
<td>0.560</td>
<td>5.22</td>
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</tr>
<tr>
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<td>1.10</td>
<td>1.37</td>
<td>0.629</td>
<td>6.26</td>
<td>1760</td>
</tr>
<tr>
<td>N-15</td>
<td>1.5</td>
<td>1.30</td>
<td>1.70</td>
<td>0.876</td>
<td>9.05</td>
<td>1480</td>
</tr>
</tbody>
</table>

\[
\tau_i = \frac{F_{vi}}{A_i} \quad (1)
\]

\[
G_{vi} = \frac{\tau_i}{\theta_i} \quad (2)
\]

The graph on Fig. 5a presents relationships between the shear stress $\tau_i$ and angle of distortion $\theta_i$. These relationships are nearly linear in the elastic range for the shear stress from 0 to $\tau_{cr}$. After diagonal cracking $\tau_i$-$\theta_i$ relationships show the ductility of the sheared masonry with the characteristic hardening evident for the specimens simultaneously sheared and compressed. The higher values of $\tau_{cr}$ and $\theta_{cr}$ accompanying first diagonal cracking and also the ultimate shear stresses $\tau_u$ were observed when the compression was stronger, as well (see also Table 1).

In Fig. 5b the relationships between the shear stiffness $G_{vi}$ and the shear stresses in range from 0 to $\tau_{cr}$ are presented. The dependence of $G_{vi}$ values on the shear stress is nonlinear. In the early stage of loading the shear stiffness decreases rapidly to stabilize when the shear stress increase, which is the result of microcracks formation, detachment and
slipping between the mortar joints and the masonry units. The strongly masonry were compressed the higher values of shear stiffness were calculated in the nearly whole range of the shear stresses from 0 to $\tau_c$.

Effect of the compressive stress $\sigma_c$ on the angle of distortion at the moment of diagonal cracking $\theta_{cr}$ is shown in Fig. 6a. The higher values of $\theta_{cr}$ were obtained the higher compressive stress accompanied the vertical shearing. Dependence of the shear stiffness $G_{v,cr}$ calculated on the basis of the shear stress and the angle of distortion obtained at the moment of first diagonal cracking is presented in Fig. 6b. In this case the influence of compressive stress cannot be clearly specified but the highest values of the shear stiffness were obtained for $\sigma_c$ stresses from 0.3 to 0.9 N/mm$^2$.

![Fig. 5](image1.png)

**Fig. 5.** The relationships between shear stress $\tau_i$ and: (a) angle of distortion $\theta_i$, (b) shear stiffness $G_{v,i}$ in range from 0 to $\tau_i$.

![Fig. 6](image2.png)

**Fig. 6.** The influence of compressive stress $\sigma_c$ on: (a) angle of distortion $\theta_{cr}$ and (b) shear stiffness $G_{v,cr}$ accompanying first diagonal cracking.

4. Conclusions

Results of the described tests lead to the following conclusions:

- Vertically sheared solid clay brick masonry can be considered as elastic-plastic material; linear elasticity occurs to the moment of the diagonal cracking and then the deformations are plastic with hardening for the masonry simultaneously sheared and compressed.
- The compressive stress accompanying the vertical shearing (in analysed range of compression) has positive influence on the cracking resistance and the capacity of the vertically sheared masonry.
- The dependence of the shear stiffness on the shear stresses is highly non-linear. The shear stiffness decreases rapidly to stabilize at a certain level close to the value occurring just before the diagonal cracking.
- The shear stiffness is bigger in almost whole range of the analysed shear stresses from 0 to $\tau_c$ when the masonry is compressed stronger.
References