Effect of connector density on shear capacity of reinforced masonry wallettes

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Received 27 September 2010; accepted 21 March 2011

The aim of this study is to evaluate the effect of connector density on reinforced masonry wallettes. Firstly, the properties of bricks and mortar are determined. Six densities of connectors and unreinforced specimens are tested in diagonal compression. For each density at least seven probes are tested. Results show that no difference ($p \leq 0.05$, means that results are only 5% likely or less) is found for connector density, concluding that connector density is not relevant to increase the shear capacity of reinforced masonry. However, all reinforced wallettes show a ductile failure.

Keywords: Connector density, Wallettes, Shear stress

In Mexico the use of masonry is widely spread for construction of low rise buildings and houses. However, masonry performance is not understood in the aspect of strength, due to its complex behaviour and it non-homogeneity which makes it difficult to model. As it is known masonry hardly resist tension forces, so reinforcing masonry by means of adding a steel mesh embedded in the mortar cover has been proposed to solve the problem. The Mexican Construction Code proposes the use of steel mesh and specifies the number of connectors but it does not specify what the advantages of using more or less connectors for tighten the steel mesh are. The main purpose for the research in this paper is to investigate the contribution of connectors to the strengthening of reinforced masonry.

Materials and Methods

First some of the mechanical properties of single bricks and the mortar that were used to make the wallettes were determined, and then the shear capacity of welded wire reinforced wallettes was evaluated.

Mortar

The volume proportioning of mortar was 1:0.25:3 (cement, lime and sand). Seven groups of six cubes (50×50×50 mm) of mortar were made. The mortar compression strength was determined at 28 days. The mortar cubes did not receive any curing, as in most construction sites.

Single bricks

The determined properties were general dimensions, volumetric weight, initial absorption, maximal absorption, saturation coefficient, compression strength and modulus of rupture, in order to characterize the material.

Dimensions and mechanical properties of single bricks were experimentally determined according to the corresponding Mexican Norms and the procedure proposed by Tena and Miranda.

Wallettes construction

All single bricks were put together into masonry wallettes, these assemblages were left for two weeks under shade, and then the steel mesh was tied to the masonry using steel nails of 63.5 mm long and 3 mm diameter and covered with a layer of mortar 20 mm thick. The wallettes were left 28 days more under shade as a curing period.

Experimental design

A group of seven wallettes without mortar cover and without steel reinforcement were evaluated in order to determine the effect of cover plus reinforcement.

Six different densities per square meter of connectors for tied the steel mesh to the masonry were studied, 22.22, 14.81, 11.11, 7.41, 5.55 and 4.94 (Fig. 1). At least seven probes were tested for each connector density. The masonry wallettes of 4.94 connectors per square meter were taken as a control group. The reason why this group was taken as a
control is that it corresponds to the Mexican Norm which specifies a minimum separation of 450 mm for connectors.

The steel used as reinforcement was provided in a 6x6-10/10 steel mesh (150 mm by 150 mm squares and 3 mm of each cord diameter with \( f_y = 500 \text{ MPa} \)). The steel mesh was covered with a layer of mortar of 20 mm thick. The final dimensions of the masonry wallettes were, approximately 700 mm each side and 180 mm thick (Fig. 2).

The masonry wallettes were tested carrying a load applied on its two opposite corners, along its diagonal. For each probe the strains along diagonals were measured and from them the angular drift ratio was calculated (Fig. 3).

The mechanical properties determined were the shear strength \( (v_m^*) \) on the net area along its diagonal and the shear modulus \( (G_m) \), both properties were determined according to the Mexican Norm\(^{10}\) and the procedure proposed by Tena and Miranda\(^{15}\).

The shear strength resistance \( (v_m^*) \) were computed from Eq. (1).

\[
V_m^* = \frac{\overline{V}_m}{1 - 2.5C_m} \quad \ldots (1)
\]

where \( \overline{V}_m \) is the average from the single measurements on the masonry wallettes determined as the load of failure divided on the net area along the diagonal and \( C_m \) is the resistant stress variation coefficient for the masonry wallettes, its value should not be less than 0.2.

The shear modulus of the masonry was determined from the curves shear stress- angular drift ratio and was defined by interpolation, the shear stress \( (\tau) \) corresponding to a shear strain of 0.00005 and the angular deformation corresponding to 40% of the maximum shear stress \( (\tau_2) \).

The shear modulus was calculated from Eq. (2).

\[
G_m = \frac{\tau_2 - \tau_1}{\gamma_2 - 0.00005} \quad \ldots (2)
\]

where \( G_m \) is shear modulus; \( \tau_1 \) is shear stress corresponding to 0.00005 of angular deformation; \( \tau_2 \) is shear stress corresponding to 40% of maximum loading; \( \gamma_2 \) is angular deformation due to \( \tau_2 \).

The angular drift ratio was computed from Eqs (3)-(5).

\[
\gamma = |\varepsilon_c| + |\varepsilon_t| \quad \ldots (3)
\]

\[
\varepsilon_c = \frac{\delta_c}{l_0_c} \quad \ldots (4)
\]

\[
\varepsilon_t = \frac{\delta_t}{l_0_t} \quad \ldots (5)
\]

where \( \varepsilon_c \) is strain along the compression diagonal; \( \varepsilon_t \) is strain along the tension diagonal; \( \delta_c \) is change in dimension measured along the compression diagonal; \( \delta_t \) is change in dimension measured along the tension diagonal; \( l_0_c \) is initial dimension measured along the compression diagonal between transducers; and \( l_0_t \) is initial dimension measured along the tension diagonal between transducers.
Equipment description

The machine used to carry out the diagonal compression test of masonry wallettes, was a Forney Testing Machine; model LT-1150, with 150 ton of carrying capacity, with accuracy of 25 kg. The machine used for the testing of the mortar cubes was a Tinius Olsen; model 290 Display, with 30 ton of carrying capacity, with an accuracy of 0.001 kg. The indicators used to measure linear deformations were TTC brand from Chinese origin, with an accuracy of 0.0254 mm.

Results and Discussion

Mortar properties

The average compression strength obtained from the seven groups of cubes was 8.40 MPa. This result was below the expected value of 12.5 MPa, according to the Mexican Norm\textsuperscript{10}. This low value can be explained due to the lack of curing for the mortar cubes.

Single bricks

The properties found for the single bricks are shown in Table 1. From these results it can be seen that single bricks do not meet the requirement of the Mexican standard. However, the mechanical properties of masonry wallettes were acceptable. This may be attributable to the quality of mortar; the compression strength for the mortar was higher than the one for the single bricks, 8.40 and 2.20 MPa, respectively.

Mechanical properties of masonry wallettes

The wallettes fail in a typical diagonal tension failure. This failure occurred when the masonry wallettes failed in tension along the diagonal, breaking the wall and the cover (Fig. 4).

Table 1—Physical and mechanical properties for single bricks

<table>
<thead>
<tr>
<th>Properties</th>
<th>Experimental determination</th>
<th>* Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions, mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length =</td>
<td>287</td>
<td>---</td>
</tr>
<tr>
<td>With =</td>
<td>138.3</td>
<td></td>
</tr>
<tr>
<td>Height =</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>Volumetric weight, kN/m\textsuperscript{3}</td>
<td>12.60</td>
<td>---</td>
</tr>
<tr>
<td>Initial absorption, g/min</td>
<td>24.46</td>
<td>Max 30</td>
</tr>
<tr>
<td>Maximal absorption, %</td>
<td>13.35</td>
<td>Max 15</td>
</tr>
<tr>
<td>Saturation coefficient</td>
<td>0.67</td>
<td>&lt; 0.8</td>
</tr>
<tr>
<td>Compression strength, MPa</td>
<td>2.20</td>
<td>Min 10</td>
</tr>
<tr>
<td>Modulus of rupture, MPa</td>
<td>1.33</td>
<td>Min 0.8</td>
</tr>
</tbody>
</table>

* NMX-C-404-ONNCCE
Average values from twelve pieces

The masonry wallettes without reinforcement showed a brittle failure (Fig. 5a) a group of eight wallettes is shown, this same behaviour is found in concrete beams without reinforcement\textsuperscript{16}. All reinforced masonry wallettes showed a ductile failure.
(Fig. 5b) only the A group is shown. As in most reinforced concrete structures a ductile failure is wanted. The presence of steel mesh gives the masonry a ductile behaviour which prevents a brittle failure. This point is important as contributes to increase the safety of masonry constructions.\(^{17}\)

An analysis of variance of the shear stress resistance \((v_{\text{m}}^{*})\) and for shear modulus \((G_{\text{m}})\) did not show statistical difference \((p \leq 0.05)\), among the different connectors densities, thus the connectors quantity did not have influence over the strengthening of reinforced masonry (Fig. 6). This makes sense as it is known that in masonry or concrete elements the reinforcement does not work until the section is already cracked.\(^{16}\)

Conclusions

The density of connectors were not relevant in order to increase the shear capacity of reinforced masonry, however it was found that the reinforced masonry increases the resistance on 55 and 77% and showed a ductile failure comparing with the non reinforced masonry wallets. It was also found a great dispersion on the values for the shear modulus due to the natural heterogeneity of the masonry materials. The results suggest that the bond force between masonry and mortar cover is an important factor for increasing the strength of masonry as well as the presence of a steel mesh.

Acknowledgment

Authors thank FIFI-2009 of Queretaro State University for its economical support and for providing the facilities to carry out this work.

References