CONSTITUTIVE MATERIAL MODEL FOR BLOCK MASONRY AND ITS MECHANICAL PROPERTIES

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Abstract

This research work aims at the development of a material model for concrete block masonry used in the load-bearing wall as well as masonry infill. To accomplish this, various tests were performed on concrete block (solid) units and concrete block masonry assemblage. A concrete block having a size of 12 x 8 x 6 inches, were fabricated in a mortar ratio of 1:4, 1:2:2, 1:8 and 1:4:4. The compressive strength of concrete block prisms having size 24.36 x 8.04 x 18.72 inches, was also determined by conducting the compressive strength test. The shear strength of square prisms, having size 26.76 x 8.04 x 25.20 inches, was found by applying diagonal loading. To investigate the bond shear strength of concrete block masonry, triplet tests were carried out on block masonry prisms. Before conduct, a test on block assemblage specimens, the constituent materials of block assemblage i.e. block and mortar were also tested for different properties. The average compressive strength of concrete block (12”x8”x6”) was 302.25 psi and the average unit weight was 119.83 lb/ft³. The compressive strength of mortars of 1:4, 1:2:2, 1:8 and 1:4:4 was 2367, 1752, 815 and 1332 psi respectively.

Keywords: Concrete Solid Blocks, Cement, sand and khaka mortar, Compressive Strength, Shear Strength, bond Shear strength
I. Introduction

An assembly of unreinforced concrete block masonry load-bearing walls and the reinforced concrete roof is normally used for building construction in earthquake-affected areas of Pakistan. On October 8, 2005, a devastating earthquake struck northern Pakistan and Kashmir in which thousands of buildings were either partially or fully collapsed including those made of stone masonry, brick masonry, and concrete block masonry were either partially or completely damaged. Over 72,019 buildings were destroyed and additional 182,886 buildings were severely damaged. The structural damage observed is expected, owing to the poor quality of construction of traditional housing and modern RC structures not designed to resist earthquake action (Durrani et al. 2005). At those times, the most used masonry unit for masonry buildings was stone and burnt clay brick. The main cause of the collapse of both types is the heavyweight of the roof which attracts large inertia forces. However, the use of concrete blocks was also observed in the infill as well as in load-bearing walls. The widespread destruction and afterward huge reconstruction resulted in the increased demand for masonry units. Together with high demand, transportation cost and energy cost resulted in a manifold increase in the unit price of burnt clay brick in the affected area. Stonemasonry has been discouraged by experts because of its poor performance during an earthquake. This increased the demand for concrete block masonry which was fulfilled by the locally established factories in that area. The use of concrete block as the major construction unit increased because of its low cost and its local availability in the earthquake-affected areas and its surroundings. The performance of the indigenous concrete block masonry was not properly investigated in Pakistan. In Pakistan and other neighboring countries like India, Bangladesh and Iran bricks are used extensively as masonry infill and load-bearing walls. A lot of work was done by researchers on various properties of brick masonry such as direct shear strength, diagonal tensile strength, and compressive strength. However, no work has been reported on the shear characteristics of block masonry. In several areas, bricks are not available or soil properties are not appropriate for preparing good quality bricks e.g. Northern areas of Pakistan. Construction of brick masonry in such areas becomes infeasible. Block masonry structures can be investigated for their use as alternative construction in those areas where the use of brick masonry is not efficient. Moreover, the use of block masonry as infill units in reinforced concrete frames has been on the rise. Block masonry infill panels provide an efficient and cheap alternate to brick masonry infill panels. There are different types of masonry units used in different parts of the world. The most commonly used masonry units are burnt clay brick, concrete block and stone. Concrete block is important building material used due to its low cost and local availability. Less workmanship involved with blockwork has greatly increased its use. Nowadays, the designer must know about the basic mechanical properties of concrete blocks and mortar, not as individual parts but as assemblage. Specifically, in the case of the unreinforced masonry, these characteristics play a critical role in proper analysis, namely modulus of elasticity (E), modulus of rigidity (G), diagonal tensile (shear) strength, and compressive strength etc. In this regard, various pieces of literature were reviewed. As there is little research work done worldwide and no research work done in Pakistan, therefore, there was a dire need to investigate the properties of concrete block masonry.

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Therefore, this research work has been initiated to investigate the behavior of the concrete block masonry under the influence of gravity as well as lateral load. The basic properties of masonry units like compressive strength were determined. The masonry assemblage properties like compressive strength, shear strength and diagonal tensile strength were also evaluated.

II. Experimental Program

II.i. Material Model

For the preparation of samples select blocks of maximum compressive strength and reasonable unit weight from various factories of Peshawar city. Three (3) blocks from each factory were taken and the unit weight and compressive strength of each block are determined.

For the preparation of assemblage’s select different mortar types having different batching mixes that are commonly used in construction sites. To investigate the compressive strength of each mortar type prepared mortar cubes of 2x2x2 inches according to ASTM-C-109. Later on, the compressive strength of each mortar cubes is determined after 28 days.

The assemblage is prepared for various tests such as compression test, direct shear test and diagonal tension tests according to the following ASTM and Euro codes which also describes the detailed testing procedures and dimensions.

II.ii. Test Setup

II.ii.a. Compressive strength of concrete block per ASTM-C-140-03

This test method covers the sampling and testing of concrete masonry units for dimensions, compressive strength, absorption, unit weight (density), and moisture content.

Minimum three numbers of samples are tested to obtain the mean compressive strength of concrete masonry units. Blocks are placed under the loading jaws of UTM a steel plate is placed on a concrete block to uniformly distribute the load over the entire bearing area. Research has shown that the thickness of bearing plates has a significant effect on the tested compressive strength of masonry units when the bearing area of the platen is not sufficient to cover the area of the specimen. Plate bending results in non-uniform stress distributions that can influence the failure mechanisms of the tested specimens. The required compressive strength of blocks is determined by dividing the maximum load on the bearing area.
II.iib. Mortar Test Per ASTM-C-109

This standard is regarding the test procedure of mortar compressive strength. The mould size of the compressive mortar sample is 2x2x2 inches. Apply oils and greases using an impregnated cloth or other suitable means. Wipe the mold faces and the base plate with a cloth as necessary to remove any excess release agent and to achieve a thin, even coating on the interior surfaces. Mortar of different types with different batching mixes are prepared by pouring mortars into the mould in three layers each layer is to be compacted by 32 strokes with a tamping rod.

After 24 hours remove the mortar cubes from mould and placed the mortar cubes in the water tub. After 28 days remove the mortar cubes from the water tub and dry the mortar cubes after drying the mortar cubes find their compressive strength on UTM. The mortar cubes are placed under the loading jaws of UTM and the maximum load at which the mortar cube crush is determined. The compressive strength of mortar cubes is obtained by dividing the maximum load on surface area (2”x2”).

Figure 1. Compressive strength of block

Figure 2. Compressive strength of mortar.

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II.i.c. Compressive Strength of masonry prism per ASTM-C-1314-03b

Construct a set of prisms for each combination of materials and each test age at which the compressive strength of masonry is to be determined.

The masonry prism that is constructed for the investigation of compressive strength of concrete block masonry having length 2'-3/8", width 8" and height of 1.56' having a mortar thickness of 3/8" bonded in running bond.

Minimum three numbers of assemblages are tested to obtain the mean compressive strength of concrete masonry assemblages after 28 days. Assemblages are placed under the loading jaws of UTM a steel plate is placed on concrete assemblages to uniformly distribute the load over the entire bearing area.

The required compressive strength of assemblage is determined by dividing the maximum load on the bearing area. The gauge length that is to be installed should not be less than six times the aggregate size to investigate the strain profile during the load application the gauge should be installed at the center of assemblages to cater to the maximum depth of masonry assemblages.

![Figure 3. Compression test of block assemblages](image)

II.i.d. Diagonal Tensile test per ASTM-E-519-02

This test method covers the determination of the diagonal tensile or shear strength of 1.2 by 1.2-m (4 by 4-ft) masonry assemblages by loading them in compression along one diagonal thus causing a diagonal tension failure with the specimen splitting apart parallel to the direction of load.

The masonry prism that is constructed for the investigation of diagonal tensile strength of concrete block masonry having length 2'-3/8"", width 8” and height of 2.1’ having a mortar thickness of 3/8” bonded in running bond. Minimum three numbers of assemblages could be tested to obtain the mean diagonal tensile strength of concrete masonry assemblages after 28 days. Assemblages are placed under the loading jaws of loading assemble accompanied with loading shoe as discussed above.

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As a research test method used only to evaluate the effects of variables such as type of masonry unit, mortar, workmanship, etc., a smaller size specimen could be used if the available testing equipment will not accommodate a 1.2-m (4-ft) square specimen. However, there is a lack of experimental data that would permit an evaluation of the effect of specimen size on the shear strength or to permit a correlation between the results of small-scale specimen tests and larger specimens.

Shear Stress—Calculate the shear stress for specimens based on net area. Calculate the shear stress of the specimen as follows:

\[ S_s = \frac{0.707p}{A_n} \]

Where:
\( S_s \) = shear stress on net area, MPa (psi),
\( P \) = applied load, N (lbf), and
\( A_n \) = net area of the specimen, mm\(^2\) (in.\(^2\)), calculated as follows:

\[ A_n = \left(\frac{w + h}{2}\right)tn \]

Where:
\( w \) = width of the specimen, mm (in.),
\( h \) = height of specimen, mm (in.),
\( t \) = total thickness of specimen, mm (in.), and
\( n \) = percent of the gross area of the unit that is solidly expressed as a decimal.

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**Figure 4.** (a) Diagonal tensile test (b) Samples for diagonal tensile test
II.ii.e. Direct Shear Strength per EN 1052-3

This test method covers the determination of the direct shear strength of masonry assemblage in both triplet and couplet. In couplet single shear area is involved while in triplet double shear area is involved. The block triplets consist of three blocks arranged one over the other and joined with each other by mortar joints. The top and bottom blocks were restrained to any movement and the middle block was sheared with the help of a horizontal load applied to it. This is a case of a double shear with two joints sheared by the force. The block couplet consist of two blocks arranged over one another with a mortar joint, in this case, the bottom block is restrained and the top block is a slide by applying load in the lateral direction.

The masonry prism that is constructed for the investigation of triplet test of concrete blocks having length 12”, width 8” and height of 18.72” has a mortar thickness of (3/8)” bonded.

During testing, the left and the right side blocks were restrained by a steel rod at the joint. For uniform distribution of load, a steel plate is placed at the middle one and load is applied in the vertical direction at the middle one and the maximum load was determined. Minimum three numbers of assemblages should be tested to obtain the mean direct shear strength of concrete block assemblages after 28 days.

![Figure 5. Triplet test of block assemblages](image)

II.iii. Instrumentation

II.iii.a. Compressive strength of concrete blocks

For this test, block samples are collected and tested according to the ASTM C-140-03 by a universal testing machine (UTM) the schematic diagram is shown in fig. a.

II.iii.b. Compressive strength of mortar cubes

The mortar cubes were tested according to the ASTM-C-109 by universal testing machine the schematic diagram is shown in fig. b.
II.iii.c. Triplet test of blocks assemblages
The samples were tested according to the EN 1052-3 by universal testing machine the schematic diagram is shown in fig. C.

II.iii.d. Compressive strength of blocks assemblages
The samples were tested according to the ASTM-C-1314-03b by universal testing machine the schematic diagram is shown in fig. D.

II.iii.e. Diagonal Tensile strength of blocks assemblages
The samples were tested according to the ASTM-E-519-02 by straining frame schematic diagram is shown in fig. E.
III. Results and discussion

Results of various tests which were conducted under the specifications of their specified codes are presented in accompanied with brief discussions over its results and also a comparison between the shear strength of block with brick is presented in the form of a table.

III.i. Compressive strength of concrete blocks

For the selection of blocks, samples were taken from various factories and the block to be used in the preparation of samples should be of maximum compressive strength and reasonable unit weight because masonry units having higher unit weight may cause overloading of the structure. The samples taken from various factories were tested according to the ASTM C-140-03.
The above bar charts show the unit weight and compressive strength of block samples collected from various factories of Peshawar city respectively. Qamar Din Garhi ring road factory blocks (12”x8”x6”) have reasonable unit weight and maximum compressive strength among the other factory blocks that’s why we use blocks of that factory in assemblage preparation for compression, direct shear and diagonal shear strength tests.

![Image](image1.png)

**Figure 8.** (a) & (b) Dimensions of concrete block

### III.ii. Compressive strength of mortar cubes

For the preparation of assemblages, the selected different mortar types having different batching mixes that are commonly used in construction sites are tabulated in the next table having water to cement ratio that was used in the preparation of mortar of different types having different proportions are as under:

| S.No | Mortar                  | Proportions | Water/Cement ratio |
|------|-------------------------|-------------|--------------------|
| 1    | Cement sand mortar      | 1:4         | 1                  |
|      |                         | 1:8         | 0.8                |
| 2    | Cement sand khaka mortar| 1:2:2       | 1.25               |
|      |                         | 1:4:4       | 0.75               |

Minimum three mortar cubes should be tested to obtain the mean compressive strength of mortar cubes after 28 days.

The mortar cubes were tested according to the ASTM-C-109. The below table shows the compressive strength of mortar cubes of different mortar type having different batching ratios are as under.

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It is observed that by replacing one-half of the volume of sand in CS 1:4 mortar by khaka the compressive strength of mortar increased by 31.16% and by replacing one-half of the volume of sand in CS 1:8 mortar with khaka the compressive strength of mortar cube increased by 38.41% respectively.

III.iii. Triplet test of blocks assemblages

To determine the direct shear strength of block masonry, an assemblage consist of three blocks arranged one over the other and joined with each other by mortar joints. The masonry prism that is constructed for the investigation of triplet test of concrete blocks having length 12”, width 8” and height of 18.72” having a mortar thickness of 3/8” bonded. Minimum three numbers of assemblages should be tested to obtain the mean direct shear strength of concrete block assemblages after 28 days. The samples were tested according to the EN 1052-3.

The below table shows the Direct shear strength of concrete block assemblage bounded in different mortar types having different batching ratios are as under.
It is observed that by replacing one half of volume of sand in CS 1:4 mortar by khaka the direct shear strength of block masonry assemblage increased by 49.09% and by replacing one half of the volume of sand in CS 1:8 mortar with khaka the direct shear strength of block masonry assemblage increased by 39.81% respectively.

III.iv. Compressive strength of blocks assemblages

to determine the Compressive strength of block assemblage. The assemblage that is constructed for the investigation of compressive test of concrete blocks having length 24.37”, width 8” and height of 18.72” has a mortar thickness of (3/8)” bonded. Minimum three numbers of assemblages should be tested to obtain the mean compressive strength of concrete block assemblages after 28 days. The samples were tested according to the ASTM-C-1314-03b.

The below table shows the Direct shear strength of concrete block assemblage bounded in different mortar types having different batching ratios as under.

| Mortar Type | Compressive Strength |
|-------------|----------------------|
| CS 1:4      | 173                  |
| CSK 1:2:2   | 177                  |
| CS 1:8      | 165                  |
| CSK 1:4:4   | 193                  |

**Figure 11.** Mean compressive strength of block assemblages

It is observed that by replacing one half of the volume of sand in CS 1:4 mortar by khaka the compressive strength of block masonry assemblage increased by 2.26% and by replacing one half of the volume of sand in CS 1:8 mortar by khaka the compressive strength of block masonry assemblage increased by 14.5% respectively.

III.v. Diagonal Tensile strength of blocks assemblages

To determine the diagonal tensile strength of concrete blocks, masonry assemblages were constructed and tested. The masonry prism that is constructed for the investigation of diagonal tensile strength of concrete assemblage having length 24.38”, width 8” and height of 25.2” having a mortar thickness of 3/8” bonded in running bond. Minimum three numbers of assemblages should be tested to obtain the mean diagonal tensile strength of concrete block assemblages after 28 days. The samples were tested according to the ASTM-E-519-02.

The below table shows the diagonal tensile strength of concrete block assemblage bonded in different mortar types having different batching ratios as under.

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Figure 12. Diagonal tensile strength of block assemblages

It is observed that by replacing one half of the volume of sand in CS 1:4 mortar by khaka the diagonal tensile strength of block masonry assemblage increased by 34.52% and by replacing one half of the volume of sand in CS 1:8 mortar by khaka the diagonal tensile strength of block masonry assemblage increased by 34.64% respectively.

IV. Conclusion

Based on results of various tests were conducted under the specifications of their specified codes are presented in accompanied with recommendations. As a result of extensive research carried out on concrete blocks specimens and block masonry assemblages for assessment of their behavior, the following conclusions are made:

a. A greater difference in compressive strength of concrete block was observed due to the use of inappropriate water to cement ratio and less care is taken in proportioning constituents of concrete for the preparation of block in factories.

b. The average compressive strength of concrete block is 302.25 psi and the mean unit weight is 119.83 lb/ft³.

c. Cost comparison clearly shows that concrete block masonry is an economical alternative to brick masonry. The difference in cost is almost 30%, moreover, the time of construction for the concrete block masonry is about half to that of brick masonry. Hence the use of concrete block masonry can be preferred over the brick masonry in low seismic zones.

d. It is recommended for future research work to use small size blocks available in factories for the sake of easy carriage and handling.

e. The addition of khaka to the mortar mixes increases the strength and workability.

f. The use of khaka in block masonry assemblages shows better results in direct shear, diagonal tensile and compressive strength.

Conflict of Interest:

Authors declared: No conflict of interest regarding this article

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References

I. Ali, Q. et al., 2012. Experimental Investigation on the Characterization of Solid Clay Brick Masonry for Lateral Shear Strength Evaluation. *International Journal of Earth Sciences and Engineering*, 05(4), pp. 782-791

II. Ahmad A, Hamid, B.E Abboud, and H.G Harris. To evaluate the use of concrete blocks in modeling of concrete block masonry under axial compression.

III. Ahmad Jan Durrani, Amr Salah Elnashai, Youssef M.A. Hashash, Sung Jig Kim and Arif Masud., ‘The Kashmir earthquake of October 8, 2005 a quick look.’

IV. Ali, et al. 2012. Development of shear strength constitutive material model for brick masonry. Department of Civil Engineering, University of Engineering and Technology, Peshawar. Shahzada Khan (2011), “Seismic Risk Assessment of Buildings in Pakistan (Case Study Abbottabad City), PhD thesis, Department of Civil Engineering, University of Engineering and Technology, Peshawar.

V. ASTM-C-109, Specifications and Standards of Compressive Strength of Cement Sand Mortar.

VI. ASTM-E-519, Specifications and Standards of Principle Tensile Strength of Masonry Assemblage.

VII. ASTM-C-1314-03b, Specification and testing procedure about the compressive strength of the masonry assemblage.

VIII. ASTM C-140-03, Specification and testing procedure about the compressive strength of the concrete masonry units.

IX. EN-1052-3, European Standard for Bond Shear Strength of Masonry Assemblage.

X. Blocks and Bricks Review by Andrew Brown, Distinction between lightweight aggregate block and dense grade aggregate block.

XI. Rafiq Adil, Muhammad Fahad, Mohammad Adil, ‘Macro-Scale Numerical Modeling of Unreinforced Brick Masonry Squat Pier Under In-Plane Shear’. *J. Mech. Cont. & Math. Sci.*, Vol.-15, No.-11, November (2020) pp 72-84. DOI: 10.26782/jmcs.2020.11.00007

XII. Muhammad Rizwan, Hanif Ullah, Ezaz Ali Khan, Nayab Khan, Talha Rasheed. ‘EXPERIMENTAL INVESTIGATION OF MECHANICAL PROPERTIES OF SOLID CONCRETE BLOCK MASONRY EMPLOYING DIFFERENT MORTAR RATIOS’, *J. Mech. Cont. & Math. Sci.*, Vol.-16, No.-1, January (2021) pp 107-120. DOI: 10.26782/jmcs.2021.01.00009