Design and Shape Optimization of Solid Concrete Blocks for Masonry Structures in Northern Areas of Pakistan

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Abstract- *This research paper aims at the development of new type of concrete block by introducing frog in the traditional solid concrete block. The main objectives are to improve the bond shear strength, diagonal shear strength, improve handling ability and reduce the weight of the optimized block to counter health injuries during construction process. Intensive comparative assessment of solid and frog concrete block was conducted. Final results concluded that frog concrete block was far superior in structural, economy, quality and handling performance.*

Index Terms- Earthquake, Economy, Frog Concrete Block, Shear Strength, Solid Concrete Block.

I. INTRODUCTION

In developing countries i.e. Pakistan, India, and Bangladesh, getting a home ownership is extremely difficult for low income holder because of the exorbitant increase in construction and materials cost. Whereas, in developing countries, there are effective policies and housing programs set by governmental and financial institutes which grants aid to needy citizen in helping them out by providing cheap housing ownership keeping all imperative living standards in consideration**[1]**.

In 2005, Pakistan was hit by devastating earthquake of magnitude 7.6 which resulted in enormous human causalities and infrastructural damage. According to the government of Pakistan, the death toll was estimated to be 100,000 while 3.5 million people render homeless. The monetary damage was projected to be $ 5.3 billion. In addition, 203,579 housing units were completely destroyed, while, more than 196,574 units were severely damaged; which were designated unfit for living. Additionally, 55,000 units were moderately damaged but were cleared for livelihood **[2]**.

In Pakistan, the factor of economized building is normally misunderstood. Most of the time while incorporating the factor of economy other structural parameters are largely compromised. It was revealed in 2005 damage assessment report conducted by World Bank and Asia Development Bank in collaboration with Ministry of Planning and Development Division that the substantial damage was the direct outcome of poor structural design, low quality of construction materials, poor workmanship, fewer knowledge about different masonry materials, lack of confinement of masonry wall, and suboptimal construction practices **[3]**.

Masonry construction is one of the oldest form constructions dating back to 7500 BC. Usually, the most commonly masonry materials that are used all over the word are bricks and concrete blocks. In Pakistan, different masonry materials are used for construction. After 2005 earthquake, building topology assessment was conducted which revealed that the construction environment is mostly dominated by brick masonry with staggering 62.38% of the total construction environment. Other construction materials that are used in Pakistan are given in Figure 1**[4]**.

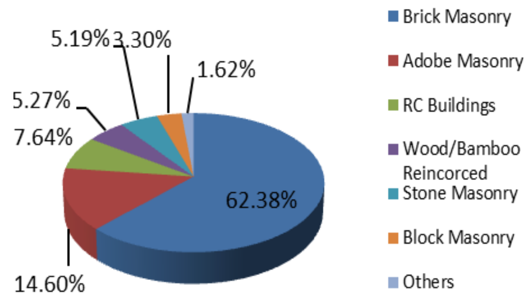


Figure 1: Building Topology of Pakistan

The annual production of bricks in Pakistan is roughly estimated to be 45 billion units **[5]**.

Now-a-days the use of brick as masonry materials is largely discouraged because they are not considered sustainable. These industries are responsible for 5% of total carbon dioxide emission and a total of 4.5% of artificial global warming **[6]**. Furthermore, the use of stone as a construction material is widely discouraged by designers due to its poor structural performance in earthquake regions. In addition, the production of bricks in mountainous regions is usually not feasible due to unusual climatic situation i.e. high rainfall **[7]**.

Besides, concrete blocks are preferred due to various advantages: thermal and sound insulation; durable; adequate strength and structural ability; fire resistant; low maintenance (no efflorescence); reduction in mortar consumption; environmentally friendly (constituents can be replaced by waste products like rice husk, fly ash etc); better architectural features; faster and easier construction **[8]**.

The above statements from designers and environmental experts skyrocketed the demand for concrete blocks in northern areas of Pakistan which were soon accommodated by locally established factories in that region. Moreover, in Pakistan, mostly solid concrete blocks are used and knowledge about hollow concrete block is very limited. Solid concrete blocks are heavy and causes health issues i.e. neck and back pain injuries during material handling process. In addition, solid concrete block masonry is weak in shear strength, hence, fails to cater the demand of lateral force (earthquake), and ultimately contributes in collapse of the structure. Additionally, solid concrete blocks are costly when compared with other masonry construction materials i.e. stone and brick masonry. Therefore, this research addresses the aforementioned issues by optimizing the shape of solid concrete block by introducing frog in traditionally available concrete block and then comparing it with latter. It is pertinent to mention that no research work has been done in Pakistan on the shape optimization of solid concrete blocks.

II. OBJECTIVES OF THIS RESEARCH

The main objectives of this research are;

i. To introduce frog (depression) in traditional concrete block;
ii. To compare basic properties of solid and frog concrete blocks;
iii. To compare mechanical properties of solid and frog concrete blocks;
iv. To improve shear strength of concrete masonry structure;
v. To conduct economic analysis of concrete masonry structure with other masonry materials.

III. EXPERIMENTAL SETUP & TEST RESULTS

Production of Solid and Frog Concrete Blocks:

The concrete block dimensions which is commonly used in northern region is 12 in x 9 in x 5 in (length x width x height). The dimension of frog provided in solid concrete block is 8 in x 5 in x 1 in (length x width x depth). The details of the frog concrete block are given in Figure 2.

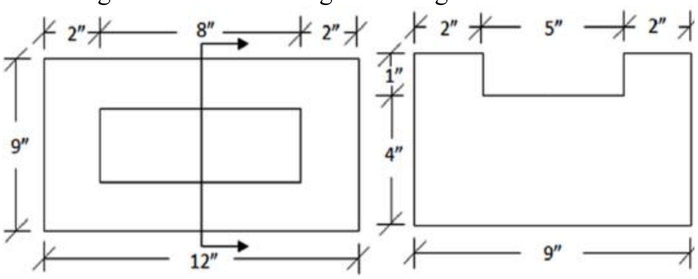


Figure 2: X-Sectional Details of Frog Concrete Block

Both type of concrete block were manufactured in 1:4:8 ratio (cement: fine aggregate: coarse aggregate), through semi-automatic molding machine as shown in Figure 3.

Figure 3: Semi-Automatic Concrete Block Machine

Figure 4: Frog Concrete Block Specimen

Basic Properties of Solid and Frog Concrete Blocks:

Basic unit tests i.e. unit weight, absorption test, compressive strength test, and modulus of rupture test were performed to analyze and compare the properties of solid and frog concrete blocks in compliance with ASTM C-140.

Table 1: Unit Test Comparisons

Test Name	*Solid Concrete Block*	*Frog Concrete Block*
Weight	41.23 lb	32.09 lb
Unit Weight	132.82 lb/ft^3	129.34 lb/ft^3
Absorption Test	4.21 %	4.54 %
Compressive Strength Test	953.90 psi	934.24 psi
Modulus of Rupture Test	142.53 psi	159.01psi

The test arrangement for unit compressive strength test was in accordance with ASTM C-140 as shown in Figure 5.

Figure 5: Unit Compressive Strength Test

The modulus of rupture test was performed in compliance with ASTM C-67. The test arrangement is shown in figure 6.

Figure 6: Modulus of Rupture Test

Mechanical Properties of Solid and Frog Concrete Blocks:

It is very essential that an engineer is well aware of basic mechanical properties not as an individual entity but also its behavior as an assemblage. Specially, in unreinforced masonry, assemblages tests play an imperative role in accurately assessing the structural performance of a masonry structure.

The mortar which was used for prisms construction had a ratio of 1:6 (cement: sand) with w/c of 0.85. The average 28 day strength was 1768.70 psi with COV of 5.71 %.

Compressive strength prisms were constructed as per guidelines set by ASTM C-1314. A total of three prisms were constructed in running bond with height to thickness ratio of 1.67. The prisms were cured for 28 days. Before testing, specimens were properly capped as per ASTM C-1552 specifications. The test arrangement for compression prism test is shown in figure 7. Results of the test are given in Table 2.

Figure 7: Compression Prism Test

Diagonal shear strength prism construction and test was performed as per ASTM E-519. The dimension of diagonal test prism was 25 in x 25 in x 9 in (length x height x thickness). A total of 3 prisms were constructed and were cured for 28 days before testing. The test arrangement for diagonal test prism is shown in Figure 8. The test results are given in Table 2.

Figure 8: Diagonal Shear Strength Test

The bond shear strength was performed according to BS EN 1052-3 standard. A total of 3 prisms in a triplet arrangement were constructed. The prism consists of three blocks arranged one over the other bonded with each other by mortar. The dimension of prism was 12 in x 9 in x 15 in (length x width x height). Prisms were cured for 28 days before testing. The test arrangement is shown in Figure 9. The test results are given in Table 2.

Figure 9: Bond Shear Strength Test (Triplet Test)

The detail test results of masonry assemblage are given in Table 2.

Table 2: Masonry Assemblage Test Comparison

Test Name	*Solid Concrete Block*	*Frog Concrete Block*
Compression Prism Test	865.98 psi	848.23 psi
Compression Test (Masonry Structure)	785.96 psi	779.85 psi
Diagonal Shear Strength Test	447.61 psi	512.33 psi
Bond Shear Strength Test (Triplet Test)	51.83 psi	98.53 psi

IV. Analysis & Discussion Of Results

The solid concrete block volume was reduced by 7.41% when frog was introduced; which contributed in 22.17 % weight reduction. In addition, the absorption rate and the unit weight of solid and frog concrete blocks were practically identical.

Regarding the unit compressive strength comparison, 2.06% drop was recorded in frog concrete block specimen due to reduction in the volume. Hence, it proved that reducing the quantity of specimen material will have negative implication on the compressive strength. Since, the compressive strength is already too great, the reduction will have no significant impact on the frog concrete block masonry. The COV of solid and frog concrete block specimens were recorded to be 13.98% and 11.28%.

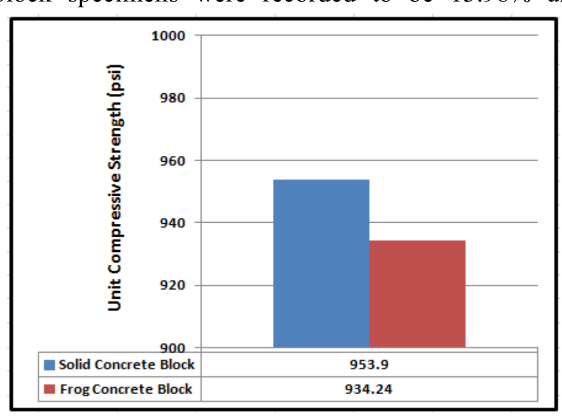


Figure 10: Unit Compressive Strength Test Comparison

Flexure capacity of solid and frog concrete block was evaluated and the result comparison is given in Figure 11. The flexure capacity of frog concrete block was improved by 11.57%. The COV of solid and frog concrete block specimens were recorded to be 7.78% and 3.33%.

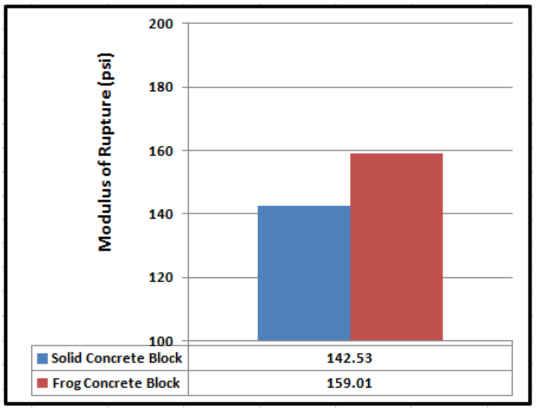


Figure 11: Modulus of Rupture Test Comparison

The compression test values of prisms constructed from frog and solid concrete block were compared. It was found that the marginal plummet recorded in the unit compressive strength test of frog concrete block was compensated by excess mortar. Hence, the compressive strength of both type of prism specimens were nearly identical as shown in Figure 11. The compressive strength of masonry structured was computed by multiplying a correction factor based on height to thickness ratio as shown in Figure 12. According to this, the height to thickness ratio was 1.67 and the correction factor for the aforementioned ratio was 0.9076. Usually, it has been proved that if the height to thickness is kept in between 2 to 5, there will be rapid decline in the compressive strength of masonry prism **[9]**. Furthermore, the strength of mortar usually does not play a major role in improving the compressive strength of masonry structure as the difference is usually trivial **[10]**. The COV of prism constructed from solid and frog concrete blocks were recorded to be 7.98% and 9.24%.

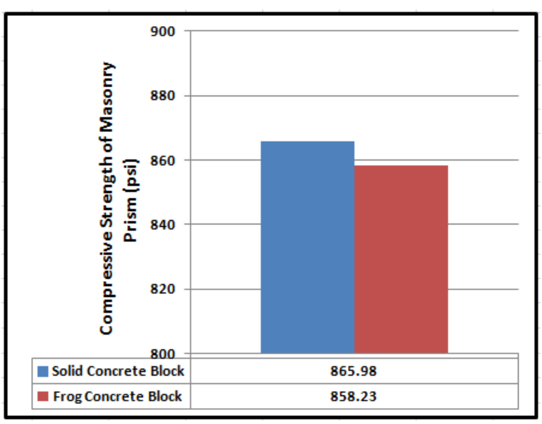


Figure 12: Compression Prism Test Comparison

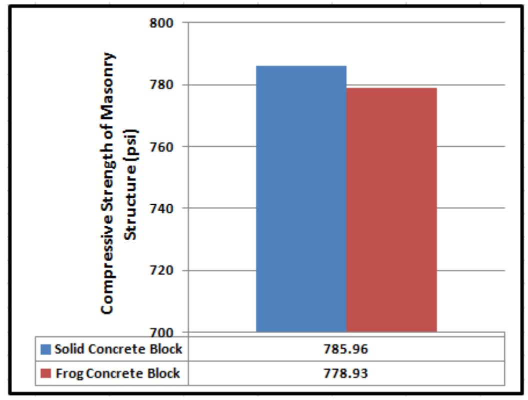
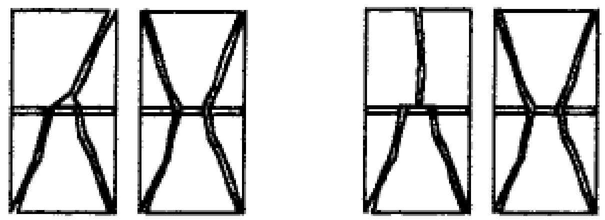


Figure 13: Compression Masonry Comparison

The failure mode of compression prisms were drawn and are given in Figure 14. Figure 14 (a) represent cone and shear type of failure, while Figure 14 (b) represent cone and split failure.



(a) Solid Concrete Block Prism

(b) Frog Concrete Block Prism

Figure 14: Modes of Failures – Compression Test

The test results of diagonal shear strength of masonry also known the principal tensile strength, of solid and frog concrete block were compared as shown in Figure 15. Prism constructed from frog concrete blocks improved the shear strength significantly by a total of 14.46%. Hence, providing frog in traditional concrete block will potentially improve the shear strength and will improve masonry structural performance in earthquake regions. The COV of prism constructed from solid and frog concrete blocks were recorded to be 5.49% and 4.01%.

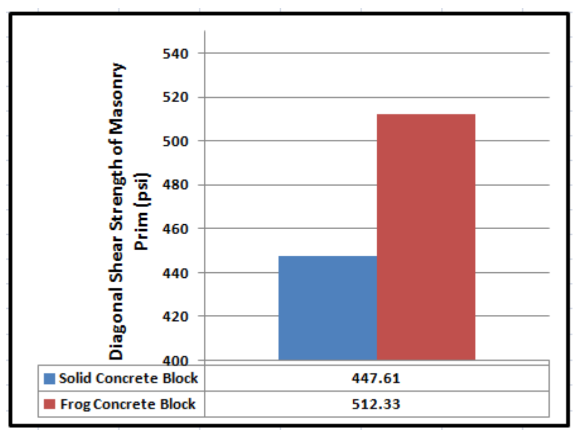


Figure 15: Diagonal Shear Strength Test Comparison

For the in-plane shear strength, triplet test was performed on specimens constructed from solid and frog concrete blocks and then the results were compared as shown in Figure 16. Block assemblage constructed from frog concrete block amplified the in-plane shear strength by almost 90%. Furthermore, it was also proved that altering mortar ratio had noteworthy effect on the bond shear strength. So, providing frog in concrete block will enormously improve the capacity of masonry structure for catering the lateral force in earthquake region. The COV of prism constructed from solid and frog concrete blocks were recorded to be 6.98% and 7.33%.

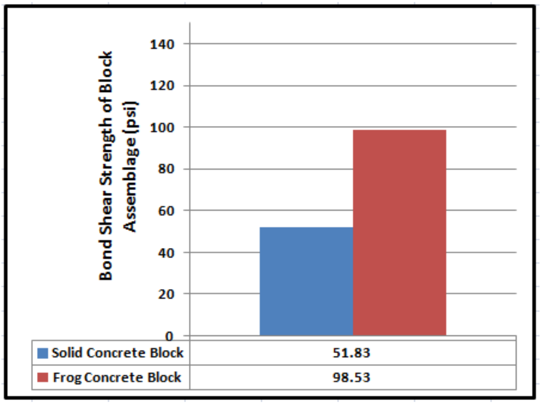
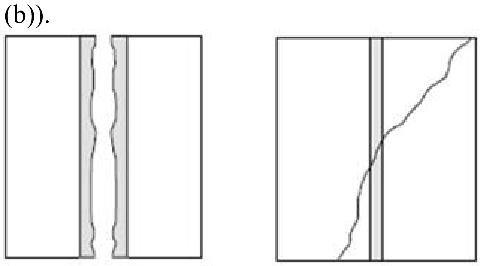


Figure 16: Bond Shear Strength Test Comparison

The failure modes of solid and frog concrete block assemblage were also noted as given in Figure 14. In solid concrete block assemblage, shear failure in mortar was observed, due to weak bond shear strength (Figure 17 (a)). In frog concrete block assemblage, crushing and splitting failure was observed (Figure 17 (b)).



(a) Solid Concrete Block Assemblage **(a) Frog Concrete Block Assemblage**

Figure 17: Modes of Failure – Triplet Test

For economic comparison, a theoretical study of flood protection wall was conducted having length of 250 ft, and height of 5 ft. The thickness of flood protection wall was kept 9 in – a usual field practice widely adopted in Pakistan. The unit price of brick in Pakistan is Rs. 7/unit. The dimensions of brick which is used in Pakistan are 9 in x 4.5 in x 3 in (length x width x height). A total of 13,333 units were required to construct this flood protection wall with a cost of Rs. 93,333. The unit price of solid concrete block in northern area of Pakistan is Rs. 22/unit. A total of 3000 units were required to construct the flood protection wall with a total cost of Rs. 66,000. Lastly, since the dimension of solid and frog concrete block were same, same number of units were required for the construction of flood protection wall, while, the only major difference was the unit price. After duel consultation with number of factory owners, they decided to sell the frog concrete block at Rs. 18/unit, if the product was commercialized. So, a total of 3000 units were required to construct the flood protection wall with a total cost of Rs. 54,000. Upon conclusion, it was proved that frog concrete block was 43% more cost-effective than brick masonry and 19% more efficient than solid concrete block masonry.

V. Conclusion & Recommendation

Based on intensive experimental work and meticulous investigation of masonry units and masonry assemblage's specimens of traditional concrete block and optimized concrete block, we have reached a conclusion that optimized version of concrete block, also known as frog concrete block, performed better in compressive strength, flexure strength and compression prism strength: the values of both type of specimen were nearly identical, hence, the difference can be ignored, as it had no potential impact on the structural performance. Additionally, the optimized concrete block specimens for diagonal shear strength and bond shear strength superseded in strength compared with its traditional counterpart, the solid concrete block. Lastly, the optimized concrete block was far more economical than solid concrete block and brick that are locally available in an exorbitant amount.

In order to analyze more closely its behavior in earthquake regions, it is recommended to perform full fledge 'Shake Table Test' to understand it structural performance and different modes of failure and to provide effective countermeasures to improve its performance.

In addition, more work shall be done on the dimension of frog. Optimized concrete block specimens shall be constructed with different frog dimensions. Different tests shall be performed to find out the dimension of frog that will produce maximum optimum results without compromising other parameters.

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