Stress strain characteristics of reinforced hollow concrete block masonry melded with mesh reinforcement

Manish S Dharek1*, S Raghunath2, Prashant C Sunagar3, Aravind H Bhashyam4, Sreekeshava K S5

1 Civil Engg Dept, BMS Institute of Technology and Management (affiliated to VTU, Belagavi), Bengaluru, India
2 Civil Engg Dept, BMS College of Engineering (affiliated to VTU, Belagavi), Bengaluru, India
3 Civil Engg Dept, Ramaiah Institute of Technology, Bengaluru, India
4 Civil Engg Dept, Christ University, Bengaluru, India
5 Civil Engg Dept, Jyothy of Technology (affiliated to VTU, Belagavi), Bengaluru, India

*Corresponding Author: manish.shashikant@gmail.com

Abstract. Plain Masonry similar to unreinforced concrete, is resilient in compression and weak in tension. Masonry gains strength with age similar to concrete. Inspite of these resemblances, there exist numerous differences between masonry and concrete. The major difference is the regular pattern of horizontal joints (known as bed joints) at specific intervals along the height of walls introduce due to the method of construction of masonry. These bed joints make masonry a direction dependent material possessing orthotropic properties, unlike concrete which is usually regarded as isotropic at least in the elastic range. Mechanical properties such as compressive strength, tensile strength, flexural strength are a prerequisite as part of the design of masonry walls. The present study deals with the experimental study to evaluate the mechanical properties of hollow concrete block masonry specimens for varying cement mortar proportions melded with mesh reinforcement at bed joints. Parameters such as compressive strength, modulus of elasticity, failure pattern have been studied and compared for reinforced and unreinforced hollow concrete block prisms. The study showed higher compressive strength and improved elastic modulus for specimens with higher grade of mortar.

1. Introduction
Masonry may be defined as an assembly of masonry units along with mortar laid in a predetermined orientation. The building units may be of stones, bricks or precast blocks of concrete. It is the simplest of all building techniques in which mason stacks the pieces of material over the top of one another with mud or mortar used as a binding material. Masonry, similar to concrete, is strong in compression and weak in tension, gains strength with age and also properties of masonry are affected by site practices such as handling, placing and curing as well as weather condition similar to concrete. In spite of these similarities, there exist several differences between masonry and concrete; the major one being the relative insensitivity of masonry compressive strength to the water-cement ratio of the mortar – indeed, minimal attention is paid to the water-cement ratio of mortar commonly produced on-site. The second major difference is the regular pattern of horizontal joints (known as bed joints) at specific intervals along the height of walls introduced due to the method of construction of masonry.
These bed joints make masonry a direction dependent material possessing orthotropic properties, unlike concrete which is usually regarded as isotropic, at least in the elastic range. While common concrete construction is largely dependent on formwork, the requirement of no formwork for masonry construction is regarded as a significant advantage, because formwork is expensive and construction of formwork always lies along the critical path of most multi-storied building construction scheduling.

Masonry structure are efficient than RC framed structure however, construction practices are limited because the use of huge number of masonry units, requirement of skilled labour, its performance against lateral loading etc. To improve the efficiency of masonry structure, reinforcements are strategically introduced into it. The introduction of reinforcement not only increases its lateral load carrying capacity also improvises its compressive load carrying capacity. In European countries, reinforcement is introduced in bed joint for controlling crack width but its capacity of increasing the load bearing property is neglected. This style of introducing bed reinforcement in masonry is very common in Germany. Placing of vertical reinforcement in case of concrete blocks can be done by making use of blocks which have cores/openings in it to accommodate the reinforcement. This cores can be later plugged with free flowing grout or concrete. This practice of reinforced masonry construction is very popular in the seismically active regions in Latin America. This methodology also has proved to be comparably stronger and ductile when compared with RC Framed structures when subjected to earthquakes. The present work deals with comparative study of strength and elastic properties of solid block masonry prisms with mesh reinforcement and hollow block masonry prisms by varying the cement mortar mix proportions.

2. Literature Review
Matthias Ernst et al [1] studied the effect of vertical and horizontal reinforcement of perforated clay block under compression and shear loading. The increase in flexural strength, shear and compression strength as well as an increased ductility of brittle material was observed during experimentations The application of reinforcement in load bearing wall to increase the compression strength is low but reinforcements were widely used to control the crack in the structure. The use of horizontal reinforcement has increased 15% of compression strength and vertical reinforcement is 40% were observed when compared to unreinforced masonry. The ultimate strain for unreinforced masonry was given by approximately 15% (diameter of 6 mm) and vertically (2 number of 12 mm diameter) reinforced specimens by 25%. Mohamad et al [2] carried out experimental studies on brick masonry prisms subjected to axial compressive loading. The variation in elastic modulus of brick units and mortar governed the failure mechanism wherein the nonlinear behavior of masonry was predominantly governed by mortar. Gumaste et al [3] studied the mechanical properties of brick masonry prisms made of table moulded bricks and wire cut bricks of Indian origin for varying grade of mortar. It was concluded that the masonry prisms made with wire cut bricks showed a better correlation. Bryan and Mervyn [4] studied the stress strain characteristics of unconfined and confined clay brick masonry. The presence of confinement plates placed within the bed joints controlled the lateral expansion of joint and reduced the differential expansion between the brick and the mortar joint. About 40% improvement in ultimate strength was observed. Jagadish et al [5] studied the effect of containment reinforcement in masonry buildings to arrest the post cracking deflections. Since the failure pattern of masonry buildings is brittle which can lead to ultimate failure of buildings, introduction of containment reinforcement played vital role in improving the ductility of masonry. Oliveira et al [7] studied the performance of brick masonry prisms under cyclic loading and concluded that the stress strain characteristics was bilinear in nature.

3. Engineering Properties of block and mortar
The materials used as part of current experimentations comprised of hollow concrete block and solid concrete blocks of 150mm thickness acquired locally from Bengaluru. The properties of solid and hollow blocks adopted for casting masonry specimens have been summarized and presented in Table 1 and Table 2 respectively conforming to IS 2185-2003- part 1 and part 2 [6]. The mortar used in the present study was cement sand mortar(CSM) in three different proportions i.e. CSM 1:3, CSM 1:6,
CSM 1:8. The cement used comprised of OPC-53 grade conforming to IS 12269-2013[9] and sand conforming to IS 2116-1980[10]. The properties of mortar are presented in Table 3.

| Property                  | No. of specimens | Solid concrete blocks | COV (%) |
|---------------------------|------------------|-----------------------|---------|
| Dimensionality-(mm)       | 20               | 402.9 x 151.5 x 201.5| ----    |
| Water absorption-(%)      | 03               | 6.17                  | 9.88    |
| Initial rate of absorption (kg/m²/min) | 03   | 0.83                  | 27.37   |
| Block Density-(g/cc)      | 03               | 2.036                 | 4.2     |
| Compressive Strength-(MPa)| 08               | 3.46                  | 15.36(%)|
| Modulus of Elasticity-(MPa)| 03             | 6278                  | 7356    |

| Property                  | No. of specimens | Hollow concrete blocks | COV (%) |
|---------------------------|------------------|------------------------|---------|
| Dimensionality-(mm)       | 20               | 401.5 x 150.6 x 199.7 | ----    |
| Water absorption-(%)      | 03               | 4.85                   | 3.70    |
| Initial rate of absorption (kg/m²/min) | 03   | 0.34                  | 23.76   |
| Block Density-(kg/m³)     | 03               | 1.26                   | 4.2     |
| Compressive Strength-(MPa)| 08               | 9.03                   | 15.36   |
| Flexural Strength-(MPa)   | 03               | 2.01                   | 7.90    |

| Property                  | Cement sand mortar (CSM) proportion | COV (%) |
|---------------------------|------------------------------------|---------|
| Mean Compressive strength (MPa) | 1:3          | 13.6/3    |
| Mean Tensile strength (MPa)  | 1:6          | 0.86      |
| Mean Flexural strength (MPa) | 1:8          | 3.23      |
| Mean Compressive strength (MPa) | 1:3          | 12.05     |
| Mean Tensile strength (MPa)  | 1:6          | 10.58     |
| Mean Flexural strength (MPa) | 1:8          | 13.26     |

4. Experimental programme
In order to determine the compressive strength of masonry, IS 1905-1987 [8] recommends casting and testing of masonry prisms. Masonry prism is an assemblage of individual masonry units and mortar that has been casted as a test specimen in order to evaluate its compressive strength. In the present study, masonry prisms were casted in stack bonded pattern as shown in figure 1(a) for testing of compressive strength in accordance with provisions given in IS 1905-1987 [8]. Suitable precaution was taken to ensure that the verticality was maintained truly plumb to avoid eccentricity if any. The blocks used were pre wet before casting of prisms. In case of the reinforced solid block masonry prisms, horizontal reinforcement comprising of welded wire mesh of 1.25-inch gauge and 2.4mm
thickness. Vertical reinforcement of 6mm diameter an 8mm diameter were used in case of prisms casted with hollow blocks. These were filled with free flowing pre mixed cementitious grout obtained from FOSROC chemicals “Conbextra GP1”. Slump tests were conducted by varying the water/powder ratio to obtain a slump greater than 300mm to eliminate compaction. A slump value of 340mm was obtained for a water/powder ratio of 1.8. The h/t ratio in case of these prisms were equal to 4.2 within the range of 2 to 5 and a correction factor of 1.314 was applied to obtain the actual prism test. In total, three masonry prisms which were cured for 28 days were tested in a Universal testing machine by placing nominal sheets of 4mm plywood at top and bottom till the specimen underwent failure for various combinations shown in Table 4. The failure load of the specimen was noted down. Displacement values required to compute the strain values were noted down using digital demountable mechanical gauge. The test set up of the same is shown in figure 1 (b). The breakup of the specimens is shown in Table 4.

**Table 4. Details of Prisms casted and their nomenclature**

| Designation of prism | Blocks | Mortar | Detail of reinforcement        |
|----------------------|--------|--------|--------------------------------|
| UA                   | Solid  | 1:3(H1 type) | Unreinforced                   |
| UB                   | Solid  | 1:6(M2 type)  | Unreinforced                   |
| UC                   | Solid  | 1:8(L1 type)  | Unreinforced                   |
| HB                   | Hollow | 1:6     | Unreinforced                   |
| RA                   | Solid  | 1:3     | Horizontally reinforced 1.25” gauge 2.4mm |
| RB                   | Solid  | 1:6     | Horizontally reinforced 1.25” gauge 2.4mm |
| RC                   | Solid  | 1:8     | Horizontally reinforced 1.25” gauge 2.4mm |
| RHB6                 | Hollow | 1:6.    | Vertically reinforced 6 mm diameter |
| RHB8                 | Hollow | 1:6    | Vertically reinforced 8 mm diameter |

![Figure 1](a) Masonry prisms stacked after casting, (b) Test Set up of prisms

The corrected prism strength (Mean) which is a product of Prism strength and correction factor for various combination of specimens have been tabulated and indicated in Table 5 above. Typical stress strain curve obtained for Reinforced hollow block masonry prism with vertical reinforcement-6mm is shown in Figure 3.
5. Results and Discussions

The Elastic modulus obtained from stress strain curve for the different specimens is tabulated in Table 5. The values clearly indicate that the reinforced masonry prisms have shown higher elastic modulus. In general, the prisms casted using reinforced hollow blocks have shown better prism strength and elastic modulus. These specimens also showed enough resistance before undergoing failure clearly indicating the role played by the vertical reinforcement. The solid block masonry prism with horizontal mesh reinforcement showed an improvement in prism strength and elastic modulus when compared with unreinforced solid block masonry prisms. This clearly indicates the effectiveness of horizontal mesh reinforcement also.

### Table 5. Details of Masonry Prism strength tested

| Designation of prism | Mean Prism strength N/mm² | Mean Corrected prism. strength (Correction factor = 1.314) N/mm² | COV(%) | Elastic Modulus (MPa) |
|----------------------|---------------------------|---------------------------------------------------------------|--------|-----------------------|
| UA                   | 3.22                       | 4.23                                                          | 12.35  | 4800                  |
| UB                   | 2.88                       | 3.78                                                          | 10.68  | 3800                  |
| UC                   | 2.25                       | 2.95                                                          | 13.32  | 2765                  |
| HB                   | 6.10                       | 8.01                                                          | 8.15   | 6850                  |
| RA                   | 4.10                       | 5.39                                                          | 11.38  | 5897                  |
| RB                   | 3.53                       | 4.64                                                          | 12.67  | 4767                  |
| RC                   | 3.50                       | 4.6                                                           | 13.66  | 3124                  |
| RHB6                 | 6.56                       | 8.62                                                          | 14.28  | 10,822                |
| RHB8                 | 7.80                       | 10.25                                                         | 13.04  | 13,465                |
6. Conclusions
The following broad conclusions are drawn from the experimental investigations
- The compressive load carrying capacity of solid block masonry prism with mesh reinforcement was higher with H1 type of mortar. This was about 11.90% higher than the prism of M2 mortar and around 43.33% higher in case of prism made of L1 mortar.
- The compressive load carrying capacity of hollow block masonry prism with 8mm reinforcement was 18.9% higher than the prism with 6mm reinforcement. This was about 27.9% higher than unreinforced hollow block masonry prism.
- Typical compression failure was observed in prisms during testing. It was observed that the vertical cracks started in the middle of the prism, near the masonry unit – mortar interface and propagated toward the ends of the prism. In later stages of loading, spalling of brick or block was observed on the vertical sides of the prisms.
- The effectiveness of mesh reinforcement and vertical reinforcement in improving the load carrying capacities can be clearly seen from the experimental investigations.

REFERENCES
[1] Matthias Ernst, Gert Konig 2006 Shear Strength and Compressive Strength of Reinforced Perforated Clay Block Masonry. Institut fur Massivbau 221-242.
[2] Mohamad, Lourenço PB, Roman HR 2005 Mechanical behavior assessment of concrete block masonry prisms under compression International Conference on Concrete for Structures (INCONS), Coimbra, p. 261.
[3] Gumaste K S, Nanjunda Rao K S, Venkatarama Reddy B V 2007 Mater. Struct. 40 241.
[4] Bryan D E, Mervyn J K 2004 J. Struct. Eng. @ ASCE 650.
[5] Jagadish K S, Raghunath S, Nanjunda Rao 2002 J. Struct. Engg 29 9-17.
[6] Specification for concrete masonry units Part II hollow and solid lightweight concrete block, IS-2185-1983-Part II, Bureau of Indian Standards, New Delhi.
[7] F. Oliveira, J. De Hanai. Sao Carlos N 2008 Ibracon structures and materials Jr. 1 58-170.
[8] Code of Practice for structural use of Unreinforced masonry, IS-1905-1987, Bureau of Indian Standards, New Delhi.
[9] Specifications for 33 grade ordinary Portland cement, IS 12269-2013, Bureau of Indian Standards, New Delhi.
[10] Sand for masonry mortars – Specifications, IS 2116-1980, Bureau of Indian Standards, New Delhi.