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Effect of moisture on the compressive strength of low-strength hollow concrete blocks

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Abstract. In order to study the effect of moisture on the compressive strength of low-strength hollow concrete blocks, an experimental study was carried out on 96 samples of locally manufactured hollow concrete blocks collected from three different locations. Uniaxial compression tests were conducted on dry specimens and three types of saturated specimens with moisture contents of 30%, 50% and 80% respectively. The range of moisture content adopted covered the range within which the concrete block samples are saturated in the dry and monsoon seasons. The compressive strength of low-strength hollow concrete blocks decreases with increase in moisture content and the relationship between compressive strength of hollow concrete blocks and their moisture content can be considered to be linear. However, the strength degradation of 30% moist concrete blocks with respect to dry blocks is relatively low and can be considered to be comparable to dry concrete blocks. A formula indicating the relationship between the moisture content and compressive strength of low-strength hollow concrete blocks is also proposed.

Keywords: hollow concrete blocks; masonry; low-strength; moisture

1. Introduction

Hollow concrete blocks are extensively used in masonry constructions in rural and semi-urban areas of the state of Meghalaya, India. The cavity in hollow concrete blocks provides them with good thermal and acoustic insulating properties. The larger size hollow concrete blocks also increase the speed of masonry wall construction as compared to smaller size clay bricks, thereby, reducing the cost of construction. The easy availability of ingredients for the manufacture of concrete blocks and a simple manufacturing process make these blocks a popular building construction material in these areas. However, to compete with other building materials such as clay bricks, these hollow concrete blocks are manufactured with high percentages of aggregate content resulting in low-strength hollow concrete blocks. Their use is therefore limited to low and medium rise building constructions (Fig. 1).

Structures in the state of Meghalaya are subjected to the severest rainfall in India where the average annual rainfall for the year 2017 was 4472.4 mm, the highest in India (Report of the Indian Meteorological Department 2017). The top two wettest places in the world are also located in the state of Meghalaya (www.worldatlas.com 2017). The need to study the effect of such harsh weather conditions on the building construction materials situated in these wet areas becomes relevant for building structures situated in such areas.

Cook and Haque (1974) studied the effect of moisture on the strength of desiccated concrete. The moisture content of the specimens was not exactly measured but rather specimens were placed in fog rooms (by controlling the relative humidity) after which the specimens were tested at 1, 3 and 7 days. It was observed that the compressive strength of the specimens decreased with the number of days the specimens were placed in the fog room. The strength reduction due to the increase in moisture content is attributed to the shrinkage and swelling of the microstructure as water is added in the pore structure of the concrete (Yaman *et al.* 2002).

Fig. 1 Hollow concrete block masonry building

Ranjit *et al.* (2008) on studying the effect of displacement rate and moisture content on the mechanical properties of concrete observed that the strength of wet concrete is significantly lower in comparison with the strength of dry concrete specimen at the same displacement rate. The concrete specimens, in this study, were first oven dried before saturating them to 10%, 20% and 100% degree of saturation. Shoukry *et al.* (2011) conducted a thorough experiment to study the effect of moisture and temperature on the mechanical properties of concrete. An environment

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chamber was designed that could measure the stress-strain relation of the concrete at the desired temperature and moisture level. The test results indicated a gradual decrease in the compressive strength of the concrete samples with the increase of moisture content. Chen *et al.* (2012) also studied the effect of moisture content on the compressive and tensile strength of concrete. In order to achieve the desired moisture content, the cured specimens were first oven dried at 105±1℃ for 3 days after which they were completely saturated with water again. The saturated specimens were eventually dried to the desired moisture content. The test results indicated a decrease of compressive strength of concrete with increasing moisture content. However, there was an increase in the compressive strength at fully saturated condition probably due to the pore water pressure in the concrete.

However, contrasting results were reported for the effect of moisture content on the modulus of elasticity of concrete. Sereda *et al.* (1966) while studying the effect of sorbed water on the mechanical properties of hydrated portland cement pastes and compacts observed that there is an increase in the elastic modulus only after 50% of relative humidity. Liu *et al.* (2014) on studying the effect of moisture content in the static elastic modulus of concrete also reported an increase in the modulus of elasticity of concrete with the increase of moisture content. Shoukry *et al.* (2011) on the other hand reported a continual decrease in the elastic modulus with increasing moisture content much in the same pattern as was with compressive strength in relation to moisture content.

There is an increasing research interest in masonry form of construction in recent years, due to the satisfactory performance of improved masonry construction methods such as confined masonry and reinforced masonry in recent seismic activities (Meli *et al.* 2011, Penna *et al.* 2014). In addition, their cost-benefiting attributes also place greater relevance to such research, especially in developing countries. In this regard, the study of hollow concrete blocks has been actively undertaken by researches as this form of masonry construction is prevalent in many countries of the world. The compressive strength of hollow concrete blocks has been studied at the unit level as well the level of prisms to capture their mechanical characteristics as a single unit and a masonry unit and their corresponding relationship. Murthy *et al.* (2012) performed experimental investigations on high strength hollow concrete blocks from a single production site with a mean compressive strength of 33.99 MPa. Gayed *et al.* (2012) while establishing the correlation between unit block strength and masonry prism strength of hollow concrete blocks, carried out compressive strength tests on 20 unit hollow concrete block specimens of different strength grades and recorded compressive strengths ranging from 8.68–48.80 MPa. Jonaitis and Zavalis (2013) performed compression tests on 4 series of highly hollow concrete blocks (hollowness of 50 percent or more) recording a normalized compressive strength ranging from 6.78–10.78 MPa. Al-Amoudi and Alwathaf (2014) while studying the compressive behaviour of hollow concrete block masonry also studied the compressive strength characteristics of hollow concrete blocks that were collected from a single site source. The compressive strength of such blocks were18.08 and 17.15 MPa for two types of blocks.

(a) (b)

Fig. 2 (a) Fine stone chips used as coarse aggregate (b) Formwork used for the manufacture of hollow concrete blocks

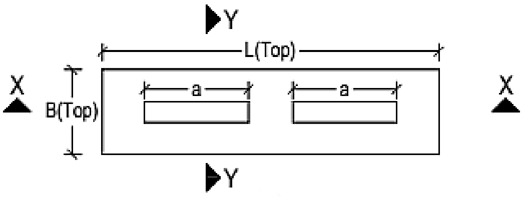
While the effect of moisture content has been studied by various researches, the samples for the studies were either concrete cylinders or concrete rectangular cubes that are prepared under laboratory conditions. Where the trend of prescriptive design is giving way to performance-based design, the study of the effect of moisture content directly on the construction materials becomes essential. Most hollow concrete block tests have been performed on moderate to high strength blocks. There is a need to study the behaviour of low-strength hollow concrete blocks.

The objective of the present study is to, therefore, determine the effect of moisture on the compressive strength behaviour of low-strength hollow concrete blocks. The study is also aimed at capturing the on-site characteristics of the hollow concrete blocks that actually go into construction activities. As such locally made hollow concrete blocks from three different locations were selected for the study. The selection of three different manufacturing sites would also capture the variability in the hollow concrete blocks produced in the region.

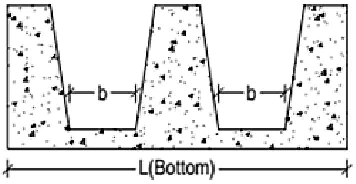
2. Hollow concrete blocks

For the experimental study, a total of 96 hollow concrete block specimens were collected from three different sites (32 from each site from the same batch). The concrete blocks were collected from the same batch. The hollow concrete block specimens employed in the study are locally manufactured. The coarse aggregates that are used in the manufacture of hollow concrete blocks are fine stone chips (Fig. 2(a)) that are waste from stone crushers of nearby stone quarries. The hollow blocks are hand-made one at a time using a steel formwork as shown in Fig. 2(b). Volume batching is adopted in the manufacture of blocks in all the 3 sites. The cement-sand-aggregate ratio adopted in the three sites is approximately 1:0.5:6 while the water-cement ratio is about 0.5.

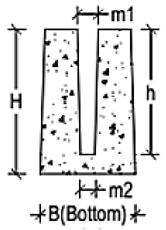
Sampling of the concrete block specimens has been made as per Indian Standard code of practice IS 2185 Part 1:2005. The densities of the concrete blocks were evaluated as per ASTM C140 since IS 2185 Part 1:2005 evaluates the densities based on the gross volume of the block irrespective of the cavities. The dimensions and the physical



(a) Top view



(b) Section X-X



(c) Section Y-Y

Fig. 3 Hollow concrete block

Table 1 Dimensions of hollow concrete blocks

L(T)	L(B)	B(T)	B(B)	H	a	b	m1	m2	h	% hollowness
Site 1										
358	359	93	100	149	120	85	35	20	140	15.52
Site 2										
357	359	90	100	151	110	70	25	25	120	10.43
Site 3										
351	352	87	90	161	105	70	30	20	120	10.62

The dimensions are in mm
The values are average of 20specimens

Table 2 Physical properties of Hollow concrete blocks

	Density (ASTM C140 (kg/m^3))	Water Absorption (%)
Site 1	2083.2	12.94
Site 2	1983.38	11.93
Site 3	2110.37	10.15

The values are average of 5 specimens

properties of the hollow concrete blocks (Fig. 3) are given in Table 1 and Table 2 respectively. The blocks are made partially hollow, for easy placement of mortar where the blocks are placed upside down with the hollow part facing downward during the placement of blocks in masonry construction. The blocks from site 1 and 2 are similar in sizes as compared to blocks of site 3 that are around 10 mm smaller in width and 10 mm higher in height.

The densities of the concrete blocks from all the sites were much less than the standard density of concrete being 2400 kg/m^3 indicating that the concrete blocks were less dense that would ultimately reflect on their compressive strength. The water absorption of concrete blocks of all the sites is less than the recommended value of 10% as per IS 2185 Part 1:2005. The concrete blocks of site 3 have better water absorption properties as compared to the other two sites.

Fig. 4 Polythene wrapped specimens

3. Experimental study

In order to study the effect of moisture content on the compressive strength of hollow concrete blocks, four saturation states of the concrete blocks were chosen for the purpose - dry, 30% moist, 50% moist and 80% moist. A maximum of 80 % moisture content was chosen as the wet samples collected during the monsoon season fall around this value. For each of these saturation state, 8 specimens of concrete blocks were tested following the test guidelines as per IS 2185 Part 1:2005. From each site, 32 concrete blocks were tested, totaling 96 concrete blocks from three sites.

In this study, four hollow concrete block specimen types are prepared; dry specimen and three types of moist specimens, i.e., 30%, 50% and 80% moist. And for each saturation state, 8 samples were tested. The total number of blocks from a single site was 32. The block specimens were collected from three different sites. Therefore the total number of block specimens collected and tested from three sites was 96. The block specimens collected were at least 28 days old.

3.1 Preparation of samples

The use of moisture sensors for the control of moisture being an expensive proposition, a cost-effective test protocol has been devised for moisture control. The specimens collected were first completely immersed in water for 24 hours, after which the specimens were then oven dried at 105°C for another 24 hours. From the saturated weight and dry weight, the wet weight of the specimens for the required moisture content is calculated from Eq. (1).

$$\text{Moisture Content (\%)} = \frac{W_r - W_d}{W_s - W_d} \times 100 \tag{1}$$

where W_r is the required weight for the required moisture content of the block, W_d is the dry weight of the block and W_s is the saturated weight of the block. The specimens are then carefully immersed in water in a trial and error method to obtain the required weight of the target moisture content. This method of moisture control is similar to the one adopted by Chen *et al.* (2012). The error in measured moisture contents for 30%, 50% and 80% moisture content are less than ±1.88 %, ±2.44% and ±2.29% respectively. The specimens that have attained the target moisture content are then wrapped in polythene sheets (Fig. 4) to retain the moisture till their tests. The dry specimens are not completely dry, i.e., 0% moist, but allowed to retain moisture at normal room temperature and humidity to

Fig. 5 Gypsum capping of the specimen

Fig. 6 Compression testing machine

reflect the actual dry specimens that would be used in construction. The moisture contents of such specimens are around 10%.

The concrete block specimens being rough- textured requires smoothening of the top and bottom faces in order to allow the uniform distribution of forces under a compression testing machine. This is achieved by capping the hollow concrete block specimens with gypsum (Fig. 5) in accordance with provisions of IS 2185 (Part 1):2005 and ASTM C 1552-03(a).

3.2 Testing of the blocks

The compression tests of the prepared specimens are then conducted 24 hours after they have been capped and air-tight wrapped, in a compression testing machine (Fig. 6). The specimens are placed with the hollow part facing down in the manner the blocks are placed during masonry construction. The rate of loading applied was 0.1 kN/sec. The equation used for the computation of compressive strength was

$$\sigma = \frac{P}{A} \tag{2}$$

where P is the load at failure (kN), A is the cross-sectional area of the concrete block and σ is the stress (MPa)at failure (compressive strength). Since the concrete block is partially hollow, the gross cross-sectional area was adopted for the computation of compressive strength without accounting for the hollow cavity which is in line with the recommendations of IS 2185 Part 1:2005. Steel plates of thickness 12 mm were placed at the top and bottom of the specimen (Fig. 6) as the length of the concrete blocks exceeded that of the platen of the compression testing machine by 30 mm on either side (IS 2185 Part 1:2005)

Table 3 Average compressive strength of hollow concrete blocks

Moisture content (%)	Average Compressive strength (MPa)			
	Site 1	Site 2	Site 3	Average
Dry	3.27 (0.20)	2.56 (0.18)	4.61 (0.18)	3.48
30	3.12 (0.18)	2.26 (0.15)	4.37 (0.18)	3.25
50	2.82 (0.13)	2.17 (0.18)	3.58 (0.20)	2.86
80	2.59 (0.19)	1.92 (0.19)	3.34 (0.19)	2.62

The values in braces are the coefficient of variation

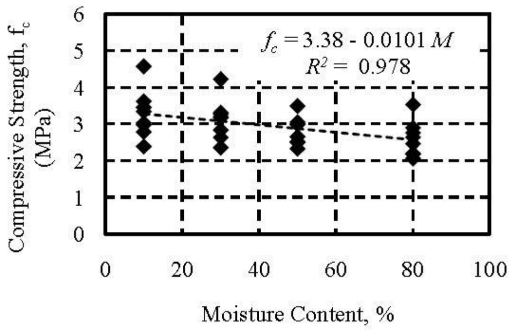


Fig. 7 Effect of moisture content on the compressive strength of concrete blocks (Site 1)

4. Results and discussions

The results of the compressive tests of hollow concrete blocks specimens for three different sites are tabulated in Table 3. The average is for 8 specimens of each saturation type.

From Table 2 and 3, it can be inferred that the compressive strengths of the concrete blocks are directly proportional to their densities, greater the density greater the compressive strength. Similarly, the compressive strengths of the concrete blocks are inversely proportional to the water absorption capacity of the concrete blocks. However, the concrete blocks from site 2 have shown contrasting behaviour, that can be considered to be a mere deviation from the normal. Being the densest and having the lowest water absorption capacity, the concrete blocks of site 3 possess the greatest compressive strength than the concrete blocks from the other two sites. The average compressive strengths of dry concrete blocks for all saturated states of site 1 and 2 are less than the minimum recommended average compressive strength of 3.5 MPa as per IS 2185 Part 1:2005 whereas that of site 3 is above the recommended minimum for the dry sample and 30% moist samples but drops below the minimum for the remaining two saturated states. The hollow concrete blocks studied can, therefore, be categorized as low-strength hollow concrete blocks.

With the increase in moisture content of the concrete blocks, there is a continual decrease of compressive strength of the blocks for all the 3 sites that could be represented as a linear relationship between moisture content and compressive strength of the concrete blocks (Figs. 7, 8 and 9). The Regression coefficient (R^2) is evaluated over the average values of the compressive strengths for their respective moisture contents with values

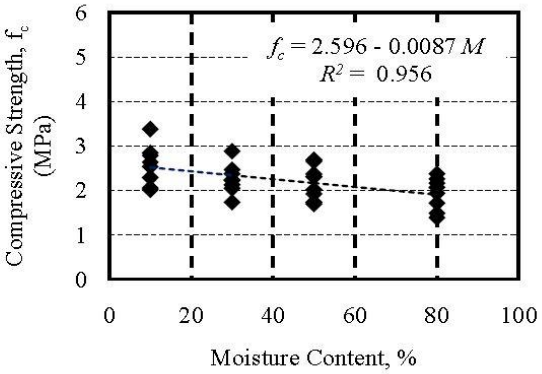


Fig. 8 Effect of moisture content on the compressive strength of concrete blocks (Site 2)

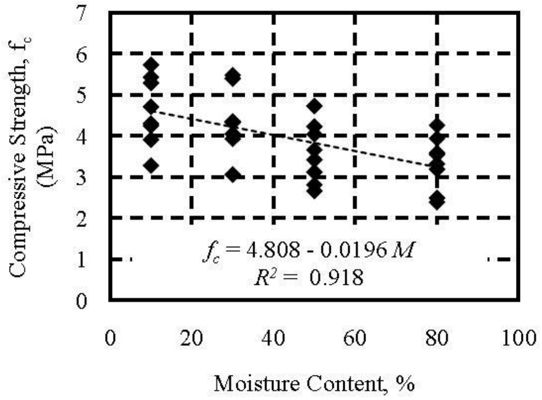


Fig. 9 Effect of moisture content on the compressive strength of concrete blocks (Site 3)

of 0.978 (site 1), 0.956 (site 2) and 0.918 (site 3). The values indicate that a proportional relationship exists between compressive strength and moisture content. Fig. 10 depicts the ensemble of data of all the sites including the average relation between compressive strength and moisture content of the hollow concrete blocks.

From the experimental data, the relation between the moisture content and compressive strength can be expressed by Eq. (3).

$$f_c = 3.595 - 0.0128\,M \tag{3}$$

where f_c denotes the compressive strength (MPa) and M the moisture content (%). Since the equation has been formulated based on the result of tests on 3 sites only, the equation has to be used with caution. Further studies are necessary to consolidate the above equation.

Table 4 shows the percentage decrease of compressive strength of hollow concrete blocks with respect to the dry specimen for the three different sites. This would indicate the amount of strength degradation the concrete blocks would undergo under the presence of moisture with respect to the dry specimen. From the results, there is 7.17% strength degradation for 30% moist samples which can be considered small enough with respect to dry strength concrete blocks. The maximum strength degradation is 24.45 % for 80% moist concrete blocks.

Table 4 Percentage decrease of compressive strength of hollow concrete blocks

Moisture content (%)	Site 1	Site 2	Site 3	Average
30	4.59	11.72	5.21	7.17
50	13.76	15.23	22.34	17.11
80	20.80	25.00	27.55	24.45

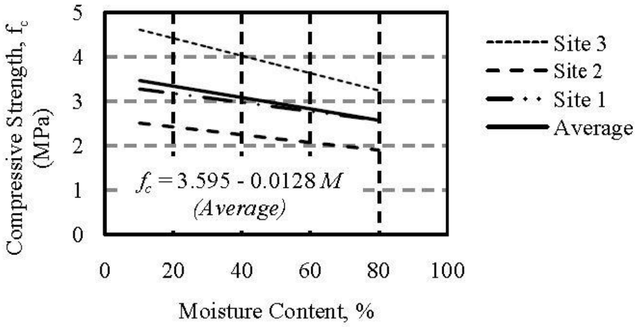


Fig. 10 Effect of moisture content on the compressive strength of concrete blocks

5. Conclusions

The following conclusions could be drawn from the experimental study on low-strength hollow concrete blocks:

- The hollow concrete blocks studied are low-strength concrete blocks whose average dry compressive strength fall below the recommended minimum as per IS 2185 Part 1:2005.
- Moisture content plays a significant role in affecting the compressive strength of low-strength hollow concrete block masonry. There is a continual decrease in the compressive strength of hollow concrete blocks with increasing moisture content in the concrete blocks, their relationship being linear. The range of moisture content adopted for the study is in the range of 10-80% within which the hollow concrete blocks are saturated between dry and monsoon season in the region of study.
- The compressive strength degradation of 30% moist samples is quite low so that they can be comparable to dry samples. This is a significant result that could have implications in the design of masonry structures.
- Based on the results of the experimental investigation, a formula indicating the relationship between moisture content and compressive strength of low-strength hollow concrete blocks is proposed. The formula, however, needs further consolidation with more experimental investigations.

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