Nonloadbearing Concrete Blocks with Various Damping Devices

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Abstract. Through time masonry block has improved construction method and structural performance. Not many investigations have been conducted to propose new concept for nonloadbearing concrete blocks because strict limitation provided by the existing standards. Three types of concrete blocks have been identified and benchmarked to be potential blocks to embed with each specific damping system, namely, Seer i-Block, V-Block and B-Block. In the production of the blocks, factory casting used dry-cast cement block and air cured for a period of time. It is difficult to check the strength of the materials and impossible to run an analysis, as the mechanical properties were untested. Each of the nonloadbearing concrete blocks was then tested to anticipate initial characteristics and the capacity of its material properties by slowly increasing it to multiple failures. The results showed V-Block has higher pressure from the static loading as all the benchmarked cement blocks failed in accordance with BS 6073 and ASTM C129. In comparison, Seer i-Block has a better average gross area failure at 5.78 MPa compression strength, followed by V-Block (5.34 MPa) and B-Block (2.88 MPa). Therefore, i-Block has been considered to be suitable with embedded damping ability of Tuned Liquid Damper (TLD). The obtained mechanical properties enabled further research in the numerical analysis in a bigger scale, the behaviour and capacity of the blocks can cheaply be obtained for dynamic excitation.

Introduction

Manufacturing factory for construction material has been operating for a long time. The production has a repeated process and the deviation from the work process will not be well received. The management of the factory focus more on the financial stability of the factory, but never invested in Research and Development (R&D). Such has occurred because focus was based on profits that are more tempting. This paper introduces the reinvented masonry system by manufacturing process with improvement to the previous masonry system. Although it is yet to perfection, this is to diversify the masonry block into sustainable wall with structural retrofitting advantage from a nonloadbearing cement block.

The variation of the masonry as reiterated in Jaafar et al. [1], and Ananda and Ramurthy [2], [3] was where a development of interlocking dry stackable block masonry units that can be laid without mortar layers. The primarily search for a more rapid and less labour intensive building system has led to the development. It proves that the further improvement in research does in fact increase the profits for the conventional production process. Whereas, a solid interlocking block masonry system influence on construction method to water permeation to both side of walls. Simulated by Anand and Ramamurthy [4], predominantly concentrated on tests without a surface finish revealed the interlocking block masonry system that adopted ASTM E 514 for rain protection and suitable interior walls. Another new concept of construction claimed by Ali et al. [5]–[7], proposed a mortar-free column made of coconut fibre reinforced concrete interlocking blocks tested under harmonic and earthquake loadings to understand the structural seismic behaviour.

In another notes, Poon and Lam [8] reported productions of recycled aggregates that are mainly produced from building and demolition wastes. However, the research has seemed a potential problem with affected angular shape and rough surface texture that decreases the workability of the fresh concrete. Nevertheless, suitable processed and sorted recycled aggregates have been used to replace natural aggregates. It has been another milestone for another potential development of masonry. Li et al. [9] has altered the material properties of the bricks by replacing lime in the production with recycled calcined oyster-shells ash. The study achieved 28-day strength and durability within grade intended. Walker and Stace [10] maximise locally available materials and benefited the production by reducing energy consumption in production. The use of compressed earth blocks only limited to understating of some basic material properties but lack of appropriate building standards. In another result, Pilar et al. [11] produce bricks with insulation and in a more sustainable way, the application of spent mushrooms compost as a new additive added into the properties of fired clay bricks. It achieved reduction of thermal transmittance, that means a better insulation of buildings and thus is an important energy saving. The pumice aggregate concrete blocks were found by Kus et al. [12]. Study was conducted on hygrothermal performance of the block walls using a calibrated hotbox method, where temperature and humidity measurements were carried out at the surfaces of the test wall and in the hollows of blocks on different courses. The results indicated that the hollows of blocks perform better in terms of thermal transmittance than the lightweight solid parts of them.

In this report, the main concern toward new masonry has been underway, however, standard requirement were always be the limitation to allow for further improvement. Therefore, in Michel [13] state-of-the-art report, Uniform Code for Building Conservation procedure were reviewed. There has been the nature of seismic risk and the other engineering constraints that shed a new and different perspective on the problem. Concerns regarding the seismic performance of existing unreinforced masonry, construed the absence of mandatory earthquake design requirements. It was recognised as the type of construction most vulnerable to earthquakes.

In 2002, Campobasso earthquake in Italy, threatened the collapse of landmark building, Faraboschi [14] described the main points of the repair and seismic retrofitting of the town. The seismic retrofitting had to meet the new Italian seismic code that was issued immediately after this earthquake. This proves the effectiveness of applying post-tensioned bonded tendons to masonry structures, in order to significantly increase both the stiffness and the lateral load-carrying capacity of a masonry building. The structural rehabilitation was limited because of the requirements to stay true to the original aspect (conservation of the bare-surface stone masonry, without plaster), notwithstanding the similar highlight was provided by others as in Giovanni et al. [15]. While in another enquiry, Masonry Society Joint Committee (MSJC) requested seismic design guidance for engineers and designers for interlocking compressed earth blocks as there was none. Therefore, Kennedy [16] identified the need for the masonry system for a low-cost, sustainable housing alternative to aid in disaster reconstruction in developing countries where material costs are high and human capital is abundant. And Griffith et al. [17] presented the results of static and dynamic tests on unreinforced brick masonry wall panels. The force-displacement relationship is proposed so that masonry system can be substituted in a displacement-based method analysis.

Methodology

The mould has to be identified to withstand the impact of wooden stick by worker during compaction. In this study, steel mould was suitable for many casts as it was durable for repeated productions. Constant hitting to the bedding of the mixer was causing the metal to bend and be dented, continuous maintenance and repair has to be provided. The beginning of the preparation started with mould oiling work to all the inner surfaces of the mould by oil brush.

Blending material machine (mixer) through time has accumulated a thick layer of waste sticking on the wall and remain that will affect that materials during crumbling process of the machine as laitance from the wall will fall and mix with the cast. Therefore, hitting to the outer surface of the mixer to loose off additional materials was a continuous process until all the waste has been removed.

Next, mixer was filled with sand and stirred well to wash off additional waste from previous laitance through the discharge opening at the bottom of the mixer. The surface of the mixer was then wetted. The mixtures were mixed one more time again, sand will be weighted and poured in, while mixer started at a slower pace with cement gradually poured and stirred to pulverise the cement and sand evenly. Once the dry ingredients were thoroughly mixed, water was gradually added until the appropriate consistency was attained in proportion to the weight. The cast was pulverised for 3 to 5 minutes, and mixer turned off to "slake" for 2 to 3 minutes, restart the mixer and mix for an additional 2 to 3 minutes by adding water as necessary until the materials mixed thorough. The blocks were to be compacted immediately after the mixture had been wet mixed for around 2 minutes.

Workspace for casting work has to be provided, sprinkled with water and wetted before the material in the mixer to be transferred. The existing casting (with zero slump value) shall be placed into the steel moulds in three layers of about the equal thickness before being compacted each. The last layer was prepared by slightly overfilling the top of the mould (approximately 5 mm) and the overflow materials were subjected to static compaction 10 to 15 times at 200 ~ 400 mm high of drop by hammering a wooden plank on the bedding of the mould to conform to the desired shape. The compaction technique has been derived from Lee et al. [18] dry-cast method. However, in current preparation, minor modification substantiated the compaction in order to justify the requirement by using machine pressing. Cubes test were conducted based on ASTM C1552 [19] to determine the adequate compression capacity to obtain the maximum compressive capacity with the condition of the factory setting. In addition to that, three prisms test at 100 x 100 x 500 mm have been cast and tested by Standard ASTM C293 [20]. And nine cylinders test at the dimension of 100 mm radial to 150 mm height has been cast and to be tested by tensile testing in compliance with ASTM C496 [21].

Excessive materials were removed and final surface was trowelled and evenly finished. The blocks were opened from mould immediately after casting. The specimens were left in the factory in a shelter platform at the average temperature of 27 ± 3 ^{o}C and relative humidity of 70 ± 15 % for 7, 14, and 28 days until the date of testing and subsequently transferred to laboratory testing. However, air dry condition in accordance with BS EN 772 -1 [22] stated the specimens for at least 14 day in laboratory at temperature more than or equal to 15 ^{o}C and relative humidity less than or equal to 65 %. The humidity has not been able to achieve lesser than 65 % as the temperature was difficult to obtain in an open factory environment of tropical climate. The tropical climate has a higher humidity value than the colder country. In addition to that, British Code has also mainly concentrated on four season condition, but tropical climate was only with one weather condition and has no significant fluctuation of temperature and humidity throughout the year. But in order to justify the code requirement, the test samples in air dried condition were exposed to longer duration before further testing were conducted on predominantly 28 days cubes test.

No machine compaction was used but human, as the machine compaction was not feasible by that time. The blocks were under research and the management of the factory decided not to invest heavily on the automated casting machine, as the moulds with machine casting have to be custom made. Heavy costing was not an option for factory to invest in R&D purposes.

The physical requirements in accordance to nonloadbearing concrete ASTM C129 concrete masonry stated that all units shall be sound and free of cracks or other defects that interfere with the proper placement of the unit or significantly impair the strength or permanence of the construction. Visual observation was conducted to determine and reject the blocks and all the test samples in regard to the requirement of the code.

Data Analysis

Test fineness moduli conducted to characterize the overall coarseness of fineness of fine aggregate as show in Figure 1. Three fine aggregate samples of natural sand have been used to define grading of fineness modulus (FM) in accordance to ASTM-C33-03 [23]. The standard was used to estimate the proportions of fine and coarse aggregates by fineness modulus in concrete mixtures. Number and size of sieves has been selected according to initial few trial tests for the sieve analysis depending on the particle sizes that were present in the sample and the grading requirements. Sieve analysis was performed to determine the particle size distribution, or grading, of the aggregate sample. The aggregate caught in sieving was determined by mass of the aggregate retained on each sieve and on the pan. Test sample overall mass has balance less than 0.1% over the total mass. Results have been recorded in Table 1 with some or all of the following quantities retained on each sieve, total percentage retained on each sieve, and total percentage passing each sieve. Standard specification for concrete aggregates masonry units [24] as in calculations [25]–[27] resulted in average 1.90 fineness modulus which were not fulfilling the passing marks. Standard requires 2.3 to 3.1 to ensure satisfactory materials for most concrete [39, 40]. However, the materials fulfilled the passing requirement as less than 45% sand were retained on each of the next consecutive sieves. The relevant criteria was meant for dried cement-sand casting work of cement block, exception was to be provided for fine aggregate used in concreting work. In the cement block manufacturing plant, material and production cost has to be minimum, therefore low fineness modulus has been deemed to be suitable for the cement sand dried cast of cement block. In addition, cement block was not part of load-bearing wall therefore low strength cast only was required. Calculated Fineness Modulus (FM) as the sum of the retained percentage on the series of sieves divided by 100 is as followed;

FM = (Σ Cumulative percent retained) / 100

Table 1. Fineness modulus with weight of retained fine aggregate.

Standard Sieve Size #	Sieve Size (mm)	Total Percentage of Mass Retained (%)
3/8 in (9.5 mm)	9.5	1
No.4 (4.75 mm)	4.75	3
No. 8 (2.36 mm)	2.36	8
No. 16 (1.18 mm)	1.18	26
No. 30 (600 □m)	0.6	61
No. 50 (300 □m)	0.3	92
No. 100 (150 □m)	0.15	1
Fineness Modulus		1.899

The sieve testing was only conducted after the sand was air dried. The sand has been collected in three begs of 0.59 kg each. The samples have been air dried and exposed to a period of three weeks and were weighted before and after the drying process. The recorded percentage of differences of moisture content of the sand to laboratory setting is 5.6 % before and after drying.

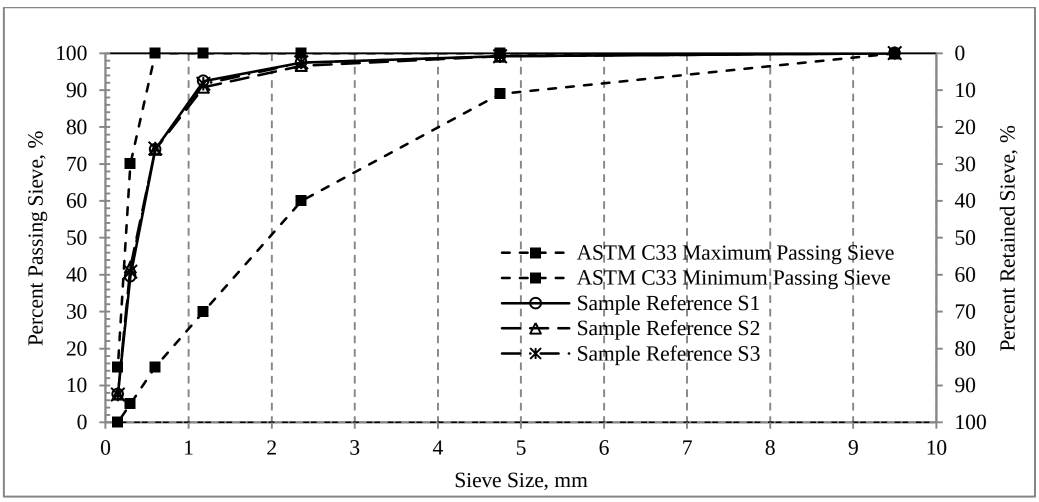


Figure 1: Material grading of retained sand versus sieve size for natural aggregate in sample 1, 2 and 3.

Cube test

Trial-error method was used to determine the compressive strength of dry cast concrete. Normal trial mix design was not used to determine the strength because the material has missing coarse aggregate and lack of water for workable concrete. Cubes has been prepared in five mixtures of *cement:water:sand* matrix each was divided by cement contents. Mixture #4 was predominantly chosen because the compressive strengths were recorded slightly higher than the rest combinations at 24.884, 24.121 and 27.284 N/mm^2. Therefore, the compressive strengths of 1:0.19:2.10 mixtures under the factory setting have better cast in strength, but weak in workability, in regard to cement-water ratio. In concrete masonry, block production was supposed to be working in a low water-cement ratio condition, as compression machine shape was conformed in a control environment and quality was tested in accordance to ASTM C1314 [29]. The combination of sand was reduced in sand-cement ratio for Mixture #4. The natural resources of sand have less binder properties and that was determined to be the main reason for lack of strength because binders were reduced if otherwise opted as shown in Table 2. Therefore, cement as binder was increased in Mixture #4 to allow for higher compressive strength and increase the overall performances. Also, the compressive strength recorded was slightly similar in early strength to 28 days, allowing early handling and making better profits.

Table 2: Compression Strength

Mixture #4	**Compressive Strength, f'_c**		
	7 Days	**14 Days**	**28 Days**
1:0.19:2.10	22.955	23.188	24.884
	22.472	23.055	24.121
	21.453	24.169	27.284

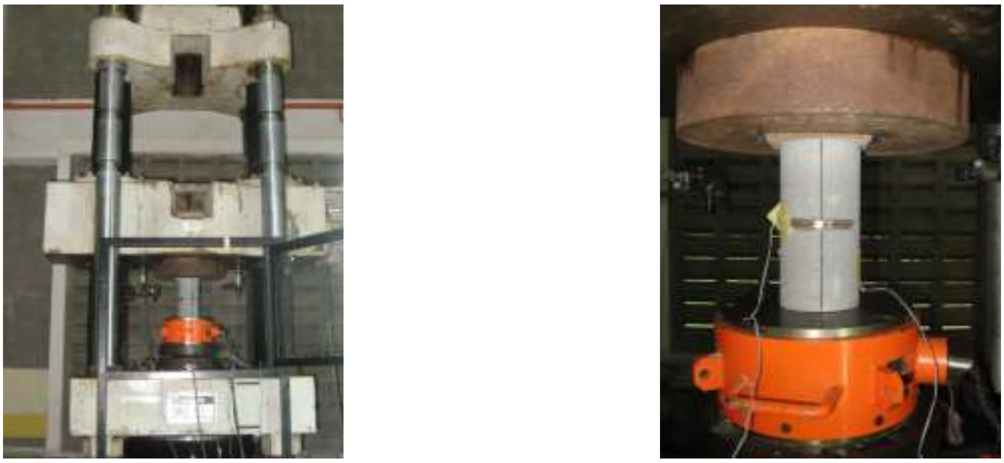
Young's Modulus Determination

The determinations of modulus of elasticity and Poisson's ratio under longitudinal compressive stress have been tested on three cylinders cast under controlled environment. Specimen preparation of nonloadbearing concrete specimen having diameter of 100 mm in circular section and height of 200 mm had been prepared. The lengths of the cylinders were marked in its mid-point perpendicular to each other and to be drawn across the longitudinal section. Centre surface along the longitudinal marking was determined and cleaned thoroughly with sand paper and wiped with ethanol to clean off the dust. The centre of the cylinder was installed with strain gauge at the longitudinal and lateral direction. The strain gauge was left to dry for 24 hours after fast-cured adhesive applied to the surface where strain gauges were pasted at. TINIUS OLSEN Super "L" Universal Testing Machine with 3MN capacity was used to load specimens of controlled constant loading rate at 0.4 ± 0.01 mm/min. The vertical axial deformations of the machine were recorded by three long linear variable differential transducers (LVDTs) of 50 mm each. The LVDTs were located at the top of the moving compression plate onto the stagnant loading columns to monitor the overall movement of the compression machine and the specimens as in Figure 3.

The transverse deformations of the specimens were obtained by using two bonded strain gauges mounted circumferentially at diametrically opposite points at the mid-height of the specimen and capable of measuring circumferential strain to the nearest of 5 millionths. The type of strain gauges was of PL-60-11-3L at the length of 60 mm, from TML Tokyo Sokki Kenkyujo manufacturer each with 3 m long lead wires connected to 100 channels data logger.

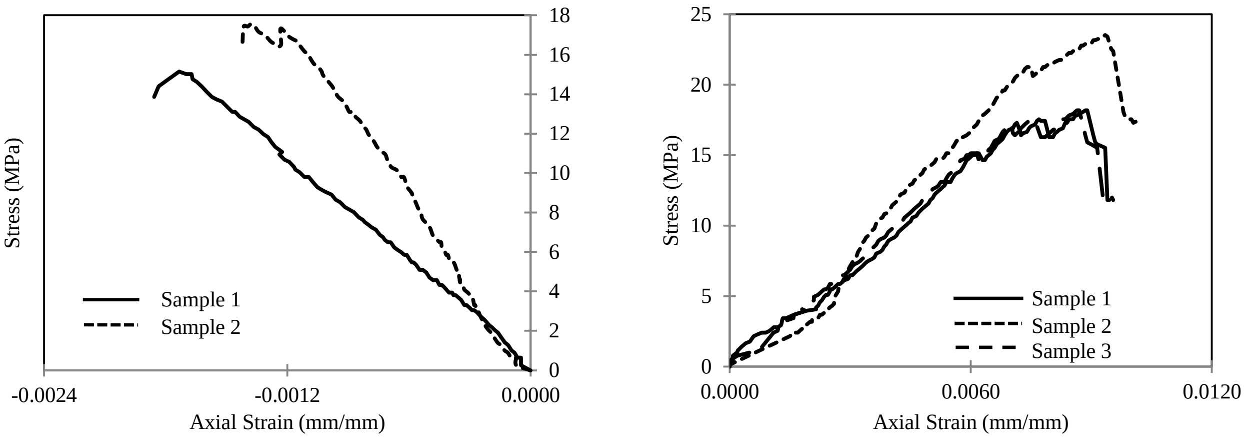
The longitudinal strains were obtained by particular measured of the length of the LVDTs divided by the average cylinder height. All the contributing data were measured using the data logger to record the values of load, displacement, and strain. Any cracking pattern, buckling, deformation, etc., were recorded during testing. The specimens were tested in accordance to ASTM C39/C39M of compressive strength as discussed previously.

The overall view of the specimen set up and diagram for the loading machine and measuring equipment are as shown in Figure 2.



(a) (b)

Figure 2: Indicating the placement of Young's modulus and Poisson's ratio a) TINIUS OLSEN Super "L" Universal Testing Machine with 3MN capacity and b) close-up strain measuring arrangement.



(a) (b)

Figure 3: (a) indicating horizontal deformation of axial stress to lateral strain and (b) indicating vertical deformation of axial stress to longitudinal strain.

Seer i-Block

Seer i-Block was invented to cater for Tuned Liquid Damper. The block serves as non-loadbearing block for external and internal wall system. The dimension of 280 mm (L) x 142 mm (W) x 235 mm (H) and weight at approximately 11.5 kg was considered because of its compact and assuming small size to ease the handling purposes. The size came with consideration for the insertion of TLD in the block cavity. Apparently, the header of the blocks caters for interlocking tongue and groove system. The middle of the block was deliberately conformed and left empty to insert the tuned liquid damper. Solid plastic containers designed with 2mm lesser in overall dimension to the cavity of the blocks were meant to be inserted into the block. The moment the blocks were incorporated with TLD, the containers have permanently sealed the liquid that has been tuned to desired natural frequency. Apart from that, the frog of the bedding was meant for the insertion of the vertical placement. Tests were conducted to determine the compression strength on selected T1, T2, T3, T4 samples in compliance to dimension check of BS 6073 [30] and BS EN 772 [31]. The average gross compression strength for 28 days was recorded at 4.74 N/mm^2. Although the weight has additional 60% in comparison to V-Block and 50% for B-Block, numerical analysis showed that i-Block could only be statically achievable with such geometrical layout and weight. Therefore, the orientation and layout in order to benchmark i-Block as the potential block has been chosen. The material properties will be further illustrated and explained in following discussion.

V-Block

V-Block was an existing type of production block in the manufacturing plant. The block has been identified to be potentially high in gravitational resistance due to its additional support in the middle of the block. The blocks were in 229 mm (L) x 102 mm (W) x 229 mm (H) in dimension. The weight of the block was averaging 4.63 kg which is similar in size with B-Block but was slightly smaller compared to i-Block. The block has a smaller span that made bed stronger, not to mention the middle support resist the excessive deflection and collapse. The thickness at the face of the block indicated thickness of 24 mm. V1, V2, V3, V4 samples were chosen for compression testing, the 28 days strength recorded average value at 4.38 N/mm^2 which is second to the i-Block.

B-Block

B-Block applied dual direction bracing for the damping system. The block has just two thinner vertical supports as in i-Block. The Block has been tested at B1, B2, B3, B4 with similar dimension to V-Block at 229 mm (L) x 102 mm (W) x 229 mm (H). The average compression strength is 2.72 N/mm^2 at the average weight of 5.83 kg. The cast was homogeneous throughout where the block dimension was almost similar to V-Block with addition to two direction bracing supports for lateral restraints. The compression capacity was the smallest of all, and it failed the code requirement in ASTM C129 -14a [32].

(a) (b) (c)

Figure 4: (a) Seer i-Block, (b) V-Block, and (c) B-Block

Conclusion

The variation of compressive strength of each individual blocks with weight shows that, different block has different weight. The weight has different compressive strength, and the higher weight, the higher the strength. The method of the compaction process during casting was determined to be the reason for weight related strength capacity. The reduction of weight related compressive strength was due to the manual control of the vibration time and pressure inserted during the block casting. Notwithstanding the block has been categorised into three types. The block units having weight between 14.0 to 14.4 kg were considered as Seer i-Block as the block was mainly concerned at with a basic average strength of 4.74 N/mm^2 and standard deviation of 1.08 N/mm^2.

For V-Block consideration, the blocks having a very modest weight higher than 4.5 kg but not less than 4.7 kg were considered to be V-Block at strength of 4.38 N/mm^2 and standard deviation of 1.03 N/mm^2. The high compressive strength of the cube strength compared to the Seer i-Block was due to the effect of the slenderness of block intermediate supports (ratio of 1.5 times more vertical support system in the block individual unit).

Another block with the weight of higher than 10.4 but not less than 12.6 kg showed 21 % variation. Yet, the block compressive strength was only 2.72 N/mm^2 and standard deviation of 3.66 N/mm^2 has been high in comparison. However, each of the casting was setup under the factory and cast under the exposed environment. Thus the quality control as mentioned in B-Block has suffered significantly bad, as the variation of standard deviation was 3 N/mm^2. The average compressive strength of the test cube to the individual block was found to be 11% to 19% only. Basically, at such a small final compression value better compressive strength has to be sought and replaced the existing method, or higher graded compression strength concrete to be used. Such an incident can be contributed from the manual casting method, or simply the aggregate that has to be complying with the ASTM-C33-03. The standard requires 2.3 to 3.1 fineness modulus. The natural sand obtained was currently averaged at1.90 fineness modulus of 17 % under achievement. The above measure was very important to control the variation in the quality of the blocks so that the results were accurate and reflective of the behaviour of block individual units at nearly similar strengths. In addition, although the block production machine was manually controlled, the quality of the blocks produced could be considered satisfactory if there was control from this level.

All the mixtures were rudimentary cast, where the mixtures of highest compressive strength supposed to be adopted for overall casting. The mixture #4 in materials testing with the highest average compressive strength at 25.45 N/mm^2 was chosen under the pretext that the strength was to withstand high compression loads. However, this does not indicate that the shape and the dimensions of the blocks had little effect on the compressive strength of the block compared to the concrete mix strength used, they did however affect the compression strength as shown in orientation of Seer i-Block > V-Block > B-Block as shown in Figure 4.

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