BEHAVIOUR OF DRY STACK CONCRETE MASONRY BLOCKS UNDER ECCENTRIC COMPRESSION

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SUMMARY

As part of a research project on dry stack concrete masonry (DSCM) walling system, a series of tests have been carried out on the concrete masonry blocks. Blocks containing one, two and three holes were tested. Three-high stack bonded prisms have primarily been tested. Three levels of eccentricities ($e = t/6$, $t/3$ and $5t/6$ where t is the gross thickness of the block in the direction of eccentricity) have been considered. This paper describes the failure and deformation behaviour of these concrete blocks under vertical and eccentric compression and the results are related to other published works where possible.

INTRODUCTION

As dry stack concrete masonry (DSCM) is assembled using interlocking concrete blocks (without any mortar either in the bed or in the perpend joints), the properties of block will have marked effect on the response of the assembly to loading (Hines (1993), Vergas(1988)). Hence the geometry, strength and stress-strain characteristics under uniform axial compression and the behaviour under eccentric compression of the blocks have been examined as part of a research on the out-of-plane response of DSCM walls.

Several researchers (Boults(1975), Grimm (1975), Drysdale and Hamid (1983), Shrive and Jessop (1987), Page and Shrive (1988), Ganesan and Ramamurthy (1992), Ramamurthy and Ganesan (1993) and Kumar(1995)) have determined the effect of geometry of blocks to the compressive strength of the prism (mortared). Only a limited work is immediately obvious for dry-stacked masonry (Drysdale and Gazzola (1991), Haztinikolas et al (1986), Vargas (1988)). Therefore, it was felt that the determination of the compressive strength of various shapes of interlocking blocks in dry stack condition was necessary. This paper describes the experimental procedure and test results of DSCM three-high stack bonded prisms.

Geometry of Interlocking Blocks

The blocks contain special interlocking tongue and groove system to lock properly when stacked vertically one above the other. Blocks are available in three sizes containing single/ double/ triple holes (Figure 1) termed as $1/3$, $2/3$ and full blocks respectively.

The face shells of the interlocking blocks are tapered more than the web shells and the cores are designed in such a way that both the web and the face shells have uniform thickness. The tongue and groove locking arrangements provide integrity to the finished product in addition to maintaining vertical alignment during construction. The geometry of the 1/3 and 2/3 blocks suits the geometry of the full block when dry-stacked one above the other by allowing for a 3 mm to 6 mm perpend gap.

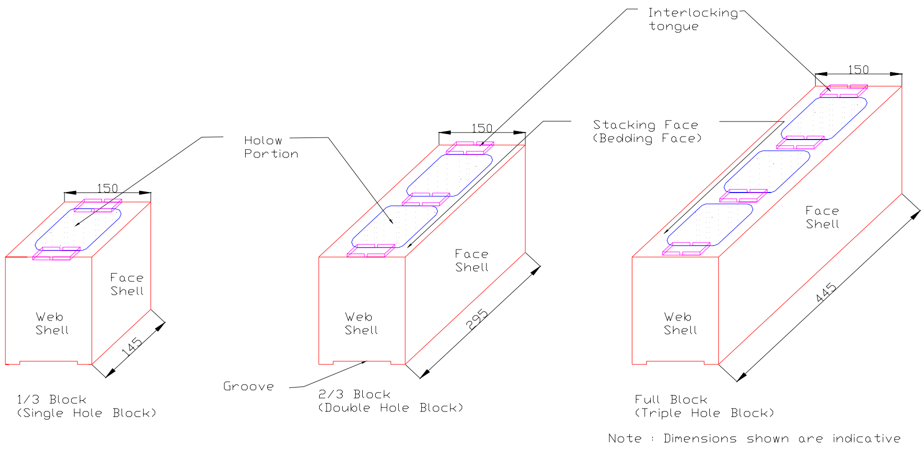

Figure 1. Geometry of Interlocking Blocks

Compressive strength of Interlocking Blocks and DSM Prism

Care must be given to the testing of brittle materials under compression, because the compressive strength of masonry units is influenced by factors such as the type of capping materials, type of the loading platen and the rate of loading in addition to the specimen size, shape, and properties of the basic materials of the block. The influence of capping materials and platen restraint to the failure of hollow masonry unit and prism is well explained by Page and Shrive (1988). Generally harder capping and patterns of higher rigidity imparts higher apparent compressive strength due to non-uniform triaxial state of stress in the bearing surfaces of the test specimens. To minimise the effects of platen restraint and to keep the test specimen under uniform stress state, friction between the platen and the specimen was minimised by the use of brush platens by Page (1981) and Dhanasekar *et al.* (1985). As brush platens are expensive option, many researchers achieve uniform compressive stress in specimens through other means (especially plywood capping) in such a way that the specimens fail due to cracking through the whole body (not just in the vicinity of bearing surfaces) with a series of cracks appearing parallel to the surface of the compression.

Testing Program

Tests were conducted on individual blocks and tri-stacked prisms subjected to axial compression using Avery compression testing machine of 1800 kN capacity. Two mild steel platens of 30 mm thick were used at top and bottom of the machines to ensure uniform distribution of load and 4 mm thick plywood capping were provided on top and bottom in between the steel platen and blocks along the face shell to account for the unevenness surface of the specimen. Care was taken to align the centre of the spherical head of the Avery

compression machine with the centre of the specimen to avoid accidental eccentricity. After placing the specimen in position, the spherical head of the testing machine was lowered and positioned to contact with the steel platen. The blocks were loaded on the face shell under uniform axial compression and the typical failure mode is shown in Figure 2.

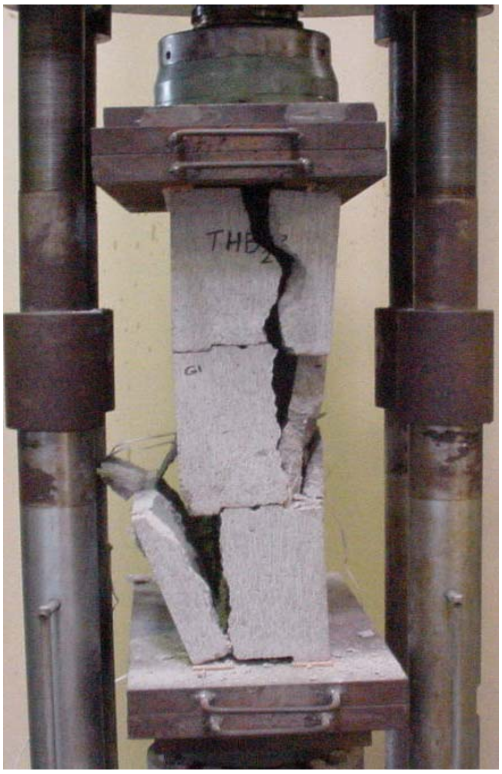

Figure 2. Failure of Tri-stacked Prism under Axial Compression

For all tri-stacked prisms, the deformation of the middle block was also determined in addition to the strength. Two strain gauge rosettes on both sides of the prism were affixed to the mid-surface of the face shells of the middle block and the corresponding strains were averaged out. In all tests the load was applied at a rate of 90 kN /min.

Modes of Failure

From the mode of failure observed, it was concluded that the dry stack prisms failed due to the generally accepted theory of deep beam action of web shell splitting induced collapse (Shrive, 1982). The failure of face shell bedded prisms was initiated by developing vertical cracks at the header face followed by minor cracks at the stretcher face near end webs. The loaded face shells appeared to have acted as a deep beam spanning between the stretcher faces and bending action developed cracking due to larger tensile stress concentration at the ends of central and end webs. The dry stack prism strength is therefore regarded as a good representative of the actual strength of blocks. Attempt to test individual blocks using the same platens did not eliminate corner crushing mode indicating uneven stress distribution and hence the results were disregarded.

Test Results

The tri-stacked prisms made from $1/3$, $2/3$ and full blocks were of 145mm, 295mm and 445mm long respectively. All prisms, however, were of 150mm thick and 600mm high providing a height-to-thickness ratio of 4.0. The mean compressive strengths of dry-stacked prisms were 35.0MPa, 29.0MPa and 28.0MPa respectively (based on average face shell thickness that was taken as 27mm). The corresponding coefficients of variation were 1.5%, 3.4% and 5.7% respectively. This shows that under uniform compression the single hole blocks (1/3 blocks) are the strongest and least variable in quality whilst the full blocks are the weakest with higher variability. In spite of this observation, even the highest variability is much lower than 10%, which is consider to be an acceptable norm for masonry materials. From the results it could be concluded that the $1/3$ blocks exhibit higher strength compared to $2/3$ and full blocks. The strength of $2/3$ and full blocks is not significantly different and hence are grouped as “lesser strength group” as compared to $1/3$ blocks, which are “higher strength group”.

Stress-strain relationship

Strain rosettes were affixed on opposite sides of the mid block to record the longitudinal and lateral strains with a view to eliminating any unintended eccentricity. The compressive stress is plotted against the lateral and axial strains for 1/3 block (SHB), 2/3 block (DHB) and full block (THB) prism series as presented in Figure 3.

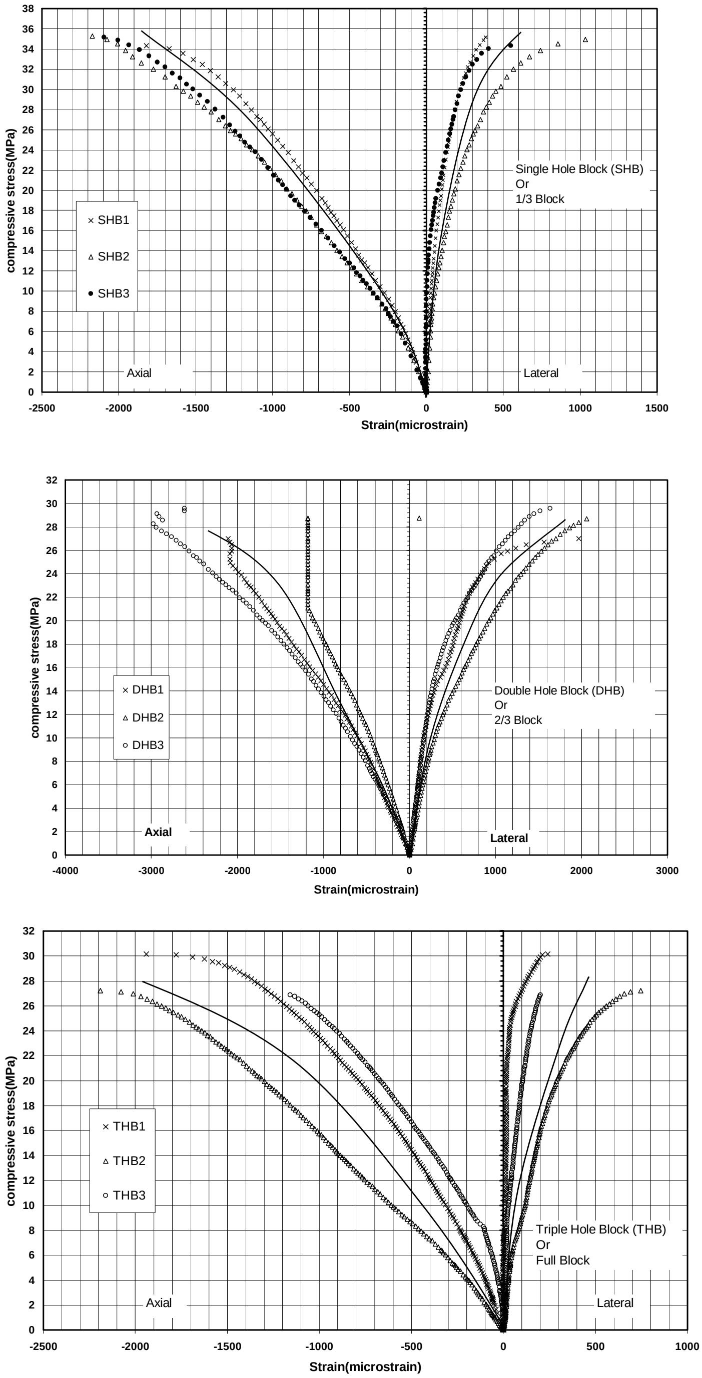

Figure 3. Stress-Strain Curves of Concrete Block in Tri-stacked DSCM Prisms Subjected to Axial Compression

The maximum and yield stresses and the corresponding strains were calculated from the average curve of each series and are presented in Table 1. Elastic properties (E and υ) were also determined.

Table 1. Test results for prisms-Uniform compression

Specimen Designation	Stress (MPa)		Strain (microstrain)		E (GPa)	Poisson's ratio υ
	Max	Yield	Max	Yield		
SHB series	35.0	18.0	1800	800	33.3	0.22
DHB series	29.0	17.0	2100	1150	20.0	0.20
THB series	28.0	16.0	1950	825	22.9	0.15

From the test results it was observed that the modulus of elasticity of 1/3 block is relatively higher than that of other blocks, perhaps due to the geometry of the 1/3 blocks (a good compact cell structure).

Eccentric Compressive strength of Tri-stacked Prism

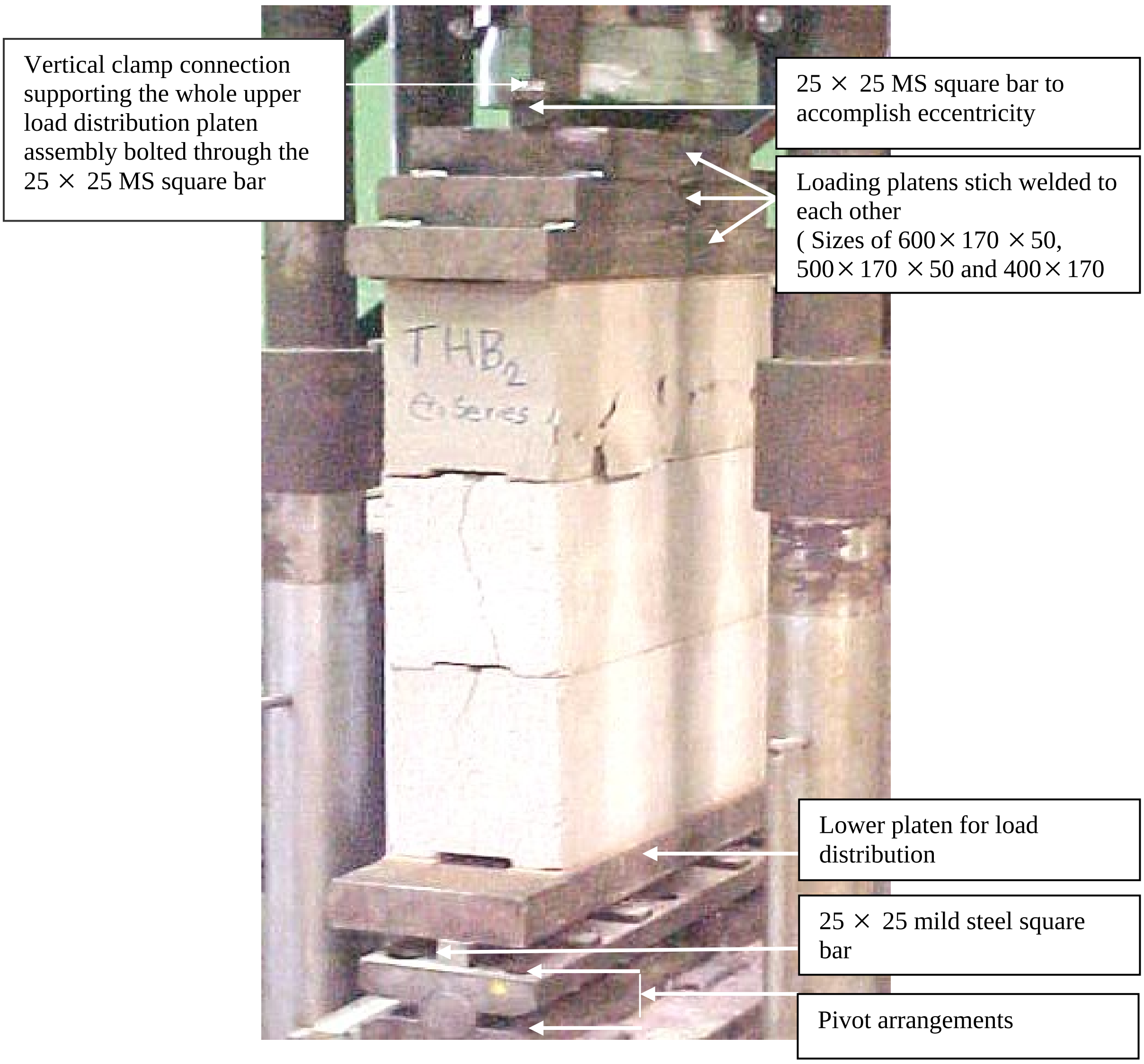

Figure 4. Loading Platens for Eccentric Compression

Tests were carried out on three high stack bonded dry-stacked prisms consisted of $1/3$ blocks, $2/3$ blocks and full blocks subjected to compression with varying eccentricity. Universal compression testing machine of 1800 kN capacity was used and a special loading platen (Figure 4) was fabricated for this purpose. The platen contains a special hinge arrangement to accomplish the eccentric loading. Similar tests were carried out by Shrive (1982), Drysdale and Hamid (1983), Hatzinikolas *et al.* (1991), Anand and Ramamurthy (2000) and Kumar (1995).

Testing Program

The projected nibs of the blocks in top course were smoothened to enable proper application of the compressive loading along the face shell. A 4 mm thick plywood capping was provided along the face shells both at the top and at the bottom. The alignment of the end faces and side faces was examined carefully prior to loading. As the thickness *t* of blocks (and hence that of the prisms) remained constant 150mm for 1/3, 2/3 and full block series, the eccentricities ($e_1 = t/6$; $e_2 = t/3$; $e_3 = 5t/12$) were 25mm, 50mm and 62.5mm respectively.

Failure modes

The first crack initiated approximately at 30% of the ultimate load along the face shell followed by web splitting, face shell shear failure and some local crushing of blocks. The typical failure for e_1 series is shown in Figure 5.

Figure 5. Failure of DSCM prisms under eccentric loading - e_1 series

Drysdale and Hamid (1983) reported similar failure of splitting of block for grouted prisms. The spalling of compression face for e_3 series of their grouted samples was similar to that of

the failure observed in our test. Hatzinikolas *et al.* (1991) reported that the mode of failure changed from crushing to splitting while the load was applied at an eccentricity of $t/20$ on a five course high concrete wall. In the current testing, tilting of specimens in addition to the shear failure and web splitting were observed for e_2 series and only tilting effect was observed in e_3 series as shown in Figure 6.

Figure 6. Testing of DSCM Prisms in e_2 series and e_3 series

Test Results

The test results for all the 1/3, 2/3 and full block prisms under eccentric compression are presented in Table 2. The mean strength at different eccentricities t/6, t/3 and 5t/12 calculated by dividing the ultimate load by the area of the face shell at mid-high irrespective of the rotations of individual blocks in response to load eccentricity and the ratio of the mean strength under eccentric compression to the corresponding strength under uniform compression are shown in the table.

The strength ratios are plotted against the eccentricity (e) in Figure 7. The reduction in strength ratio with the increase in eccentricity (e) is obvious for all block types. However, the rate of strength ratio reduction in full block is much lesser than that of the 1/3 and 2/3 blocks (both 1/3 and 2/3 blocks exhibit similar trend in reduction of strength ratio with the increase in eccentricity.

Table 2. Strength of prisms under Eccentric loading

Block Type	Strength								
	$e = t/6$ = 25mm			$e = t/3$ = 50mm			$e = 5t/12$ = 62.5mm		
	Mean (MPa)	COV (%)	Eccentric / Uniform	Mean (MPa)	COV (%)	Eccentric / Uniform	Mean (MPa)	COV (%)	Eccentric / Uniform
1/3 Block	29	6	0.82	18	9	0.52	10	2	0.27
2/3 Block	26	5	0.89	20	4	0.68	15	6	0.53
Full Block	18	5	0.64	16	5	0.57	11	**7**	0.39

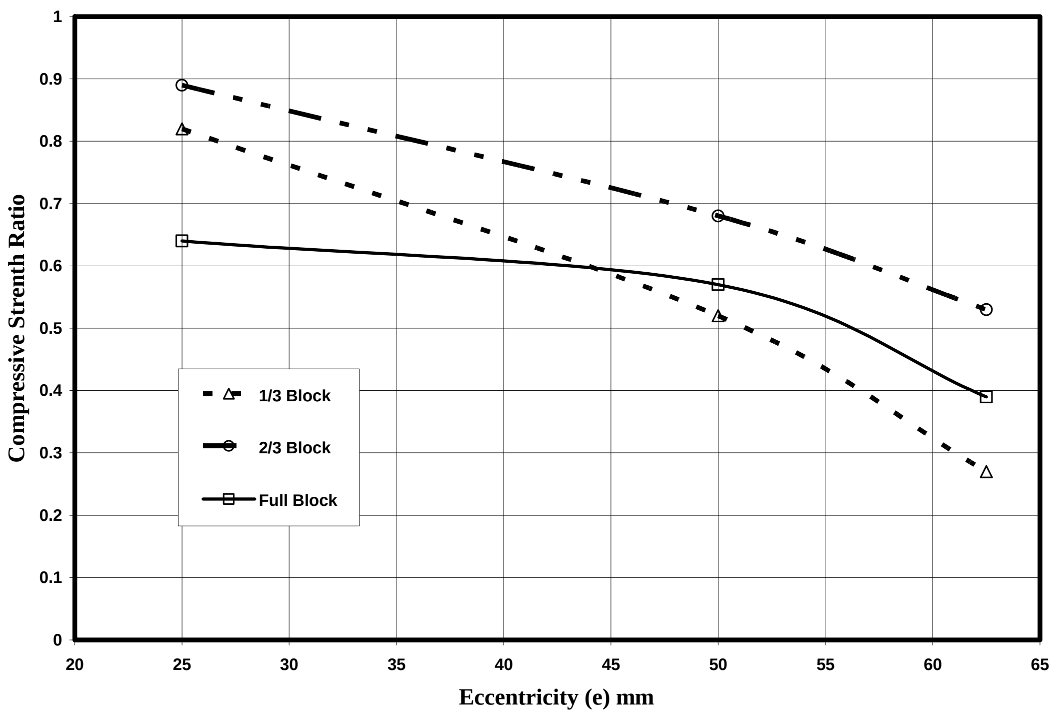

Figure 7. Effect of Eccentricity in Loading to Compressive Strength Ratio

From the data presented in Table 2 and Figure 7 it could be inferred that even small eccentricity affects the strength of full blocks seriously (36% strength reduction for an eccentricity of t/6). However at higher (e/t) ratios the strength reduction of full block prism is comparable to that of the other prisms. Although the full block prisms and 2/3 block prisms exhibited similar strength under axial compression (29.0MPa and 28.0MPa respectively), their behaviour under eccentric compression was markedly different, presumably due to the geometric compactness of the plan view. The 2/3 block has suffered the smallest reduction in strength due to eccentricity for all three eccentricities tested.

The 1/3 block, on the other hand, having possessed the highest strength amongst the three block types, have exhibited the highest rate of reduction in strength due to eccentricity. From these results it is clear that the geometric configuration has significant influence to strength reduction due to eccentricity in loading. Similar conclusions are found in the literature (Shrive (1982), Drysdale and Gazzola (1991), Hatzinikolas *et al.* (1991), Ramamurthy and Ganesan (1993), Kumar (1995) and Anand and Ramamurthy (2000)). It is also possible to optimise the geometry of blocks so that the *strength reduction rate* is minimised. Such an attempt was made by Anand and Ramamurthy (2000) although the shapes of the blocks at times lost symmetry in their theoretical study.

SUMMARY AND CONCLUSIONS

This paper has reported the experimental procedure, data and limited analysis of the properties of the blocks used in the DSCM system. The blocks were tested under direct and eccentric compression in a three-block high prism (dry-stacked) configuration.

Three types of blocks were tested – single holed, double holed and triple holed configurations termed as (1/3) block, (2/3) block and full block respectively. From the experiments the following observations were made:

1. Single holed (1/3) blocks have exhibited the highest strength (35.0MPa) and stiffness (Young's Modulus, E = 33.3GPa) properties.

2. Double holed (2/3) and triple holed (full) blocks have exhibited similar strength (29.0MPa and 28.0MPa respectively) and stiffness (20.0GPa and 22.9GPa respectively) properties.

3. The Poisson's ratio of the three types of blocks varied from 0.15 to 0.22.

4. Eccentricity in compression adversely affected the strength properties of all three types of blocks.

5. Under small eccentricity ($e = t/6$) the full block suffered significant (36%) loss of strength; other configurations have exhibited 18% and 11% reduction in strength .

6. Rate of reduction in strength is the most sensitive to increase in eccentricity for the single holed (1/3) blocks and the least sensitive to increase in eccentricity for the full blocks. The 2/3 block prisms exhibited the least reduction in strength due to eccentricity in loading for all three eccentricities tested in the program.

7. From the results presented in this paper, it is clear that the geometric configuration of the plan views of the prisms – the compactness or otherwise - significantly influence the rate and quantum of strength reduction due to eccentricity in loading. It is therefore possible to optimise the geometry of blocks so that the *strength reduction rate* is minimised. Further work in this area would be of interest.

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