Some Factors Affecting the Compressive Behaviour of Structural Masonry at Small Scales

A. Mohammed and T. G. Hughes

***Abstract*—**This paper presents part of a research into the small scale modelling of masonry. Small scale testing of masonry has been carried out by many authors, but few have attempted a systematic determination of the parameters that affect masonry at a small scale. The effect of increasing mortar strength and different sand gradings under compression were investigated. The results show masonry strength at small scale is influenced by increasing mortar strength and different sand gradings.

***Keywords*—**Compression, masonry, models, mortar, sand gradings

I. Introduction

A research programme undertaken using a geotechnical centrifuge on sixth and twelfth scale masonry arch bridges as well as various other model studies on masonry-infilled frames, walls and other masonry components and structures has necessitated further investigation into the small scale experimental and structural behavior of masonry. Small scale masonry model testing has been carried out for many decades. Early researchers in this area include [1-3]. Most of these tests have established that it is possible to model masonry behavior at reduced scales but not the strength and stiffness, this has also been reported by [4-6]. The first phase of this research programme has also established good prototype and model scale (half, fourth and sixth) correspondence under compressive stress obtained by normalising their masonry compressive strength with respect to their respective unit strengths [7]. The higher masonry strength in the smallest model scales was attributed to the higher unit strengths in the fourth and sixth scales due to size effect phenomenon [8]. However no size effect was observed between prototype and half scales masonry compressive strengths [9]. Historically the value in scale models lies in being able to predict the behavior of a prototype from the scale model. Presently small models are usually used to validate numerical models which will then be used to predict the structural behavior of whole structures like model arch bridges and buildings.

However for a researcher to be able to predict this with some degree of confidence, knowledge is required of the effect of size or scale on the model material on one hand and the extent to which parametric effects can be investigated at reduced scales on the other.

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This becomes more important in the case of composites like masonry where the constituent brick and mortar have different properties. But this depends to a large extent on the parameters that influence the mortar bed which could be modelled at small scale.

The aim of this paper is to determine the effects of some parameters that affect mortar like grading of aggregate and mortar strength on the sixth scale model brickwork behavior while under compression, in order to identify through the investigations the challenges related to parametric studies of small scale masonry modelling. This is necessary in order to accurately model the behaviour of large masonry structures like bridges at small scale, and also to serve as a basis of validating numerical model studies of these large structures.

The parameters under investigation are sand grading and mortar strength. These parameters are all related to the properties of the mortar bed, because it is the bed that ensures a good composite action between the units and the mortar. The importance of the mortar bed in determining the strength characteristics of the composite has been reported by various authors including [10] who found that the compressive strength and deformation of stack bonded masonry specimens were influenced primarily by the mortar, but that was not the limiting failure criteria. They concluded that even though failure of the masonry was as a result of the lateral tensile strength of the unit, it is the mortar that induces the tensile stresses.

II. Materials And Methods

A. Materials

Solid prototype bricks of standard UK size (215 x 102.5 x 65mm) were used for producing the model bricks of approximately 35.8 x 17.1 x 10.8mm. The bricks were cut from the prototype by using an adapted sawing machine in the laboratory. The method has been used by other researchers [11, 12] to produce various model bricks of different scales and sizes. This method of model brick manufacture does not have the disadvantage of kiln fired model brick manufacture, which usually leaves the model bricks burnt sometimes with a slight curvature. Some mechanical properties of the bricks are presented in Table 1.

Congleton HST 60 and 95 sands were used for making the cement-lime mortar. HST 95 was used to make the benchmark mortar (a reference mortar of designation iii; BS 5268[13]), it is the finer of the two sands as it can be seen in Fig. 1, which shows the grading of the two sands in relation to the grading limits of BS EN 13139:2002[14]. In all, three mortar designations were used, namely; ii, iii and iv to determine the effect of increasing mortar strength for mortars made with each of the two sands. This resulted in six mortar types namely; M95ii, M95iii, M95iv, M60ii, M60iii and M60iv. The joint thickness adopted for all test specimens is 1.6mm, obtained by dividing a prototype joint thickness of 10mm by 6**.** Some mechanical properties of the mortars are shown in Table 2.

B. Specimen preparation

The bricks were first pre-wetted by totally immersing in a water tank for 20 minutes before laying them on their sides in a horizontal position as is usually done in prefabricated masonry panels. Pre wetting of the units was necessary so as to condition the suction properties of the units in order to achieve a good bond between the units and mortar bed. The horizontal method of construction was employed for both the prototype and models, in order to achieve a repeatable and controllable way of making the specimens since the traditional laying method is amenable to significant workmanship variations that could mask the structural behavior of brickwork. This point has also been made by Baker [15], who employed a similar method in the manufacture of panels for wind loading tests. The bricks were separated by tile spacers of the desired mortar bed joint thickness of 1.6mm..

C. Masonry Tests

The compressive strength tests on the model brickwork were performed on three units' high stack bonded specimens commonly termed as triplets. The test was undertaken in displacement control at a rate of 0.06mm/min. Deformation measurements for the determination of the stiffness of the specimens were measured with Model Masonry Clip Gauge's (MMCG) [5], which were fixed to both faces of the triplets. The stiffness, E_i of an individual masonry specimen was evaluated as a secant modulus from the mean of two measuring positions, occurring at a stress equal to one third of the maximum stress reached according to the provisions of BS EN 1052-1[16].

III. Results And Discussions

A. M95 mortar designation ii, iii and iv

The failure of specimens in this test corresponds with the observed and established tensile cracking patterns along the direction of load application as seen from prototype specimens. These tensile splitting cracks run across the bed joints and through the masonry units. The summary of the test results are shown in Fig. 2 and Table 3. From the results it is seen that that there is an increase in masonry strength as the mortar strength is increased. There is about an 11% strength increase from designation iii to designation ii, and a 20% increase from designation iv to iii. This is also true for other tests conducted at different model scales, as detailed by [4]. (Vogt, H. 1956) has also reported increasing masonry strength with increase in mortar strength for fourth scale model masonry tests. The reason for the increase in masonry strength is because, as the mortar becomes stiffer with increasing strength (increasing cement content) which therefore implies that more force is needed to create the frictional forces that induce the tensile stresses that cause failure in the units and ultimately the masonry

B. M60 mortar designation ii, iii and iv

The failure mode here was also characterized by the usual vertical tensile splitting cracks. The results for the M60 mortar tests from Fig. 3 and Table 3, show that, as in the case of the previous test, there is a clear trend of an increase in the masonry strength as the mortar strength is increased. In this case there is about an 8% increase from designation iii to designation ii mortar and about an 18% increase from designation iv to designation iii mortar. The percentage increase in this case from one designation to the other also agrees with those from the M95 tests, an indication that it is possible to use a sixth scale masonry model to look at the effects of increasing mortar strength.

C. Sand grading

The combined plot for the variation of masonry strength with mortar strength for both M95 and M60 tests is also shown in Fig. 4. It is seen that the trend line for the M95 test is steeper than that for the M60 test. This could imply that the M95 tests are more receptive to changes in cement content because the sand grading is finer than in the M60 tests. Another interesting point from the plot is that even though the M60 mortars are stronger than the M95 mortars in all three designations; the masonry strength is still stronger for the triplets made with M95 mortar. This may be because as the mortar bed is compressed, tensile stresses are induced in the unit because of their different stiffness properties. But since these stresses are initiated by the friction at the mortar-brick interface, it could be that a mortar with coarser sand grading might develop a higher friction than a mortar with finer sand grading, and consequently result in a lower failure stress in the unit.

D. Stiffness

The stiffness results for M95 mortar shown in Fig. 5 also reveals that masonry stiffness increases with increasing mortar strength which corresponds with the trend seen in the results of masonry strength against increasing mortar strength. The mean stiffness of the designation iii triplet was determined to be 6000 N/mm^2, while the mean stiffness for the triplets with designation ii mortar was 53% more.

IV. Conclusions

The results show that in the case of the compressive strength tests, masonry strength was observed to increase with increasing mortar strength. Significantly it was also observed that, even though the M60 mortar strengths were higher, the M95 masonry tests gave higher results.

Overall, the results suggest that small masonry models like the sixth scale here could be used to investigate parametric effects on masonry strengths like the effect of variation in mortar strength and different sand gradings. This will be useful in the validation of masonry data for computer modelling of large masonry structures like bridges.

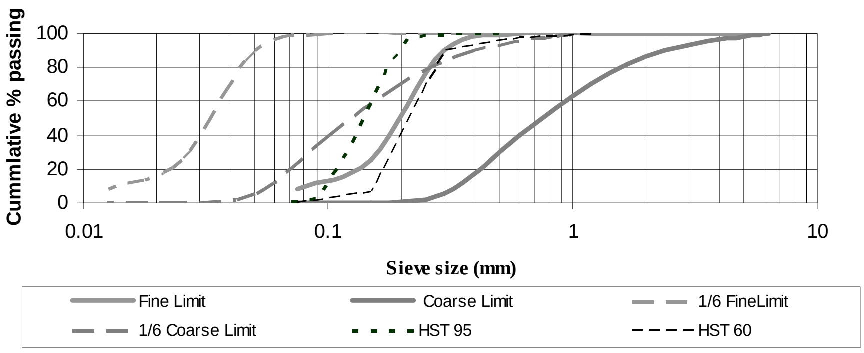

Fig. 1 Grading curves for prototype and model sands within the BS limits

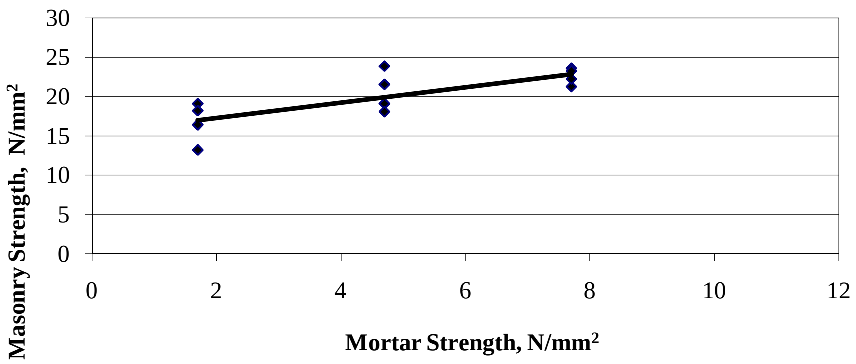

Fig. 2 Variation of masonry compressive strength with M95 mortar strength

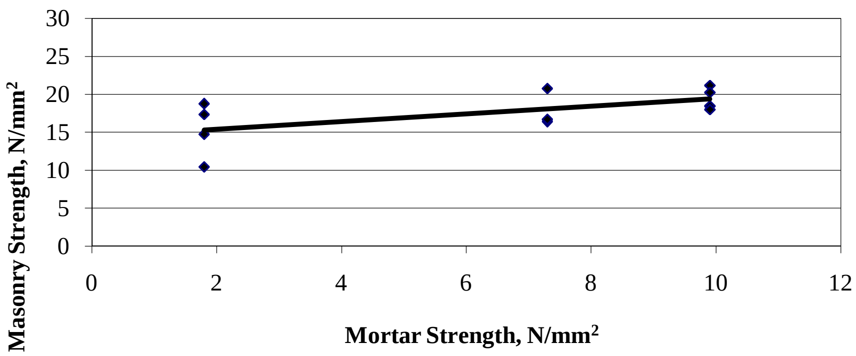

Fig. 3 Variation of masonry compressive strength with M60 mortar strength

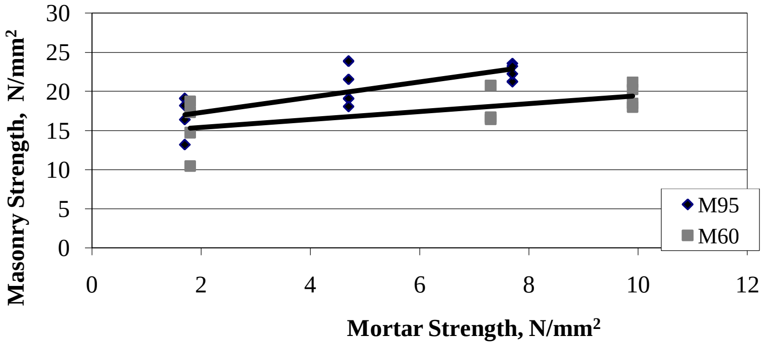

Fig. 4 Variation of masonry compressive strength with different sand grading of mortar

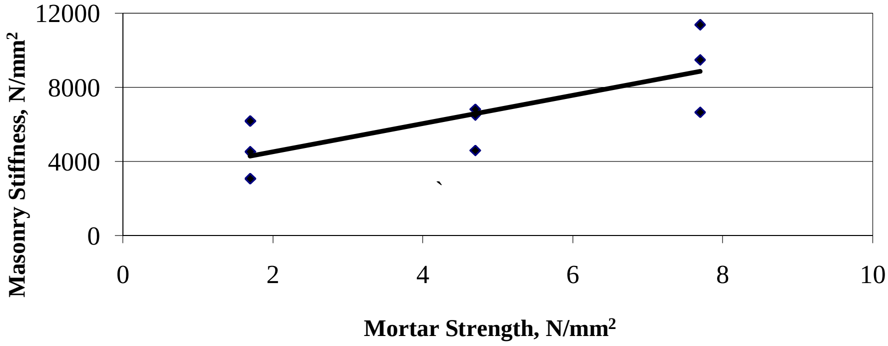

Fig. 5 Variation of masonry stiffness with mortar strength for M95 mortar test

TABLE I
PROPERTIES OF SIXTH SCALE MODEL BRICKS

Test	
Compressive Strength, N/mm^2	47.4
COV, %	32.7
Flexural Strength, N/mm^2	4.4
COV, %	24.8
Indirent tensile strength, N/mm^2	2.4
COV, %	22.5
Water Absorption, %	16.3
COV, %	16.7

TABLE II
PROPERTIES OF MODEL MORTARS (COV IN BRACKETS)

	HST95ii	HST95iii	HST95iv	HST60ii	HST60iii	HST60iv
Mortar Designation	ii	iii	iv	ii	iii	iv
Vol. Proportions	1 : 1/2 : 4	1 : 1 : 6	1 : 2 : 9	1 : 1/2 : 4	1 : 1 : 6	1 : 2 : 9
W/c ratio	1.25	1.8	2.58	1.11	1.41	2.20
Modulus of Elasticity,	12900(7.9)	6500(8.7)	4500(12.7)	17000(2.96)	12500(5.22)	6800(5.51)

TABLE III
SUMMARY OF MASONRY COMPRESSIVE STRENGTH TEST RESULTS

Test No	Mortar Type	Joint thickness mm	Compressive Strength, N/mm^2	COV %	Stiffness N/mm^2	COV %	Mortar Cube Strength, N/mm^2
1	M95-iii	1.6	20.3	26.2	6000	20.1	4.7
2	M95-ii	"	22.6	4.6	9200	34.3	7.7
3	M95-iv	"	16.7	15.5	4600	33.8	1.7
4	M60-iii	"	18.0	13.6	-	-	7.3
5	M60-ii	"	19.5	7.7	-	-	9.9
6	M60-iv	"	15.3	23.8	-	-	1.8

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