THE INFLUENCE OF MORTAR TYPE ON THE FLEXURAL STRENGTH OF MASONRY

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ABSTRACT: Masonry wallettes of the type prescribed in the UK Code of Practice for Structural Masonry have been used to study the effect of the mortar composition on the flexural strength of brickwork and blockwork.

Three types of mortar have been compared: lime plasticised cement-sand mortar; aerated cement-sand mortar, and masonry cement-sand mortar.

Additionally, three cement contents have been used equivalent to that in 1:¼:3,, 1:1:6 and 1:2:9 cement:lime:sand mixes by volume.

All measurements were made after 28 days storage in the laboratory. To give a reasonable range of suction states three bricks were used; a perforated wire cut with an intermediate water absorption (WA) of 76% and a low initial rate of absorption (IRA) of 0.53 $kg/m^2/min$, a perforated wire cut with a WA of 8.9% and an IRA of 0.99 $kg/m^2/min$ and a semi-dry pressed brick with a high WA and IRA. Additionally the high absorption brick was laid in three states: as received/standard consistence mortar, dipped in water/standard consistence mortar and as received/mortar consistency adjusted. To complete the picture a range of three types of concrete block was also included.

No mortar type stood out as either suitable for all uses or unusable and, taken overall, mortars complying with the Code prescriptions gave adequate flexural strength. Taken individually the lime mortars gave the best performance overall but were subject to inexplicable isolated lapses in performance. The masonry cement mortars performed less well overall but with no lapses. The plasticised mortars gave the worst performance overall but may have performed better if the higher cement content option in the Code had been used to bring their strength up to the prescribed levels.

1. INTRODUCTION

The UK Code of Practice for the Structural use of Masonry BS5628, Part 1, has had a section dealing with the design of panels for lateral (wind) loads since publication in 1978. The main basis of both the method of design and of the characteristic strength values ascribed to the various forms of brick masonry was a large body of test work on storey-height walls and associated wallettes reported by West et al[2]. This work covered a wide range of types of clay brick and the three common mortar designations as material variables. There was also a limited study of different edge support condition although most of the work was on a standardised 3-sided support condition.

Characteristic strengths were derived statistically from the results obtained by testing wallettes in the two orthogonal directions such as to give failure either across the bed joint (weaker vertical spanning direction) or across the perpend joint (stronger horizontal spanning direction). The wallette testing method is described in reference 2. In a companion paper[3] Haseltine et al give a design method based on the yield line principle which relates the load

resistance of storey-height brickwork panels to the characteristic strengths derived from wallette tests.

Since this and other contemporary work by Hendry[4], Anderson[5] and Lawrence[6], the database for other materials has been extended, eg for sand:lime bricks[7] and concrete blocks[8].

Throughout this work, however, only one generic type of mortar was used - the lime-plasticised cement:sand mortar. This was used at three designations: (i) 1:¼:3; (iii) 1:1:6; (iv) 1:2:9 cement:lime:sand by volume. In all the UK Codes of Practice however, three generic types of mortar are allowed:

Type 1. Cement:lime:sand plasticised by the presence of the hydrated lime.

Type 2. Cement:sand plasticised by use of air entraining admixtures.

Type 3. Masonry cement:sand plasticised partly by incorporation of inert fine material with the cement and partly by air entrainment.

Table 1 of BS5628, reproduced as Table 1 here, gives a range of prescribed mixes based on the three formulations which have been found to be equivalent in respect of the resultant compressive strength of masonry. There are, however, a number of reasons why such mortars may not be wholly equivalent in respect of the resultant lateral strength of masonry.

One of the main differences is that of water retentivity. Ryder[9] in some early work demonstrated that the lower water retentivity of aerated cement:sand mortars can reduce the perpend joint strength of wallettes made with high suction bricks to very low values.

The work described here was therefore carried out to check the assumption that the alternative mortar types still would give equally safe structures when substituted for the more tried and tested lime mortars in laterally loaded panels of masonry.

2. EXPERIMENTAL METHOD

The apparatus and specimen formats are described in reference 2 and are also specified in BS5628:Part 1:1978, Appendix A3. Throughout this series of experiments wallettes were built in accordance with Appendix A3 and stored, close covered with polythene, for 28 days until test. Samples of the mortar used for the tests were cast into 100 mm cubes and tested for strength in accordance with BS4551[10]. Throughout the work five replicate specimens were used for each test condition.

3. EXPERIMENTAL PROGRAMME

The main experiment was carried out with clay brick masonry. The three types of mortar were all used at two Code designations: (iii) and (iv).

Designation (i) mortar is only allowed under the Code to be in the composition range 1:3 cement:sand to 1:¼:3 cement:lime:sand but as an experiment a plasticised 1:3 cement:sand mix was tested. In view of the uncertain composition of masonry cement an 'equivalent' designation (i) masonry cement mix was not included. The composition and measured properties of the mortars are given in Table 2. Three bricks were used which are listed in Table 3 together with their key properties. The high absorption (Fletton) brick was additionally used in three ways:

1. As received with normal mortar.

2. Dipped in water and drained such as to reduce the initial rate of absorption to approximately 1.

3. As received but laid with mortar with a higher water cement ratio and an admixture to increase the water retentivity.

Wallettes were made for both bed joint and perpend joint strength measurements.

Thus the complete design was five bricks or states versus three mortar designation versus three mortar types versus two orientations with a missing data-block for designation (i) Type 3 mortar. Since the two orientations are so widely different in strength they were analysed separately using 3-way analysis of variance for the other three factors.

A supplementary experiment was carried out using three types of concrete block, two mortar designations (ii) and (iv) and the two non-lime mortars only. The results of a previous experiment using lime mortar are, however, reported.

All the specimens were built and tested at the laboratories of the British Ceramic Research Association under contract to the Building Research Establishment.

4. RESULTS AND DISCUSSION

The results of the brick wallette tests are given in Tables 4 and 5 for, respectively, bed joint and perpend joint specimens. The results of the block wallette specimens are given in Table 6 for the two non-lime mortars together with results of previous tests of the same block types using lime mortars. Unfortunately, except for the lightweight aggregate blocks, the lime mortar results are clearly very different due to the use of completely separate batches of what were nominally similar blocks. For this reason these results are not included in the analyses of variance as they would introduce a further non-distinguishable variable (block batch) into the analyses. Strength and additional data for the mortar used for the block wallettes is given in Table 2.

The results of analyses of variance are given in Table 7 for all the work. Those for the bricks were complicated because of the missing set for masonry cement mortar designation (i) and have been done in four forms:

1. All bricks, all mortar types but only designations (iii) and (iv).

2. All bricks, lime/aerated mortar, all designations.

3. Absorptive bricks only, all mortar types, designations (iii) and (iv).

4. Absorptive bricks only, lime/aerated mortar, all designations.

In all these cases replicated three way analysis was used.

It should be noted that there were a number of apparently anomalous results both for individual values and for some sets of five and these have made it difficult to clarify the trends.

4.1 Mortar

Although made carefully using a sand complying with the grading requirements of BS1200[11] and ordinary Portland cement to BS12[12], the mortars did not reach the strength indicated in Table 1 for laboratory trials and in some cases failed even to reach the site strength. This was particularly evident for the plasticised cement:sand mixes where 9 out of a total of 15 mixes failed to reach site strength with the two stronger designations performing the worst. For the lime and masonry cement mixes the numbers failing to reach strength were 3 out of 18 and 3 out of 10 respectively. Even discounting the non-Code 1:3 mix the plasticised mortar performed worst giving 5 'failures' out of 10 mixes.

The Code embodies a relationship between masonry flexural strength and mortar designation which, to some extent, implies a correlation with mortar strength. This relationship was investigated for these results and found to be statistically significant for the bed-joint results (see Figure 1) assuming a linear regression but not for the perpend joint results. No attempt was made to allow for the different brick types in the regression given in Figure 1. Thus, the lower cube strengths of the plasticised mortars may explain the lower flexural strength of the brickwork. Higher cement contents might correct this shortcoming.

4.2 Bricks

The overall result was that there was no significant effect due to the type of mortar on the perpend joint strength which was encouraging although there were quite strong interactions of mortar type with designation and to a lesser extent with brick type/state. For the absorptive brick alone the interactions with brick state were fairly weak but there was some effect of type and an interaction with designation.

The bed joint specimens showed a much greater effect due to mortar type giving statistically significant effects for both the main variable and the interactions with designation and brick type. This is as would be expected since the bed joint strength is wholly dependent on mortar/brick interaction and should be very sensitive to the strength and bond of the mortar. Surprisingly, however, the experiment indicated very little effect of the state of the absorptive unit on the strength and no interaction of this variable with the type of mortar effect.

Generally the results obtained were reasonable but it was difficult to obtain a general picture from the variance analyses because of the overall variability and occasional apparently anomalous results.

In order to answer the basic question posed in the Introduction 'Are the mortars all equally satisfactory when used in accordance with the Code?' a simpler form of analysis was adopted. Each strength value in the Table (Sobs) was divided by the characteristic strength for the appropriate brick/mortar combination given in Table 1 of the Code (fkx) to give a ratio. As a general rule ratios of Sobs/fkx equal to or greater than one indicate satisfactory performance and those less than one are unsatisfactory. The Code fkx is however a confidence limit based on the 95% probability level and therefore it is reasonable to expect some values less than one in any population of measurements. Thus a Chi-squared test was applied to each group of results with the null hypothesis that for a satisfactory performance the expected fraction of ratio values (Sobs/fkx) would be 0.95 equal to or greater than one and 0.05 less than one.

The results of the Chi-squared analysis are given in Table 8 for each set of five results and also grouped results by brick mortar designation and overall for mortar type.

Since the ratio is very close to 1:0 groups containing no ratios under one do not give a significant result and all significant results are those which fail the null hypothesis in having a significant number of occurrences of the ratio less than one, ie unsatisfactory. Apart from two inconsistent sets made with lime mortar, the only unsatisfactory sets are from among the plasticised cement:sand mixes, ie designation (i) bed and perpend joint and designation (iii) bed joint only. The groupings by designation, brick type and overall for mortar type only reflect the results of the individual sets, ie indicate that plasticised cement:sand mixes and designation (i) mixes were giving problems and particularly that designation (i) plasticised cement:sand mixes were consistently under-performing.

4.3 Blocks

The analyses of variance in Table 7 only apply to the two non-lime mortars and so give less useful information. Surprisingly the mortar type was only significant for the perpend joint specimens and despite very strong main effects (unit and designation) the interaction with mortar type are weak or non-existent.

Applying again the Chi-squared analysis technique it becomes obvious that most of the unsatisfactory sets of results are those obtained using the aerated concrete blocks with non-lime mortars. (The Chi-squared test can validly be applied to the lime mortar results as a group). Under-performance of aerated blocks has been noted previously in reference 6 and upon investigation it was concluded that the existing test method (as used in the present study) was unfair to this class of unit. Some amendments to the test method have since been proposed. Again the plasticised cement:sand mixes seem to have under-performed in comparison to the others but only marginally.

5. CONCLUSIONS

Taken overall there was a reasonable degree of equivalence between the three types of mortar studied in respect of the flexural strength of both the resultant clay brickwork and concrete blockwork.

Leaving aside a few isolated sets and the aerated concrete block results, designation (iv) mortars of any type gave satisfactory results overall and designation (iii) mortars gave satisfactory values for all the block specimens and for perpend joint brick specimens but under-performed to a small extent in the plasticised cement:sand/brick/bed-joint specimens.

The results support the Code Prohibition of the use of plasticising agents for making designation (i) mortars in respect of masonry designed to resist lateral loads and indicate that vertically spanning masonry using such mortar could be seriously deficient. It would be difficult to deduce from the results a preferred method of dealing with high absorption bricks from the three methods used, ie (1) laid dry, (2) docked and (3) laid in mortar with a higher water content and a water retention admixture. It would appear that a satisfactory performance should be possible using any of the approaches and any type of mortar provided the mortar is of the appropriate consistency.

Masonry cement mortars performed adequately and it must be concluded that reports of poor performance from site experience must generally be due to misuse, eg proportioning of mixes as though it were straight Portland cement.

The use of the higher cement content options in the Code for the non-lime mortars would probably improve their overall performance.

6. ACKNOWLEDGMENT

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7. REFERENCES

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(12) BS12:1978. "Ordinary and rapid hardening Portland Cement".

Table 1. Requirements for mortar

	Mortar designation	Type of mortar (proportion by volume)			Mean compressive strength at 28 days	
		Cement : lime : sand	Masonry cement : sand	Cement : sand with plasticizer	Preliminary (laboratory) tests	Site tests
↑ Increasing strength / Increasing ability to accommodate movement, e.g. due to settlement, temperature and moisture changes ↓					N/mm^2	N/mm^2
	(i)	1 : 0 to ¼ : 3	–	–	16.0	11.0
	(ii)	1 : ½ : 4 to 4½	1 : 2½ to 3½	1 : 3 to 4	6.5	4.5
	(iii)	1 : 1 : 5 to 6	1 : 4 to 5	1 : 5 to 6	3.6	2.5
	(iv)	1 : 2 : 8 to 9	1 : 5½ to 6½	1 : 7 to 8	1.5	1.0
Direction of change in properties is shown by the arrows		Increasing resistance to frost attack during construction → Improvement in bond and consequent resistance to rain penetration ←				

TABLE 2: VOLUME PROPORTIONS AND PROPERTIES OF MORTARS USED

Mortars	Cement:Lime:Sand			Plasticised Cement:Sand			Masonry Cement:Sand		
Designations	(i)	(iii)	(iv)	(i)	(iii)	(iv)	(i)	(iii)	(iv)
Proportions	1:¼:3	1:1:6	1:2:9	1:3	1:6	1:8	-	1:5	1:6½
Brick tests:									
Strength	See Table 4/5				See Table 4/5			See Table 4/5	
Consistence	*	*	*	*	*	*	-	*	*
Block tests:									
Strength	-	3.83 N/mm^2	1.36 N/mm^2	-	2.77 N/mm^2	1.98 N/mm^2	-	5.15 N/mm^2	2.57 N/mm
Consistence	-	11.2 mm	11.1 mm	-	11.4 mm	11.2 mm	-	10.7 mm	10.6 mm
Flow	-	-	-	-	150%	153%	-	143%	140%
Air content	-	-	-	-	15.1%	13.2%	-	10.6%	10.2%

*Consistence maintained at 11 ± 0.5 mm

TABLE 3: PHYSICAL PROPERTIES OF UNITS

Unit	Compressive Strength N/mm^2 (CV)	Water Absorption % (CV)	Initial Rate of Absorption kg/m^2/min (CV)	Transverse Strength N/mm^2	Bulk Density kg/m^3
Sixteen hole wirecut facing brick.	67.2 (8.1%)	7.6 (18.7%)	0.53 (57.1%)	-	-
Three hole wirecut facing brick.	64.2 (6.1%)	8.9 (21.8%)	0.99 (47%)	-	-
Semi-dry pressed	28.1 (9.4%)	19.6 (7.4%)	2.61 (16.8%)	-	-
Dense aggregate block					
used with lime mortar	10.5*	9.4	8.0	1.59	1745
used with other mortars.	10.5*	9.4	5.16	-	-
Lightweight aggregate block					
used with lime mortar	3.5*	29.0	5.9	1.33	1162
used with other mortars	3.5*	29.0	5.9	1.33	1162
Aerated concrete block					
used with lime mortar	3.5*	116.0	2.0	1.03	689
used with other mortars.	3.5*	111.6	1.83	-	-

* Nominal strength grading.

TABLE 4: RESULTS OF BRICK/BED JOINT SPECIMENS

Mortar Type	Cement:Lime:Sand					2 Plasticised Cement:Sand					3 Masonry Cement:Sand				
Brick type/ condition	16 hole	3 hole	Fletton	Fletton Docked	Fletton Adjusted Mortar	16 hole	3 hole	Fletton	Fletton Docked	Fletton Adjusted Mortar	16 hole	3 hole	Fletton	Fletton Docked	Fletton Adjusted Mortar
Mortar	0.45	0.79	0.72	0.81	0.74	0.80	0.61	0.50	0.37	0.22	-	-	-	-	-
Designation	0.50	1.03	0.79	0.78	0.75	0.73	0.52	0.55	0.47	0.33	-	-	-	-	-
(i)	0.48	0.88	0.61	0.69	0.79	0.63	0.41	0.46	0.35	0.37	-	-	-	-	-
	0.47	0.79	0.64	0.67	0.82	0.65	0.70	0.32	0.64	0.38	-	-	-	-	-
	0.57	1.03	0.54	0.73	0.72	0.58	0.39	0.36	0.75	0.27	-	-	-	-	-
Mean	0.49	0.90	0.66	0.74	0.76	0.68	0.53	0.44	0.52	0.31	-	-	-	-	-
CV%	9.3	13.4	14.7	7.0	5.3	12.8	25.0	21.9	33.7	21.7	-	-	-	-	-
Code fkx	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.4	-	-	-	-	-
Mortar Strength	15.1	15.3	14.5	15.2	14.6	9.3	11.3	9.2	9.5	9.8	-	-	-	-	-
	0.74	0.69	0.62	0.75	0.45	0.86	0.38	0.47	0.41	0.24	0.46	0.48	0.53	0.52	0.61
	0.56	0.69	0.82	0.61	0.66	0.74	0.33	0.43	0.50	0.41	0.42	0.51	0.57	0.61	0.70
(iii)	0.93	0.67	0.54	0.76	0.52	0.64	0.57	0.40	0.38	0.40	0.48	0.52	0.70	0.48	0.60
	0.75	0.91	0.60	0.50	0.52	0.69	0.70	0.25	0.53	0.35	0.45	0.53	0.53	0.61	0.60
	0.75	0.86	0.42	0.74	0.74	0.70	0.68	0.49	0.56	0.44	0.43	0.44	0.42	0.41	0.62
Mean	0.75	0.76	0.60	0.67	0.58	0.73	0.53	0.41	0.48	0.37	0.45	0.50	0.55	0.53	0.63
CV%	17.5	14.7	24.3	16.9	20.8	11.4	31.9	23.3	16.3	21.3	5.3	7.4	18.3	16.4	6.7
Code fkx	0.4	0.4	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3
Mortar Strength	2.9	2.5	3.1	3.6	2.4	2.3	2.1	2.5	2.1	2.0	2.0	2.3	2.5	2.7	2.4
	0.43	0.64	0.38	0.17	0.42	0.53	0.70	0.44	0.32	0.53	0.49	0.54	0.49	0.60	0.51
	0.52	0.63	0.39	0.32	0.40	0.57	0.35	0.39	0.35	0.43	0.53	0.47	0.55	0.64	0.61
(iv)	0.56	0.55	0.46	0.23	0.57	0.44	0.36	0.35	0.40	0.52	0.47	0.44	0.32	0.48	0.50
	0.58	0.63	0.52	0.35	0.53	0.50	0.31	0.38	0.45	0.59	0.53	0.55	0.42	0.56	0.61
	0.59	0.59	0.44	0.30	0.47	0.49	0.77	0.32	0.38	0.64	0.51	0.49	0.44	0.53	0.62
Mean	0.54	0.61	0.44	0.27	0.48	0.51	0.50	0.38	0.38	0.54	0.51	0.50	0.44	0.56	0.57
CV%	12.1	6.2	13.0	26.6	15.0	9.5	43.9	12.0	13.0	14.6	5.2	9.4	19.3	11.0	10.5
Code fkx	0.35	0.35	0.25	0.25	0.25	0.35	0.35	0.25	0.25	0.25	0.35	0.35	0.25	0.25	0.25
Mortar Strength	0.8	1.6	0.8	1.0	0.9	1.4	1.2	0.7	1.5	1.0	1.3	1.5	1.2	1.4	1.4

TABLE 5: RESULTS OF BRICK PERPEND JOINT SPECIMENS

Mortar type	Cement:Lime:Sand Mortar					Plasticised Cement:Sand					Masonry Cement:Sand				
Brick type/ condition	16 hole	3 hole	Fletton	Fletton Docked	Fletton Adjusted Mortar	16 hole	3 hole	Fletton	Fletton Docked	Fletton Adjusted Mortar	16 hole	3 hole	Fletton	Fletton Docked	Fletton Adjusted Mortar
Mortar	2.00	2.18	1.66	1.77	1.62	1.69	2.02	0.52	1.76	1.11	-	-	-	-	-
Designation	1.81	2.05	1.34	1.63	1.69	2.05	2.17	1.17	1.69	1.55	-	-	-	-	-
(i)	2.11	2.38	1.45	1.75	1.51	1.60	2.01	0.97	1.75	1.18	-	-	-	-	-
	1.92	2.30	1.72	1.48	1.43	1.84	2.18	1.20	2.00	1.05	-	-	-	-	-
	1.57	2.42	1.53	1.62	1.47	2.58	2.20	0.95	1.83	1.46	-	-	-	-	-
Mean	1.88	2.27	1.54	1.65	1.54	1.95	2.12	0.96	1.81	1.27	-	-	-	-	-
CV%	11.0	6.7	10.0	7.1	7.0	20.0	4.4	28.3	6.6	17.5	-	-	-	-	-
Code fkx	1.5	1.5	1.1	1.1	1.1	1.5	1.5	1.5	1.1	1.1	-	-	-	-	-
Mortar Strength	15.1	15.3	14.5	15.2	14.6	9.3	11.3	9.2	9.5	9.8	-	-	-	-	-
	2.24	1.83	1.67	1.65	1.34	2.06	1.80	1.24	1.24	1.60	1.90	1.73	1.59	1.46	1.07
	2.58	1.99	1.49	1.62	1.68	2.52	2.18	1.48	1.18	1.81	1.48	1.76	1.57	1.54	1.33
(iii)	1.86	1.55	1.74	1.35	1.43	1.90	2.21	1.36	1.12	1.75	1.56	1.79	1.53	1.24	1.29
	2.76	1.98	1.44	1.71	1.63	2.54	1.99	1.87	1.27	1.27	1.48	1.30	1.41	1.31	1.30
	2.64	2.06	1.52	1.73	1.82	1.94	2.20	1.16	1.20	1.60	1.43	1.80	1.52	1.39	1.33
Mean	2.42	1.88	1.57	1.61	1.58	2.19	2.08	1.42	1.20	1.61	1.57	1.68	1.52	1.39	1.26
CV%	15.1	10.8	8.1	9.5	12.3	14.3	8.6	19.6	4.8	13.0	12.1	12.6	4.6	8.5	8.7
Code fkx	1.1	1.1	0.9	0.9	0.9	1.1	1.1	0.9	0.9	0.9	1.1	1.1	0.9	0.9	0.9
Mortar Strength	2.9	2.5	3.1	3.6	2.4	2.3	2.1	2.5	2.1	2.0	2.0	2.3	2.5	2.7	2.4
	1.79	1.71	1.10	1.11	1.33	1.69	1.78	1.00	1.19	1.26	1.38	1.72	1.12	1.52	1.56
	1.50	1.14	0.91	1.00	1.19	2.12	1.65	1.32	1.46	1.29	1.44	1.58	1.43	1.55	1.73
(iv)	1.62	1.80	1.04	1.05	1.13	1.37	1.69	1.07	1.31	1.47	1.52	2.11	1.51	1.54	1.49
	1.59	1.85	1.17	1.14	1.41	1.95	1.78	1.15	0.92	1.26	1.34	1.97	1.43	1.72	1.74
	1.66	1.16	1.67	1.09	1.26	2.54	1.46	1.10	0.98	1.22	1.41	1.84	1.26	1.14	1.52
Mean	1.63	1.53	1.18	1.06	1.26	1.93	1.67	1.13	1.17	1.30	1.42	1.84	1.35	1.49	1.61
CV%	6.50	23.0	24.7	6.0	8.8	22.8	7.8	10.7	19.2	7.6	4.8	11.2	11.7	14.3	7.4
Code fkx	1.0	1.0	0.8	0.8	0.8	1.0	1.0	0.8	0.8	0.8	1.0	1.0	0.8	0.8	0.8
Mortar Strength	0.8	1.6	0.8	1.0	0.9	1.4	1.2	0.7	1.5	1.0	1.3	1.5	1.2	1.4	1.4

TABLE 6: RESULTS OF BLOCK SPECIMENS (*CEMENT:LIME:SAND RESULTS FROM DIFFERENT BATCHES)

Orientation and Mortar Designation	Plasticised Cement:Sand			Masonry Cement-Sand			Cement-Lime-Sand*		
	Dense Aggregate	Lightweight Aggregate	Autoclaved Aerated	Dense Aggregate	Lightweight Aggregate	Autoclaved Aerated	Dense Aggregate	Lightweight Aggregate	Autoclaved Aerated
Perpend joint									
	1.52	0.81	0.36	1.53	1.10	0.45	0.84	0.80	0.67
	1.50	0.96	0.36	1.52	0.92	0.40	1.11	0.88	0.55
(iii)	1.52	1.01	0.38	1.46	1.00	0.42	0.96	0.99	0.66
	1.45	0.92	0.37	1.58	0.86	0.44	1.03	1.01	0.66
	1.54	0.98	0.40	1.55	0.97	0.44	0.88	0.87	0.57
Mean	1.50	0.94	0.37	1.53	0.97	0.43	0.96	0.91	0.62
CV%	2.3	8.3	4.5	2.9	9.3	4.5	11.2	9.7	9.5
Code fkx	0.75	0.45	0.45	0.75	0.45	0.45	0.75	0.45	0.45
	1.44	0.86	0.42	1.46	0.96	0.35	0.76	0.85	0.49
	1.40	0.83	0.36	1.44	0.81	0.40	0.61	0.84	0.44
(iv)	1.26	0.84	0.39	1.45	0.99	0.47	0.88	0.83	0.38
	1.25	0.91	0.38	1.51	0.91	0.42	0.87	0.75	0.46
	1.26	0.94	0.35	1.51	0.88	0.35	0.65	0.76	0.49
Mean	1.32	0.88	0.38	1.47	0.91	0.40	0.76	0.80	0.45
CV%	6.7	5.4	6.8	2.2	7.5	11.9	14.5	6.1	10.3
Code fkx	0.6	0.4	0.40	0.60	0.40	0.40	0.60	0.40	0.40
Bed joint									
	0.67	0.32	0.29	0.54	0.37	0.21	0.57	0.40	0.41
	0.46	0.38	0.24	0.58	0.54	0.21	0.87	0.56	0.35
(iii)	0.37	0.40	0.28	0.42	0.41	0.20	0.54	0.42	0.48
	0.45	0.35	0.23	0.42	0.44	0.24	0.61	0.59	0.41
	0.50	0.32	0.25	0.47	0.41	0.25	0.75	0.40	0.39
Mean	0.49	0.35	0.26	0.49	0.43	0.22	0.67	0.47	0.41
CV%	22.3	10.0	10.2	14.2	14.0	9.0	20.8	19.2	11.5
Code fkx	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	0.29	0.33	0.22	0.21	0.28	0.22	0.05	0.20	0.14
	0.28	0.27	0.18	0.24	0.35	0.23	0.07	0.23	0.09
(iv)	0.37	0.28	0.16	0.28	0.33	0.26	0.36	0.23	0.13
	0.41	0.31	0.25	0.11	0.27	0.22	0.26	0.29	0.18
	0.33	0.37	0.18	0.26	0.24	0.19	0.30	0.15	0.16
Mean	0.34	0.31	0.20	0.22	0.29	0.22	0.21	0.22	0.14
CV%	16.4	13.0	18.4	29.9	15.8	11.3	67.6	23.5	25.6
Code fkx	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

TABLE 7: RESULTS OF ANALYSES OF VARIANCE

Scope of Analysis	Factors / Data	Mortar Type A	Unit Type B	Mortar Designation C	Interaction A/B	Interaction A/C	Interaction B/C	Interaction A/B/C
Perpend Joint Tests			BRICKS					
5 Bricks	DOF	2/120	4/120	1/120	8/120	2/120	4/120	8/120
3 mortar types	V/R	1.32	44.0	45.2	7.4	21.5	2.5	1.8
Designations (iii), (iv)	SIG	NS	99.9	99.9	99.9	99.9	95.0	NS
5 Bricks	DOF	1/120	4/120	2/120	4/120	2/120	8/120	8/120
Lime/aerated mortar	V/R	2.2	65.2	40.9	2.6	5.2	6.0	2.8
3 Designations	SIG	NS	99.9	99.9	95.0	99.0	99.9	99.0
Absorptive brick state	DOF	2/72	2/72	1/72	4/72	2/72	2/72	4/72
3 mortar types	V/R	4.9	3.8	26.5	1.8	18.2	2.7	3.5
Designations (iii), (iv)	SIG	97.5	95.0	99.9	NS	99.9	NS	97.5
Absorptive brick state	DOF	1/72	2/72	2/72	2/72	2/72	4/72	4/72
Lime/aerated mortar	V/R	11.4	4.8	28.5	3.2	4.7	9.7	6.0
3 Designations	SIG	99.0	97.5	99.9	95.0	97.5	99.9	99.9
Bed Joint Tests								
5 Bricks	DOF	2/120	4/120	1/120	8/120	2/120	4/120	8/120
3 mortar types	V/R	11.4	8.4	33.1	6.5	15.8	3.4	3.94
Designations (iii), (iv)	SIG	99.9	99.9	99.9	99.9	99.9	97.5	99.9
5 Bricks	DOF	1/120	4/120	2/120	4/120	2/120	8/120	8/120
Lime/aerated mortar	V/R	61.7	13.9	27.8	8.7	14.7	5.2	4.6
3 Designations	SIG	99.9	99.9	99.9	99.9	99.9	99.9	99.9
Absorptive brick state	DOF	2/72	2/72	1/72	4/72	2/72	2/72	4/72
3 mortar types	V/R	16.0	3.8	21.2	1.2	15.8	6.9	5.3
Designations (iii), (iv)	SIG	99.9	95.0	99.9	NS	99.9	99.0	99.9
Absorptive brick state	DOF	1/72	2/72	2/72	2/72	2/72	4/72	4/72
Lime/aerated mortar	V/R	63.2	0.6	22.7	1.9	26.3	7.7	2.7
3 Designations	SIG	99.9	NS	99.9	NS	99.9	99.0	95.0
Perpend Joint Tests			BLOCKS					
3 Blocks	DOF	1/48	2/48	1/48	2/48	1/48	2/48	2/48
Aerated/masonry mortar	V/R	13.2	1790	19.5	1.4	1.1	4.5	3.1
2 Designations	SIG	99.9	99.9	99.9	NS	NS	97.5	NS
Bed Joint Tests								
3 Blocks	DOF	1/48	2/48	1/48	2/48	1/48	2/48	2/48
Aerated/masonry mortar	V/R	0.6	44.3	58.7	3.4	3.0	13.7	3.8
2 Designations	SIG	NS	99.9	99.9	95.0	NS	99.9	95.0

Abbreviations: DOF = Degree of Freedom: V/R = Variance Ratio: SIG = Significance Level

TABLE 8 - RESULTS OF CHI-SQUARED ANALYSES (SIGNIFICANCE)

Unit, Orientation, Designation \ Mortar type		Cement lime sand						Plasticised cement sand						Masonry cement-sand					
	Global mortar designation	16 hole	3 hole	Solid	Solid docked	Solid adjusted mortar	Grouped result all units	16 hole	3 hole	Solid	Solid docked	Solid adjusted mortar	Grouped result all units	16 hole	3 hole	Solid	Solid docked	Solid adjusted mortar	Grouped result all units
BRICKS																			
Bed Joint																			
(i)	55.7(99.9)	31.8(99.9)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	2.6(NS)	0.3(NS)	12.9(99)	12.9(99)	12.9(99)	95(99.9)	80(99.9)	-	-	-	-	-	-
(iii)	1.8(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)	0.3(NS)	12.9(99)	2.4(NS)	0.3(NS)	2.4(NS)	6.4(99)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)
(iv)	0.2(NS)	0.3(NS)	0.3(NS)	0.3(NS)	12.9(NS)	0.3(NS)	0.5(NS)	0.3(NS)	2.4(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.1(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)
Grouped all designations		7.1(99)	0.8(NS)	0.8(NS)	2.2(NS)	0.8(NS)	-	0.8(NS)	25.4(99.9)	7.1(99)	2.2(NS)	38.7(99.9)	-	0.5(NS)	0.5(NS)	0.5(NS)	0.5(NS)	0.5(NS)	-
Grouped overall							0.4(NS)						41.7(99.9)						2.6(NS)
PERPEND JOINT																			
(i)	0.9(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)	0.3(NS)	0.3(NS)	31.8(NS)	0.3(NS)	2.4(NS)	6.4(99)	-	-	-	-	-	-
(iii)	3.9(95)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)
(iv)	3.9(95)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	0.3(NS)	1.3(NS)
Grouped all designations		0.8(NS)	0.8(NS)	0.8(NS)	0.8(NS)	0.8(NS)	-	0.8(NS)	0.8(NS)	7.1(99)	0.8(NS)	0.8(NS)	-	0.5(NS)	0.5(NS)	0.5(NS)	0.5(NS)	0.5(NS)	-
Grouped overall							3.9(95)						0.2(NS)						2.6(NS)
BLOCKS				DENSE	LWA	AERATED				DENSE	LWA	AERATED				DENSE	LWA	AERATED	
Bed Joint																			
(iii)	-	-	-	0.3(NS)	0.3(NS)	0.3(NS)	0.8(NS)	-	-	0.3(NS)	0.3(NS)	12.9(99)	2.2(NS)	-	-	0.3(NS)	0.3(NS)	59.2(99.9)	6.8(99)
(iv)	-	-	-	12.9(99)	2.4(NS)	95(99.9)	73.8(99.9)	-	-	0.3(NS)	0.3(NS)	31.8(99.9)	7.1(99)	-	-	2.4(NS)	0.3(NS)	2.4(NS)	2.2(NS)
Grouped all designations		-	-	4.7(95)	0.5(NS)	42.6(99.9)	-	-	-	0.5(NS)	0.5(NS)	42.6(99.9)	-	-	-	0.5(NS)	0.5(NS)	42.6(99.9)	-
Grouped overall							29.6(99.9)						8.6(99)						14.2(99.9)
PERPEND JOINT																			
(iii)	-	-	-	0.3(NS)	0.3(NS)	0.3(NS)	0.8(NS)	-	-	0.3(NS)	0.3(NS)	95(99.9)	25.4(99.9)	-	-	0.3(NS)	0.3(NS)	59.2(99.9)	6.8(99)
(iv)	-	-	-	0.3(NS)	0.3(NS)	2.4(NS)	0.8(NS)	-	-	0.3(NS)	0.3(NS)	59.2(99.9)	14.8(99.9)	-	-	0.3(NS)	0.3(NS)	12.9(99)	2.2(NS)
Grouped all designations		-	-	0.5(NS)	0.5(NS)	0.5(NS)	-	-	-	0.5(NS)	0.5(NS)	15.2(99.9)	-	-	-	0.5(NS)	0.5(NS)	63.7(99.9)	-
Grouped overall							0.2(NS)						39.5(99.9)						14.2(99.9)

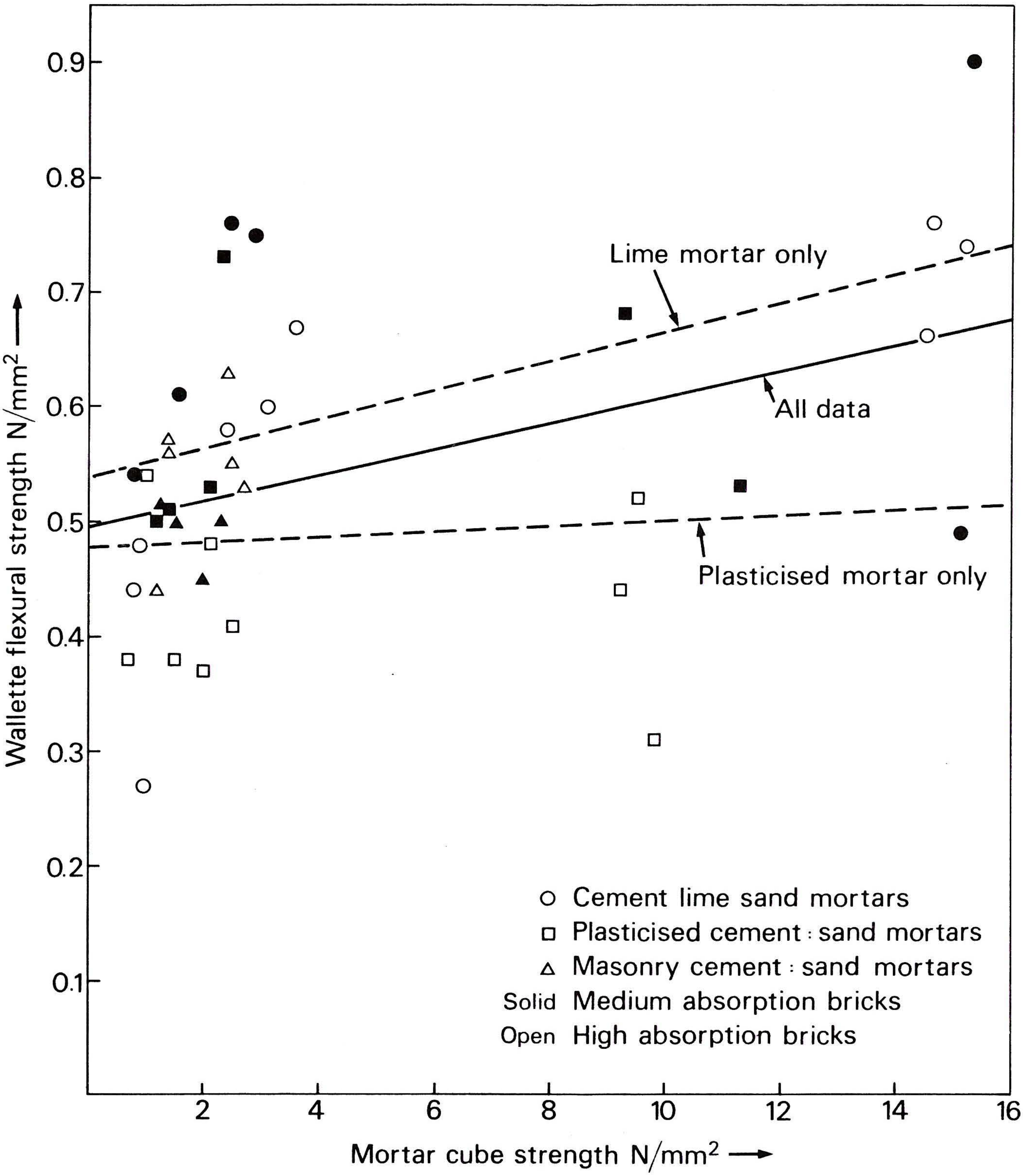

Figure 1 Relationship of bed joint flexural strength to mortar strength