IV–12. The Resistance to Lateral Loads of Walls Built of Calcium Silicate Bricks

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ABSTRACT

Flexural strength tests have been carried out on wallettes built from a representative selection of calcium silicate bricks currently being produced in the U.K. Three standard cement:lime:sand mortars were used. From the results of these tests, values of characteristic flexural strength for calcium silicate brickwork were determined and incorporated in the new Code of Practice for the Structural Use of Masonry B.S. 5628: Part 1: 1978. In addition the effect of various physical properties of the bricks on the flexural strength of brickwork was investigated. There was little evidence of correlation between brick strength and the flexural strength of brickwork, and though a relationship between wallette strength and the water absorption of the bricks had been found for clay bricks, a similar relationship could not be established for calcium silicate bricks. The practice of acid dipping was investigated and it was found that though its effect was variable the tendency was for flexural strength to be increased. The lateral load resistance of storey-height walls built with three of the bricks and 1:1:6 mortar was determined and showed that the experimental failure pressures exceeded the pressures calculated in accordance with B.S. 5628: Part 1: 1978.

Des essais de résistance au fléchissement ont été effectués sur des petits murs construits d'une sélection de briques types en silico-calcaire à présent en production au Royaume Uni. Trois mortiers standard de sable, chaux, ciment, furent employés. D'après les résultats de ces essais, les valeurs de résistance caractéristique au fléchissement pour une maçonnerie en briques silico-calcaires furent déterminées et incorporées dans le nouveau 'Code of Practice for the Structural Use of Masonry' (Règles de pratique pour l'emploi de maçonnerie pour l'ossature), BS5628:Part 1:1978. En addition, des recherches furent effectuées sur l'effet des diverses propriétés physiques des briques sur la résistance au fléchissement de la maçonnerie de briques. Il n'y eut pas beaucoup d'évidence de corrélation entre la résistance des briques et la résistance au fléchissement de la maçonnerie et, bien qu'il ait été trouvé un rapport entre la résistance des petits murs et l'absorption d'eau pour les briques argileuses, il ne fut pas possible d'établir un rapport similaire pour les briques silico-calcaires. Des recherches furent effectuées concernant la pratique d'immersion dans l'acide et il apparut que bien que les effets en étaient variables, la résistance au fléchissement avait tendance à augmenter. La résistance aux charges latérales de murs de hauteur d'étage construits avec trois des briques et du mortier 1:1:6 fut déterminée et elle indiqua que les pressions expérimentales de rupture dépassaient les pressions calculées suivant la BS5628:Part 1:1978.

Biegeprüfungen wurden an kleinen Wänden durchgeführt, die mit einer repräsentiven Auswahl der heute in Großbritannien gefertigten Kalziumsilikatziegeln gebaut waren. Drei normale Mörtel aus Zement, Kalk und Sand wurden verwendet. Die Ergebnisse dieser Prüfungen dienten als Unterlage für die Bestimmung der charakteristischen Biegefestigkeit von Kalziumsilikatmauern, und diese wurde in einen neuen Anwendungscode für das Mauern, BS 5628: Teil 1, 1978, verkörpert. Außerdem wurde der Einfluß von verschiedenen physikalischen Eigenschaften der Ziegeln auf die Biegefestigkeit des Mauerwerks untersucht. Eine Abhängigkeit zwischen Ziegelstärken und Biegefestigkeit des Mauerwerks konnte kaum bewiesen werden, und zwar konnte eine Abhängigkeit zwischen Wandstärke und Wasseraufnahme der Ziegel für Lehmziegel festgestellt werden, jeodoch war es nicht möglich, einen ähnlichen Zusammenhang für Kalziumsilikatziegel zu bestimmen. Die gewöhnliche Säurebehandlung wurde untersucht und es stellte sich heraus, daß obgleich die Einwirkung unterschiedlich war, eine Tendenz zur Erhöhung der Biegefestigkeit besteht. Der Widerstand von den aus den drei Ziegelsorten und Mörtel 1 : 1 : 6 gebauten geschoßhohen Wänden wurde bestimmt und es konnte festgestellt werden, daß die im Versuch festgestellten Ausfalldrücke nach BS 5628: Teil 1: 1978 berechneten überschritten.

Prove di resistenza a flessione sono state effettuate su piccoli muri costruiti con una scelta di tipi rappresentativi di mattoni di silicato calcio prodotti correntemente nella Gran Bretagna. Sono stati usati tre tipi standard di malta, cemento : calce : sabbia. Dai risultati di queste prove sono stati derivati valori della resistenza a flessione per costruzioni in mattoni di silicato di calcio, e questi valori sono stati incorporati nelle nuove Norme per l'uso strutturale di murature BS 5628 : Parte 1 : 1978. È stato anche studiato l'effetto di varie proprietà fisiche dei mattoni sulla resistenza a flessione delle costruzioni in mattoni. Si è trovata poca evidenza di correlazione tra la resistenza dei mattoni e la resistenza a flessione delle costruzioni in mattoni; sebbene si fosse trovata una

relazione tra la resistenza di piccoli muri e l'assorbimento d'acqua dei mattoni quando i mattoni sono d'argilla, nessuna relazione di questo tipo è stata individuata per mattoni in silicato di calcio. È stato studiato l'uso dell'immersione in acidi e si è trovato che sebbene il suo effetto fosse variabile, la tendenza era verso un innalzamento della resistenza a flessione. La resistenza a sollecitazioni laterali di muri di altezza uguale a un piano di un edificio e costruiti con tre dei tipi di mattoni e malta 1:1:6, è stata determinata ed ha mostrato che le pressioni di rottura determinate sperimentalmente sono più alte delle pressioni di rottura calcolate in base alle Norme BS 5628 Parte 1 1978.

INTRODUCTION

While wind loads on structures had been considered,[1,2,3,4] as a design problem there was no experimental data on the resistance of masonry until HALLQUIST,[5,6] and HALLQUIST and GRANHEIM[7] compared the deflection obtained from the lateral loading of a number of clay brick walls using air-bags, with those calculated by finite element analysis. A simplified design method based on elastic analysis was postulated, together with tables of deflection and moment coefficients calculated for walls supported on four sides.

LOSBERG and JOHANSSON[8] and NILSSON and LOSBERG[9] carried out lateral tests on prefabricated brickwork panels (2.80 × 1.96 m), with and without reinforcement, using air-bags. It was suggested that the lateral resistance could be estimated by the yield line theory, but this conclusion was reached on the basis of only a few experimental results.

The state of knowledge at that time on laterally loaded reinforced brick walls was summarized by HENDRY.[10] He considered some possible theories of failure in relation to model tests carried out at Birminrham University and some early full-scale wall tests at the British Ceramic Research Association and concluded that there was insufficient experimental evidence to determine the accuracy of the calculations.

Since then a considerable amount of work has been carried out and published by the British Ceramic Research Association, the most recent being a two-part paper presented to the Institution of Structural Engineers in November 1977. Part 1 by WEST, HODGKINSON and HASELTINE[11] was concerned with test methods and results, and Part 2 by HASELTINE, WEST and TUTT[12] was devoted to Design. Surprisingly, there is nothing in the literature on work of a similar nature on calcium silicate brickwork. This paper fills that gap.

EXPERIMENTAL

Properties of Materials and Test Specimens

Bricks

The bricks were chosen from nine manufacturers and cover a range of raw materials, brick properties and manufacturing processes and are believed to comprise a representative selection of those available in the U.K. (Table 1). The solid bricks have been manufactured by pressure normal to their stretcher faces while the frogged bricks have been formed by pressure normal to their bed faces.

The compressive strengths were determined by both BS 187[14] (frogs unfilled) and BS 3921[15] (frogs filled). The initial suction rate of ten bricks was determined in accordance with the method in SP 56[16] and then the water absorption (5h boil) determined on the same set of bricks according to BS 3921.[15] The frog depth was measured and the frog volume determined by filling with very fine-grained dry sand.

Mortar

The sand used for all mortars was obtained from one source; each delivery was sampled and found to comply with the grading requirements of BS 1200[17] at the fine end. The lime used was Limbux conforming to BS 890: 1966.[18] 'Typical' cement was supplied by the Cement Marketing Co. This cement is carefully selected and prepared to be as standard as possible. The mortars were prepared by weighing the required amount of each ingredient, calculated from their respective bulk densities, to provide the desired volume proportions. The three mortars used were 1:¼:3, 1:1:6 and 1:2:9 cement:lime:sand, designated (i), (iii) and (iv) respectively. For each mortar designation an initial mix was prepared and the water adjusted to suit all the bricklayers by agreement. The consistence and water content of this mixture was determined and adopted as a standard. No deviation by knocking-up with added water was permitted. The moisture content of each barrowful of sand was determined and the necessary allowance made to the gauging water. Random checks of consistence were made on samples taken from the mortar spot board. No mortar older than 2h was used.

Wallette Specimens

For each combination of brick and mortar five wallettes were made 10 courses (approx 750 mm) high and 2 bricks (approx 450 mm) long to test the flexural strength parallel to the bend joints and five wallettes 4 courses (approx 300 mm) high and 4 bricks (approx 900 mm) long to test the flexural strength normal to the bed joint. These wallettes are the pattern described for clay bricks and tested in the same way.

The wallettes were constructed on a firm flat surface, one half brick thick (approx 102 mm) using 10 mm mortar joints. Immediately after building, all wallettes were enclosed in polythene bags until the moment of testing, which was carried out after 28 days.

Storey-Height Walls

For each brick tested four different lengths of storey-height (2.6m) walls were constructed. The lengths of the four walls were 5.50 m, 4.57 m, 3.66 m and 2.44 m. The walls were all built with mortar (iii), and tested after 28 days.

The walls were built within steel frames constructed of 254 × 76 mm channel to simulate a steel or reinforced

concrete frame building. A course of bricks was first bedded on the base of the frame then a layer of mortar, followed by a bituminous felt damp-proof course and another layer of mortar on which the second course of bricks was laid. The walls were connected to the side frames at intervals of four courses using ties constructed by cutting in half galvanised vertical twist ties and welding the head of a 10mm set pin to each half; the threaded portion passed through a clearance hole in the frame and was retained by a nut, which was left slack when the wall was built and fully tightened immediately prior to testing. Movement of the bottom course was restrained by a steel angle welded to the base of the main frame, and the gap between the angle and the brickwork filled with mortar. The top course of bricks was left free of the underside of the top section of the frame to simulate the compressible joint which would be placed beneath the floor in a framed building.

Testing

All the wallettes were tested under four-point loading in a vertical aspect with hydraulic bolsters to spread the load over any possible surface irregularities. One of each pair of bolsters was pivoted at its midpoint to permit alignment to wallettes which were not plane. The load was applied by hydraulic jack at a uniform rate of 2.5 kN/min.

The storey-height walls were tested by applying the lateral load by means of multiple air-bags connected in parallel, the reaction being taken by a light steel frame clad with plywood which was clamped to the main frame at the time of testing. The air pressure was measured by a water manometer and the lateral deflections of the walls measured at salient points by displacement transducers and a digital voltmeter coupled to a data-logger. The pressure was applied at 0.1 kN/m^2 per min and the lateral deflections logged at pressure intervals of 0.1 kN/m^2.

RESULTS AND DISCUSSION

The means of the spot checks of mortar consistence are given in Table 2. These all lay within ± 0.5 mm which is the tolerance given in BS 4551.[19] Also shown in Table 2 is the mean compressive strength of all the mortar cubes made from each mix used in the wallette construction. The mortar strengths for the storey-height walls are given in the same table as the results for the walls.

Wallette Tests

The flexural strength results for wallettes are given in Table 3. There were two separate sets of wallettes built along with the storey height walls in brick 38. Four sets of wallettes were built with brick 39 at different times. The means of all the results are given in each case.

The relationship between the flexural strength of wallettes and the compressive strength of bricks was investigated graphically. Generally speaking there is little evidence of correlation between the two properties. It so happens that for results normal to the bed joint solid bricks give some evidence of positive correlation for mortar (i) and to a lesser degree for mortar (iv), but the absence of such correlation for mortar (iii) casts doubt on the reality of the effect. In view of the limited numbers of results for solid bricks it would be unwise to make too much of this apparent correlation.

A correlation between the flexural strength of wallettes and the water absorption of the brick had been found for clay bricks. Water absorption is not included in BS 187[14] as one of the properties of calcium silicate bricks to be measured. Examination of the results for the possibility of correlation between flexural strength and water absorption does not enable any firm conclusions to be drawn. There appears to be a moderate degree of correlation for all three mortars in the normal to bed joint direction, but for results parallel to the bed joint the correlation, if it exists at all, is very tenuous.

Comparing solid bricks with frogged bricks, the results normal to bed joint for solid bricks tend to be lower than for frogged with mortar (i) but with (iii) and (iv) there is no clear-cut evidence. Parallel to bed joint the results for solid bricks tend to be lower than for frogged bricks with mortar (iii) but with (i) and (iv) mortar the results are indefinite.

Some manufacturers dip certain of their coloured facing bricks in a dilute solution of hydrochloric acid after autoclaving. This has the effect of removing the thin film of calcium hydrosilicate binder from the surface thereby revealing more completely the pigment incorporated in the brick and hence producing richer colours. Although no distinction between acid-dipped and non-dipped bricks is made in BS 187[14], they have been considered separately in this report, as it was felt that the dipping process could lead to differences in the surface texture, and if so any differences in the brick/mortar interface could conceivably be reflected in the values for the flexural strength obtained in brickwork specimens.

A statistical analysis of the results for acid-dipped bricks shows that for mortar (i) in the case of the two sand-lime bricks 21 and 22 from the same manufacturers, the acid-dipped brick 22 has benefited from the treatment parallel to bed joint, but not normal to bed joint. The difference here is in the opposite direction but it is not significant. In the case of the two flint-lime bricks from another manufacturer, the results for the acid-dipped brick 25 are significantly stronger than the undipped brick 26 in both directions.

With the (iv) mortar, the differences are significantly in favour of the acid-dipped bricks in the normal direction, but are not significant in the parallel direction. With the (iii) mortar the results are again significantly in favour of the acid-dipped bricks but only barely so for brick 22 normal to bed joint.

For the two sand-lime bricks 34 and 35 from a third manufacturer, tested in (i) and (iv) mortar only, the results for the acid-dipped brick 35 are significantly stronger for both mortars and in both directions. Taken overall the results show that though acid dipping is variable in its effect, it appears on the whole to be beneficial.

The distribution of the wallette results for the different mortars is shown on the histograms in Figure 1. The characteristic flexural strength values adopted in BS 5628: Part

1: 1978[13] are indicated on the histograms as strong vertical lines. They are 0.9 N/mm² normal to bed joint and 0.3 N/mm² parallel to bed joint for mortar designations (i), (ii) and (iii), and 0.6 N/mm² in the normal direction and 0.2 N/mm² in the parallel direction for mortar designation (iv).

The mean value of the ratio of the strengths in the two orthogonal directions is not significantly different for the three mortars, 3.73 for mortar (i), 3.60 for mortar (iii) and 3.56 for mortar (iv). The overall mean is 3.62 and the range is 2.2 to 6.1 with a considerable concentration around 3.5, comparable to the mean value of 3.16 found by WEST[19] for similar tests on clay bricks.

Effect of Brick Condition

All the bricks were used as received throughout the whole of the main investigation. Separate tests were carried out, however, on brick 1 to examine the effect of brick conditioning on the strength of brickwork. The wallettes were built with the three designations of mortar and with the bricks in four different states, (1) untreated, (2) dried out at 105°C, (3) docked for 5 minutes and (4) soaked for 7 days.

During the building of the wallettes, a sample of 10 bricks was taken from each set, and the initial suction rate and water content as laid determined. These results are given in Table 4.

The results of the wallette tests are given in Table 5. The oven-dried bricks gave the lowest results, though for normal to bed joint tests with (iii) and (iv) mortars the soaked bricks and the untreated bricks gave low results also.

Uniform results were achieved by docking the bricks, for both modes of testing. For mortar (i) the results with docked bricks were slightly exceeded by those for soaked bricks, but the differences were not significant. Although the differences made by docking compared with untreated bricks were in some cases small and hardly significant, they were consistent in direction and, taken as a whole, significant. Docking had the advantage of giving a reasonably stable orthogonal ratio for the different mortars.

Effect of Mortar Consistence

The consistence of the mortar used in the construction of the wallettes and walls had been standardized at 11 ± 0.5 mm penetration of the dropping ball. Tests were carried out on wallettes built with high and low suction rate bricks and with mortars of different consistences to determine the effect of mortar consistence on flexural strength. The tests were made on bricks 22 and 27, which are two unfrogged, acid-dipped, sand lime bricks, with initial suction rates of 1.18 and 0.40 kg/m²/min respectively. Wallettes were built with each brick using mortar (iii) at two different consistences, 9.8 and 12.6 mm. Both mortars were reasonably workable, but construction with the stiffer mortar was not easy, particularly with the higher suction rate brick. No difficulty was experienced with the softer mortar though the mix was softer than generally preferred by the bricklayer.

The results of the tests on the various brick and mortar combinations are compared in Table 6 with the results obtained at the standard consistence of 11.0 mm.

For the high suction rate brick 22, both high and low consistence values gave flexural strengths normal to bed joint which are significantly lower than for the standardized consistence. Parallel to bed joint the stiffer mortar gave a low result, although the difference was of doubtful significance. The softer mortar made no appreciable difference.

With the low suction brick 27 the stiffer mortar gave a significantly lower result normal to bed joint whereas the softer mortar made no appreciable difference. Parallel to bed joint the results show no significant differences.

It would appear from these results, therefore, that there was no advantage in using mortars much different from the bricklayers preferred consistence. The stiffer mortar in addition to creating difficulties for the bricklayer tends to result in brickwork with lower flexural strength whereas the high consistence mortar shows very little difference from the standardized consistence but is softer than generally preferred by the bricklayer. Furthermore at the preferred consistence the standard of workmanship is likely to be higher.

Effect of Alternative Mortars

In Table 7 the results of tests made on wallettes built with modified mortar are compared with those obtained with a conventional (iii) cement:lime:sand mortar. Two different bricks were used in the tests, one unfrogged, low water absorption (8.3%) brick 17 and the other the frogged, comparatively high water absorption (16.0%) brick 18.

Four different mortars were examined. Two were equivalent mortars 1:4½ Walcrete:sand mortar, and 1:6 cement:sand with Febmix admix, a mortar plasticiser, which was introduced to the mix in the gauging water at the rate of 280 ml for each 50 kg cement in accordance with the maker's instructions.

The other two mortars were 1:1:6 cement:lime:sand mortars to which 0.5% of Celacol M2500 had been added based on the weight of cement. In one the Celacol was premixed with the dry ingredients prior to adding the water. In the other, the Celacol was dissolved in a portion of the gauging water.

Comparing the results of the equivalent mortars with those for the conventional mortars, both the Walcrete and the Febmix mortars gave significant reductions in strength normal to bed joint for both bricks. Parallel to bed joint the strength was significantly lower for brick 18 but not for brick 17.

Both the Celacol mortars gave results with brick 18 which are significantly lower, both normal and parallel to the bed joint, than the conventional mortar (iii). Celacol gave higher results when introduced to the mix in solution, though the difference was not significant parallel to bed joint.

With brick 17 Celacol had little effect on the strength although normal to bed joint the dry premixed Celacol gave a slightly lower value. The differences between Cela-

col added dry and in solution were significant at the 5% level for both normal and parallel but in opposite directions.

Lateral Resistance of Storey-Height Walls

Three sets of storey-height walls built with different bricks have been tested to determine their lateral resistance. Two of the bricks examined were sand-lime; one frogged (brick 18) and one unfrogged (brick 39). The third (brick 38) was a frogged flint-lime brick which was also acid-dipped. Bricks 38 and 39 were in fact repeat consignments of bricks 25 and 21 respectively. All the walls were built with mortar (iii) at the standardized consistence.

The lateral failure pressure for the storey-height walls is given in Table 8. This is the pressure at which there was a large increase in deflection together with the appearance of cracks. All the failure patterns are characteristic of three-sided restraint. The similarity of the results for bricks 18 and 39, which had almost identical physical properties, were such that the relationship between wall length and lateral resistance, shown in Figure 2 can be conveniently represented by one curve. The curve for brick 38, which is a less porous brick than either 18 or 39, runs more or less parallel with, but considerably higher than, the curve drawn for bricks 18 and 39.

In Figure 3 the results for the storey-height walls are plotted on the basis adopted by HASELTINE, WEST and TUTT.[12] The failure pressure is plotted against the flexural strength of brickwork divided by the square of the length. The flexural strength of brickwork in this instance is the strength normal to bed joints determined by the wallette test the results of which are reported in Table 3.

It can be seen that the walls built with brick 18 and with brick 39 which produce virtually the same curve when lateral pressure is plotted directly against the wall length in Figure 2, give a different picture when plotted on the basis adopted by HASELTINE, WEST and TUTT.[12] This is due to the flexural strength, normal to bed joint, of wallettes built with brick 18 being considerably stronger than for the wallettes built with brick 39, thus affecting the value of the abscissa in Figure 3.

The calculated best fit line for the three sets of walls is drawn in on Figure 3, and also shown is the line calculated by HASELTINE, WEST and TUTT[12] from earlier results for clay bricks and other materials. The equations for the two lines are respectively.

$$\rho = 1.1 + 0.0123 \frac{f_x}{L^2} \text{ kN/m}^2$$

and

$$\rho = 1.8 + 0.0127 \frac{f_x}{L^2} \text{ kN/m}^2$$

where ρ is the failure pressure in kN/m^2

L is the wall length in m

and

fx is the flexural strength in kN/m^2

The basis of the equations may require to be modified but at present the similarity of the respective intercepts and slopes indicates that walls built of calcium silicate bricks behave in a similar manner to walls built of clay bricks and other materials.

DESIGN

The research carried out on clay bricks at B.C.R.A. led to adoption of a bending moment coefficient approach to the design of laterally loaded wall panels.[12] While it is accepted that yield line theory, from which the bending moment coefficients have been derived, should not strictly be applied to a brittle material such as brickwork, the method shows good correlation with the lateral loading experimental results on clay brickwork. In Figure 4 the pressures for the calcium silicate storey-height walls calculated using the above method have been plotted against their experimental failure pressures, using the actual flexural strength of brickwork from wallette results and allowing for the estimated edge restraint. The calculated values are listed in Table 9.

In the clay brickwork research, special tests were developed to provide some measure of the restraint afforded by the wall ties to the side members of the test rig. This research suggested that the restraint value was independent of the bricks used, being related only to the mortar in the wall. This assumption has been used, in lieu of any tests on calcium silicate brickwork, in the derivation of the values in Table 9.

It can be seen from Figure 4 that this approach for calcium silicate brickwork gives a similar correlation between calculated and experimental results as that found for clay brickwork, especially at lower pressures. Again, as with clay brickwork the best correlation is for the 5.5 m walls, the 2.44 m walls failing at rather lower pressures than calculated. Whether this is due to the high h/L ratio for the 2.44 m walls or the higher failure pressures involved is difficult to say; work on varying height walls in clay brickwork suggests that it may be the latter.

Table 9 also lists pressures calculated in accordance with BS 5628: Part 1,[13] using the code values for characteristic flexural strength and bending moment coefficients etc., and in Figure 5 they are plotted against the actual failure pressures. Also included are four walls tested much earlier. These fall within the general relationship.

All the results in Figure 5 are above the exact prediction line, even at the higher pressures. One obvious reason for this is that the restraint values of the side connections have been neglected, but a more important reason is that the flexural strengths used are the characteristic values.

CONCLUSIONS

1. A study of the distribution of wallette results for different mortars enabled values of characteristic flexural

strength for calcium silicate brickwork to be determined. These values have been incorporated into the new Code of Practice for the Structural Use of Masonry B.S. 5628: Part 1: 1978.

2. There was little evidence of correlation between the compressive strength of bricks and the flexural strength of brickwork.
3. Though a correlation between the water absorption of the brick and the flexural strength of wallettes has been found for clay bricks, there was not sufficient evidence to conclude that a similar relationship existed in the case of calcium silicate bricks, nor is water absorption a property specified in B.S. 187: 1978.
4. There was no clear-cut evidence to suggest that frogged bricks behaved differently from bricks without frogs.
5. The effect of acid dipping bricks on the flexural strength of wallettes is variable, but appears on the whole to be beneficial.
6. The flexural strength of brickwork is influenced to some extent by the moisture content of the brick when laid. Bricks which have been oven-dried do not perform as well as bricks containing moisture. The best results were achieved with bricks which had been untreated or had been docked prior to building. The latter also gave uniform results.
7. None of the alternative mortar mixes examined performed better than conventional cement:lime:sand mortars of the same designation.
8. The experimental lateral failure pressures of storey-height walls all exceeded the pressures calculated in accordance with B.S. 5628: Part 1: 1978, using the values for characteristic flexural strength and bending moment coefficients etc., given in the code.

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TABLE 1—Physical Properties of Bricks

				Compressive strength							
				To BS 187		To BS 3921		Water absorption		Initial rate of suction	
Brick	Manufacturer	Frog depth (mm)	Frog volume (%)	Mean (N/mm²)	C.V. (%)	Mean (N/mm²)	C.V. (%)	Mean (%)	C.V. (%)	Mean (kg/m²/min)	C.V. (%)
SOLID											
4	B	—	—	27.0	11.2	28.5	15.7	21.6	6.4	0.86	17.3
14	E	—	—	22.8	8.6	21.9	10.5	13.7	5.0	0.63	13.5
(17)	F	—	—	46.5	8.4	47.7	6.2	8.3	7.5	0.25	23.3
21	G	—	—	23.7	18.5	25.9	17.2	17.7	2.5	1.42	13.8
22	G[a]	—	—	20.4	12.0	20.5	14.9	15.5	5.5	1.18	16.1
(27)	F[a]	—	—	30.3	5.5	30.2	3.3	11.1	5.0	0.40	20.0
(36)	G	—	—	18.0	5.5	18.1	8.2	16.3	2.2	1.92	20.7
39	G	—	—	28.7	6.3	29.4	6.5	16.3	2.9	1.00	10.3
FROGGED											
1	A	10.0	5.2	31.8	15.0	31.5	10.0	16.6	6.4	0.97	16.3
8	C	11.5	5.7	44.8	14.8	50.4	10.1	13.6	3.8	0.70	11.7
15	E	14.0	6.4	24.2	8.3	24.6	12.2	13.1	4.3	0.76	12.9
16	B	14.0	6.4	41.1	9.8	34.9	6.6	19.0	3.9	0.65	13.8
18	C	11.0	5.5	31.0	11.9	32.7	8.4	16.0	7.6	0.97	20.9
19	D	10.0	4.6	Frog unfilled method not used due to the indistinct edge of the frogs on these bricks		30.1	6.5	17.4	2.3	0.62	11.3
(20)	D	8.0	3.8			40.7	8.6	14.0	4.2	0.47	16.8
(24)	B	14.0	6.4	29.8	16.8	33.0	9.2	13.8	6.5	1.20	22.1
(25)	C[a]	11.0	5.5	49.3	6.6	44.7	5.0	13.9	3.7	1.19	10.7
(26)	C	11.0	5.5	43.0	5.3	44.0	4.1	14.3	2.7	0.96	8.4
34	H	11.0	4.8	22.5	11.2	21.3	8.3	18.9	4.3	1.17	10.0
35	H[a]	11.0	4.8	19.9	8.4	21.5	10.0	16.9	5.7	1.20	20.5
37	I	14.0	6.3	25.7	6.1	28.7	7.6	17.1	3.0	1.13	8.4
(38)	C[a]	11.0	5.5	52.2	10.9	52.2	7.4	13.4	4.3	0.57	14.4

a = acid dipped   Number in ( ) Flint Lime, the rest Sand Lime

TABLE 2—Mortar Consistence and Compressive Strength

		Compressive Strength			
Mortar Grade	Consistence mm	Mean Strength N/mm²	Standard Deviation N/mm²	Coeff. of Variation %	Range N/mm²
(i)	10.7	16.2	1.4	8.5	14.19–18.77
(iii)	11.0	4.1	0.5	11.9	3.14– 4.87
(iv)	11.2	1.7	0.2	11.6	1.25– 2.08

TABLE 4—Water Content and Initial Suction Rate of Conditioned Bricks

	Water Content (%)			Initial Suction Rate (kg/m²/min)		
Mortar	Un-treated	5-Minute Docked	Soaked (7 days)	Un-treated	5-Minute Docked	Soaked (7 days)
1:¼:3	3.7	6.6	14.0	0.56	1.00	0.18
1:1:6	3.6	6.4	14.1	0.53	1.02	0.31
1:2:9	3.8	6.8	14.3	0.56	0.97	0.18

TABLE 3—Mean Ultimate Flexural Tensile Stress of Wallettes at 28 Days

	Mortar								
	(i)			(iii)			(iv)		
Brick No.	Normal (N/mm^2)	Parallel (N/mm^2)	Orthogonal ratio	Normal (N/mm^2)	Parallel (N/mm^2)	Orthogonal ratio	Normal (N/mm^2)	Parallel (N/mm^2)	Orthogonal ratio
1	1.65	0.41	4.0	1.30	0.40	3.3	0.59	0.27	2.2
4				1.04	0.33	3.2			
8	1.75	0.57	3.1	1.42	0.43	3.3	0.98	0.37	2.6
14				1.40	0.32	4.4			
15	1.79	0.71	2.5	1.75	0.47	3.7	1.17	0.33	3.5
16	0.97	0.33	2.9	0.82	0.29	2.8	0.59	0.21	2.8
17	2.32	0.52	4.5	1.53	0.37	4.1	1.16	0.41	2.8
18				1.57	0.35	4.5			
19	1.85	0.31	6.0	1.38	0.38	3.6	0.79	0.23	3.4
20	1.29	0.36	3.6	1.28	0.41	3.1	0.83	0.21	4.0
21	1.25	0.38	3.3	1.31	0.32	4.1	0.77	0.19	4.1
22	1.16	0.53	2.2	1.48	0.40	3.7	0.91	0.19	4.8
24	1.68	0.32	5.3	1.43	0.42	3.4	1.13	0.36	3.1
25	2.04	0.43	4.7	1.67	0.47	3.6	1.18	0.21	5.6
26	1.52	0.25	6.1	1.22	0.31	3.9	0.76	0.16	4.8
27	1.68	0.55	3.1	1.50	0.31	4.8	0.96	0.29	3.3
34	1.34	0.35	3.8				0.80	0.28	2.9
35	1.55	0.62	2.5				1.40	0.35	4.0
36	1.06	0.32	3.3				0.85	0.31	2.7
37	1.41	0.56	2.5				1.24	0.32	3.9
38				1.41	0.43	3.3			
39				1.09	0.28	3.9			

TABLE 5—Effect of Brick Condition on Wallette Strength

		Normal to Bed Joint		Parallel to Bed Joint		
Brick Condition	Mortar	Mean Flexural Stress (N/mm^2)	Coefficient of Variation (%)	Mean Flexural Stress (N/mm^2)	Coefficient of Variation (%)	Orthogonal Ratio
Untreated	(i)	1.65	6.9	0.41	12.4	4.0
	(iii)	1.30	9.0	0.40	6.8	3.3
	(iv)	0.59	9.7	0.27	18.9	2.2
Oven dried (5 days)	(i)	0.89	10.0	0.17	14.4	5.2
	(iii)	0.77	9.1	0.22	15.8	3.5
	(iv)	0.59	15.8	0.16	10.6	3.7
Docked (5 min)	(i)	1.76	9.8	0.53	10.1	3.3
	(iii)	1.45	6.6	0.48	7.8	3.0
	(iv)	1.05	8.4	0.32	13.1	3.3
Soaked (7 days)	(i)	1.78	9.3	0.56	4.6	3.2
	(iii)	0.77	5.3	0.28	17.5	2.8
	(iv)	0.63	10.9	0.22	15.1	2.9

TABLE 6—Effect of Mortar Consistence on the Flexural Strength of Wallettes

		Normal to Bed Joint		Parallel to Bed Joint		
Brick	Mortar Consistence (mm)	Mean Flexural Stress (N/mm^2)	C.V. (%)	Mean Flexural Stress (N/mm^2)	C.V. (%)	Orthogonal Ratio
22	9.8	1.12	11.4	0.33	22.1	3.4
22	11.0	1.48	7.3	0.40	12.5	3.7
22	12.6	1.18	9.0	0.41	7.6	2.9
27	9.8	1.17	21.4	0.35	15.7	3.3
27	11.0	1.50	8.8	0.31	16.1	4.8
27	12.6	1.46	10.4	0.35	19.1	4.2

TABLE 7—Flexural Strength of Wallettes Built with Modified Mortars

		Normal to Bed Joint		Parallel to Bed Joint		
Brick	Mortar	Mean Flexural Stress (N/mm^2)	Coefficient of Variation (%)	Mean Flexural Stress (N/mm^2)	Coefficient of Variation (%)	Orthogonal Ratio
	(iii)	1.53	12.9	0.37	9.8	4.1
	Walcrete	1.14	13.5	0.40	15.8	2.9
17	Febmix	1.21	11.4	0.32	31.1	3.8
	Celacol dry	1.34	14.3	0.37	5.4	3.6
	Celacol soln.	1.57	3.0	0.32	3.4	4.9
	(iii)	1.57	8.3	0.35	14.4	4.5
	Walcrete	1.04	20.6	0.19	16.0	5.5
18	Febmix	1.15	8.9	0.15	19.3	7.7
	Celacol dry	0.91	8.7	0.23	10.6	4.0
	Celacol soln.	1.10	13.8	0.25	7.9	4.4

TABLE 8—Lateral Resistance of Storey-Height Walls

Brick	Wall No.	Wall Length m	Type of d.p.c.	Mean Mortar Strength N/mm^2	Lateral Failure Pressure kN/m^2
	1067	5.50	Bitumen	5.53	1.5
18	1069	4.57	Bitumen	5.67	1.5
	1070	3.66	Bitumen	4.73	2.3
	1074	2.44	Bitumen	4.23	3.6
	1209	5.50	Bitumen	4.41	2.1
38	1230	4.57	Bitumen	3.87	2.4
	1208	3.66	Bitumen	3.89	3.1
	1215	2.44	Bitumen	4.18	5.0
	1222	5.50	Bitumen	4.20	1.3
39	1229	4.57	Bitumen	3.78	1.5
	1220	3.66	Bitumen	3.96	2.1
	1223	2.44	Bitumen	4.27	3.6

TABLE 9—Laterally Loaded Storey-Height Walls, Calculated Pressures Compared to Failing Pressures

Brick	Wall No.	Length (m)	Mean Failing Pressure (kN/m^2)	Calculated Pressure Partial End Restraint (kN/m^2)	Calculated Pressure BS 5628 (kN/m^2)
P	793	5.50	1.17	**	0.79
P*	794	5.50	1.03	**	0.53
Q	848	5.50	1.37	**	0.79
Q	849	5.50	1.34	**	0.79
18	1067	5.50	1.47	1.78	0.79
18	1069	4.57	1.50	2.35	1.06
18	1070	3.66	2.25	3.42	1.47
18	1074	2.44	3.55	6.89	2.84
38	1209	5.50	2.10	1.81	0.79
38	1230	4.57	2.40	2.26	1.02
38	1208	3.66	3.10	3.35	1.47
38	1215	2.44	5.00	6.68	2.84
39	1222	5.50	1.30	1.54	0.79
39	1229	4.57	1.50	1.94	1.02
39	1220	3.66	2.10	2.97	1.47
39	1223	2.44	3.60	6.05	2.84

*Built with mortar designation (iv). All other walls were built with mortar designation (iii).

**As no wallette results are available for walls of P, P* and Q brick/mortar combinations, pressure allowing for the actual flexural strength could not be calculated.

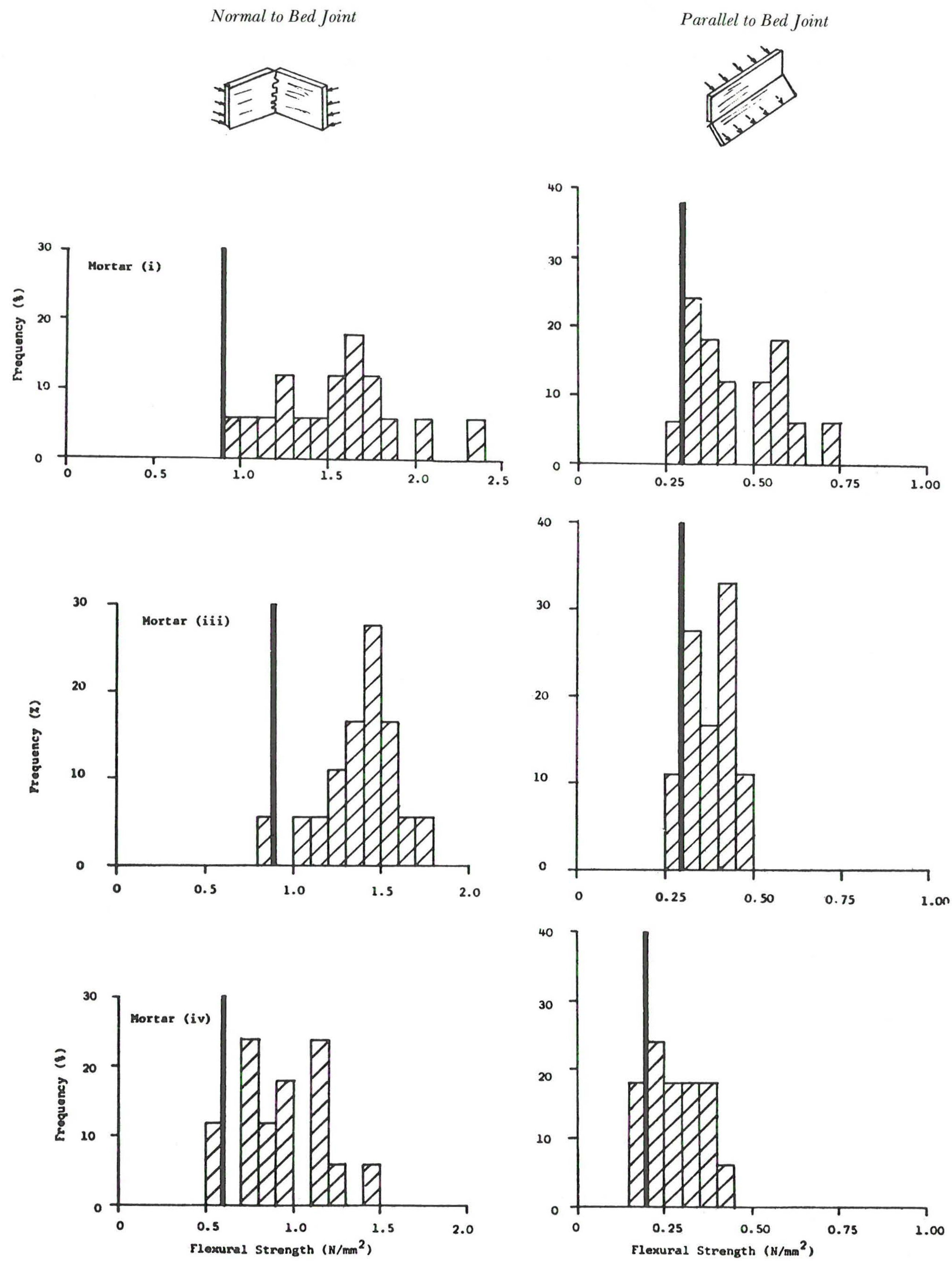

Figure 1. Distribution of flexural strength results of Wallettes

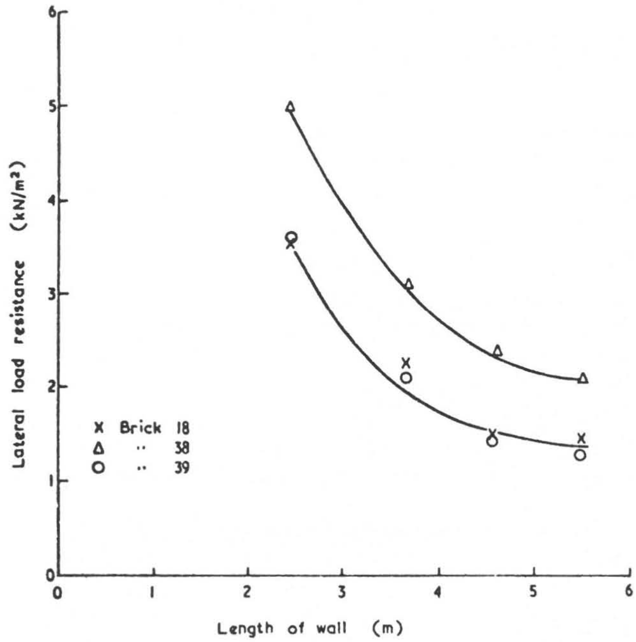

Figure 2. Relationship between wall length and lateral load resistance

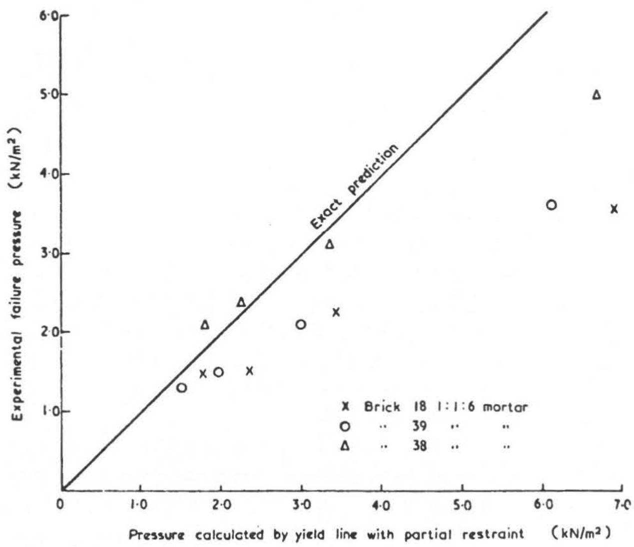

Figure 3. Relation of failure pressure to ratio of flexural strength to (Length)²

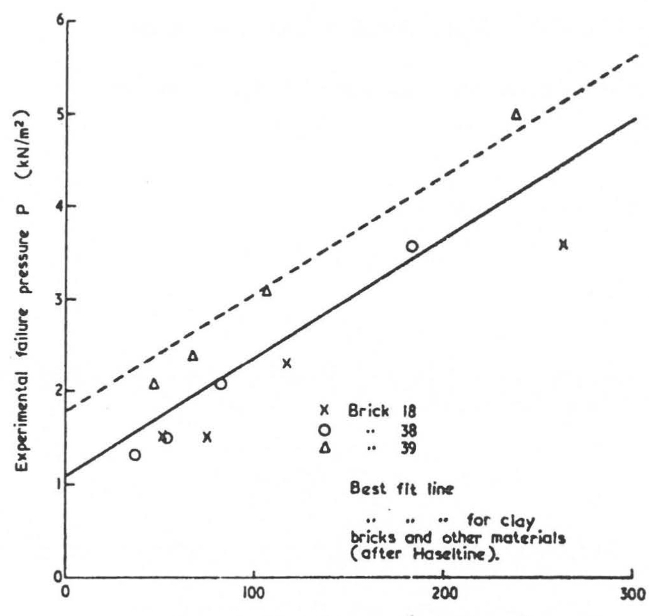

Figure 4. Relation of failure pressure to calculated pressure allowing for partial restraint

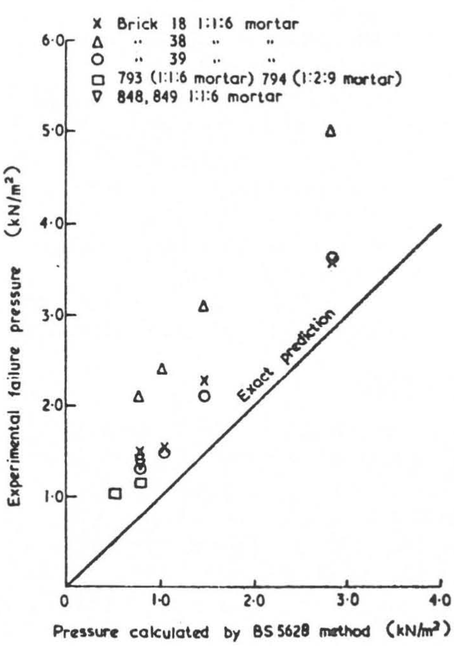

Figure 5. Relation of failure pressure to pressure calculated according to BS5628 method