Statistical Variations of Brickwork Tests on Multistorey Structural Brickwork.

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SUMMARY

This paper reports the results and statistical variations obtained in full site control tests on structural brickwork buildings. The results are compared with the requirements of AS1640 Brickwork Code and the Draft Australian Standard for Masonry in Buildings. This work was done on four multistorey buildings which have been constructed in Brisbane.

The work involved a series of preliminary acceptance tests for the projects and then routine testing of most sections of each building. The tests included standard mortar tests on samples of mortar taken from the site and returned to the laboratory and brick pier and wallettes which were constructed on site. The brick piers were tested on site and the wallettes were returned to the laboratory for testing. From the data collected over these four projects, statistical analysis of the results was carried out and this is reported in the paper.

1. INTRODUCTION

Load bearing structural brickwork was a normal method of construction in the beginning of this century. With the development of reinforced concrete for use in structural engineering, the building of load bearing structural brickwork for large structures was no longer an economical solution. Therefore, load bearing structural brickwork was limited to small buildings up to four stories in height which, under local council by-laws do not require an elevator, or for normal house construction. Any building above this height requires an elevator and it is normally more economical to construct these buildings using conventional concrete framed building with masonry infill panels.

In the late nineteen seventies, a project builder in Brisbane decided that he could build a multistorey building using load bearing structural brickwork as economically as a concrete framed building with masonry infill panels. From these beginnings, a number of this type of building were constructed over the last five years.

2. DESCRIPTION OF BUILDINGS INVESTIGATED

The four buildings that were constructed during this period were all designed for use as home units or flats. They have one or two levels of car parking in the basement, an entrance or ground level general service area, and above this level, a standard pattern of walls for the normal one and two bedroom home units.

2.1 Building No.1.

This site had twin buildings constructed and each of these buildings was 12 stories of structural brickwork with one or two basements made from normal reinforced concrete or reinforced concrete masonry. This varied across the site due to the natural steep slope of the land. The internal wall thickness varied from 110mm to 230mm. For the main internal structural walls, the walls were made of two (2) bricks of 110mm width or a single brick of 145mm width. The minor internal walls were constructed of a single brick of 110mm width. The internal walls were reduced in thickness from 145mm to 110mm at Level 5 in the building. The 230mm internal walls did not reduce in thickness as these were communal walls or were acting as lateral load members in the building.

For the external walls, the thickness was 305mm. This was made up of an outer skin of 110mm width, a cavity of 50mm and an inner skin of 145mm width.

The minimum compressive strength of the bricks was required to be 50 MPa and the quality of the mortar was 1: ½: 4½ (C: L: S) for all walls up to Level 8. The minimum compressive strength of the bricks for all floors above Level 8 was 30 MPa and the quality of the mortar was 1:1:6 (C: L: S).

2.2 Building No.2.

This site had a single building constructed of nine (9) stories of structural brickwork. It was a level site with one level of car parking in the basement. The wall thicknesses were similar to the previous building. Up to the fourth floor, the external walls were cavity brick with the outer skin of 110mm width and the inner skin of 145mm width. The internal walls were a mixture of 230mm and 145mm widths for this section of the building. For walls above fourth floor, all 145mm width bricks were replaced by 110mm width bricks. The minimum compressive strength of the bricks was specified as 50 MPa and the quality of the mortar was 1: ½: 4½ (c; l; s) for all walls in this building.

2.3 Building No.3.

This site had a single building constructed of nine (9) stories of structural brickwork with one basement of part only structural brickwork. The remaining sections of the basement were conventional reinforced concrete. The construction details are similar to building No.2. as all three of these buildings were designed by the same consulting engineer. This building was built by a different contractor. The builder would not accept advice on the requirements for good quality mortar and quality control of the brickwork. Therefore only limited tests were done on this building.

2.4 Building No.4.

This building was built on a very sloping site but had conventional reinforced concrete construction up to ground level and then twelve (12) stories of load bearing structural brickwork. This building was designed and built by a different consulting engineer and builder to the other three buildings. The testing programme on this structure was very complete and the quality control was excellent.

As the brick industry would not produce a brick with a width of 145mm during the period of design and construction of this building, the preliminary testing involved checking every type of brick from each brickworks in South East Queensland to obtain the strongest 110mm width brick available. The wall construction involved 270mm wall thickness for outer walls which were two leaves of 110mm width with a cavity. The internal walls were a mixture of 110mm and 230mm widths. The mortar quality was specified as 1: ½: 4½ (C: L: S) as previously.

3. STANDARD TESTS PERFORMED

The testing programme was set up on the basis of the requirements of AS1640 of one sample per 30,000 bricks or part thereof of each type delivered to the job, or one sample of each type used in each storey of the construction, whichever is the greater. Generally the work involved a visit to the site to satisfy the above requirement on a weekly basis. A sample of bricks with a mortar sample were taken from the site and brick piers and wallettes were constructed on site during the presence of the technician. This allowed for a complete set of tests on the brickwork as follows:-

(a) The minimum compressive strength of the bricks is not less than that determined by preliminary testing.

(b) The initial rate of absorption of the bricks is within the range determined by preliminary testing.

(c) The mortar has a flow before suction and water retention within the range determined by preliminary testing.

(d) The compressive strength of the mortar is not less than that determined by the preliminary testing.

(e) The bond strength and average ultimate compressive strength of the brickwork are within the requirements as specified by the design.

Where bond tests were requested, these were performed on site by bond in bending using the brick piers. The wallettes were returned to the laboratory after one week of site curing for compressive strength testing at twenty-eight (28) days.

4. QUALITY OF WORKMANSHIP

On building No.1, the consulting engineer had requested substantial timber boxes to be used to gauge the materials required for the mortar. This did work reasonably well as the bricklayers were convinced of the necessary requirements for good mortar for structural strength of the building. A further refinement of this procedure was developed by our laboratory staff for the site workmen to use volume batching on all mortar materials. This was done using plastic buckets of the same size. This refinement was put into use on the building No.2 as the same workmen and builder were used on both buildings. As can be seen from the results in Table 6, the Standard Deviation and Co-efficient of Variation are much smaller for Building No.2 than the similar values for Building No.1.

On Building No.3, the contractor had a different group of workmen who refused to volume batch. This resulted in a wide scatter of results and these are shown in Table 6 by a large co-efficient of variation and Standard Deviation for the limited number of results obtained. On Building No.4., the volume batching was used from the beginning and no low results for brickwork strength were obtained. The system worked extremely well and allowed good quality control on the workmanship and did not increase the time and labour required to produce suitable mortar.

5. METHODS OF CALCULATION

(a) Using AS1480 Brickwork Code, the value of F'm is calculated using the following formula.

$F'm = 0.75\ (\bar{x} - 0.38R)$ or $\bar{x}$ min whichever is the less.

where:-

$F'm$ = minimum compressive strength of brickwork.

$\bar{x}$ = the average compressive strength (MPa) of the test specimens considered as a group

x min = the compressive strength of the weakest specimen

R = the group range - i.e. the difference between the compressive strength of the strongest and weakest specimen.

The $F'm$ value was also corrected for height-to-thickness ratio as required by the Code.

(b) Using AS1225, Burnt Clay and Shale Building Bricks Standard, the value of C is calculated using the following formula:

$$C = \bar{x} - 0.38 R$$

where:-

C = specific minimum compressive strength of bricks.

$\bar{x}$ = average compressive strength of the test specimens.

R = group range i.e. the difference between the average of the two highest strengths and the average of the two lowest strengths in the group.

(c) Using the Draft Code for Masonry in Buildings, the value of Cu is calculated using the following formula:

$$Cu = K_c F'_b$$

where:-

Cu = characteristic unconfined compressive strength

Kc = corrected factor for aspect ratio of units

F'_b = the characteristic compressive strength of the masonry units.

Also, $F'_b \approx 0.9C$ is used to convert the method used in AS1225 for calculating C which is based on the 85 percentile to the normal 95 percentile for a characteristic strength requirement.

(d) Using the Draft Code for Masonry in Buildings, the value of F'm is calculated using the following formula:

$$F'm = \bar{x} - K_3 S$$

where $\bar{x}$ = mean strength of individual specimens

S = standard deviation of the strengths of individual prisms.

K_3 = sample size factor which is given on a table in the draft code.

6. RESULTS AND DISCUSSION

The summary results of the four buildings are detailed in Tables 1 to 4. In Table 1, the low brickwork compressive strengths occurred when the job was about half completed and the structure was up to Floor 5. These results would be expected as the mortar strength was also low. This probably occurred due to poor batching of the materials for this batch of mortar. At this stage, the workmen on the project were not using volume batching by full buckets. For Building No.2, the results are very consistent as volume batching by bucket was used. Building No.3, had low strengths due to the use of loam (sand with high silt content) and no sharp sand. On Building No.4, the results are very consistent due to very good quality control on this site.

From Table 5, it can be seen that many of the bricks failed to meet the minimum requirements that were specified by the designers for brick strength. This caused some concern to the designers that a brick could not easily be made available for this type of construction to the strength required. The minimum compressive strength of the brickwork wallettes was always lower than the compressive strength of the weakest specimen when calculated using the current Code AS1640.

Similar calculations were done for the provisions of the draft standard for masonry in buildings and these values are shown in Table 6. The calculated values generally were higher than the values obtained by the current Code As1640. This was not the case for Building No.3, as these values were less than the values obtained from the current Code Method. This was expected as the mortar strengths were low and the co-efficient of variation large compared to the number of specimens involved. The values obtained by Table 5.1 of the draft code are generally more conservative than the values obtained from test. This is normal practice in any design table. For Building No.3, the values obtained from Table 5.1 are larger than the calculated values due to using the mortar that was specified for this construction. If a lower grade of mortar was used in the Table, then these values would relate more closely to the calculated values.

From Table 7, the minimum compressive strength of all samples or specimens is higher than the equivalent value of 0.8F'm for rejection of any section

of the work. The ratio of sample minimum compressive strength over F'm calculated ranges from 88% to 230%. Therefore, assuming good quality control on the project, the value of 0.8 F'm could be increased to 0.85 F'm and in most cases could remain not reduced by any factor.

This is shown by the values obtained on Buildings Nos. 2 and 4, which had very good quality control during the whole projects. On Building No.1, this would also have occurred if the quality of workmanship had not varied when the building was half completed. The values obtained on Building No.3, are totally unrealistic due to the large range in strengths and the limited tests done on this building.

It does show up the fact that site control tests based on site data cannot give a clear picture on rejection and would need some realistic laboratory tests as the basis of rejection. This would be preliminary tests to obtain the maximum values for these construction materials for use on this site. This would give some values to gauge your site control values upon. This exercise was not to compare laboratory values against site values, but to calculate the variability of the site information obtained from these tests.

7. CONCLUSIONS

The results obtained indicate that the method of rejection of 0.8 F'm in the Draft Standard for Masonry in Building is a realistic value and can be easily satisfied. With good quality control, this value could easily be increased to 0.85 F'm or 0.9 F'm.

The method of batching all mortar by volume using full buckets as a measure gives very good quality control on the mortar. If the mortar is well made and even quality, then the results obtained from the brickwork compressive strength tests will also be excellent and satisfy all requirements for non-rejection.

8. REFERENCES

(a) Australian Standard 1640 - 1974, Brickwork Code.

(b) Draft Australian Standard - Masonry in Buildings, DR 84090.

SUMMARY OF TEST RESULTS TABLE 1.

BUILDING NO.1. (CONSTRUCTED MAY 1979 TO SEPTEMBER 1979.)

LOCATION	FRESH MORTAR		MORTAR COMP. STRENGTH (MPa)		BRICK (MPa) COMP. STRENGTH		I.R.A.		BRICKWORK COMP. STRENGTH (MPa)	
BUILDING A or B FLOOR 1-10	INITIAL FLOW	WATER RETENTION %	7 DAY	28 DAY	145mm width	110mm width	145mm width	110mm width	145mm width	110mm width
B, G to 1	160/25	71	4.7	8.1	50.0	68.0	1.20	0.65	26.0	25.0
B, 1 to 2	150/25	75	3.55	6.3	52.0	63.5	1.10	0.60	24.5	23.5
A, G to 1	140/12	61	6.7	11.2	61.5	66.0	0.55	0.60	33.0	31.0
B, 1 to 2	120/12	66	8.7	13.45	62.5	64.0	0.74	0.78	33.5	27.0
A, 1 to 2	128/12	67	7.0	12.9	61.0	68.0	0.36	0.62	33.0	27.0
A, 1 to 2	124/12	73	7.7	14.5	50.5	65.5	1.10	0.62	27.5	31.0
A, 2 to 3	121/12	66	5.7	10.3	49.5	63.0	1.30	0.66	18.0	28.5
B, 3 to 4	119/12	71	3.55	5.8	34.5	65.8	2.70	0.64	16.0	22.0
B, 4 to 5	113/12	44	2.75	4.4	42.5	66.5	1.62	0.64	13.0	15.0
A, 4 to 5	114/12	68	5.4	9.1	38.0	70.0	1.77	0.62	18.5	27.0
B, 6 to 7	142/12	87	6.5	10.1	51.0	64.5	1.26	0.68	22.0	20.0
B, 7 to 8	119/12	75	2.7	4.5	56.5	67.5	0.87	0.69	27.0	22.0
A, 7 to 8	107/12	82	7.7	13.75	51.5	68.0	1.03	0.68	24.5	26.5
B, 8 to 9	128/12	72	6.8	10.6	59.5	62.5	0.85	0.59	30.5	21.5
B, 9 to 10	121/12	71	6.8	10.8	45.5	69.0	0.96	0.47	25.0	23.0
B, 10 to roof	121/12	58	9.8	13.2	46.0	69.0	1.04	0.72	25.5	24.0
A, 9 to 10	119/12	57	6.3	9.5	61.5	56.5	1.13	0.82	26.0	23.5
A, 10 to roof	129/12	56	10.1	14.9	57.0	64.5	1.07	0.77	27.5	20.5

SUMMARY OF TEST RESULTS

TABLE 2.

BUILDING NO.2. (CONSTRUCTED MARCH 1980 TO MAY 1980)

LOCATION	FRESH MORTAR	BRICK COMP. STR. (MPa)		BRICKWORK COMP. STR. (MPa)	
FLOOR	INITIAL FLOOR	145mm width	110mm width	145mm width	110mm width
2	132/12	46.5	-	23.5	-
2	133/12	44.5	-	20.0	-
3	-	43.5	-	-	-
3	133/12	40.0	-	21.0	-
4	-	40.0	-	-	-
4	136/12	47.0	67.5	-	23.0
5	130/12	-	70.0	-	28.0
6	-	-	-	-	24.5

TABLE 3.

BUILDING No.3. (CONSTRUCTED DECEMBER 1980.)

FRESH MORTAR		MORTAR COMP. STRENGTH (MPa)	BRICK COMP. STRENGTH (MPa)		BRICKWORK COMP. STR. (MPa)	
INITIAL FLOW	WATER RET.	14 DAYS	145mm width	110mm width	145mm width	110mm width
123/12	72	2.4	48.0	43.0	23.5	15.0
105/12	-	3.0	46.0	43.5	17.0	16.0
GROUND FLOOR ONLY						

SUMMARY OF TEST RESULTS TABLE 4

BUILDING NO.4. (CONSTRUCTED MAY 1982 TO AUGUST 1982.

LOCATION	FRESH MORTAR		MORTAR COMP. STRENGTH (MPa)	BRICK (MPa) COMP. STRENGTH		I.R.A.		BRICKWORK COMP. STR. (MPa)		BOND IN BENDING (piers) MPa	
FLOOR	INITIAL FLOW	WATER RETENTION %	7 DAY	COMMON 110	FACE 110	COMMON 110	FACE 110	COMMON 110	FACE 110	COMMON 110	FACE 110
1 to 2	103/12	78	15.5	56.5	-	1.02	-	34.0	-	0.79	-
1 to 2	101/12	82	12.0	54.0	-	0.82	-	30.5	-	0.76	-
1 to 2	99/12	86	12.8	-	41.0	-	0.11	-	18.5	-	0.58
2 to 3	99/12	83	13.4	56.5	40.5	0.99	0.15	26.0	18.0	1.07	0.61
3 to 4	112/12	81	11.5	51.0	47.0	0.83	0.39	24.0	22.5	0.44	0.56
4 to 5	107/12	80	15.1	54.5	50.0	0.60	0.29	27.5	22.5	0.65	0.53
5 to 6	123/12	86	17.4	48.0	51.5	0.79	0.25	25.0	24.5	0.91	0.69
6 to 7	96/12	88	17.1	47.5	50.1	0.77	0.33	24.5	26.5	0.56	0.49
7 to 8	104/12	88	10.2	37.5	30.5	0.77	0.22	28.5	29.0	0.68	0.64
8 to 9	-	-	-	47.2	46.9	0.93	0.22	28.8	31.8	0.88	0.67

AUSTRALIAN STANDARD 1640 - BRICKWORK CODE TABLE 5.

BUILDING NO.	BRICKS					BRICKWORK				
	Type of Brick	No. of Specimens in Test	Range (R) of Comp. Str.(MPa)	Av. Comp. Strength (MPa) ($\bar{x}$)	Min. Comp. Str. (MPa) C= $\bar{x}$ -0.38R	No. of Specimens in Test	Range of Comp. Str. (MPa)	Average Comp.Str. (MPa)($\bar{x}$)	Min.Comp.Str.(MPa) F'm=0.75($\bar{x}$-0.38R)	Comp.Str. of Weakest Specimen
1.	145mm width	100	46.8	50.5	32.7	53	23.0	25.2	11.5	11.5
	110mm width	108	33.5	65.7	53.0	54	20.1	24.4	12.6	13.5
2.	145mm width	46	28.8	43.2	32.2	12	11	21.5	12.1	16.5
	110mm width	12	13.5	68.5	63.4	8	7.3	25.7	17.2	22.5
3.	145mm width	12	11.3	47.0	42.7	5	14.4	20.8	10.7	15.3
	110mm width	12	11.5	43.3	38.9	6	6.2	15.3	9.7	11.7
4.	110mm common	108	38.8	50.2	35.5	27	14.0	27.6	16.7	22.0
	110mm face	96	33.8	44.7	31.9	27	16.5	23.6	13.0	16.0

BRICKWORK - DRAFT STANDARD FOR MASONRY IN BUILDINGS - TABLE 6.

BUILDING NO.	Type of Brick	No. of Bricks in Test	85% to 95% F'b ≈ 0.9C	Cu = $K_c F'_b$	Table 5.1 ** F'm x 1.1	No. of Brick-work Specimens	Mean $\bar{x}$	Standard Dev. S.	Coef. of Variation	F'm
1	145mm width	100	29.4	23.5	10.6	53	25.2	5.97	23.7	14.9
	110mm width	108	47.7	40.5	15.3	54	24.4	4.41	18.1	16.8
2.	145mm width	46	29.0	23.0	10.5	12	21.5	2.67	12.4	16.5
	110mm width	12	57.0	48.5	15.3	8	25.7	2.36	9.2	20.9
3.	145mm width	12	38.5	30.8	12.5*	5	20.8	5.73	27.6	7.4
	110mm width	12	35.0	29.8	12.5*	6	15.3	2.48	16.2	9.5
4.	110mm common	108	31.9	27.2	11.8	27	27.6	3.49	12.7	21.5
	110mm face	96	28.7	24.4	11.0	27	23.6	4.89	20.8	15.0

* Type A Mortar, refer to Table 3 for actual mortar strength

** 1.1 is a factor to change these values from 7 days to 28 days.

BRICKWORK TABLE 7.

AS1640 BRICKWORK CODE				DRAFT STANDARD FOR MASONRY IN BUILDINGS					
Building No.	Type of Brick	Minimum Comp Strength -F'm	Comp.Strength of Weakest Specimen	F'm Table 5.1	Minimum F'm for Rejection 0.8 F'm	F'm Calculated	Minimum F'm for Rejection 0.8F'm	Minimum Comp. Strength for Sample *	Sample Min % / F'm Cal
1.	145mm width	11.5	11.5	10.6	8.5	14.9	11.9	13.2	88 (1)
	110mm width	12.6	13.5	15.3	12.2	16.8	13.4	15.2	90 (1)
2.	145mm width	12.1	16.5	10.5	8.4	16.5	13.2	19.5	118
	110mm width	17.2	22.5	15.3	12.2	20.9	16.7	24.5	117
3.	145mm width	10.7	15.3	12.2	10.0	7.4	5.9	17.0	230 (2)
	110mm width	9.7	11.7	12.2	10.0	9.5	7.6	14.8	156 (2)
4.	110mm common	16.7	22.0	11.8	9.4	21.5	17.2	23.7	110
	110mm face	13.0	16.0	11.0	8.8	15.0	12.0	17.8	119

* Average of three specimens in sample.

Note (1) One sample of 3 specimens only were under F'm calculated

(2) Large range in strengths and limited tests done on this building.