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PARAMETRIC STUDIES ON THE STRENGTH AND STIFFNESS OF REINFORCED CLAY BLOCK MASONRY

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1. ABSTRACT

This paper contains the results of the tests on fifty one four high stack bonded clay block masonry prisms with and without grout and reinforcement. The compressive strength and elastic properties are included. Effect of strength and workability of grout, percentage of longitudinal steel reinforcement and the presence of lateral tie stirrups on the strength and stiffness of masonry is discussed. The experimental results are compared with the predictions of the Australian Masonry Standard and some general and specific conclusions derived.

2. INTRODUCTION

The compressive strength and elastic properties of grouted reinforced masonry depend on large number of parameters including the properties of its constituents, method and quality of construction, curing history and testing methods. This paper describes the strength and elastic properties of grouted clay block masonry with and without reinforcement derived from compression tests on prisms. As part of an on going research at the University of Central Queensland, several prisms were tested with varying quality of grout and percentage of reinforcement of which the results of fifty one tests are included in the paper. The hollow block unit type and mortar proportion are kept constant in all the tests.

Keywords: Clay Block; Grouted Masonry; Reinforced Masonry; Strength; Stiffness.

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Hollow block masonry construction is usually face shell bedded. However when they are grouted, the fresh grout escapes through the unbedded web shell face during compaction and leave the slurry in the gaps. With a view to avoiding the practical problems, all grouted and reinforced prisms were constructed full bedded in this research. To facilitate application of the test result to the popular practical method of construction, face shell bedded prisms were also fabricated and tested. A minimum of three specimens were tested in each type.

The prisms were tested under monotonically increasing compressive load. Axial and lateral deformations were measured and failure load recorded in all tests. The load deformation and ultimate load readings were used to study the performance of the prisms under axial compression. Some interesting findings emerged out of the study which may be summarised as follows:

The grouted masonry fails at a lower stress level compared to hollow masonry. The slump and strength of the grout are found to have significant effect on the strength of the grouted masonry. For the strength of masonry used in the experimental program, an optimum strength of grout has been identified which maximised the strength of the grouted masonry. The optimal value increased with the increase in the slump of the grout. However the optimal grouted masonry strength is lower than the strength of hollow masonry. The reduction in the strength of grouted masonry has been attributed to the development of bursting fluid like pressure from within the cores due to the lateral expansion of the grout. The grout induced lateral strain is a function of the strength of grout with the “optimal grout” exerting the minimum lateral strain. Strength of grout lower or higher than the optimal strength developed more lateral strain and subsequently lowered the ultimate strength of masonry.

Reinforced masonry prisms constructed with the optimal grout and varying percentage of reinforcement exhibited increase in strength with the increase in the percentage of longitudinal reinforcement. However the presence of lateral tie stirrups were found to have no significant effect on the strength properties of masonry.

Grouted reinforced masonry piers exhibited marked nonlinear stress - strain behaviour. The stiffness of grouted and reinforced prisms were found to lie between the stiffness of ungrouted hollow masonry (lower limit) and that of the unconfined grout cylinder. Grouted prisms were significantly stiffer than the hollow prisms while the reinforced prisms were stiffer than their grouted and hollow counterparts. No systematic increase in stiffness of grouted prisms were apparent with the increase in the strength of grout. Introduction of lateral tie stirrups improved the effectiveness of longitudinal reinforcement which inturn improved the stiffness of reinforced prisms.

The prisms with increased stiffness exhibited lower ductility.

The present provisions in the Australian Masonry Code, AS3700⁽¹⁹⁾ were found to significantly under estimate the strengths of hollow masonry prisms. However the estimation of the strength of grouted and tied reinforced prisms is non conservative.

3. PREVIOUS RESEARCH

Failure of masonry is extensively covered in the literature. The subject matter reported range from solid masonry (1, 12, 13, 16) to grouted masonry (2, 3, 4, 9, 10, 11, 14, 17). While the investigations are primarily based on experiments, some theoretical work are also reported (3, 5, 7, 18). Most researchers used concrete masonry (2, 3, 4, 5, 6, 8, 12, 14, 17) and some used clay block masonry (10, 11). Methods of testing of masonry with particular reference to the effects of capping material were studied numerically and experimentally and the results have been well presented in the literature (1, 5, 7, 13, 15).

Several failure mechanisms of masonry were developed (2, 3, 6, 17, 18).

4. EXPERIMENTAL PROGRAM

Hollow, grouted and reinforced clay block masonry prisms were tested under monotonic compressive loading in the program. The hollow prisms were both faceshell and full bedded. The grouted prisms were made with varying slump and strength of grout. The reinforced prisms were made with varying percentage of longitudinal steel and with and without lateral tie stirrup at mid height of prisms.

4.1 Construction of Prisms

All prisms were made with hollow clay units of 310 x 150 x 76mm gross dimensions with two 100 x 80mm cores accounting for 34.4% core area laid in 10mm thick 1:1:6 (cement: lime: sand by volume) mortar bed. The mortar constituents were weighed batched to gain consistency at each pour.

The grouted prisms were constructed first by forming the shell and cleaning the mortar droppings and then filling the holes with three equal layers of grout compacted manually by a 16mm rod. The cores were overfilled to 25mm above the top surface to allow for the shrinkage and the excess removed after one hour of pouring. Only four high stack bonded prisms were fabricated and all prisms were moist cured for 28 days.

All prisms were tested in an Avery Compression Testing machine of 1800 kN capacity. Between the bearing surface of the prisms and the platen, a 4mm plywood capping was used as per the Australian Standard AS3700 (19). Demac points at gauge lengths of 150mm were pasted both in the longitudinal and lateral directions of the specimen prior to testing. A constant load rate of 400 kPa/sec. was maintained in all the tests. Demac points were read approximately at steps of 50 kN interval.

In the hollow prisms series face shell and full bedded prisms were constructed and tested. The hollow faceshell bedded prisms are denoted as FSP and the full bedded prisms as FBP in the subsequent sections of the paper.

In the grouted prism series seven types of grout mixes were used to fill the cores of blocks. The details of mixes used are summarised in Table 1.

TABLE 1 - DETAILS OF GROUT MIX USED

Mix Type	1	2	3	4	5	6	7
Cement Content kg/m ³	310	340	390	550	340	390	444
Water Content kg/m ³	←	275	→	→	←	240	→
10mm Aggregate kg/m ³	←	←	768	→	→	→	→
Coarse Sand kg/m ³	860	787	747	610	882	837	798
Density kg/m ³	2163	2170	2180	2203	2230	2240	2250
f_c MPa	16.10	18.50	29.00	42.00	27.20	37.65	42.78
Cylinder Designation	GC1	GC2	GC3	GC4	GC5	GC6	GC7

The value of f'_c shown in Table 1 were calculated based on compression test on cylinders fabricated using non absorbent standard steel moulds. A minimum of three cylinders were tested in each category. With a view to assessing the effect of absorbent core on the strength of grout, three grout prisms of size 80 x 100 x 160 were fabricated from type 3 mix. The characteristic strength of the grout prisms cast in absorbent cores of clay block were found to be 38.84 MPa which represents an increase of 33.9% over the strength of the corresponding grout cylinders (which is 29 MPa). This increase in strength may be attributed to the loss of moisture to the core of clay block which results in the reduction in w/c ratio. This findings is in contradiction to the findings of Scrivener and Baker (17) and in good agreement with the well established theories of concrete mix design. The masonry prisms fabricated with the seven grout mix types and referred as GP1, GP2, GP3, GP4, GP5, GP6 and GP7 respectively where GP stands for grouted prisms and the number 1 - 7 stands for the grout types.

In the reinforced prism series, area of longitudinal steel was varied from 2Y12 bars to 4Y16 bars in six steps which gave the reinforcement percentage as 0.47, 0.86, 1.33, 0.68, 0.95 and 1.72 corresponding to 2Y12, 2Y16, 2Y20, 4Y10, 4Y12 and 4Y16 bars respectively. The six category of prisms are referred as RP1, RP2, RP3, RP4, RP5 and RP6 in the paper. The 4Y10, 4Y12 and 4Y16 category prisms were also investigated for the effect of lateral ties at mid height of prism. R6 bars were used as ties. The three tied prisms are referred as TP1, TP2 and TP3 in the paper.

5. FAILURE OF MASONRY PRISMS

The results of the experimental investigation are summarised in Table 2. The mean and characteristic strengths of the prisms and the initial tangent modulus and the initial lateral strain to longitudinal strain ratio (Poisson's ratio in hollow prisms) are included in the Table. This section describes the strength properties of the prism while the ensuing section contains discussion on the elastic properties.

5.1 Modes of Failure

The failure modes of FSP, FBP, GP, RP and TP categories of prism are shown photographically in Figure 1. The FSP failed by developing vertical cracks first at the external web shells (unbedded shells) with subsequent minor crackings at the face shells usually confined to the corners.

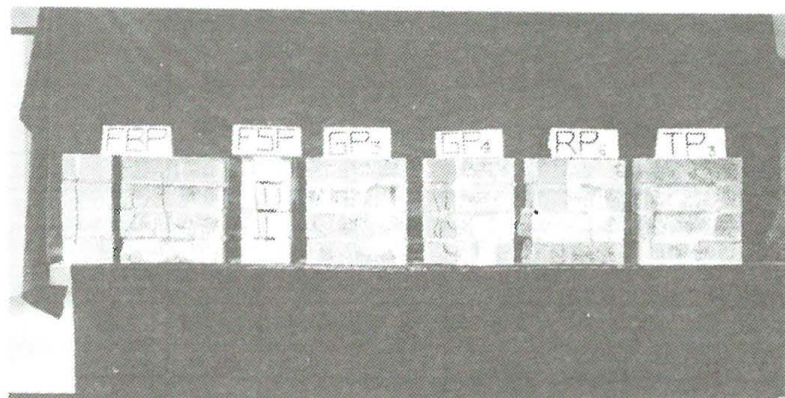


Figure 1 - Failure modes of prisms in axial compression

The FBP failed due to vertical cracks in face shells.

The failure of GP categories were characterised by the development of the cracks on the face and web shells at levels 30% of ultimate load and subsequent spalling of the shells at ultimate load level. The grout, due to confinement derived from the shell, did not typically exhibit visual cracking. GP3 category prisms showed some visual cracking and some distress in the grout infill at failure.

The failure characteristics of RP categories were similar to that of GP categories. The TP category prisms also behaved similar to RP category ones but the crack initiation and opening were noisy and the ultimate failure explosive.

TABLE 2 - SUMMARY OF TEST RESULTS

Prism Category	No. of Prisms	Mean Strength (MPa)	COV	Charact. Strength (MPa)	AS3700 Prediction (MPa)	$\frac{(6)-(5)}{(5)} \times 100\%$	E (GPa)	$\frac{E_{Lateral}}{E_{Longiude}}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
FSP	3	19.20	11.0	12.60	8.00	-58%	-	-
FBP	6	23.94	9.8	16.64	8.25	-101%	8.50	0.13
GP1	3	14.52	2.8	12.94	12.36	-5%	17.50	0.30
GP2	3	18.20	4.0	12.54	12.49	-0.5%	17.60	0.25
GP3	3	24.44	11.9	15.17	12.83	-18%	12.50	0.20
GP4	3	18.90	11.2	12.60	13.25	+5%	13.33	0.27
GP5	3	17.70	1.8	12.54	12.79	+2%	-	-
GP6	3	22.29	8.7	15.17	13.13	-2%	-	-
GP7	3	16.30	8.9	10.53	13.27	+21%	-	-
RP1	3	21.64	6.4	14.86	↑	-16%	15.0	0.16
RP2	3	22.74	5.4	15.34	↑	-20%	14.2	0.27
RP3	3	23.86	5.0	16.74	12.83	-30%	18.0	0.35
RP4	3	22.50	5.0	15.97	↓	-25%	14.0	0.31
RP5	3	23.00	5.1	16.10	↓	-26%	14.4	0.26
RP6	3	25.75	2.0	18.10	↓	-41%	16.3	0.22
TP1	3	24.30	3.8	17.60	15.60	-13%	13.65	0.36
TP2	3	23.50	6.7	15.32	16.60	+8%	15.63	0.42
TP3	3	26.00	3.3	18.10	19.70	+8%	18.00	0.41

5.2 The Strength of Prisms

The mean strengths of the varying categories of the prism shown in column 3 of Table 2 have coefficients of variation in the range of 1.8% - 11.9% as shown in column 4. The characteristic compressive strengths were worked out to account for this variability based on AS3700⁽¹⁹⁾ using the following relation for a test size of 3:

$$f_m = 0.72f_{\min} \quad (1)$$

where f_{\min} = least of the individual results in a set. The characteristic strengths (Column 5) which represent 95% confidence level will only be addressed in this paper.

Strength of hollow prisms has been estimated from the strength of units and the proportion of the mortar using the relationship given in AS3700⁽¹⁹⁾ and presented in column 6 of Table 2. To evaluate the values, characteristic unit strengths of 33.23 MPa and 31.65MPa for faceshell and full bedded loading respectively were used. AS3700⁽¹⁹⁾ method underestimates the strengths of FSP category prisms by 58% and FBP prisms by 101%. FBP category is 33% stronger than the FSP category. This finding is in good agreement with the theoretical studies reported by Ganesan and Ramamurthy(5).

Strength of grouted prism (GP categories) were estimated using the following formula of AS3700⁽¹⁹⁾:

$$f_{gp} = \left[f_m A_b + 1.2 \sqrt{\frac{f_c}{1.3}} A_g \right] / [A_b + A_g] \quad (2)$$

where f_m = characteristic strength of masonry derived from prism tests.

f_c = characteristic strength of grout.

A_b = area of bed joint and A_g = Area of grout.

The AS3700⁽¹⁹⁾ method of estimating GP categories of prism is non conservative particularly for the grouted clay masonry with higher strength grout than the block strength.

A graphical presentation of the effect of grout strength on the prism strength is shown in Figure 2. Effect of workability and strength of grout on the strength of masonry is clearly evident from this graph.

From Figure 2, it appears that there exists an optimal grout strength which maximises the prims strength for each workability category. With the limited number of tests presented in the paper, for the masonry strength of 16.64 MPa, a grout strength of 33 MPa which is approximately twice the strength of masonry appears optimal. Further testing is necessary to conclude this finding.

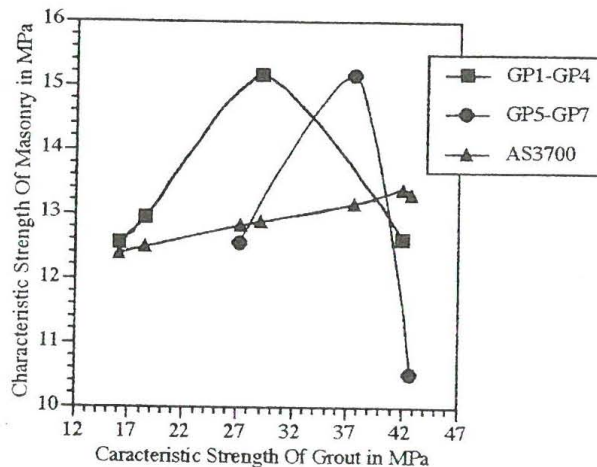


Figure 2 - Effect of grout on masonry strength

Differential lateral strain developed between the masonry shell and infill grout is taught to be the reason for the variation of prism strength. This hypothesis is further developed in the ensuing section.

Reinforced masonry prisms exhibited increase in strength with the increase in percentage of reinforcement as shown in Figure 3.

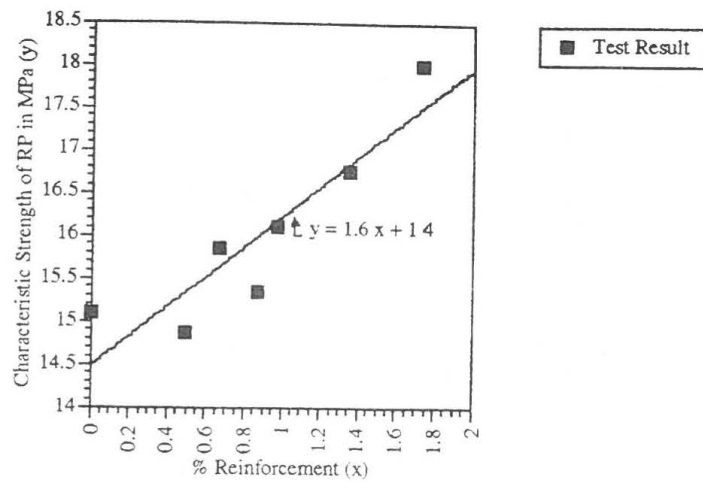


Figure 3 - Effect of the percentage of vertical steel on the strength of masonry

The AS3700 (19) prediction for RP categories were based on the following formula.

$$f_{rp} = \left[f'_m A_b + 1.2 \left(\sqrt{\frac{f'_c}{1.3}} \right) Ag + f'_{sy} A_s / [A_b + A_g] \right] \quad (3)$$

in which $f'_{sy} = 400$ MPa and $A_s =$ zero (for untied reinforcements the area is neglected to allow for lateral buckling of steel).

The predicted results were significantly lower than the experimental results. For tied prisms (TP categories) the strength was estimated using the formula (3) with the correct value of A_s substituted. It is interesting to notice that for very small longitudinal reinforcement ratio (0.68%) the prediction is conservative, but for higher amount of reinforcement the experimental values are lower than the predicted values. By comparing the results of (RP4 - TP1), (RP5 - TP2) and (RP6 - TP3), it may be seen that the tie stirrups are effective only for prisms with smaller reinforcement percentages. This finding may have some relation to the diameter of the stirrup used as reported recently by Khalaf et al (8).

6. THE ELASTIC PROPERTIES OF MASONRY PRISMS

The stress-strain behaviour of the various categories of prisms are included in Figures 4 and 5. Figure 4 illustrates the effect of grouting on the stiffness of prism while the effect of reinforcing is shown in Figure 5. The lateral strains measured in each case are also included in the figures.

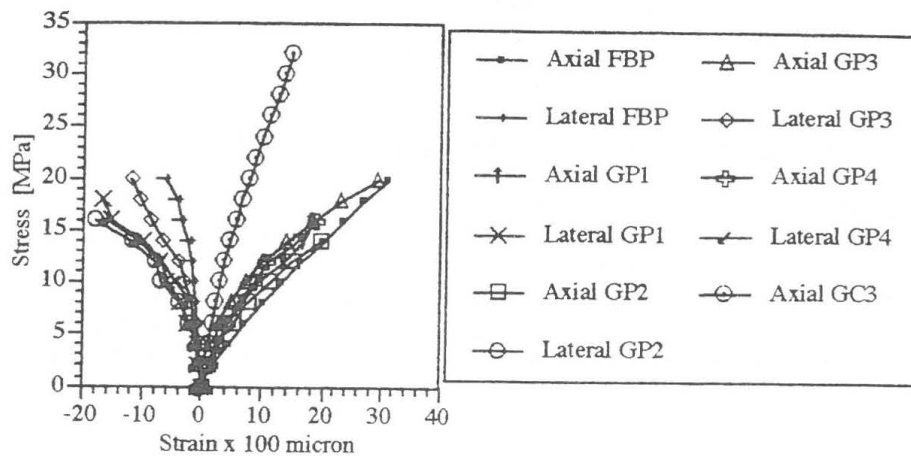


Figure 4 - Stress strain curves of ungrouted and grouted prisms

From the initial slopes of the axial stress - axial strain diagram, the E values were worked out and included in column 8 of Table 2. The initial linear slopes of lateral strain - axial strain diagram are presented in column 9 of Table 2.

While the grouted prisms are generally stiffer than their ungrouted counterparts, the increase in stiffness is found to vary from a minimum of 47% (GP3) to a maximum of 107% (GP2). No systematic increase in stiffness with the increase in strength of grout is however, apparent.

The stiffness of the prism increases with the inclusion of reinforcement. Even a 0.47% of reinforcement (RP1) increased the stiffness of the prism by 20% in comparison with the unreinforced grouted counterpart (GP3). No systematic increase in stiffness with the increase in % of steel is also apparent. At higher values of longitudinal reinforcement ratio, the tied prisms (TP2 & TP3) were found to be stiffer than the untied counterparts (RP5 & RP6).

The ratio of lateral to longitudinal strain presented in column 9 corresponding to the hollow prisms represents Poisson's ration of masonry. The values corresponding to GP, RP and TP category prisms are however affected by the differential lateral expansion of the grout and masonry and hence cannot be regarded as Poisson's ratio. Assuming the lateral strains measured in such prisms could be expressed as the sum of lateral strains due to Poisson's effect of masonry and grout expansion, the lateral strain exerted by the grout on the prism shell at varying axial strain levels could be determined using the following relation.

$$\epsilon_{lateral}^{grout} = \epsilon_{lateral}^{measured} - \nu^{masonry} \epsilon_{axial}^{masonry}$$

in which $\nu^{masonry} = 0.13$ from Table 2.

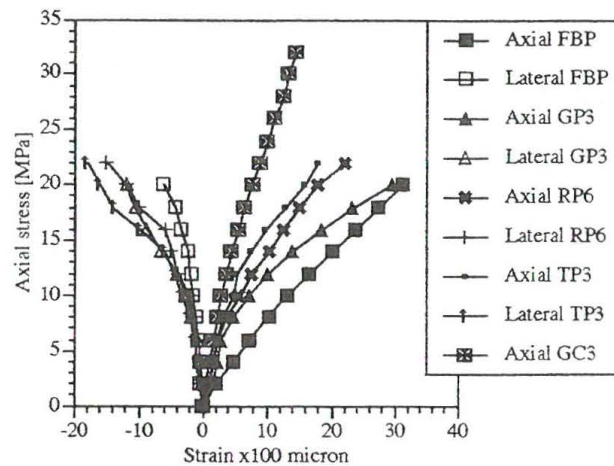


Figure 5 - Stress strain curves of ungrouted, grouted, reinforced and tied prisms

The values of the lateral strain due to grout pressure has been worked out for axial strain levels of 10, 12 and 16 micro strains for GP1, GP2, GP3 and GP4 categories of prism and graphically presented in Figure 6. It is interesting to note that at the axial strain levels chosen, GP3 category prisms registered the lowest values. It may be recalled from Figure 3 that this category of prism was close to the optimal value. The minimum differential lateral strain explains the maximum strength of the prisms of GP3 category.

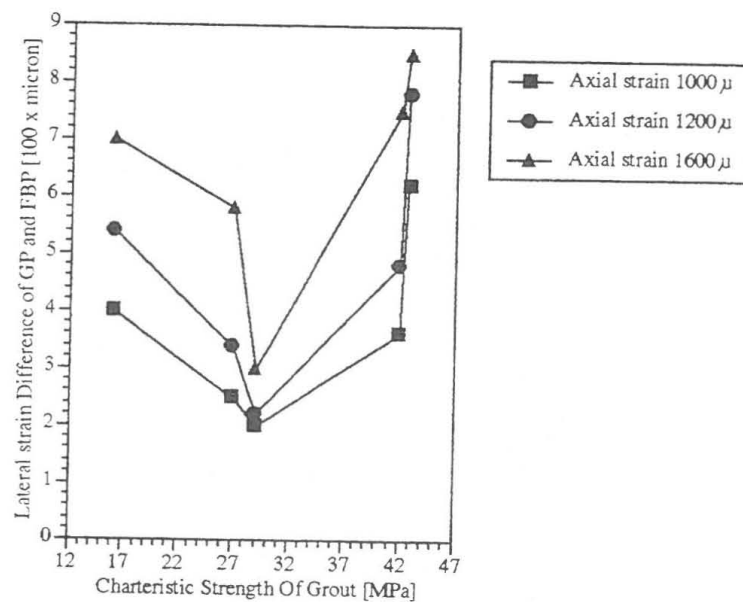


Figure 6 - Effect of grout on the lateral strain difference.

7. SUMMARY

The compressive strength and elastic properties of grouted clay block masonry with and without reinforcement derived from tests on fifty one four high stack bonded prisms were reported in the paper. The following are some general conclusions:

- (i) Full bedded prisms are at least 33% stronger than the face shell bedded prisms.
- (ii) Full bedded hollow prisms are stronger than the grouted prisms.
- (iii) Grouted prisms are stiffer than the hollow prisms.
- (iv) Reinforced prisms are stronger and stiffer than the unreinforced grouted prisms.

The following conclusions are specific to the type of masonry tested:

- (i) There exists an optimal grout strength for the type of masonry tested. The optimal grout strength is approximately equal to twice the strength of masonry.
- (ii) The AS3700 (19) method of estimating strengths of grouted and tied reinforced masonry is non conservative.

8. ACKNOWLEDGMENT

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9. REFERENCES

- (1) Brooks, J.J. and Ajmad, M.A., "Elasticity and Strength of Clay Brickwork Test Units", Proceedings 8th IB²Mac, Dublin, Ireland, September 1988, pp 342-349.
- (2) Colville, J. and Wolde-Tinsae, A., "Compressive Strength of Grouted Concrete Masonry", Proceedings 9th IB²Mac, Berlin, Germany, October 1993, pp 149-156.

- (3) Cheema, T.S. and Klingner, R.E., "Compressive Strength of Concrete Masonry Prisms", ACI Journal, January - February 1986, pp 88-97.
- (4) Drysdale, R.G. and Hamid, A.A., "Behaviour of Concrete Block Masonry Under Axial Compression", ACI Journal, June 1979, pp 707-72.
- (5) Ganesan, T.P., and Ramamuthy, K., "Behaviour of Concrete Hollow Block Masonry Prisms Under Axial Compression", No 7, July 1993, pp 1751-1769.
- (6) Hamid, A.A., and Drysdale, R.G., "Suggested Failure Criteria for Grouted Concrete Masonry", ACI Journal, October 1979, pp 1047-1061.
- (7) Hamid, A.A., and Chukwunenge, A.O., "Effect of Bearing Plate Properties on the Behaviour of Block Masonry Prisms Under Axial Compression", J. of Testing and Evaluation, ASTM, Vol 14, No 3, May 1986, pp 156-159.
- (8) Khalaf, F.M., Hendry, A.W., and Fairbairn, "Reinforced Brickwork Masonry Columns", ACI Structures J. Vol 90, No. 5, September - October 1993, pp 496-504.
- (9) Kingsley, G.R., Tulin, L.G., and Noland J.L., "Parameters Influencing the Quality of Grout in Hollow Clay Masonry", Proceedings 7th IBMac, Melbourne, February 1985, pp 1085-1092.
- (10) Kingsley, G.R. and Atkinson, R.H., "Comparison of the Behaviour of Clay and Concrete Masonry in Compression", 4th Canadian Masonry Symposium, 1986.
- (11) Kumar, M., and Dhanasekar, M., "Effect of Grout on the Compressive Strength of Clay Block Masonry", Proceedings PG Symposium, UCQ, Rockhampton, August 1993, pp 93-102.
- (12) Orr, D.M.F., and Mannion, M.P., "Shell Bedded Solid Concrete Block Masonry", Proceedings 9th IB²Mac, Berlin, Germany, October 1991, pp 229-225.
- (13) Page, A.W., "Influence of Brick and Brickwork Prism Aspect Ratio on the Evaluation of Compressive Strength", Proceedings 7th IBMac, Melbourne, February 1985, pp 653-663.
- (14) Page, A.W., Simundic, G. and Xie, H., "A Study of the Relationship between Unit, Prism and Wall Strength for Hollow Masonry Loaded in Compression", Proceedings 9th IB²Mac, Berlin, Germany, October 1993, pp 236-243.
- (15) Page A.W., and Kleeman, P.W., "The Influence of Caping Material and Platen Restraint on the Failure of Hollow Masonry Units and Prisms", Proceedings 9th IB²Mac, Berlin, Germany, October 1993, pp 662 - 670.
- (16) Schubert, "Compressive and Tensile Strength of Masonry", Proceedings 8th IB²Mac, Dublin, Ireland, September 1988, pp 406-419.
- (17) Scrivener, J.C., and Baker, L.R., "Factors Influencing Grouted Masonry Prism Compressive Strength", Proceedings 8 IB²Mac, Dublin, Ireland, September 88, pp 875-883.
- (18) Shrive, N.G., "Compressive Strength and Strength Testing of Masonry", Proceedings 7th IBMac, Melbourne, Australia, February 1985, pp 699-709.
- (19) Standards Association of Australia, "AS3700" Masonry in Buildings", 1988.