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RÉSUMÉ

L'effet de différents facteurs sur la résistance à la compression de petits échantillons de maçonnerie (prismes) est vérifié à l'aide de deux types de briques d'argile et de deux largeurs de bloc creux en béton. Les résultats d'essai sont ensuite examinés.

PROCEEDINGS

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ABSTRACT

The effect of different factors on the compressive strength of small masonry specimens (prisms) is checked using two types of clay brick and two widths of hollow concrete block. The test results are reviewed.

INTRODUCTION

The Canadian masonry design standard for buildings (1) allows two methods of determining compressive strength of masonry: tabular values based on unit strength and mortar type, or axially loaded prisms such as two-course blockwork stacks. The latter method is more accurate and usually gives higher allowable design stresses, but to have confidence in the result a number of factors (2) should be considered. This paper describes the effects of various factors on prism strength, based on tests in progress at the Division of Building Research. Some of the factors considered have already been investigated (2).

The work is part of a larger masonry test program designed 1) to provide information on the variability of compressive strength and compressive modulus, partly in preparation for the introduction of limit states design for masonry in Canada, 2) to compare the compressive strength of small specimens (prisms) with that of large specimens (walls), and 3) to check the table in the Canadian masonry design standard relating masonry compressive strength to the compressive strength of the units.

The work on prisms has so far considered two types of brick and two sizes of hollow concrete block. It is the purpose of this paper to give an overview of the results of current investigations:

1) Effect of height to thickness ratio
2) Effect of capping - dental plaster versus fibreboard
3) Face-shell and full mortar bedding
4) Workmanship
5) Loading rate
6) Stack versus running bond

7) Age: 7- versus 28-day strength

Item 3 applies to hollow units; items 4 to 7 have so far been investigated only for brick.

MATERIAL PROPERTIES

Units

Two clay bricks with three circular perforations were used, one a high-strength extruded brick, the other a low-strength pressed brick. Their properties are given in Table 1.

The properties of the 140 mm and 190 mm thick, 2-core, autoclaved, hollow concrete blocks are given in Table 2. The wet strength of the block is also given to illustrate the effect of moisture on strength.

Mortar

Two mortar mixes were used, with mix proportions by volume of normal portland cement:hydrated lime:sand of 1:0.5:4.5 (Type S) for brickwork and 1:1:6 (Type N) for blockwork. The average strength of 50 mm mortar cubes at 28 days was 10.1 and 6.6 MPa, respectively (3). The mortar was batched by weight and mixed in a 0.1 m^3 (4 cu ft) standard mortar mixer.

CONSTRUCTION

All units were randomly redistributed (except for some inital tests) to ensure a uniform distribution of unit properties before prism construction. A minimum of ten (usually twelve) replicates were tested for each factor. Unless otherwise noted, the test specimens were four-course stacks for brickwork and two-course stacks for blockwork. Most prisms were built by a technician using a jig to ensure that the prism was plumb and the coursing correct. Full mortar joints were ensured by use of a mortar template allowing the top of the joint to be screeded flat before the next unit was placed.

Prisms built to investigate workmanship and compare stack to running bond were built by a mason. He used neither a jig nor a mortar template, but a course rod was provided and a level was used to keep prisms level and plumb.

Brickwork prisms were cured in the laboratory under polyethylene until tested at 7 or 28 days, except for those built by the mason (as part of the wall test program); these were cured under polyethylene for 7 days and then in air until tested at 28 days. Blockwork prisms were cured in air.

Where dental plaster was used for capping, the work was done before the units were incorporated in the prism. Running bond prisms were capped with mortar and screeded flat.

TEST PROCEDURE

All tests were carried out in a 1.8 MN (400,000 lbf) Riehle test machine. Prisms were capped with 11 mm thick fibreboard, except for some tested with a plaster cap only. Blockwork prisms with face-shell bedding were capped with fibreboard strips placed on the face-shell area (full capping causes premature vertical tensile cracking as a result of bending in the web sections not bedded in mortar).

The loading rate was chosen so that the test duration from half to maximum load would take approximately 1 to 2 min. This resulted in load rates of 180 kN/min for the extruded brick prisms and 135 kN/min for the pressed brick prisms and blockwork. Running bond prisms, workmanship prisms, and load rate prisms were tested at a slower rate. At failure, the load controls were not altered, thereby approximating to a constant strain rate instead of a constant load rate.

RESULTS

Height-to-Thickness Ratio

The ultimate masonry prism strength in the masonry standard is derived from prisms with a height-to-thickness (h/t) ratio of 5 for brick masonry and 2 for concrete block and structural clay tile masonry. If prisms with different h/t ratios are tested, a correction factor is applied to the result (see Table 3). This factor assumes that the lower the h/t ratio, the stronger the prism. Variation in strength with h/t is assumed to be the same for all prisms.

The test results from the present program are given in Table 4. The results for the 140 mm block prisms include the strength of a single block tested with fibreboard on the face-shell area. Figure 1 shows the variation in strength with h/t ratio by setting the strength at h/t ratios between 5 and 6 equal to one. It also shows the assumed increase in prism strength, based on correction factors given in the masonry standard. As the factors are based on the same experimental data (4,5), the same relation is used for both concrete block and brick masonry. The assumed increase in strength is shown to be too large for the prisms tested, expecially for the concrete block prisms.

Capping

Prisms are normally capped to ensure a more uniform load distribution. The masonry standard (1,6) specifies a sulfur or a dental plaster capping, but if many prisms have to be tested this requirement means much extra work. The use of fibreboard capping as an alternative was therefore investigated. Fibreboard is simple, cheap and quick and has been commonly used to test concrete blocks for quality control purposes. Tables 5 and 6 give the results for prisms tested with fibreboard and plaster capping. The mean strengths are similar, with fibreboard capping giving slightly lower results (0.97 and 0.96 for the brickwork and 0.99 and 0.92 for the blockwork).

Face-shell versus Full Mortar Bedding

Plain, hollow unit masonry is normally laid with mortar on the face-shells but not on the webs. Prisms should also reflect this practice because prisms with face-shell bedding fail at a lower stress than do those with full bedding (mortar on face-shells and webs) if, as is normally the case, the net block area is used in determining the failure stress. This problem can be avoided if it can be shown that failure stresses are similar if the mortar bedded area is used instead of the net block area.

Prism test results using both face-shell and full mortar bedding are given in Table 6. The ratios of failure stress, based on mortar bedded area, are 0.99 and 1.10 (face-shell bedding/full bedding).

Workmanship

Most of the prisms in the present program had full mortar joints and were made in a jig by a technician. They represent "ideal" workmanship. Prisms made by a mason may give different results. A mason was therefore employed to build 7-course, stack-bonded prisms without a jig; at the same time, and using the same mortar, similar prisms were built by a technician. The results are shown in Table 5. The strength ratio of mason-built to jig-built specimens was 0.92 and 0.66 for pressed and extruded brick, respectively. Workmanship is shown to be an important factor for high-strength, extruded-brick masonry, probably owing to incompletely filled mortar joints primarily caused by furrowing of the mortar joint. The pressed brick has larger perforations, so that incomplete filling along the centre of the joint may not be so critical.

Loading Rate

The load rates (in terms of stress) used for the brickwork ranged from 9.5 MPa/min for the extruded brick prisms to approximately 0.3 MPa/min for the running bond prisms made from pressed brick. The latter rate was slow to allow time for strain measurements and crack detection.

Four-course brickwork stacks were tested to discover whether a slow load rate affected strength. The normal load rate of 9.5 MPa/min or 7.5 MPa/min for extruded and pressed brick prisms, respectively, was applied up to 80 per cent of the ultimate characteristic strength. The rate was then reduced to 0.30 MPa/min until failure (at failure the load controls were not adjusted to keep up the load rate). The results are shown in Table 5. The ratios of strength for slow to normal load rate were 0.93 and 0.96, indicating a slight reduction.

Stack versus Running Bond

Prisms are normally built in stack bond, although the walls they are meant to represent are normally in running bond. Table 5 gives the results of some mason-built brickwork prisms, one a set of 7-course, stack bond prisms, the other 7-course, 1 1/2 brick long prisms in running bond. The running bond prisms gave lower results - ratios of 0.87 and 0.94 for the two types of brick tested.

Age

The standard test age is 28 days, but shorter periods such as 7 days may be more convenient, especially if prisms are used for quality control. The present design code permits the 7-day test provided the 7 to 28-day strength ratio is determined; alternatively, this ratio may be taken to be 0.9. Test results for the 7 and 28-day strengths are given in Table 5, which shows that the ratio of 7 to 28-day strengths varies from 0.81 to 0.90.

DISCUSSION

The mean strength is used in this paper in comparing the test results. Mean strength, however, is not used directly for design. The masonry standard requires the use of the characteristic strength, a value below which only approximately 10 percent of the test results will fall. Its value is given by $\bar{x}(1 - 1.5v)$ where $\bar{x}$ is mean strength and v is coefficient of variation. The characteristic strength, which is more uncertain than the mean strength, should be based on a sample large enough to give reasonably reliable results. Beech (7) recommends a minimum of ten replicates, although this minimum will increase with higher coefficients of variation. The test results in this paper are usually based on twelve replicates, although more are often used, especially for unit tests.

Some general conclusions have been drawn from the present results, but they should be taken only as suggestions until more data are reviewed and further test results become available. A future paper will review existing data on the compressive strength of prisms.

The correction factors in the masonry standard for height-to-thickness ratio given in Table 3 are meant to be conservative, but this is not the case for blockwork prisms with h/t ratios greater than two. If the correction factor of 1.2 is used for the three-course, 190 mm block prism tested (h/t = 3), this overestimates the strength by 18 percent in comparison with the two-course prism (h/t = 2). The test results indicate that height-to-thickness correction factors may not be necessary in many cases. Minimum prism size could instead be specified. Except for the shortest prisms the number of units in a stack-bonded prism may be more significant, depending on variability in the strength of the units, because the more units in a prism the greater is the likelihood of a weak unit.

Fibreboard is a viable alternative to plaster capping. Prisms having irregular surfaces would still need to be capped with plaster or mortar in addition to fibreboard. In comparison with plaster capping, fibreboard gave slightly lower results. Other results (8) comparing fibreboard with mortar capping for two high concrete block prisms with full mortar bed gave a lower ratio: an average of 0.90 compared with 0.92 and 0.99 in the present tests.

Ultimate stresses based on mortar bedded area gave similar results for both face-shell and full mortar bedding. This agrees with other experimental results (9).

The relation between 7- and 28-day strength is also similar to that of previous results (10). The value of 0.9 adopted in the masonry standard is meant to be an upper limit, and agrees with the values for the prisms tested.

Running bond gave somewhat lower results than stack bond, although earlier results have shown no change in strength (11). The earlier results are based on prisms with full bed joints (no furrowing allowed).

A slow load rate gave a slight reduction in strength, but further tests are needed to confirm this.

Although the factors under discussion affect prism strength, thay can be minor in comparison with such factors of workmanship as incomplete filling of the mortar joint. This can cause a large reduction in strength in solid brick prisms. Previous work on brick prisms by Anderson (12) showed such a result. Although the pressed brick prisms in the present tests did not show a large difference between mason-built and jig-built prisms, a large change was observed for the extruded brick prisms. It was even more marked in terms of characteristic strength, since the variation in strength is greater for the mason-built prisms. The characteristic strength of these prisms was 23.2 MPa in comparison with 40.3 MPa for the jig-built prisms. The masonry standard tabular value, based on unit strength and mortar type, is also higher than for the mason-built prisms (25 MPa for Type S mortar and a characteristic brick strength of 99 MPa). Thus, workmanship must be taken into account when building brick prisms, especially because the practice of furrowing the mortar joint is common.

CONCLUSIONS

Care must be taken that prism construction is representative of practice on the building site, including the use of face-shell bedding instead of full bedding with hollow concrete blocks (unless stresses are based on mortar bedded area) and furrowing of the mortar joints in masonry using solid units.

The masonry standard correction factors applied to hollow concrete block prisms with height-to-thickness ratios greater than two should be no larger than one(the factor for a height-to-thickness ratio of two).

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NOTATION

A_f = mortar bedded face-shell area
A_g = gross area
A_n = net area
h = height
IRA = initial rate of water absorption
n = number of replicates
t = thickness
v = coefficient of variation
$\bar{x}$ = mean value

TABLE 1 BRICK PROPERTIES

Property	Pressed Brick $\bar{x}$ (n=24)	Pressed Brick v%	Extruded Brick $\bar{x}$	Extruded Brick v%	Extruded Brick n
Mass (kg)	1.66	1.6	1.89	1.0	15
Density (kg/m^3)	2019	2.5	2092	0.6	15
24-hr water absorption(%) by wt	8.6	16	7.3	11	15
by vol	17.3	13	15	11	15
Percent solid	79	1.0	84	0.7	15
IRA ($kg/m^2/min$)	3.2	40	1.8	14	20
Dimensions(mm) length	193	0.8	204	0.3	30
height	53	1.0	57	0.8	30
thickness	93	1.2	93	0.6	30
Compressive strength (MPa) plaster	33	24	114	8.9	30
fibrebd.	27	24	95	11	29

Note: All tests on air-dry units stored in the laboratory; compressive strength based on gross area, IRA on net area; prism tests comparing plaster with fibreboard capping used a different batch of extruded bricks ($\bar{x}$ = 98 MPa, v = 6.9%, n = 33).

TABLE 2 BLOCK PROPERTIES

Property	140 mm $\bar{x}$ (n = 10)	140 mm v%	190 mm $\bar{x}$	190 mm v%	n
Mass (kg)	12.60	1.2	17.15*	0.5	10
Density (kg/m^3)	2161	0.5	2107	0.4	20
24-hr water					
absorption(%) by wt	5.69	1.3	5.95	3.6	20
by vol	12.3	1.0	12.5	3.3	20
Percent solid	56.5	0.6	55	0.8	20
Dimensions(mm) length	391	0.0	397	0.1	40
height	188	0.4	193	0.3	40
thickness	140	0.0	194	0.2	40
Compressive strength					
(MPa) plaster	21.4	3.9	22.0	8.5	20
fibrebd., dry	18.2	6.3	18.6	13.9	51
wet	15.0	5.2	14.9	6.4	20

*Mass of block with two end recesses. Block with one end recess: 17.32 kg, v = 0.6%, n = 10. Other results in column based on blocks with one and two end recesses.

Note: All tests on air-dry units stored in the laboratory; compressive strength based on net area; wet units soaked for 1 to 2 days (water abs by wt approx 6%); a second batch of 190 mm blocks gave similar results: compressive strength (fibreboard cap)-
Dry unit $\bar{x}$ = 18.9 MPa, v = 10.3%, n = 24;
Wet unit $\bar{x}$ = 13.4 MPa, v = 9.8%, n = 12

TABLE 3 CORRECTION FACTORS FOR PRISMS
(Based on Table 1, CAN3-S304-M78)

Ratio h/t	Correction Factor: Brick Masonry	Correction Factor: Concrete Block	Assumed Increase in Strength: Brick-work	Assumed Increase in Strength: Blockwork	
1.5	-	0.86	-	1.16	1.59*
2.0	0.73	1.00	1.37	1.00	1.37
2.5	0.80	1.11	1.25	0.90	1.23
3.0	0.86	1.20	1.16	0.83	1.14
3.5	0.91	-	1.10	-	
4.0	0.95		1.05		
4.5	0.98		1.02		
5.0	1.00		1.00		

*Adjusted so that the factors are the same for brickwork and blockwork at h/t = 2.0.

TABLE 4 PRISM STRENGTH VERSUS HEIGHT TO THICKNESS RATIO

Courses	Jig			Mason		Jig			Mason	
	h/t	$\bar{x}$ MPa	v %	$\bar{x}$ MPa	v %	h/t	$\bar{x}$ MPa	v %	$\bar{x}$ MPa	v %
	Pressed Brick					Extruded Brick				
3	2.1	17.6	13	-		2.1	39.5	6.3	-	
4	2.8	17.1*	16	17.9	15	2.8	36.7	8.3	31.1	15
5	3.5	17.0	17	-		3.5	34.1	6.6	-	
6	4.3	15.7	21	-		4.3	34.6	5.1	-	
7	5.0	15.8	15	17.6	12	5.0	36.1	8.7	29.0	13
	140 mm Block, n = 10					190 mm Block				
1	1.3	20.1	4.7	-		-				
2	2.8	14.7	4.8			2.0	14.9	3.6		
3	4.2	14.3	3.0			3.1	14.5	5.4		
4	5.6	13.9	4.3							
5	-					5.2	14.3	3.9		

* n = 36

Note: Stresses based on gross area for brickwork and mortar bedded area for blockwork; blockwork: face-shell bedding; A_f/A_g = 0.44 (140 mm), 0.39 (190 mm); 7-day test except mason-built prisms tested at 28 days; 12 replicates except as noted.

TABLE 5 BRICKWORK PRISM RESULTS

		Pressed Brick		Extruded Brick	
		$\bar{x}$ (MPa)	v (%)	$\bar{x}$ (MPa)	v (%)
Load Rate					
Jig	slow	15.9	12	35.3	4
	standard	17.1[1]	16	36.7	8
	ratio	0.93		0.96	
Bond Pattern[2]					
Mason					
	running bond	15.3	9	27.2	17
	stack bond	17.6	12	29.0	13
	ratio	0.87		0.94	
Age					
Jig	7 day	17.1[1]	16	37.2	5
	28 day	19.1	13	41.8	5
	ratio	0.90		0.89	
Mason	7 day	14.6	24	25.3	17
	28 day	17.9	15	31.1	15
	ratio	0.82		0.81	
Workmanship[2]					
	mason	17.6	12	29.0	13
	jig	19.1	11	43.7	5
	ratio	0.92		0.66	
Capping					
Jig	fibreboard	17.1[1]	16	35.2[3]	7
	plaster	17.7[4]	15	36.6[5]	8
	ratio	0.97		0.96	

[1] n = 36 [2] 7 courses; h/t = 5; 28d [3] n = 32 [4] n = 24 [5] n = 33

Note: Stresses based on gross area; all tests at 7 days except as noted; all values average of 12 except as noted.

TABLE 6 BLOCKWORK PRISM RESULTS

	140 mm Block		190 mm Block	
	$\bar{x}$ (MPa)	v (%)	$\bar{x}$ (MPa)	v (%)
Capping				
Fibreboard	14.7	5	13.9	14
Plaster	14.8	6	15.2	5
Ratio	0.99		0.92	
Fibreboard	-		14.0*	4
Fibrebd. + plaster	-		14.0*	7
Ratio	-		1.00	
Mortar bedding				
Face-shell	14.7	5	13.9	14
Full bed	14.8	4	12.6	10
Ratio	0.99		1.10	

* n = 12

Note: All prisms 2 course stacks, tested at 7 days.
Face-shell bedding except as noted.
Values average of 10 except as noted.
Stresses based on mortar bedded area:

A_f/A_g 0.44 (140 mm); 0.39 (190 mm)

A_n/A_g 0.56 ; 0.55

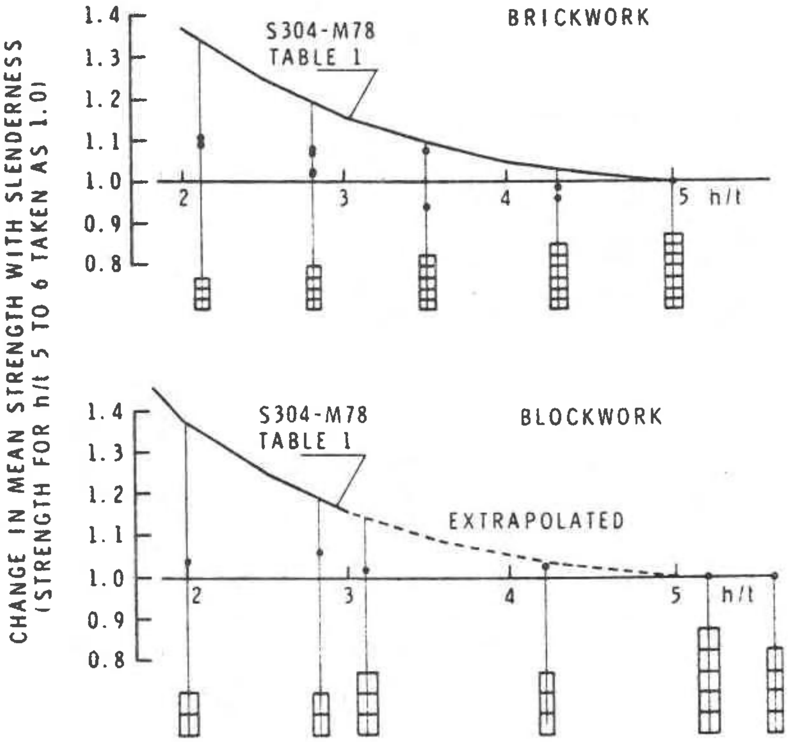

FIGURE 1

MEAN STRENGTH VS HEIGHT TO THICKNESS RATIO

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