Structural performance of Benex masonry – hollow and solid blocks

Report number DTS767
CSIRO job number JK13ATS3468
Date of issue 31 October 2007

Client
Benex Technologies Pty Ltd
Lot 102 Canobolas Road
Orange NSW 2800
ABN/ACN 113 137 232

Commercial-in-confidence

CSIRO Materials Science & Engineering

Structural Engineering Laboratory

14 Julius Avenue Riverside Corporate Park
North Ryde NSW 2113 Australia

www.csiro.au/org/CMSE

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Structural performance of Benex masonry – hollow and solid blocks

1 INTRODUCTION

CSIRO has been involved in evaluating the structural performance of Benex masonry for more than one year with the aim of the investigation to establish the characteristic performance as per the BCA (Building Code of Australia) requirements. As far as structural requirements are concerned the BCA governs masonry by setting down a general performance requirement and then deeming that any masonry complying with the SAA masonry code (AS3700-2001) satisfies this requirement. The standard AS3700 provides basic information and methods of design and construction which can be used by architects, engineers and contractors to satisfy the BCA.

The standard AS3700 covers the requirements for the design and construction of masonry (including unreinforced, reinforced and prestressed) built with manufactured clay, calcium silicate, concrete units laid in mortar, AAC (autoclaved aerated concrete) laid in thin-bed mortar, and square-dressed natural stone laid in mortar. Benex masonry is an innovative masonry construction system in which a lightweight block (Benex soild and hollow block) is laid in a thin-bed of mortar similar to AAC. Being a newer system it is not covered by the existing standard and reliance is placed on appraisals and accreditation.

With this in mind, Benex Technologies commissioned CSIRO to investigate the applicability of the AS3700 provisions to Benex masonry.

2 OBJECTIVES

The method of structural design of a masonry element is dependent on the manner of loading. Masonry elements are usually loaded by vertical compressive forces due to dead loads and live loads. Masonry elements which provide sway resistance to a structure, such as shear walls and in-fill panels, are required to resist in-plane shearing loads. The exernal wall element must resist wind loads acting normal to the wall. Frequently, masonry is required to resist a combination of these loading types. However, for simplicity of analysis, it is common to consider only one aspect of loading at a time for a given element.

This investigation aims to study the behaviour of Benex masonry under the action of the following loads:

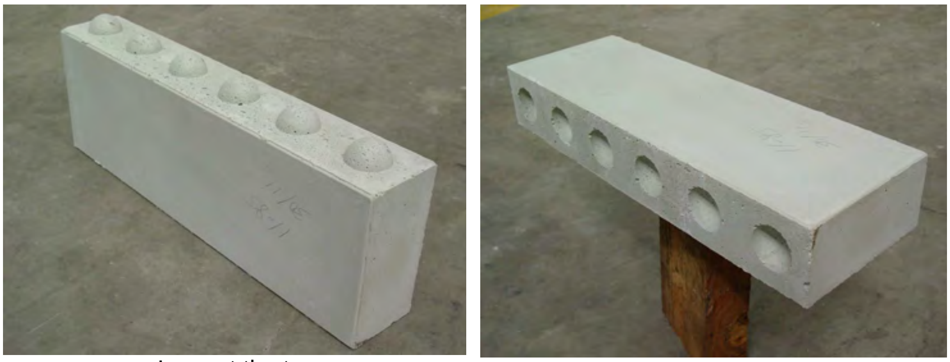
- Vertical loads
- In-plane lateral loads (shear forces)
- Out-of-plane loads

In order for Benex masonry to be covered by AS3700 a number of clauses need to be altered or included because of the different material and construction practices involved with it. Also, structural properties of masonry elements need to be assessed for their compliance with the overall approach of AS3700.

Since resistance to leakage of water through single-leaf masonry and durability of materials are important aspects of performance, this investigation also aims at assessing those characteristics as well.

3 THE BENEX BLOCK

Benex blocks are produced by “Benex Technologies Pty Ltd”. The Benex block is a nominally 600mm long x 200mm high unit, and produced in two different shapes; as a 100mm thick solid block and 200mm thick hollow block. The solid block is accommodated with precise locating lugs on the top face and matching holes at the bottom face. This lug-hole combination gives the solid Benex block its unique feature, which allows walls to be built even by an un-skilled person with a minimal understanding of laying masonry. The hollow block is accompanied with protruding ribs on the top face and matching recesses at the bottom face for easy alignment as for the solid blocks. The Benex block is made out of a cementitious compound mixed with polystyrene beads.



Lugs at the top Holes at the base

Figure 1. Benex 100mm solid block

Recess at the base Protruding ribs at the top

Figure 2. Benex 200mm hollow block

Of the two 200mm x 600mm vertical faces, the Benex block has a fairly smoother face on one side and a rougher face on the other side. Therefore, it could be used without any external render, depending on the preferred finished face on the exterior face of the building.

The Benex block is relatively lighter compared to its competitors. This is quite a significant factor in terms of speed of construction and stresses induced due to the self weight of the walls.

The Benex block, which is constituted of polystyrene beads embedded in a cementitious mix, has the potential to resist high thermal transmission.

Laying of solid blocks

Laying of hollow blocks

Figure 5. Laying of Benex blocks

Once the wall is built, the excess mortar on the face is wiped off with a sponge.

Figure 6. Finishing the surface of the wall

4 TESTS AND PRESENTATION OF RESULTS

A large number of test specimens were prepared to investigate performance characteristics under different test conditions. The details of those investigations are reported in the proceeding sections.

The various design parameters evaluated for Benex masonry are compared with the provisions of AS3700. New design rules have been proposed where necessary.

5 WEATHER PERFORMANCE & DURABILITY

5.0 Resistance to water penetration

5.0.1 Background

The resistance of buildings to moisture penetration from wind driven rain is dependent upon both the permeability of the masonry and the effectiveness of water proofing details of doors and windows. While most leakages in buildings result from the latter factors, the correct details to prevent such failures are well documented.

The permeability of masonry material is becoming increasingly important with the use of thin single leaf masonry walls built with either solid or hollow masonry units, whose thickness is equal to the width of the masonry unit. Whatever the thickness, a single leaf wall is generally not regarded as being sufficiently impervious by AS3700 without further protection.

There are no set criteria in AS3700 to assess the resistance to water penetration through masonry subjected to wind driven rain other than to state that walls should have low a probability of failure against water penetration (Clause 2.3.6). However, it is deemed satisfactory to requirements for cavity walls and masonry veneer walls (Clause 2.4.6 and Clause 4.7). The use of single leaf concrete masonry with a water proof coating is being accepted by local authorities in some parts of Australia. Therefore, it has been worthwhile to investigate whether Benex masonry could resist moisture penetration with and without a water proofing membrane applied on the external face of the wall.

Two overseas test procedures for water permeability of masonry are available – BS 4315 Part 2 and ASTM 514-06. These standards are almost identical and the ASTM method was chosen for this investigation.

5.0.2 Preparation of specimens

Types of masonry units used included 100mm thick Benex solid masonry blocks and 200mm thick hollow Benex blocks.

One single leaf test panel was built from each of the block types. Panels were constructed in the laboratory and were approximately 1800mm high x 1200mm wide. Both test panels were built by an experienced block/brick layer using the Benex thin-bed mortar.

5.0.3 Test set-up

The apparatus used for testing the water penetration of the panels and the test procedure complied with ASTM E514-06 ‘Standard Test Method for Water Penetration and Leakage through Masonry’.

The test apparatus enclosed an area 1070mm x 1600mm on the test face of the panel. The test chamber was positioned on the specimen and clamped firmly in place, compressing a rubber seal which prevented any loss of water and air pressure. Figure 7 shows this apparatus and set-up.

Figure 7. Test set up

Water was sprayed into a spray pipe near the top of the test area which sprayed water directly onto the test face. The rate of flow of water ((138L/m^2/hour) was maintained constant throughout the test. The water flow was measured with the aid of a flow meter. The air pressure inside the chamber was maintained at 500Pa using an inclined water manometer.

Observations were made for the appearance of damp patches on the back of the wall at 30 minute intervals during the first 8 hours. Although the test is supposed to be terminated at 4 hours, it was continued for 24 hours.

5.0.4 Observations

The observations made in the tests are reported in Table 1 and the rear faces of both walls, at the end of the 24 hour period, are shown in Figure 9.

Wall Type	Test Date	Test Commenced	Test Terminated	Comments
100mm thick solid block wall	3 April 07	9:44am	9:44am (on 4 April 07)	Note 1
200mm thick hollow block wall	29 March 07	10:40am	10:40am (on 30 March 07)	Note 2

Table 1. Water penetration test results

Note 1: The test was conducted at 21^{0}C and 86% RH. There was no leakage of water through the masonry within the 24 hour test period. No wet patches behind the wall were observed.

Note 2: The test was conducted at 21^{0}C and 83% RH. There was a very slight leakage of water through the masonry at mid-height within the first 4 hour test period (possibly due to an air cavity-hole on front face) but ceased after a time. No wet patches behind the wall were observed.

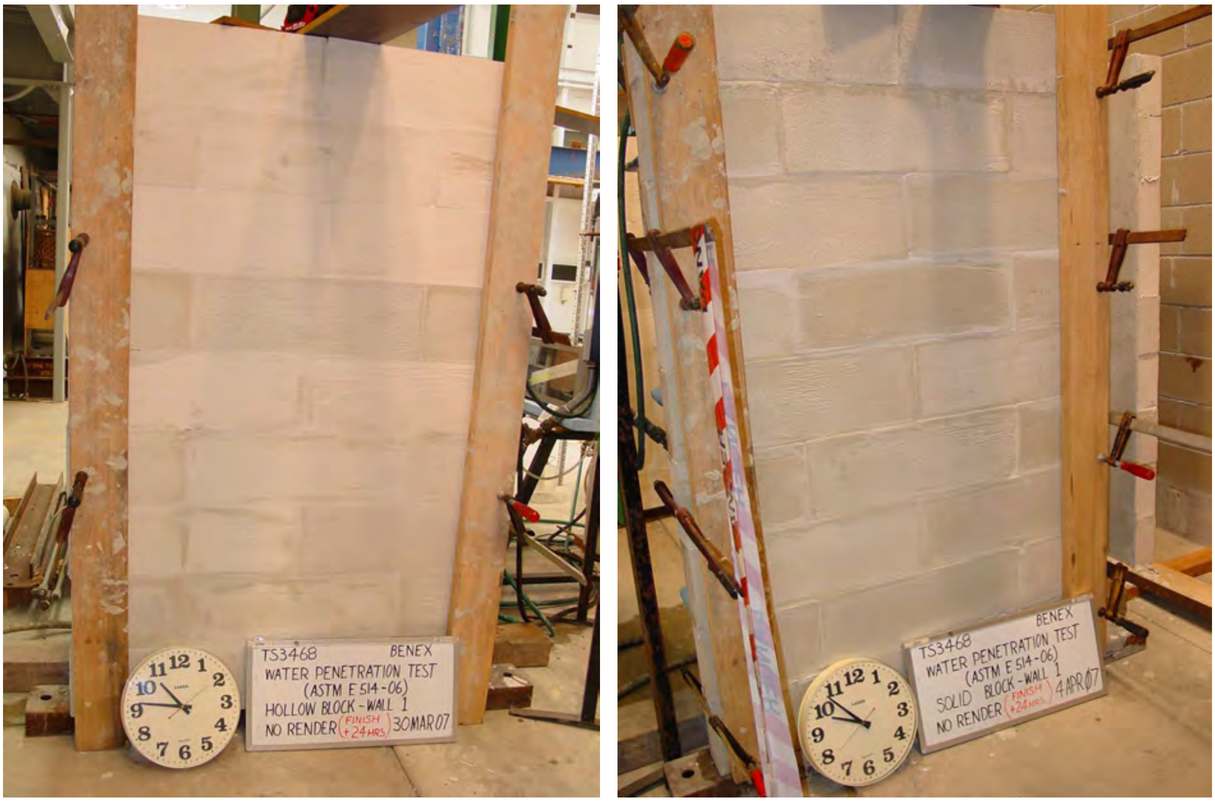


Figure 9. Post test observations

5.0.5 Comments

The results from this testing showed that the Benex masonry units, 100mm solid and 200mm hollow, resisted water penetration through the masonry element to the rear face of the test wall.

Hence, it may be concluded that properly built Benex masonry walls can resist the conditions imposed by the ASTM water permeability test for more than 24 hours, without failure. In general, rendered Benex masonry walls can be considered as impervious without further protection since any tiny holes in the mortar joints can be fully covered by the render.

5.1 Durability to salt exposure

5.1.0 Background

As per AS3700-2001 (Clause 5.3) masonry units must satisfy the salt attack resistance grade given in Table 5.1. The standard AS/NZS 4456.10:2003 details the requirements for testing masonry units for resistance to salt attack. Durability grades for masonry units are given in AS/NZS 4456.10:1997 but not in the 2003 version.

5.1.1 Test procedure

Specimens of 50 mm long, 25 mm wide and 20 mm high were taken from two separate solid Benex blocks (S1 and S2) and 50 mm long, 25 mm wide and 40 mm high taken from three Benex hollow blocks (H1, H2 and H3) were subjected to cycles of soaking in salt solution (14% NaCl), oven drying and cooling as recommended by method B of AS/NZS 4456.10:2003.

The weather exposed surface of the Benex block is quite different to its interior, unlike for common masonry units. Therefore, in addition, a separate series of specimens, from both solid and hollow samples, were prepared by applying Vaseline to cover the interior cut surfaces before been subjected to salt exposure. Hence, only the exterior face of the masonry unit of the test sample would be exposed to salt solution.

All the specimens were exposed to a total of 40 cycles and the weight changes of the specimens after each cycle was recorded.

5.1.2 Results

Figure 10 shows the change of weight of the test specimens obtained from the solid Benex block during the salt exposure cycles. The specimens without Vaseline (S1-3, S1 -4, S1- 5, S2 -3, S2 -4 & S2-5) show a gradual increase in weight up to about 30 cycles and reaching constant thereafter. In contrast, the Vaseline treated samples (S1-1V, S2-1V and S2-2V) shows little or no change in weight throughout the testing cycles. Apart from the salt deposits on the surface of these samples, no cracks or any other deterioration signs were observed. Furthermore, there were no solid deposits found in the solutions.

Figure 11 shows the change of weight of the specimens prepared from hollow Benex block during the salt exposure cycles. As with the solid specimens, these specimens also showed a gradual increase in weight with the exposure up to about 35 cycles. No significant change in weight was observed with Vaseline treated specimens (H1 V and H2 V). Also, no solid deposits were found in the solutions.

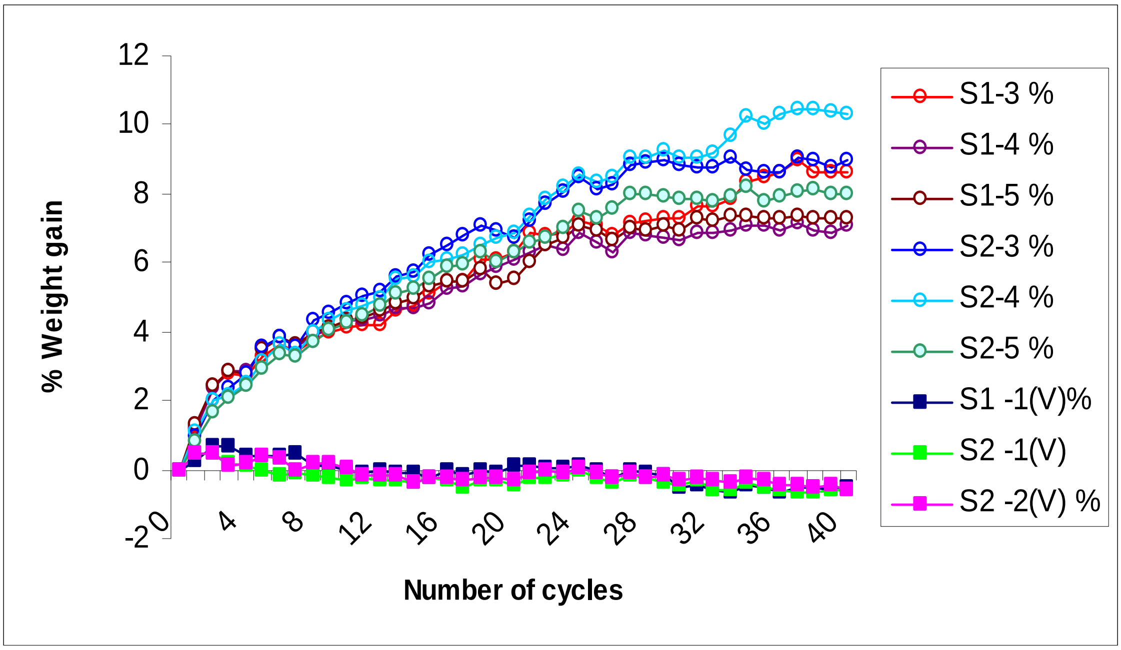


Figure 10. Percentage weight change of specimens taken from solid blocks (Vaseline treated samples contain "V" in the name)

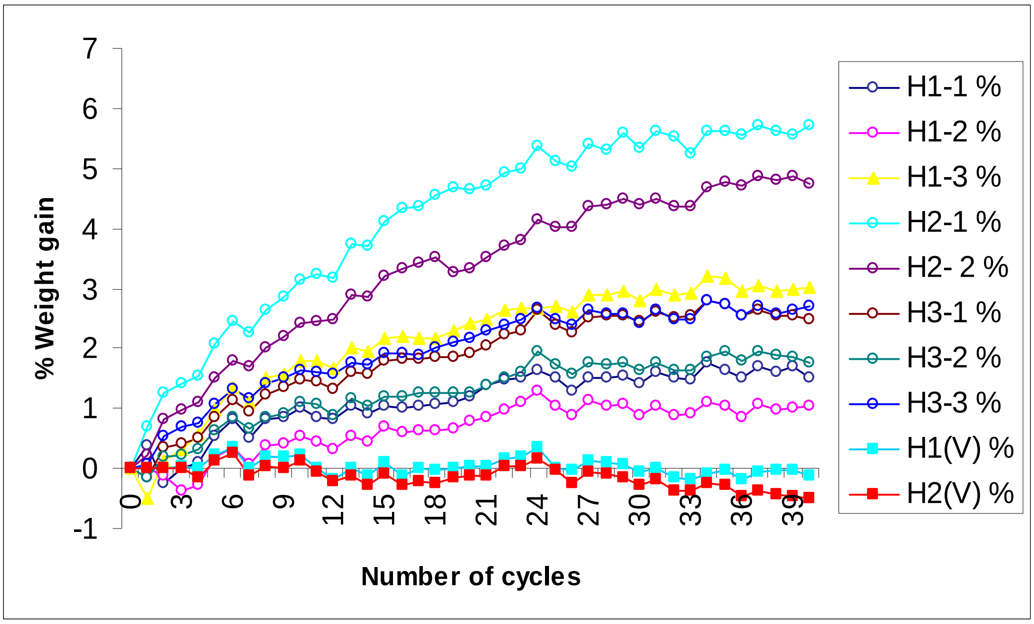


Figure 11. Percentage weight change of specimens taken from hollow blocks (Vaseline treated samples contain "V" in the name)

5.1.3 Discussion

The procedure used in this work is the recommended standard method to determine the resistance to salt attack of materials other than stone (method B). The gradual increase in weight of the non-Vaseline treated samples indicates absorption and diffusion of salt through the specimens. This was also clearly visible by the salt deposits found on the surface, towards the end of the treatment cycles. It is normally believed that salt depositions (crystallization) within the cement phase can lead to expansions and crack formations. However, there was no visible deterioration signs/cracks with any of the specimens studied. Therefore, it is possible that the polystyrene embedded medium in the tested specimens can withstand against any resistance/expansion created by salt deposits. A detailed analysis of the microstructure may help in establishing the mechanism that takes place in these samples.

The results of the Vaseline applied specimens also show that salt absorption does not occur or is minimal through the external surfaces of solid and hollow Benex units, which is the case in real life applications.

As per AS/NZS 4456.10:1997, both solid and hollow Benex blocks can be graded as "exposure" type.

5.1.4 Conclusions

As per AS/NZS 4456.10:2003 method B, both solid and hollow samples of Benex blocks seem to be resistant to salt attack.

Salt diffusion occurs only through open (cut) surfaces of the specimens. Capped surfaces seem to be impermeable towards salt movement.

Both solid and hollow Benex blocks can be categorized as "Exposure Grade" as per AS/NZS 4456.10:1977. Hence, they can be used in aggressive environments such as severe marine environments and aggressive soils; as per Clause 5.2.5 of AS 3700-2001.

6 COMPRESSION

6.0 Background

The compressive strength of masonry primarily depends upon the properties of the units and mortar. The common understanding about the behaviour of masonry in compression is that failure is initiated by the lateral expansion of mortar joints. Because mortar with a low strength generally has a lower elastic modulus, it has a greater lateral expansion under load, and therefore a high tendency to split the units. Hence, formation of vertical tension cracks in the units causes failure of the masonry. The thicker the mortar-joint relative to the height of the units the higher the splitting force on the unit. Hence, the compressive strength of conventional masonry decreases as the ratio of unit height to joint thickness decreases.

Typical values for characteristic compressive strength of conventional masonry are given in Table 3.1 of AS3700-2001. These values are related to the characteristic unconfined compressive strength of various unit types and the mortar composition. In order to account for the influence of the ratio of unit height to mortar joint thickness, the values obtained from Table 3.1 are modified by a factor (k_h) given in Table 3.2 of AS3700-2001.

For AAC masonry with thin bed mortar, the relationship between the unit and masonry strength is defined as:

$f'_m = f'_{uc}$

Where,
f'_m – characteristic compressive strength of masonry
f'_{uc} – characteristic unconfined compressive strength of AAC units

To enable the characteristic compressive strength of Benex masonry to be assessed in a manner similar to AS3700-2001, the following were investigated:

- Unconfined compressive strength of units
- Masonry prism strength

6.1 Compressive Strength of Units

The standard length of a Benex block is 600 mm. These blocks are too long to test in most common testing machines and therefore half-length blocks were cut and both halves tested to take into account any variability due to the manufacturing process.

6.1.0 Test specimens

Ten specimens 300 mm long x 200 mm wide were cut from 5 standard blocks of both solid and hollow blocks. In the solid blocks, all the circular lugs were cut flush with the top face of the block. In the hollow blocks, the protruding ribs of the blocks were removed so that both bedding surfaces were flat.

The solid 100mm thick blocks were tested with the load applied uniformly on the 25mm bedding surface of the block whereas the 200mm hollow blocks were uniformerly loaded on the 50mm edge strips as shown in Figure 12. The face shell thickness of the hollow blocks at the top surface is 50mm but at the bottom surface is 35mm. Hence, the compressive strength of hollow blocks was calculated based on the minimum face shell thickness (i.e. 35mm).

(a) Solid block

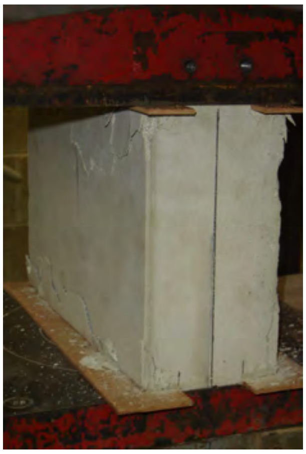
(b) Hollow block

Figure 12. Test set up for compression on hollow & solid blocks

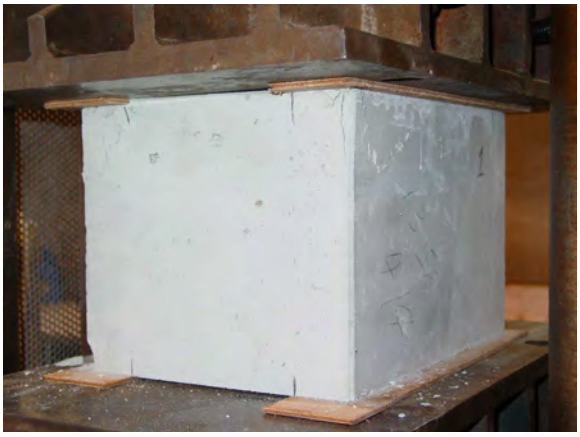
The specimens were tested in an 'Avery' Compression Testing Machine complying with Grade A requirements of AS2193-1978.

6.1.1 Test results

The solid 100mm thick blocks initially showed signs of distress by crumbling at the external hard skin near the platens. The load indicator of the testing machine momentarily stopped at this load (identified as the first crack load) and thereafter gradually increased until the maximum load (identified as the maximum load) was reached. For the hollow blocks the maximum load resisted was recorded since the difference between the loads at first sign of cracking and the final failure was not significant. Typical failure modes are shown in Figure 13.



(a) Solid block



(b) Hollow block

Figure 13. Typical failures of blocks under compression

A summary of results is given in Table 2 and the detailed results are available in Appendix A. The strengths have been calculated based on the maximum loads resisted by the specimens. All individual compressive strengths were converted to an equivalent unconfined value (using Table 1 of AS/NZS4456.4:1997) to eliminate the effect of platen restraint of the testing machine. The characteristic strength is calculated as per AS3700-2001 Appendix B.

	100mm solid block	200mm hollow block
Number of Specimens	10	10
Average Comp. Strength (MPa)	15.68	7.07
Standard Deviation (MPa)	2.99	1.05
Coefficient of Variation	0.19	0.15
Characteristic Compressive Strength (MPa)	11.50	4.92
Characteristic Unconfined Compressive Strength f'_{uc} (MPa)	8.92	4.92

Table 2. Compressive strength of Benex blocks

6.2 Masonry Compressive Strength

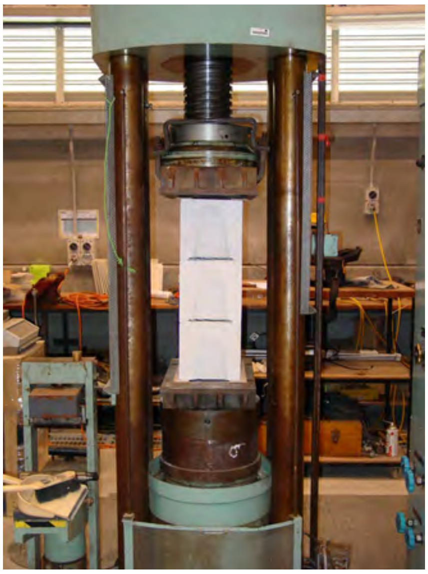
Masonry prisms were constructed and tested in accordance with Appendix C of AS3700-2001.

6.2.0 Test specimens

Both solid and hollow 600 mm long blocks were cut into two 300 mm long pieces and built into prisms. Ten prisms, stack bonded three courses high, were built.

The specimens were cured in the laboratory for seven days under a polythene cover and tested in an 'Avery' Compression Testing Machine complying with Grade A requirements of AS2193-1978 (see Figure 14).

(a) 100mm thick solid block masonry



(b) 200mm thick hollow block masonry

Figure 14. Test set up for masonry compressive strength

Similar to the testing of units, these prisms were also tested by applying the test load only on the bedding area of the joint. Hence, for the solid block prisms and hollow block prisms the load was applied on two, 25mm strips and 50mm strips respectively. However, the effective loading strip width of the hollow block prism is 35mm due to the narrow width at the base of each block.

6.2.1 Test results

A summary of results is given in Table 3 and Table 4 for samples tested with solid and hollow blocks respectively. The detailed results are given in Appendix B.

All prism strengths have been adjusted for aspect ratio as required by Clause C7.2 of AS3700-2001, permitting comparisons to be made on an 'unconfined' basis with any other type of masonry unit.

	7-day
Number of Specimens	10
Average Comp. Strength (MPa)	11.30
Standard Deviation (MPa)	1.08
Coefficient of Variation	0.10
Characteristic Compressive Strength f'_{uc} (MPa)	8.47
Characteristic Unconfined Compressive Strength f'_{uc} (MPa)	8.47

Table 3. Compressive Strength of 100mm solid block Benex Masonry Prisms

	7-day
Number of Specimens	10
Average Comp. Strength (MPa)	5.37
Standard Deviation (MPa)	0.49
Coefficient of Variation	0.09
Characteristic Compressive Strength f'_{uc} (MPa)	4.05
Characteristic Unconfined Compressive Strength f'_{uc} (MPa)	4.05

Table 4. Compressive Strength of 200mm hollow block Benex Masonry Prisms

Typical failure modes are illustrated in Figure 15. Initially the hardened outer skin failed in the solid block masonry, followed by internal failures. With hollow blocks mostly the middle block failed at the interface between outer face-shell and the cross web.

(a) Solid block prism (b) Hollow block prism

Figure 15. Typical failure of a prism under compression

6.2.2 Comments

The coefficient of variation is within the default value of 0.15 provided in AS3700-2001. As per AS3700-2001 for AAC masonry with thin bed mortar, the value of the characteristic compressive strength of solid Benex masonry is the same as the characteristic strength of the units. However, this is different for hollow Benex masonry with thin bed joints, where the characteristic strength of masonry is less than the characteristic strength of the units.

For Benex masonry the following relationship holds:

For solid block masonry $f'_m = 1.0f'_{uc}$
For hollow block masonry $f'_m = 0.82f'_{uc}$

Where,
f'_m – characteristic compressive strength of masonry
f'_{uc} – characteristic unconfined compressive strength of Benex blocks

6.3 Benex Masonry under Concentrated Loads

The assessment of bearing strength of masonry walls subjected to in-plane concentrated loads from beams, lintels etc, is a problem commonly encountered in masonry design. It is usual practice to allow higher bearing stresses due to the restraining effect of the surrounding material.

The magnitude of the bearing strength enhancement depends on many factors such as the area loaded, location of the load, geometry of the wall, load type, type & strength of masonry material, spreader beams, flexibility of the loading plate, effect of adjacent loads etc. Because of the large number of variables involved AS3700 recommends a simple design approach. It defines the strength enhancement as a function of the loaded area ratio (area loaded in relation to the total cross sectional area) and the load location.

According to AS3700, strength enhancement applies to all types of masonry built with solid and cored units but not for face-shell hollow masonry. Therefore, the same rule should apply to hollow Benex masonry, which needs to be verified.

The rules in AS3700 (clause 7.3.5) have been developed from a large number of concentrated load tests performed on a range of masonry types in various countries. However, its ability to enhance the strength of Benex solid block masonry needs to be investigated.

Because of the large number of variables involved, a comprehensive test program on Benex masonry is not warranted. Therefore, a limited range of tests has been carried out to test the applicability of AS3700 rules.

6.3.0 Test procedure

Concentrated load tests were carried out on a range of wall configurations as shown in Table 4 and Figure 16. For simplicity, relatively small wall panels have been tested. Although they may not be fully representative of the behaviour of full-scale walls the degree of enhancement of bearing strength estimated by small panels is more conservative, when applied to large walls.

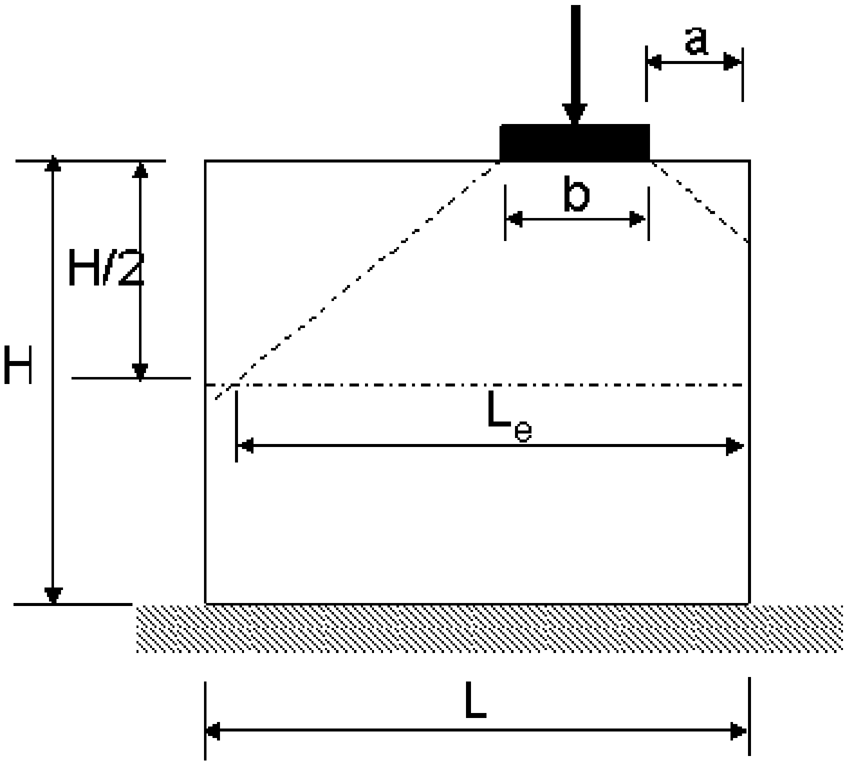


Figure 16. Load dispersion under concentrated load

Two replicates were built for each test type and tested at 7 days of age. A 35mm deep by 90 wide, timber spreader was kept on top of the wall to simulate real life condition at the top of the wall. The concentrated loads were applied at the top of the wall through a 25mm thick rigid plate over the full thickness of the timber spreader. The wall was uniformly supported at the base. Figure 17 shows the test set up.

(a) Solid block wall – set up for mid length loading (b) Hollow block wall – set up for edge loading

Figure 17. Test set up for concentrated load tests

6.3.1 Test results

The failure loads, wall dimensions and load positions are shown in Table 5.

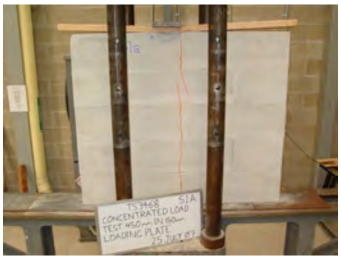
Block Type	Test No.	Spreader thickness (mm)	L (mm)	H (mm)	b (mm)	a (mm)	Maximum load (kN)
100mm solid block	SB-1A	90	1200	1000	150	450	158
	SB-1B	90	1200	1000	150	450	190
	SB-2A	90	900	1000	75	0	75
	SB-2B	90	900	1000	75	0	79
	SB-3A	90	900	800	50	225	87
	SB-3B	90	900	800	50	225	85
200mm hollow block	HB-1A	190	1200	1000	150	450	176.0
	HB-1B	190	1200	1000	150	450	146.0
	HB-2A	190	900	1000	75	0	70.0
	HB-2B	190	900	1000	75	0	70.0
	HB-3A	190	900	800	50	225	111.0
	HB-3B	190	900	800	50	225	94.0

Note: SB & HB refers to solid and hollow block respectively. Notations are as per Figure 16.

Table 5. Results of concentrated load tests

Although the timber spreader beam was placed above the wall to simulate the real life condition, it started to lift off from the unloaded portions with the gradual increase of load, and hence the effective area of the load applied was equal to the contact area between the steel plate and the timber beam. This effect is shown in Figure 18 and Figure 19 with failure modes.

At failure, cracks propagated vertically underneath the loading plate through the joints and the block. In some cases, crushing occurred underneath the loading pad.


Specimen SB-1A

Specimen SB-1B

Specimen SB-2A

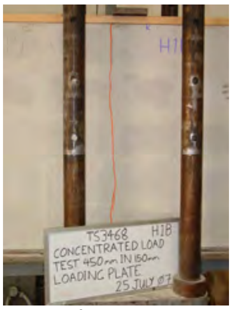

Specimen SB-2B


Specimen SB-3A

Specimen SB-3B

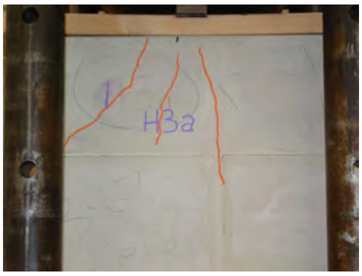
Figure 18. Failure modes – Solid block wall specimens


Specimen HB-1A


Specimen HB-1B

Specimen HB-2A

Specimen HB-2B



Specimen HB-3A


Specimen HB-3B

Figure 19. Failure modes – Hollow block wall specimens

6.4 Analysis and comments

From the test results, comparisons were made between bearing strength and the mean uni-axial compressive strength to derive the strength enhancement factors as shown in Table 6. The values calculated according to the AS3700 rules are also included in the Table for comparison.

The results are graphically shown in Figure 20 and Figure 21 for solid and hollow block walls respectively.

Test reference	Bearing strength (MPa)	Strength enhancement factor (as per test)	a/L	A_{ds}/A_{de}	Strength enhancement factor (As per AS 3700)
SB-1A	12.59	1.11	0.375	0.123	1.31
SB-1B	14.07	1.25	0.375	0.123	1.31
SB-2A	11.11	0.98	0	0.117	1.12
SB-2B	11.70	1.04	0	0.117	1.12
SB-3A	19.33	1.71	0.25	0.067	1.51
SB-3B	18.89	1.67	0.25	0.067	1.51
HB-1A	6.18	1.23	0.375	0.130	1.00
HB-1B	5.12	1.02	0.375	0.130	1.00
HB-2A	4.91	0.98	0	0.124	1.00
HB-2B	4.91	0.98	0	0.124	1.00
HB-3A	9.26	1.85	0.25	0.070	1.00
HB-3B	9.05	1.81	0.25	0.070	1.00

Table 6. Strength enhancement factor under concentrated loads

Notes to Table 6:

1. Bearing strength = Failure load/Bearing area
2. Bearing strength for hollow blocks was calculated on gross dimensions of hollow blocks as a conservative measure.
3. Strength enhancement factor = Bearing strength / Average compressive strength of that masonry
4. A_{ds} – Bearing area
5. A_{de} – Effective area of load dispersion at mid height (L_e x thickness of the wall)

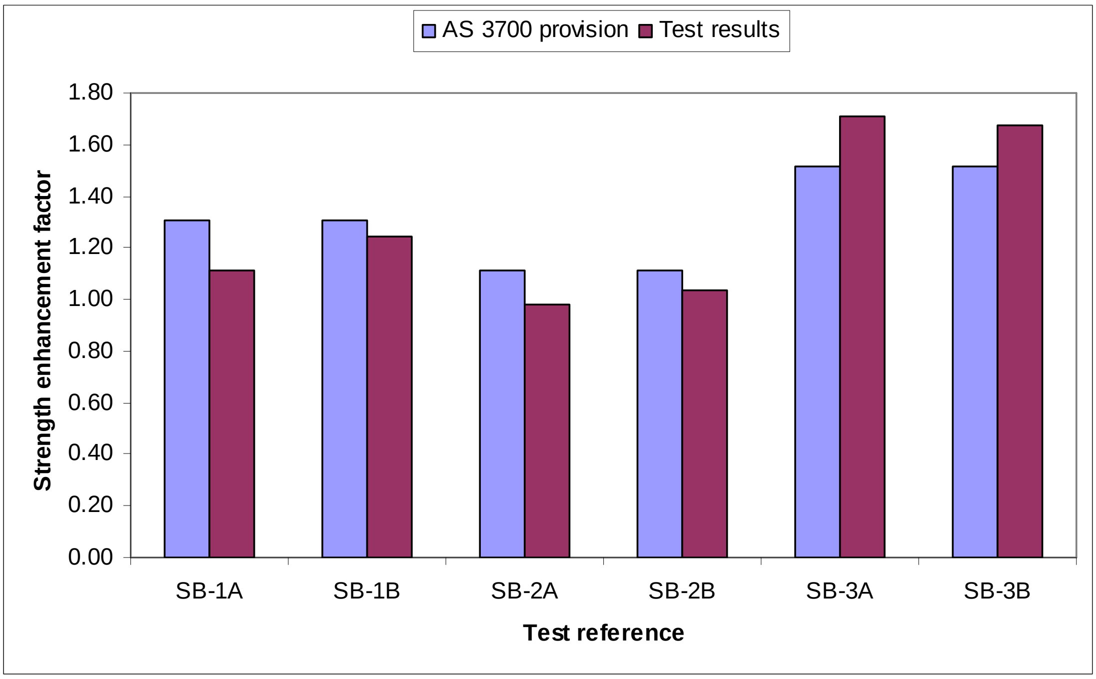


Figure 20. Strength enhancement factor under concentrated loads for solid blocks

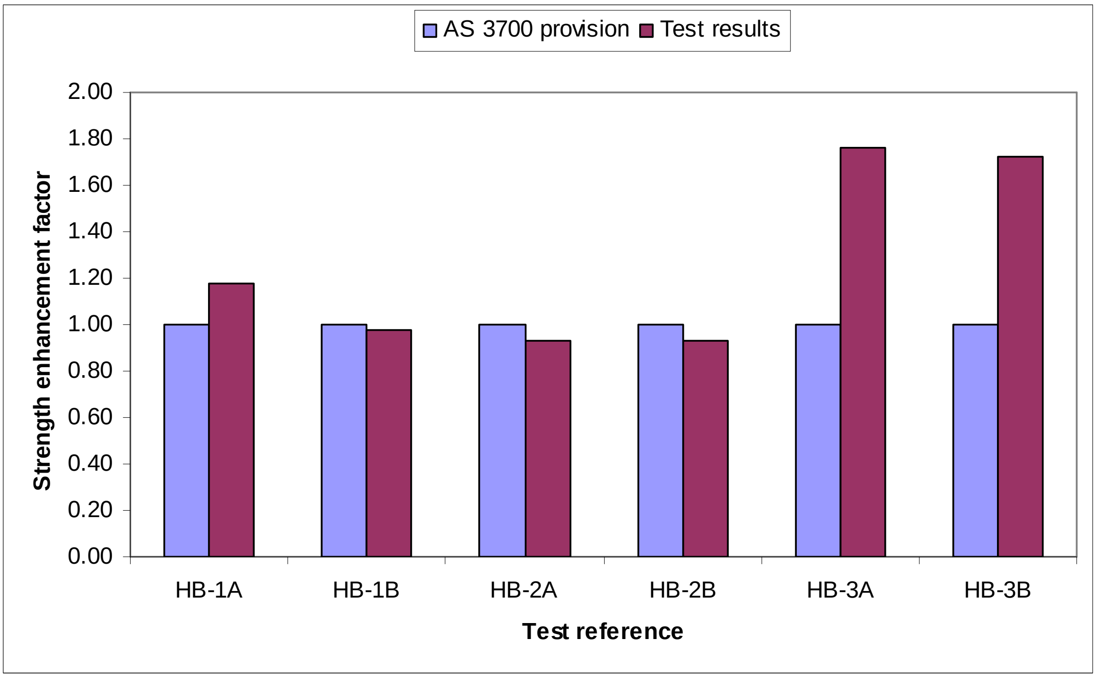


Figure 21. Strength enhancement factor under concentrated loads for hollow blocks

The strength enhancement factors computed from test results for solid block masonry reasonably match with the AS3700 values. Even the hollow block walls comply with the AS3700 recommendation, except in two cases where the test values are significantly higher.

Failure modes observed are similar to those of conventional masonry. Typically, when a concentrated load is applied to a masonry panel, high local stresses are developed in the region directly beneath the load. In the zone directly beneath the loading plate a triaxial compressive stress state is developed, whereas further down the wall the stress state changes to one of vertical compression and biaxial tension. Since conventional masonry is generally weak in tension, cracking comes in this region. However, with Benex masonry the majority of the failures were by local crushing in the vicinity of the loading pad due to the relatively low compressive strength of the units.

In general, the test results reveal that the simplified rules in AS3700 can be safely used with both solid and hollow Benex masonry.

6.5 Conclusions

The vertical load carrying capacity of Benex masonry can be predicted as per AS3700-2001 with minor modifications to some of the formulae as briefed below.

Basic compression capacity:

As per Clause 7.3.2 of AS3700-2001, for ungrouted masonry,
$F_o = \Phi f'_m A_b$

Where,
Φ – Capacity reduction factor as per AS3700-2001, which is equal to 0.45

A_b – the bedded area of masonry cross section
For 100mm solid masonry: bedding width = 2 x 25mm = 50mm
For 200mm hollow masonry: bedding width = 2 x 35mm = 75mm

f'_m – characteristic compressive strength of respective masonry
f'_m of 100mm solid masonry = $1.0f'_{uc}$
f'_m of 200mm hollow masonry = $0.82f'_{uc}$

Where, f'_{uc} is the characteristic unconfined compressive strength of units.
f'_{uc} of 100mm solid block = 8.92
f'_{uc} of 200mm hollow block = 4.92MPa

A Benex masonry member can be designed as per Clause 7.3.3 of AS3700-2001.

Designing under concentrated loads:

Both solid and hollow Benex masonry can be designed as per Clause 7.3.5 of AS3700-2001.

7 FLEXURE

7.0 BACKGROUND

The structural design of masonry walls in low rise buildings is often governed by the resistance to out-of-plane loads caused by wind or earthquake. When un-reinforced walls with a low level of compressive stress are subjected to out-of-plane lateral forces the critical property is the flexural tensile strength of the masonry. This property is highly variable and cannot be predicted with any degree of certainty.

The failure mechanism of masonry wall panels under lateral loading is complex and not fully understood. The design rules given in AS3700 are semi-empirical and based on results from a large number of full-scale tests. Assessment of Benex masonry under lateral loads is virtually impossible in the absence of published data.

Design of masonry spanning in two directions is calculated using the moment capacities in the vertical and horizontal directions. The vertical flexure moment capacity depends on the flexural tensile strength of the bed joints. In horizontal flexure, the toothed action of the stretcher bonding, together with the interlocking action of the Benex block's lugs or ribs, provides a vital component of the resistance to moments.

Formulas for computing the vertical and horizontal moments are given in AS3700. Two fundamental properties of masonry are required for these computations; characteristic flexural tensile bond strength of joints and characteristic modulus of rupture of units. It is important to verify whether these AS3700 rules can be satisfactorily used for Benex masonry built with thin bed adhesives.

7.1 Flexural Tensile Bond Strength

7.1.0 Test Method

For the bond strength tests, ten, four high prisms were constructed (ie. 30 joints) for tests at 7 and 28 days for both solid and hollow blocks. The 600 mm long blocks were cut into two halves and both were used in the prisms. In addition, six control specimens, built in parallel with each full-scale wall for lateral load testing, were tested for flexural bond strength. Prior to making the test specimens all blocks were washed. A portion of Bycol was added into the water prior to mixing with the dry adhesive when preparing the bonding adhesive.

Tests were performed using the bond wrench method in accordance with AS3700-2001. Loads on the bond wrench were applied manually and the load at failure was recorded.

A typical test set up is shown in Figure 22.

100mm solid block under test

200mm hollow block under test

Figure 22. Bond wrench test set up

7.1.1 Test Results

Characteristic strengths were calculated in accordance with AS3700 Appendix B. A summary of results is shown in Table 7. The number of specimens tested for seven days was 15, whereas for 28 day tests 43 and 58 joints were tested for solid and hollow blocks respectively. The detailed results are given in Appendix C.

Parameter	100mm solid block		200mm hollow block	
	7 day	28 day	7 day	28 day
Mean (MPa)	0.99	1.23	0.47	0.48
Standard Deviation (MPa)	0.15	0.17	0.07	0.10
Coefficient of Variation	0.15	0.14	0.16	0.21
Characteristic Bond Strength (MPa)	0.56	0.83	0.27	0.32

Table 7. 7 and 28 day bond strengths of solid and hollow blocks

The results in Table 7 are graphically shown in Figure 23 and Figure 24. The characteristic values were calculated as per AS3700-2001: Appendix B.

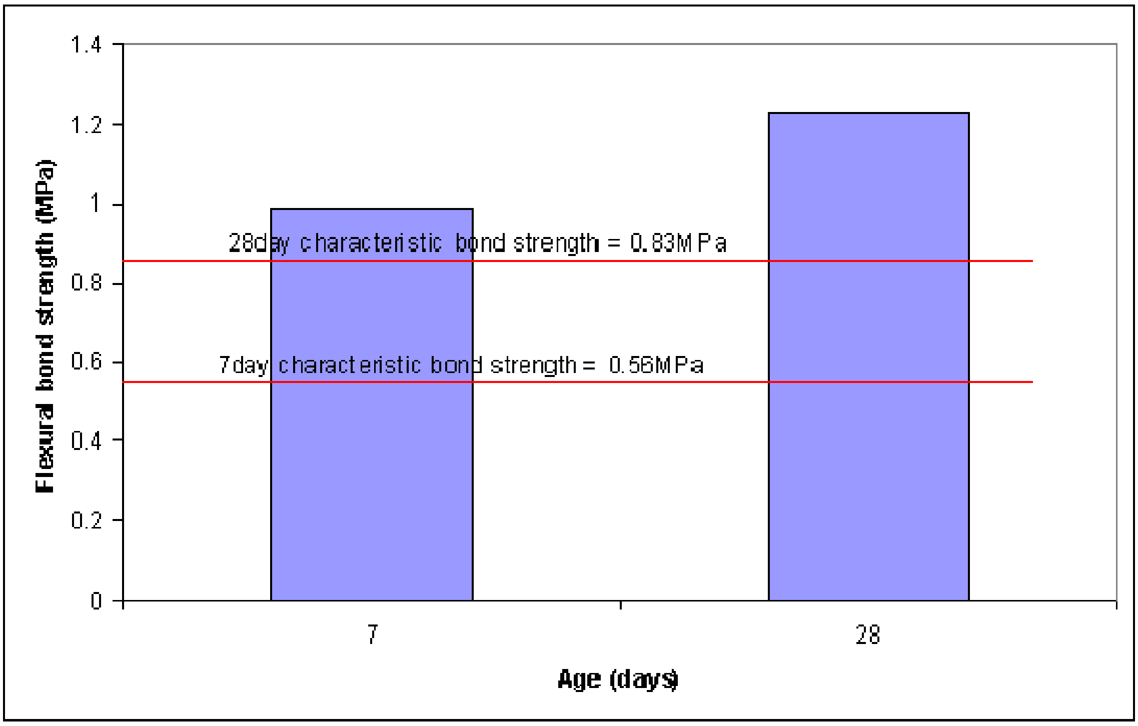


Figure 23. 7-day & 28-day flexural bond strength of 100mm thick solid Benex masonry

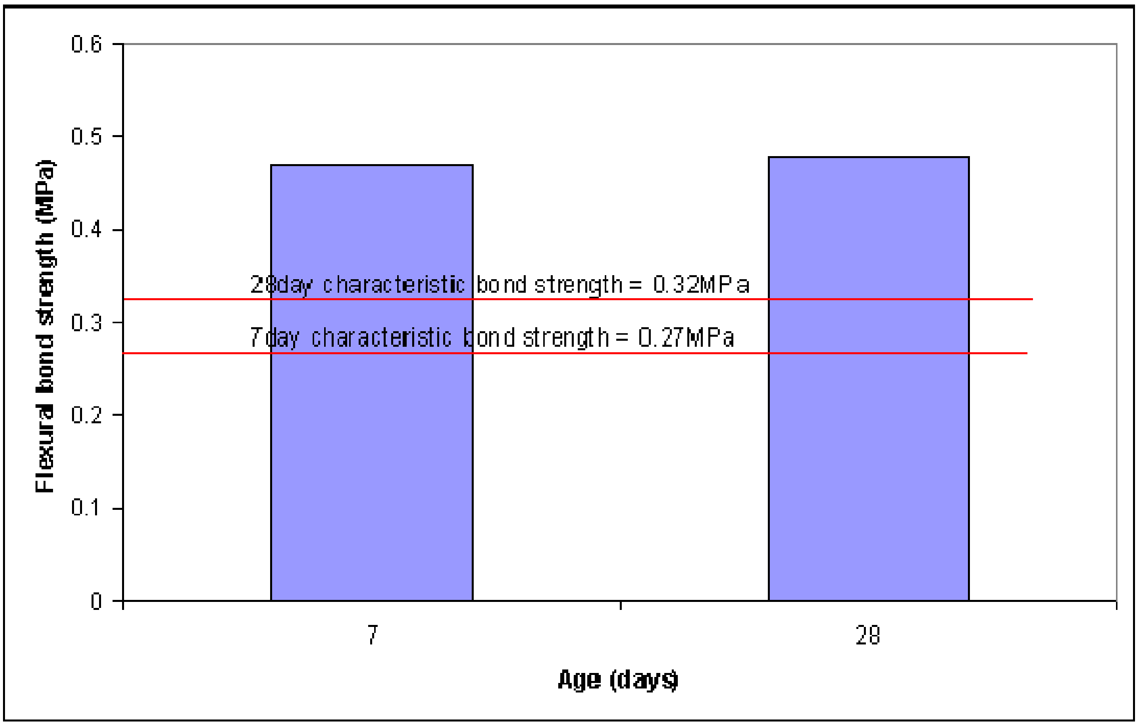


Figure 24. 7-day & 28-day flexural bond strength of 200mm thick hollow Benex masonry

For the sake of comparison, the flexural bond strength results obtained during the lateral load tests are also reported in Table 8 and Table 9 for walls supported on all four sides and three sides, respectively. Six joints were tested with each wall.

Test reference to wall type	Wall size Length x width	Age of bond wrench test specimens	Mean (MPa)	Standard Deviation (MPa)	Coefficient of Variation
Solid block wall SB-1A	6m x 3m	13 days	1.32	0.23	0.17
Solid block wall SB-2A	3.8m x 3.0m	14 days	0.87	0.14	0.16
Solid block wall SB-3A	2.6m x 3.0m	12 days	1.14	0.24	0.21
Hollow block wall HB-1A	6m x 3m	7 days	0.49	0.16	0.32
Hollow block wall HB-2A	3.8m x 3.0m	9 days	0.52	0.12	0.23
Hollow block wall HB-2A (repeat test)	3.8m x 3.0m	13 days	0.58	0.08	0.14
Hollow block wall HB-3A	2.6m x 3.0m	10 days	0.48	0.04	0.08

Note: A refers to walls supported on four sides

Table 8. Bond strengths of solid and hollow blocks performed in parallel with full-scale lateral load tests (walls supported on four sides)

Test reference to wall type	Wall size Length x width	Age of bond wrench test specimens	Mean (MPa)	Standard Deviation (MPa)	Coefficient of Variation
Solid block wall SB-1B	6m x 3m	11 days	1.33	0.28	0.21
Solid block wall SB-2B	3.8m x 3.0m	8 days	0.81	0.11	0.14
Solid block wall SB-3B	2.6m x 3.0m	10 days	0.98	0.15	0.15
Hollow block wall HB-1B	6m x 3m	21 days	0.55	0.04	0.08
Hollow block wall HB-2B	3.8m x 3.0m	9 days	0.46	0.04	0.10
Hollow block wall HB-3B	2.6m x 3.0m	11 days	0.52	0.06	0.11

Note: B refers to walls supported on three sides

Table 9. Bond strengths of solid and hollow blocks performed in parallel with full-scale lateral load tests (walls supported on three sides)

All the flexural bond results are graphically shown in Figure 25 and Figure 26 for solid and hollow block masonry, respectively. Due to unavoidable reasons lateral load tests were carried out at different ages, and hence, bond strength results correspond to those ages.

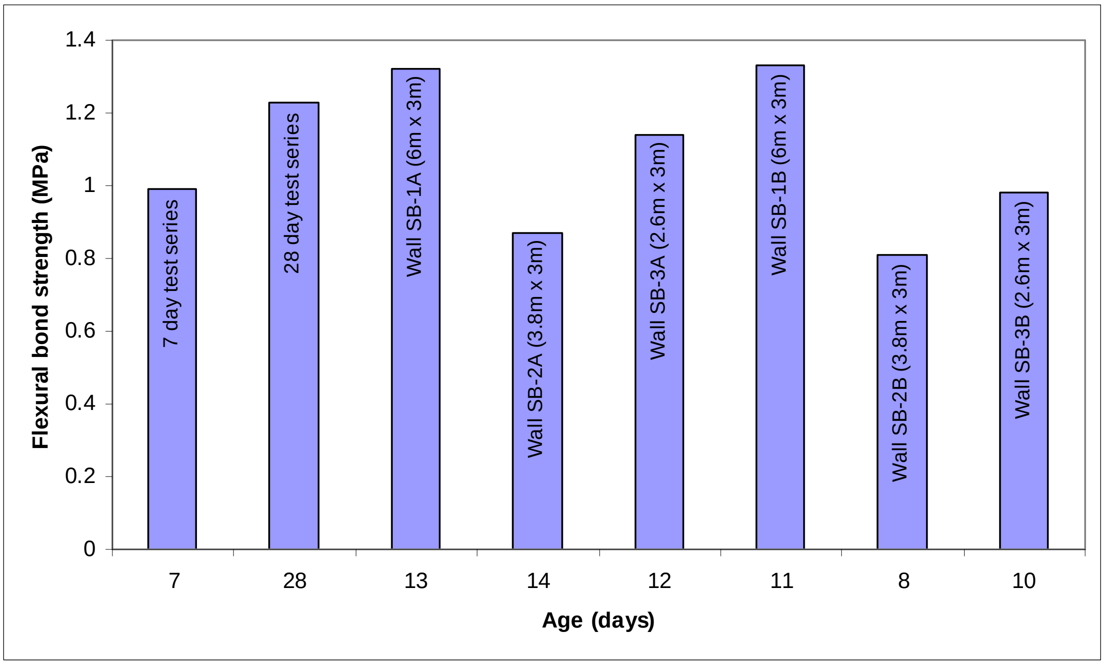


Figure 25. Average flexural bond strength at different ages of 100mm thick solid Benex masonry

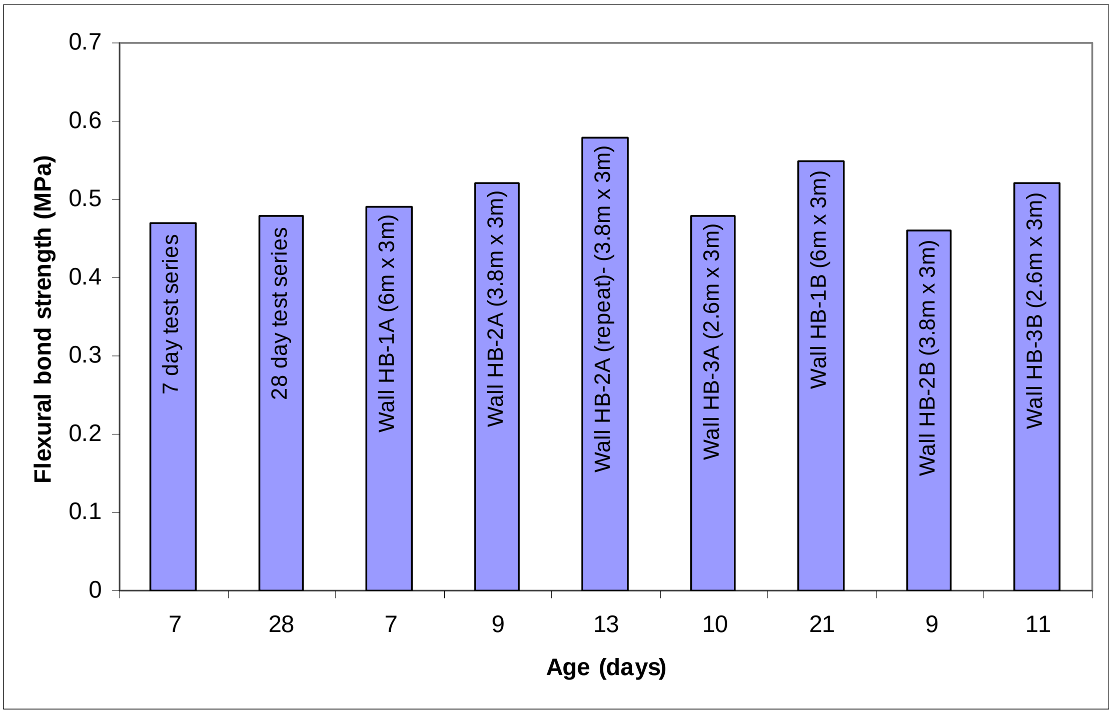


Figure 26. Average flexural bond strength at different ages of 200mm thick hollow Benex masonry

In 7 day & 28 day tests failure was sometimes within the joint and other times it was a combined block/joint failure. In the combined block/joint failures the protruding lugs/ribs failed under the action of the tensile force. Typical failure modes are shown in Figure 27.

Interface bond failure of solid block

Block failure at interface of solid block

Interface bond failure of hollow block

Block failure at interface of hollow block

Figure 27. Modes of flexural bond failures

7.1.2 Comments

The 7 day and 28 day characteristic strengths of masonry built with Benex blocks are greater than the default maximum value (0.2 MPa) specified in AS3700-2001. The results exhibit variability as in conventional masonry. However, the coefficients of variation for bond strength are lower than the default value (0.30 MPa) stipulated in AS3700 for small samples.

The average 28 day bond strength for the solid Benex block shows a significant increase from the 7-day, indicating that age influences the bond strength after 7 days. However, the hollow blocks appear to gain full strength in 7 days, probably due to the 25mm wide mortared bedding strips on the webs drying faster and reaching the optimum strength in 7 days.

7.2 Modulus of Rupture of Units

AS3700-2001 does not specify a minimum value for the modulus of rupture of units. This property is required in assessing the resistance of walls to out-of-plane horizontal bending. Tests have been carried out to assess this property for Benex blocks.

7.2.0 Test Method

The solid blocks were tested (as per AS/NZS 4456.15:2003) in four-point bending with a load span of 200 mm and a support span of 560 mm. The load was applied using an 'Avery' testing machine. The test set up is shown in Figure 28.

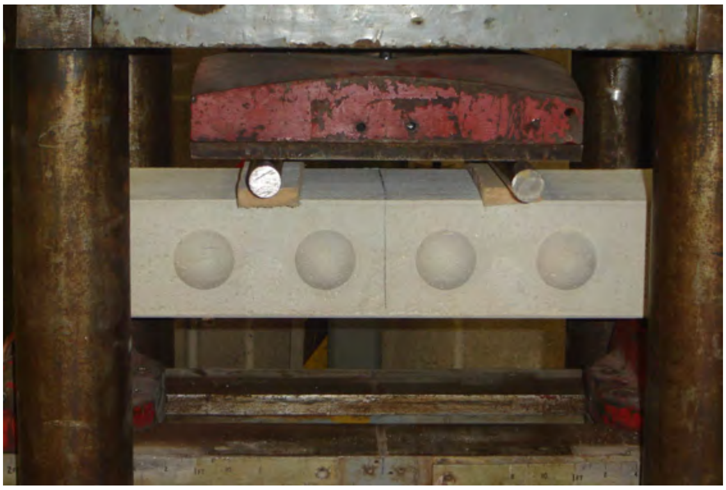
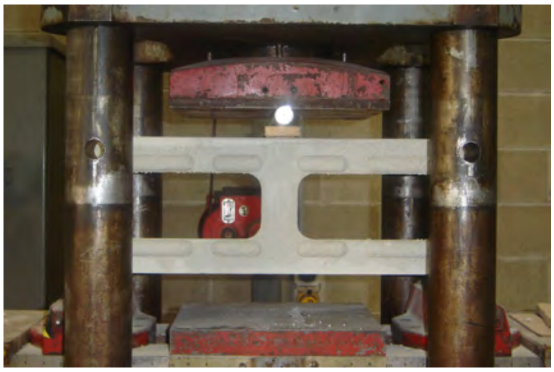


Figure 28. Test set up for modulus of rupture of Benex solid block

The hollow blocks could not be tested in four-point bending due to premature shear failure across the web (see Figure 29). Therefore, hollow blocks were tested in three-point bending where the simply supported specimen (span=560mm) was subjected to a gradually increasing load at the centre of the span (see Figure 29).

abandoned test method



adopted test method

Figure 29. Test set up for modulus of rupture of Benex hollow block

Each test sample contained thirty specimens.

7.2.1 Test Results

A summary of the results are shown in Table 10. The characteristic values were calculated as per AS3700-2001: Appendix B.

The detailed results are given in Appendix D of this report.

	100mm Solid Block	200m hollow block
Mean (MPa)	3.28	1.97
Standard Deviation (MPa)	0.09	0.09
Coefficient of Variation	0.03	0.05
Characteristic MOR (MPa)	2.65	1.52

Note: MOR – Modulus of Rupture

Table 10. Modulus of rupture of Benex blocks

7.2.2 Comments

There is no default value given in AS3700 for f'_{ut} (characteristic lateral modulus of rupture). However, AS3700-2001 allows using a value of 0.8MPa in the absence of test data. The characteristic modulus of rupture values to be used for Benex masonry design are 2.65MPa and 1.52MPa for 100mm solid and 200mm hollow blocks, respectively.

7.3 Horizontal Bending Moment Capacity

When masonry is bent about an axis perpendicular to the bed joint direction, two failure modes are possible with conventional masonry. Failure through perpend and bed joints in a zigzag pattern occurs when the units have a high value of modulus of rupture relative to the bond strength. If the modulus of rupture of the units is relatively low, propagation of a crack through the perpend and the units is likely to occur.

A designer calculates the horizontal bending moment capacity of masonry by the lowest of three expressions given in AS3700-2001 Clause 7.4.3.2 for conventional masonry and by a separate expression for AAC masonry laid in thin-bed mortar. These expressions are empirical and based on the tensile bond strength and the lateral modulus of rupture of the units. In spite of the lack of a rational basis, these expressions give reasonable estimates of horizontal flexural capacity for conventional masonry and AAC masonry.

Due to the empirical nature of the expressions used to calculate the horizontal moment capacity, there is a need to either verify its applicability or develop a new expression for Benex masonry.

7.3.0 Test Method

Two block long, and four course high stretcher-bonded panels were built with both 100mm thick solid and 200mm thick hollow Benex blocks. Ten specimens were built and tested after 7 days.

The specimens were supported as simple beams and loaded with a line load at the central perpend joints. The support span was 1150 mm. Compressible fibreboard strips were used to even out irregularities under the load and support bars. The load was applied steadily using a 'Dartec' hydraulic power actuated ram. A specimen under test is shown in Figure 30.

Figure 30. Test set up for horizontal beam test

7.3.1 Test Results

A summary of results is shown in Table 11 and the detailed results are given in Appendix E of this report.

Parameter	100mm solid block		200mm hollow block	
	7 day	28 day	7 day	28 day
M_h - Mean horizontal bending moment capacity of masonry (kN.m/m)	1.13	1.34	1.91	2.48
Standard Deviation (kN.m/m))	0.07	0.16	0.14	0.22
Coefficient of Variation	0.06	0.12	0.07	0.09
M_{ch} - Characteristic horizontal bending moment capacity of masonry (kN.m/m)	0.74	0.83	1.30	1.53

Table 11. Horizontal bending moment capacities of Benex masonry

Graphical illustrations of the 7-day and 28-day horizontal moment capacities are shown in Figure 31 and Figure 32 for solid and hollow blocks, respectively.

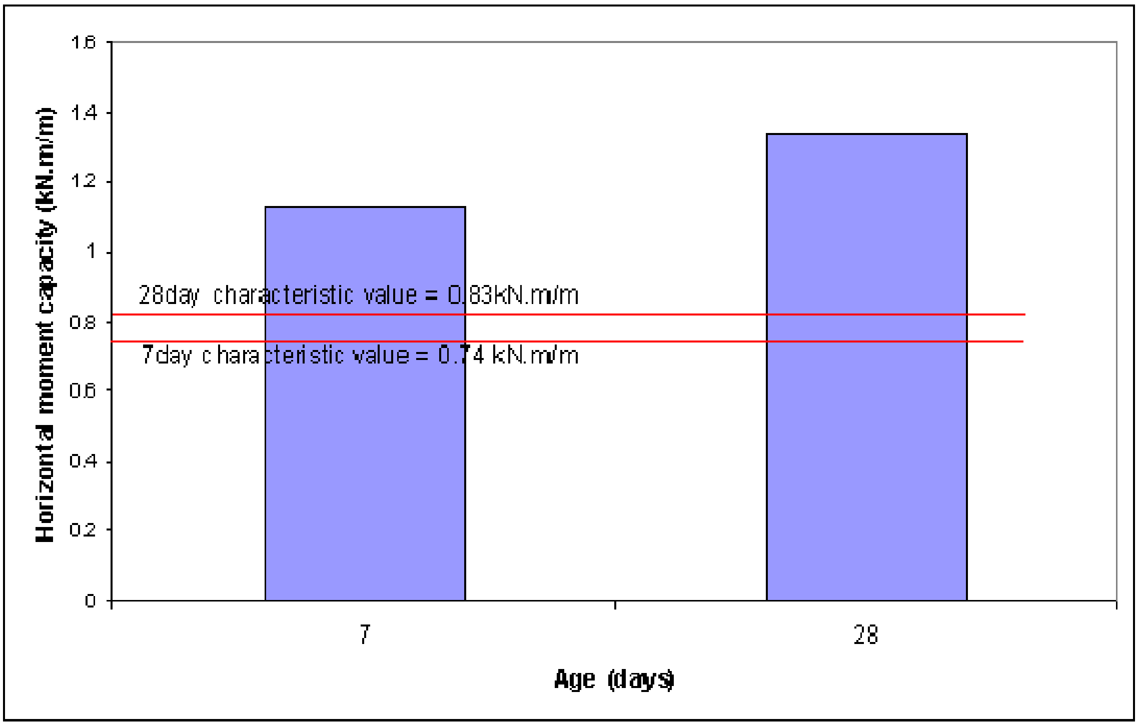


Figure 31. 7-day & 28-day horizontal moment capacities of 100mm thick solid Benex masonry

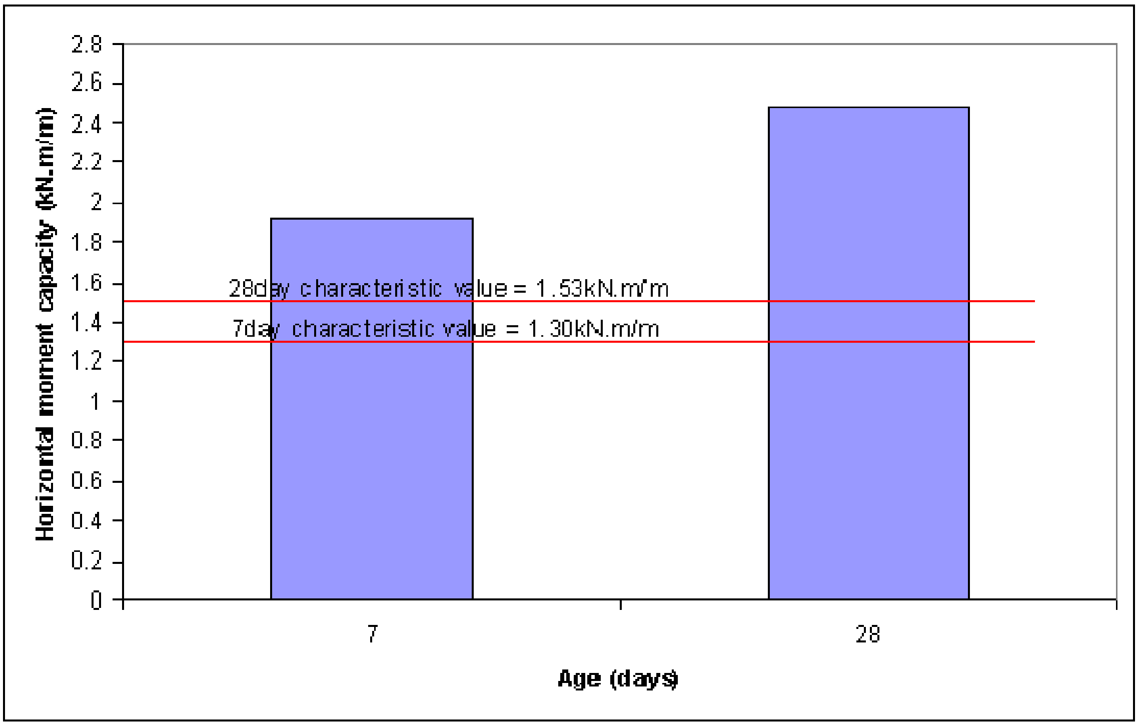


Figure 32. 7-day & 28-day horizontal moment capacities of 200mm thick hollow Benex masonry

The horizontal beam test results obtained during the lateral load tests are also shown in Table 12 and Table 13 for walls supported on all four sides and three sides, respectively. Five specimens were tested with each wall.

Test reference to wall type	Wall size Length x width	Age of horizontal beam test specimens	Mean (kN.m/m)	Standard Deviation (kN.m/m)	Coefficient of Variation
Solid block wall SB-1A	6m x 3m	13	1.23	0.08	0.07
Solid block wall SB-2A	3.8m x 3.0m	15	1.30	0.20	0.16
Solid block wall SB-3A	2.6m x 3.0m	12	0.93	0.11	0.12
Hollow block wall HB-1A	6m x 3m	7	2.66	0.40	0.15
Hollow block wall HB-2A	3.8m x 3.0m	9	2.62	0.32	0.12
Hollow block wall HB-2A (repeat test)	3.8m x 3.0m	14	2.09	0.15	0.07
Hollow block wall HB-3A	2.6m x 3.0m	9	2.22	0.24	0.11

Note: "A" refers to walls supported on four sides; "SB" & "HB" refers to hollow block & solid block walls

Table 12. Horizontal moment capacities of solid and hollow blocks performed in parallel with full-scale lateral load tests (walls supported on four sides)

Test reference to wall type	Wall size Length x width	Age of horizontal beam test specimens	Mean (kN.m/m)	Standard Deviation (kN.m/m)	Coefficient of Variation
Solid block wall SB-1B	6m x 3m	11 days	1.33	0.36	0.27
Solid block wall SB-2B	3.8m x 3.0m	8 days	0.74	0.08	0.10
Solid block wall SB-3B	2.6m x 3.0m	9 days	1.12	0.11	0.10
Hollow block wall HB-1B	6m x 3m	20 days	2.75	0.49	0.18
Hollow block wall HB-2B	3.8m x 3.0m	9 days	1.96	0.07	0.04
Hollow block wall HB-3B	2.6m x 3.0m	9 days	2.22	0.24	0.11

Note: "B" refers to walls supported on three sides; "SB" & "HB" refers to hollow block & solid block walls

Table 13. Horizontal moment capacities of solid and hollow blocks performed in parallel with full-scale lateral load tests (walls supported on three sides)

All the horizontal bending moment results of samples tested at different times in parallel with lateral load tests on full-scale walls are graphically shown in Figure 33 and Figure 34 for solid and hollow blocks respectively.

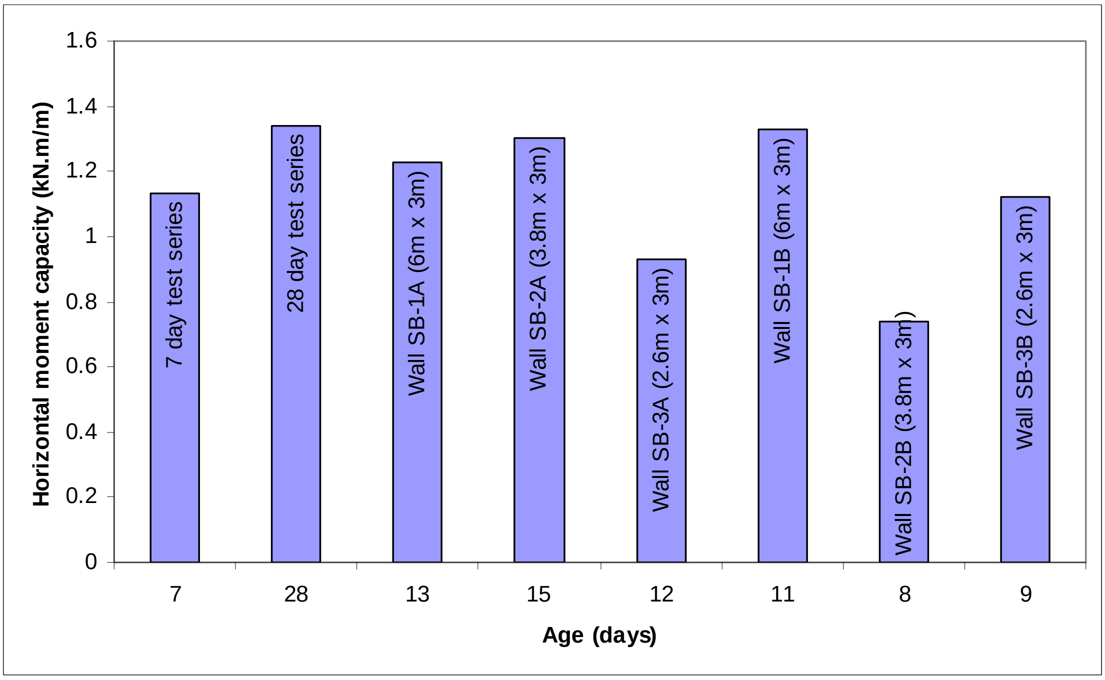


Figure 33. Average horizontal moment capacity at different ages of 100mm thick solid Benex masonry

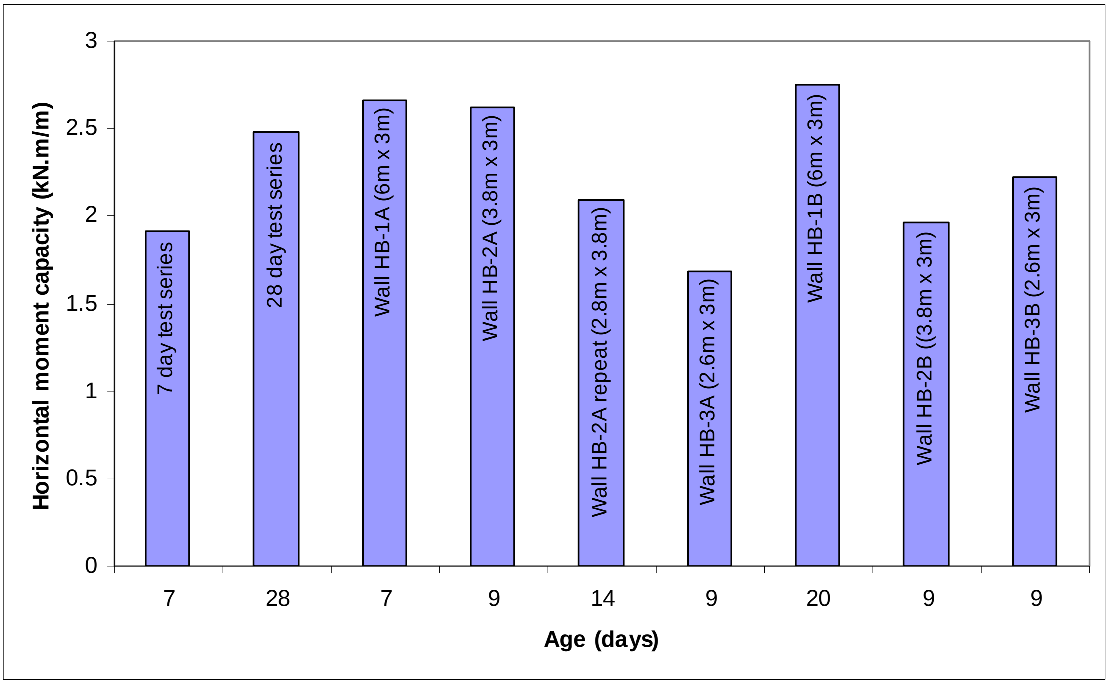
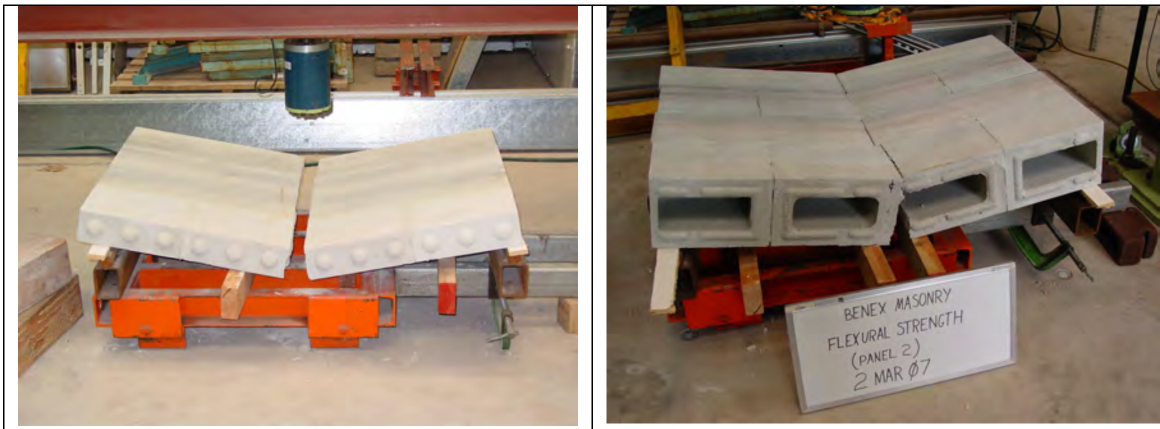


Figure 34. Average horizontal moment capacity at different ages of 200mm thick hollow Benex masonry

In all the tests, specimens failed through the blocks and the perpend joints along the centre of the panel. The failure was sudden and none of the bed joints were cracked (see Figure 35).



Solid block beams | Hollow block beams

Figure 35. Typical failures of specimen subjected to horizontal bending

7.3.2 Comments

One would assume that the most appropriate approach for calculating the design horizontal bending moment capacity for Benex masonry is by using the code formula recommended for AAC masonry. AAC masonry is somewhat similar to Benex masonry since units are laid in with thin-bed mortar joints like in Benex masonry. Also, previous experience revealed that 200mm thick AAC block masonry panels under horizontal bending tests fail in a mode similar to Benex masonry. However, Benex masonry differs from AAC masonry primarily due to two reasons.

1. AAC block masonry use full-bedding of units whereas Benex block masonry uses strip bedding (25mm thick bedding strip along the edges of the block) for both hollow and solid blocks.

2. The provision of lugs/ribs in Benex in masonry units provides a significant contribution to the torsional shear resistance under horizontal bending.

The design horizontal bending moment capacity stipulated in AS3700 for AAC masonry (Clause 7.4.3.2) with thin bed mortar is given below.

$M_{ch} = \varnothing\,(0.22f'_{ut} + 0.33\,k_{mt}\,f'_{mt})\,Z_d$

Where,

M_{ch} – characteristic horizontal bending moment capacity

f'_{ut} – characteristic modulus of rupture of units

f'_{mt} - characteristic bond strength

k_{mt} – a bedding factor, which is equal to 1.3 for AAC

Z_d – section modulus of bedding area

$\varnothing$ - capacity reduction factor

Because of the nature of strip-bedding the following formula would be suggested for Benex masonry, which separately takes into account the lateral section modulus of the units and the mortar at the perpend joints.

For 100mm solid block Benex masonry: $M_{ch} = \varnothing\,(\alpha\, f'_{ut}\; Z_u + \beta\, f'_{mt}\; Z_p)$

For 200mm hollow block Benex masonry: $M_{ch} = \varnothing\,(\delta\, f'_{ut}\; Z_u + \theta\, f'_{mt}\; Z_p)$

Where,

Z_u – lateral section modulus of the masonry unit

Z_p – lateral section modulus based on the mortar contact area

α, β, δ and θ are constants.

Theoretically, the total moment resisted by the panel should be equal to the moment resisted by the perpend joints and the masonry units along the crack path. Hence, it can be proved that;

$\alpha + \beta = 1$ and
$\delta + \theta = 1$

When conventional masonry demonstrates a failure through the perpend joints and the units, AS3700-2001 recommends the values of 0.44 and 0.56 for those two constants. However, this is not to be the same with AAC masonry where the sum of the constants is 0.5 (which is 0.22 + 0.33). Since the values of those constants have been derived through experimental data, its validity cannot be argued.

In order to establish suitable values for α, β, δ and θ, initially, moment capacities were predicted for each test sample prepared at different times with the full-scale walls using the average values of flexural bond strength (f_{mt}) and the modulus of rupture of units (f_{ut}). Different combinations of values were tried out and compared with the average horizontal bending moment capacities given in Table 12 and Table 13. Using statistical methods, the most suitable values for α, β, δ and θ were derived as;

$\alpha = 0.25$ and $\beta = 0.75$ for 100mm solid block Benex masonry;

$\delta = 0.30$ and $\theta = 0.70$ for 200mm hollow block Benex masonry.

Hence, the average horizontal bending moment capacity (M_h) for Benex masonry can be predicted using the following formulae.

For 100mm solid block Benex masonry: $M_h = (0.25\, f_{ut}\; Z_u + 0.75\, f_{mt}\; Z_p)$

For 200mm hollow block Benex masonry: $M_h = (0.3\, f_{ut}\; Z_u + 0.7\, f_{mt}\; Z_p)$

Comparisons of predicted average horizontal bending moment with actual capacities for solid and hollow Benex masonry are shown in Figure 36 and Figure 37, respectively.

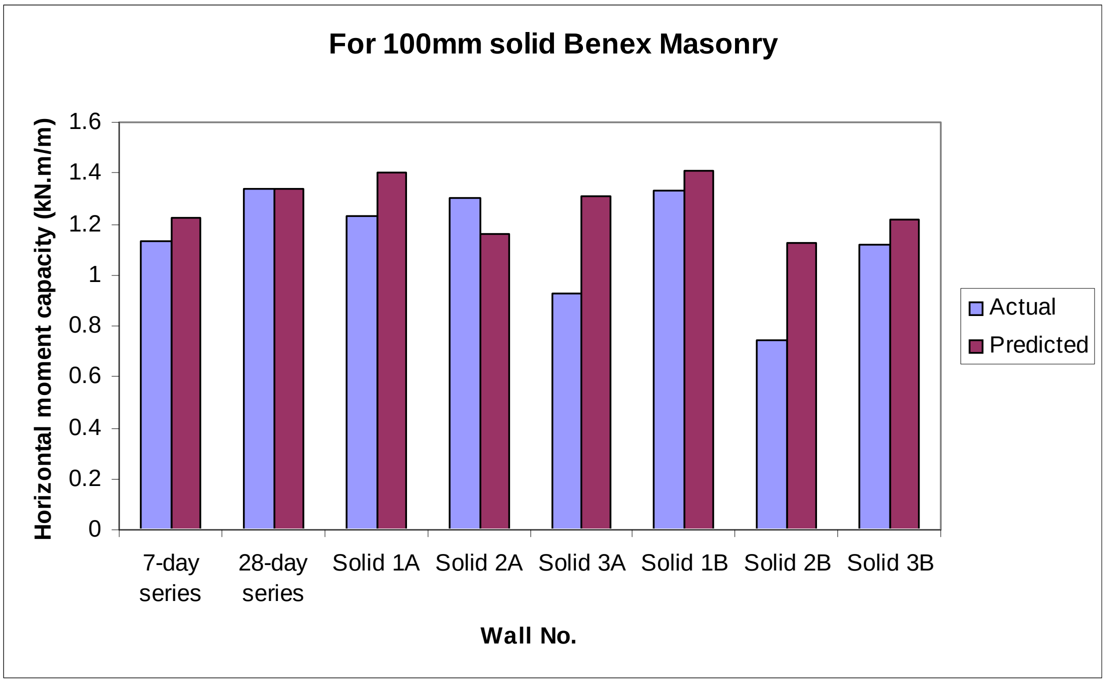


Figure 36. Comparison of Benex horizontal beam results with predicted capacities for solid block masonry

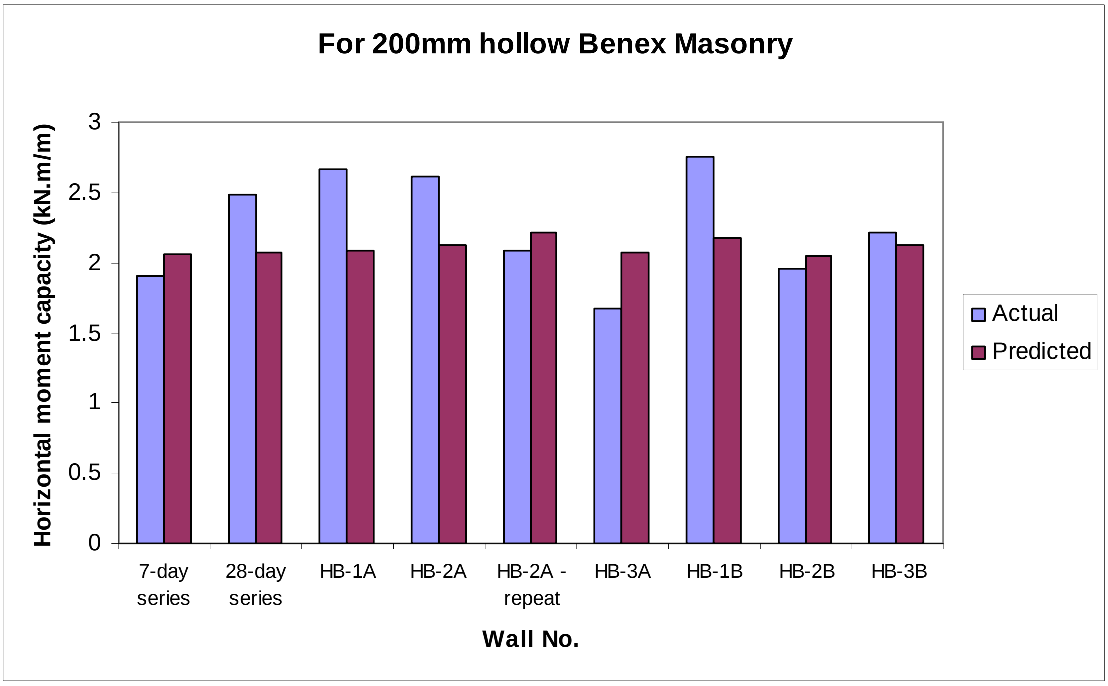


Figure 37. Comparison of Benex horizontal beam results with predicted capacities for hollow block masonry

The predicted horizontal bending moment capacities compare well with the actual results. Therefore, the characteristic horizontal bending moment capacity for Benex masonry may be predicted using the characteristic modulus of rupture of units and characteristic flexural bond strength using the following formulae on the assumption that variability of each parameter is within acceptable range.

For 100mm solid block Benex masonry: $M_{ch} = \varnothing\,(0.25\,f'_{ut}\,Z_u + 0.75\,f'_{mt}\,Z_p)$

For 200mm hollow block Benex masonry: $M_{ch} = \varnothing\,(0.3\,f'_{ut}\,Z_u + 0.7\,f'_{mt}\,Z_p)$

Comparison of characteristic horizontal bending moment capacities derived from the 7-day horizontal beam test series and the predicted values using the 7-day characteristic flexural bond strength and the characteristic modulus of rupture of units is shown in Figure 17. Although the predicted results appear to be slightly higher than the actual results for the 7-day tests, this can be accepted due to the fact that the prediction was based on a large number of test samples tested at different ages.

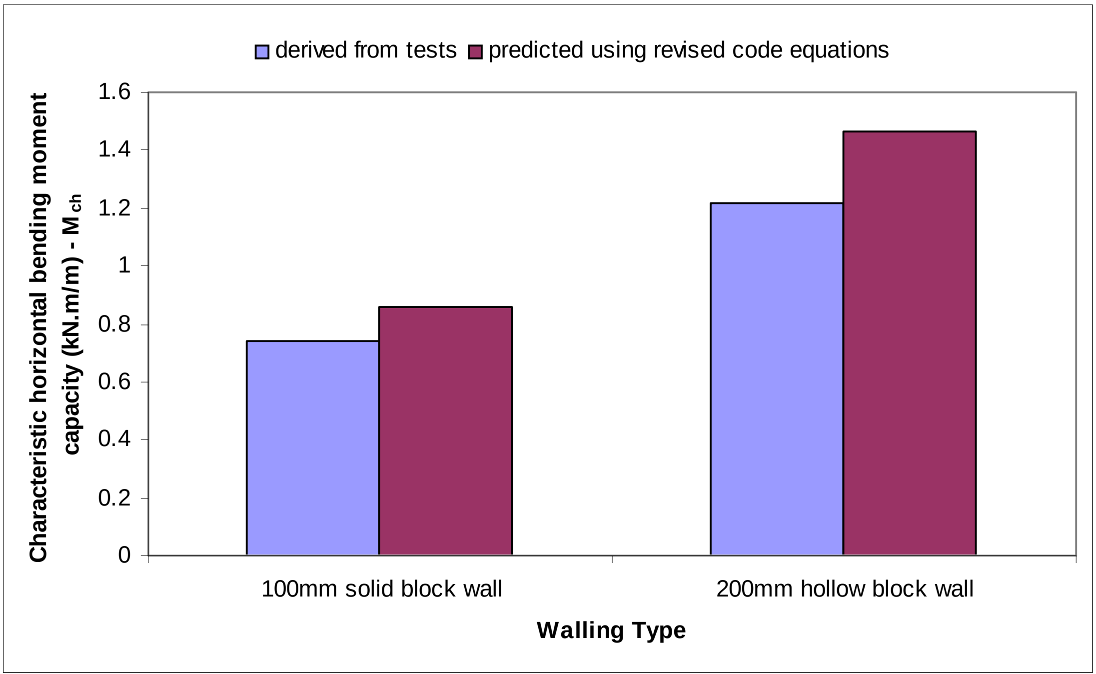


Figure 38. Comparison of Benex 7-day horizontal beam results with recommended formulae

7.4 Design for two-way bending of Benex masonry

7.4.0 Full-scale wall tests

In order to verify the code formulae for Benex masonry, several full-scale walls were tested under two support configurations.

1. All four edges simply supported
2. Three edges simply supported while the top edge was un-supported.

For each block type, six wall configurations were tested. The aim of the study was to understand the behaviour of walls built from Benex units and to confirm whether the factors incorporated in AS3700-2001 for the design of such walls are satisfactory.

7.4.1 Test Method

The variables considered for the tests are the aspect ratio of the wall and the boundary conditions. The details of the walls tested are given in Table 14.

The test rig comprised a large steel frame of stiff supporting members. The load was uniformly applied to the surface of the wall by air bags. The flow of air into the bags was controlled by a set of pressure regulators which enabled the load to be applied steadily. The air pressure was measured by two pressure transducers, a water manometer and a digital manometer connected to the manifold.

The wall displacements were measured by displacement transducers mounted on free-standing supports and readings were made on the front surface of the test wall.

Constant monitoring of loads and displacements was achieved by logging data to a computer via a data acquisition unit.

With each wall, two prisms, each four units high, were built and each of the resulting six joints was tested at the time of testing the wall, for its flexural bond strength by the bond wrench. Also, five, two courses long and four courses high, horizontal beams were made and tested, for its horizontal bending moment capacity.

A typical test set up is shown in Figure 39.

Figure 39. Lateral load test set up

7.4.2 Test results

The failure pressures of the full-scale walls are given in Table 14. Flexural bond strength and the horizontal beam results are shown in Table 8, Table 9, Table 12 and Table 13. During the tests, initial cracking was detected by an acoustic monitor and by a sudden change in the pressure-deflection curve.

Test reference	Wall size Length x width	Support conditions	Age of the test panel (days)	First crack pressure (kPa)	Ultimate pressure (kPa)
Solid block wall SB-1A	6m x 3m	S.S. all four sides	13	1.68	1.68
Solid block wall SB-2A	3.8m x 3.0m	S.S. all four sides	14	2.48	3.89
Solid block wall SB-3A	2.6m x 3.0m	S.S. all four sides	12	4.2	4.5
Solid block wall SB-1B	6m x 3m	Top edge free and other 3 sides S.S.	10	1.26	1.40
Solid block wall SB-2B	3.8m x 3.0m	Top edge free and other 3 sides S.S.	7	1.58	1.90
Solid block wall SB-3B	2.6m x 3.0m	Top edge free and other 3 sides S.S.	9	2.43	2.6
Hollow block wall HB-1A	6m x 3m	S.S. all four sides	7	2.1	2.32
Hollow block wall HB-2A	3.8m x 3.0m	S.S. all four sides	9	Test terminated since shear failure at the support occurred	
Hollow block wall HB-2A (repeat test)	3.8m x 3.0m	S.S. all four sides	13	4.9	5.2
Hollow block wall HB-3A	2.6m x 3.0m	S.S. all four sides	10	4.86	8.25
Hollow block wall HB-1B	6m x 3m	Top edge free and other 3 sides S.S.	20	2.71	3.38
Hollow block wall HB-2B	3.8m x 3.0m	Top edge free and other 3 sides S.S.	8	2.71	3.38
Hollow block wall HB-3B	2.6m x 3.0m	Top edge free and other 3 sides S.S.	9	5.0	5.1

Table 14. Failure pressures of full-scale walls

The test wall HB-2A failed along one of the vertical support edges in a shear mode failure due to the fact that the hollow blocks touching the support did not have the cross web at the end of the wall. Hence, in the subsequent tests (including the repeat test on wall HB-2A), end blocks along the vertical edge where there was no cross web in the blocks were filled with a sand and cement mix.

Generally, all the walls failed as expected. In the walls supported along the four sides the first crack observed was always horizontal, through a bed joint near the mid height of the wall. Failure then took place with the formation of vertical cracks over the full height of the wall as shown in Figures 40(a) to 40(f).

The walls supported along three sides first failed with a vertical crack followed by diagonal cracks propagating downward [see Figures 41(a) to 41(f)]. The pressure-deflection curves at the mid-span for walls supported on four edges are shown. For walls supported on three edges, the centre span deflection at the top edge has been shown in addition to the deflection at centre of the wall. The crack patterns are also shown with the load-deflection curves.

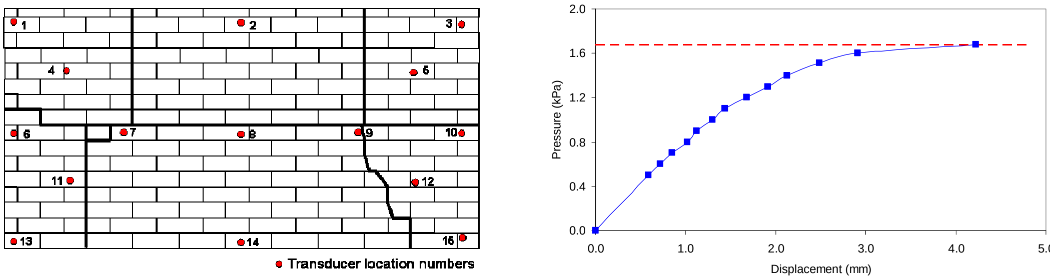


Figure 40 (a). Crack pattern and deflection at centre for solid block wall (6m x 3m) supported on all 4 sides

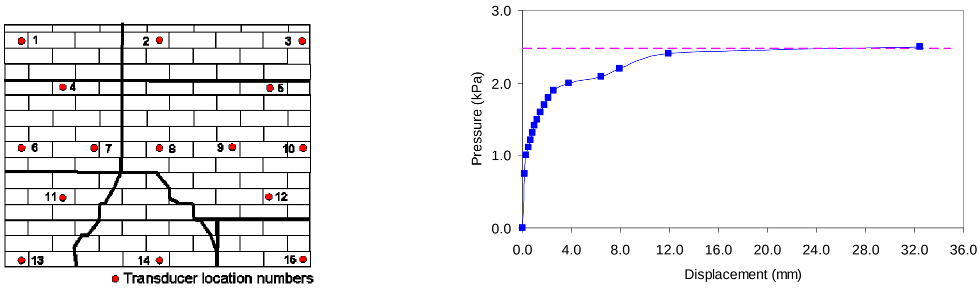


Figure 40 (b). Crack pattern and deflection at centre for solid block wall (3.8m x 3m) supported on all 4 sides

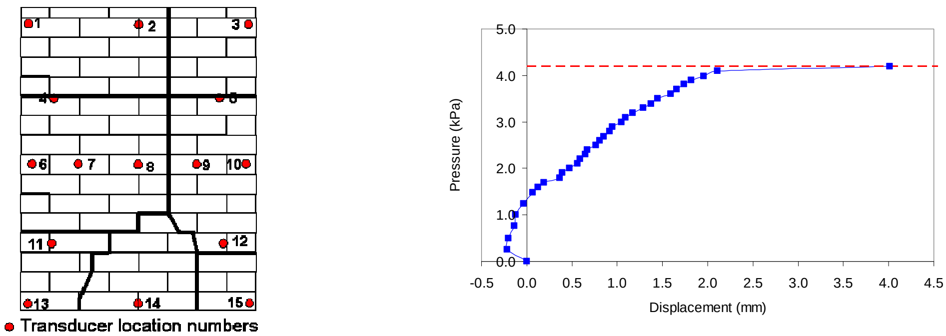


Figure 40 (c). Crack pattern and deflection at centre for solid block wall (2.6m x 3m) supported on all 4 sides

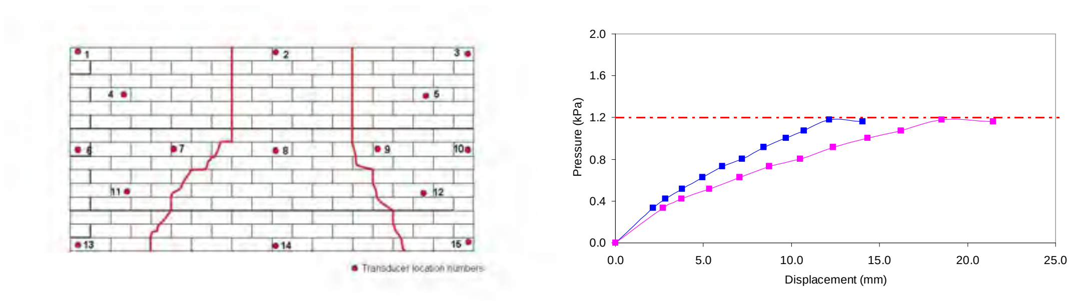


Figure 40 (d). Crack pattern and deflection at centre for solid block wall (6m x 3m) supported on 3 sides with top side free

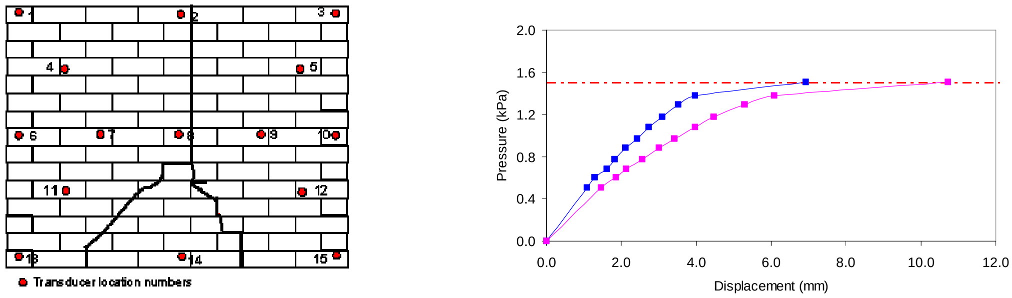


Figure 40 (e). Crack pattern and deflection at centre for solid block wall (3.8m x 3m) supported on 3 sides with top side free

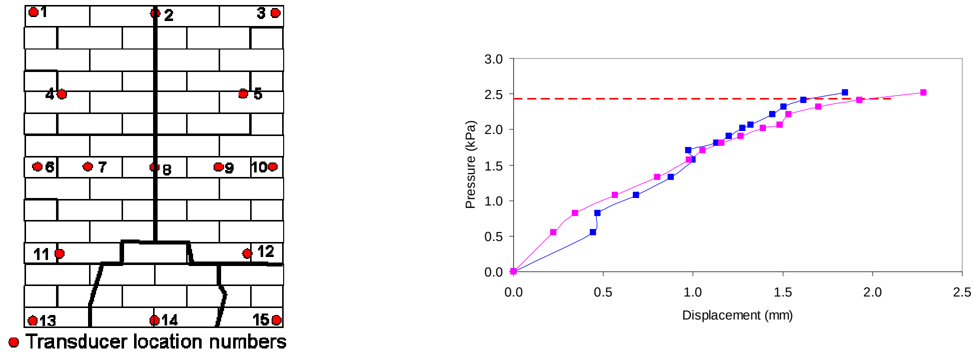


Figure 40 (f). Crack pattern and deflection at centre for solid block wall (2.6m x 3m) supported on 3 sides with top side free

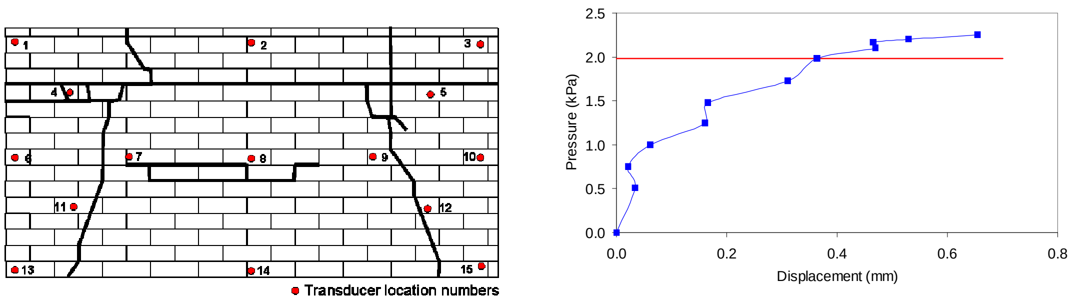


Figure 41 (a). Crack pattern and deflection at centre for hollow block wall (6m x 3m) supported on all 4 sides

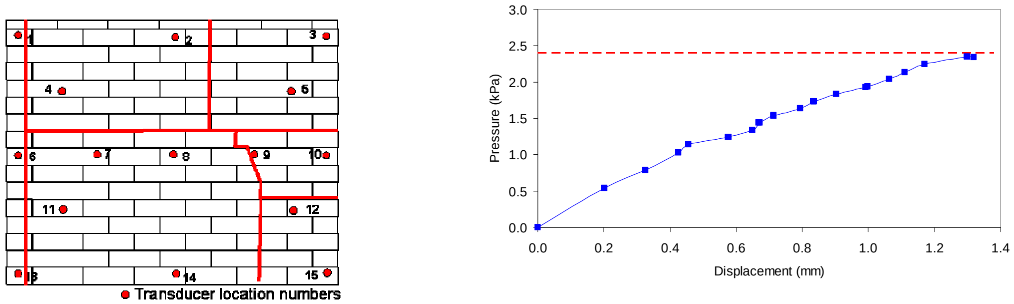


Figure 41 (b). Crack pattern and deflection at centre for hollow block wall (3.8m x 3m) supported on all 4 sides

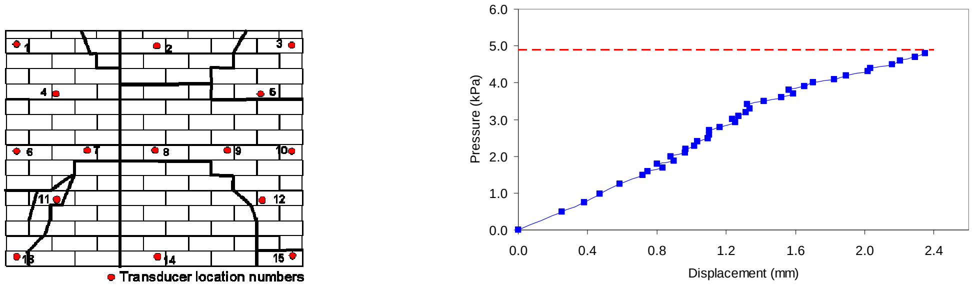


Figure 41 (c). Crack pattern and deflection at centre for hollow block wall (3.8m x 3m) supported on all 4 sides – repeat test

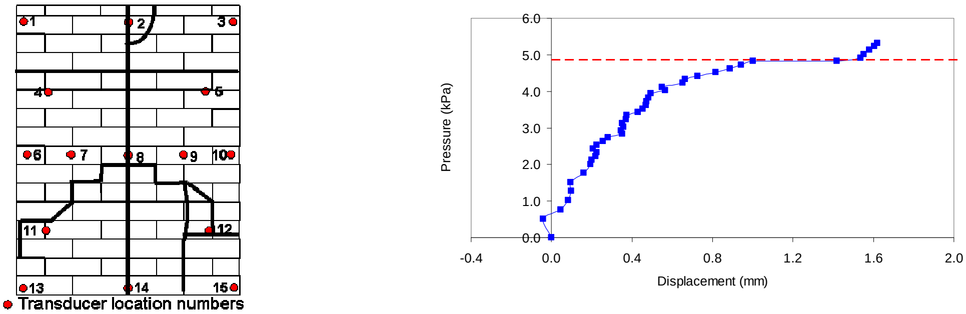


Figure 41 (d). Crack pattern and deflection at centre for hollow block wall (2.6m x 3m) supported on all 4 sides

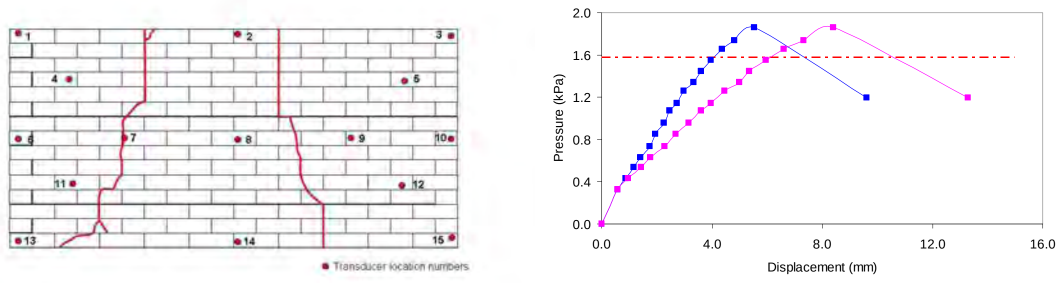


Figure 41 (e). Crack pattern and deflection at centre for hollow block wall (6m x 3m) supported on 3 sides with top side free

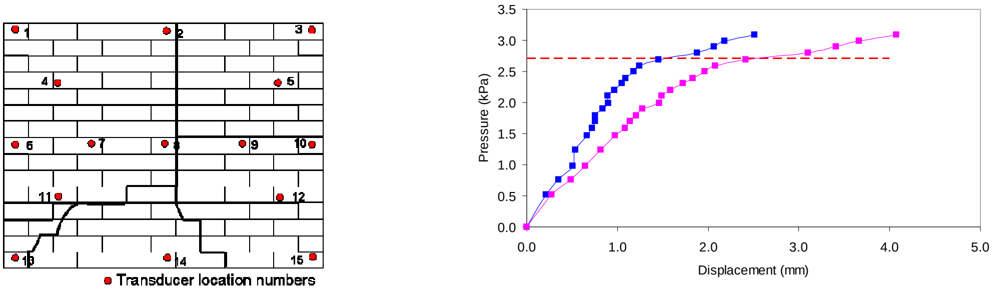


Figure 41 (f). Crack pattern and deflection at centre for hollow block wall (3.8m x 3m) supported on 3 sides with top side free

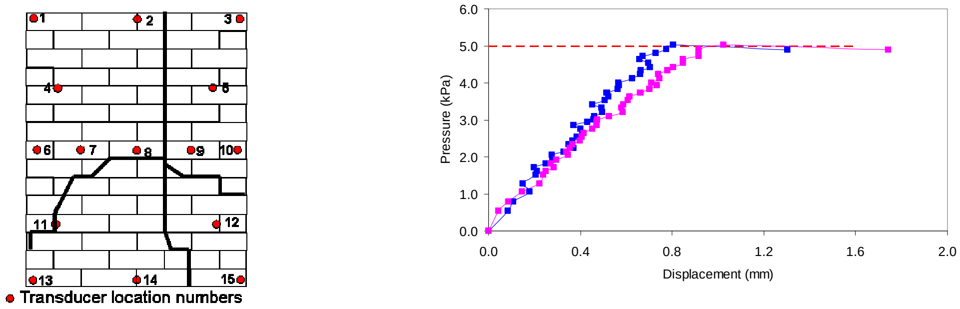


Figure 41 (g). Crack pattern and deflection at centre for hollow block wall (2.6m x 3m) supported on 3 sides with top side free

Graphs of failure pressures for all the test walls are shown in Figure 42 and Figure 43 for solid and hollow block masonry.

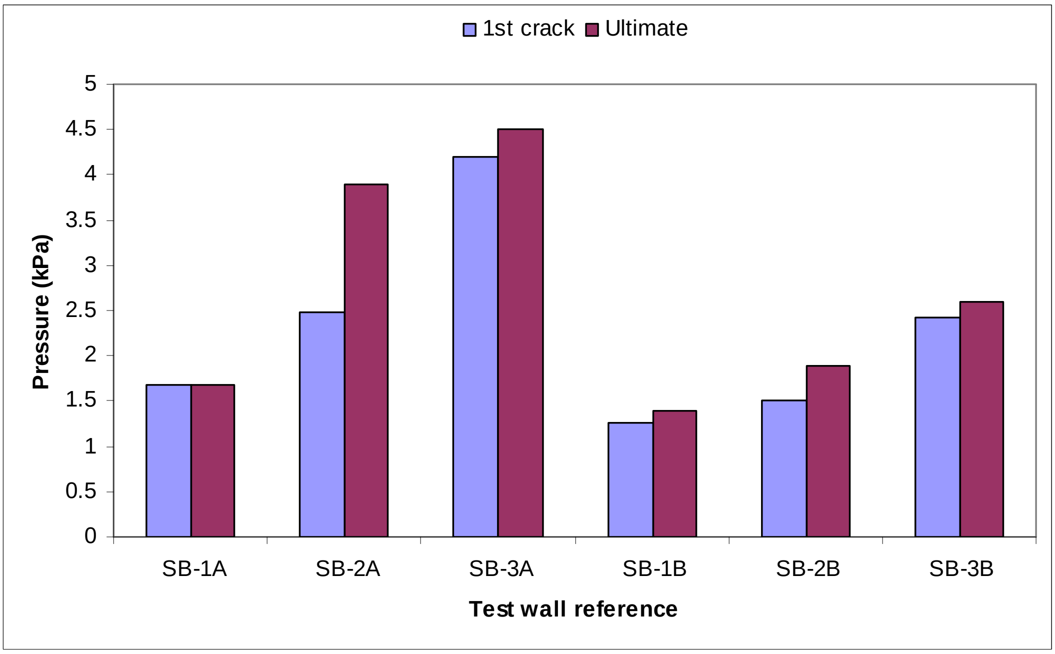


Figure 42. Failure pressures of test walls built with 100mm solid blocks

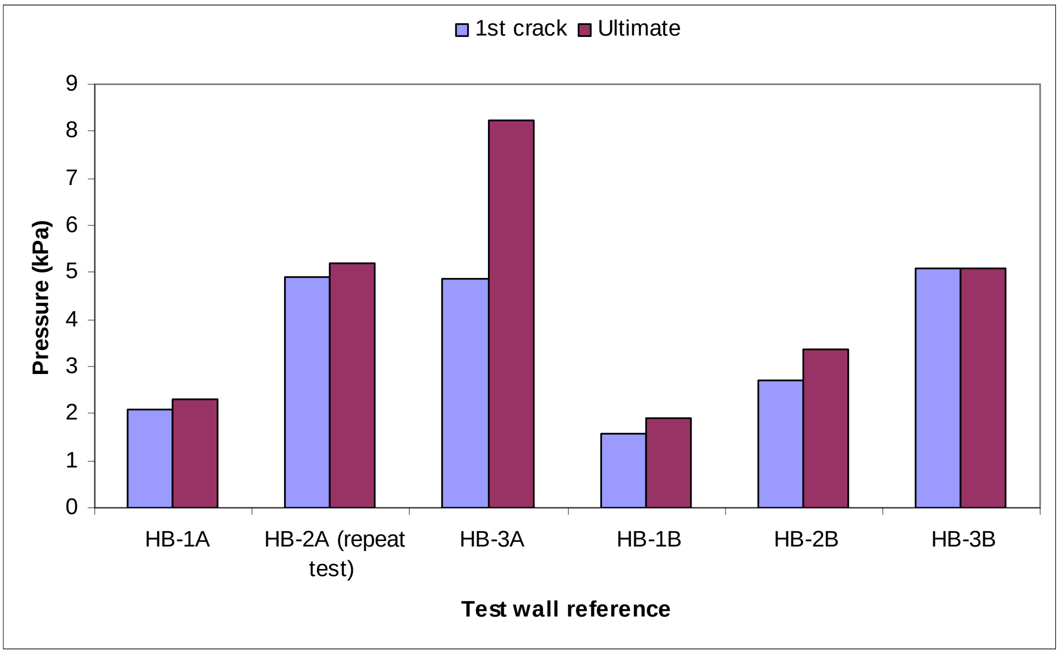


Figure 43. Failure pressures of test walls built with 200mm hollow blocks

7.4.3 Comments

Clause 7.4.4 of AS3700-2001 details the procedure involved in designing an un-reinforced masonry wall subjected to two-way bending under the action of wind load. Clause 7.4.4.3 recommends an equation to predict the design load for AAC units laid in thin-bed mortar which is re-produced below.

$$w_d \leq 12\frac{H}{L}\left(\frac{b_v M_{cv}}{H^2}+\frac{b_h M_{ch}}{L^2}\right)$$

Where,

w_d – design wind pressure

H – clear height of the wall between horizontal supports

L – clear length of the wall between vertical supports

b_v and b_h – vertical and horizontal bending co-efficients as per Table 7.5 of AS3700-2001

M_{cv} – characteristic vertical bending moment capacity derived from characteristic flexural bond strength

M_{ch} – characteristic horizontal bending moment capacity derived from characteristic flexural bond strength and characteristic modulus of rupture of units

A similar expression should be valid for Benex masonry, too. Hence, a general equation to predict the design load capacity under lateral wind pressure can be written as:

$$w_d \leq k\frac{H}{L}\left(\frac{b_v M_{cv}}{H^2}+\frac{b_h M_{ch}}{L^2}\right)$$

Where, “k” is a constant.

During the lateral load tests, average horizontal bending capacity and the average flexural bond strength of the Benex masonry were established for each test wall. Hence, for each test wall, the parameter $\frac{H}{L}(\frac{b_v M_v}{H^2}+\frac{b_h M_h}{L^2})$ was calculated using average properties and plotted against the ultimate lateral pressure (Figure 44 & Figure 45) to evaluate the value of the constant “k” for solid block and hollow block Benex masonry. Hence, the recommended design pressure for walls supported on at least 3 edges, and not containing openings, can be given as:

$w_d \leq 14\frac{H}{L}(\frac{b_v M_{cv}}{H^2}+\frac{b_h M_{ch}}{L^2})$ for 100mm solid block Benex masonry

$w_d \leq 15\frac{H}{L}(\frac{b_v M_{cv}}{H^2}+\frac{b_h M_{ch}}{L^2})$ for 200mm hollow block Benex masonry

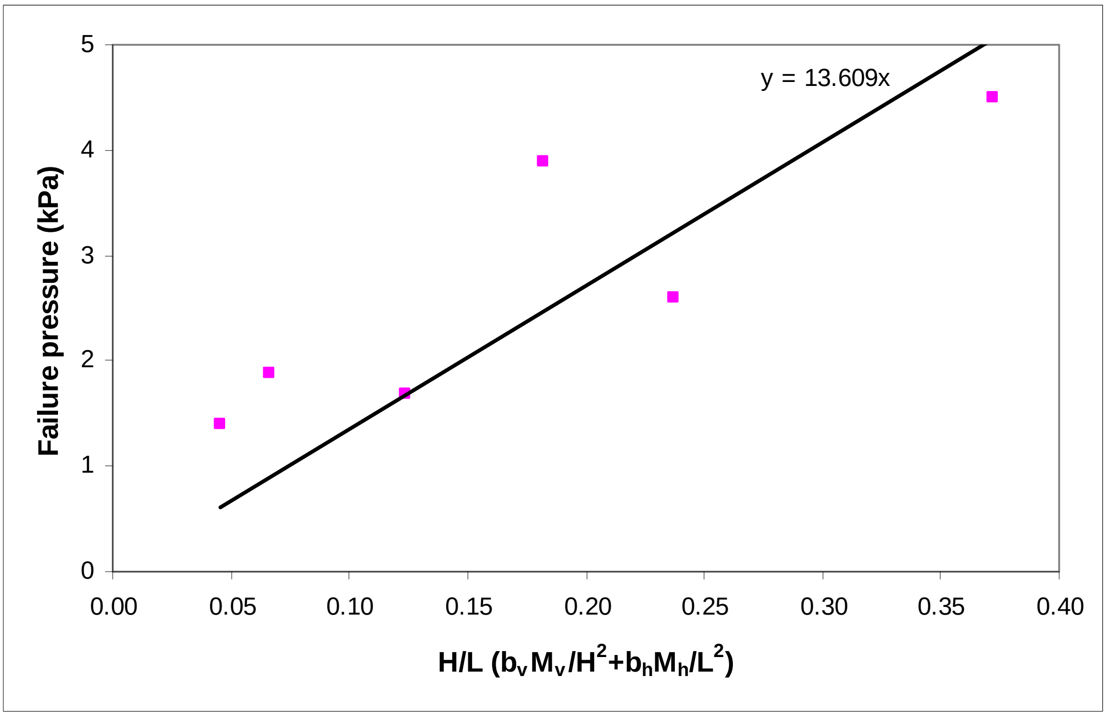


Figure 44. Assessment of “k” for 100mm solid block masonry

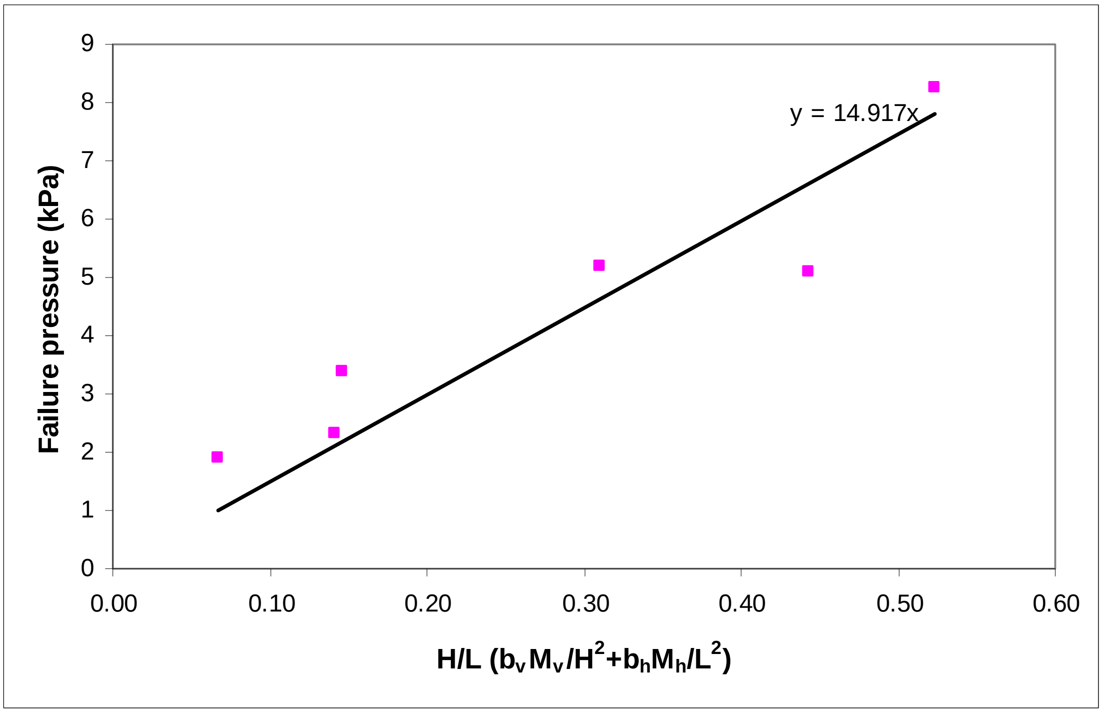


Figure 45. Assessment of "k" for 200mm hollow block masonry

Figure 46 and Figure 47 show the actual pressures at failure and the predicted pressures using characteristic and the average properties of materials.

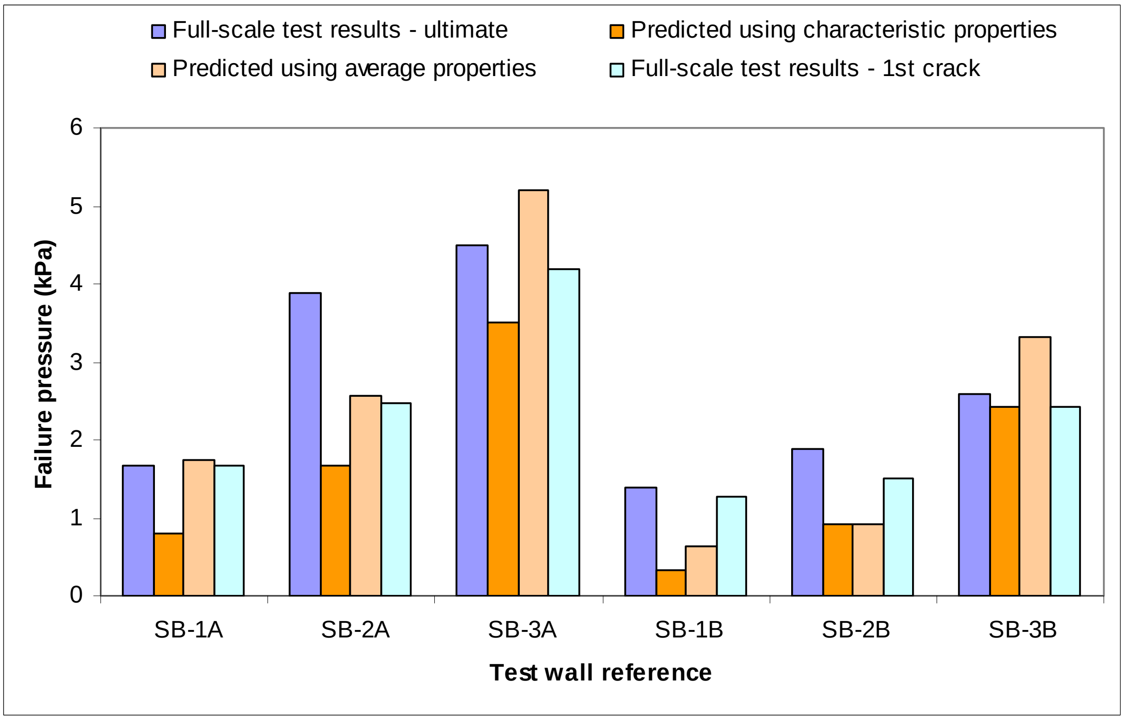


Figure 46. Predicted failure pressures for 100mm solid block masonry

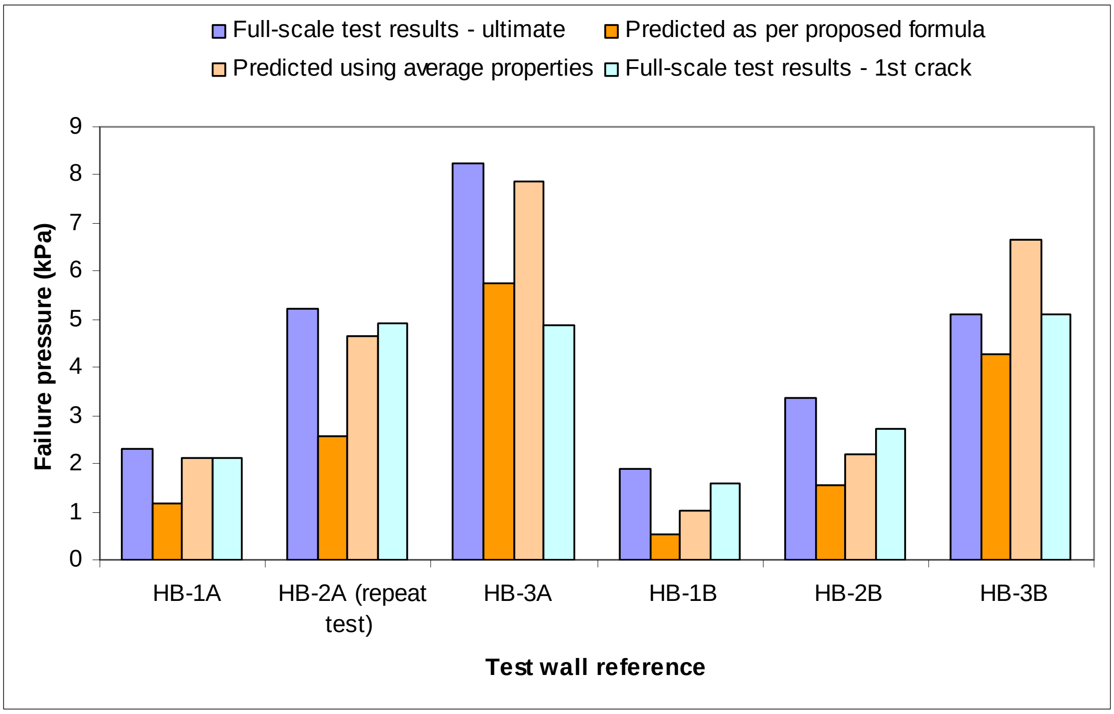


Figure 47. Predicted failure pressures for 200mm hollow block masonry

The predicted pressures using average properties (horizontal bending moment capacity and the flexural bond strength) compares well with the actual failure pressures observed during the tests. The predicted pressures using characteristic properties of materials (flexural bond strength and the modulus of rupture of units) as per the proposed formula give the design pressure.

7.5 Conclusions

The lateral load capacity of Benex masonry can be predicted as per AS3700-2001 with minor modifications to some of the formulae as briefed below.

7.5.0 Horizontal bending moment capacity (M_{ch})

For 100mm solid block Benex masonry: $M_{ch} = \varnothing\,(0.25\, f'_{ut}\; Z_u + 0.75\, f'_{mt}\; Z_p)$

For 200mm hollow block Benex masonry: $M_{ch} = \varnothing\,(0.3\, f'_{ut}\; Z_u + 0.7\, f'_{mt}\; Z_p)$

7.5.1 Lateral load capacity of walls supported on at least 3 edges

$$w_d \le 14\frac{H}{L}\left(\frac{b_v M_{cv}}{H^2} + \frac{b_h M_{ch}}{L^2}\right)$$ for 100mm solid block Benex masonry

$$w_d \le 15\frac{H}{L}\left(\frac{b_v M_{cv}}{H^2} + \frac{b_h M_{ch}}{L^2}\right)$$ for 200mm hollow block Benex masonry

The definition of the parameters used in the above equations are as per AS 3700-2001.

7.5.2 Characteristic properties of Benex materials

(a) 100mm solid blocks

7-day characteristic flexural bond strength = 0.56MPa
Characteristic lateral modulus of rupture of units = 2.65MPa

(b) 200mm hollow blocks

7-day characteristic flexural bond strength f'_{mt} = 0.27MPa
Characteristic lateral modulus of rupture of units f'_{ut} = 1.52MPa

The above properties can be improved with further development of the materials used with Benex masonry. Hence, in such situations new values for f'_{mt} and f'_{ut} may be assigned after proper testing.

7.5.3 Geometrical properties of Benex masonry units

(a) 100mm solid blocks

Lateral section modulus of unit per meter length Z_u = 888333mm^3
Lateral section modulus of mortar contact area of the perpend joint per meter length Z_p = 729167mm^3 (assuming 25mm thick strip bedding)

(b) 200mm hollow blocks

Lateral section modulus of unit per meter length Z_u = 2417916mm^3
Lateral section modulus of mortar contact area of the perpend joint per meter length Z_p = 1927083mm^3 (assuming 25mm thick strip bedding)

8 SHEAR STRENGTH

8.0 Shear Strength in a Horizontal Plane

8.0.1 Introduction

An important requirement of masonry is the ability to withstand lateral loads which may be induced by earthquakes or wind loadings. The lateral loads acting on facades are usually transmitted to the foundation through shear wall action of masonry walls.

In AS3700, Clause 7.5 describes the method of assessing the shear resistance of a masonry wall. Calculation of the shear capacity is the same regardless of whether the force is acting in the plane of the wall, or normal to the plane of the wall. It is defined as a linear function of the compressive stress acting on the shear plane as shown below.

Shear capacity = $V_o + V_1$ for normal masonry, and
Shear capacity = $V_{Ao} + V_{A1}$ for AAC masonry.

Where

V_o = Shear bond capacity of the section derived from characteristic flexural bond strength

V_1 = Shear friction capacity of the section which depends on the compressive stress acting on the joint

V_{Ao} = Shear rupture capacity of the section

V_{A1} = Shear friction capacity of the section which depends on the compressive stress acting on the joint

Masonry exhibits distinct directional properties due to the influence of the mortar joints. Depending upon the orientation of the joints to the applied stresses, failure can occur in the joints alone, or in some form of combined mechanism involving the mortar and the masonry unit. When a masonry wall is subjected to in-plane shear forces, it assumes that the joint resistance is attributed to the initial bond strength between the mortar and the masonry unit and to the frictional resistance which is said to be proportional to the compressive stress normal to the bed joint. The code's formula for assessment of the shear capacity is based on this principle. In other words, it assumes the shear failure is primarily along the mortar joints. However, this may not be the same for Benex masonry where joint strength is far superior compared to the block tensile strength. Hence, under racking shear forces a wall would fail in a combined block/joint failure.

The shear bond capacity is a characteristic property of the masonry material. It is difficult to develop a representative shear test to determine this property since application of a shear force to a joint (very likely the shear plane) usually results in a non-uniform shear stress distribution. For this reason, no test has been given in AS3700, and an empirical relationship in terms of the flexural tensile strength has been specified for conventional masonry.

For AAC masonry, instead of shear bond capacity, shear rupture capacity has been proposed since interface bond failure is unlikely to occur but a combined joint/block failure at the interface.

The shear friction capacity contributes to the frictional property of the shearing plane as explained earlier. This is calculated using a shear factor given in Table 3.3 of AS 3700-2001. A conservative value of 0.30 has been proposed by AS3700 for all types of masonry, where as 0.12 for AAC.

For Benex masonry the behaviour under shear would be more similar to AAC, since the block characteristics are more like those of AAC. However, experimental evidence is required to demonstrate the AS3700 method can be used to design Benex walls subject to shear forces.

The stress distribution within a shear wall can be complex and mostly depends upon the geometry of the wall and the type of load application. Hence, a large number of full-scale tests have been carried out in the past for the purpose of deriving design recommendations given in AS3700. As full-scale tests are expensive to perform, relative small panels were tested with Benex masonry under uni-axial loading which can reproduce the state of stress within the critical region of a large shear wall.

8.0.2 Shear-rupture capacity at block-joint interface

8.0.2.1 In-plane shear using triplets

Three courses high prisms (triplets) were prepared and tested as shown in Figure 48 while simulating the in-plane shear action. According to the test arrangement, failure would take place along the weakest bedding plane. Ten specimens were tested.

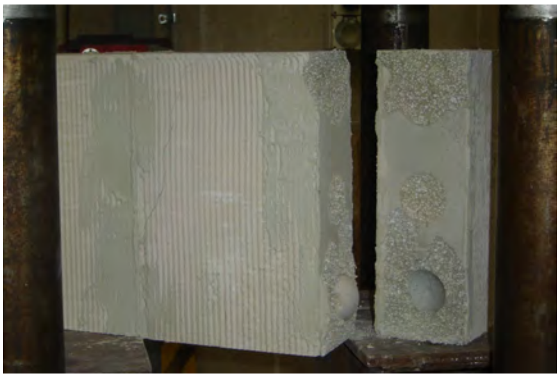
Solid block specimen

Hollow block specimen

Figure 48. In-plane shear test setup for triplets

8.0.2.1.1 Test results

All the solid wall specimens failed in a combined bond and block failure (lug failure) whereas hollow block specimens failed primarily at the interface bond with shearing off of the ribs. Typical modes of failures are shown in Figure 49.



Solid block specimen

Hollow block specimen

Figure 49. Typical in-plane shear rupture failure of triplets

A summary of results for both solid and hollow block specimens are shown in Table 15. Detailed results are shown in Appendix F and Appendix G.

	100mm solid block	200mm hollow block
Average (MPa)	1.28	0.61
Standard deviation (MPa)	0.28	0.18
Coefficient of variation	0.18	0.29
Characteristic shear rupture capacity (MPa)	0.71	0.33

Table 15. Shear-rupture capacity at block-joint interface

8.0.2.2 Out-of-plane shear using triplets

Three courses high prisms were prepared and tested as shown in Figure 50 while simulating the out-of-plane shear action. According to the test arrangement, failure would take place along the weakest bedding plane. Ten specimens were tested.

Figure 50. Out-of-plane shear test set up

8.0.2.2.1 Test results

As in the in-plane shear tests, all the specimens failed in a combined bond-block failure mechanism (see Figure 51).

Solid block specimen Hollow block specimen

Figure 51. Typical out-of-plane shear rupture failure

A summary of results for both solid and hollow block specimens are shown in Table 16. Detailed results are shown in Appendix H and Appendix I.

	100mm solid block	200mm hollow block
Average (MPa)	0.46	0.56
Standard deviation (MPa)	0.21	0.10
Coefficient of variation	0.45	0.19
Characteristic shear rupture capacity (MPa)	0.17	0.33

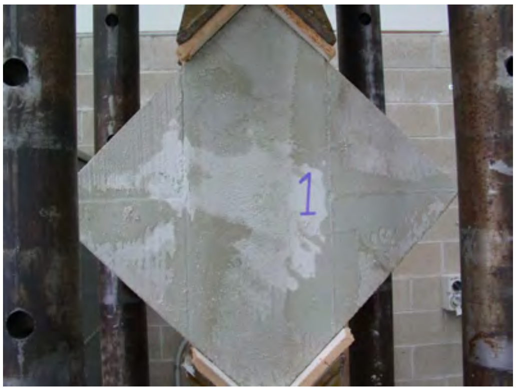
Table 16. Out-of-plane shear rupture capacity of triplets

8.0.3 Diagonal shear capacity

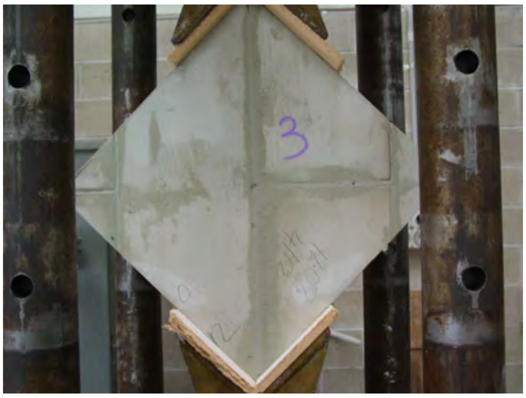
In order to investigate the shear failure under the combined action of compression and shear along the bed joints, a series of tests were conducted under uni-axial compression with the load applied at varying angles to the bed joint direction. Hence, square shaped specimens with different bed joint orientations were cut from larger wall panels and tested under compression along one of the diagonals. The orientation of the bed joint direction of the test panel to the loading direction and the location of the centre of the panel (either middle of a block or joint intersection) varied. Two different panel sizes were used; 400mm and 600mm square.

Figure 52 shows typical test arrangements used for solid Benex masonry. Similar test arrangements were used for hollow Benex masonry as well.

The test load was applied in an Avery compression testing machine through a set of rigid loading blocks. The hollow block specimens were stiffened at the loaded ends to avoid localised buckling failure of the flanges.



Loading parallel to bed joint with a block at the centre of the 400mm square panel



Loading parallel to bed joint along a joint with joint intersection at the centre of the 400mm square panel

Loading perpendicular to bed joint with a block at the centre of the 400mm square panel

Loading perpendicular to bed joint with a joint intersection at the centre of the 400mm square panel

Loading approximately at 30^0 to bed joint with a joint intersection at the centre of the 600mm square panel

Figure 52. Test specimens prepared with different bed joint orientations for 100mm solid Benex masonry

8.0.3.1 Test results

Both 100mm thick solid and 200mm thick hollow test walls failed along the loaded diagonal due to the tensile splitting stress. Typical failure modes are shown below (Figure 53 and Figure 54).

Under diagonal loading the test specimen was subjected to a state of biaxial stress, and the most critical combination of principal stresses (tension – compression) occurs at the centre of the panel. However, an average shear stress is calculated to predict the shear strength capacity.

Shear strength = 0.707 P/A

Where,
P = maximum diagonal load
A = cross sectional area of the panel (150mm x 850mm)

(a) 100mm solid block walls

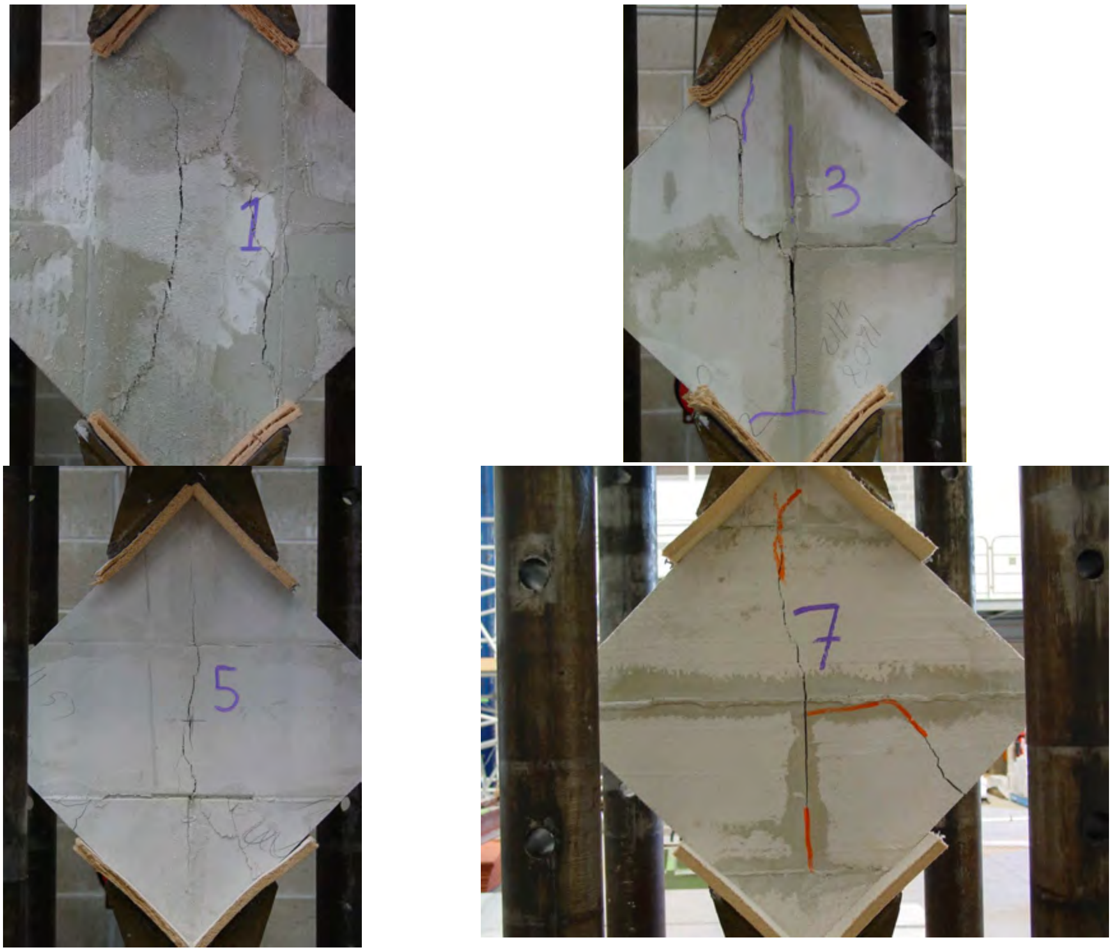


Figure 53. Typical failure modes of 100mm thick solid Benex masonry under diagonal load

Failure loads of the specimens and the corresponding shear strength are shown in Table 17.

Specimen No.	Direction of diagonal load relative to joint direction	Location of panel centre	Maximum load (kN)
Tests on 400mm square panels			
1S	parallel to bed joint	Block	133
2S	parallel to bed joint	Bed joint	145
3S	parallel to bed joint	Bed joint	132
4S	parallel to bed joint	Block	136
5S	Perpendicular to bed joint	Block	108
6S	Perpendicular to bed joint	Block	105
7S	Perpendicular to bed joint	Bed joint	105
8S	Perpendicular to bed joint	Bed joint	106
9S	parallel to bed joint	Bed joint and head joint intersection	137
10S	parallel to bed joint	Bed joint and head joint intersection	147
11S	parallel to bed joint	Bed joint and head joint intersection	126
12S	parallel to bed joint	Block	176
13S	parallel to bed joint	Block	140
14S	parallel to bed joint	Block	134
Tests on 600mm square panels			
15S	30^0 to the bed joint direction	Head joint	116
16S	28^0 to the bed joint direction	Head joint	125
17S	29^0 to the bed joint direction	Bed & head joint intersection	123
18S	30^0 to the bed joint direction	Bed Joint	104

Table 17. Diagonal load capacity of solid block square panels with different joint orientations to the loading direction

The shear strengths of 400mm and 600mm square panels calculated on the basis of stresses at the centre of the loaded panel are given in Table 18. The bedding width was taken as 50mm (thickness of the bedding width of the two glue lines on either side of the lugs).

	400mm panel	600mm panel
Average Failure load (MPa)	130.71	117.00
Average shear strength (MPa) based on 50mm bedding area	4.62	2.76
Standard deviation (MPa)	19.93	9.49
Coefficient of variation	0.15	0.08
Characteristic shear strength (MPa) based on 50mm bedding area	2.58	1.38

Table 18. Shear strengths of solid block panels

(b) 200mm hollow block walls

Figure 54. Typical failure modes of 200mm thick hollow Benex masonry under diagonal load

Failure loads of the specimens and the corresponding shear strength are shown in Table 19.

Specimen No.	Direction of diagonal load relative to joint direction	Location of panel centre	Maximum load (kN)
Tests on 400mm square panels			
1H	Parallel to bed joint	Bed and head joint intersection	144
2H	Perpendicular to bed joint	Block	98
3H	Perpendicular to bed joint	Bed and head joint intersection	98
4H	Perpendicular to bed joint	Block	94
5H	Perpendicular to bed joint	Bed and head joint intersection	103
6H	Parallel to bed joint	Bed and head joint intersection	141
7H	Parallel to bed joint	Block	192
8H	Parallel to bed joint	Block	163
Tests on 600mm square panels			
9H	Parallel to bed joint	Block	129
10H	13^0 to the bed joint direction	Bed and head joint intersection	112
11H	Parallel to bed joint	Block	169
12H	1^0 to the bed joint direction	Bed Joint	161
13H	76^0 to the bed joint direction	Block	117
14H	Perpendicular to bed joint direction	Block	87

Table 19. Diagonal load capacity of hollow block square panels with different joint orientations to the loading direction

The shear strengths of 400mm and 600mm square panels calculated on the basis of stresses at the centre of the loaded panel are given in Table 20. The bedding width was taken as 70mm (thickness of the bedding width of the two face-shells).

	400mm panel	600mm panel
Average Failure load (MPa)	129.13	129.17
Average shear strength (MPa) based on 70mm bedding area	3.26	2.17
Standard deviation (MPa)	36.48	31.05
Coefficient of variation	0.28	0.24
Characteristic shear strength (MPa) based on 70mm bedding area	1.65	0.93

Table 20. Shear strengths of hollow block panels

8.0.3.2 Comments

Under diagonal loading, the failure initiated at the centre of the panels due to the critical combination of principal stresses (as shown in Figure 55) irrespective of the size of the panel. This is confirmed by the fact that the average maximum load at failure for both 400mm and 600mm panels are more or less the same for both hollow and solid panels.

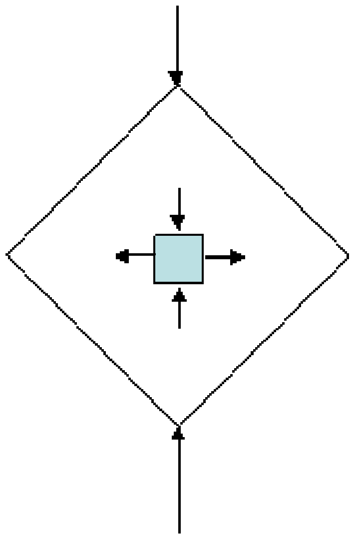


Figure 55. Schematic diagram showing principal stresses at the centre of panel under diagonal loading

Under the action of a racking load, failure can occur in a typical masonry wall in the joints alone, or in some form of combined mechanism involving the mortar and the masonry units. The mode of failure primarily depends on the level of compression force acting on the bed joints. The location of first crack would depend on the aspect ratio of the wall. Since conventional masonry exhibits anisotropic characteristics due the presence of mortar joints acting as planes of weakness, the failure is determined by the critical combination of the principal stresses and their orientation to the bed joint direction as schematically shown in Figure 56.

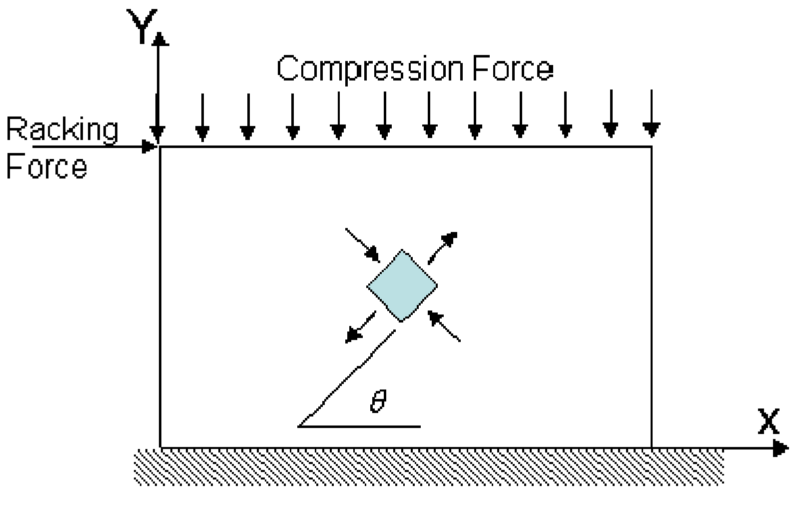


Figure 56. Schematic diagram showing principal stresses within a wall subjected to racking shear

The principal stresses within an element in the wall can be can be shown with stresses normal and parallel to the bed joint direction as shown in Figure 57, where σ_t and σ_c are principal tensile and compressive stresses, and σ_x , σ_y and τ are direct stresses and shear stress parallel and normal to the bed joint direction.

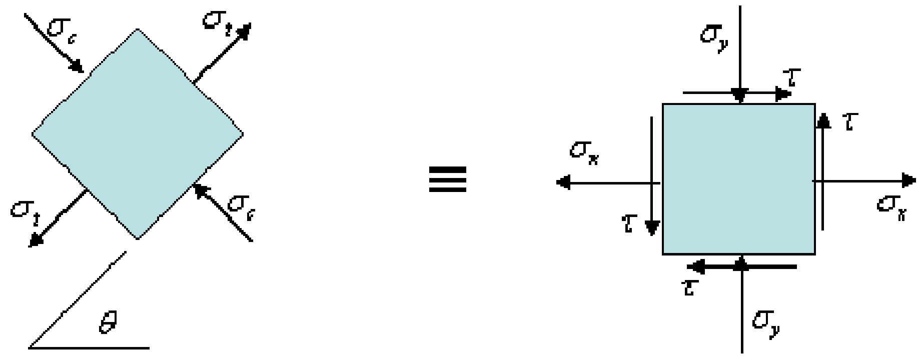


Figure 57. Stresses within an element in the wall subjected to racking shear

The results of the diagonal loading tests on Benex masonry reveal that the joint orientation to the principal stress direction does not significantly influence the strength of the wall. This is a fundamental difference in behaviour compared to conventional masonry and hence, it acts more like an isotropic material. Therefore, shear rupture failure is more likely to occur in Benex walls rather than a shear bond failure under a racking load.

When specimens are tested under a diagonal load, they failed due to the combined action of principal stresses at the centre (Figure 58). Idealised stresses parallel and perpendicular to the potential bed joint direction (X and Y) are shown in Figure 59.

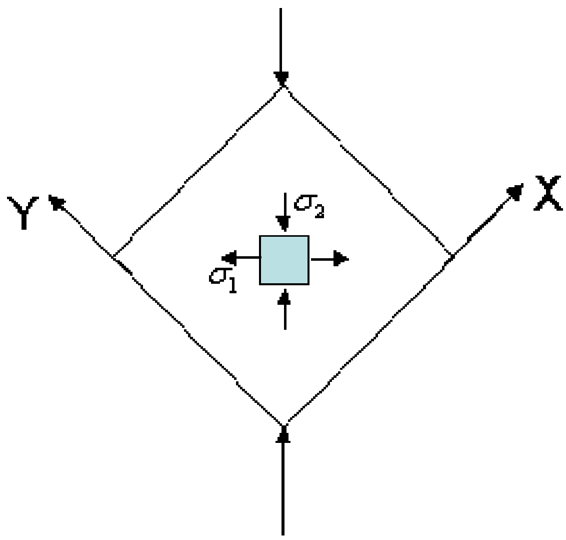


Figure 58. Stresses within an element in a wall subjected to a diagonal load

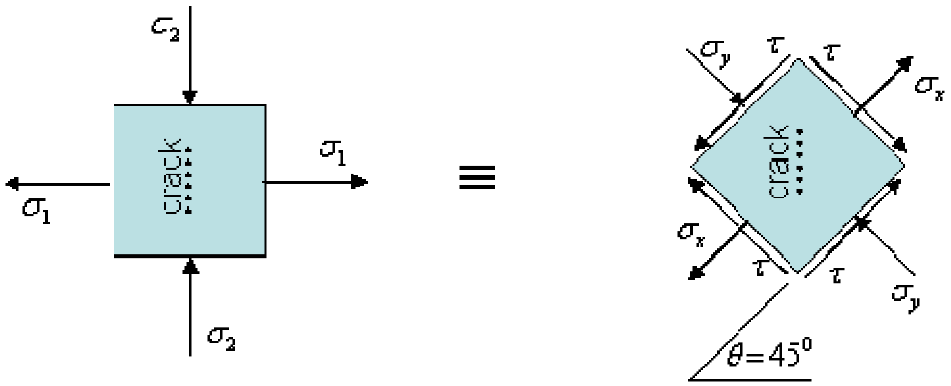


Figure 59. Principal stresses converted to normal stresses

It can be theoretically prove that the ratio between principal stresses at the centre is 1:3.

Hence;

$$\frac{\sigma_2}{\sigma_1} = 3$$

Hence, σ_1 and σ_2 can be derived if the shear stress at a plane 45^0 to the horizontal is τ .

$$\sigma_1 = \frac{\tau}{2} \text{ and } \sigma_2 = \frac{3\tau}{2}$$

For simplicity, the shear strength is calculated on the conservative assumption that the shear stress across the whole width of the specimen (at angle 45^0 to the loading direction) is uniform. Generally, the shear stress peaks at the centre of the panel and gradually reduces to zero towards the ends. Therefore, when averaging the shear stress across the whole width of the panel, the 600mm square panel resulted in lower shear strength relative to the 400mm square panel. Hence, it is more appropriate to use the results derived from 400mm panels.

The shear strength reported above (Table 20) is based on the bedding area of the blocks. However, it is very clear from the failure modes that the joints are much stronger than the blocks and rupture failure occurred in the blocks. Hence, shear strengths calculated based on the block thickness of the wall is more appropriate for Benex masonry. For hollow block panels the effective bedding thickness is the same as the block-web thickness at the narrowest point (2 x 35mm = 70mm). However, for the solid blocks the effective bedding thickness is 50mm where as the thickness of the block is 100mm. The shear strengths calculated based on bedding area and the block area are reported in Table 21.

	Characteristic shear strength based on bedding area (MPa)	**Characteristic shear strength based on effective area of block (MPa)**
100mm solid masonry	2.58	1.29
200mm hollow masonry	1.65	1.65

Table 21. Shear strengths of solid & hollow block panels

AS3700 stipulates the shear strength of a masonry wall in the following form assuming the failure is predominantly at the unit and mortar joint interface.

$v = v_o + k_v f_d$

Where, v_o = shear bond or rupture strength at the interface, k_v = shear factor (frictional component) and f_d is the design compressive stress on the bed joint. Hence, in order to present the results similar to the code's equation, the shear factor was calculated from the available results.

Table 22 summarises the shear rupture capacity at the block-joint interface (given in Table 15) and the shear capacity derived from diagonal loading tests (given in Table 21). In order to present the results similar to the code's equation, the shear factor was calculated from the graph plotted in Figure 60 and Figure 61 using available results.

	Shear rupture capacity at block-joint interface (MPa)	**Shear capacity from diagonal loading tests (MPa)**
100mm solid masonry	0.71	1.29
200mm hollow masonry	0.33	1.65

Table 22. Comparison of shear strengths derived from triplets and square panels

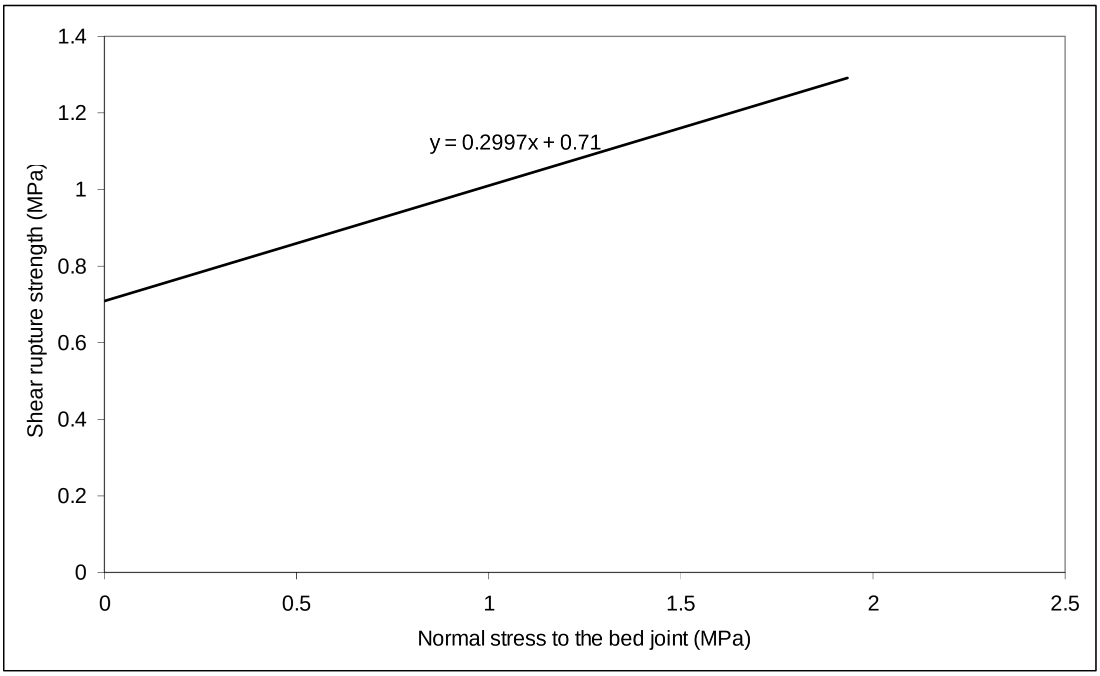


Figure 60. Relationship between shear rupture and normal stress for 100mm thick solid Benex masonry

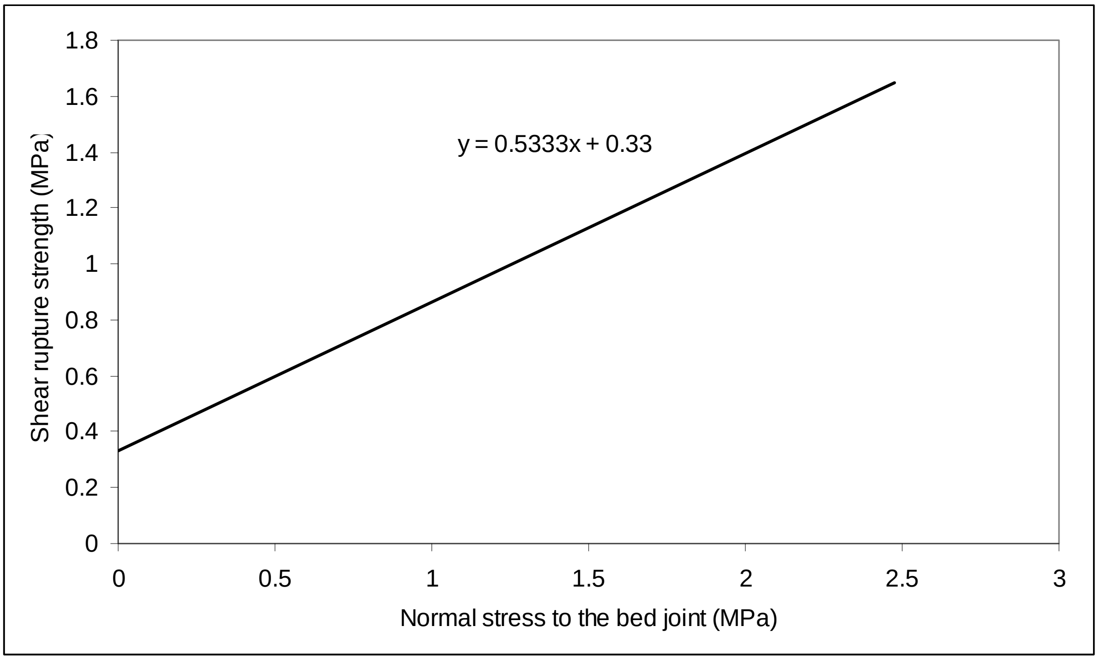


Figure 61. Relationship between shear rupture and normal stress for 200mm thick hollow Benex masonry

The shear factor derived from Figure 60 and Figure 61 are:

For 100mm solid masonry: $k_v = 0.3$
For 200mm hollow masonry: $k_v = 0.5$

Therefore, for Benex masonry the following relationship holds for shear capacity.

100mm thick solid masonry

Characteristic shear strength (MPa) = $0.7 + 0.3\ f_d$
Design shear capacity (N) = A_s x $(0.7\ \Phi + 0.3\ f_d)$

where,
f_d – design compressive stress on the bed joint (not greater than 2MPa)
A_s – Cross sectional area of the wall (mm^2)
Φ – Capacity reduction factor derived from Table 4.1 of AS 3700-2001 which is equal to 0.60

200mm thick hollow masonry

Characteristic shear strength = $0.3 + 0.5\ f_d$
Design shear capacity (N) = A_h x $(0.3\ \Phi + 0.5\ f_d)$

where,
f_d – design compressive stress on the bed joint (not greater than 2MPa)
A_h – face shell area of the hollow blocks in the wall without the web area (mm^2)
Φ – Capacity reduction factor derived from Table 4.1 of AS 3700-2001 which is equal to 0.60

8.1 Shear Strength in a Vertical Plane

8.1.0 Introduction

The shear resistance in a vertical plane at the interface between two structural members is an important parameter. It preserves the monolithic action between walls to achieve structural integrity. For example, at the intersection of an external wall with a shear wall, monolithic structural action is required to transfer the horizontal wind load to the shear wall. A similar condition would occur at a wall-pier connection. Movements of structural elements can also occur due to thermal, shrinkage and creep movements or due to movements in foundations.

The monolithic action between masonry walls relies on the degree of tying between them. These ties must be capable of transferring shear forces from one wall to the other and must have adequate strength and stiffness. The shear strength depends upon the bond between the mortar and unit at the interface, and the contribution of other elements such as metal ties or header units which may intersect the shear plane.

The normal practice in Benex walls is bonding header faces of units of the cross wall at the interface to the side face of the blocks in the wall running in a perpendicular direction of the cross wall using the thin-bed adhesive. Shear connectors are also provided at each bed joint to maintain structural integrity.

The ability to transfer shear forces at a typical vertical interface in Benex masonry has been investigated here.

8.1.1 Test Method

Three course high test specimens were prepared with 200 mm high Benex blocks as shown in Figure 62. Three types of specimen were built to evaluate the shear resistance of vertical planes; solid wall to solid wall, hollow wall to solid wall & hollow wall to hollow wall.

The shear connectors supplied by Benex were10-8x100mm countersunk ribbed head screws (see Figure 63) which are generally used with timber. Two connectors were used at the interface between two blocks. Hence, along the three-course high specimen, there were 6 screws on each side as shown in Figure 62. One of the screws was driven from the middle block to the abutting outer block and the other from the outer block to the inner block.

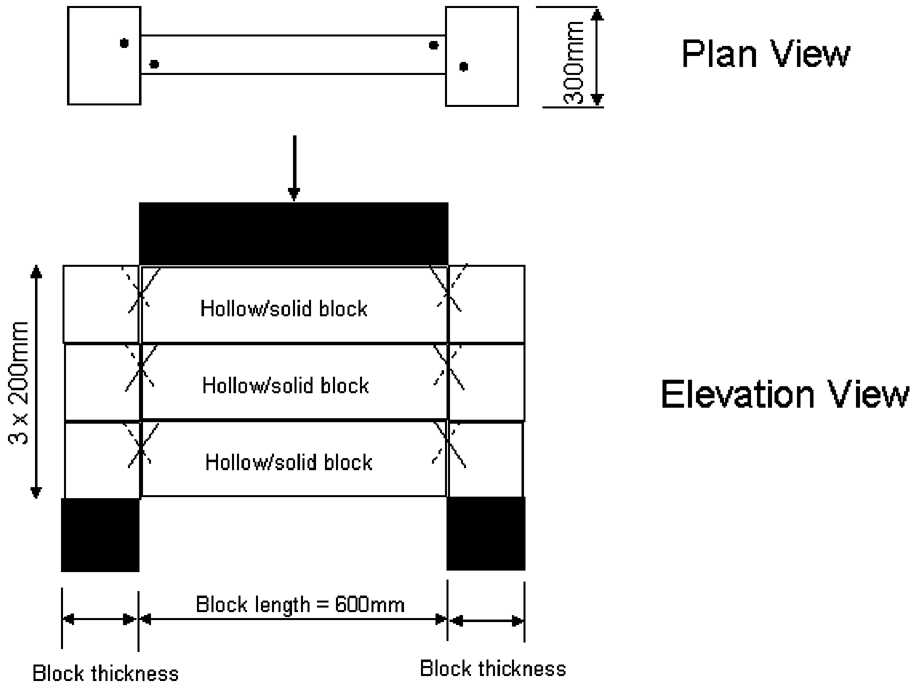


Figure 62. Schematic diagram of the test set up

Figure 63. Shear connectors used for Benex masonry

Gluing of the solid blocks and fixing of shear connectors is illustrated in Figure 64.

Gluing the first layer of blocks

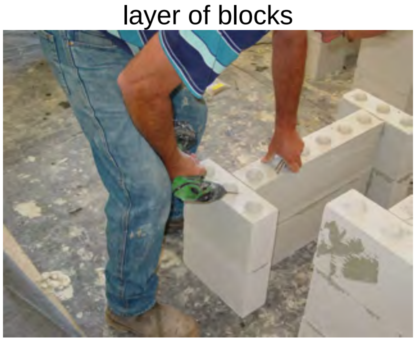
Screw driven from outer block to inner block

Screw driven from outer block to inner block

Spreading mortar for the second layer of blocks

Mortar on the header face and bed face

Finishing the 2nd course of blocks



Fixing connectors on one end

Fixing connectors on the other end

Preparation for the the 3rd corse of blocks

Figure 64. Preparation of a test specimen for vertical shear at solid to solid wall interface

For an interface of hollow block walls the screws are driven between the face shell and side shell of the blocks abutting each other (see Figure 65).

Driven from inside to outside

Driven from outside to inside

Figure 65. Preparation of a test specimen for vertical shear at hollow to hollow wall interface

Ten specimens of each type were prepared and tested after 7 days in an 'Avery' compression testing machine. Typical test set up is shown in Figure 66.

hollow block and solid block wall interface

Hollow block and hollow block interface

Figure 66. Test set up for shear at vertical interface

8.1.2 Test Results

All the specimens failed along the interface between the two leaves by breaking the bond and pulling away the screw connectors. In some cases failure took place simultaneously along both sides.

Figure 67. A typical interface shear failure at the butted face

The shear stresses were computed by dividing the first crack load by the bedding area of both shear planes. For the solid blocks, the bedding strip width was 25mm whereas for the hollow blocks 40mm. A summary of results is given in Table 23 and the detailed results are given in Appendix J, Appendix K and Appendix L.

	Interface at		
	Two 100mm solid walls	**Two 200mm hollow walls**	**200mm hollow wall butted with 100mm solid wall**
Mean (MPa)	0.74	0.54	1.09
Standard Deviation	0.18	0.12	0.13
Coefficient of variation	0.25	0.21	0.12
Characteristic vertical shear strength	0.33	0.26	0.65

Table 23. Shear strength on a vertical plane – at butted interface

8.1.3 Comments

Where monolithic structural action is required across a vertical joint between two leaves of a wall, the interface must be intersected either by masonry header units or connectors which tie the two leaves together. Engagement of header units is not permitted in Benex masonry, but screw fasteners as ties.

The connectors recommended in AS3700 are supposed to embed within mortar joints. However, the ties recommended for Benex simply connect the blocks without any engagement with the mortar. Therefore, it is not possible to use any of the clauses used in AS3700 to assess the shear capacity on a vertical plane for Benex masonry other than using the test values as recommended by Clause 7.5.3 (b).

The design shear strength on a vertical plane = Φ x characteristic vertical shear strength derived from the tests (see Table 9).

Φ – Capacity reduction factor derived from Table 4.1 of AS 3700-2001 which is equal to 0.75

8.2 Conclusions

8.2.0 Shear capacity

As per Clause 7.5.1(b) of AS3700-2001 for AAC masonry, the shear capacity for Benex masonry should be expressed in terms of shear rupture capacity and the shear friction capacity at the interface.

Shear capacity = $V_{Ao} + V_{A1}$

V_{Ao} = the shear rupture capacity of the shear section
V_{A1} = the shear friction capacity of the shear section

For 100mm solid Benex masonry and 200mm hollow Benex masonry shear capacity are given in Table 24.

	Shear rupture capacity at block-joint interface V_{Ao} (N)	**Shear friction capacity V_{A1} (N)**
100mm solid masonry	$\Phi \times 0.7 A_s$	$0.3 f_d A_s$
200mm hollow masonry	$\Phi \times 0.3 A_h$	$0.5 f_d A_h$

Note 1: Φ - Capacity reduction factor as per AS 3700-2001 (which is equal to 0.6)
Note 2: A_s - Cross sectional area of the wall (mm^2)
Note 3: A_h - Face shell area of the hollow block without the web (mm^2)
Note 4: f_d – design compressive stress on the bed joint (not greater than 2MPa)

Table 24. Design shear capacity of Benex masonry

8.2.1 Shear strength on a vertical plane

Where it is required to transfer shear forces across a vertical plane between two leaves of Benex masonry walls, screw connectors (Type 10-8 x 100mm) must be used as described together with thin-bed mortar butt joints. The design shear strength of such interfaces can be summarised as in Table 25.

Interface type	**Design shear strength on the vertical plane (MPa)**
Solid wall butted with a solid wall with screw connectors	0.33Φ
Hollow wall butted with a solid wall with screw connectors	0.65Φ
Hollow wall butted with a hollow wall with screw connectors	0.26Φ

Note: Φ = 0.75

Table 25. Design shear strength on a vertical plane

8.2.2 Shear strength on a horizontal plane under lateral loads

Benex masonry exhibits different shear characteristics under in-plane loads and out-of-plane loads due to the influence of ribs/lugs in the blocks. The design shear strength at the bed joints under the action of lateral loads can be summarised as in Table 26.

Interface type	Transverse design shear strength at the bed joint (MPa)
At bed-joint interface of 100mm solid block walls	0.17Φ
At bed-joint interface of 200mm solid block walls	0.33Φ

Note: Φ = 0.60

Table 26. Design shear strength at a bed joint under lateral loads

9 SUMMARY & RECOMMENDATIONS

Benex masonry is an innovative masonry system and hence design methodology and construction details are not yet covered by any Australian standard. Benex produces two types of blocks, namely 100mm thick solid and 200mm hollow blocks. Both types of blocks are manufactured with polystyrene beads embedded in a cementitious material.

Benex blocks are laid in thin-bed adhesive. AS3700 incorporates clauses related to thin-bed masonry, but only with AAC blocks.

This section summarises the tests carried out on behalf of Benex Technologies Pty Ltd and presents recommendations for design in relation to the provisions of AS3700-2001.

9.0 Summary of tests

Benex Technologies Pty Ltd in Australia wish to have their masonry system covered by the clauses stipulated in AS3700. However, since the Benex type of masonry is not within the scope of AS3700, in order to meet the design and construction requirements of AS3700, certain clauses, expressions and design parameters have to be modified. In view of this, the following areas were experimentally investigated with Benex solid and hollow masonry.

- Resistance to moisture penetration
- Durability of Benex blocks
- Compressive strength of Benex blocks and Benex masonry
- Behaviour under concentrated loads
- Flexural tensile bond strength of Benex masonry
- Modulus of rupture of Benex blocks
- Horizontal bending moment capacity
- Behaviour of full-scale masonry walls supported at three and four edges under lateral loads
- In-plane shear resistance of joints in masonry
- Out-of-plane shear resistance of joints in masonry
- Shear strength in a vertical plane

A large number of specimens were tested, using methods in accordance with AS3700 wherever possible. For certain cases standard tests are not given in AS3700 due to the complex behaviour of masonry under the action of respective forces. In such situations, widely accepted and most common test methods were used to investigate the required property.

Benex supplied all the blocks and the thin-bed mortar required for the investigation. The adhesives were supplied in 20kg bags. All the test specimens were built by Benex employees at CSIRO's North Ryde laboratories. Blocks were pre-wetted prior to making the test specimens.

Table 27 summarises the important information about the tests performed with each block type. The relevant standard to the tests are also noted, whenever tests are done to an existing Australian standard.

Property Investigated	Specimen Type	Number of specimens tested		Age at test	Relevant Standard
		Solid	*Hollow*		
Resistance to moisture penetration	1.2m x 1.8m Wall panel	1	1	28 days	ASTM 514-06
Durability of blocks	50mm x 25mm specimens Solid – 20mm thick Hollow – 40mm thick	9	10	-	AS/NZS 4456.10:2003
Unconfined compressive strength of units	300mm long specimens cut from 600mm long blocks	10	10	-	AS/NZS 4456.4:2003
Unconfined compressive strength of masonry	300mm long x 3 course high prisms	10	20	Solid - 7 days Hollow – 7 & 28 days	AS 3700-2001
Concentrated bearing factor	Wall panels	6	6	7 days	-
Flexural tensile bond strength	4-course high prisms	15 & 43	15 & 58	7 & 28 days	AS 3700-2001
Modulus of rupture of units	600mm long blocks	30	30	-	AS/NZS 4456.15:2003
Horizontal bending moment capacity	2 blocks long x 4 course high beams	10 & 10	10 & 10	7 & 28 days	-
Lateral load capacity of walls	Full-scale walls of different sizes	6	7	7 – 14 days	-
In-plane shear resistance at horizontal joints	3 course high triplets	10	10	7 days	-
Ou-of-plane shear resistance at horizontal joints	3 course high triplets	10	10	7 days	-
Diagonal shear strength					
Shear strength in a vertical plane	4 course high Wall panels solid-solid solid-hollow hollow-hollow	10 10	10	7 days	-

Table 27. Summary of tests using solid and hollow blocks

9.1 Recommendations

9.1.0 Resistance to water penetration

Since the use of single-leaf masonry (with a suitable waterproof coating) is accepted by local government authorities in some parts of Australia, the performance of sinle-leaf Benex masonry for wind driven rain was investigated.

The results revealed that both solid and hollow block masonry (if properly built) can resist wind driven rain without any difficulty. In general, rendered Benex masonry walls can be considered as impervious without further protection since any tiny holes in the mortar joints can be fully covered by the render.

9.1.1 Resistance to salt attack

Since the Benex block is a novel material composition of cement binder and polystyrene beads, its resistance to salt attack, especially when built in coastal areas, is very important.

It was found that both solid and hollow blocks are resistant to salt attack when tested in accordance with AS/NZS 4456.10:2003. Capped surfaces of the blocks are quite impermeable towards any salt intrusion. Hence, they can be categorised as “Exposure Grade” as specified in AS/NZS 4456.10:1977 and can be used in severe marine environments and aggressive soils.

9.1.2 Performance under compressive forces

9.1.2.1 Compressive strength

The characteristic compressive strength of Benex masonry for use in design can be expressed as follows:

For 100mm solid block masonry: $f'_m = f'_{uc}$
For 200mm hollow block masonry: $f'_m = 0.74f'_{uc}$

Benex masonry laid with a thin-bed mortar behaves somewhat different to conventional masonry when subjected to compression stresses. In conventional masonry, mortar being softer than the units, the mortar joints undergo a state of biaxial tension and compression. However, softer Benex blocks could induce a state of triaxial compression under uniform compression, and hence tends to enhance the strength of the units compared to conventional masonry.

The default value for the coefficient of variation provided in Appendix B of AS3700-2001 (0.15) can be used with Benex masonry when small samples are tested.

9.1.2.2 Concentrated bearing factor

AS3700-2001 Clause 7.3.5.4 for concentrated loads can be safely used for Benex masonry. The expression given in AS3700 for calculation of the Concentrated Bearing Factor is applicable.

9.1.3 Performance under out-of-plane forces

9.1.3.1 Characteristic flexural bond strength

The characteristic flexural bond strength of both solid and hollow block Benex masonry at 7 days is more than 0.2MPa, which is the maximum value recommended for normal conventional masonry. For special masonry, AS3700 recommends to use values derived from tests but not greater than 1MPa. Hence, Benex masonry could be categorised as a special masonry, where the test characteristic values are reported as below.

For 100mm solid block masonry at 7 days: $f'_{mt} = 0.57$MPa
For 200mm hollow block masonry at 7 days: $f'_{mt} = 0.27$MPa

Their 28 days characteristic flexural bond strengths are:

For 100mm solid block masonry at 7 days: $f'_{mt} = 0.83$MPa
For 200mm hollow block masonry at 7 days: $f'_{mt} = 0.32$MPa

The default value for the coefficient of variation provided in Appendix B of AS3700-2001 (0.30) can be used with Benex masonry when small samples are tested.

9.1.3.2 Characteristic modulus of rupture of units

The value specified in AS3700 in the absence of test results for conventional masonry and AAC units is 0.8MPa. The recommended values for Benex blocks are:

For 100mm solid block: f'_{ut} = 2.65MPa
For 200mm hollow block: f'_{ut} = 1.52MPa

9.1.3.3 Horizontal moment capacity

The horizontal moment capacity of Benex masonry cannot be computed using the expressions in AS3700-2001. Instead, the following expressions are recommended.

For 100mm solid block Benex masonry: $M_{ch} = \varnothing\,(0.25\, f'_{ut}\, Z_u + 0.75\, f'_{mt}\, Z_p)$
For 200mm hollow block Benex masonry: $M_{ch} = \varnothing\,(0.3\, f'_{ut}\, Z_u + 0.7\, f'_{mt}\, Z_p)$

(a) 100mm solid blocks

Lateral section modulus of unit per meter length Z_u = 888333mm^3
Lateral section modulus of mortar contact area of the perpend joint per meter length Z_p = 729167mm^3 (assuming 25mm thick strip bedding)

(b) 200mm hollow blocks

Lateral section modulus of unit per meter length Z_u = 2417916mm^3
Lateral section modulus of mortar contact area of the perpend joint per meter length Z_p = 1927083mm^3 (assuming 25mm thick strip bedding)

9.1.3.4 Lateral wind load capacity

Clause 7.4.4.3 of AS3700-2001 must be modified for Benex masonry panels which are at least supported on three edges as shown below.

$w_d \leq 13\frac{H}{L}\left(\frac{b_v M_{cv}}{H^2} + \frac{b_h M_{ch}}{L^2}\right)$ for 100mm solid block Benex masonry

$w_d \leq 15\frac{H}{L}\left(\frac{b_v M_{cv}}{H^2} + \frac{b_h M_{ch}}{L^2}\right)$ for 200mm hollow block Benex masonry

The definition of the parameters used in the above equations is as per AS3700-2001.

9.1.3.5 Shear capacity

The characteristic shear strength of Benex masonry can be obtained from the following relationship.

<u>In-plane shear capacity</u>

For 100mm solid block masonry at 7-day: $f'_{ms} = 0.71\Phi$ MPa
For 200mm hollow block masonry at 7-day: $f'_{ms} = 0.33\Phi$ MPa

The shear capacity under the action of pre-compression forces can be obtained from the following expressions:

For 100mm solid block masonry: Design shear capacity (N) = A_s x (0.7 Φ + 0.3 f_d)
For 200mm hollow block masonry: Design shear capacity (N) = A_h x (0.3 Φ + 0.5 f_d)

Where,
f_d – design compressive stress on the bed joint (not greater than 2MPa)
A_s – Cross sectional area of the wall (mm^2)
A_h – face shell area of the hollow blocks in the wall without the web area (mm^2)
Φ – Capacity reduction factor derived from Table 4.1 of AS 3700-2001 which is equal to 0.60

Out-of-plane shear capacity

For 100mm solid block masonry at 7-day: f'_{ms} = 0.17Φ MPa
For 200mm hollow block masonry at 7-day: f'_{ms} = 0.33Φ MPa

Where,
Φ – Capacity reduction factor derived from Table 4.1 of AS3700-2001 which is equal to 0.60

9.1.3.6 Shear strength in vertical planes

Where monolithic structural action is required across a vertical joint between two leaves of a wall, Benex recommends using screw fasteners. They simply connect the blocks without any engagement with the mortar. Therefore, it is not possible to use any of the clauses used in AS3700 to assess the shear capacity on a vertical plane for Benex masonry other than using the test values as recommended by Clause 7.5.3(b). Hence, the following values are recommended.

Solid wall butted with a solid wall with screw connectors	0.33Φ
Hollow wall butted with a solid wall with screw connectors	0.65Φ
Hollow wall butted with a hollow wall with screw connectors	0.26Φ

Where,
Φ – Capacity reduction factor derived from Table 4.1 of AS 3700-2001 which is equal to 0.75

Table 28. Recommended values for shear strength in vertical planes

Dr Sam Samarasinghe
Project Leader – Structural Engineering

David Milanoli
Technical Officer – Structural Engineering

CSIRO Materials Science & Engineering

PO Box 310, North Ryde, NSW 2113, AUSTRALIA

14 Julius Avenue, Riverside Corporate Park
North Ryde, NSW 2113, AUSTRALIA

T: +61 2 9490 5444 F: +61 2 9490 5538

Appendices

Appendix A – Compressive strength of units

Appendix B – Masonry compressive strength

Appendix C – Flexural bond strength tests performed on soild & hollow block prisms to establish characteristic flexural bond strengths

Appendix D – Characteristic Lateral Modulus of Rupture of Benex solid & hollow blocks

Appendix E – Characteristic horizontal bending moment capacity of Benex masonry buit with solid and hollow blocks

Appendix F – In-plane shear tests on triplets made with 100mm solid blocks

Appendix G – In-plane shear tests on triplets made with 200mm hollow blocks

Appendix H – Out-of-plane shear tests on triplets made with 100mm solid blocks

Appendix I – Out-of-plane shear tests on triplets made with 200mm hollow blocks

Appendix J – Vertical shear strength at interface between bonded hollow and solid block walls with screw connectors

Appendix K – Vertical shear strength at interface between bonded solid and solid block walls with screw connectors

Appendix L - Vertical shear strength at interface between bonded hollow and hollow block walls with screw connectors

Appendix A – Compressive strength of units

Appendix A1 – Compression strength of 100mm solid blocks

Client : Benex Masonry
Test Date: 10-Aug-07
Test: Compression Tests on solid blocks

Test Condition: Blocks were tested on two 25mm strips

Loading width = 2 x 25 = 50 mm
Block height = 200 mm
Block width = 100 mm

Spec. No.	Length (mm)	Thickness (mm)	Maximum Load (kN)	Failure Stress (MPa)
1	300	50.0	139	9.27
2	299	50.0	226	15.12
3	297	50.0	197	13.27
4	296	50.0	249	16.82
5	300	50.0	290	19.33
6	297	50.0	289	19.46
7	296	50.0	226	15.27
8	294	50.0	215	14.63
9	295	50.0	245	16.61
10	299	50.0	255	17.06

Average = 15.68
S.D. = 2.99
C. of V. = 0.19

Ch. Compressive Strength of block based on maximum load resisted (MPa) = 11.50 for Kk = 0.87 for CV = 0.15
Aspect Ratio = 2.00
Aspect Ratio Factor = 0.78 (ref: Table 1 of AS/NZS 4456.4:2003)
Ch. Unconfined Compressive Strength of block based on maximum load resisted (MPa) = 8.92

Appendix A2 – Compression strength of 200mm hollow blocks

Client : 200mm thick Hollow Block Benex Masonry
Test Date: 20-Apr-07

Test: Compression Tests on half-sized blocks

Preparation: The protrusions and recesses were cut off
Blocks were cut into halves in oredr to accommodate in the testing machine
Nominal loading strip at block faces is 35mm
Hence, minimum face shell thickness = 35 mm
Hence, bedding width = 70 mm

Spec. No.	Height (mm)	Length (mm)	Thickness (mm)	Failure Load (kN)	Failure Stress (MPa)
1	186.0	300.0	199.0	120.0	5.71
2	187.0	301.0	199.0	132.0	6.26
3	188.0	301.0	198.0	172.0	8.16
4	188.0	301.0	199.0	154.0	7.31
5	186.0	300.0	199.0	130.0	6.19
6	186.0	299.0	198.0	188.0	8.98
7	186.0	301.0	198.0	154.0	7.31
8	187.0	300.0	199.0	124.0	5.90
9	187.0	300.0	199.0	158.0	7.52
10	185.0	300.0	199.0	154.0	7.33

Average = 7.07
S.D. = 1.05
C. of V. = 0.15

Ch. Unit Compressive Strength of Hollow Block (MPa) = 4.92 for Kk = 0.86 for CV = 0.15
Aspect Ratio = 5.33
Aspect Ratio Factor = 1.00
Ch. Unconfined Unit Compressive Strength of Hollow Block (MPa) = 4.92

Appendix B – Masonry compressive strength

Appendix B1 – 7 day Compression strength of 3 course high prisms built with 100mm solid blocks

Client : Benex Masonry
Test Date: 21-Aug-07
Test: Compression Tests on solid block masonry (100mm thick with circular lugs)

Preparation: Blocks were cut into halves and made prisms in oredr to accommodate in the testing machine
10, 100mm x 300mm x 600mm specimens were tested at 7 days.

Test Condition: Circular lugs on top of the blocks were removed.
Prisms were cured in the laboratory for 7 days under polythene cover.
Load was applied on 25mm wide bedding strips on either side of the lugs along the length of the half block

Loading width = 2 x 25mm = 50 mm
Prism height = 600 mm
Prism thickness = 100 mm

Spec. No.	Length (mm)	Loading width (mm)	Failure Load (kN)	Failure Stress (MPa)
1	300	50.0	196.0	13.07
2	299	50.0	190.0	12.71
3	297	50.0	155.0	10.44
4	296	50.0	162.0	10.95
5	300	50.0	164.0	10.93
6	297	50.0	152.0	10.24
7	296	50.0	172.0	11.62
8	294	50.0	163.0	11.09
9	295	50.0	144.0	9.76
10	299	50.0	182.0	12.17

Average = 11.30
S.D. = 1.08
C. of V. = 0.10

Ch. Compressive Strength of Masonry (MPa) = 8.47 for Kk = 0.87 for CV = 0.15
Aspect Ratio = 6.00
Aspect Ratio Factor = 1.00 (ref: Table C1 of AS/NZS 3700-2001)
Ch. Unconfined Compressive Strength of Masonry (MPa) = 8.47

Appendix B2 – 7 day Compression strength of 3 course high prisms built with 200mm hollow blocks

Client : 200mm thick Hollow Block Benex Masonry
Test Date: 29-Aug-07
Laid on: 22-Aug-07 Age: 7days
Test: Compression Tests on 3-block high prisms

Preparation: The protrusions and recesses were cut off
Blocks were cut into halves in oredr to accommodate in the testing machine
Nominal loading area at block faces 35mm x 320mm
Hence, minimum face shell thickness = 35 mm
Hence, bedding thickness = 70 mm

Spec. No.	Height (mm)	Length (mm)	Thickness (mm)	Failure Load (kN)	Failure Stress (MPa)
1	600.0	297	200.0	118.0	5.68
2	603.0	297	200.0	113.0	5.44
3	600.0	298	200.0	134.0	6.42
4	600.0	298	200.0	105.0	5.03
5	600.0	295	200.0	100.0	4.84
6	601.0	299	200.0	106.0	5.06
7	599.0	298	200.0	110.0	5.27
8	600.0	300	200.0	116.0	5.52
9	598.0	299	200.0	100.0	4.78
10	600.0	299	200.0	119.0	5.69

Average = 5.37
S.D. = 0.49
C. of V. = 0.09

Ch. Compressive Strength of Masonry (MPa) = 4.05 for Kk = 0.85 for CV = 0.15
Aspect Ratio = 17.15
Aspect Ratio Factor = 1.00
Ch. Unconfined Compressive Strength of Masonry (MPa) = 4.05

Appendix B3 – 28 day Compression strength of 3 course high prisms built with 200mm hollow blocks

Client : 200mm thick Hollow Block Benex Masonry
Test Date: 2-Apr-07
Laid on: 26-Feb-07 Age: 34days
Test: Compression Tests on 3-block high prisms

Preparation: The protrusions and recesses were cut off
Blocks were cut into halves in oredr to accommodate in the testing machine
Nominal loading area at block faces 35mm x 320mm
Hence, minimum face shell thickness = 35 mm
Hence, bedding thickness = 70 mm

Spec. No.	Height (mm)	Length (mm)	Thickness (mm)	Failure Load (kN)	Failure Stress (MPa)
1	600.0	320.0	200.0	95.0	4.24
2	603.0	320.0	200.0	105.0	4.69
3	600.0	320.0	200.0	138.0	6.16
4	600.0	320.0	200.0	103.0	4.60
5	600.0	320.0	200.0	112.0	5.00
6	601.0	320.0	200.0	132.0	5.89
7	599.0	320.0	200.0	126.0	5.63
8	600.0	320.0	200.0	112.0	5.00
9	598.0	320.0	200.0	118.0	5.27
10	600.0	320.0	200.0	107.0	4.78

Average = 5.13
S.D. = 0.61
C. of V. = 0.12

Ch. Compressive Strength of Masonry (MPa) = 3.65 for Kk = 0.86 for CV = 0.15
Aspect Ratio = 17.15
Aspect Ratio Factor = 1.00
Ch. Unconfined Compressive Strength of Masonry (MPa) = 3.65

Appendix C – Flexural bond strength tests performed on soild & hollow block prisms to establish characteristic flexural bond strengths

Appendix C1 – 7 day Flexural strength properties of 100mm solid masonry

Job No :	TS3468		Test Date :	23/Mar/07	Specimens built: 16-Mar-07
Client :	Benex		Age tested :	7day	
Unit Type :	Benex circular lug Block		Mortar Type:	Adhesive with litlle Bycol added to water when mixing	
Length:	300	mm	Thickness:	100	
Weight:	6.1	Kg			

Prism No.	Specimen Number	Load (N)	Moment (N.mm)	Bond (MPa)	
P1	1	315.3	470118	1.04	Block failed at interface
	2	334.9	497695	1.11	Block failed at interface
	3	386.2	569874	1.27	Block failed
P2	4	331.1	492348	1.09	Combined joint & block failure at interface
	5	239.2	363045	0.80	Joint failure at interface
	6	306.5	457736	1.02	Block failed at interface
P3	7	318.4	474479	1.05	Block failed
	8	262.7	396109	0.88	Block failed at interface
	9	258.7	390481	0.87	Block failed at interface
P4	10	145.2	230787	0.51	Joint failure at interface
	11	208.8	320272	0.71	Block failed at interface
	12	282.2	423546	0.94	Primarily Joint failure at interface - picture taken
P5	13	274.1	412149	0.91	Block failed at interface
	14	323.7	481936	1.07	Block failed
	15	346.6	514157	1.14	Block failed

Note: The blocks laid for these tests were wet
When making adhesive mortar a bit of Bycol was added into water prior to mixing the dry adhesive
The result of specimen No. 10 was statisticaly rejected as an outlier.

Average	0.96				
S.D	0.19				
C.V.	0.20				
Characteristic Value =	0.56	at KK =	0.78	and CV =	0.3

After removing outliers (result 10))

Average	0.99
S.D	0.15
C.V.	0.15
Characteristic Value =	0.56

Appendix C2 – 28 day Flexural strength properties of 100mm solid masonry

Job No : TS3468 Test Date : 16/Apr/07 Specimens built: 16-Mar-07
Client : Benex Age tested : 28day
Unit Type : Benex circular lug Block Mortar Type: Adhesive with litlle Bycol added to water when mixing
Length: 300 mm Thickness: 100
Weight: 6.1 Kg

Specimen Number	Load (N)	Moment (N.mm)	Bond (MPa)
1	263.0	396531	0.88
2	409.7	602938	1.34
3	319.0	475323	1.06
4	383.3	565794	1.26
5	327.2	486861	1.08
6	211.8	324493	0.72
7	363.4	537794	1.20
8	355.4	526538	1.17
9	396.8	584788	1.30
10	305.9	456892	1.01
11	481.0	703257	1.57
12	188.6	291851	0.65
13	268.9	404833	0.90
14	254.7	384853	0.85
15	402.4	592667	1.32
16	339.3	503886	1.12
17	382.8	565090	1.26
18	413.3	608004	1.35
19	358.9	531463	1.18
20	410.8	604486	1.35
21	405.5	597029	1.33
22	396.9	584929	1.30
23	413.7	608566	1.35
24	411.2	605049	1.35
25	377.8	558055	1.24
26	321.5	478841	1.06
27	327.3	487002	1.08
28	312.8	466600	1.04
29	388.9	573673	1.28
30	338.7	503041	1.12
31	401.6	591542	1.32
32	481.2	703539	1.57
33	230.7	351085	0.78
34	359.5	532307	1.18
35	370.1	547221	1.22
36	351.2	520629	1.16
37	333.2	495303	1.10
38	405.3	596748	1.33
39	401.7	591682	1.32
40	493.3	720564	1.60
41	399.1	588024	1.31
42	424.1	623199	1.39
43	445.4	653168	1.45

Average 1.20
S.D 0.22
C.V. 0.18
Characteristic Value = 0.83 at KK = 0.94 and CV = 0.14

After removing outliers (results 12, 6 and 33)

Average 1.23
S.D 0.17
C.V. 0.14
Characteristic Value = 0.83

Appendix C3 – 7 day Flexural strength properties of 200mm hollow masonry

Job No : TS3468 Test Date : 23/Mar/07 Specimens laid on: 16-Mar-07
Client : Benex Age tested : 7day
Unit Type : Hollow Block Mortar Type: Adhesive with litlle Bycol added to water when mixing
Length: 300 mm Bedding web Thickness: 25 bedding depth on a flange
Weight: 6.7 Kg Block width : 200

Prism No.	Specimen Number	Load (N)	Moment (N.mm)	Bond (MPa)
P1	1	486	690900	0.56
	2	200	299223	0.24
	3	319	462467	0.37
P2	4	367	528066	0.42
	5	500	709662	0.57
	6	347	500813	0.40
P3	7	302	439323	0.35
	8	93	152549	0.12
	9	388	557237	0.45
P4	10	379	544637	0.44
	11	450	641324	0.52
	12	502	713360	0.57
P5	13	431	615988	0.49
	14	421	601745	0.48
	15	421	602156	0.48

max = 0.57
min = 0.12

Average 0.43
S.D 0.13
C.V. 0.29
Characteristic Value = 0.00 at KK = 0.78 and CV = 0.3

Note: When making adhesive mortar a bit of Bycol was added into water prior to mixing the dry adhesive
Bond strength results of specimens 2 & 8 were statistically rejected as outliers.

Average 0.47
S.D 0.07
C.V. 0.16
Characteristic Value = 0.27 at KK = 0.77 and CV = 0.270738

Appendix C4 – 28 day Flexural strength properties of 200mm hollow masonry

Job No : TS3468 Test Date : 16/Apr/07 Specimens laid on: 16-Mar-07
Client : Benex Age tested : 28day
Unit Type : Hollow Block Mortar Type: Adhesive with litlle Bycol added to water when mixing
Length: 300 mm Bedding web Thickness: 25 bedding depth on a flange
Weight: 6.7 Kg Block width : 200

Specimen Number	Load (N)	Moment (N.mm)	Bond (MPa)
1	572.3	782772	0.63
2	324.4	443273	0.35
3	408.0	557763	0.45
4	430.9	589125	0.47
5	371.9	508324	0.41
6	325.0	444095	0.35
7	456.1	623636	0.50
8	377.4	515856	0.41
9	416.4	569267	0.45
10	365.8	499970	0.40
11	511.0	698822	0.56
12	267.6	365485	0.29
13	277.8	379454	0.30
14	576.7	788798	0.63
15	396.9	542562	0.43
16	363.1	496273	0.40
17	418.1	571595	0.46
18	334.0	456420	0.36
19	541.4	740454	0.59
20	581.5	795371	0.64
21	410.3	560913	0.45
22	373.5	510515	0.41
23	421.8	576662	0.46
24	375.6	513391	0.41
25	407.5	557078	0.44
26	337.3	460939	0.37
27	554.5	758395	0.61
28	604.2	826459	0.66
29	358.3	489699	0.39
30	435.3	595150	0.48
31	532.2	727855	0.58
32	553.4	756888	0.61
33	317.4	433686	0.34
34	437.9	598711	0.48
35	530.5	725527	0.58
36	404.8	553381	0.44
37	451.4	617199	0.49
38	726.4	993812	0.80
39	374.8	512296	0.41
40	458.1	626375	0.50
41	491.8	672527	0.54
42	520.5	711832	0.57
43	895.4	1225257	0.99
44	516.8	706765	0.57
45	387.0	529004	0.42
46	385.8	527360	0.42
47	599.0	819338	0.66
48	526.7	720323	0.58
49	368.6	503805	0.40
50	449.1	614050	0.49
51	463.4	633633	0.51
52	379.0	518048	0.41
53	415.8	568445	0.45
54	469.8	642398	0.51
55	444.2	607339	0.49
56	391.9	535714	0.43
57	346.4	473402	0.38
58	403.1	551053	0.44

Average 0.49
S.D 0.12
C.V. 0.25

After rejecting data No. 43 as an outlier

Average 0.48
S.D 0.10
C.V. 0.21

Characteristic Value = 0.32 at KK = 0.92 and CV = 0.3

Appendix D – Characteristic Lateral Modulus of Rupture of Benex solid & hollow blocks

Appendix D1 – Lateral modulus of rupture of 100mm solid blocks

Client : Benex Masonry Test Date : 26-Apr-07

Job No : JK13ATS3468 Unit Type : Cementitious polystyrene solid block

Beam Length	:-	600	(mm)
Beam Width	:-	200	(mm)
Beam Depth	:-	100	(mm)
Beam Weight (block wt.)	:-		(kg)
Load Span	:-	200	(mm)
Load Beam Weight	:-	2.973	(kg)
Support Span	:-	560	(mm)

Z : 333333.333 mm^3

No	Load (kN)	Wt. of Block (kg)	Moment (kN.m)	Strength (MPa)
1	3.8	12.23	0.35	1.06
2	5.2	11.84	1.07	3.20
3	6.2	12.66	1.14	3.43
4	6.1	11.87	1.07	3.21
5	6.5	12.10	1.09	3.28
6	4.7	11.94	1.08	3.23
7	5.4	11.99	1.08	3.25
8	5.4	11.79	1.06	3.19
9	5.8	11.57	1.04	3.13
10	5.1	12.52	1.13	3.39
11	6.0	11.87	1.07	3.21
12	5.6	11.75	1.06	3.18
13	5.7	12.26	1.11	3.32
14	6.6	12.23	1.10	3.31
15	5.8	11.62	1.05	3.15
16	6.3	11.87	1.07	3.21
17	5.4	11.73	1.06	3.17
18	7.4	12.56	1.13	3.40
19	6.4	12.30	1.11	3.33
20	6.3	12.27	1.11	3.32
21	5.4	11.61	1.05	3.14
22	5.2	11.94	1.08	3.23
23	6.6	12.46	1.12	3.37
24	5.5	12.72	1.15	3.44
25	5.5	12.11	1.09	3.28
26	5.7	12.41	1.12	3.36
27	5.0	12.38	1.12	3.35
28	5.4	12.38	1.12	3.35
29	5.0	12.10	1.09	3.27
30	5.1	12.18	1.10	3.30

Number	30
Average	3.202
Sample SD	0.414
Sample CV	0.129

The result 1 was rejected as an outlier.

Ch. MOR of Hollow blocks = 2.65 MPa at S.D. = 0.09 at C.V. = 0.3
(since the number of units used for ch. value evaluation is 29, the code specified default value for C.V was used)

Number	29
Average	3.28
Sample SD	0.09
Sample CV	0.03

Appendix D2 – Lateral modulus of rupture of 200mm hollow blocks

Client : Benex Masonry Test Date : 30-Apr-07

Job No : JK13ATS3468 Unit Type : Cementitious polystyrene hollow block

Beam Length	:-	600	(mm)
Beam Width	:-	200	(mm)
Beam Depth	:-	200	(mm)
Face shell thickness		35	
Beam Weight (block wt.)	:-	13.29	(kg)
Load Span	:-	0	(mm)
Load Beam Weight	:-		(kg)
Support Span	:-	560	(mm)

Z : 967166.667 mm^3

No	Load (kN)	Wt. of Block (kg)	Moment (kN.m)	Strength (MPa)
1	3.6	13.29	0.51	0.53
2	4.3	13.47	1.89	1.96
3	3.7	13.09	1.84	1.90
4	4.2	14.31	2.01	2.08
5	4.2	13.83	1.95	2.01
6	4.1	13.64	1.92	1.98
7	4.3	13.46	1.89	1.96
8	4.3	13.39	1.88	1.95
9	4.7	14.03	1.97	2.04
10	4.2	13.24	1.86	1.93
11	3.9	13.12	1.85	1.91
12	4.3	14.19	2.00	2.06
13	4.3	13.24	1.86	1.92
14	4.3	13.64	1.92	1.98
15	4.6	13.51	1.90	1.96
16	4.3	13.23	1.86	1.92
17	4.4	13.91	1.96	2.02
18	4.0	13.02	1.83	1.89
19	4.3	13.41	1.89	1.95
20	4.6	14.03	1.97	2.04
21	4.2	13.40	1.88	1.95
22	3.9	13.02	1.83	1.89
23	4.1	13.81	1.94	2.01
24	4.1	13.39	1.88	1.95
25	3.3	12.26	1.72	1.78
26	3.1	11.83	1.66	1.72
27	4.0	12.44	1.75	1.81
28	5.0	15.07	2.12	2.19
29	4.8	14.80	2.08	2.15
30	2.7	12.97	1.82	1.89

Number	30
Average	1.911
Sample SD	0.278
Sample CV	0.146

The results 1& 2 were rejected as outliers.

Ch. MOR of Hollow blocks = 1.52 MPa at S.D. = 0.09 at C.V. = 0.3

(since the number of units used for ch. value evaluation is 28, the code specified default value for C.V was used)

After rejecting results 1 & 2:

Number	28
Average	1.97
Sample SD	0.09
Sample CV	0.05

Appendix E – Characteristic horizontal bending moment capacity of Benex masonry buit with solid and hollow blocks

Appendix E1 – Horizontal bending moment capacity of 100mm solid block walls at 7 days age

Client : Benex Masonry   Test Date : 25/Mar/07

Job No : JK13ATS3468   Age tested : 7

Unit Type : Cementititious Polystyrene Block

Beam Length	:-	1200	(mm)
Beam Width	:-	800	(mm)
Beam Depth	:-	100	(mm)
Beam Weight	:-	100	(kg)
Load Span	:-	0	(mm)
Load Beam Weight	:-	28	(kg)
Support Span	:-	1000	(mm)

No	Load (N)	Moment (kN.m)	Moment kN.m per m width	Comments
1	2900.00	0.89	1.11	Failed along the centre span
2	2550.00	0.80	1.01	Failed along the centre span
3	2980.00	0.91	1.14	Failed along the centre span
4	3100.00	0.94	1.18	Failed along the centre span
5	2850.00	0.88	1.10	Failed along the centre span
6	2903.00	0.89	1.12	Failed along the centre span
7	2890.00	0.89	1.11	Failed along the centre span
8	3400.00	1.02	1.27	Failed along the centre span
9	2950.00	0.90	1.13	Failed along the centre span
10	2960.00	0.91	1.13	Failed along the centre span

Number	10					
Average	1.13	kN.m/m				
Sample SD	0.07					
Sample CV	0.06					
Mch	0.74		for Kk =	0.95	for CV =	0.06

Appendix E2 – Horizontal bending moment capacity of 100mm solid block walls at 28 days age

Client : Benex Masonry Test Date : 07/Mar/07 Cast Date: 7-Feb-07

Job No : JK13ATS3468 Age tested : 28days

Unit Type : Cementititious Polystyrene Block

Beam Length	:-	1190	(mm)
Beam Width	:-	800	(mm)
Beam Depth	:-	100	(mm)
Beam Weight	:-	97.6	(kg)
Load Span	:-	0	(mm)
Load Beam Weight	:-	1.6	(kg)
Support Span	:-	1150	(mm)

No	Load (N)	Moment (kN.m)	Moment kN.m per m width	Comments
1	3960.00	1.28	1.59	Failure along the center line with joints
2	3150.00	1.04	1.30	Failure along the center line with joints
3	3610.00	1.18	1.47	Failure along the center line with joints
4	3260.00	1.07	1.34	Failure along the center line with joints
5	2720.00	0.92	1.15	Failure along the center line with joints
6	2800.00	0.94	1.18	Failure along the center line with joints
7	3240.00	1.07	1.34	Failure along the center line with joints
8	2790.00	0.94	1.17	Failure along the center line with joints
9	3750.00	1.22	1.52	Failure along the center line with joints
10				

Number	9					
Average	1.34	kN.m/m				
Sample SD	0.16					
Sample CV	0.12					
Mch	0.83	for Kk =	0.72	for CV =	0.30	

Appendix E3 – Horizontal bending moment capacity of 200mm solid block walls at 7 days age

Client : Benex Masonry Test Date : 14/Feb/07 Cast Date: 7-Feb-07

Job No : JK13ATS3468 Age tested : 7 days

Unit Type : Cementititious Polystyrene Block

Beam Length	:-	1190	(mm)
Beam Width	:-	800	(mm)
Beam Depth	:-	200	(mm)
Beam Weight	:-	107.6	(kg)
Load Span	:-	0	(mm)
Load Beam Weight	:-	1.6	(kg)
Support Span	:-	1150	(mm)

No	Load (N)	Moment (kN.m)	Moment kN.m per m width	Comments
1	5500	1.73	2.00	Failure along the center line with joints
2	4300	1.39	1.78	Failure along the center line with joints
3	5600	1.76	2.20	Failure along the center line with joints
4	4800	1.53	1.91	Failure along the center line with joints
5	5000	1.59	1.99	Failure along the center line with joints
6	4800	1.53	1.91	Failure along the center line with joints
7	4980	1.58	1.98	Failure along the center line with joints
8	4100	1.33	1.81	Failure along the center line with joints
9	4300	1.39	1.78	Failure along the center line with joints
10	4400	1.42	1.77	Failure along the center line with joints

Note; First test was done under 4-pont bending where as others under 3-point bending
The failure of the first test was more influenced by the local shear failure of the block rather than bending. Hence, that result was discarded.

Number	10					
Average	1.91	kN.m/m				
Sample SD	0.14					
Sample CV	0.07					
Mch (kN.m/m)	1.30	for Kk =	0.73	for CV =	0.30	

Appendix E4 – Horizontal bending moment capacity of 200mm solid block walls at 28 days age

Client : Benex Masonry Test Date : 06/Mar/07 Cast Date: 7-Feb-07

Job No : JK13ATS3468 Age tested : 28 days

Unit Type : Cementititious Polystyrene Block

Beam Length	:-	1190	(mm)
Beam Width	:-	800	(mm)
Beam Depth	:-	200	(mm)
Beam Weight	:-	107.6	(kg)
Load Span	:-	0	(mm) (except for the 1st test where load span = 650mm)
Load Beam Weight	:-	1.6	(kg)
Support Span	:-	1150	(mm)

No	Load (N)	Moment (kN.m)	Moment kN.m per m width	Comments
1	9170	1.29	1.62	Failure along the outer line of perpend joints
2				Broke prior to test
3	5980	1.87	2.34	Failure along the center line with joints
4	6090	1.90	2.38	Failure along the center line with joints
5	6020	1.88	2.35	Failure along the center line with joints
6	6420	2.00	2.50	Failure along the center line with joints
7	7590	2.33	2.92	Failure along the center line with joints
8	5840	1.83	2.29	Failure along the center line with joints
9	6670	2.07	2.59	Failure along the center line with joints
10				Broke prior to test

Note; First test was done under 4-pont bending where as others under 3-point bending
The failure of the first test was more influenced by the local shear failure of the block rather than bending. Hence, that result was discarded.

Number	7					
Average	2.48	kN.m/m				
Sample SD	0.22					
Sample CV	0.09					
Mch	1.53	for Kk =	0.67	for CV =	0.30	

Appendix F – In-plane shear tests on triplets made with 100mm solid blocks

Client : Benex Masonry   Test Date : 22/Aug/07

Job No : JK13ATS3468   Age tested : 7

Unit Type : Cementititious Polystyrene Block with circular lugs
Triplet: 3 half-sized blocks stack bonded with strip bedding

Bedding strip width	:-	25	(mm)
Width of block	:-	100	(mm)
Height of bedding strip	:-	300	(mm)
Weight of loading pad	:-	0.496	(kg)

No	Maximum Load (kN)	Weight of middle block (kg)	Max shear stress (MPa)	Comments
1	34.0	5.795	1.70	shear failure along the joint
2	19.8	5.915	0.99	shear failure along the joint
3	31.5	5.897	1.58	shear failure along the joint
4	23.5	6.085	1.18	shear failure along the joint
5	21.5	5.932	1.08	shear failure along the joint
6	25.0	5.828	1.25	block failure combined with joint failure
7	26.5	5.785	1.33	shear failure along the joint
8	23.5	6.471	1.18	shear failure along the joint
9	24.5	6.600	1.23	shear failure along the joint

Number	9					
Average	1.28	MPa				
Sample SD	0.23					
Sample CV	0.18					
f'ms	0.71	for Kk =	0.82	for CV =	0.18	

Appendix G – In-plane shear tests on triplets made with 200mm hollow blocks

Client : Benex Masonry Test Date : 20/Aug/07

Job No : JK13ATS3468 Age tested : 7

Unit Type : Cementititious Polystyrene Block with circular lugs
Triplet: 3 half-sized blocks stack bonded with strip bedding

Bedding strip width	:-	35	(mm)
Width of block	:-	200	(mm)
Height of bedding strip	:-	300	(mm)
Weight of loading pad	:-	1.904	(kg)

No	Maximum Load (kN)	Weight of middle block (kg)	Max shear stress (MPa)	Comments
1	8.4	6.795	0.30	shear failure along the joint
2	14.2	6.448	0.51	shear failure along the joint
3	15	7.045	0.54	shear failure along the joint
4	15.6	6.928	0.56	shear failure along the joint
5	22.2	6.372	0.80	shear failure along the joint
6	12.6	6.237	0.45	shear failure along the joint
7	16.8	6.747	0.60	shear failure along the joint
8	20.0	6.907	0.72	shear failure along the joint
9	21.8	6.964	0.78	shear failure along the joint
10	24.4	6.769	0.87	shear failure along the joint

Number	10					
Average	0.61	MPa				
Sample SD	0.18					
Sample CV	0.29					
f'ms	0.33	for Kk =	0.72	for CV =	0.30	

Appendix H – Out-of-plane shear tests on triplets made with 100mm solid blocks

Client : Benex Masonry Test Date : 28/Aug/07

Job No : JK13ATS3468 Age tested : 7

Unit Type : Cementititious Polystyrene Block with circular lugs
Triplet: 3 half-sized blocks stack bonded with strip bedding

Bedding strip width	:-	25	(mm)
Width of block	:-	100	(mm)
Height of bedding strip	:-	300	(mm)
Weight of loading pad	:-	1.894	(kg)

No	Maximum Load (kN)	Weight of middle block (kg)	Max shear stress (MPa)	Comments
1	4.5	6.350	0.23	shear failure along the joint
2	7.9	5.940	0.40	shear failure along the joint
3	18.3	5.852	0.92	shear failure along the joint
4	8.5	5.863	0.43	block/joint failure
5	8.0	5.651	0.40	block/joint failure
6	4.5	6.072	0.23	block/joint failure
7	6.2	5.934	0.31	shear failure along the joint
8	12.2	5.893	0.61	block/joint failure
9	10.2	5.605	0.51	block/joint failure
10	11.6	5.973	0.58	block/joint failure

Number	10					
Average		0.46 MPa				
Sample SD		0.21				
Sample CV		0.45				
f'ms		0.17	for Kk =	0.73	for CV =	0.30

Appendix I – Out-of-plane shear tests on triplets made with 200mm hollow blocks

Client : Benex Masonry

Test Date : 17/Aug/07

Job No : JK13ATS3468

Age tested : 7

Unit Type : Cementititious Polystyrene Block with circular lugs
Triplet: 3 half-sized blocks stack bonded with strip bedding

Bedding strip width	:-	35	(mm)
Width of block	:-	200	(mm)
Height of bedding strip	:-	300	(mm)
Weight of loading pad	:-	1.894	(kg)

No	Maximum Load (kN)	Weight of middle block (kg)	Max shear stress (MPa)	Comments
1	16.2	6.795	0.58	shear failure along the joint
2	18.4	6.448	0.66	shear failure along the joint
3	17.2	7.045	0.62	shear failure along the joint
4	12.6	6.928	0.45	shear failure along the joint
5	12.6	6.372	0.45	shear failure along the joint
6	20	6.237	0.72	shear failure along the joint
7	12.4	6.747	0.45	shear failure along the joint
8	18.2	6.907	0.65	shear failure along the joint
9	17.2	6.964	0.62	shear failure along the joint
10	12.4	6.769	0.45	shear failure along the joint

Number	10					
Average	0.56	MPa				
Sample SD	0.10					
Sample CV	0.19					
f'ms	0.33	for Kk =	0.73	for CV =	0.30	

Appendix J – Vertical shear strength at interface between bonded hollow and solid block walls with screw connectors

Client : Benex Masonry
Date: 15-May-05
Test: Vertical Shear Tests at interface between hollow and solid block walls

Preparation: The specimens were 3-courses high
The middle block was 600mm long and the side blocks were 300mm long
The middle block was solid and the side blocks were hollow.
During laying the side blocks and the middle blocks were glued on edges and connected with 10-8 x 100mm screws at the top at each course

Average weight of solid block = 12.5 kg
Specimen height = 600 mm
Bedding width = 50 mm (two 25mm wide glue strips on one side)

Test Condition: Specimens were cured in the laboratory for more than 7 days and tested under dry condition.

Spec. No.	Bonded area in vertical shear planes (mm^2)	Weight of middle wall (kg)	Failure Load (kN)	Failure Stress (MPa)
1	60000.0	37.5	64.0	1.07
2	60000.0	37.5	66.5	1.11
3	60000.0	37.5	66.5	1.11
4	60000.0	37.5	64.5	1.08
5	60000.0	37.5	65.5	1.10
6	60000.0	37.5	66.0	1.11
7	60000.0	37.5	54.0	0.91
8	60000.0	37.5	55.5	0.93
9	60000.0	37.5	82.5	1.38
10	60000.0	37.5	62.5	1.05

Average = 1.09
S.D. = 0.13
C. of V. = 0.12

Characteristic shear strength at vertical interface = 0.65 for Cv = 0.30 and Kk = 0.72

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Appendix K – Vertical shear strength at interface between bonded solid and solid block walls with screw connectors

Client : Benex Masonry
Date: 22-May-05
Test: Vertical Shear Tests at interface between solid and solid block walls

Preparation: The specimens were 3-courses high
The middle block was 600mm long and the side blocks were 300mm long
The middle block was solid and the side blocks were solid.
During laying the side blocks and the middle blocks were glued on edges and connected with 10-8 x 100mm screws at the top at each course

Average weight of solid block = 12.5 kg
Specimen height = 600 mm
Bedding width = 50 mm (two 25mm wide glue strips on one side)

Test Condition: Specimens were cured in the laboratory for more than 7 days and tested.

Spec. No.	Bonded area in vertical shear planes (mm^2)	Weight of middle wall (kg)	Failure Load (kN)	Failure Stress (MPa)
1	60000.0	37.5	47.5	0.80
2	60000.0	37.5	45.0	0.76
3	60000.0	37.5	60	1.01
4	60000.0	37.5	61.5	1.03
5	60000.0	37.5	39.5	0.66
6	60000.0	37.5	27.0	0.46
7	60000.0	37.5	47.5	0.80
8	60000.0	37.5	43.0	0.72
9	60000.0	37.5	35.5	0.60
10	60000.0	37.5	34.0	0.57

Average = 0.74
S.D. = 0.18
C. of V. = 0.25

Characteristic shear strength at vertical interface = 0.33 for Cv = 0.3
and Kk = 0.73

Appendix L – Vertical shear strength at interface between bonded hollow and hollow block walls with screw connectors

Client : Benex Masonry
Date: 11-May-05
Test: Vertical Shear Tests at interface between hollow and hollow block walls

Preparation: The specimens were 3-courses high
The middle block was 600mm long and the side blocks were 300mm long
The middle block and the side blocks were hollow.
During laying the side blocks and the middle blocks were glued on edges and connected with 10-8 x 100mm screws at the top at each course

Average weight of solid block = 12.5 kg
Specimen height = 600 mm
Bedding width = 80 mm (two 40mm wide glue strips on one side)
Test Condition: Specimens were cured in the laboratory for more than 7 days and tested.

Spec. No.	onded area in vertical shear plane (mm^2)	Veight of middle wal (kg)	Failure Load (kN)	Failure Stress (MPa)
1	96000.0	37.5	39.0	0.41
2	96000.0	37.5	61.5	0.64
3	96000.0	37.5	45.5	0.48
4	96000.0	37.5	54.5	0.57
5	96000.0	37.5	33.5	0.35
6	96000.0	37.5	43.0	0.45
7	96000.0	37.5	55.0	0.58
8	96000.0	37.5	61.5	0.64
9	96000.0	37.5	68.5	0.72
10	96000.0	37.5	51.5	0.54

Average = 0.54
S.D. = 0.12
C. of V. = 0.21

Characteristic shear strength at vertical interface = 0.26 for CV = 0.30
for Kk = 0.73

END OF REPORT