ARCHING CONCRETE BLOCK BASEMENT WALLS: TESTS

R. G. Drysdale[1], K. Hughes[2], J. Wierzbicki[3], B. R. Banting[4], and W. W. El-Dakhakhni[5]

[1] Professor Emeritus, Centre for Effective Design of Structures, Department of Civil Engineering, McMaster University, Hamilton, ON, L8S 4L7, Canada, drysdale@mcmaster.ca
[2] M.A.Sc. Candidate Department of Civil Engineering, McMaster University, hughekj@mcmaster.ca
[3] M.A.Sc. Candidate Department of Civil Engineering, McMaster University, wierzbj@mcmaster.ca
[4] M.A.Sc. Candidate Department of Civil Engineering, McMaster University, bantinbr@mcmaster.ca
[5] Martini Mascarin and George Chair in Masonry Design, Centre for Effective Design of Structures, Department of Civil Engineering, McMaster University, eldak@mcmaster.ca

ABSTRACT

This paper reports on full scale laboratory tests of concrete block walls reinforced with surface mounted ties to create a tied arch structural system. The intent is to use this system in basement wall construction so that hollow 20cm concrete block can be used in a cost-effective manner. Ten tests were performed on 3m high walls to investigate use of various reinforcing tie cross sections and various methods of anchoring the ties at the top and bottom of the wall to develop the tie strength. Although choice of an economical tie design was found to be important, it was readily apparent that development of simple anchoring systems would have the greatest impact on both cost and marketing success. Forty-six tests of various methods of anchoring the ties were carried out. The results of the wall and anchorage tests provide proof of the structural concept and form the basis for seeking code approval for use of arching concrete block basement walls.

KEYWORDS: Arching, backfill, basements, bending, concrete block, reinforcing, soil pressure, tied arch, ties.

INTRODUCTION

In Canada, the use of concrete block in basement construction for single-family homes has steadily declined to the point where this once major market forms a relatively small part of masonry construction. Reasons for the decline may be varied, but the single most important factor in regaining market share is to be able to compete on the basis of cost. The use of reinforcement in grouted 20 cm block or the use of concrete block larger than 20 cm is required in Part 9 if the NBCC [1] for 2.4 m or higher concrete block basement walls having more than 1.2 m height of backfill. Such designs have not proven to be competitive in most regions.

As discussed in the companion paper [2] to this paper, it is conceptually feasible to use hollow 20 cm block basement walls for heights up to 3 m and with backfill near the top of the wall if they are constructed to use arching action for enhanced resistance to lateral soil pressure. In this regard, attachment of a vertical reinforcing element along the interior face of the wall can provide the tie for a tied arch form of construction. Whereas the design and positioning of the tie itself is simple and not expensive, the more challenging factor is to achieve adequate anchorage of the tie to develop its tensile strength in a manner that is economical in use of materials and labour and that is simple to construct properly with minimal supervision. Tests done to confirm adequate wall strength and to develop appropriate methods of anchoring the reinforcing ties.

WALL TEST PROGRAM

Details of Test Walls and Test Procedures. Seven 0.80 m long walls were constructed in running bond using 15 courses of 20 cm (8 in.) hollow concrete blocks and Type S Portland cement and hydrated lime mortar[3]. The average compression strength of the block used was 29.2 MPa from tests of 3 blocks. Tests of four 4-block high prisms gave an average prism compression strength of 21.5 MPa. An experienced mason built the walls within tolerance for joint thickness and vertical alignment.

The 0.80 m wall length was chosen so that a symmetric placement of two lines of reinforcing ties could be used. Prior to attachment of the reinforcing ties, the first 6 walls were post-tensioned with 2 lengths of threaded rod so that they could be lifted and positioned horizontally without cracking. These walls were tested in the horizontal position for ease of testing as illustrated in Figure 1. Each wall was supported on the ends with one end pinned using a 50 mm diameter roller confined top and bottom within grooves machined into bearing plates. The other end was positioned on a 50 mm diameter roller placed between two flat plates so that it was free to roll. Load distribution beams were positioned across the length of the wall at 450 mm spacing and load was transferred to these using the spreader beam shown in Figure 1.

Using the formulations developed in the companion paper [2], for a 3 m high wall with backfill up to 0.2 m from the top, the factored maximum moment for the 0.8 m long wall is 8.52 kN-m.

Wall Test Results. Preliminary tests 1 and 2 on Walls 1 and 3 used 18 gauge (1.10 mm) track shaped reinforcing ties with 51 mm wide flanges and web. The ends of the ties were anchored in the end blocks of each wall with six 87 mm long ¼ in. (6.3 mm) diameter self-tapping concrete screws. Wood blocks were inserted between the flanges of the tie so that the concrete screws fastened both flanges to the face of the block. Also chip angles were screwed to the web at each end of the tie using 4 No. 8 metal screws and subsequently to the wall using four 38 mm long self-tapping concrete screws. This meant that, in addition to the flange against the wall, the strengths of the web and outstanding flange were partially developed.

These initial tests produced moment capacities of 15.44 kN-m and 16.09 kN-m corresponding to an average calculated tensile force [2] of 87.3 kN and an average stress of 287 MPa in the ties where the area lost due to screw holes was taken into account. Cracking of the blocks along the line of the concrete screws and pull out of the screws was the mode of failure. These very uniform test results indicate excellent reliability and that adequate screw anchorage of the reinforcing tie could be achieved. However, it seemed doubtful whether this type of anchorage would be economically commercially feasible.

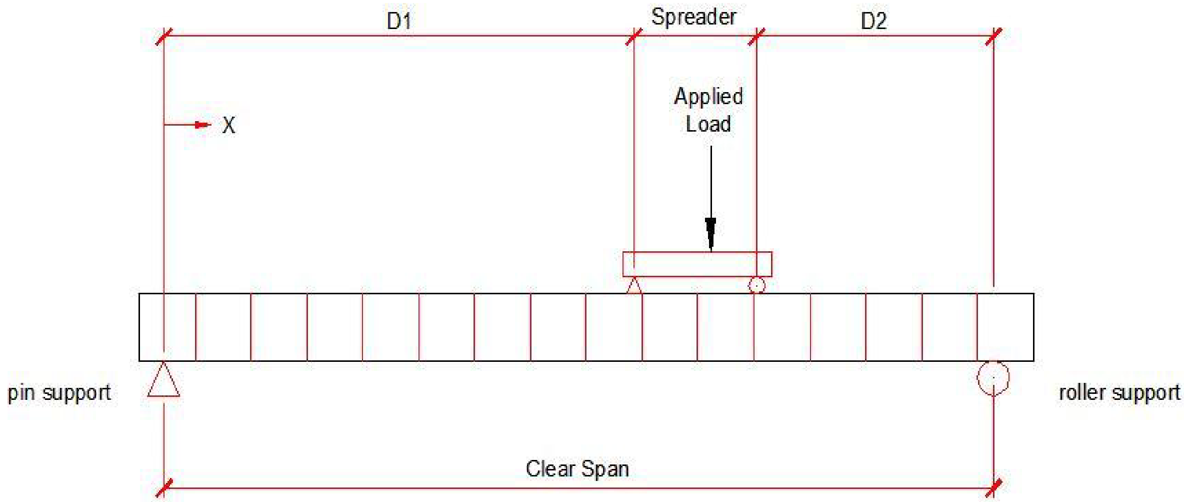


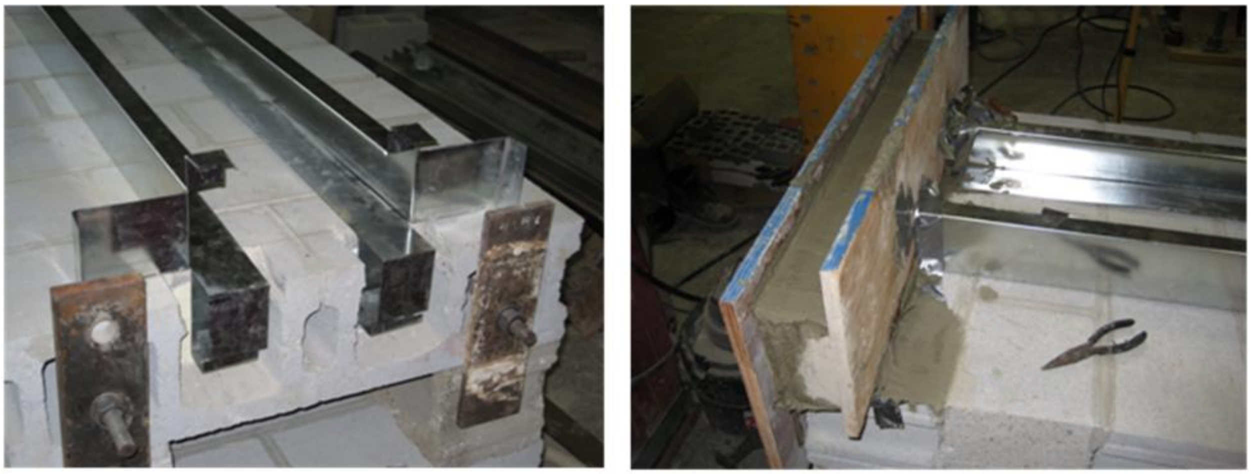
Figure 1: Experimental Test Set-up for Wall Tests 1 to 9

As mentioned in the companion paper [2], deflection does not affect resistance to lateral soil pressure. At unfactored (service) loads, it was decided that deflection would not be critical at less than wall height divided by 240. (The NBCC [1] allows deflections of up to wall height divided by 180 when most of the deflection occurs prior to attaching the gypsum board.) At maximum test load, the deflections were 25 mm and 33 mm for Tests 1 and 2, respectively, and both were less than 10 mm at half load.

Test No. 3 was a retest of Wall 3 with the same anchor conditions as in Tests 1 and 2 but using ties made from 20 gauge (0.83 mm) steel. The stud type of tie had a folded over 76 mm flange next to the wall, a 51 mm wide web and a 40 mm flange with a 6 mm return located farthest from the wall surface. The damaged top block from previous test was removed and the supports were placed closer. Even though the eventual block failure and pull out of the ¼ in. diameter self-drilling concrete screws was the same as for Test 1, the greater area of steel and increased total thickness of the double thickness flange results a 6.7% increase in capacity to 16.47 kN-m.

Tests 4 and 5 were performed on Wall 2 and a retrofitted Wall 2. This wall was reinforced with the same 20 gauge (0.83 mm) studs as in Test 3. In these tests, one end of the wall used anchorage consisting of 16 self-drilling concrete screws plus added brackets in an effort to force the failure to occur at the other end which had been anchored into grout-filled cells of the upper course of block. At 14.42 kN-m and 12.98 kN-m capacities, both tests failed prematurely and have value only as lower bound indications of the capacity of the grouted anchorage. These 2 results demonstrated the difficulty with using a large number of self-drilling concrete screws for anchorage. The deflections at maximum moment were 18.5 and 12 mm, respectively.

Tests 6 and 7 on Wall 4, Test 8 on Wall 5, and Test 9 on Wall 6 used a steel stud reinforcing tie shape similar to that used in Tests 4 and 5 except that a 100 mm wide web was used and 25 gauge material (0.41 mm) was bent into the required shape. However, due to manufacturing limitations for prototype modified stud shapes, the second thickness of 76 mm wide flange was a separate 76 mm wide steel strip. As shown in Fig. 2(a), the larger double flange was bent into the bottom block through a knock-out in the face shell using the bent shape shown in Figure 5 (option 2) in reference[2]. Then, as shown in Fig. 2(b), a 100 mm thick section representing the basement floor was poured to anchor these ends in place. The anchorage into the top course of block was similar except that no knock-outs were used and the cells at anchor points were filled with grout over the entire height of the top course.



a) Anchoring of Steel Stud Reinforcing Ties at the Bottom of Wall (Tests 6-9)

b) Pouring of Concrete Floor to Anchor Reinforcing Tie into the Bottom of the Wall

Figure 2: Photographs of Grouted Anchorage at Base of Wall

Unfortunately, relatively low strengths of 9.45, 11.66, 11.67, and 13.19 kN-m, were observed for the respective 4 tests. After Test 6, dismantling of the wall showed that the two separate parts of the anchored flange had not been loaded equally and the separate strip had failed. In the other 3 tests attempts were made to attach the two parts of the flange together using metal screws. Although these modifications improved the capacity, failure of one flange thickness still controlled. The average capacity of 11.5 kN-m represents a tie force of 31.9 kN/tie which equates to 256 MPa tensile stress if both thicknesses of flange are considered effective. This is well below the 345 MPa yield strength of the material. If Test 6, with no attempt to combine the 2 flange thicknesses, is neglected, the remaining 3 tests provide an average strength of 12.17 kN-m with a standard deviation of 0.88 kN-m. In turn, this provides a characteristic design strength at the 95% confidence level of 12.17-1.64(0.88) = 10.72 kN-m which is further reduced to 0.85(10.72) = 9.11 kN-m to account for material variability. Therefore, these tests showed that the grouting method of anchoring had a lower bound strength that is greater than the required 8.52 kN-m factored design moment previously calculated for the most severe loading condition. A one-piece tie would be expected to perform better.

Test No. 10 was performed on Wall 7. This wall was tested vertically to more clearly represent and illustrate the actual conditions for basement walls. The bottom of the wall was supported on a 150 mm thick concrete footing as shown in Figure 3. The wall was reinforced using 2 folded over 20 gauge (0.866 mm) strip ties with a width of the 63 mm and a 15 mm outstanding leg all formed using a single width of steel sheet. The top course on the wall was made using lintel blocks. The top and bottom of the reinforcing ties were bent as shown in Figure 2(a) and positioned on the wall using a 38 mm self-drilling screw in the second courses from the top and bottom of the wall. A horizontal No. 15 reinforcing bar was positioned in the lintel block and two 15 mm diameter anchor bolts with washers were placed so that the washers were below the bar prior to filling the lintel blocks with fine grout. The ties were anchored at the bottom of the wall by pouring a 100 mm thick basement floor as shown in Figure 3. The fluid concrete flowed through the knock-outs at the bottom of the wall and anchored the bend ends of the reinforcing tie in the cells. The top of the wall was fitted with a 38 by 189 wood sill plate and representative floor joists were nailed to the sill plate to complete the illustration of basement construction. Testing was stopped when it seemed clear that the reinforcing ties had begun to yield because load capacity remained constant with increased deflection.

Figure 3: Wall 7 in Vertical Position for Lateral Load, Test No. 10

Detailed Analysis of Test 10. Wall 7 closely represents the intended on-site construction of arching concrete block basement walls. The following calculations illustrate the reliability of the calculated arching behaviour. With a clear height of 2.99 m and the maximum applied load of 24.8 kN, the corresponding moment capacity is M=14.85 kN-m. Since the steel used in this tie had a measured yield strength of 52,600 psi (361 MPa) at 0.2% offset, the theoretical capacity is

$$
\begin{aligned}
M_{\max} &= T_d = A_s f_y\,(0.95\times190) \\
&= (2(2.5\times25.4)\,0.866)\left(\frac{52.360)}{145}\right)(180.5)\times10^{-6} \\
&= 14.34\,kN.m
\end{aligned}
$$

which is 3.6 % less than the measured value. This difference can be accounted for by the conservative moment arm assumption and the use of an equivalent yield strength. With the 0.85 material resistance factor applied to the measured capacity, the 14.85(0.85) = 12.62 kN-m design capacity is 1.48 times the required 8.52 kN-m capacity previously calculated. Thus a smaller area of steel or wider spacing of ties would be possible.

ANCHORAGE CAPACITY TESTS

Details of Tests. A variety of anchorage methods have been tested to provide data to predict capacity of arching concrete block basement walls. In conformance with CSA A370-2004[4] (Clause 12.1.5) five repetitions of tests are adequate provided that the coefficient of variation does not exceed 15 percent. Otherwise, a minimum of 10 tests is required.

Table 1 contains a summary of the test results where the reinforcing tie type used in Wall Test 10 was used for the first 8 series of tests. For Series 9 to 13, a tie having a single thickness of 16 gauge (1.36 mm) material and the same dimensions and shape as the other tie were used. Individual ties were attached to one or more vertically stacked blocks using the anchor method chosen for that test series. The block masonry with attached tie was supported on the top platen of the test machine and the other end of the tie was gripped in a jaw capable of holding it in place as tension force was applied. Figure 4(a) is a photograph of the anchorage test set-up.

As shown in Table 1, only 3 test repetitions were completed for Series 1 with the tie anchored using two 38mm long self-drilling screws into the face shell of 20 cm hollow concrete block. An average strength of 12.3 kN was reached before the block failed. Series 2 also had three tests where 4 self-drilling screws were anchored into 2 courses of block. The average strength of 29.8 kN coincided with pullout of the screws sometimes accompanied by cracking of the block along the line of the screw holes. Series 3 used 1 screw in one block and the 5 tests gave an average strength of 9.1 kN with a C.O.V. of 9.2 percent. Since this meets the requirement of CSA A370, this result can be used to determine anchorage design strength in accordance with CSA A370. In this regard, it is noted that the relationship between number of screws and strength was not linear and that block failure occurred along a path following the line of the screws. Figure 4(b) shows a typical splitting failure along a line of screw holes in the block.

Series 4, 5 and 6 were single tests done to evaluate the benefit of limiting the number of screws anchored into each block. Clearly, there is some benefit to staggering the positions of the screws and to limiting the number in a block because the full benefit of an added screw is not obtained if it is inserted into a block already containing a screw.

Series 7 consisted of two tests on the same specimen (anchored as in Option 2 of Fig. 5 (b) in Ref.[2]) where the unanchored end of the tie in the first test failed as it began to tear in the jaws of the test machine. It appeared that the two layers of tie in the folded over configuration were not gripped equally. When the tie was re-gripped in the machine, the retested tie failed at the anchorage end but not until the applied load was about 23 percent higher than the 0.866(2 x 63) x

361= 39.7 kN yield strength of this section indicating that tearing did not occur until well beyond the yield strength of the tie.

Table 1: Wall Summary of Anchorage Tests for Reinforcing Ties

Series No.	Description of Test+	Average Strength (kN)	C.O.V (%)	Comments and Failure Mode	Number of Tests
1	2 screws in 1 block	12.3	12.3	Crack along line of screw holes	3
2	4 screws in 2 blocks	29.8	22.3	Crack along line of screw holes	3
3	1 self drilling screw in 1 block	9.1	9.2	Mainly pull-out of self-drilling screw	5
4	2 screws in 1 block (staggered position)	9.0	-	Inclined crack passed through staggered holes	1
5	2 screws in 2 courses of block	20.0	-	Screws failed	1
6	2 screws in bottom course and 1 in top course of 2 courses	25.0	-	Crack along line of screws	1
7	1 block with strip tie anchored into knock-out*	45.0	-	Tensile Failure of Tie	2
8	Tie anchored in cell of top course, plus 1 positioning screw	45.3	9.5	2 experienced tie failure, 3 blocks cracked	5
9	Tie anchored into grouted lintel block	39.6	3.4	Tie failures	5
10	Single bend tie anchored into grouted lintel block	24.2/ 30.3	26.1/ 12.5	3 block cracked, 2 pull-out of poorly compacted grout / excluding the 2 poor compacted specimens	5 / 3
11	Grouted in Ashlar with double bent tie as shown in Ref.[2]	19.6	16.1	Cracking in ashlar block and pullout of tie	4
12	Grouted in knock-out with bend for anchorage**	31.4	21.4	Block cracked and strip tie pulled out	5
13	Grouted in ashlar block with double bent tie	27.2	11.8	Ashlar block cracked, grouted cracked and tie pulled out	4

+ See Figure 5 in Ref.[2] for grouted anchorage configurations
*Bent shape like Option 2 in Figure 5(b) in Ref.[2]
**Bent shape like Option 1 in Figure 5(b) in Ref.[2]

a) Testing capacity of tie anchorage (Test Setup)

b) Failure of block along line of screws

c) Typical steel failure at top anchorage

d) Tie anchorage in ashlar block before grouting

Figure 4: Photographs Related to Anchorage Tests

Series 8 consisted of 5 tests of the reinforcing strip tie anchored into the grouted cell of one block. The original final test was faulty as the anchor block failed due to uneven bearing against the top platen of the test machine. Therefore, this test was repeated. Based on the 5 tests, the average strength is 45.3 kN with a 9.5 % c.o.v. For this result, in accordance with CSA A370, the design or characteristic strength is 45.3(1.0 – 1.64(0.095)) = 38.3 kN which is only slightly lower than the nominal yield strength of 39.7 kN.

Series 9 consisted of tests of the top anchorage as used in Wall Test 10. The average strength of 39.60 kN had a C.O.V. of 3.4 percent which gives a design or characteristic strength of 39.6 x

(1.0-(0.164(0.034))=37.4 kN. Figure 4(c) shows a typical strip tie failure. The significant extent of pull-out of the tie was a post-yielding phenomenon but failure was tearing of the tie.

Series 10 consisted of tests with an simple bend anchor arrangement shown in Figure 4(d). Instead of cutting a slot in the face shell of the bottom course of block and anchoring the reinforcing tie in the cell space, a 30 cm sized 90 mm high hollow ashlar block is used at the bottom of the wall. Then the bent end of the reinforcing strip tie is inserted into the cell of the ashlar block and is positioned under the bottom 20 cm concrete block. Anchoring of the tie was completed by filling the cell of the ashlar block with Type S mortar made using Type S masonry cement. A typical failure was pull out of the tie but 2 of the tests yielded very low results as the result of failing to fully embed the tie in the mortar/grout. Based on the 3 tests where reasonable embedment was observed, the average strength of 30.3 kN had a C.O.V. of 12.5 percent.

From study of the Series 10 results, it was decided that the better bent shape shown in Fig. 5 (c) in the companion paper[2] was required for Series 11. The 5 tests gave an average strength of 19.6 kN with a C.O.V. of 16.1 percent. The anchorages failed prematurely by cracking through the ashlar block and grout followed by pull-out of the tie.

Series 12 used the single thickness strip tie bent similarly to the ties in Series 8 and 9. However the failure of the block led to a significantly lower capacity. Similarly, Series 13 with the same tie bend detail as illustrated in the companion paper[2] for anchorage in an ashlar block, failed by splitting of the blocks and did not develop the yield strength of the tie. Since a factored tie force of only 23.6 kN is the minimum required to produce the largest factored design moment (8.52 kN-m), the recorded strengths would be adequate for most conditions. However, a new series of tests with thinner gauge material in a double thickness configuration will be tested to try to obtain tie failure results similar to Series 7, 8, and 9 and leading to the excess capacity observed in Wall Test 10.

CONCLUSIONS AND RECOMMENDATIONS

A method of strengthening 20 cm hollow concrete block basement walls was described and evaluated in this report. It was shown that a modified cold formed steel stud section could be used as a reinforcing tie to greatly enhance the resistance to soil pressure. Alternatively, it was shown that a strip type of tie could be adequately anchored to achieve the required resistance to soil pressure. In the former case, the modified stud will serve directly as the support for completing the internal finish in the basement. In the case of the strip ties, either independent or members attached to the strip tie can provide a platform for finishing the basement.

Since the wall tests showed and it is known that that the capacity of tied arches can be predicted accurately, it is sufficient for the anchoring method itself to be tested without the need to retest the entire system when new ties or anchorage methods are considered.

In terms of capacity requirements, a 3m high wall with soil backfilled to 0.2m from the top requires a factored tie strength of 23.6 kN for ties spaced at 400 mm. However, where soil is up to 0.20 m from the top of a 2.4 m wall, less than half of this capacity is required. Therefore, as can be seen from the results in Table1, even use of 2 to 4 self-drilling concrete screws is technically feasible for moderate wall heights and levels of backfill.

The cost of the tie material itself does not appear to be the main consideration in successful marketing of this new way of producing strong and reliable basement structures. Mark-ups from distributors, labour costs, and costs of additional parts such as screws are the main concern. For this reason, the construction was kept as simple as possible and it is suggested that only 2 or 3 tie sizes be made available to reduce inventory requirements and to simplify design. Although the arching basement wall can be equally well used for unfinished basements, it is suggested that the main application and most cost effective application will be for finished basements. In this regard, except for the shape of the stud or the possible use of a strip tie to attach a steel section to support drywall, no new building envelope materials or construction methods are proposed. In the long term, some changes may be beneficial but for initial market penetration, it is suggested that using familiar methods will reduce market resistance to adopting the new structural system.

In addition to acquiring a CCMC Evaluation, it will be necessary for the concrete block industry to market this new concept and to train builders in efficient construction methods. Although marketing will introduce a business cost in the short term, it also provides an opportunity to gain favourable contacts with designers and builders who may be amenable to considering other applications of block construction.

ACKNOWLEDGEMENTS

The research reported in this paper was sponsored by Canadian Concrete Masonry Producers Association. The assistance of Canada Masonry Design Centre and the Canadian Masonry Contractors Association is also acknowledged.

REFERENCES

1. NBCC (2005). National Building Code of Canada, Institute for Research in Construction, National Research Council of Canada, Ottawa, ON, Canada.
2. R. G. Drysdale, J. Wierzbicki, K. Hughes, B. R. Banting, and W. W. El-Dakhakhni "Arching Concrete Block Basement Walls: Concept" 11th Canadian Masonry Symposium, Toronto, Ontario, May 31- June 3, 2009.
3. Canadian Standards Association (CSA 2004). "CAN/CSA-A179-04: Mortar and Grout for Unit Masonry" CSA, Mississauga, ON,
4. Canada Canadian Standards Association (CSA 2004). "CSA-A370-04: Connectors for Masonry" CSA, Mississauga, ON, Canada