ARCHING CONCRETE BLOCK BASEMENT WALLS: CONCEPT

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ABSTRACT

In modern house construction, the use of increased head room and the trend toward greater depths of backfill have led to reduced use of concrete block in basement construction. This paper provides conceptual information on use of 20 cm concrete block basement walls fitted with external surface mounted ties anchored into the top and bottom of the wall to create tied arch action. Test results verify that this structural system works well. It also provides a cost efficient alternative to existing basement wall construction systems with minimal changes to traditional construction techniques.

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

INTRODUCTION

Background. The market share for concrete block basements has steadily declined over the past three decades. In this regard, the traditional 20 cm (8 in.) hollow concrete block basement is often no longer technically viable as a result of using greater wall heights to increase head room and the trend to having backfill near to the top of the basement wall. Both factors significantly increase the bending moments that basement walls must be designed to resist. While thicker walls using larger hollow concrete blocks or reinforced 20 cm (8 in.) blocks are satisfactory technical solutions, these solutions result in significantly increased costs and thus negatively affect the competitive position of concrete block basements.

Modern house construction has relied increasingly on basement space as habitable areas. As such, there is a growing desire to increase heights of basement walls for added head room. Use of basements as desirable living space and implementation of energy saving regulations require providing insulation, air/vapour barriers, and an interior finish. Typically, to achieve this, some form of strapping is attached to the basement wall to serve as the platform for holding insulation in place as well as providing support for gypsum board or other paneling. The insulated spaces between the straps are used for installation of electrical and communication circuits. Overall, finishing of the basement is an added cost but one that is very cost-effective in terms of creating useable space.

This paper provides analytical and experimental evaluations of using steel reinforcing attached to the interior face of the wall as a low cost, technically simple and reliable means of strengthening concrete block basements. The objective is to enable 20 cm (8 in.) hollow concrete block walls to satisfy strength requirements for head room up to a least 3 m (10 ft.) combined with levels of backfill to within 200 mm (8 in.) of the top of the wall. In many cases, a slightly reconfigured old formed steel stud can be used as both the steel reinforcing and as strapping for completing the interior finishing of the basement.

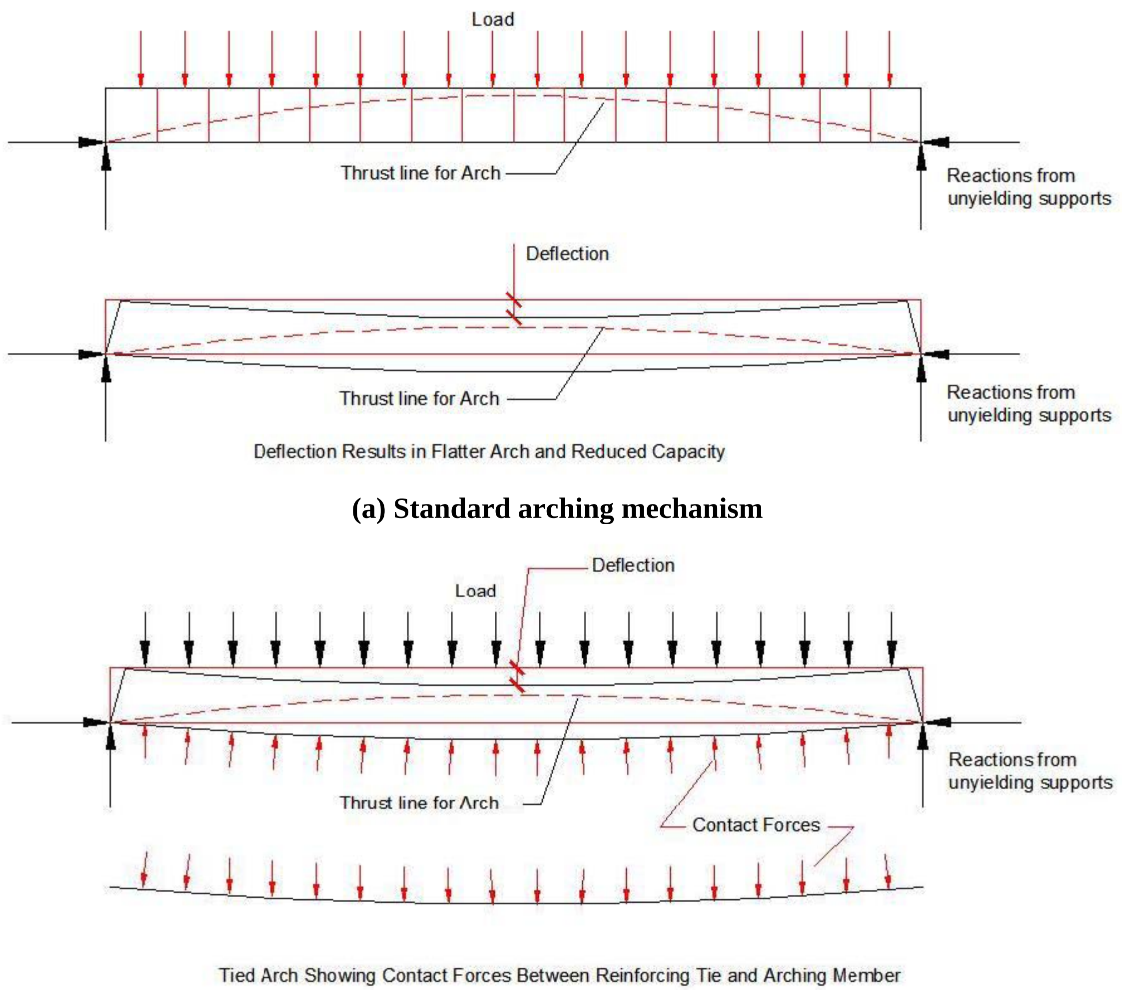
CONCEPT OF USING ARCHING ACTION

Traditionally, reinforcement bonded within or on the surface of tension-weak, compression-strong materials such as masonry has been used to greatly increase bending capacity to resist lateral loads. However, the utilization of arching action to avoid the need to create cross section bending capacity is an even older tradition in masonry construction. As such, it is not necessary for the masonry to employ an arch shape to span a space. Instead, provided that a linear (straight) masonry member has sufficient thickness, the arch (arching action) can be created within that thickness as illustrated in Figure 1(a). In addition, for any arch to function, sufficiently rigid supports must be provided to resist the compressive thrust from the arch and avoid having the arch collapse due to outward movement of those supports.

The presence of vertical strapping over the interior height of a basement wall provides an opportunity to prevent spreading of the basement wall supports and creates what is known as a tied arch. Steel strapping such as cold formed steel dry wall studs can act as the reinforcement (or tie). Anchorage of this stud or other reinforcing shape into the bottom block and over the top of the top block in the basement limits in-plane movement of the top and bottom of the basement wall and creates the support for arching action. In this regard, the tied arch is actually a superior method of creating arching action since deflection of the wall does not reduce the effective height of the arch. The reason is that contact between the tie (strapping) and the convex shape of the deflected wall creates a counteracting force that fully compensates for the effect of the deflection. This concept is illustrated in Figure 1(b). Hence, the key technical considerations are choice of reinforcement (a tie) to provide sufficient tensile strength to resist the outward compressive thrust from the arch and anchorage of the tie to develop the required tie force.

ANALYSIS OF TYING REQUIREMENTS FOR BENDING DUE TO SOIL PRESSURE

Part 9 of the National Building Code (2005) [1] provides advice for design of basements and retaining walls where, for simplicity, an equivalent fluid pressure is specified. Clause 9.4.4.6 specifies a minimum equivalent fluid density of 480 kg/m^3**.** This number is compatible with a soil density of 1,600 kg/m^{3}and an internal angle of friction of 30° consistent with using a well drained granular backfill. Friction between the face of the wall and the soil is conservatively neglected.



(a) Standard arching mechanism

(b) Tied arch contact forces between reinforcing ties and arching member

Figure 1: Arching Within Thickness of Wall

For the triangular distribution of soil pressure resulting from the equivalent fluid assumption as shown in Fig. 2(b) and the geometry shown in Figure 2(a), the point of maximum bending moment, h_s, is located at the point of zero shear where simple support conditions at the top and bottom of the wall are assumed. This results in horizontal reaction forces equal to the end shear forces shown in Fig. 2(c). From statics, the distance from the top of the wall to the point of zero shear is:

$$h_s = \sqrt{\frac{(h - h_o)^3}{3h}} + h_o \tag{1}$$

where h_o is the distance from the top of the wall to the upper surface of the soil and, at this height, the maximum bending moment (kN-m/m) in the basement wall is

$$M_{\max} = 4.7\ \frac{(h_s - h_o)^2}{2}\ \frac{(2h_s + h_o)}{3} \qquad (2)$$

These equations can then be used to determine the unfactored design moments, M_{max}, for various clear heights of basements, h, and distances between the top of the basement wall and the surface of the ground. In the limit states method of design utilized in the NBC (2005)[1], safety is created by factoring the load up by a load factor of 1.5; the factored design bending moment that must be resisted is 1.5 M_{max}. Additional safety and the means to account for variability of resistance are introduced by reducing the calculated or measured capacity by a material resistance factor. In CSA S304 (2004) [2], a material resistance factor of 0.85 is applied to steel strength aspects (tie or screw controlled failure) whereas 0.60 is applied to conditions controlled by masonry strength (pull-out of anchors or compression crushing of the masonry). These factors are applied consistently also in the masonry connectors standard (CSA A370 (2004) [3]).

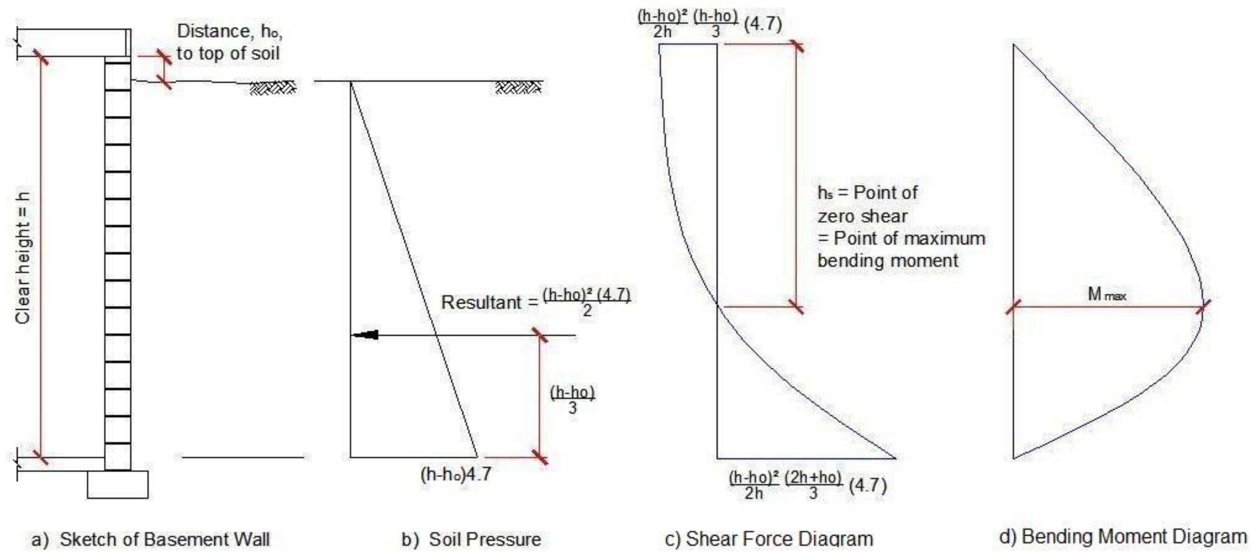


Figure 2: Analysis of Forces Due to Soil Pressure

Therefore, the tie strength, T_S, or anchorage capacity T_A, predicated by test or analysis is reduced to obtain the factored tie force. In design, this means that

$$0.85\ T_S d \geq 1.5\ M_{max} \qquad (3\text{-a})$$

and

$$0.60\ T_A d > 1.5\ M_{max} \qquad (3\text{-b})$$

must be satisfied depending on which strength controls. In the above equations, the term d represents the effective height of the arch created within the thickness of the concrete block wall. A conservative approximation of d can be calculated by assuming a compression zone depth

equal to 10 percent of the wall thickness (as done in the British code) so that the compression resultant is 0.5(0.10 x thickness) from the compression face. Then,
d = thickness – 0.5(0.10 thickness) = 0.95(thickness) = 0.95(190) = 180.5mm = 0.1805m

for walls constructed using 20 cm (8 in.) (nominal) concrete block. The reinforcement (tie) strength is defined as the product of net area times yield strength of the tie material.

On this basis and considering the economic advantage of using steel with a minimum yield strength of 345 MPa (50 ksi), the required area of steel, A_s, considering anchorage failure not to control is

$$A_s = \frac{1.5 M_{\max}}{0.85\left(345)(0.1805)\right)} \; mm^2 / m \tag{4}$$

With regard to the above calculation of arch capacity, it should be observed that the effect of deflection on the height of the arch is not included in the calculation. Although a reduction in arch capacity due to deflection would be applied where an arch reacts against fixed independent reaction points, the fact that the tie rests against the surface of the wall means that its tension force remains at the same distance from the arch compression zone, regardless of the magnitude of the deflection. Therefore, within an acceptable range, deflection is of importance only from a serviceability limit states point of view.

CHOICE OF TYING MEMBER SHAPE

Two types of sections were designed to provide the reinforcing member (tie) in the tied arch form of construction. The first involves reconfiguration of the shape of a standard cold formed steel stud so that a larger fraction of the total steel area would be positioned directly on the face of the wall. As shown in Figure 3, the larger flange of the stud can be doubled over as required to provide sufficient steel reinforcing positioned directly on the surface of the block wall. (In some cases, a single thickness may be sufficient.) The width of this flange is variable depending on steel area required but typically should be at least 50 mm to be larger than the other 38 mm wide flange. This facilitates positioning the stud on the wall using self-tapping screws. The 100 mm depth of the web of the stud can be altered to match the thickness of insulation to be fitted within the stud space. The 38 mm flange located furthest from the face of the concrete block serves as the mounting platform for gypsum board sheets or other panelling and has a 6 mm return to provide extra stiffness for installing self-drilling screws. This section is intended mainly for thinner material such as from 25 gauge (0.411 mm) (0.0162 in.) to perhaps 20 gauge (0.866 mm) (0.0341 in.) thickness.

The other section consisted of a flat strip attached directly to and in intimate contact with the interior surface of the basement wall. It can be folded over to create a double thickness or be a single strip of steel mounted directly on the surface of the wall. A separate section, as shown in Fig. 4, can be held in place vertically by attachment to the strip tie. This vertical steel shape will hold insulation in place as well as support gypsum board or other interior sheathing. Another option is to include slots in the flange shown in the strip tie in Fig. 4. These slots can be designed to position and lock in place a horizontally positioned channel or Z shaped section to hold the

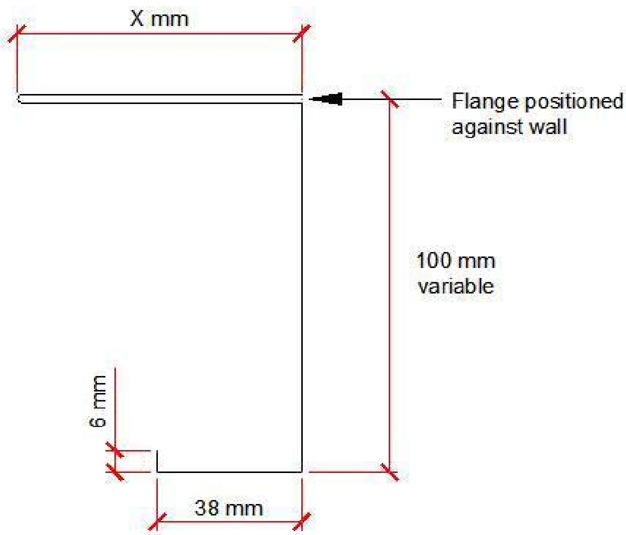


Figure 3: Reshaped Cold Formed Steel Stud

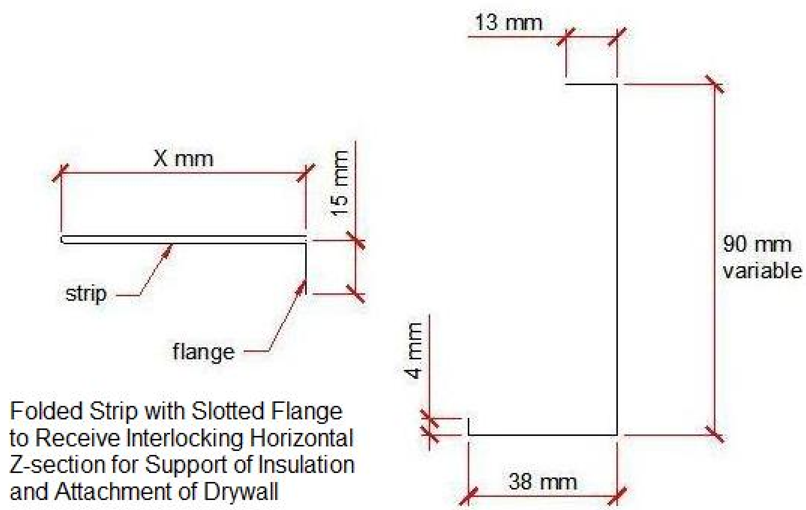


Figure 4: Steel Strip Type of Reinforcing Tie

insulation in place and provide support for the attached gypsum board or other surface finish. (The add-on sections are not part of the basement reinforcement as they are not rigidly attached to the strips and can slip to avoid sharing in resisting load. They relate only to the building envelope construction.) Depending on strength requirements, the strip type of reinforcing tie can be fabricated with various gauges of material and with various strip widths that can be either single thickness. For the strip type of reinforcing tie shown in Fig. 4, the added flange adds stiffness to the section which aids in shipping and handling. The added stiffness also helps in positioning the strip flat against the concrete block wall without any looseness.

In the choice of shape of tying member to be used as reinforcement, it should be noted that the area of stud section utilized in calculating tie strength is the area contained within the strip or the large flange that is positioned directly on the surface of the wall. Although it is possible to at least partially anchor other parts of the reinforcing tie, this involves difficult and time-consuming construction methods. As a result, the decision was made only to anchor the part of the section in direct contact with the wall and ignore the small contribution of the remaining unanchored parts of the reinforcing tie.

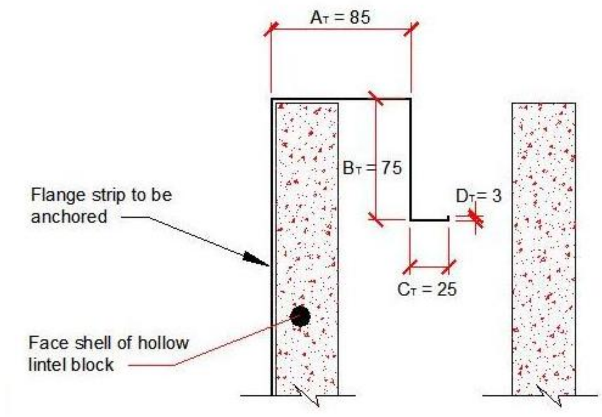
CHOICE OF METHOD OF ANCHORING THE REINFORCING TIE

The investigated methods of anchoring reinforcing ties include: (a) use of self-tapping screws drilled into the concrete block, (b) epoxy bonding of the stud ties near the top and bottom of the wall, (c) use of wooden blocks between the flanges of the stud section to anchor the outstanding flange to the wall using self-tapping screws through the flanges and the wood block and into the concrete block, (d) use of angle sections (brackets) to attach webs of studs to the block wall, and (e) embedment of parts of the ends of the reinforcing tie into grout in the top course of block masonry and into the base of the wall below the upper surface of the basement floor.

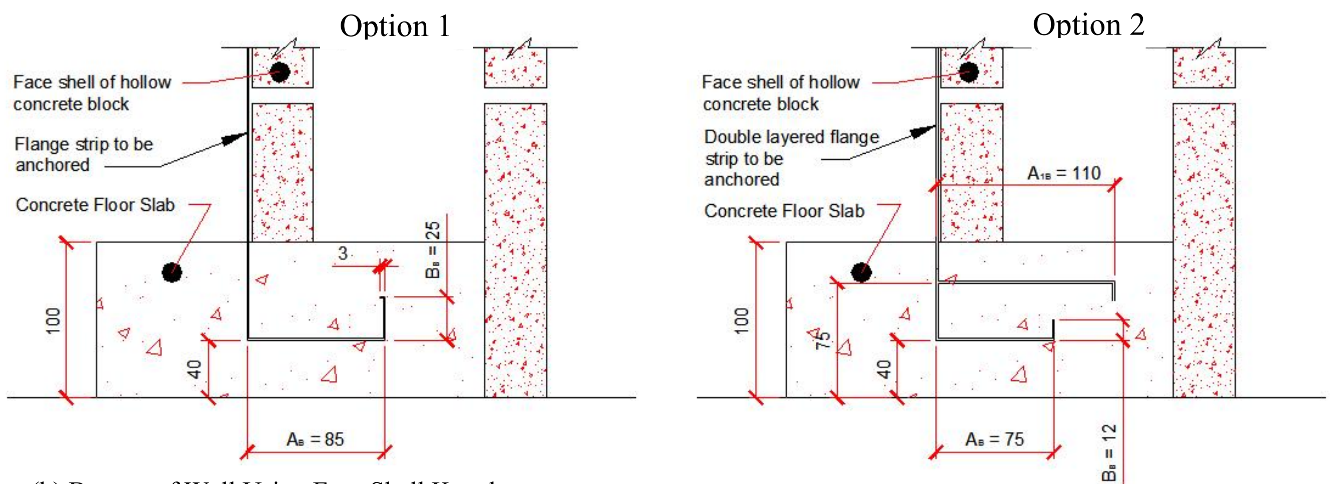
For light gauge steel, it was found that self-tapping screws could be employed to develop part of the strength of the reinforcing tie. However, the final conclusion was that cost of the screws and installation costs made this only economically feasible where retrofit of existing block walls was required. For thicker gauge materials, the large number of self-tapping screws required tended to result in splitting of the blocks along the line of the screw holes thus limiting the number of screws that could be used effectively. This limited the cross section area that could be anchored.

Anchorage of the large flange of a stud section or the metal strip for the strip reinforcing into grouted block at the top and bottom of the wall proved to be a simple and reliable construction procedure. As shown in Figure 5(a), at the top of the wall, the large flange or strip can be bent over the face shell of a hollow block or lintel block and then down to be anchored in the grout. A bend at the bottom of this downward leg adds additional anchorage, and in the case of a lintel block or knock-out web block, it can be used to position a longitudinal reinforcing bar to create a bond beam. For this configuration, it is important that the first bend over the face shell is tight to the block and that the horizontal length of tie is supported over its entire length on the block face shell and the grout filled level with the top of the block and the underside of the tie.

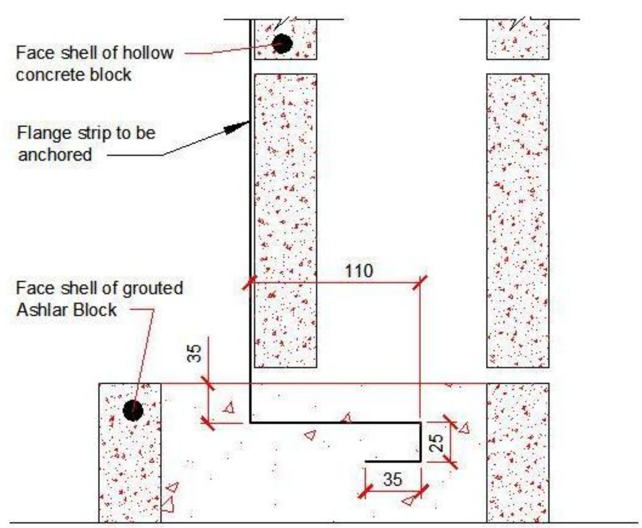
At the bottom of the wall, anchorage into the bottom course of 20 cm (8 in.) block can be achieved where, as shown in Fig. 5 (b), a 90 mm high knock out section in the face shell allows the bend at the end of the tie to penetrate into the lower part of the bottom block. When the basement floor is poured, the concrete flows into the bottom 100 mm of wall and bonds the end of the tie in place to anchor it. However, this approach requires either that the basement floor be poured or a strip next to the wall be grouted prior to backfilling around the basement.



(a) Top of Wall



(b) Bottom of Wall Using Face Shell Knock-outs



(c) Bottom of Wall Built Using 30 cm Ashlar Block

Figure 5: Embedment Anchorage of Reinforcing Ties

As shown in Figure 5(c), to avoid the need to co-ordinate pouring the floor or forming for local grouting, a second approach is to build the 20 cm (8 in.) wall on top of a 30 cm (12 in.) half height ashlar block placed directly on top of the footing. With the extra width of ashlar block extending toward the basement side of the wall, the exposed cells in the ashlar units provide access for the end of the tie to extend down to near the top of the footing and under the 20 cm wall with bends to create anchorage. The cells of the ashlar units can then be grouted or mortar filled to provide anchorage and enable backfilling to proceed prior to pouring the basement floor. When the 100 mm thick basement floor is poured, the upper surface coincides with the top of the filled ashlar unit. The joint between the ashlar unit and the floor is hidden within the stud space for insulated basement walls.

Grouting with standard fine or coarse grout is standard practice and, according to table 5 in CSA A179 [4], fine grout can be mixed using Portland cement, hydrated lime and masonry sand. Therefore, the materials used in standard Type S mortar required for foundation walls are available for mixing the grout. The only difference are reduced the lime content and additional water to create a more fluid mix with a slump of about 250 mm. Although testing for grout compressive strength is not required when the proportion specification is used, it is known that the actual strength exceeds the minimum compressive strengths of 6 MPa at 7 days and 10 MPa at 28 days. This is important to ensure anchorage of the reinforcing ties. However, for small amounts of grout, designers may allow the masonry contractor to use Type S mortar in proportion by volume of 1.0:0.5: 2.25 to 3.0 with water added for increased fluidity.

OTHER CONSTRUCTION CONSIDERATIONS

It was decided that the top course of the block basement could be built using either lintel block or block with half height knock-out webs. This allows placement of a No. 15 bar (or 2-No 10 bars) around the perimeter of the basement. Thus the top course will provide solid support for the superstructure and the horizontal reinforcement will improve the performance of the basement wall. The solid top course accommodates installation of standard anchor bolts and, where required, minimum sill plates of 38 × 89 mm cross section can be used (Clause 9.23.7)[1] and end support for joists can be as little as 40 mm in conformance with Clause 9.20.8.3[1]. Otherwise, any floor system that is approved for use in conjunction with concrete block basement walls can be used. It is worth noting that vertical compressive load by the structure on the basement wall reduces the magnitude of the required tie force. Compressive loads located off centre toward the interior face of the basement wall also produce a bending moment that counteracts the bending moment due to soil pressure. Therefore, neglecting the effects of vertical compression in testing and in the analysis of basement walls is a conservative approach in terms of resistance to soil pressure.

Initial tests on concrete block basement walls reinforced with a modified steel stud tension tie shape similar to that shown in Figure 3 showed that, near ultimate load as the wall reached large deflection, the outer flange and web of the steel stud started to buckle. It should be noted this had no effect on the capacity of the reinforcing tie which depends only on the stud flange or strip positioned directly on the interior face of the wall. Although such buckling did not begin to occur until near reaching the maximum capacity, it was felt that this behaviour should be addressed to avoid home owner concerns where the technical reasons might not be understood. Installation of wood blocks between the stud flanges and screw attachment of these stiffened sections to the wall prevented this behaviour but also added a significant construction cost. [Note that the strip tie shown in Figure 4 does not experience this behaviour which is associated with the outer flange displacing to reduce the energy stored due to tension caused by bending.]

Re-examination of this behaviour showed that standard attachment of gypsum board sheets using screws prevented this buckling without adding a cost. If there are cases where gypsum board or other panelling is not in place as in the case of unfinished basements, any observed buckling of the outer flange or web of the stud provides warning that the basement wall itself is being overloaded. This is valuable so that the cause of wall overload can be addressed. Examples of possible overloading are cases where soil drainage is not occurring or where heavy surcharge loads are located near the basement wall. Both lead to significantly increased lateral soil pressure. A major advantage of the arching action compared to standard unreinforced concrete and masonry walls is that failure is not sudden and large deflections provide warning of a problem.

CONCLUSION

The information reported in this paper provided the technical bases for proceeding with additional research and thus served as the planning for an experimental program reported in a following companion paper[5]. It was concluded that use of arching action to increase the strength of concrete block basement walls has the potential to help significantly increase the masonry industry's market share of basement construction. However, to achieve this objective, development of simple and economic construction details, easy to use design information, building code approvals, and effective marketing are required.

ACKNOWLEDGEMENTS

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