INVESTIGATION

OF

CAVITY WALL TIES

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BY

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To my newly born son Christopher

who, by coming into this world on July 17, 1980

has added much joy to my life.

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ABSTRACT:

This report contains the results of an exploratory investigation into the strength (compressive and tensile) of the most commonly used cavity wall ties. Z, Truss, Ladder and Corrugated metal ties were tested in the Applied Dynamics Laboratory at McMaster University.

A total of 110 specimens were constructed and tested. Fifty-five specimens were tested in compression, another 55 specimens were tested in tension. The influence of different cavity widths and lengths of mortar imbedment on the strengths of the ties were also investigated.

The ultimate load capacity, for each tie investigated, was related to loading on a unit of wall area by taking into consideration the recommended spacings for each tie.

A strength comparison of the ties tested was made. Finally, conclusions were drawn and recommendations made.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 Background

This report contains the result of an exploratory investigation into some aspects of the behaviour of some of the most commonly used masonry wall ties. Interest in this topic was stimulated by the almost complete lack of authoritative information on which design criteria could be based. The need for such information is evident if it is considered that the conditions and uses made of wall ties have been changing rapidly during the last ten years, whereas design provisions have not been evaluated to see if they also need to be up-dated.

The principal uses of wall ties is either in the tying together of the two leaves (called wythes in North America) of a cavity wall or the attachment of masonry veneers to the back-up walls. In discussions of this topic there is often considerable confusion, misunderstanding and misuse of terms such as cavity walls, veneers, ties, anchors, fasteners, tying and bonding. These terms therefore, will be defined below and are consistent with the official usage (1) in Canada.

- Cavity wall means a construction of masonry laid up with a cavity between wythes which are tied together with metal ties or bonding units.
- Veneer means a non-load bearing facing of masonry attached to the backing but not relied upon to exert a common reaction under load.

- Tie means a device for connecting two or more wythes or for connecting a masonry veneer to its structural backing.
- Anchor means a device used to connect masonry walls at their intersections or to attach them to their supports, or to other structural members or systems.
- Fasteners means a device used for fixing equipment or fixtures to buildings.
- Tying refers to the use of metal ties to connect two or more wythes.
- Bonding refers to the use of stones or other masonry units which project laterally into the back-up wall to tie the wall together.

The use of cavity walls or veneers has had a recent revival because of the inherent advantages of such systems. The presence of a continuous air space (cavity) between the interior and exterior walls, offers several advantages for the exterior walls of a building. Traditionally the air space has permitted the application of the rain screen principle, where, by venting the exterior layer, equalized air pressure is maintained in the cavity, and water which penetrates the exterior wall will drain down along the interior side and be directed to the exterior again using through-the-wall flashing at the level of the weep holes.

With the increased importance of conserving energy, the cavity is not only the convenient but also the best location for adding insulation. The placing of insulation in the cavity has an obvious interaction with the positioning of the ties and since up to 3 in. (76mm) of insulation are currently being used, there has been the effect of increased width of cavity.

Although cavity walls consist of two separate wythes separated by an air space, it has been common practice to include some form of connection between the wythes. Originally these wythes were connected at regular intervals by bond stones or other masonry units. This form of connection enabled the wythes to share in resisting lateral loads because they were forced to deflect the same amount. In addition, because of the fact that the bonding units provided a significant shear connection between the wythes, some composite action took place which resulted in a considerable increase in bending resistance since the two wythes acted partially together.

However, there are several major problems with using the practice of bonding for cavity wall construction. As the wythes of the wall become thinner, the amount of moisture migrating through and across the bonding units produces a more significant deteriorating effect. Furthermore, the presence of bonding units makes the placing of thermal insulation more difficult as well as providing large areas where thermal bridging can occur. In addition, the normally expected beneficial effect of composite action, produced by bonding, can actually be seen to have the potential of causing structural problems, since it prevents the cyclic movements of the exterior wythe due to climatic and other conditions. When there is a tendency for differential movement between the separate wythes due to elastic or inelastic strains, thermal expansion, moisture expansion or shrinkage, it is preferable to let the two wythes elongate independently. Otherwise, it is quite possible to introduce stresses into the wall which may result in the formation of cracks(2). Because of such problems, the utilization of metal ties in cavity wall construction should be recommended.

The primary purpose of metal ties in a cavity wall is to connect the two wythes together, so that the structural failure,under lateral loads, of one wythe will not occur independently of the other. The ties are not intended to act as shear connectors between the two wythes and thus produce composite action. Such unit action would require ties of large stiffness and would not be economically feasible. Cavity wall ties should be adequately strong in compression and tension to cause both wythes to deflect equally under lateral loads, so that the flexural strength of the wall as a whole is the sum of the moment resistances for both wythes at the maximum deflection of the controlling wythe.

1.2 Review of available literature

A survey of the available literature revealed a need for research on the strength of cavity wall ties.

Tests conducted at the I.I.T. Research Institute (formerly Armour Research Foundation) were performed to obtain information on the compression and shear strength of Z, rectangular and truss ties (with and without moisture drip), on the tensile strength of rectangular adjustable ties, and on the effect of metal ties on the flexural strength of cavity walls, (3, 4, 5). All of those tests, however, were performed using constant cavity widths, length of tie embedment and wythe material. The test results, therefore, are limited by the characteristics of the specimens tested. Other literature [6, 7] was also consulted and found to be of limited value for the purpose of this investigation.

Although the market offers several types of ties, product literature from manufacturers does not contain any information on the performance characteristics of the available ties. In addition, there is a great lack of information in current codes and standards to guide designers in their selection of ties. CSA Standard S-304-1977 [8] for instance, specifies only minimum size and spacing. In order to overcome this limitation of information and to provide designers with working loads for ties and anchors, a technical committee of the Canadian Standards Association (CSA) is currently preparing the proposed new CSA Standard Can 3-A370-M [9], the committee has already produced a draft of this standard which is being reviewed at the present time.

In March of 1980, the writer of this report met with Mr. B. Hastings, (of Hastings and Aziz Limited, London, Ontario, Canada) the chairman of the committee on the new CSA Standard Can 3-A370-M, to review with him any available literature on the topic. As a result of that meeting, it was concluded that adequate information on the strength of wall ties was simply not available.

Some exploratory work on testing techniques for wall ties, was recently outlined in a report by Mr. G. Pacitti (of Peto MacCallum Limited, Hamilton, Ontario, Canada), to guide the CSA committee on the new CSA Standard Can-3-A370-M. This report was consulted prior to the design of the experimental programme discussed in this paper.

In the field of theoretical research on cavity walls, a recent paper (October 1979) by Brown and Elling [10] indicates that, among other factors, the degree of participation of each wythe in resisting lateral loads is also a function of the number of ties and their stiffness. It is interesting to note that the list of references in this paper does not contain any literature on the strength of wall ties which was not consulted by the writer of this report. This supports the conclusion that information on the topic is not available.

1.3 Objectives and Scope

In view of the lack of information on the strength of the most commonly used cavity wall ties, it was decided to undertake an exploratory investigation for the purpose of ascertaining the following:

1. The strength (compressive and tensile) of the most commonly used cavity wall ties.
2. The mode of failure of the ties chosen for testing.
3. The influence which parameters such as different cavity width and length of mortar embedment have on the strength of the ties and on their mode of failure.
4. A performance comparison of the ties chosen for testing.
5. Any other pertinent information incidental to the above.

In addition, it was felt that this initial information would not only be used to make design recommendations or verify existing practices, but could also be utilized to establish what aspects or parameters were most important. This, in turn, would help future investigators in the design of other experiments.

Due to the fact that the testing equipment and all materials, except concrete blocks, were provided in imperial units, test results, dimensions and other figures are presented in imperial units. However, all pertinent summaries of information are also converted to SI (metric) units.

CHAPTER 2

MATERIALS

2.1 Introduction

The basic geometric and mechanical properties of the materials used in the experimental program are presented in the remainder of this chapter. In many cases the properties listed are those supplied by the manufacturers of the materials.

2.2 Cavity Wall Ties

The present market offers a very large number of cavity wall ties, some of which are adjustable. Although adjustable ties are quite popular with masons because they permit adjustments for differences in level between courses of masonry units, they were excluded from the experimental program, since they lead to many other additional parameters such as eccentricity, lack of alignment and looseness of fit. In addition, adjustable ties are not being considered in the proposed CSA Standard Can-3-370-M [9].

Since the non adjustable ties available in the market are many, testing every type of available tie was considered to be beyond the scope of this investigation; it was therefore decided to test only those ties whose use and application appeared to be and continue to be popular in the industry. The following ties were therefore chosen:

1. Z. Tie

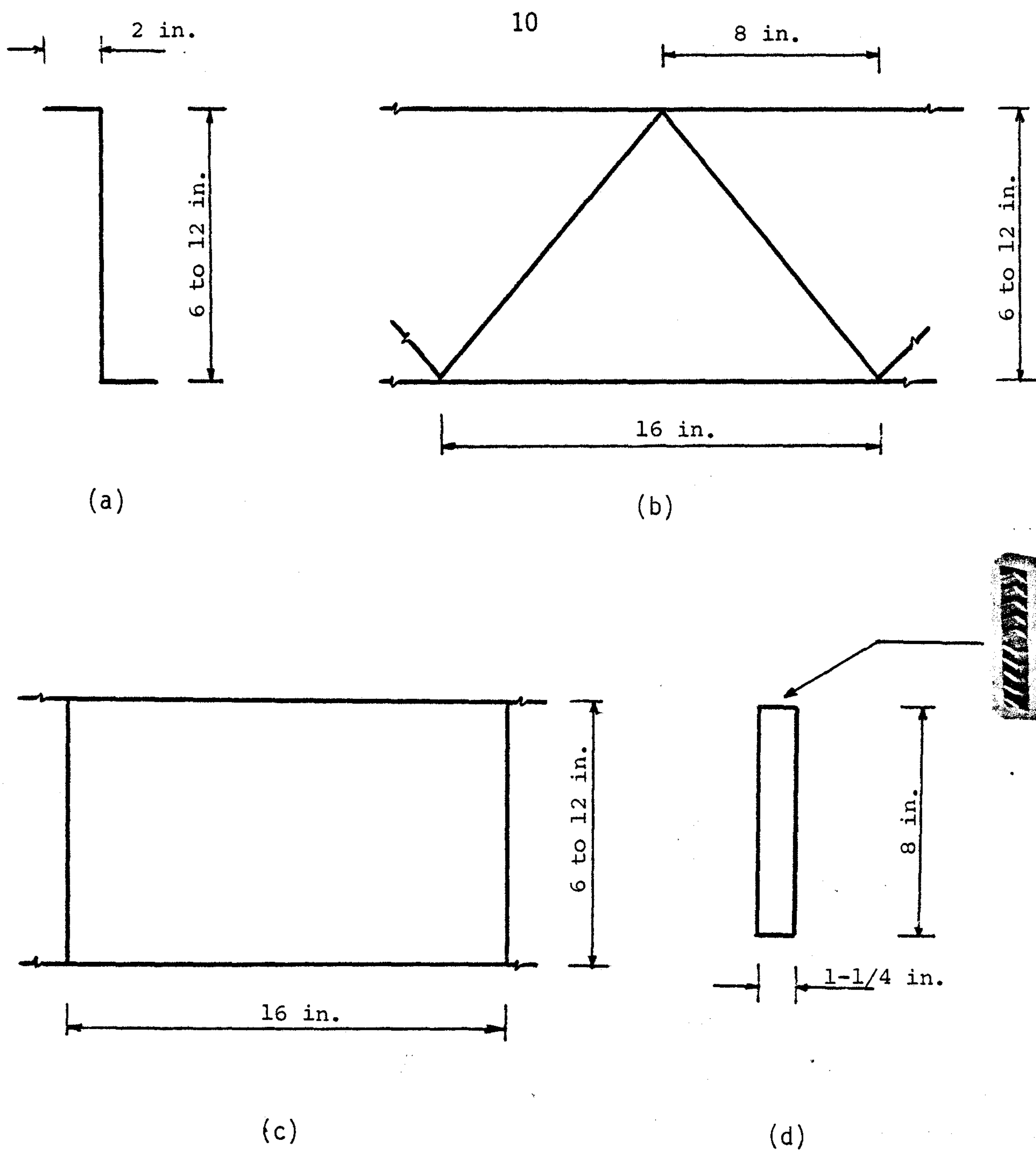
This type of tie is made with either 3/16 in. (4.76 mm) or 1/4 in. (6.35 mm) steel wire, has a leg length of 2 in. (51 mm) and comes in length ranging from 6 in. (152 mm) to 12 in. (305 mm). The 3/16 in. (4.76 mm) diameter tie was selected for testing, since it is the maximum size of wire permitted in a 3/8 in. (10 mm) mortar joint, (See Fig. 2.1 a).

2. Truss Tie

A truss tie is a continuous metal tie which is normally used as horizontal joint reinforcement between courses of masonry units. However, this tie can be and is often utilized as a cavity wall tie. Ties of this type are available for wall thicknesses ranging in size from 8 in. (203 mm) to 16 in. (406 mm) and are classified as "Standard" (No. 9 ga. side rods x No. 9 ga. cross rods; "Heavy Duty" (3/16 in. (4.76 mm) side rods x No. 9 ga. cross rods); and "Extra Heavy Duty" 3/16 in. (4.76 mm) side rods and cross rods). The cross rods are continuous and are flush welded to the side rods at 8 in. (203 mm) spacings. The standard and heavy duty types are the most commonly used and since both of them have No. 9 ga. cross rods, the standard type was selected for testing, (See Fig. 2.1 b).

3. Ladder Tie

This type of tie is also a continuous metal tie used normally as horizontal joint reinforcement between courses of masonry units. Ladder ties are available for wall thicknesses ranging in size from 4 in. (102 mm) to 16 in. (406 mm) and are classified in the same manner as truss ties. The cross rods are perpendicular to the side



(a) 3/16 in. (4.76 mm) Dia. Z Tie
(b) No 9 Ga. Truss Tie
(c) No 9 Ga. Ladder Tie
(d) No 24 Ga. Corrugated Tie

Note:
1 in.= 25.4 mm

Fig. 2.1 TIES CHOSEN FOR TESTING.

rods and are welded onto the top of the side rods at 16 in. (406 mm) spacings. As for the truss tie the standard ladder tie was selected for testing, (See Fig. 2.1 c).

(Note: Although Z, truss and ladder ties were also available with a moisture drip they were excluded from the experimental program. It was felt, in fact, that the claimed advantages of preventing moisture flow along the ties were more than offset by the loss of strength and stiffness caused by the moisture drip. Furthermore, the presence of the drip creates a potential durability problem due to the disruption of the galvanizing. It has also been found that mortar droppings tend to fill the moisture drip and transmit water anyway.)

4. Corrugated Metal Tie

There are many types of corrugated metal ties in the market with different proprietary deformations. The type that was considered for testing is available in two sizes; No. 28 gauge (7/8 in. (22 mm) wide and 7 in. (178 mm) long) and No. 24 gauge (1¼ in. (32 mm) wide and 8 in. (203 mm) long. The No. 24 gauge appears to be the most popular and was therefore chosen for testing, (See Fig. 2.1 d).

2.3 Properties of Steel Wire

The steel wire used in the manufactuing of the Z, truss and ladder ties complies with the requirements of CSA G.30.3 and ASTM A82 for cold drawn steel wire. The physical and mechanical properties of the wire are listed in Table 2.1.

TABLE 2.1

PROPERTIES OF STEEL WIRE

(MANUFACTURERS INFORMATION)

No. 9 gauge wire	: 0.1443 in. (3.67 mm) diamater
3/16 in. wire	: 0.1875 in. (4.76 mm) diameter
Steel tensile strength	: 80,000 psi (551.6 MPa)
Steel yield point	: 70,000 psi (482.6 MPa)
Finish	: Class 1 mill galvanized (CSA B12 and ASTM A 116-CL1).

2.4 Concrete Blocks

Two block sizes, 140 mm (5.5 in.) and 190 mm (7.5 in.)nominal thickness, were used throughout the test program. Both blocks contained two pear shape hollow cores, the nominal height and length for both of them were 190 mm (7.5 in.) and 390 mm (15.4 in.) respectively. The 140 mm block had a face shell and web thickness of 25 mm (1 in.), the 190 mm block instead, had a face shell thickness of 32 mm. (1.26 in.) and a web thickness of 25 mm. (1 in.). These types of blocks had been previously tested at McMaster University [11]. Their pertinent properties are listed in Table 2.2.

TABLE 2.2

PROPERTIES OF CONCRETE BLOCKS

Compressive strength of half block tested flatwise	: 3,450 psi (23.8 MPa) on net area
Splitting tensile strength	: 270 psi (1.9 MPa)
Initial rate of absorption	: 10 gm./30 in.^{2}/min.(0.52 kg / m^2 min.)
Net to gross area ratio	: 0.59 for 140 mm block 0.54 for 190 mm block

2.5 Clay Bricks

Eight in. (203 mm) x 3-5/8 in. (92 mm) x 2¼ in. (57 mm) clay bricks were used in the test program. The bricks had three circular hollow cores and the properties listed in Table 2.3.

TABLE 2.3

PROPERTIES OF CLAY BRICKS

Compressive strength	: 18.7 Ksi (128.9 MPa)
Flexural tensile strength	: 1.72 Ksi (11.9 MPa)
Initial rate of absorption	: 37.5 gm./30 in.^{2}/min. (1.94 kg / m^2 min.
Net to gross area ratio	: 0.82

2.6 Mortar

Type S mortar, which is the most popular type for structural work, conforming to CSA Standard A 179 was used throughout the experimental program. Portland cement type 10 and lime were used as cementitious materials. The mortar proportions by volume with the weight shown in brackets are listed in Table 2.4.

TABLE 2.4

TYPE S MORTAR PROPORTIONS

CEMENT	LIME	SAND	WATER
1	0.5	4.0	
(1)	(0.21)	(4.24)	(0.9)

For better control, the proportions were actually measured by weight rather than by volume. Three 2 in. (51 mm) mortar cubes were cast for each mortar batch. The cubes were air cured in the laboratory under the same conditions as the tie test specimens. Twenty one cubes were tested yielding an average compressive strength of 2,067 psi (14.3 MPa) with a coefficient of variation of 12 % .

CHAPTER 3

TEST SPECIMENS

3.1 Introduction

All test specimens were carefully fabricated on the floor of the Applied Dynamics Laboratory at McMaster University, (See Fig. 3.1). When the mortar had gained sufficient strength to allow the movement of the specimens, they were stock-piled in the laboratory and air cured for a period of 28 days.

Five specimens were manufactured for each specimen set. It was felt, in fact, that a replication of five was a compromise between statistical considerations and practical limitations. The particulars relating to the choice of the different test specimens are reported in the following sections. Testing procedures are described in the next chapter.

3.2 Z Tie Specimens

A total of thirty-five specimens were constructed using Z Ties. Ten specimens were prepared for the compression tests and twenty-five for the tension tests.

1. Z Tie Compression Specimens

Figure 3.2 shows the Z tie compression specimens with pertinent dimensional data. The specimens were constructed using 3/16 in. (4.76 mm) Z ties, 190 mm (7.5 in.) blocks and 3-5/8 in. (92 mm) bricks.

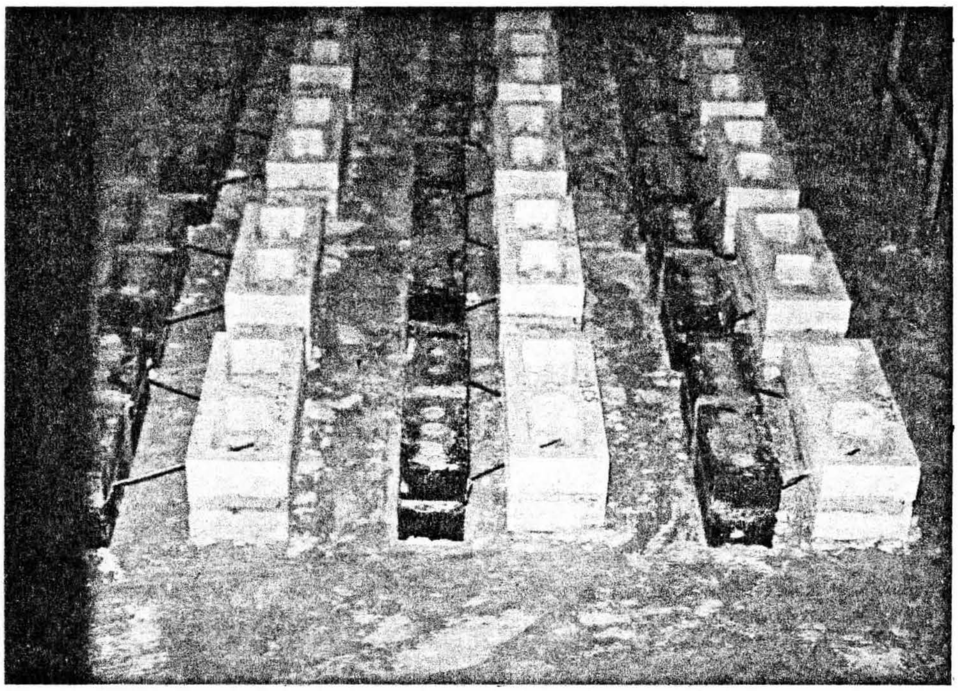
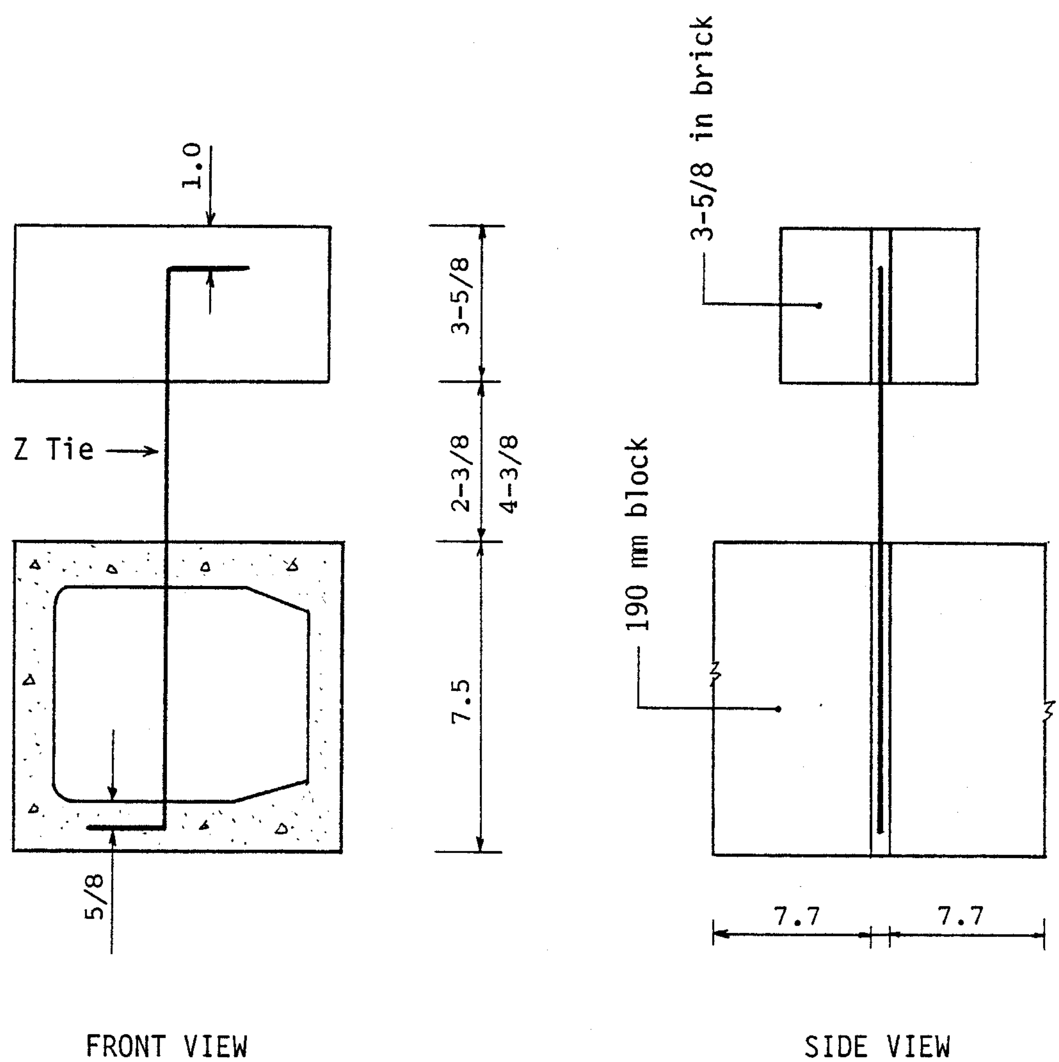


Fig. 3.1 SPECIMENS ON THE FLOOR OF THE APPLIED DYNAMICS LABORATORY AT McMASTER UNIVERSITY.



Note : All dimensions in inches , 1 in. = 25.4 mm

Fig. 3.2 Z TIE COMPRESSION SPECIMENS

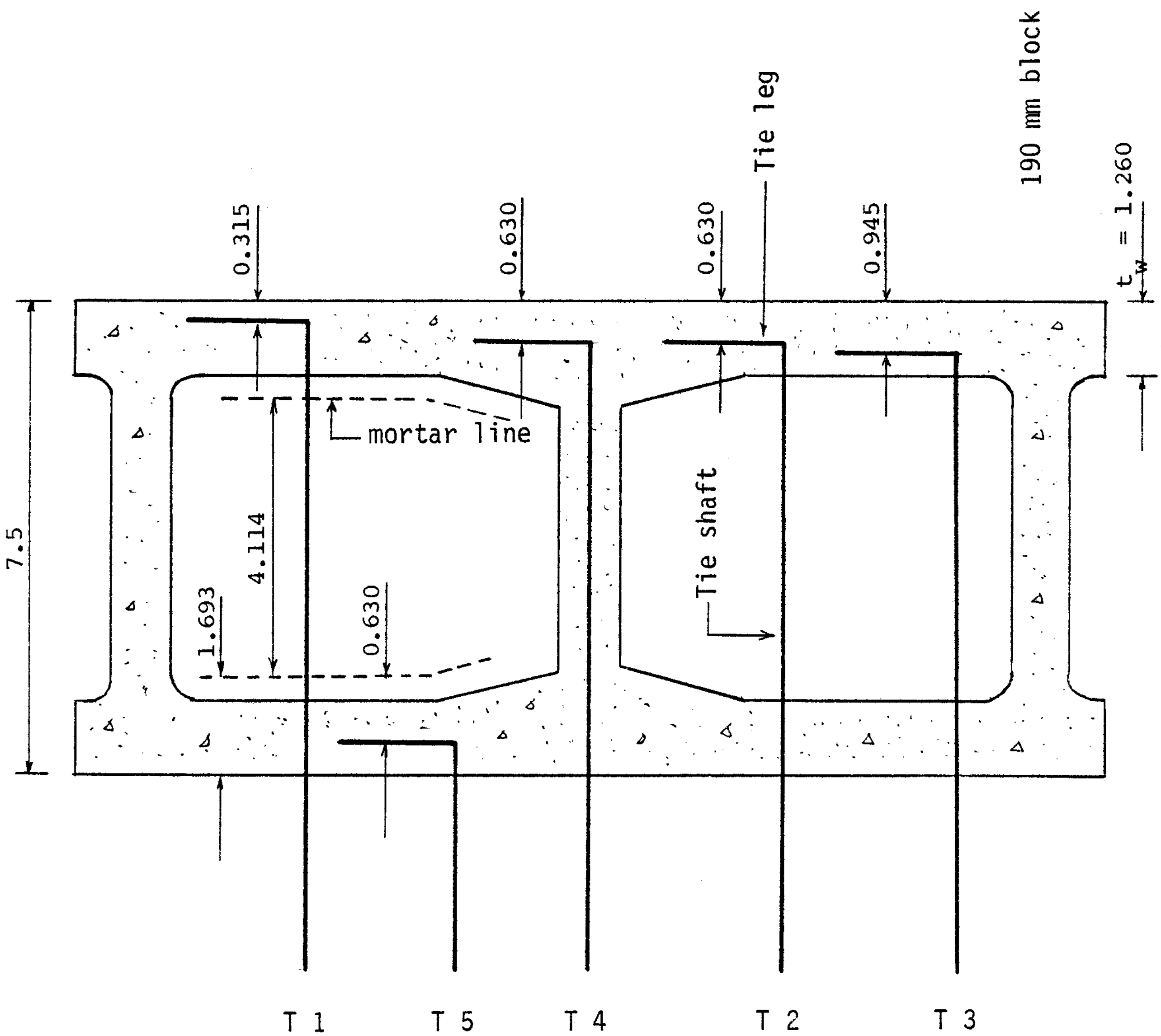
Five specimens were constructed with a 2-3/8 in. (60 mm) cavity space and another 5 with a 4-3/8 in. (111 mm) cavity space. All specimens were constructed with 3/8 in. (10 mm) mortar joint. Particular care was taken to position the tie in the center of the mortar joint and to locate it accurately in the cross section.

As can be seen in Figure 3.2, the Z tie was positioned across the void of the block and not across the web. This represents the worst installation condition for this tie. A 5/8 in. (16 mm) cover on the block face shell was used; being the minimum cover specified in CSA Standard S-304-1977. The block was cut longitudinally to decrease the weight of the specimen and thus facilitate handling.

2. Z Tie Tension Specimens

Figure 3.3 shows the Z tie tension specimens with pertinent dimensional data. The specimens were constructed using 3/16 in. (4.76 mm) Z ties and 190 mm (7.5 in.) blocks. The bricks were eliminated since it was obvious that the weakest resistance in tension occured in the block (where the tie had the shortest length embedment) and not in the brick. The Z ties were specially made to have only one 2 in. (51 mm) leg and a length of 24 in. (610 mm) to facilitate clamping of the free end of the tie in the testing machine. The block was cut in half longitudinally to decrease the weight of the specimen and facilitate its handling.

For the purpose of obtaining test data for various lengths of embedment 5 sets of 5 specimens each were constructed. Each set contained a tie with a chosen installation feature as described below and shown in Figure 3.3 The objective was to evaluate the influence of the range of possible tie embedment conditions.



Notes : All dimensions in inches , 1 in. = 25.4 mm
Half blocks were used for T1 , T2 , T3 , and T5
Full blocks were used for T4

Fig. 3.3 Z TIE TENSION SPECIMENS

T1 Set: 2 in. (51 mm) leg in outer face shell with tw/4 cover

T2 Set: 2 in. (51 mm) leg in outer face shell with tw/2 cover

T3 Set: 2 in. (51 mm) leg in outer face shell with 3/4 tw cover

T4 Set: Tie across block web with 2 in. (51 mm) leg in outer face shell with tw/2 cover

T5 Set: 2 in. (51 mm) leg in inner face shell with tw/2 cover

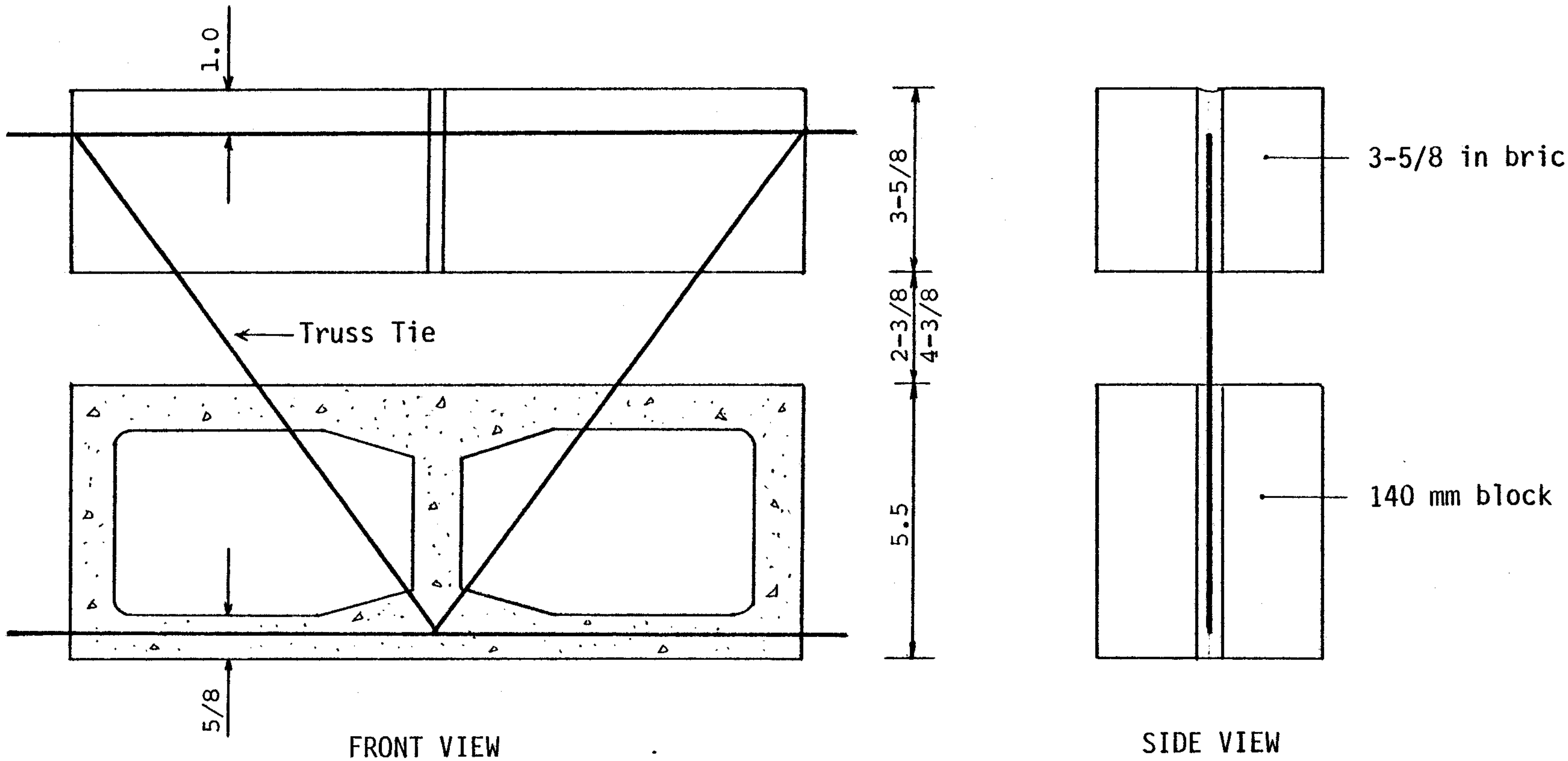
3.3 Truss Tie Specimens

1. Truss tie compression specimens

Figure 3.4 shows the truss tie compression specimens with pertinent dimensional data. The specimens were constructed using No. 9 ga. "Standard type" truss ties, 140 mm (5.5 in.) blocks and 3-5/8 in. (92 mm) bricks. Two brick lengths, with a generous thickness of mortar head joint, were required in order to accomodate the 16 in. (406 mm) panel length of the truss tie diagonal wires. For the purpose of reducing the weight of each specimen and facilitate its handling, the block was cut longitudinally at both the thicker and thinner ends to obtain two block slices of the same height as that of the bricks; i.e. 2¼ in. (57 mm). The block slices were then joined by the mortar joint. Five specimens were constructed with a 2-3/8 in. (60 mm) cavity space; another five specimens with a 4-3/8 in. (111 mm) cavity space. All specimens were constructed with 3/8 in. (10 mm) mortar bed joints.

2. Truss tie tension specimens

The truss tie tension specimens were constructed in exactly the same manner as the 2-3/8 in. (60 mm) cavity space compression spec-



Note : All dimensions in inches , 1 in. = 25.4 mm

Fig. 3.4 TRUSS TIE SPECIMENS

imens. A total of five specimens were constructed.

3.4 Ladder Tie Specimens

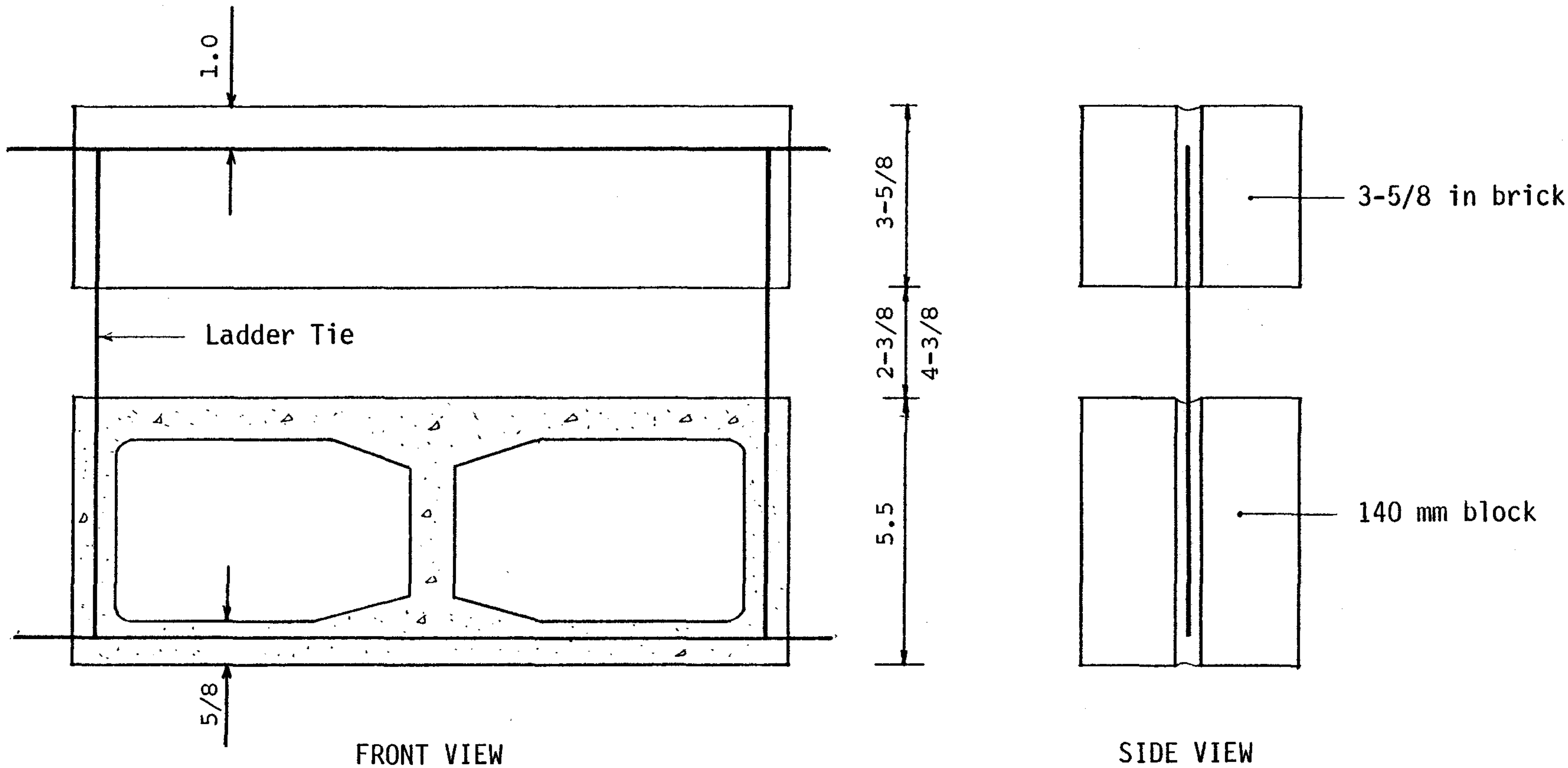
1. Ladder Tie compression specimens

Figure 3.5 shows the ladder tie compression specimens with pertinent dimensional data. The specimens were constructed using No. 9 ga. "Standard type" ladder ties, 140 mm (5.5 in.) blocks and 3-5/8 in. (92 mm) bricks. The blocks were cut longitudinally at both ends in the same manner and for the same purpose as previously described for the truss tie specimens. Five specimens were constructed with a 2-3/8 in. (60 mm) cavity space, another five specimens with a 4-3/8 in. (111 mm) cavity space. All specimens were constructed with 3/8 in. (10 mm) mortar bed joints.

It was also found that the distance between the cross rods of the ladder tie was greater than and did not coincide with the distance between the webs at each end of the block, (of course this problem would not exist in wall construction because of the thickness of mortar joints at each end of the block). To rectify this problem the longitudinal wires of the tie had to be cut, spliced and welded so that the cross rods coincided with the center of the block webs.

2. Ladder Tie Tension Specimens

The ladder tie tension specimens were constructed in exactly the same manner as the 2-3/8 in. (60 mm) cavity space compression specimens. A total of five specimens were constructed.



Note : All dimensions in inches , 1 in. = 25.4 mm

Fig. 3.5 LADDER TIE SPECIMENS

3.5 Corrugated Tie Specimens

1. Corrugated Tie Compression Specimens

Figure 3.6 shows the corrugated tie compression specimens with pertinent dimensional data. The specimens were constructed using No. 24 ga. 8 in. (203 mm) long corrugated ties, 190 mm (7.5 in.) blocks and 3-5/8 in. (92 mm) bricks. The blocks were cut longitudinally in the manner and for the purpose described under truss tie specimens.

In order to obtain test data for different lengths of embedment, cavity space and for the effect of mortar on one versus two sides of the tie, five sets of five specimens each were constructed. Each set contained a tie with a chosen installation feature as described below and as shown in Figure 3.6.

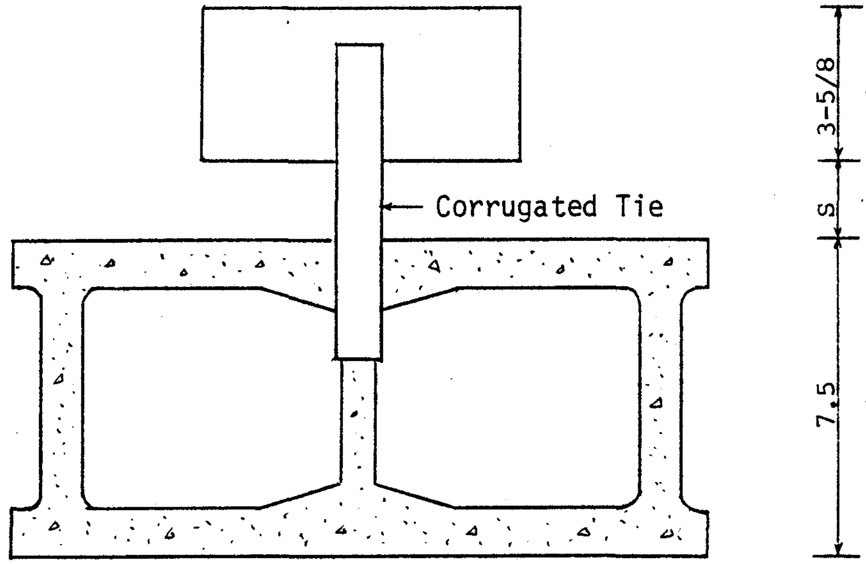
C1 Set : 3/4 in. (19 mm) cavity, tie on web of block, equal 3-5/8 in (92 mm) embedment length in block and brick, mortar on both sides of tie.

C2 Set : 3/4 in. (19 mm) cavity, tie on web of block, equal 3-5/8 in.(92mm) embedment length in block and brick, mortar on one side of tie.

C3 Set : 3/4 in. (19 mm) cavity, tie crossing face shell of block, equal 3-5/8 in. (92 mm) embedment length in block and brick, mortar on both sides of tie.

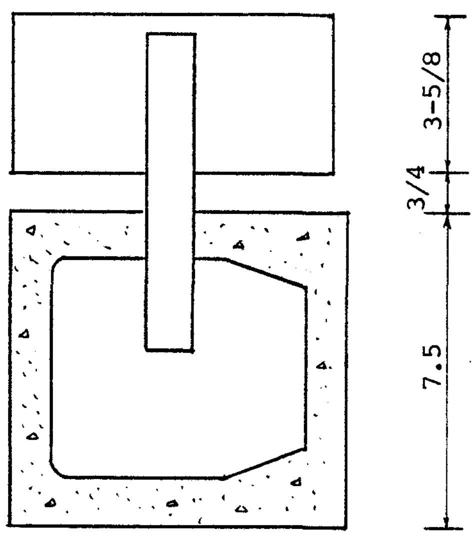
C4 Set : 2-3/8 in. (60 mm) cavity, tie on web of block, equal 2-13/16 in. (71 mm) embedment length in block and brick, mortar on both sides of tie.

C5 Set : 4-3/8 in. (111 mm) cavity, tie through web of block, equal 1-13/16 in. (46 mm) embedment length in block and brick, mortar on both sides of tie.

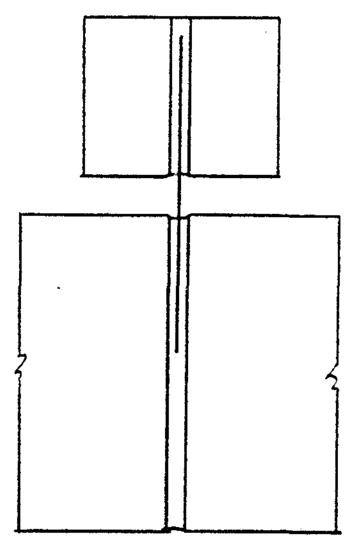


SPECIMENS C1, C2, C4, C5 (FRONT VIEW)

C1 : S = 3/4 in. mortar on both sides of tie
C2 : S = 3/4 in. mortar on one side of tie only
C4 : S = 2-3/8 in. mortar on both sides of tie
C5 : S = 4-3/8 in. mortar on both sides of tie



SPECIMEN C3 (FRONT VIEW)



SIDE VIEW (ALL SPECIMENS)

Note : All dimensions in inches , 1 in. = 25.4 mm

Fig. 3.6 CORRUGATED TIE COMPRESSION SPECIMENS

The fabrication of the specimens with mortar on one side only (Set C2) originated from the fact that quite often masons place the corrugated tie on the masonry units prior to the spreading of the joint mortar, Consequently the ties are installed in the field with mortar on one of their sides only.

2. Corrugated Tie Tension Specimens

Figure 3.7 shows the corrugated tie tension specimens with pertinent dimensional data. The specimens were constructed using No. 24 ga. 8 in. (203 mm) long corrugated ties, and 190 mm (7.5 in.) blocks. The bricks were eliminated since it was obvious that the weakest resistance in tension occurred in the block (where the tie had the shortest length of embedment) and not in the brick.

In order to obtain test data for different conditions of installation four sets of five specimens each were constructed. The features of each set are described below and shown in Figure 3.7.

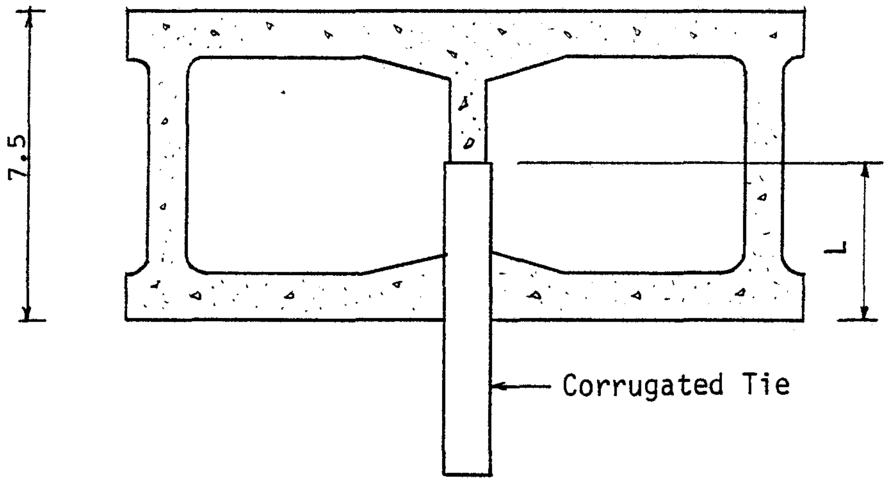
T1 Set : 4 in.(102 mm) embedment on web of block, mortar on both sides of tie.

T2 Set : 2 in. (51 mm) embedment on web of block, mortar on both sides of tie.

T3 Set : tw embedment (tw = thickness of face shell , 32 mm (1.26 in.) for 190 mm block) on face shell of block, mortar on both sides of tie.

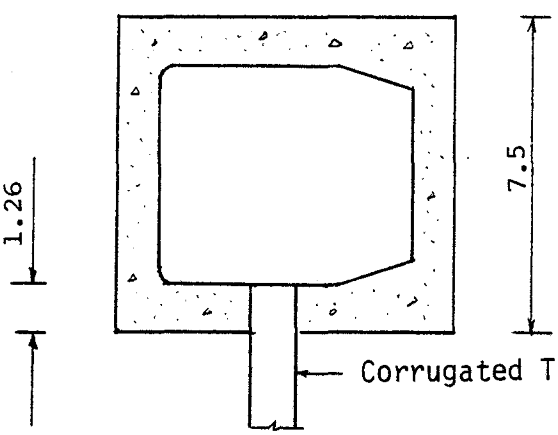
T4 Set : tw embedment on face shell of block, mortar on one side of tie.

The fabrication of the specimens in set T4, where the ties had mortar on one of their sides only, originated from the same reasons as



SPECIMENS T1, T2 (FRONT VIEW)

T1 : L = 4 in. , mortar on both sides of tie
T2 : L = 2 in. , mortar on both sides of tie



SPECIMENS T3, T4 (FRONT VIEW)

T3 : mortar on both sides of tie
T4 : mortar on one side of tie only

Note : All dimensions in inches , 1 in. = 25.4 mm

Fig. 3.7 CORRUGATED TIE TENSION SPECIMENS discussed under the preceding section.

3.6 Summary

The test program outlined above was thought to be sufficiently thorough to provide some initial data that would be of benefit to design code committees. Furthermore, the program was designed to explore several parameters in order to identify those which most influence the behaviour of wall ties. The results of the test are presented and discussed in Chapter 4.

CHAPTER 4

TEST PROCEDURE AND RESULTS

4.1 Test Procedure

1. Compression Tests

All compression tests were carried out using a 120,000 lbs. (533760 N) Tinius-Olsen Universal Testing Machine. Figures 4.1 and 4.2 show two typical compression test set-ups. The load was applied through steel plates which covered the bearing surface of each type of specimen tested. Three quarter inch (19 mm) plywood strips were placed in direct contact with the brick and block ends of the specimen on both sides of the mortar joint. These acted as capping material and incorporated sufficient space for the ties to push through the mortar, in the event of such a type of failure.

No special provision was taken against sideways effects, since it was felt that the friction developed at each end of the specimen was sufficient to prevent any lateral movement before failure. Each specimen was carefully placed in the testing machine and accurately centered so that the applied load was concentric with the axis of the tie. A small load of approximately 50 lbs. (222 N), was then applied to accomodate any slack within the test head of the machine. When necessary the specimen was re-adjusted and metal shims used to ensure the axial and symmetrical application of the test load. The

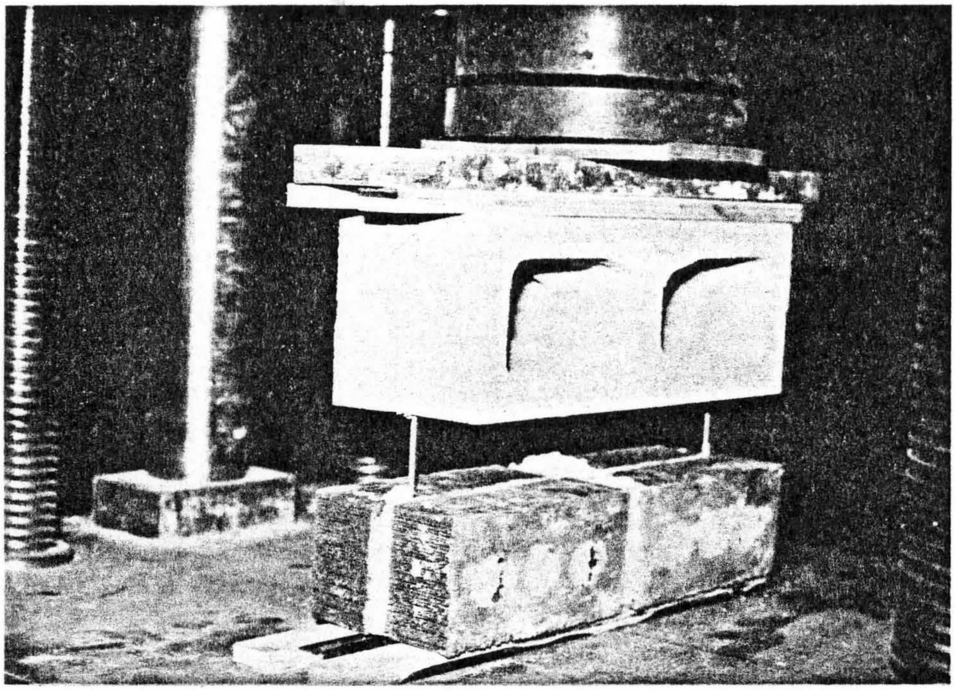


Fig. 4.1 COMPRESSION TEST SET-UP FOR LADDER TIE

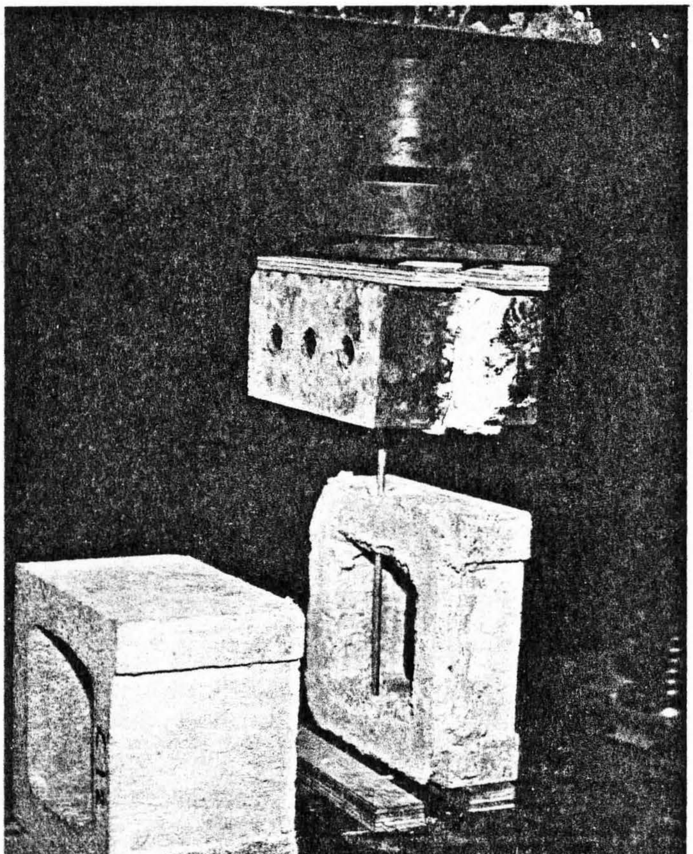


Fig. 4.2 COMPRESSION TEST SET-UP FOR Z TIE

load was then increased slowly, continuously and without shocks until the needle of the scale stopped rising. The reading on the scale was taken and recorded as the maximum load carried by the specimen. A careful visual inspection of the specimen followed to identify the type of failure and whether that failure had occurred solely in the tie, the mortar or in a combination of these. Following this, additional load was applied to magnify deformations.

Two Z tie specimens were tested with compression forces on the bed joints to study the effect of compression in the wall on the capacity of the ties. The pressure was measured using a load cell and was applied to the blocks, through steel plates and plywood capping, by tightening the nuts at each end of a threaded rod passing through the core of the block(See Figure 4.3).

2. Tension Tests

All tension tests were carried out with the same testing machine used for the compression tests. Figures 4.4 and 4.5 show the tension test set-ups for the truss tie and Z tie respectively.

The testing machine, in addition to the loading bench, has a fixed platform at the top, and a moving platform below the fixed one. By fastening one end of the specimen to the fixed platform, the other end to the moveable platform and then lowering the latter, a tensile force is applied to the specimen. For the truss tie and ladder tie tests, the tension force was applied from the cavity ends of the specimens, outwards through a combination of steel plates, rods and angles as shown in Figure 4.4. The Z ties and corrugated ties were ten-

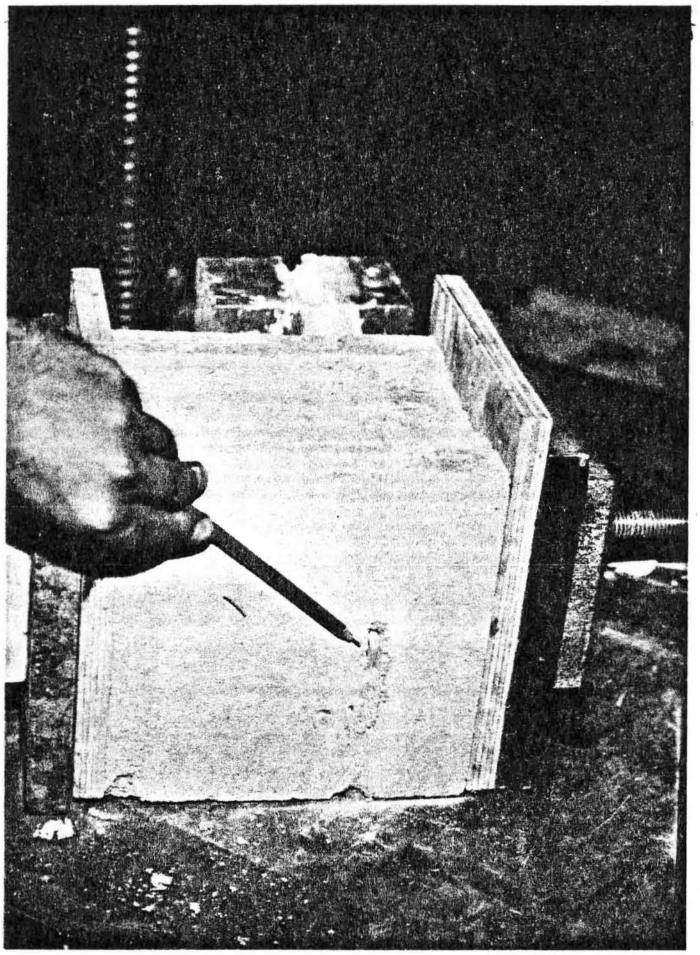


Fig. 4.3 Z TIE COMPRESSION SPECIMEN WITH SET-UP FOR APPLICATION OF COMPRESSION NORMAL TO THE MORTAR JOINT BETWEEN THE BLOCKS

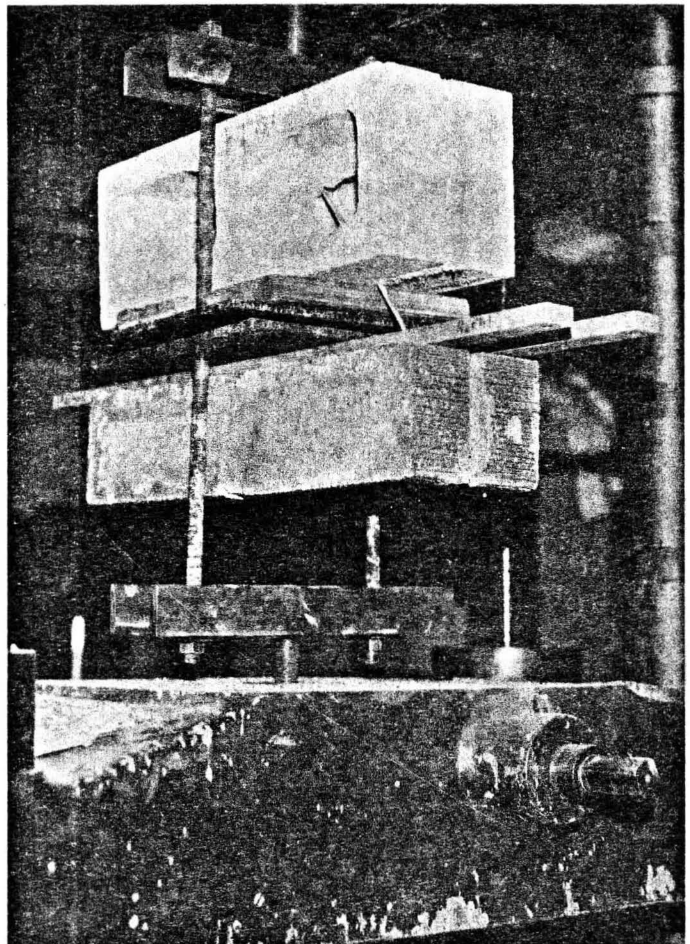


Fig. 4.4 TENSION TEST SET-UP FOR TRUSS TIE

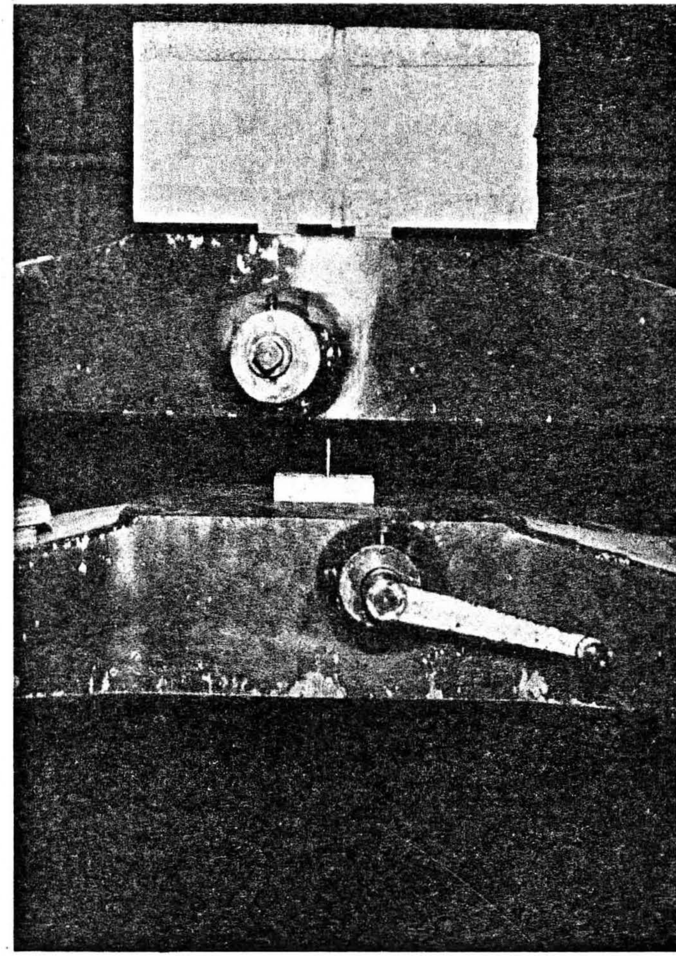


Fig. 4.5 TENSION TEST SET-UP FOR Z TIE

sioned by placing the specimens over the fixed platform (with the ties) through it), clamping the free end of the tie in the jaws of the moveable platform and then lowering the latter. Three quarter inch thick (19mm) plywood was used to distribute the load over the loaded surfaces. As was the case for the compression tests, care was taken to properly align the specimens, and make adjustments to ensure that the applied load was concentric with the axis of the tie. The overall test procedure followed the same steps used in the compression tests.

4.2 Test Results for 3/16 in (4.76 mm) Z Ties

1. Compression Tests

Table 4.1 lists the compression test results for the 3/16 in. (4.76 mm) diameter Z ties. As indicated in the table, the mode of failure for all of the tests was push through of the Z tie at the block end.

It is important to note that when the ties (Z ties and all other types) were received from the manufacturer, they were found to be coated by some kind of lubricating compound which obviously would be expected to have had an adverse effect on their bonding resistance.

Since the failure was in the mortar joint, it is not surprising that increasing the cavity width from 2-3/8 in. (60 mm) to 4-3/8 in. (111 mm), only resulted in an 11% decrease in the capacity of the tie. It should be pointed out that the average failure load due to push through of the tie is lower than the predicted theoretical buckling load of the tie itself. Assuming, in fact, a 3/16 in. (4.76 mm) compression member, 2-3/8 in. (60 mm) long, partially fixed at both ends, (i.e. assume an effective length of 80% of the actual length), and fu=

TABLE 4.1

3/16 in. Z TIE : COMPRESSION TEST RESULTS

Specimen	Cavity (in)	Load (lbs)	Mode of failure	Data + lbs (N)
C 1.1	2-3/8	750	Push through of tie from mortar joint at blocks, for all specimens.	M = 737 (3278) V = 16.7 %
C 1.2	"	575		
C 1.3	"	920 *		
C 1.4	"	875		
C 1.5	"	750		
C 2.1	4-3/8	645	As above .	M = 660 (2936) V = 8.9 %
C 2.2	"	590		
C 2.3	"	900 *		
C 2.4	"	730		
C 2.5	"	675		

* Specimen C 1.3 was tested with a pressure of 10 psi on the gross area of block.

* Specimen C 2.3 was tested with a pressure of 86 psi on the gross area of block.

* Both excluded from mean and coefficient of variation.

\+ M = Mean , V = Coefficient of variation.

80,000 psi (552 MPa) the predicted ultimate buckling load, according to the Rankine Strut Formula, is 1,520 lbs. (6761 N). This load is 2.06 times greater than the actual average failure load of the tie in the 2-3/8 in. (60 mm) cavity.

Two specimens, namely C 1.3 and C 2.3, were tested with normal compression to the block's mortar joints, to study the effect of compression in the wall on the capacity of the ties. The application of the 10 psi (69 K Pa) and 86 psi (593 K Pa) compression stresses normal to the bed joints, resulted in strength increases of 25% and 36% respectively, when compared to the means for the other four results. While such a limited sample cannot be taken as definite evidence, it does seem apparent that compressing the mortar bed joint should give greater resistance to push through of the tie.

2. Tension Tests

Table 4.2 lists the tension test results for the 3/16 in (4.76mm) diameter Z ties. As indicated in the table, the mode of failure for all of the tests was pull out of the tie from the mortar joint between the blocks.

An examination of Table 4.2 and Figure 3.3 clearly reveals that the position of the tie on the block, and the length of mortar embedment along the tie had a definite influence on the tensile resistance of the Z ties. For the purpose of evaluating this influence Table 4.3 was prepared. In this table, the length of the mortar embedment for each specimen set, was calculated by taking into account the width of the excess mortar inside the void of the block. This excess width was taken to be equal to 11 mm (0.433 in.), being the difference in face shell thickness

TABLE 4.2

3/16 in. Z TIE : TENSION TEST RESULTS

Specimen	Cavity (in)	Load (lbs)	Mode of failure	Data * lbs (N)
T 1.1	N/A	1,115		
T 1.2	"	1,235	Pull out of tie from	M = 1,444
T 1.3	"	1,435	mortar joint at blocks,	(6423)
T 1.4	"	1,720	for all specimens.	V = 19.0 %
T 1.5	"	1,715		
T 2.1	N/A	1,075		
T 2.2	"	1,045		M = 1,168
T 2.3	"	1,215	As Above	(5195)
T 2.4	"	1,245		V = 8.6 %
T 2.5	"	1,260		
T 3.1	N/A	750		
T 3.2	"	745		M = 759
T 3.3	"	725	As Above	(3376)
T 3.4	"	700		V = 9.0 %
T 3.5	"	875		
T 4.1	N/A	1,700		
T 4.2	"	1,560		M = 1,777
T 4.3	"	2,025	As Above	(7904)
T 4.4	"	2,140		V = 16.5 %
T 4.5	"	1,460		
T 5.1	N/A	275		
T 5.2	"	350		M = 347
T 5.3	"	290	As Above	(1543)
T 5.4	"	390		V = 19.0 %
T 5.5	"	430		

* M = Mean , V = Coefficient of variation

TABLE 4.3

LENGTH OF EMBEDMENT VERSUS FAILURE LOAD FOR

Z TIE TENSION SPECIMENS

SPECIMEN SET	LENGTH OF EMBEDMENT IN. (mm)	FAILURE LOAD LBS.(N).
T 1	3.071 (78)	1,444 (6423)
T 2	2.756 (70)	1,168 (5195)
T 3	2.441 (62)	759 (3376)
T 4	6.870 (174)	1,777 (7904)
T 5	0.630 (16)	347 (1543)

between the top and bottom of the 190 mm (7.5 in.) block. Therefore, the total width of the mortar joint was taken to be equal to the thickness of the face shell at the top of the block, or 43 mm (1,693 in.), See also Figure 3.3. An examination of the figures in Table 4.3, clearly reveals that, as long as the leg of the Z tie was placed on the outer face shell, any small increase in the length of embedment resulted in a substantial increase in the tensile resistance of the tie.

We can also utilize the above table to study the strength contribution of mortar embedment along the tie shaft. Considering specimens T2 and T4, both ties had the same mortar cover over their legs. The only difference between these two ties was the length of mortar embedment along the tie shaft. Tie T2 crossed the void of the block, while tie T4 rested on the web of the block. Tie T4 had, therefore, 4.114 in. (104 mm) of extra embedment along its shaft when compared with tie T2. The difference in ultimate load between tie T4 and tie T2 was 1,777 lbs. - 1,168 lbs. = 609 lbs. (2709 N), or 148 lbs. (658 N) per extra inch of mortar embedment along the tie shaft. It can be seen from this that the strength contribution due to bonding along the tie shaft was not substantial, and that the major tensile resistance of the tie depended on the anchorage force developed by the shear resistance of the mortar at the leg of the tie. It is also useful to note that the theoretical ultimate tensile resistance of a 3/16 in. (4.76 mm) dia. wire, assuming a minimum fu = 80,000 psi (551.6 M Pa), is 2,209 lbs. (9826 N). This figure is quite close to the test result for specimen T 4.4 which failed at 2,140 lbs. (9519 N).

4.3 Test Results for No. 9 Ga. Truss Tie

1. Compression Tests

Table 4.4 lists the compression test results for the No. 9 ga. truss tie. As indicated in the table, the mode of failure for all of the tests was buckling of one diagonal wire across the cavity. Increasing the cavity width from 2-3/8 in. (60 mm) to 4-3/8 in. (111 mm) resulted in a 25% decrease in the capacity of the tie. The actual buckling load for one diagonal wire was lower than the theoretical one. This can be attributed to two reasons: The possible uneven distribution of load between the two diagonal wires due to unavoidable imperfections of the specimens and the fact that the diagonal wire was not straight, but had a compound curvature with an inflection point at mid-length which was probably produced by the manufacturing process. Buckling always occured above or below the inflection point of the diagonal wire and took place suddenly.

2. Tension Tests

Table 4.5 lists the tension test results for the No. 9. ga. truss tie. As indicated in the table, the mode of failure of the ties in tension was not consistent for all of the tests. Specimens T 1.1 and T 1.2 in fact, failed when the intersection of the diagonal wire and the longitudinal wire pulled out from the mortar joint between the bricks. The pull-out failure of these two specimens could well be attributed to the lack of continuity of the tie past the side end of the brick. (See also Figure 3.4). In specimen T 1.3, the weld at the intersection of the diagonal and longitudinal wires at the brick, broke suddenly. In specimen T 1.4 the diagonal wire broke suddenly across the cavity. The actual

TABLE 4.4

No 9 Ga. TRUSS TIE : COMPRESSION TEST RESULTS

Specimen	Cavity (in)	Load (lbs)	Mode of Failure	Data + lbs (N)
C 1.1	2-3/8	1,060		
C 1.2	"	905	Buckling on one diagonal wire within the cavity, for all specimens.	M = 901
C 1.3	"	810		(4008)
C 1.4	"	840		V = 10.8%
C 1.5	"	890		
C 2.1	4-3/8	575		
C 2.2	"	650		M = 680
C 2.3	"	820	As Above	(3025)
C 2.4	"	680		V = 13.0%
C 2.5	"	675		

TABLE 4.5

No 9 Ga. TRUSS TIE : TENSION TEST RESULTS

Specimen	Cavity (in)	Load (lbs)	Mode of Failure	Data + lbs (N)
T 1.1	2-3/8	1,115	Pull out of wire at brick	
T 1.2	"	1,390	"	M = 1,330
T 1.3	"	1,400	Weld broke at brick	(5916)
T 1.4	"	1,415	Dia. wire broke across cavity.	V = 10.8%
T 1.5	"	N.G.*		

* Sidesway occured

\+ M = Mean , V = Coefficient of variation.

tensile resistance of the diagonal wire in specimen T 1.4 was 75% lower than the theoretical one for a No. 9 ga. wire.

4:4 Test Results for No. Ga. Ladder Tie

1. Compression Tests

Table 4.6 lists the compression test results for the No. 9 ga. ladder tie. As indicated in the table, with the exception of specimen C 2.5, all ladder tie compression specimens failed by buckling of one cross wire across the cavity. Buckling always occured at mid-height within the cavity and took place suddenly. The actual buckling load for one cross wire was found to be lower than the theoretical one. Part of this could possibly be attributed to the uneven distribution of load between the two cross wires, due to unavoidable imperfections of the specimens. Specimen C 2.5 failed by the push through of the cross wire at the block, this mode of failure can be attributed to the lack of continuity of the longitudinal wire past the side end of the specimen. Increasing the cavity width from 2-3/8 in. (60 mm) to 4-3/8 in. (111 mm) resulted in a 27% decrease in the capacity of the tie.

2. Tension Tests

Table 4.7 lists the tension test results for the No. 9 ga. ladder tie. As indicated in the table, all ladder tie tension specimens failed when the intersection of the cross wire and the longitudinal wire pulled out from the mortar joint between the blocks. This mode of failure can be attributed to the lack of continuity of the longitudinal wire past the side of the specimen. The predicted ultimate tensile resistance of two No. 9 ga. wires is 97% in excess of the average failure load.

TABLE 4.6

No 9 Ga. LADDER TIE : COMPRESSION TEST RESULTS

Specimen	Cavity (in)	Load (lbs)	Mode of Failure	Data * lbs. (N)
C 1.1	2-3/8	1,510	Buckling of cross wire within cavity, for all specimens.	M = 1,474 (6556) V = 11.0%
C 1.2	"	1,355		
C 1.3	"	1,620		
C 1.4	"	1,625		
C 1.5	"	1,260		
C 2.1	4-3/8	1,015	Buckling of cross wire	M = 1,081 (4808) V = 7.3%
C 2.2	"	980	"	
C 2.3	"	1,160	"	
C 2.4	"	1,130	"	
C 2.5	"	1,120	Push through at block	

TABLE 4.7

No 9 Ga. LADDER TIE : TENSION TEST RESULTS

Specimen	Cavity (in)	Load (lbs)	Mode of Failure	Data * lbs (N)
T 1.1	2-3/8	1,085	Pull out at block, for all specimens	M = 1,323 (5885) V = 16.8%
T 1.2	"	1,395		
T 1.3	"	1,660		
T 1.4	"	1,300		
T 1.5	"	1,175		

* M = Mean , V = Coefficient of variation.

4.5 Test Results for No. 24 Ga. Corrugated Tie

1. Compression Tests

Table 4.8 lists the compression test results for the No. 24 ga, corrugated tie. As indicated in the table, all corrugated tie compression specimens failed by buckling of the tie within the cavity. Considering the installation features as described in Section 3.5, as shown in Figure 3.6 and the test results presented in Table 4.8, the following observations were made:

a) 3/4 in. (19 mm) cavity, Specimen sets C 1, C 2 and C3.

-The strength of a tie, placed across the web of the block, is not affected by whether or not the mortar is placed on one or two sides of the tie, (specimen sets C1 and C2.)

-The strength of a tie, placed across the inner face shell of the block with mortar on both sides, is more or less the same as that of a tie placed across the web of the block, (specimen set C-3); even though the latter has a much longer length of embedment than the former.

b) 2-3/8 in. (60 mm) and 4-3/8 in. (111 mm) cavities, Specimen sets C4 and C5.

-The strength of the tie is largely dependent on the cavity width. Increasing the cavity width from 2-3/8 in (60 mm) to 4-3/8 in. (111 mm) resulted in a 63% decrease in the capacity of the tie.

2. Tension Tests

Table 4.9 lists the tension test results for the No. 24 ga. corrugated tie. As indicated in the table, the mode of failure for all

TABLE 4.8

NO. 24 GA. CORRUGATED TIE : COMPRESSION TEST RESULTS

Specimen	Cavity (in)	Load (lbs)	Mode of Failure	Data * lbs (N)
C 1.1[a]	3/4	400		
C 1.2	"	600	Buckling of tie within	M = 546
C 1.3	"	680	cavity, for all specimens	(2429)
C 1.4	"	600		V = 21.4%
C 1.5	"	450		
C 2.1[b]	3/4	415		
C 2.2	"	610		M = 532
C 2.3	"	475	As above	(2366)
C 2.4	"	510		V = 18.2%
C 2.5	"	650		
C 3.1[c]	3/4	410		
C 3.2	"	705		M = 608
C 3.3	"	810	As Above	(2704)
C 3.4	"	525		V = 25.5%
C 3.5	"	590		
C 4.1[a]	2-3/8	228		
C 4.2	"	229		M = 236
C 4.3	"	227	As Above	(1050)
C 4.4	"	206		V = 14.0%
C 4.5	"	292		
C 5.1[a]	4-3/8	75		
C 5.2	"	85		M = 88
C 5.3	"	82	As Above	(391)
C 5.4	"	110		V = 14.8%
C 5.5	"	90		

(a) Tie on block web, mortar on two sides of tie.
(b) Tie on block web, mortar on one side of tie.
(c) Tie crossing face shell of block, mortar on two sides of tie.
* M = Mean , V= Coefficient of variation.

TABLE 4.9

NO. 24 GA. CORRUGATED TIE : TENSION TEST RESULTS

Specimen	Cavity (in)	Load (lbs)	Mode of Failure	Data * lbs (N)
T 1.1 (a)	N/A	1,175		
T 1.2	"	1,035	Pull out of tie at block	M = 1,241
T 1.3	"	1,395	for all specimens	(5520)
T 1.4	"	1,390		V = 12.3%
T 1.5	"	1,210		
T 2.1 (b)	N/A	1,225		
T 2.2	"	1,205		M = 1,172
T 2.3	"	1,150	As Above	(5213)
T 2.4	"	1,330		V = 11.9%
T 2.5	"	950		
T 3.1 (c)	N/A	780		
T 3.2	"	750		M = 751
T 3.3	"	845	As Above	(3340)
T 3.4	"	800		V = 13.6%
T 3.5	"	580		
T 4.1 (d)	N/A	805		
T 4.2	"	870		M = 746
T 4.3	"	625	As Above	(3318)
T 4.4	"	790		V = 14.5%
T 4.5	"	640		

(a) Tie on block with 4 in. (102 mm) of embedment.
(b) Tie on block web with 2 in. (51 mm) of embedment.
(c) Tie crossing face shell of block, mortar on two sides of tie.
(d) Tie crossing face shell of block, mortar on one side of tie.
* M = Mean , V = Coefficient of variation.

of the tests was pull out of the tie from the mortar joint between the blocks. Considering the installation features as described in Section 3.5, as shown in figure 3.7, and the test results presented in Table 4.9, the following comments can be made:

a) Specimen sets T1 and T2, 4 in. (102 mm) versus 2 in. (51 mm) embedment on block web.

The average pull out resistance of set T2 was only 5.6% lower than that of set T1. A possible explanation for this could be that the mortar in the corrugations of the tie failed near the surface, before the tie elongated enough to develop bond stress further into the joint.

b) Specimen sets T3 and T4.

There was almost no difference in the average tensile resistance between the ties on the inner face shell of the block with mortar on one side, and those with mortar on two sides. A possible explanation for this could be that failure resulted from splitting along the mortar joint between the blocks.

CHAPTER 5

DISCUSSIONS AND CONCLUSIONS

5.1 Strength Comparison of Ties Tested

In order to make a comparison of the strength of the ties tested, it is necessary to take into account the tie spacings, so that the ultimate load capacity for each tie is related to loading on a unit of wall area. This basis for comparing the test results is presented in Tables 5.1 and 5.2. In these two tables, the tie spacings and resulting values of wall area per tie, are representative of the manufacturer's recommendations and common installation practice. It should be noted that, for Z ties, the National Building Code of Canada (N.B.C.), specifies a vertical and horizontal spacing of 18 in. (457 mm) and 36 in. (914 mm) respectively. When using standard 8 in. (190 mm) high block units however, the closest possible vertical spacing to the one specified in the code is of 16 in. (400 mm) which is the figure used in tables. An examination of Table 5.1 reveals that, for the adopted tie spacings, the compressive strength of the ties in a descending order is as follows:

No. 9 Ga. Truss Tie

No. 9 Ga. Ladder Tie

3/16 in. Z Tie

No. 24 Ga. Corrugated Tie

TABLE 5.1

ULTIMATE LOADS IN COMPRESSION PER TIE AND PER UNIT OF WALL AREA

TYPE OF TIE	ULTIMATE LOAD PER TIE lbs. (N)		INSTALLATION		ULTIMATE LOAD PER AREA UNIT psf (KPa)	
	Cavity 2-3/8 in. (60 mm)	Cavity 4-3/8 in. (111 mm)	Spacing in X in (mm X mm)	Area ft^2 M^2	Cavity 2-3/8 in. (60 mm)	Cavity 4-3/8 in (111 mm)
3/16 in. (4.76 mm) Z TIE	737 (3278)	660 (2936)	36 X 16 (914 X 406)	4.000 (0.371)	184 (8.8)	165 (7.9)
No 9 Ga. TRUSS TIE	901 (4008)	680 (3025)	16 X 16* (406 X 406)	1.778 (0.165)	507 (24.3)	382 (18.3)
No 9 Ga. LADDER TIE	737 (3278)	540 (2402)	16 X 16* (406 X 406)	1.778 (0.165)	415 (19.9)	304 (14.6)
No 24 Ga. CORRUGATED TIE	236 (1050)	88 (391)	16 X 16 (406 X 406)	1.778 (0.165)	133 (6.4)	49 (2.3)

No 24 Ga. Corrugated Tie in 3/4 in. (19 mm) Cavity : Ultimate Load per Tie 562 lbs. (2500 N)
Ult. Load / Area Unit 316 psf. (15.2 KPa)

* Horizontal Spacing of Cross or Diagonal Wires

TABLE 5.2

ULTIMATE LOADS IN TENSION PER TIE AND PER UNIT OF WALL AREA

TYPE OF TIE	SPECIMEN No	ULTIMATE LOAD PER TIE lbs. (N)	INSTALLATION Spacing in X in (mm X mm)	INSTALLATION Area ft^2 (M^2)	ULTIMATE LOAD PER AREA UNIT psf (KPa)
3/16 in. (4.76 mm) Z TIE	T 2	1,168 (5195)	36 X 16 (914 X 406)	4.000 (0.371)	292 (14.0)
	T 4	1,777 (7904)	"	"	444 (21.3)
No 9 Ga. TRUSS TIE	N/A	1,330 (5916)	16 X 16 (406 X 406)	1.778 (0.165)	748 (35.8)
No 9 Ga. LADDER TIE	N/A	661 (2940)	16 X 16 (406 X 406)	1.778 (0.165)	372 (17.8)
No 24 Ga. CORRUGATED TIE	T 1 T 2*	1,206 (5364)	16 X 16 (406 X 406)	1.778 (0.165)	678 (32.5)
	T 3 T 4**	748 (3327)	"	"	421 (20.2)

* Average of T1 and T2 (T1 = 4in. (102 mm) embedment, T2 = 2in. (51 mm) embedment)

** Average of T3 and T4 (1.26 in. (32 mm) mortar embedment on one side versus two sides)

Table 5.2 instead, indicates that, on the basis of the adopted tie spacings and considering the various installation features (i.e. on block web, inner face shell and outer face shell) the tensile strength of the ties in a descending order is as follows:

No. 9 Ga. Truss Tie

No. 24 Ga. Corrugated Tie

No. 9 Ga. Ladder Tie

3/16 in. Z Tie (installed through block void).

As previously indicated in section 4.4-2, however, the tensile resistance of the ladder tie was adversely affected by the lack of continuity of the longitudinal wires past the side ends of the specimens.

5.2 Tie Strength Versus Wind Loads

Cavity walls are normally supported laterally along the top and bottom edges between floors, and at intermediate points along their length by interior walls or columns. Consequently, wind loads are transmitted in the horizontal direction to vertical supports and in the vertical direction to horizontal supports.

The distribution of the wind load in the horizontal and vertical directions varies with the ratio of the distances between supports, (or the aspect ratio of the wall panel). Usually the distance between vertical supports in a wall, is much greater than the distance between horizontal supports. Consequently, for the purposes of the following analysis, it is reasonable to assume that all of the wind load will be transmitted in the vertical direction to the floors.

When a cavity wall is subject to wind loads, each wythe acts as a beam in transmitting its portion of the wind load to the supports. The portion of the total wind load carried by one wythe is primarily a function of the ratio between the stiffness of that wythe and the stiffness of the wall as a whole. It is obvious then, that cavity wall ties are required to transmit only that portion of the wind load that is carried by the inner wythe. Furthermore, the ties nearest to the wall supports must be able to transmit the reaction of the load carried by the outer wythe to the inner wythe, where the supports are usually attached. These assumptions were made in the calculations pertaining to the wind load distribution of Appendix A, where a typical cavity wall consisting of a 100 mm (4 in.) exterior brick wythe and 140 mm (5.5 in.) interior block wythe was analysed, for the effects of a quite high wind load. It can be seen from these calculations, that the portion of the wind load which must be carried by the ties is of only 0.452 K Pa (9.44 psf), while the ultimate compressive loads per unit of wall area vary from 2.3 K Pa (49 psf) to 18.3 K Pa (382 psf) for a cavity width of 4-3/8 in. (111 mm). This gives a nominal factor of safety ranging from 5 to 40. Even if the full amount of the wind pressure, 0.838 K Pa (17.5 psf), were to be assigned to the ties, the nominal factor of safety would range from 2.7 to 21.8. It can also be seen from the calculations of Appendix A, that the reaction of the exterior brick wythe is 1158 N per linear meter of wall, while the ties investigated (excluding the corrugated tie) offer a resistance varying from 3212 to 14901 N per linear meter of wall. This gives a nominal factor of safety ranging from 2.8 to 12.9. It can therefore be concluded that, for the recommended tie spacings and with the exception of the corrugated tie, all of the other ties are sufficiently strong to transmit both the wind load and the end reaction of the outer wythe.

It should also be noted that, for the example of Appendix A and a nominal safety factor of 3, the corrugated ties would have to be spaced every 112 mm (4.41 in.) horizontally at the wall support to be able to withstand the reaction of the exterior brick wythe.

5.3 Commentary on Testing Techniques

An experimental program, consisting of the testing of specific specimens, should simulate as closely as possible the actual conditions under which a structure (or a part of a structure) will be subjected during its design life. The method of applying the load must be representative of the expected loading conditions in the field. Similarly, the specimens must be representative of the actual physical properties of the structure investigated. In addition the workmanship and other conditions affecting the construction of the structure should be accounted for.

Premising that it is quite difficult to reproduce in a laboratory the conditions pertaining to the behaviour under load of cavity wall ties, the following comments can be made.

1. All of the wall ties were carefully positioned in the specimens to ensure the axial application of the test loads. This is an ideal condition, since there is no assurance that the same would be done in the field. It would be quite possible, in fact, for a Z or corrugated tie to be placed with some inclination with respect to the longitudinal profile of the wall. In addition, masons have been known to bend down

truss and ladder ties, in order to overcome differences in level between the two wythes of a cavity wall. Considering the above, it is recommended that future investigations on the strength of cavity wall ties should consider testing with eccentric loads to represent various degrees of misalignment or on site bending of ties.

2. The test specimens were manufactured and cured in the Applied Dynamics Laboratory of McMaster University under ideal environmental conditions. The workmanship used in the fabrication of the specimens can be considered to have been good to excellent for masonry construction. Since the actual field conditions and quality of workmanship are not likely to be as ideal in wall construction, the test results should be interpreted and used with this in mind.

3. Only one type of mortar, namely type S, was used in the fabrication of the test specimens. While it is reasonable to assume that the mortar type does not affect the compressive strength of those ties which failed by buckling (truss, ladder and corrugated ties), it can be expected that the compressive and tensile resistance of Z ties (installed across the void of the block) and the tensile resistance of corrugated ties would be affected by the type of mortar used. It is therefore, recommended that consideration be given to testing with different types of mortar in future investigations.

4. With the exception of two Z tie compression tests, all of the other tests were performed with no compression stress normal to the mortar bed joints. While a zero compression in the wall represents the most critical case, this is rarely encountered in practice. Since it is

apparent (and logical) that compressing the mortar bed joint should give greater resistance to push through and pull out of wall ties, it is recommended that the influence of vertical compression in the wall on the strength of ties be thoroughly investigated.

5. The ladder and truss tie specimens had the obvious defect of lacking continuity of the longitudinal wires past the side ends of the specimens. The ladder tie tension specimens were the most critically affected by this flaw, since it resulted in the complete absence of longitudinal wire on one side of the cross rods. This meant that the anchorage resistance to pull out was only provided on one side of the cross rods and not on two sides as would occur in an actual wall. In view of this problem, it is recommended that future ladder and truss tie specimens be constructed in such a way as to incorporate a sufficient length of longitudinal wire past the side ends of the specimens.

5.4 Summary of Conclusions and recommendations

The compressive and tensile resistances of Z, truss, ladder and corrugated ties were investigated in the experimental program described in this report. On the basis of the test results and observations made during the investigation the following conclusions are drawn:

1. The mode of failure in compression of the 3/16 in. (4.76 mm) diameter Z tie, installed across the void of a 190 mm (7.6 in.) concrete block, was push through of the tie from the mortar bed joint between the blocks. This mode of failure was for both the 2-3/8 in. (60 mm) cavity and the 4-3/8 in. (111 mm) cavity. Because of the above mode of failure the average strength of the tie in the 4-3/8 in. (111 mm) cavity was

only 11% less than that in the 2-3/8 in. (60 mm) cavity. The buckling strength of the shaft of the tie was not utilized. Therefore, from a strength point of view, there does not seem to be much point in using larger diameter ties.

2. The mode of failure in tension of the 3/16 in. (4.76 mm) diameter Z tie, in a 190 mm (7.5 in.) block, was pull out of the tie from the mortar bed joint. It was observed that, as long as the leg of the Z tie was placed on the outer face shell of the block, any small increase in the length of mortar embedment along the tie resulted in a substantial increase in the tensile resistance of the tie. The major tensile resistance of the Z tie depended on the anchorage force developed by the shear resistance of the mortar surrounding the leg of the tie. It seems reasonable to assume this, also for the compressive resistance of the tie. The strength contribution due to bonding along the shaft of the tie was calculated to be 148 lbs. per linear inch (26 N per mm) of mortar embedment along the tie shaft. The tensile resistance of the Z tie installed on the web of a 190 mm (7.5 in.) concrete block, with the leg of the tie on the centre of the outer face shell of the block, came quite close to the theoretical ultimate tensile resistance of the wire from which the tie was made. Because of this, it is recommended that Z ties be installed on the web of blocks and not across block voids.

3. The mode of failure in compression of the No. 9 ga. truss tie was buckling of the diagonal wire, for both the 2-3/8 in. (60 mm) cavity and the 4-3/8 in. (111 mm) cavity. The diagonal wires of the truss tie used were found to be bent with a double curvature having an infl-

ection point at mid-length. Increasing the cavity width from 2-3/8 in. (60 mm) to 4-3/8 in. (111 mm) resulted in a 25% decrease in the capacity of the tie.

4. The mode of failure in tension of the No. 9 ga. truss tie was not consistent for all of the tests. In one specimen the weld at the intersection of the diagonal and longitudinal wires at the brick broke suddenly. In another specimen the diagonal wire broke suddenly across the cavity. Two specimens failed when the intersection of the diagonal wire pulled out from the mortar joint between the bricks. It is suggested that this last mode of failure can be attributed to the lack of continuity of the longitudinal wires past the end of the specimens. Future testing should ensure the continuity of the longitudinal wires.

5. The mode of failure in compression of the No. 9 ga. ladder tie was buckling of the cross wire within the cavity for all specimens, with the exception of one which failed by push through. Increasing the cavity width from 2-3/8 in. (60 mm) to 4-3/8 in. (111 mm) resulted in a 27% decrease in the capacity of the tie.

6. The mode of failure in tension of the No. 9 ga. ladder tie was pull out of the intersection of the cross wire with the longitudinal wire from the mortar joint between the blocks. This mode of failure can be attributed to the lack of continuity of the longitudinal wires past the side of the specimen. Therefore, the test results for this type of tie represent a lower bound value. Future investigations should ensure the continuity of the longitudinal wires in the test specimens.

7. The mode of failure in compression of the No. 24 ga. corrugated

tie was buckling of the tie within the cavity. The compressive resistance of the tie was largely dependent on the cavity. In fact, increasing the cavity width from 2-3/8 in. (60 mm) to 4-3/8 in. (111 mm) resulted in a 63% decrease in the capacity of the tie. The compressive resistance of the tie was independent of the length of mortar embedment, of whether or not the tie had mortar on one or two sides, and of the location (on block web versus block's face shell) of the tie on the block.

8. The mode of failure in tension of the 24 ga. corrugated tie was pull out from the mortar joint between the blocks. There was almost no difference in tensile resistance between the ties with 4 in. (102 mm) of embedment on the web and those with only 2 in. (51 mm) of embedment on the web. One possible explanation for this would be that the mortar in the corrugations of the tie failed near the surface before the tie elongated enough to develop bond stress further into the joint. There was also no difference in tensile resistance between the ties on the inner face shell of the block with mortar on one side and those with mortar on two sides. A possible explanation for this would be that failure resulted from splitting along the mortar joint between the blocks.

9. For the adopted tie spacings the compressive strengths of the ties investigated in a descending order are:

No. 9 Ga. Truss Tie

No. 9 Ga. Ladder Tie

3/16 in. (4.76 mm) diameter Z Tie

No. 24 Ga. Corrugated Tie.

10. For the specific example of Appendix A and for the adopted tie spacings, all of the ties investigated were found to be sufficiently strong to transmit to the back-up wall the chosen wind pressure or suction. For that example the nominal safety factor ranged from 5 to 40. Even if the full amount of wind pressure were to be assigned to the ties, the nominal factor of safety would range from 2.7 to 21.8. Also, for the example of Appendix A, all of the ties investigated, excluding the corrugated tie, were found to be sufficiently strong to transmit the end reactions of the exterior wythe under wind load.

11. Deformations were not measured during the experimental program. Since deformations are important in cavity wall construction, because the two wythes are required to deflect the same amount, it is recommended that they be measured in future investigations.

12. The topic of durability of the ties was not dealt with in this investigation. Prevention of corrosion of the ties is very important to ensure the design life of the wall. Since the ties investigated are quite strong, building code authorities should give consideration to increasing tie spacings, in conjunction with using better corrosion resistant tie materials. An increase in tie spacing would result in fewer ties and thus a cost saving proportional to the increased wall area per tie. The cost saving could then be utilized to purchase ties made with better corrosion resistant materials. For example, Z Ties could be made with stainless steel, (stainless steel Z ties currently cost four times more than mill galvanized Z ties).

APPENDIX A

WIND LOAD DISTRIBUTION IN A TYPICAL CAVITY WALL

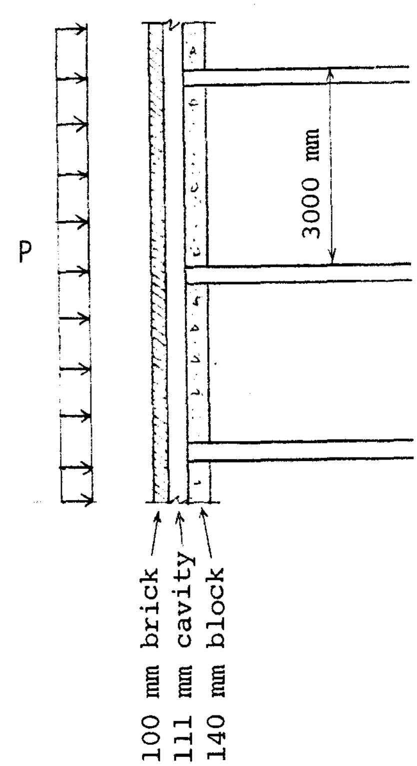
In the example below, the following assumptions are made:

1) The two wythes deflect the same amount under load.
2) The ties are sufficiently stiff to ensure that the relative displacements at corresponding points along the wythes are insignificantly small.

It seems reasonable to make these assumptions (4, 5), in view of the fact, that the anticipated strength required by the ties to transfer the wind load, is only a small percentage of the total capacity of the ties.

A typical exterior cavity wall in a multistory building is considered. The wall consists of:

A 100 mm exterior brick wythe
A 111 mm cavity space
A 140 mm interior block wythe



Properties of Materials and Wall

f' (brick) = 128.9 MPa (Units compressive strengh)
f' (block) = 14.0 MPa " " "
If type S mortar is used ,
f'_m(brick) = 26.9 MPa (Masonry compressive strength)
f'_m(block) = 7.5 MPa " " "
E (brick) = 1000 $f'_m \leq$ 20000 MPa use 20000 MPa
E (block) = 1000 $f'_m \leq$ 20000 MPa use 7500 MPa
I (brick) = 65 X 10^6 mm^4/lin. meter of wall
I (block) = 203 X 10^6 mm^4/lin. meter of wall
EI (brick) = 1.30 X 10^{12} N mm^2
EI (block) = 1.52 X 10^{12} N mm^2

Wind Load Distribution

Assume a total wind force (pressure + suction) of 1436 Pa.

Assume the wind pressure P to be 7/12 of the total wind force

P = 7/12 X 1436 = 838 Pa.

This pressure is carried by both wythes in proportion to their relative stiffnesses.

The wind pressure P_1 which must be carried by the exterior brick wythe is:

$$P_1 = P \frac{\text{EI (brick)}}{\text{EI (brick)} + \text{EI (block)}} = 838 \frac{1.30}{1.30 + 1.52} = 386 \text{ Pa}$$

The wind pressure P_2 which must be carried by the interior block wythe is :

$P_2 = P - P_1 = 838 - 386 = 452$ Pa or 0.452 KPa

For this particular cavity wall, the ties are required to transfer a a pressure of 0.452 KPa to the interior block wythe.

An examination of Table 5.1 reveals that, for a cavity width of 111 mm , all of the ties investigated are sufficiently strong to resist this pressure .

The reaction R_1 of the load (wind pressure) carried by the exterior brick wythe is assumed to be :

$R_1 = P_1$ X Floor Height = 386 X 3.00 = 1158 N / lin. meter of wall

For the recommended tie spacings, as indicated in Table 5.1, the ties investigated can provide the following resistances :

3/16 in Z Tie, 914 mm c/c horiz. , $\frac{1000}{914}$ X 2936 = 3212 N/Meter > 1158 OK

Truss Tie , 406 mm c/c horiz. , $\frac{1000}{406}$ X 3025 = 7451 " OK

Ladder Tie , 406 mm c/c horiz. , $\frac{1000}{406} \times 2402 = 5916$ N/Meter $>$ 1158 OK

Corr. Tie , 406 mm c/c horiz. , $\frac{1000}{406} \times 391 = 963$ " NG

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