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COMPOSITE WALLS

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ABSTRACT

Composite walls are defined as multi-wythe walls in which the wythes are tied together by connectors, filled collar joints, bonding units, or other means to ensure shear transfer between the wythes and effective composite action.

These types of walls have been used in North America for many years with variable results. There is evidence of separation at the collar joints between dissimilar masonry wythes bonded together by mortar or grout, and there is evidence of good performance of composite walls connected by means of a header course.

Recently composite walls have received a renewed interest with the introduction of connectors capable of transferring shear across the cavity. This paper provides an overview of composite walls and provides information on the current trends of cavity wall performance.

INTRODUCTION

In addition to the many other positive qualities of the system, the ability of a cavity wall to accommodate insulation and to provide for the structural integrity of the air/vapour barrier is well known. Cavity walls were designed to resist vertical and lateral loads by assuming that all loads were ultimately resisted by only one of the wythes, the interior wythe. Many masonry walls have been built over the years, and continue to be built, with clay brick and concrete block connected by wire ties, with the collar joint filled solid with mortar or grout. These walls are known as composite walls and can be insulated on the interior, or the cores of the inner wythe can be filled with insulating material. The evolution of

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building physics has shown these walls to perform at levels less than acceptable.

The increasing awareness of the importance of providing and protecting a continuous air/vapour barrier, and the influence of the location of the dew point in relation to the durability and thermal performance of exterior walls, has caused changes in the way buildings are designed and constructed. The cavity wall system allows for a good solution in maintaining a continuous air/vapour barrier and for providing space for insulation placement, while possessing great resistance to deterioration resulting from the condensation of moisture, if any, occurring on the warm side of the air/vapour barrier.

The main drawback of the cavity wall system has been the thickness of the inner wythe, especially for taller walls. The thick inner wythe increased the footprint of the structure, resulting in increased construction costs for the same useable floor space. This concern has been answered by the innovation of connectors capable of providing a degree of composite, or coupling, action between the two wythes. Quoting from the textbook "Masonry Structures" (Drysdale et al., (1992)), " Tying wythes together with flexurally stiff connectors will couple the wall to some extent so that the resulting bending strength and stiffness are more than the sum of the individual values." With regards to the coupling of the two wythes, the authors note that the effects of internal stresses produced by the tendency for differential movement must be taken into account. These internal stresses resulting from the mechanical shear connector coupling of the wythes can easily be designed for and certainly are far less than similar stresses arising in a composite wall coupled with wire ties and grout or mortar filled collar joint.

The shear connector as shown in Figure 1 and Figure 2, is an example of a flexurally stiff connector that typically allows the designer to reduce the thickness of the inner wythe by at least one size. Completed studies and studies currently under way at the University of Alberta, University of Saskatchewan and University of Manitoba have shown that the ability of the shear connector to transfer shear between the wythes improves both the lateral load carrying capacity and the vertical load carrying capacity of the cavity wall system.

This paper presents an overview of the development and use of the shear connector since it was introduced five years ago.

RESEARCH AND DEVELOPMENT

The research and development into connector systems capable of providing a degree of composite action between an outer brick wythe and an inner block wythe has been pursued worldwide. The following briefly summarizes a number of research programs that have investigated the effects of innovative shear connectors, such as those developed and tested in Canada (see Figure 1 and 2) and in Australia (see Figure 3).

A connector system for shear connecting two masonry wythes, as shown in Figure 3, was studied at the University of Queensland (Mullins and O'Connor (1987)) and resulted in an improved performance of the cavity wall under out-of-plane loads. The drawbacks of the connector were the difficulty and cost in constructing the wall system, as well as the discontinuity of the cavity insulation and air/vapour barrier at the location of the connector.

The University of Alberta conducted extensive studies on composite walls over the last decade. Some of that work is summarized below.

McGinley et al. (1989) tested a total of 44 full sized wall specimens to determine the effect of conventional ties and shear connectors in cavity walls and brick veneer/steel stud (BV/SS) walls. Forty two steel stud backup test walls and two concrete block backup test walls were laterally loaded with either positive or negative pressure. In the conclusions of the structural engineering report it was noted "Partial shear connection between the veneer and steel stud wall improves the performance of this type of masonry veneer wall system under out-of-plane loading".

Pacholok et al. (1989) tested eight full scale masonry cavity walls to study the effect of conventional ties versus shear connectors. Two cavity walls were constructed with conventional wire ties and plain concrete block backup. Six shear connected cavity walls were constructed, of which five had a plain concrete block backup, with one having a vertically reinforced concrete block backup. The test walls contained cavities of either 75 or 100 mm (3 or 4"), with the walls being loaded with positive lateral pressure.

The final report of the research program contained the following conclusions:

- "A shear connector was developed which is capable of transferring axial load and shear from the brick veneer to the block back-up wall. This resulted in a system with enhanced load-resisting capabilities".

- " (It was) experimentally determined that by replacing conventional reinforcement with shear connectors, load-resisting capacity was increased from 16% (for cavity walls with a 75 mm (3") cavity), and up to 100% for cavity walls (with a 100 mm (4") cavity)".

- "At comparable pressures, the lateral deflection of the wall systems using shear connectors was consistently less than that of the conventional wire truss reinforcement. Reductions in crack widths and water penetration would result from such decreased deflections".

- "When using shear connectors, an increase in cavity width results in a significant increase in load resisting capacity. Dramatically reduced deflections at comparable pressures are also achieved. This enables the cavity to be increased to allow for the placement of thicker insulation".

Papanikolas et al. (1990) tested a total of 23 prisms and 13 full scale specimens to study the effects of shear connecting the wythes of cavity walls and of shear connecting the exterior masonry wythe to the backup steel studs of BV/SS wall systems. The 23 prisms were constructed and tested to determine the capacity of the shear connectors.

Nine of the full scale walls consisted of an outer clay brick wythe shear connected to an inner concrete block wythe, with cavity widths of 25, 50 or 100 mm (1, 2 or 4"), block thicknesses of 140 or 190 mm (5.5 or 7.5"), and plain or vertically reinforced block wythe. Eight of these walls were loaded to failure with positive lateral pressure, while one was placed outside to study the effects of material and climatic effects. Four of the full scale tests consisted of an outer clay brick wythe, a 50 or 100 mm (2 or 4") cavity, and steel stud backup. These four shear connected walls were loaded to failure under positive lateral pressure.

The structural engineering report noted the following conclusions:

- "The shear connectors are capable of transferring shear and axial load from the brick veneer to the backup system".

- "From the deflected shapes of the full scale specimens under lateral pressure it is concluded that composite action between the wythes is achieved when shear connectors are used".

- "Load carrying capacity increases with concrete block width, vertical reinforcement and cavity size".

- "Both the experiment and analytical studies showed that the effects of thermal and moisture deformations on shear connected cavity walls cannot be neglected. The forces induced in the masonry components due to the restraints provided by the connectors should be calculated using a rational approach and the adequacy of the materials in resisting these forces must be checked".

The improvement of the vertical load carrying capacity of shear connected cavity walls versus single wythe walls was examined by Goyal et al. (1993). Five single wythe walls and seven shear connected cavity walls were tested. The concrete block wythe of each specimen consisted of 190 mm (7.5") wide units, vertically reinforced and grouted. The cavity walls contained a 75 mm (3") wide cavity .

The walls were vertically loaded with the eccentricity of loading ranging from 0, t/6, t/3 to t/2.5. The shear connected cavity walls showed a significant improvement in vertical load carrying capacity over the single wythe walls; i.e. an average ultimate vertical load increase of 25%, with a corresponding average ultimate moment increase of 93%.

The results of the test program were published in The Masonry Society Journal, February 1995 Issue, under the title "Preliminary Results of the Influence of Shear Connected Wythes on the Ability of Cavity Walls to Carry Vertical Load".

Goyal et al. (1994) tested sixteen full scale shear connected cavity walls under positive lateral pressure. The test results lead the authors to conclude that "the use of shear connectors and brick veneer with the sawdust block backup wythe increases the stiffness and the load carrying capacity of the assembly. The two wythes act compositely as indicated from load deflection behaviors".

Other researchers at other centres are also working on the subject. Prof. John Glanville of the Civil Engineering Department at the University of Manitoba is currently working on the development of a closed form solution based on plastic analysis for shear connected cavity wall systems. The study is entitled "Non-linear Analysis of Shear Connected Cavity Walls".

Under the direction of Prof. Vern V. Neis, two M.Sc. and one Ph.D. program have been completed at the University of Saskatchewan on the vertical load carrying ability of single wythe masonry versus that of cavity walls with the outer wythe and inner wythe attached with conventional ties or shear connectors. Dramatic improvement in vertical load capacity was observed with both the conventionally tied and shear connected cavity wall, with the shear connected walls showing the greatest improvement.

BUILDING CODE COMPLIANCE

The design of shear connected cavity walls in Canada must meet the requirements of the National Building Code of Canada and the provincial building codes. These codes reference the design standard Canadian Standards Association "CAN3-S304-M84 Masonry Design for Buildings". The CSA standard does not specifically address shear connected, or coupled, cavity walls, as the development of such walls had not occurred prior to publication of the standard. This does not mean that shear connected cavity walls cannot be designed in accordance with CAN3-S304-M84, merely that the design of these walls must follow engineering principles using the allowable stresses and material properties included within the standard.

The latest draft of CSA standard "S304.1-94 Masonry Design for Buildings (Limit States Design)" has been accepted for publication by the S304.1 technical committee and by the Canadian Standards Association, and is expected in print by the fall of 1995. It is the intent of CSA to have S304.1-94 run concurrently with CAN3-S304-M84 until the year 2000, at which time CAN-S304-M84 will be withdrawn.

Having been drafted after the development and growing usage of shear connected cavity walls, S304.1 includes provisions for the design of these walls systems. The following excerpts have been taken from the CSA accepted draft of S304.1-94.

8.3.4 Cavity Walls

8.3.4.1 Lateral Loads
Unless otherwise indicated by rational analysis, for lateral load effects the cavity wall stiffness shall be taken as the sum of the stiffnesses of the two wythes acting noncompositely, the ties acting as struts, forcing the two wythes into similar curvatures, but transferring no shear across the cavity.

8.3.4.2 Axial Load and Bending
Unless otherwise indicated by rational analysis, each wythe shall be considered to act independently and the effective thickness of each wythe shall be assumed as its actual thickness.

11.2 Minor Axis Flexure and Axial Loads

11.2.2 Composite Walls
For composite walls where shear transfer between wythes is assured by connectors and filled collar joints, or by other mechanical means, consideration shall be given to the compressive strengths and related properties of the constituent wythes in a rational analysis. The shear transfer system shall be designed with adequate strength and rigidity to ensure effective composite action.

CASE STUDIES

The shear connected cavity wall system has been used on over 100 projects within Canada, and on selected projects in the United States. The following provides a brief history of a number of shear connected cavity wall applications.

Citadel Theatre Addition, Edmonton, Canada (1989)

The first commercial use of the shear connected cavity wall system occurred on a very small section of the Citadel Theatre Addition in 1989. To facilitate the Project Architects desire to construct a 4800 mm (15.8 ft.) high, vertically spanning, infill cavity wall consisting of a 90 mm (3.5") clay brick inner wythe, air/vapour barrier, 50 mm (2") insulation sheathing, 25 mm (1") air space and a 90 mm (3.5") clay brick outer wythe, shear connectors were used to provide the necessary composite action between the wythes. Due to the height of the wall, small diameter vertical steel reinforcement was built into each wythe. Without the incorporation of the shear connectors, and even assuming load sharing between the wythes in relation to their stiffnesses, the maximum allowable height of the wall would only have been 3040 mm (10.0 ft.).

Blessed Sacraments Elementary School, Wainwright, Canada (1989)

The Blessed Sacraments Elementary School, designed by Merwin Engineering of Edmonton and constructed in the summer of 1989, was the first project to utilize the shear connected cavity wall in a load bearing application. Merwin Engineering used the system to down-size the concrete block requirements on the schools gymnasium. The wall system composition required a 90 mm (3.5") clay brick outer wythe, 25 mm (1") air space, 50 mm (2") insulation, and an inner concrete block wythe.

The shear connectors allowed for the use of 240 mm (9.5") concrete block backup (reinforced with 1-15M (1-No.5) vertical reinforcing bar at 2,400 mm (94") o.c.) to replace the conventional designed 290 mm (11.5") concrete block backup (reinforced with 1-15M (1-No.5) vertical reinforcing bar at 1200 mm (47") o.c.). The shear connected cavity wall saved the owner 6 % of the total wall cost, as well as provided 50 mm (2") more useable floor space around the interior perimeter of the gymnasium. Dr. Wilfred Sui, P.Eng. of Merwin Engineering reacted immediately to the introduction and merits of the shear connected cavity wall in utilizing the system on the Blessed Sacraments Elementary School, and has continued to exhibit his progressive engineering design philosophies through numerous other successful shear connected cavity wall projects since.

Cape Breton Regional Hospital, Sydney, Nova Scotia, Canada (1991)

As working drawings were near completion, the shear connector was introduced too late in the design stage to down-size the backup concrete block thickness for the projects infill masonry cavity walls. However, some of the benefits of the shear connected cavity wall system were realized by significantly reducing the amount of vertical reinforcing steel and grout within the inner concrete block wythe. Of the order of $30,000 in reinforcing steel costs and $8,000 in grout costs were saved through the coupling of the cavity wall system.

The Regional Hospital Board was so impressed with the exterior shear connected cavity wall system of the Cape Breton Regional Hospital that the board used it on the Halifax Infirmary (1992) located in Halifax, Nova Scotia and on the Miramichi Regional Hospital (1993) located in Miramichi City, New Brunswick.

Non-Profit Housing (9 Storeys), Guelph, Ontario, Canada (1992)

Beta Engineering Consultants Ltd. of Mississauga, Ontario recognized the advantages of the shear connected cavity wall system to satisfy the building codes and standards, as well as the building authorities in Guelph, in designing an infill wall system consisting of a 90 mm (3.5") clay brick outer wythe, 25 mm (1") air space, 50 mm (2") insulation and a 90 mm (3.5") concrete block inner wythe. In accordance with the National Building Code of Canada and the Ontario Building Code, the design of a conventional infill cavity wall required a 140 mm (5.5") concrete block inner wythe. The shear connected cavity wall system allowed the engineer to provide the owner with a thinner, lighter, and more economical exterior cavity wall system. Photo 1 shows the front elevation of the project.

Tegler Terrace, Edmonton, Canada (1992)

Tegler Terrace (see Photo 2) is a 5 storey Seniors' Residence constructed in 1992. J.A. MacDonald Architect Ltd. of Edmonton, took advantage of the shear connector to demonstrate the superiority of coupled masonry cavity walls compared to steel stud backup walls, in satisfying the infill exterior wall design parameters for Tegler Terrace; namely, required insulation R-value, air/vapour barrier, total wall width, weight, lateral load carrying capacity, and affordable cost.

J.A. MacDonald Architect Ltd. and the structural engineering firm Read Jones Christofferson Ltd. of Edmonton, provided the owner with a masonry cavity wall that either met or exceeded the performance of a brick veneer/steel stud wall system as detailed in the following.

- R-Value: Both wall systems had equal design R-values. However, the masonry cavity wall had continual cavity insulation, whereas the BV/SS wall had batt insulation between the studs. The reduction in R-value of batt insulation due to thermal bridging of the studs is significant.

- Air/Vapour Barrier: Both wall systems contained an air/vapour barrier. However, the masonry cavity wall air/vapour barrier consisted of a continuous bituthane membrane on the exterior of the block, whereas the BV/SS system used 6 mil polyethylene between the interior drywall and studs. The failure of the 6 mil polyethylene system to perform as an acceptable air/vapour barrier is well documented.

- Total Wall Width: Both wall systems were of equal thickness, 293 mm (11.5"). The masonry cavity wall consisted of: 90 mm (3.5")clay brick, 25 mm (1") air space, 50 mm (2") insulation, air/vapour barrier, 90 mm (3.5") concrete block, 25 mm (1") furring and 13 mm (0.5") drywall. The BV/SS wall consisted of: 90 mm (3.5") clay brick, 25 mm (1")air space, 13 mm (0.5") gypsum sheathing, 152 mm (6") steel stud with infill insulation, 6 mil polyethylene, 13 mm (0.5") drywall.

- Weight: The wall weights were comparable in that the structural concrete slabs, walls, and columns did not require an increase in steel reinforcement or size to support the heavier masonry cavity wall; i.e. 295 kg/m^2 (61 p.s.f.) for the masonry cavity wall and 200 kg/m^2 (41 p.s.f.) for the BV/SS wall.

- Lateral Load Carrying Capacity: Both the masonry cavity wall and the BV/SS wall systems were designed in accordance with the governing building codes and standards.

- Cost: The cost of the masonry cavity wall was \$185.00/m^2 (\$17.20/ft^2), whereas the cost of the BV/SS wall was \$153.00/m^2 (\$14.20/ft^2). Although the cost per wall area of the masonry cavity wall was noticeably higher than that of the BV/SS wall system, the effect on the overall project cost was minimal.

The shear connected masonry cavity wall system was not only favourable by the above noted wall design parameters, but it also provided the inherent advantages of masonry in terms of sound transmission, fire rating, longevity, durability and mass factor. The owner clearly received a far superior wall system at a very small premium.

CONCLUSION

The innovation of the shear connected cavity wall allows for the design of exterior masonry wall systems which are superior to conventionally tied cavity walls and traditional composite walls. Shear connected, or coupled, cavity walls can be easily designed using any plane frame program, with the design including the effects of lateral and vertical loads, as well as material and climatic effects. Modeling of the wall system for the plane frame computer analysis is illustrated in Figure 4.

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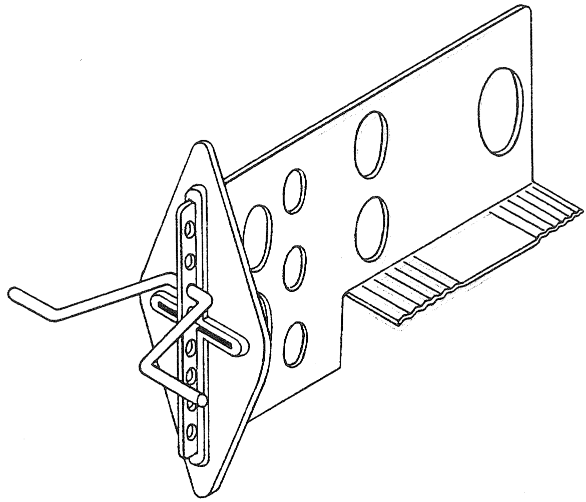

Figure 1. Shear Connector Used In University of Alberta, Saskatchewan, and Manitoba Testing and Research Programs.

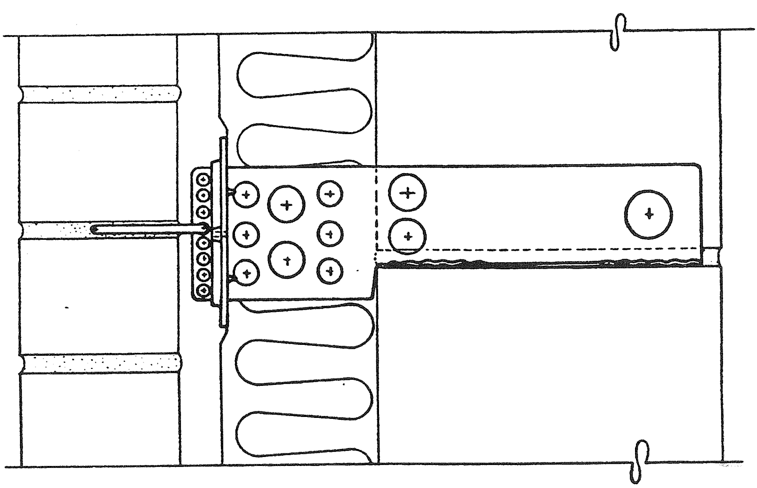

Figure 2. Shear Connector Installation

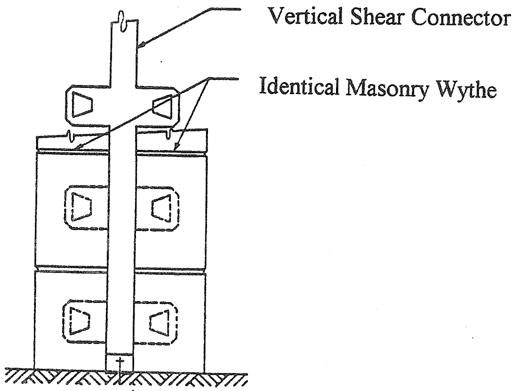

Figure 3. Shear Connector Used In University of Queensland Testing and Research Program

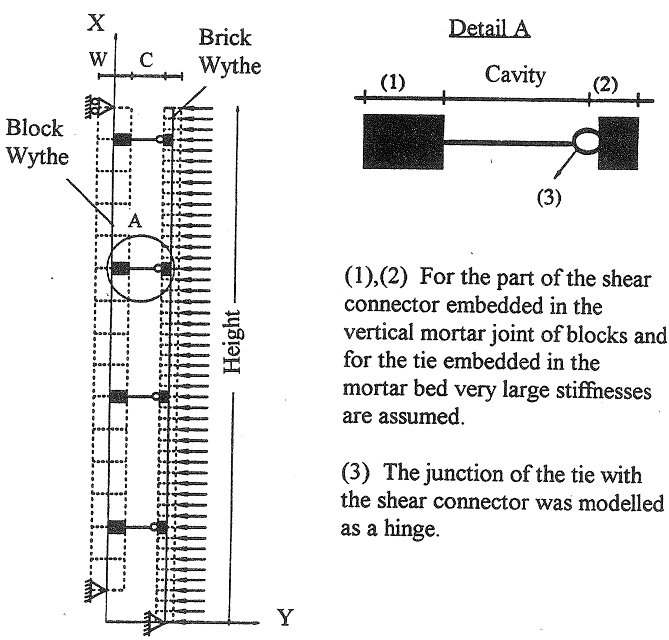

Figure 4. Modelling of the Shear Connected Cavity Wall System for Plane Frame Computer Analysis.

Photo 1. Non-Profit Housing, Guelph, Canada

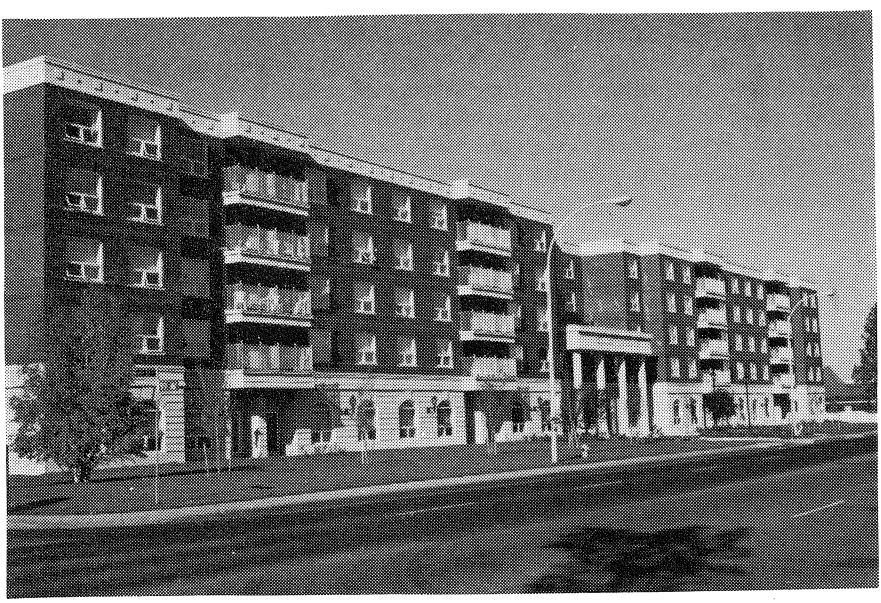

Photo 2. Tegler Terrace, Edmonton, Canada

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MASONRY PRISM GROUTED COLLAR JOINT SHEAR TESTS

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ABSTRACT

Composite structural action can only be obtained in multiwythe masonry wall construction if the masonry wythes are adequately interconnected and full shear transfer occurs across the collar joint. The filling of a collar joint by pressure injected grout through one of the masonry wythes is one possible method of providing full shear transfer between masonry wythes which were not originally adequately interconnected. Test results on several masonry prisms constructed in the laboratory with open collar joints, which were subsequently grouted using pressure injection, are presented. The test results provide average shear capacity values along the collar joints that compare favorably with existing allowable stress values for grouted collar joints (Building Code Requirements for Masonry Structures, 1992).

INTRODUCTION

The allowable shear stresses on filled collar joints between two wythes of masonry are 35 kPa (5 psi) for mortared joints and 69 kPa (10 psi) for grouted joints (Building Code

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