9th Canadian Masonry Symposium

GLASS FIBRE REINFORCED POLYMER (GFRP) SHEAR CONNECTORS FOR MASONRY

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ABSTRACT

In cavity and diaphragm wall construction, problems arise due to the use of the steel connectors. Corrosion is one of the major concerns. Tests on post-tensioned diaphragm walls also indicate that the type of connection between the webs and flanges of the wall (bonded versus tied) has a significant effect on the behaviour of the wall under structural loading. Further, shear tests on panels indicate that bed reinforcement does not increase shear strength. To eliminate the corrosion problems and in an effort to improve the strength of tied connections, the potential of using advanced composite materials as connectors has been investigated. A new Glass Fibre Reinforced Polymer (GFRP) shear connector for masonry has been developed. Tests on web-flange connections in a series of H shaped specimens have shown that there is an increase in strength with these connectors relative to regular steel connectors. The strength of these connectors versus that of bonded connections was also investigated.

Keywords: Diaphragm walls, Shear connectors, Wall ties, FRP, Bond pattern, Web/flange connections

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INTRODUCTION

In cavity and diaphragm wall construction, the connectivity between the two wythes is essential to ensure composite action between the two wythes, which in turn determines the structural performance of the wall. In cavity wall construction the connectivity must be gained through the use of ties. In diaphragm walls, however, the bond pattern can be altered so that the webs interlock with the flanges, or ties may be used instead. Typically, the ties are of galvanized steel. A major problem associated with these ties is their corrosion. Since masonry is usually the rain screen of the wall, moisture in the cavity is unavoidable. Therefore, the only viable solution to avoid corrosion problems is to use ties of a corrosion-free material. In this regard, Advanced Composite Materials (ACMs) or Fibre Reinforced Polymers (FRPs) are a useful alternative to stainless steel. The use of Carbon FRPs and Glass FRPs (GFRP) has become more and more common in the construction industry, both in new construction and in rehabilitation projects. These materials have high strength and light weight but are not as ductile as mild steel [Hercules (1995), Santoh (1993)]. They require protection from ultra-violet light but otherwise appear highly durable.

At present, ACMs are generally more expensive than traditional non-corroding materials, but on a life-cycle cost basis, ACMs are a viable alternative. The cost of ACMs is expected to decrease with their increasing popularity. The use of FRPs in masonry construction is not very frequent although continued research in this area should produce similar changes in the masonry industry as have occurred in the concrete industry.

BACKGROUND

Preliminary tests on 10 H-shaped specimens were performed at the University of Newcastle, Australia. Two replicates each of five combinations of bonding pattern and reinforcement were tested. The test arrangement used in Newcastle was the basis for the arrangement used in Calgary as described below. These tests are discussed in more detail elsewhere [Lissel, Shrive and Page, 2000]. A summary of the results obtained is presented in Table 1.

In these tests, when a bonded (or interlocked) connection was used in conjunction with ties, the tie was orientated in the same direction as in the unbonded specimens, that is, in the web direction, lying from the web into the flange. The tests indicated that the strength of an interlocked connection is far greater than that of a tied connection, but when both ties and interlocking were used, there was no conclusive evidence that the ties contributed at all. It was, however, observed that in the interlocked specimens, the flanges started to buckle under the high loads and due to the connectivity to the web. Therefore for the current test series described below, the orientation of the ties in interlocked specimens was changed to be in the direction of the flange.

Table 1 - Connection test results, Newcastle, Australia

Specimen[a]	Type of Reinforcement[b]	Bonded/ Unbonded	Ultimate Load (kN)	Shear Stress[c] (MPa)
1	GFRP 60 (WG)	Unbonded	38.3	159.5
2	GFRP 60 (WG)	Unbonded	47.4	197.4
3	GFRP 120 (GG)	Unbonded	59.8	124.5
4	GFRP 120 (GG)	Unbonded	52.1	108.6
7	None	Bonded	110.8	3.36
8	None	Bonded	153.5	4.65
10	GFRP 60 (WG)	Bonded	223.1	6.76
6	GFRP 60 (WG)	Bonded	144	4.36
5	GFRP 120 (GG)	Bonded	108.7	3.29
9	GFRP 120 (GG)	Bonded	204.2	6.19

[a] Specimens were numbered in order of testing.
[b] 60 and 120 indicate the area in mm^2 per tie. The same types of ties are used in the current tests but are designated as indicated in the parentheses.
[c] The shear area used to determine the shear stress was equal to the area of reinforcement for the unbonded specimens and equal to the brick area for the bonded specimens.

TEST SERIES

Tests were performed on H-shaped specimens, 5 bricks high, with 2 brick long flanges and a 1 brick wide web, as shown in Figure 1. The bottom brick in the web was removed prior to testing. A nominal compressive force, approximately equivalent to a normal floor load, was applied to the flanges to stabilize the specimen during and after the test. The load to cause failure was applied monotonically to the web as shown schematically in Figure 2a. The deflection of the web was monitored during the test via 4 Linear Strain Converters (LSCs) in the NW, NE, SW, and SE corners of the connection. The actual test arrangement is shown in Figure 2b.

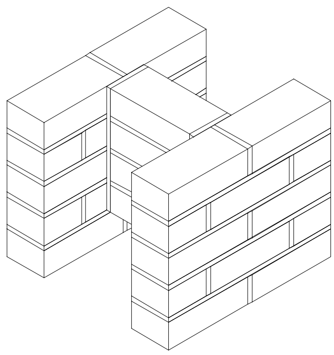


Figure 1 - Typical Test Specimen

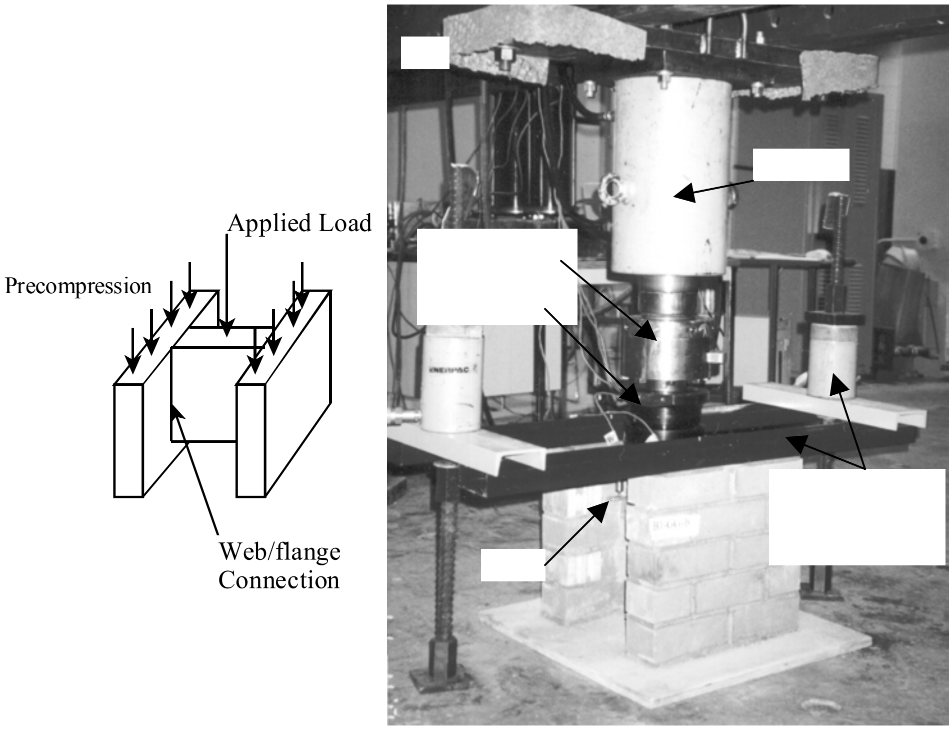


Figure 2 - a) Schematic of test arrangement, b) Actual test arrangement

Forty eight specimens were tested. The variables tested were 4 types of brick, 4 types of ties (Figure 3) and the bond pattern (tied versus interlocked). The types of ties used include standard galvanized steel brick ties, and three types of GFRP ties. The two flat strip types were the same as the ones used in Australia but with holes drilled in the strips to enhance the mechanical anchorage. The third type was a custom made T-shaped type. Three replicates each of 16 combinations of brick type, tie type, and bond pattern type were constructed and tested. The bond pattern difference for tied versus interlocked specimens is illustrated in Figure 4. For most of the tied specimens, the ties were placed across the web-flange connection above the 2nd and 4th courses as shown in Figure 5a. Thus there were 2 ties across each connection. The T-shaped GFRP ties were custom made for this purpose and only a few samples of the ties had been received at the time of construction. This limitation in available materials meant that only 2 ties could be used per specimen, or only one per connection, as opposed to two. The T-shaped ties would have overlapped if placed in the same bed joint due to the small web size, and were again placed above the 2nd and 4th courses (Figure 5b). The tie placement was changed for the interlocked specimens due to observations made in the previous test series. The ties were placed above the 2nd and 4th courses (2 on each side as for the tied specimens) but the orientation was rotated 90 degrees to reinforce the flange rather than the web-flange connection (Figure 5c), in an attempt to avoid the flange buckling.

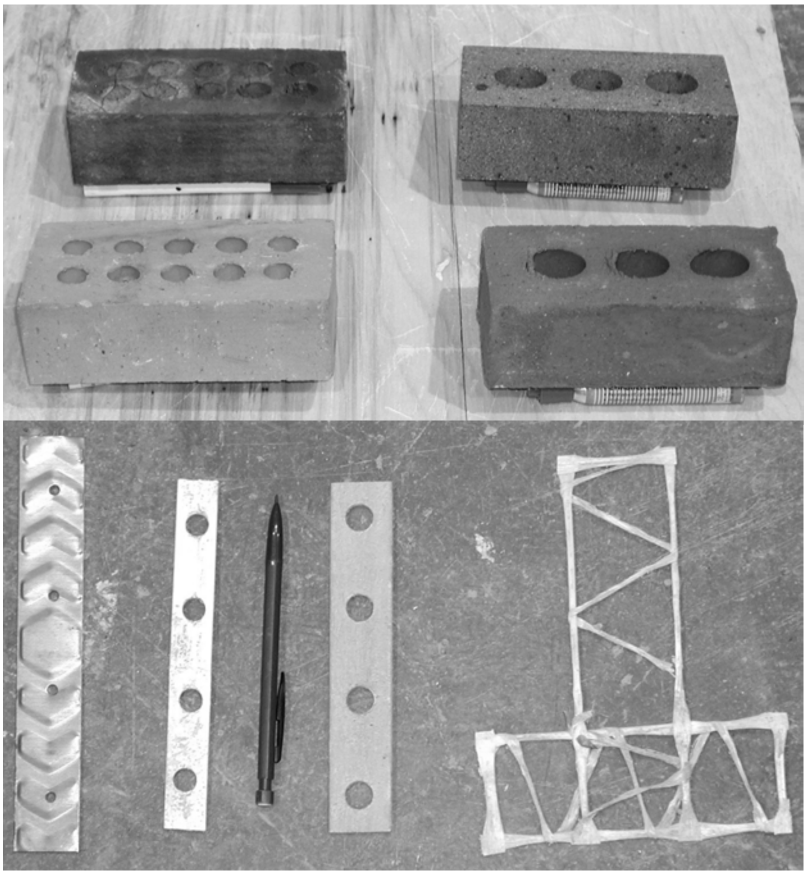


Figure 3 - Brick types: Front row L-R: Peach (B1), Salmon (B2), Back row L-R: Brown (B3), Speckled (B4); Tie types: L-R: Steel, GFRP 1 (WG), GFRP 2 (GG), GFRP 3(TG)

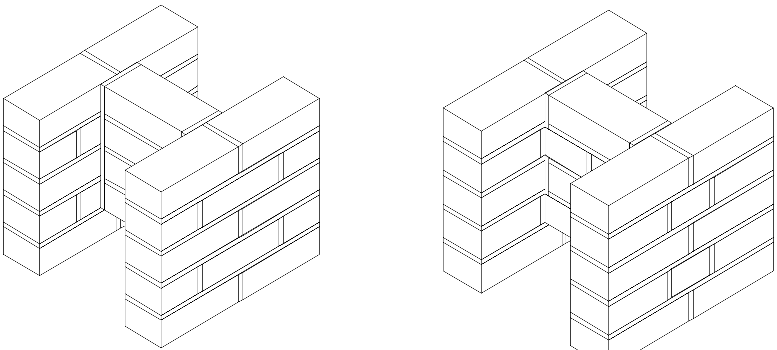
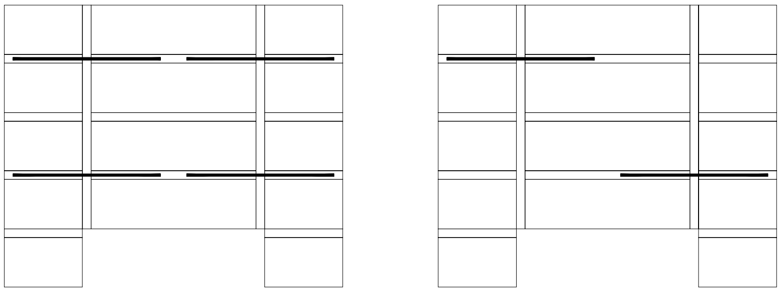


Figure 4 - Tied versus Interlocked bond pattern

a



c)

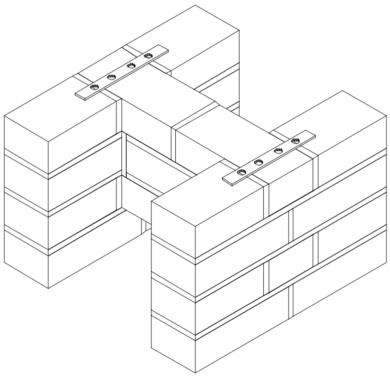


Figure 5 - a) Normal tie placement b) Tie placement for T-shaped ties, c) Tie placement for interlocked specimens

GENERAL OBSERVATIONS

The majority of the specimens were 23 to 25 days old at the time of testing, within an overall range of 23 to 33 days. The difference in age at testing did not appear to have any effect on the test results.

The buckling of the flanges that occurred during the tests in Australia occurred in only one specimen in these tests (brick type 2, no reinforcement, interlocked). That specimen, incidentally, had the highest ultimate load obtained in this series of tests (130 kN). It is difficult to conclude if changing the orientation of the reinforcement helped strengthen the flanges. The interlocked specimens tested in Newcastle failed at loads that ranged from the lowest at 110 kN to the highest of 223 kN. The highest load in the tests described here lies in this range. However, the loads were expected to be lower on average in these tests due to the smaller size of Canadian bricks compared to Australian (Canadian standard brick size: 90x57x190 mm versus Australian standard brick size: 110x75x235 mm). Hence, it is possible that the realignment of the ties did help reduce the buckling of the smaller flanges, or that the loads reached in this series were not high enough to cause the buckling effect.

The tied specimens all failed in approximately the same range of load (20-45 kN) which is in the same range as the failure of the tied specimens tested in Newcastle. One significant difference between the steel and GFRP ties is the ductility. As would be expected, the steel ties allowed much more deflection and maintained a fairly high load compared to the GFRP ties. Very few of the steel ties broke completely: most simply bent and pulled out of the mortar as the web was displaced downward. The GFRP ties, being more brittle, usually either broke or pulled out of the flange or web. Some typical failures of tied specimens are shown in Figure 6.

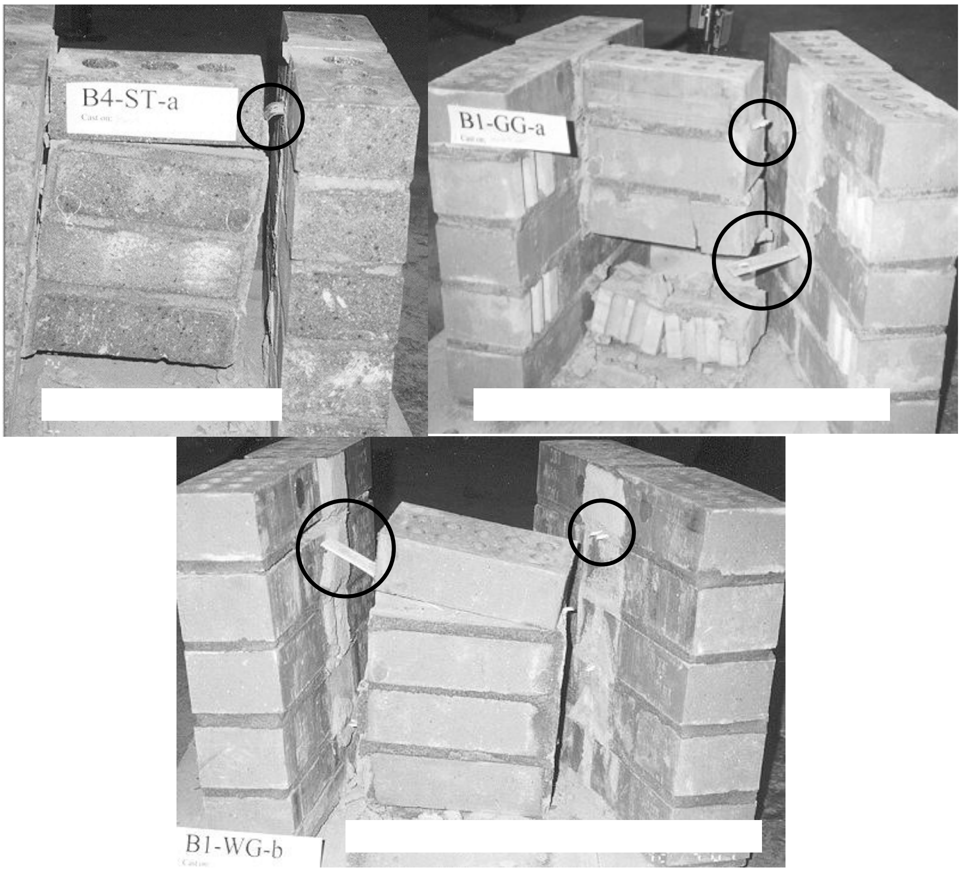


Figure 6 - Typical failure of tied specimens (Clockwise from top left: Steel ties, Grey GFRP ties, White GFRP ties)

The holes drilled in the GFRP strips, to try and create mechanical interlock between the ties and the mortar, did not appear to provide any additional strength compared to the tests in Newcastle. In the series tested in Newcastle, the grey GFRP ties (120 mm^2 cross-sectional area) provided some additional strength but not twice the strength of the smaller (white) GFRP ties (60 mm^2 cross-sectional area). The ties with the larger cross-sectional area were less effective as illustrated by comparison of the shear stresses. Similar results were observed in the current test series. The additional area of reinforcement provided no additional strength and the stresses indicate that the grey ties were the least effective.

These ties may simply be too thick to be used in masonry construction. The grey ties are 4 mm thick by 30 mm whereas the white ties are 3 mm thick by 20 mm. In terms of reinforcement stresses, the T-shaped GFRP ties are the most effective. By nature of their design, they obviously provide better anchorage, no pull out occurred with this type of reinforcement. They are also only about 2 – 3 mm thick. Figure 7 shows one of the specimens tied with the T-shaped reinforcement and one tied with steel reinforcement after failure. It is observed that the T-shaped reinforcement shows absolutely no sign of the bond failure (pull out) between mortar and tie that must occur with the steel ties as the web displaces so far. The charts in Figure 8 show load and deflection versus time for a steel tied specimen and a T-shaped GFRP specimen. The steel tied specimen has some levelling of its load carrying capacity when the web deflects more than about a millimetre, and then as the ties begin to carry the load, the capacity once again increases. At approximately 5 mm of deflection there was a significant drop in load capacity, presumably when the ties yielded and formed a plastic hinge, or had completely debonded and began to slip out of the mortar. After that point, the deflection continued to increase and there was a slow increase in load. The specimen tied with the T-shaped GFRP exhibited similar behaviour, with the ties picking up the load after the initial failure when deflection started. Again at approximately 5 mm deflection there was a significant loss in load. The specimens with the GFRP ties do not exhibit the ductile behaviour that the ones with the steel ties do.

Figure 7 - Failure in steel tied and T-shaped tied specimens

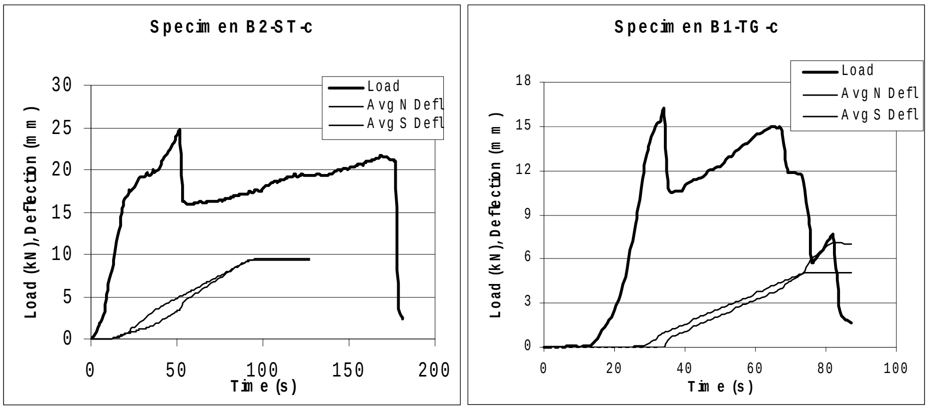


Figure 8 - Typical load and deflection curves for steel
and T-shaped tied specimens

With the interlocked specimens, the failure sometimes occurred first in one connection and then in the other. Typically, the first failure was on the same side in the test apparatus. Inspection of the test arrangement did not reveal any reason for the consistency in one-sided failure. The interlocked failures were quite sudden with a significant drop in load after the initial failure. Some load was maintained after the initial failure due to the mechanical action between the jagged parts of the failure line (Figure 9).

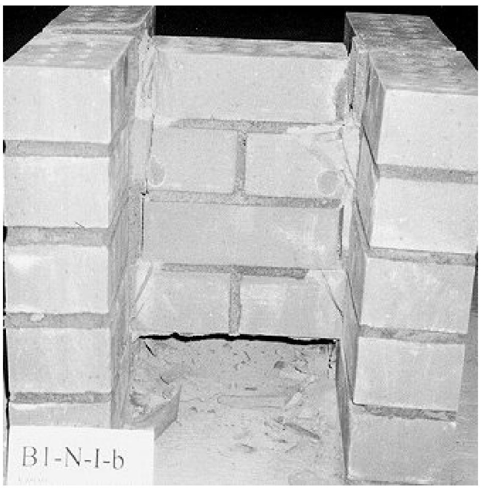


Figure 9 - Typical failure of interlocked specimen

TEST RESULTS

The average failure loads and stresses (3 replicates) are tabulated below. The loads were converted to shear stresses as follows: For tied specimens, the load was assumed to act equally on each connection and was resisted by the 2 ties on each side. The exception to this was for the specimens with T-shaped ties where only one tie was present on each side. For interlocked specimens, the load was assumed to be distributed equally between the 2 connections with two bricks resisting the failure in each connection. When the failure occurred in one connection before the other, two failure stresses were calculated. The first was obtained in the usual way, taking half the load over the area of 2 bricks. The second was obtained assuming that the remaining load capacity was redistributed by the spherical seat entirely to the second connection and then taking that load over the area of 2 bricks. This yielded similar failure stresses for both connections and was therefore thought to be reasonable.

Table 2 - Test results: Values given are average of 3 replicates

Specimen Type[a]	Failure Load (kN)	Shear Stress (MPa)
B1-ST	36.9	329.5
B2-ST	20.7	227.1
B3-ST	21.5	192.0
B4-ST	34.3	306.3
B1-GG	32.8	68.3
B1-WG	38.1	146.7
B1-TG[b]	20.8	593.3
B1-GG-I	90.8	4.23
B2-GG-I	86.9	3.66
B3-GG-I	89.9	4.53
B1-ST-I	94.4	4.18
B2-ST-I	94.7	4.01
B3-ST-I	90.1	4.33
B1-N-I	100.2	4.46
B2-N-I	108.1	4.69
B3-N-I	89.5	4.39

[a] B1= peach brick, B2= salmon brick, B3= brown brick, B4= speckled brick, ST = steel ties, GG = Grey GFRP ties, WG = white GFRP ties, TG = T-shaped GFRP ties, N = no ties, I = interlocked web/flange connection
[b] Only one T-shaped tie was used in each connection, as opposed to the 2 used in all other tied specimens

Steel ties were used with all 4 types of brick in an attempt to rule out brick type as an influence on the connection strength. From these results brick type cannot be entirely ruled out with respect to influencing connection strength. Perhaps the different absorption characteristics of the bricks affected the mortar strength and thus the ability of the tie to stay bonded in the joint and to withstand the load. Surprisingly, for the interlocked specimens, with or without ties, the test results seem to indicate that the bricks have similar shear capacities. The brick types were not all the exact same size so the differences in size were taken into account when determining the failure stress.

All tie types were used in combination with brick type 1. The interlocked connections were obviously the strongest by far. As far as the ties themselves go, all types were comparable in ultimate loads (keeping in mind that only 1 tie per connection was used for the T-shaped ties and theoretically 2 ties would be stronger). Looking at the stresses, the T-shaped GFRP ties had far better performance than the other two types of GFRP. Although the steel ties have the advantage in that they allow significant deflection while maintaining a fairly high load, the corrosion problems associated with these ties, especially when the galvanizing has been compromised by the bending of the ties, are of major concern.

SUMMARY/RECOMMENDATIONS

Shear tests on tied and bonded (interlocked) web/flange connections indicate that ties have little influence on the strength of bonded connections. Bonded connections provide, by far, the best resistance to shearing of the connection but introduce limitations into the bond pattern and construction of the wall. When ties alone are desired, several things should be considered. Steel ties provide the connection with a ductile response to shear load but are of course associated with corrosion problems. Of the GFRP ties tested, the T-shaped ties show definite promise in being able to lock into the mortar bed and transfer shear stress. Further designs and tests with this type of tie are warranted.

ACKNOWLEDGEMENT

This work was performed with the financial support of the ISIS NCE (Intelligent Sensing for Innovative Structures Network of Centres of Excellence). Bricks and mortar were supplied by I-XL Brick Supplies Ltd., Medicine Hat, Alberta – many thanks. The T-shaped ties were custom made with the cooperation of John Cyrson of Cyrson Design, Edmonton, Alberta: again, many thanks. The specimens were constructed by members of Innovative Design and Hagblom Masonry Contractors, funded by the Masonry Contractors Association of Alberta, South Chapter. This support is greatly appreciated. Last but not least, the help of the technical staff of the Civil Engineering Department at the University of Calgary is gratefully acknowledged.

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