EFFECT OF VENEER JOINT REINFORCEMENT ON BRICK TIE EMBEDMENT

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ABSTRACT

Some building codes require single wire joint reinforcement in masonry veneer walls in higher seismic zones. The current investigation examines the effect of joint reinforcement on the embedment performance of one type of brick tie under reversed cyclic loading. The embedded part of the brick tie was tested in small wall elements under three conditions: no joint reinforcement, joint reinforcement not connected to the brick ties, and joint reinforcement connected to the brick ties. Vertical surcharge loads were varied to represent conditions near the top and bottom of a one-story wall. Test procedures, apparatus and instrumentation are described. Test results and modes of failure are presented and discussed.

Keywords: Brick, Veneer, Joint Reinforcement, Tie Embedment, Cyclic Loading

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INTRODUCTION

For brick veneer, U.S. building codes require that, in higher seismic regions, joint reinforcement be provided in the courses containing brick ties. The Canadian masonry code CSA S304.1-94 does not have such a requirement for seismic regions in Canada. To determine whether this requirement is necessary, the benefits of such joint reinforcement need to be investigated.

There are two schools of thought on why joint reinforcement is required by U.S. codes. One is that the joint reinforcement helps to improve the embedment capacity of brick ties, while the other is that the joint reinforcement improves the integrity of the veneer assembly. The current phase of this investigation is concerned with only the first issue – how joint reinforcement affects the embedment performance of brick ties subjected to reverse cyclic loading.

The U.S. codes require that the joint reinforcement be connected (clipped) to the brick ties for the more severe conditions. Thus three types of construction were examined in the current investigation: brick ties without any joint reinforcement; brick ties plus a single wire of joint reinforcement that was not connected to the tie (unclipped); and brick ties that were connected (clipped) to the single wire [see Fig. 1].

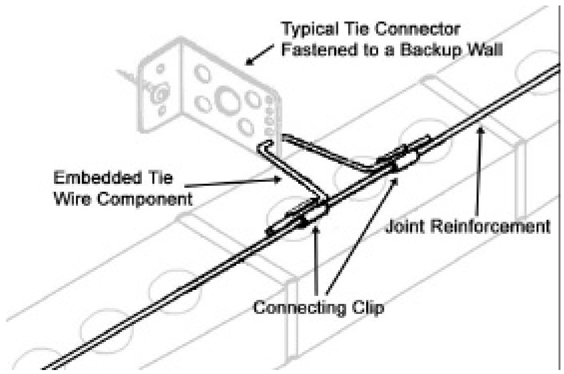


Figure 1-Two piece adjustable tie clipped to a single wire joint reinforcement (adapted from FERO, 2000)

It is well known that the location of a brick tie in a wall may significantly affect the embedment performance of the tie. The ties near the base of a wall benefit from the additional clamping stress provided by the weight of the bricks above. To examine the effect of tie location on performance, surcharges of 4.2 kPa (0.61 psi) and 60 kPa (8.7 psi) were used which simulate conditions near the top and bottom of a single story wall.

To ensure embedment failure, the tests were done on small panels and used only the embedded wire portion of a two-piece adjustable tie commonly used in Western Canada [see Fig. 1]. Additional tests are underway to examine: several U.S. tie systems that are used with wire; the influence of off-centre tie location; and other loading protocols. However, information about these tests is not included in the current paper. A comprehensive report on all the tests is currently under preparation (Wibowo, et al., 2001).

EXPERIMENTAL PROGRAM

The methodology adopted was to study an element consisting of one brick tie in a surrounding brick panel that would simulate conditions in a wall. The maximum spacing of brick ties in Canada is 600 mm (24 in.) vertically and 800 mm (32 in.) horizontally, while in the U.S. it is 450 mm (18 in.) vertically and 600 mm (24 in.) or 800 mm (32 in.) horizontally, depending on the code. The brick panel specimens used in the current investigation were 450 mm (18 in.) high and 800 mm (32 in.) wide with a single brick tie at the centre [see Fig. 2(b)]. The width used was felt to provide adequate joint reinforcement length for the investigation.

To simulate the boundary conditions of an element within an actual wall, all four edges of the brick panels were fixed against rotation [see Fig. 2(c)]. One challenge was to develop an apparatus that would restrain the top edge against rotation, but allow vertical movement, i.e., allow the surcharge to be applied to the brick element. This condition is shown schematically in Fig. 2(d). For brick elements that were meant to simulate conditions near the top of a wall where there is very little surcharge and the top edge of the panel was left completely free. Fig. 2(b) shows the lengths of the clamping plates used along the edges of the panels. To ensure that the load applied to the brick tie was perpendicular to the brick veneer, a special loading guide and clamping device were developed [see Fig. 2(a) and Fig. 3]. An earlier pilot series of test resulted in refinements to the apparatus and to the length of the embedded tie wire.

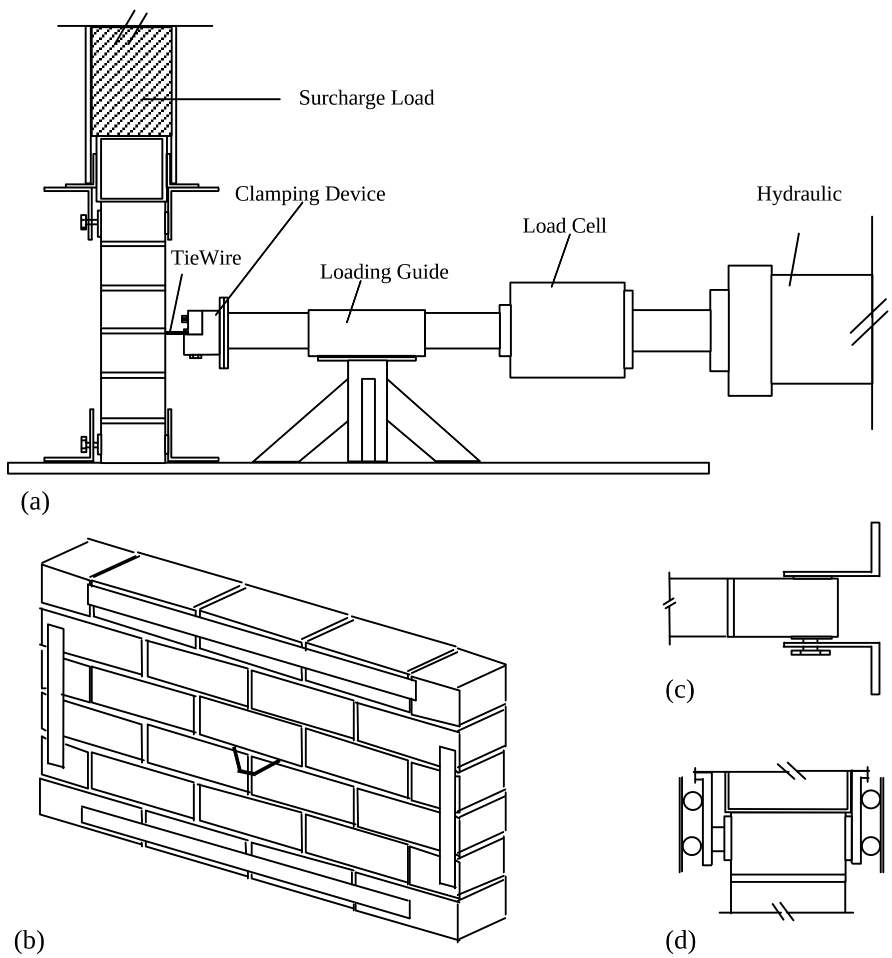
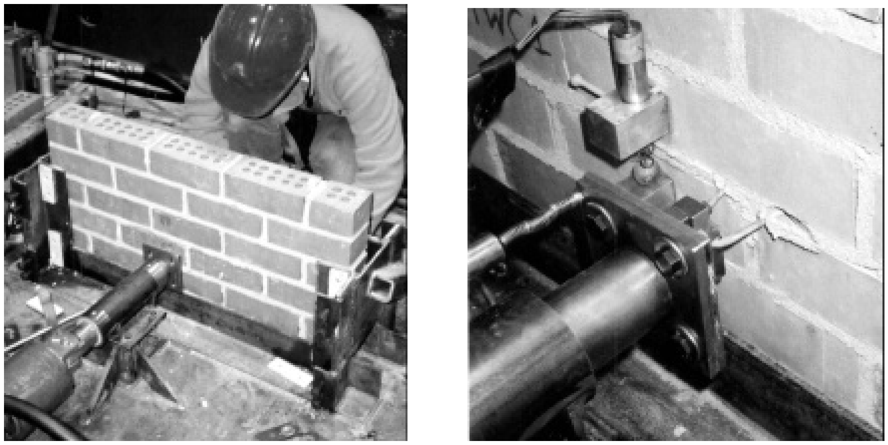


Figure 2-Experimental apparatus: (a) elevation, (b) typical brick panel specimen with edge restraint plates, (c) details of edge restrain along sides and bottom, (d) details of edge restraint along top for specimen with high surcharge



(a) (b)

Figure 3-Photographs of apparatus: (a) over-view; (b) connection to tie

The left hand columns of Table 1 describe the main characteristics of the test specimens. The variables investigated were the type of joint reinforcement and the surcharge level. Three identical specimens of each type were tested in order to determine the repeatability of the results.

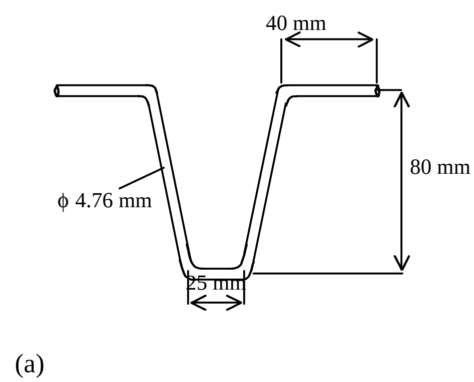
Table 1-Summary of Experimental Program

				Summary of Results							
				Tension				Compression			
				1st Cycle		3rd Cycle		1st Cycle		3rd Cycle	
Specimen Name	Horizontal Bed Joint Reinf.	Surcharge (kPa)	Age (days)	Peak Load (kN)	Displ. at Peak Load (mm)	Load at 5 mm (kN)	Load at 10 mm (kN)	Peak Load (kN)	Displ. at Peak Load (mm)	Load at 5 mm (kN)	Load at 10 mm (kN)
T1	none	4.2	47	3.41	-0.92	0.46	0.35	-4.62	-1.56	-1.24	-1.31
T2	none	4.2	54	3.12	0.55	0.52	0.44	-3.45	-1.00	-1.31	-1.18
T4	none	60	58	3.68	1.71	1.41	1.01	-2.95	-1.98	-1.92	-1.71
T5	none	60	64	3.68	1.66	1.69	1.49	-3.05	-0.68	-1.73	-1.18
T6	none	4.2	75	2.87	1.50	0.82	0.54	-2.90	-1.12	-0.87	-0.59
TW1**	wire (no clip)	4.2	51	1.21	6.81	0.66	0.79	-1.98	-5.93	-1.39	-1.11
TW2	wire (no clip)	4.2	56	2.32	0.65	0.92	0.33	-2.68	-0.95	-0.94	-1.00
TW3*	wire (no clip)	4.2	72	0.81	3.68	0.48	0.48	-2.40	-2.81	-1.45	-1.01
TW4	wire (no clip)	60	62	3.03	1.46	1.48	0.86	-4.08	-4.72	-2.35	-2.50
TW5	wire (no clip)	60	65	4.56	1.77	2.07	1.66	-4.03	-1.47	-2.81	-2.52
TW6	wire (no clip)	4.2	75	3.57	1.57	0.95	0.79	-3.87	-0.76	-1.71	-1.68
TWC1	wire - clipped	4.2	51	2.80	3.15	1.34	0.86	-2.74	-3.21	-1.28	-0.71
TWC2	wire - clipped	4.2	57	2.03	6.85	1.51	0.65	-2.68	-0.89	-1.07	-0.90
TWC3	wire - clipped	4.2	72	2.55	1.40	1.42	0.90	-2.82	-1.72	-1.38	-0.87
TWC4	wire - clipped	60	63	4.22	3.64	3.45	2.01	-3.89	-1.53	-2.39	-1.87
TWC5	wire - clipped	60	70	3.99	5.78	3.24	2.97	-5.33	-2.74	-3.48	-1.91
TWC6	wire - clipped	60	78	3.64	3.31	2.53	0.87	-5.31	-3.32	-4.01	-1.84

All specimens were built using type S cement lime mortar.
All brick ties were 80 mm V-Tie.

* Loading problem, data included in table but not in figures.
** Specimen pre-cracked, data included in table but not in figures.

The test specimens were constructed by an experienced mason using extruded clay bricks 90 mm (3.5 in.) wide, 63 mm (2.5 in.) high, and 190 mm (7.5 in.) long. A 12 mm (½in.) mortar joint was used. Type S (cement-lime) mortar was used for all specimens. A single batch of a premixed wet mortar was used to construct the 18 specimens. The compressive strength of the mortar was determined by testing 2×2 in. cubes at 44 and 69 days (at the beginning and end of the tests). The results from four tests conducted at 44 days indicated a mean compressive strength of 9.7 MPa (1406 psi) and a coefficient of variation (COV) of 14 %, while the six tests conducted at 69 days indicated a mean compressive strength of 11.1 MPa (1612 psi) and a COV of 9 %. These results exceed the requirements for type S mortar. To determine the flexural bond strength, bond wrench test samples were constructed at the same time as the test specimens. The results from 11 of these tests conducted at 44 days indicated a mean flexural bond strength of 1.1 MPa (155 psi) and a COV of 34 %, while the results from 12 tests conducted at 87 days indicated a mean flexural bond strength of 1.05 MPa (153 psi) and a COV of 33 %. These results indicate that good bond was achieved.



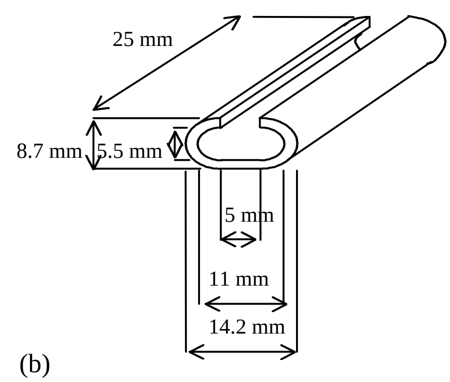


Figure 4-Geometry of: (a) the embedded wire portion of a two piece adjustable tie, and (b) the tie clip (adapted from FERO, 2000)

The instrumentation used included a load cell to measure the load applied to the brick tie, and five LVDT displacement transducers to measure: the stroke of the hydraulic actuator, the out-of-plane displacement of the brick tie, the out-of-plane displacement of the brick at the location of the tie, and the vertical displacements across the critical mortar joint on the two sides of the brick panel.

All specimens were tested using a displacement-controlled reversed-cyclic loading protocol that is commonly used in seismic investigations. A typical cycle of loading involved: applying tension until the hydraulic actuator moved by the specified target displacement amount; unloading; then applying compression until the hydraulic actuator moved the specified displacement amount, and finally unloading once again. Three cycles of loading were applied at each target displacement level. The target displacement levels were at +/-1 mm increments up to 12 mm, and then to 15 mm. While the loading protocol was defined in terms of the actuator stroke, the main displacement of interest is the movement of the tie relative to the surrounding brick.

EXPERIMENTAL RESULTS

Figure 5(a) shows a typical measured relationship between the applied force on a tie and the displacement of the tie relative to the brick. Typically the largest loads were required to displace the tie a few millimetres while the mortar was still relatively undamaged. After significant damage of the mortar due to cyclic loading, smaller loads were required to displace the tie to the larger target displacement levels. It is important to note how the hysteresis curves are very "pinched" in the later stages after the mortar is damaged. That is, very little load was required to move the tie through the middle part of the cycle with the resistance picking up sharply near the ends.

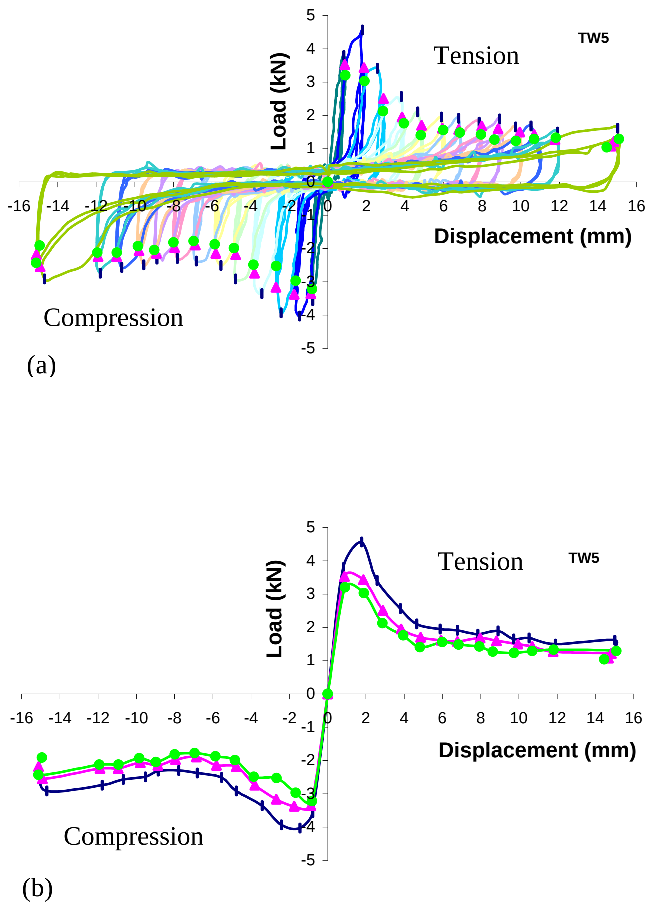


Figure 5-Typical tie load-displacement curves: (a) complete hysteresis curves,
(b) corresponding envelopes.

In order to facilitate the comparison of the different load-deformation relationships, the peak load during each cycle to each displacement level was identified, as shown by the markers in Fig. 5(a). These peak loads were used to plot the envelope curves shown in

Fig. 5(b). The maximum loads and the corresponding displacements during the first cycle of loading, as well as the loads at 5 mm and 10 mm displacements during the third cycle of loading are listed in Table 1.

One way to compare the performance of the different specimens is to compare the maximum loads (Fig. 6), which are the first cycle peak loads given in Table 1. It is important to realize, however, that the peak loads that were measured are a function of the loading protocol that was used. That is, if a different step size had been used for the target displacements, or if the specimens had been loaded monotonically, different maximum loads may have been obtained.

Figure 6 indicates that with no joint reinforcement (left side data points), the embedment strengths were similar regardless of the surcharge level, while with clipped joint reinforcement (right side data points), the surcharge had a significant influence on the strength. For the low surcharge (hollow markers) there was a slight reduction in embedment strength as joint reinforcement was added, while for the high surcharge (solid markers) there was an increase, particularly for the compression case (solid circles). Overall the strengths in tension and compression were similar.

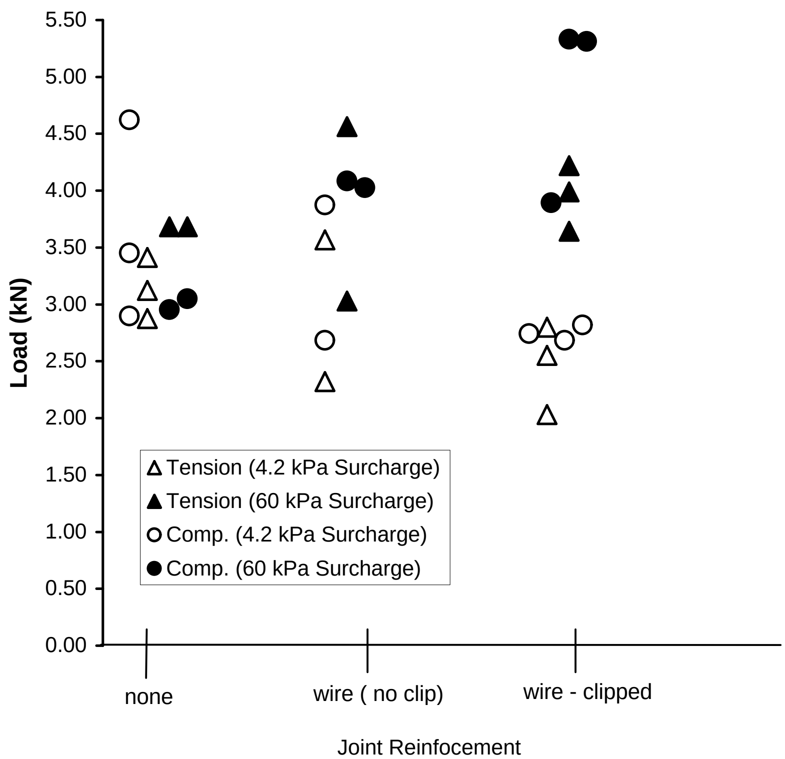
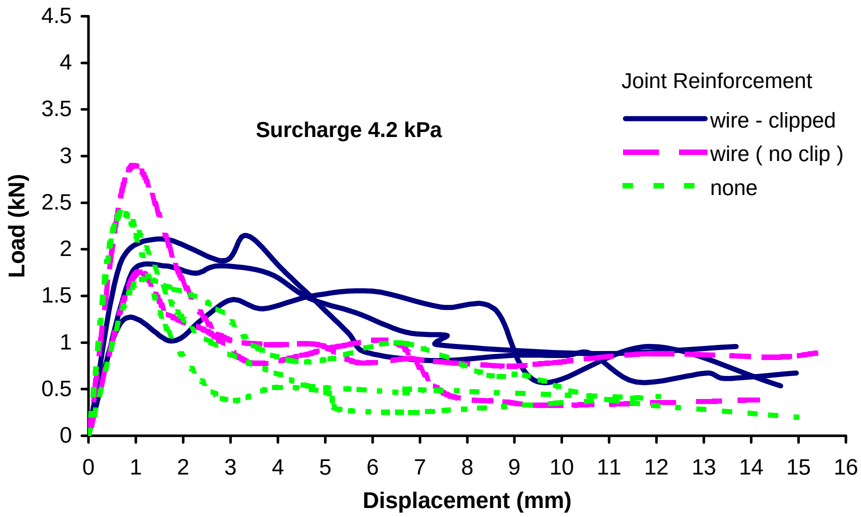
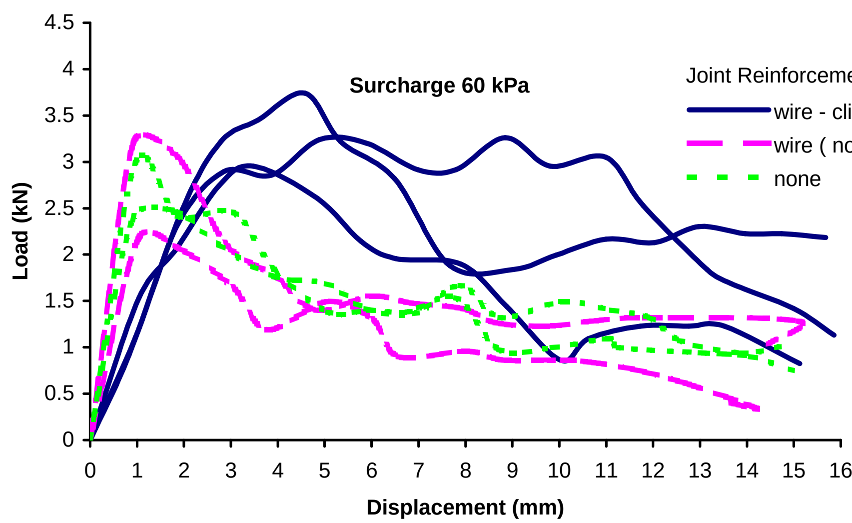


Figure 6-Maximum loads



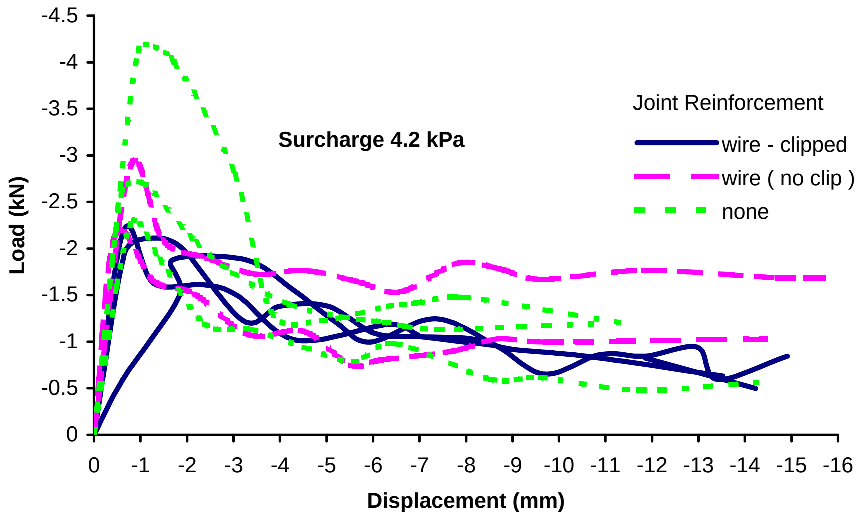
(a)



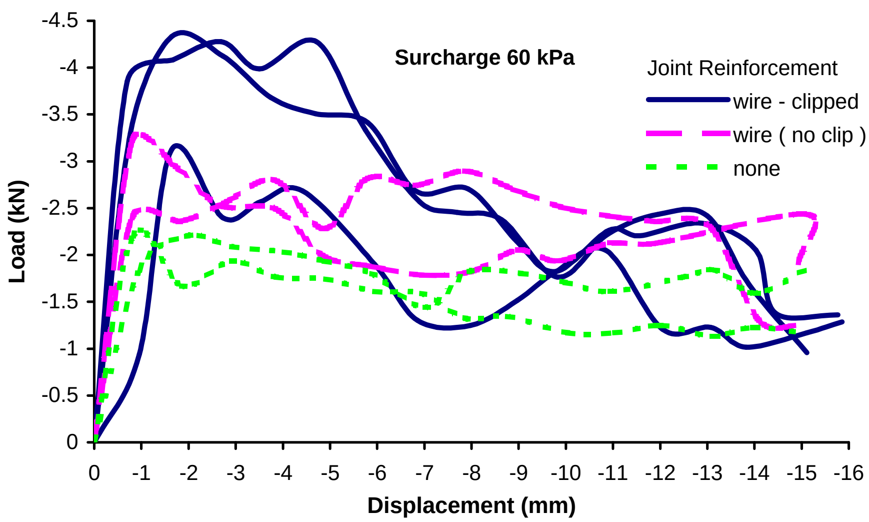
(b)

Figure 7-Influence of joint reinforcement on the third cycle tension envelopes: (a) low surcharge, (b) high surcharge

Figures 7 and 8 compare the envelopes from the third cycle of loading for all tests, Fig. 7 for tension and Fig. 8 for compression. In both figures, part (a) is for low surcharge, while part (b) is for high surcharge. To facilitate comparison, all four figures are plotted to the same scale. In general, there is a significant difference between the envelopes for low surcharge compared to the high surcharge, while there is relatively little difference between the envelopes for tension (Fig. 7) compared to the envelopes for compression (Fig. 8).



(a)



(b)

Figure 8-Influence of joint reinforcement on the third cycle compression envelopes: (a) low surcharge, (b) high surcharge.

The tension envelopes (Fig. 7) indicate that adding only joint reinforcement (no clips) had little effect (compare long dashes and short dashes), however, when the joint reinforcement was clipped to the brick tie (solid lines), there was a significant effect. For low surcharge, the clipped joint reinforcement reduces the peak loads (as was observed in Fig. 6). For both surcharges, the clipped joint reinforcement increases the force required to pull out the tie at higher displacement levels, with about a factor of two increases in load. Another observation from Fig. 7 is that for the high surcharge case, the slope of the envelope (which is different than the effective stiffness) is significantly reduced when the joint reinforcement wire is clipped to the tie.

While the tension side of the envelopes is usually of more interest, it is also useful to examine the compression side (Fig. 8). For the low surcharge (a), there is no visible trend in the envelopes from the specimens with different joint reinforcement except for peak load. For the high surcharge (b) there appears to be somewhat of a trend – the envelopes for the specimens without joint reinforcement wire are near the bottom, while the envelopes for the specimens with clipped joint reinforcement wire are near the top.

Visual observations were made during the load tests and later when the tie bed joint was exposed. For the tie-only case, there was local crushing of mortar and bending of the tie wire at the tie-bend location, along with external push-out and pull-out of mortar. The joint reinforcing case produced similar results, but also appeared to split the bed joint mortar longitudinally, as shown in Fig. 9. The joint reinforcement wire was deflected by the compression loading, but the tie wire also over-rode it at some point. The addition of the clips extended the area of the crushed mortar zone to slightly past the end of the tie wire. The clipped tie cases also experienced over-ride, and in all cases the clip became detached.

Figure 9- Photograph of a failed specimen showing mortar split due to presence of joint reinforcement wire

DISCUSSION

Embedment failure is one link in a series of possible failure mechanisms of a tie system. Metal failure, buckling of the tie and fastener failure are other potential mechanisms. The typical failure loads for these other mechanisms are of a similar magnitude to the maximum loads observed in the current tests. Therefore embedment strength is clearly an important factor in the capacity of a brick tie subjected to reversed cyclic loading.

For seismic design, the strength of the ties must be greater than the inertial forces generated by the veneer. The displacement of the brick ties will be much less than the displacement of the entire structure, and so the inertial forces from the veneer will be only slightly affected by tie displacements.

Ties are normally designed so that the factored load is less than the factored capacity. In theory, the forces on the ties should not exceed their strength, hence ductility or the capacity of the ties to carry load at larger displacement would seem to be of secondary importance. However, it is well known that tie forces are not uniform, particularly for top ties, which can have higher loads in combination with a lower surcharge. Thus it is important that the ties are able to deform while resisting an appreciable load to permit redistribution of the tie forces without overloading the adjacent ties.

The loading protocol adopted in the current study is similar to what is normally used in assessing the ductility and hysteretic properties of the main seismic load resisting members of a structure. Additional monotonic tests will be conducted to obtain the backbone curve of the embedment strength and to permit comparison with other test results in which only peak load (embedment strength) was measured. Additional reversed cyclic tests will also be undertaken to examine the effect of different loading protocols.

CONCLUSIONS

This investigation examined the effect of joint reinforcement on the embedment strength of brick ties subjected to seismic loading. This paper focuses on the results from 18 specimens on the embedded wire portion of a two-piece adjustable tie commonly used in Western Canada. Based on the results of these tests, the following conclusions can be made about the effect of joint reinforcement on the embedment strength of these particular ties.

- No improvement in embedment strength was observed when joint reinforcement was provided but not clipped to the brick tie. Thus if joint reinforcement is provided for embedment purposes, it should be attached to the brick tie.

- It is well known that ties with the low surcharge condition near the top of a wall have the highest brick tie load, and the lowest brick tie embedment resistance. The lower embedment resistance was reaffirmed in the current tests. A surprising conclusion from the current tests is that under the low surcharge condition, the addition of joint reinforcement actually reduces the peak embedment strength. Clipped wire does increase the resistance at large displacements when the brick tie is in tension but not when the tie is in compression.

- Under the high surcharge condition that occurs near the base of a one-story wall, the embedment strength is generally higher, and the addition of joint reinforcement increases the embedment strength as expected.

- The clip used in the current tests allowed the tie wire to override the joint reinforcement wire, and the two wires eventually became unclipped. It must be pointed out, however, that the loading protocol that was used may have been too harsh of a test as about 40 cycles of loading was applied.

Additional tests are currently being conducted to examine other tie types, the influence of misplacing the tie within acceptable construction tolerances, and the effect of other load histories such as monotonic and fewer cycles of reversed cyclic loading.

ACKNOWLEDGEMENTS

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