SUPPORTING MASONRY VENEER

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ABSTRACT

With the incorporation of insulation in the cavity of masonry veneer wall assemblies, providing support for the exterior wythe or veneer wall has become very expensive. The continuity of the insulation and that of the air barrier has increasingly made it necessary to install an elaborate system consisting of a gusset plate fastened or welded to the main structural elements and an angle iron bolted or welded to the gusset plate. This system is designed by a structural engineer and typically handled at the job site under miscellaneous iron at substantial cost. A new and innovative system for supporting masonry veneer is presented. The system requires no weld and thus allows installation to be performed by the masons. Out-of-plumb building tolerances can easily be accommodated during veneer construction to ensure the veneer is both plumb and has sufficient support by the shelf angle.

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INTRODUCTION

This paper presents the test results for an innovative system used to support masonry veneer. **F**ero **A**ngle **S**upport **T**echnology (FAST) brackets were designed to meet the demand for technology that allows for faster, lower-cost shelf angle installations. This new system achieves these advantages primarily through the elimination of all welded connections and the ease with which one trade can readily install the system with no down time during construction. The FAST system is comprised of 4 basic components, namely the FAST bracket, shim plates (if necessary), an anchor bolt for each bracket, and the shelf angle to support the design veneer loads. Figure 1 identifies the four components.

A full-scale testing program consisting of 44 FAST bracket specimens was performed in the I. F. Morrison Structural Engineering Lab at the University of Alberta. The objective of this testing program was to investigate the failure modes and load capacity of the FAST brackets. This paper outlines the details of the testing program, the experimental results, and provides recommendations regarding the load carrying capacity of the brackets.

EXPERIMENTAL PROGRAM

Test Specimens

Test brackets were provided by FERO Corporation. All of the brackets were fabricated from 270 MPa grade steel with a thickness of 4.76 mm. For fabrication, the specimen dimensions were laid out on flat steel sheet, laser cut, and then cold formed into the proper shape. Once formed, each bracket was hot-dipped galvanized. For comparison purposes, four brackets were tested without the hot-dip galvanizing to ensure that their properties were similar to those that received the hot-dip galvanizing.

Five different size brackets were specified for the testing program. The sizes varied in terms of the length of the outstanding legs of the bracket and in terms of the overall height of the back-face of the bracket. The distance between the outstanding legs on each bracket was found to be a constant 92 mm (3-$^{5}/_{8}$"), outside dimension, with a variation in this dimension of approximately 3mm ($^{1}/_{8}$"). The brackets will hereafter be identified by the length of their outstanding legs, specifically, 1.0", 1.5", 2.0", 3.5" and 5.0". Tables 1 to 5 provide the identity and the actual dimensions of each bracket contained within the five groups of sizes tested.

The brackets had one of two different overall heights. Brackets with an outstanding leg length greater than 50.8 mm (2") had adequate space for the head of the anchor bolt between the bracket and the shelf angle. As a result, the brackets with the outstanding leg greater than 50.8 mm (2") had a nominal overall length of 152.4 mm (6"). For the brackets with an outstanding leg length less than 50.8 mm (2"), the head of the anchor bolt would not fit between the bracket and the back of the shelf angle. To accommodate the anchor bolt, the bracket was extended approximately 38 mm (1.5") resulting in a nominal overall length of

190.5 mm (7.5").

Figure 2 shows a bracket with an outstanding leg of 38 mm (1.5"). Note that the anchor bolt will not fit in the space between bracket and the shelf angle and that the back face of the bracket extends sufficiently above the top of the shelf angle to accommodate the anchor bolt. For comparison, Figure 3 shows a bracket with an outstanding leg length of 50.8 mm (2"). Observe in this case that the anchor bolt has sufficient space to fit between the bracket and the shelf angle. This is evident by the bolt being only partially visible in this figure.

Each bracket utilized a diagonal slot cut into the back face for the anchor bolt. The purpose of the diagonal slot is to allow for alignment of the bracket during the leveling of the shelf angle in field applications. The slot forms an angle of 22.5^{o} from the vertical and can slope in either direction. In field applications, adjacent brackets should have the slots sloped in alternate directions. This critical detail minimizes the possibility of vertical slipping of the FAST brackets by simultaneously requiring the brackets to horizontally translate toward one another.

Testing Program

Testing was carried out at the University of Alberta's I. F. Morrison Structural Engineering Laboratory. An MTS 810 Universal Testing Machine was used to apply the vertical load to each specimen. Both load and stoke were determined using the MTS 810 internal measuring systems and this data was recorded using a Fluke electronic data acquisition system. All the tests were conducted using load control.

Prior to testing, a testing frame and a loading angle were fabricated. The testing frame was fabricated by welding two 19 mm (¾") plates at 90^{o} to each other. A hole to accommodate the anchor bolt was drilled into the vertical leg of the test frame angle. The loading frame was then placed in the MTS 810 and bolted to the lower reaction head of the MTS 810.

A segment of an 89 mm (3.5") and a segment of a 102 mm (4") shelf angle were specially stiffened for use in the application of transferring the load from the MTS into the FAST brackets. A preliminary testing program previously showed that an unstiffened angle would typically fail before the FAST bracket failed. Since the purpose of this investigation was to determine the capacity of the FAST bracket itself, the stiffened angle was used to ensure that the bracket failed before the angle.

The two different sizes of equal leg angles selected for this investigation were an 89 mm and 102 mm. Both of these sizes are commonly used in shelf angle applications. The FAST brackets were designed and fabricated to accommodate only these two size angles. Larger angles will not fit into the slots in the bracket and smaller angles will not stay in the brackets when loaded. Consequently, both angles were tested with each size of bracket. All tests were conducted using a ½-inch anchor bolt. The slots in the back of the FAST bracket are designed to accommodate either a ½-inch or $^5/_8$-inch bolt. Since the capacity of a ½-inch bolt is less than the capacity of a $^5/_8$-inch bolt, the ½-inch bolt was selected for testing. The load was applied through a steel shaft which was secured in the top hydraulic grips of the MTS machine. This shaft acted vertically on the stiffened shelf angle. Figure 4 shows the testing frame positioned in the MTS 810. This setup includes a 1.5" FAST bracket, the 4" shelf angle, and a ½-inch anchor bolt.

The same procedure was used to test each of the 54 FAST brackets investigated in this program. Each bracket was measured and the dimensions recorded. The bracket was then mounted in the test frame such that the anchor bolt was vertically centered in the slot in the back face of the bracket. Some of the brackets had a stiffened shim plate bolted on the inside face of the bracket. The purpose of this shim plate was to prevent the back-face of the bracket from buckling, thereby increasing the load carrying capacity of the system. Brackets were tested with and without this shim in place. The anchor bolt was then installed with a ½-inch washer between the head of the bolt and the back face of the bracket and made snug tight. A wrench was then used to tighten the bolt an additional one-half turn, as prescribed in the FAST bracket brochure.

The test frame assembly was then positioned in the MTS to align with the vertical steel rod used to apply the load. Once aligned, the test frame assembly was secured to maintain alignment during testing. A constant load rate of 6.7 kN/min was programmed in the MTS and executed in automatic run mode. The load-deflection response for each test specimen was recorded and plotted electronically so that the response could be monitored as the test progressed. Once the specimen had failed, the peak load obtained was recorded and the specimen was removed from the testing frame.

Experimental Results

Failure Modes. Three basic failure modes were observed during the testing of the 54 FAST brackets. The first failure mode, shown in Figure 5, was the tearing off of the hooks that hold the top of the shelf angle in the bracket. The second failure mode was the buckling of the back face of the bracket about the head of the anchor bolt. This buckling, coupled with the contact reactions between the angle and the hooks, promoted an outward rotation at the bottom of the hooks as shown in Figure 6. The shelf angle was then able to slip out of the bracket. The third failure mode was the anchor bolt pulling through the back face of the FAST bracket as shown in Figure 7.

Failure Loads. Tables 1.0 to 5.0 contain the failure loads recorded during testing. Two values are reported for each test specimen. The first value is the slip point for the test specimen, which was the point during testing when a sudden increase in deflection occurred with essentially no increase in load. The slip point was determined using the Load-Deflection curves for each specimen obtained during testing. A line tangent to the initial slope was drawn and the point where the experimental response deviated from this line was deemed to be the slip point. It should be noted that the tangent line drawn took into account any initial seating effects of the bracket during the initial loading. The second load value recorded was the ultimate load carried by the individual bracket during testing. The ultimate load was deemed to be the maximum load applied to the individual bracket at any time during testing. For all the brackets, the ultimate load occurred immediately prior to failure of the test specimen. The response for specimens B-1.0-A and B-1.0-B (1.0-inch brackets) showed two local maximums immediately before failure. This behaviour was observed only in these two specimens because of the limitations of the testing frame. As the test specimens passed the first peak, the deflection was great enough to cause the shelf angle to come into bearing against the bottom of the test frame, thereby exhibiting an apparent increase in load carrying capacity. This erroneous response type was eliminated by modifying the load frame.

Table 6 presents the reduced test data for each of the five FAST bracket sizes tested. Both the mean and standard deviation of for the slip load and ultimate load is shown

DISCUSSION OF RESULTS

The behaviour of the FAST bracket is best characterized through a discussion of a typical load-deflection curve. Figure 8 presents the load-deflection curve for specimen B-2.0-B. This curve was selected because it provides a clear representation of the behaviour. In Figure 8, the curve has been divided into six regions. Region “A” is the initial linear portion of the curve and continues until the behaviour reaches point “B”, which has been defined as the slip point in this project.

At the slip point, the vertical force on the bracket exceeded the frictional resistance provided by the pre-load in the anchor bolt. This accounts for the significant increase in deflection with essentially no increase in load shown in region “C” on Figure 8. Inspection of the brackets after their removal from the testing frame showed that the bolt initially made contact with the slot immediately adjacent to the location where the bolt was installed. However, as the loading increased there was evidence that the bracket had slipped downward. This evidence was manifested in the form of scrap marks up the side of the slot made from the washer. There was also evidence of a new bearing point near the top of the slot made by the anchor bolt.

After the bracket had slipped far enough for contact to be made at or near the top of the slot, the bracket was then in direct bearing against the bolt and the assembly carried additional load as shown in region “D”.

Loading beyond point "D" resulted in localized material yielding within the bracket. This is shown by the non-linear region “E” on Figure 8. The most prominent location where plastic deformations occurred was in the back face of the brackets as previously shown in Figures 6 and 7. A combination of full length bending in the back face of the bracket and localized deformation in the bolt slot region eventually permitted the anchor bolt to pull through the bracket resulting in the loss of load capacity beyond point "F".

The ultimate capacity of the FAST brackets was dependent on a number of parameters including the size of the bracket, the size of the shelf angle, and the presence of a stiffener on the back face of the bracket. However, the ultimate strength of the bracket is not the governing limit state of the FAST system. In all the testing configurations, the brackets slipped vertically prior to any material distress within the bracket system. Thus, the load capacity of the FAST system is governed by the serviceability limit state of preventing vertical slip. As reported in Table 6, the ultimate load capacity is typically greater than three times the slip load ensuring a large degree of reserve capacity should unexpected load transfer occur. From the results presented in Table 6.0, the experimental results suggest that a lower bound slip point value of 5.0 kN be used for all FAST brackets except for the 1.0" bracket. For the 1.0" bracket, a lower bound slip point value of 4.0 kN is recommended.

Table 1. Results of the 1" FAST Brackets

Specimen ID	Overall Height (mm)	Length of Outstanding Legs (mm)	Test Angle Used	Stiffener Plate?	Prop. Limit (kN)	Peak Load (kN)	Failure Mode (Ultimate)
B-1.5-A	188	37.0	4.0”	Y	7.3	30.2	HF
B-1.5-B	188	37.0	4.0”	Y	4.3	30.1	HF
B-1.5-C	188	37.1	4.0”	Y	5.5	30.8	HF
B-1.5-D	188	37.5	4.0”	Y	8.4	30.6	HF
B-1.5-E	188	37.6	4.0”	Y	6.0	30.7	HF
B-1.5-F	188	37.2	3.5”	Y	6.0	17.9	HF
B-1.5-G	188	39.0	3.5”	Y	5.5	17.6	HF
B-1.5-H	188	37.3	3.5”	Y	6.0	17.6	HF

Table 2. Results of the 1.5" FAST Brackets

Specimen ID	Overall Height (mm)	Length of Outstanding Legs (mm)	Test Angle Used	Stiffener Plate?	Prop. Limit (kN)	Peak Load (kN)	Failure[1] Mode (Ultimate)
B-1.0-A	188	25.2	4.0”	N	4.0	19.5	HRO
B-1.0-B	188	25.2	4.0”	N	6.0	18.9	HRO
B-1.0-C	188	25.2	4.0”	N	4.0	20.0	HRO
B-1.0-D	188	25.1	3.5”	N	4.0	14.1	HRO
B-1.0-E	188	25.0	3.5”	N	3.5	13.9	HRO
B-1.0-F	188	25.1	3.5”	N	3.5	13.3	HRO
B-1.0-G	188	25.2	3.5”	N	4.0	13.8	HRO
B-1.0-H	188	25.6	3.5”	N	4.4	13.7	HRO

Table 3. Results of the 2" FAST Brackets

Specimen ID	Overall Height (mm)	Length of Outstanding Legs (mm)	Test Angle Used	Stiffener Plate?	Prop. Limit (kN)	Peak Load (kN)	Failure Mode (Ultimate)
B-2.0-A	151	50.2	3.5”	N	5.0	21.1	HRO
B-2.0-B	151	50.0	3.5”	N	5.0	21.2	HRO
B-2.0-C	151	50.0	3.5”	N	6.0	21.0	HRO
B-2.0-D	151	50.2	3.5”	N	5.6	20.6	HRO
B-2.0-E	151	50.0	3.5”	N	5.0	20.7	HRO
B-2.0-F	151	50.0	4.0”	N	4.4	25.1	HRO
B-2.0-G	151	50.2	4.0”	N	6.5	26.1	HRO
B-2.0-H	151	50.0	4.0”	N	5.0	25.4	HRO

Table 4. Results of the 3.5" FAST Brackets

Specimen ID	Overall Height (mm)	Length of Outstanding Legs (mm)	Test Angle Used	Stiffener Plate?	Prop. Limit (kN)	Peak Load (kN)	Failure Mode (Ultimate)
B-3.5-A	151	89.0	3.5”	N	6.0	21.7	HRO
B-3.5-B	151	88.8	3.5”	N	6.0	21.6	HRO
B-3.5-C	151	87.9	4.0”	N	6.0	21.5	BPT
B-3.5-D	151	88.7	4.0”	N	4.4	21.7	BPT
B-3.5-E	151	88.7	4.0”	N	6.0	21.3	BPT
B-3.5-F	151	88.6	3.5”	N	5.3	23.4	HRO
B-3.5-G	151	89.0	3.5”	N	6.0	22.4	HRO
B-3.5-H	151	87.9	3.5”	Y	8.3	27.7	HRO
U-3.5-A	151	89.5	3.5”	N	6.3	18.0	BPT
U-3.5-B	151	89.4	4.0”	N	6.0	18.8	BPT

Table 5. Results of the 5" FAST Brackets

Specimen ID	Overall Height (mm)	Length of Outstanding Legs (mm)	Test Angle Used	Stiffener Plate?	Prop. Limit (kN)	Peak Load (kN)	Failure Mode (Ultimate)
B-5.0-A	151	127	4.0”	N	6.0	14.9	BPT
B-5.0-B	151	127	4.0”		no data available		
B-5.0-C	151	127	4.0”	N	6.0	13.9	BPT
B-5.0-D	151	127	3.5”	N	4.5	15.9	BPT
B-5.0-E	151	127	3.5”	N	4.5	16.0	BPT
B-5.0-F	151	127	3.5”	N	4.8	15.6	BPT
B-5.0-G	151	127	3.5”	N	5.6	15.5	BPT
B-5.0-H	151	127	4.0”	Y	8.6	34.4	HF
U-5.0-A	151	128	4.0”	N	5.4	13.1	BPT
U-5.0-B	151	128	3.5”	Y	8.6	28.0	HF

Table 6. Reduced Experimental Data

Bracket Size	89 mm (3.5") Loading Angle				102 mm (4") Loading Angle			
	Slip Load (kN)		Ultimate Load (kN)		Slip Load (kN)		Ultimate Load (kN)	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
1"	3.9	0.4	13.8	0.3	4.7	1.2	19.5	0.6
1.5" [2]	5.8	0.3	17.7	0.2	6.3	1.6	30.5	0.3
2"	5.3	0.5	20.9	0.3	5.3	1.1	25.5	0.5
3.5"	5.8	0.4	22.3	0.8	5.5	0.9	21.5	0.2
5"	4.9	0.5	15.8	0.2	6.0	0.0	14.4	0.7

Notes:

1. Failure Modes: BPT — Bolt Pulled Through slot in bracket
   HRO — Hooks Rotated Out by angle
   HF — Hooks Fractured by angle
2. All of the 1.5" brackets were tested with stiffener shims along the back face of the bracket. The remaining values reported in this table were for brackets tested without these shims.