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In-Plane and Out-of-Plane Performance of the MINI-MC Flange Connector

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IN-PLANE AND OUT-OF-PLANE PERFORMANCE
OF THE
MINI-MC FLANGE CONNECTOR

By

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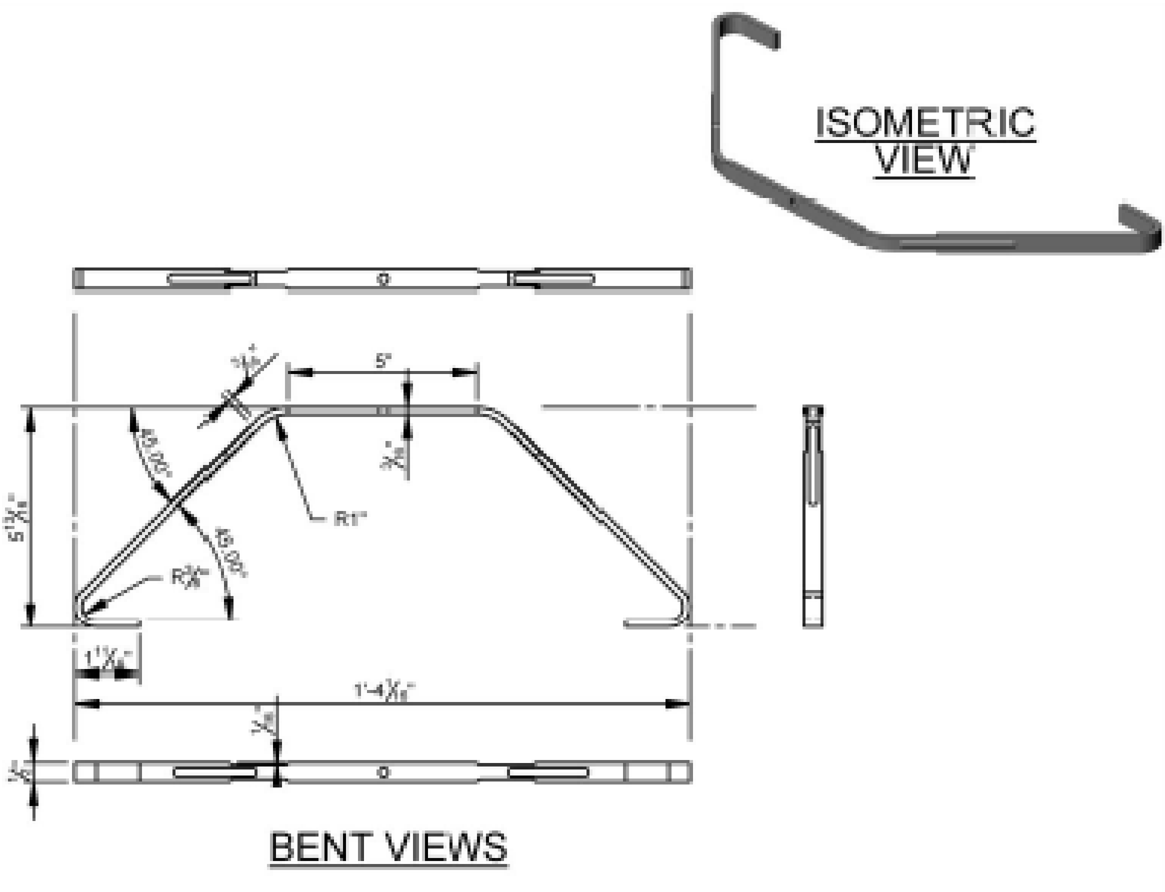
ABSTRACT

This report summarizes the in-plane and out-of-plane performance of the Mini-MC Flange Connector produced by the Metromont Corporation. The connector is intended for use as a flange-to-flange connector between precast concrete double tee panels or for connection between precast concrete wall elements. The connector was tested under cyclic in-plane shear and tension, and out-of-plane shear. The resulting capacities and associated damage are summarized in the report. This work was funded by Metromont Corporation and was conducted at the ATLSS Research Center at Lehigh University.



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BACKGROUND

As a means of assessing the displacement capacity and structural stiffness of connections in precast diaphragms, an experimental study was conducted. A subassembly consisting of the connector and a portion of the surrounding diaphragm was developed. The subassemblies include the Mini-MC flange connector embedded in 2 in. thick precast concrete panels. All specimens were fabricated at full-scale. This report summarizes the experimental results of the connector tested under displacement control in in-plane cyclic tension, cyclic shear, and out-of-plane shear.

Subassembly Details

The subassembly was developed assuming that the connectors are spaced at 4 feet and embedded in a double tee panel with a 2ft distance from the DT web to the free flange face. The test specimens are fabricated from two panels 2ft wide and 4ft long (Figure 1). The panels are connected to form a 4ft square subassembly. The panels are reinforced in plane with C-Grid® reinforcement to meet ACI temperature and shrinkage reinforcement requirements. The reinforcing conforms to the standards used by Metromont Corporation to reinforce double tee flanges. In addition to the C-grid®, conventional reinforcement is used to maintain integrity during testing. The bars are placed at the periphery of the panel to minimize influence on the connector response. The supplemental reinforcement is illustrated in Figure 3.

The Mini-MC flange connector developed by the Metromont Corporation is evaluated. The connector (Figure 2) is designed for placement in double tee flanges. The connector consists of a bent plate connector with two anchor legs, oriented at 45-degrees from the face plate. A slug is welded between the embedded connectors to provide integrity between the panels. The slug weld consists of a 3.5 in. long 0.25 in. filet fabricated using an E7018 electrode. The welds were conducted at room temperature using a SMAW process according to AWS specifications. The slugs were fabricated from ASTM A36 steel. The connectors were fabricated from ASTM A36 steel.

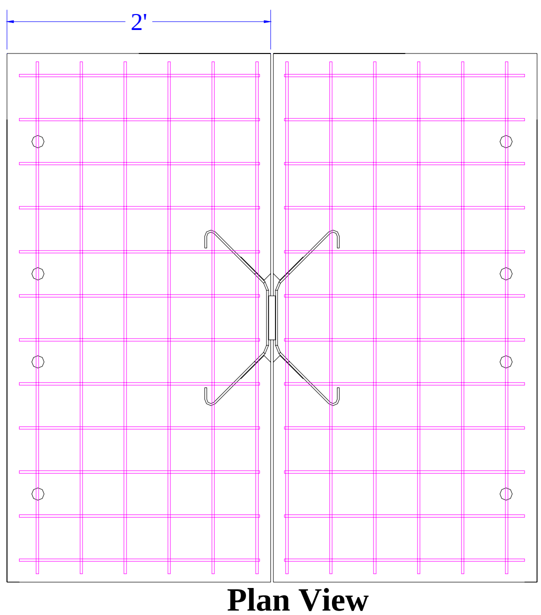


Figure 1: Specimen details

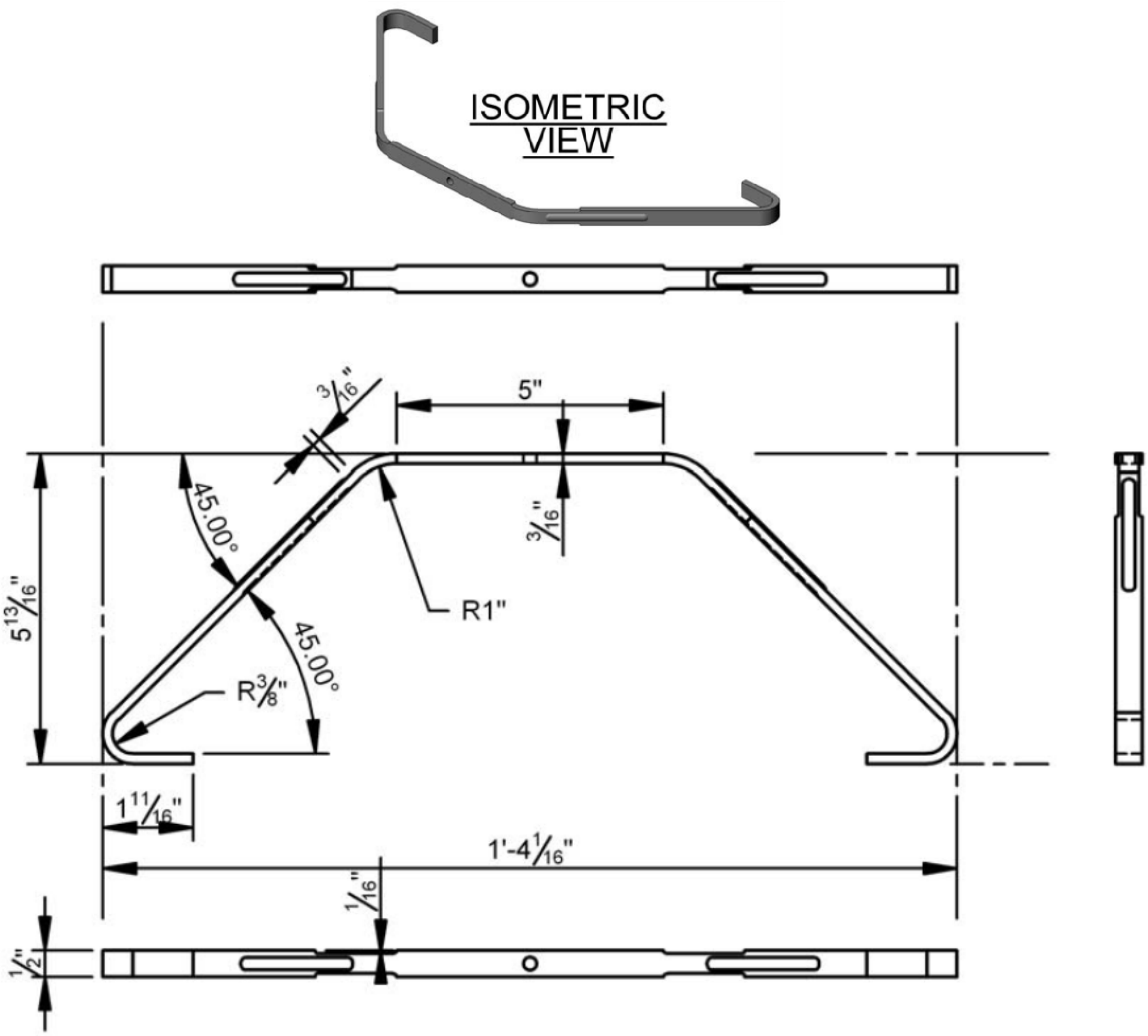


Figure 2: Connector details

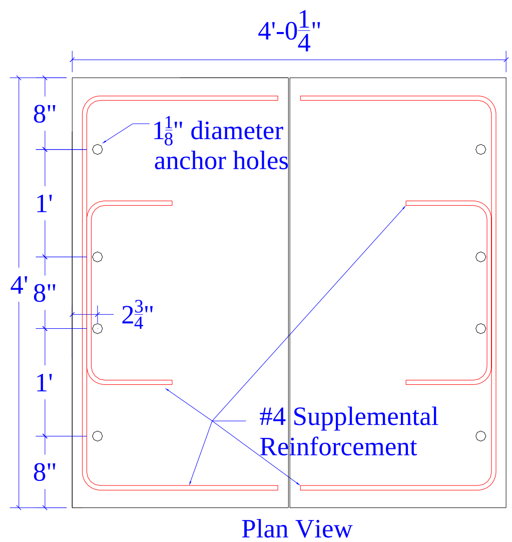


Figure 3: Supplemental reinforcement layout and construction details

Deformation Protocols

The connector was evaluated under in-plane shear, tension, and out-of-plane shear. All tests were conducted under quasi-static displacement control at a rate less than 0.05in/sec. The tests were continued until failure. Failure is defined as the point where the specimen capacity drops below 25% of the measured ultimate. Five displacement protocols have been developed to represent the spectrum of demands a local diaphragm connector could experience under lateral loading [Naito 2006[1]]. Three of these deformation protocols were used in the current study:

1. Cyclic In-plane Shear
2. Cyclic In-plane Tension / Compression
3. Out-of-plane Shear

Cyclic In-plane Shear

Cyclic shear tests provide insight on the degradation of shear properties (i.e., stiffness and ultimate strength) under loading reversals. The loading protocol is based on the PRESSS program [Priestley 1992[2]]. Three preliminary cycles to 0.01-in. are conducted to evaluate control and acquisition accuracy. The remaining protocol consisted of groups of three symmetric shear cycles at increasing deformation levels. Each level is based on a percentage of a reference deformation computed from the preceding monotonic test. The reference deformation represents the effective yield deformation of the connector. It is computed by taking the intercept of a horizontal line at the max load and a secant stiffness line at 75% of the max load (Figure 4 inset). Three elastic levels of 0.25⊿, 0.50⊿ and 0.75⊿ followed by inelastic cycles to 1.0⊿, 1.5⊿, 2.0⊿, 3.0⊿, 4.0⊿, 6.0⊿, 8.0⊿, *etc…* were conducted. The loading protocol is illustrated in Figure 4.

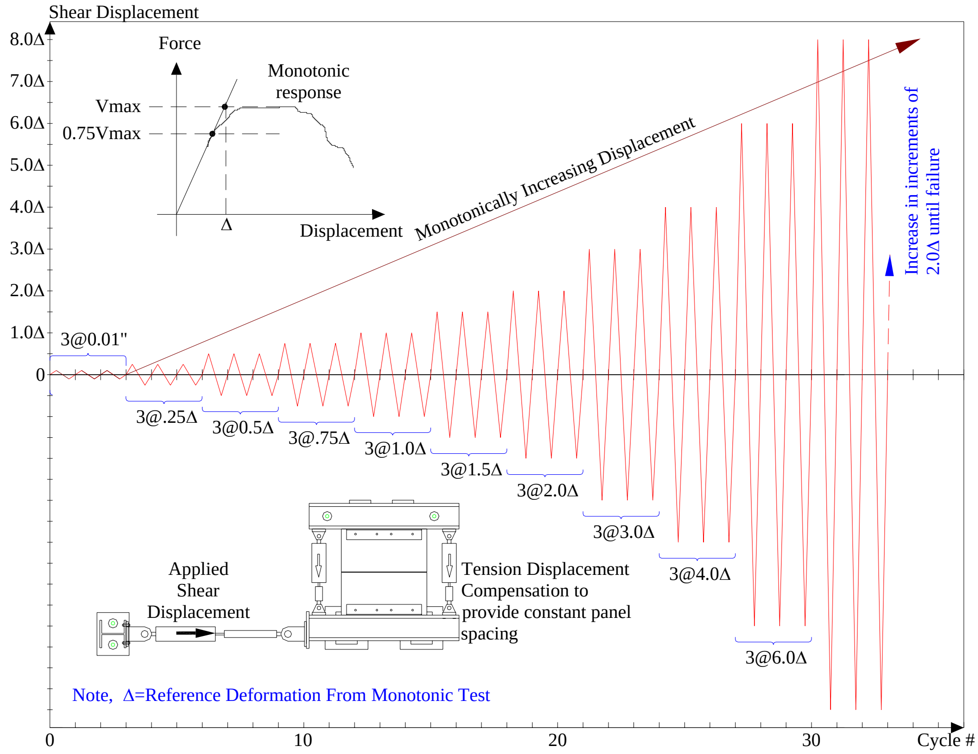


Figure 4: Shear loading protocol

[1] Naito, C., Peter, W., Cao, L., "Development of a Seismic Design Methodology for Precast Diaphragms - PHASE 1 SUMMARY REPORT," ATLSS Report No.06-03, ATLSS Center, Lehigh University, January, 2006, 118 pages.

[2] Priestley, M.J.N., "The U.S. –PRESSS Program Progress Report," Third Meeting of the U.S. –Japan Joint Technical Coordinating Committee on Precast Seismic Structural Systems (JTCC-PRESSS), San Diego, CA, November 18-20, 1992.

Cyclic In-plane Tension / Compression

Previous research indicates that connector compression stiffness can be in excess of ten times the tension stiffness [Pincheria 1998]. In order to make a comprehensive evaluation of the difference between tension and compression behavior cyclic tension/compression loading was applied. The cyclic protocol consisted of three cycles of tension and compression displacement at increasing levels of tension displacement. Each compression half cycle consisted of a displacement to 0.01-in. Four elastic displacement levels were applied. The inelastic levels increased at a rate in accordance with a protocol developed for the PRESSS program [Priestley 1992]. The loading protocol is illustrated in Figure 5.

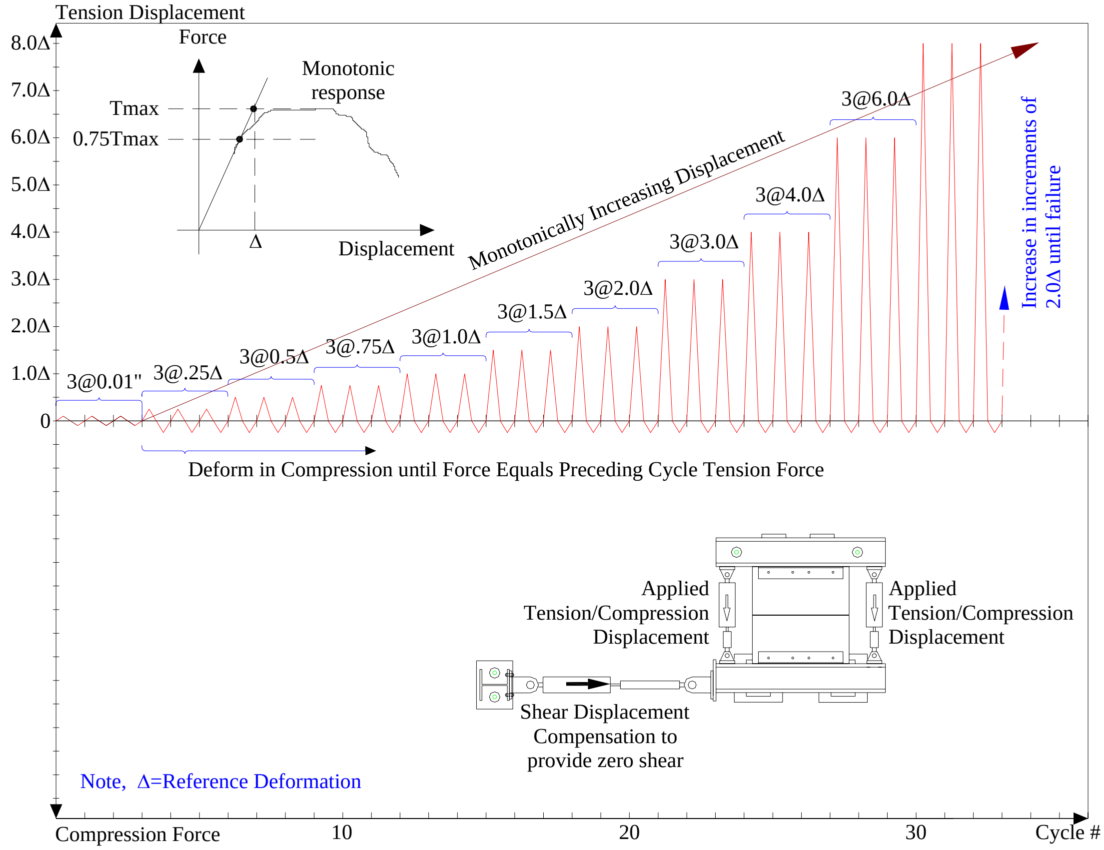


Figure 5: Tension/Compression protocol

Out of -plane Test Setup

The out-of-plane tests are performed to quantify the behavior of the conenctor when the panels are subjected to out-of-plane loads. A self-reacting frame was used as shown in Figure 6. The test frame consists of W6 section ans C6 channels. The test slab was sandwiched between the W6 sections with the 6 inch flanges bearing on the outer 6 inches of the 48 inch slab width.

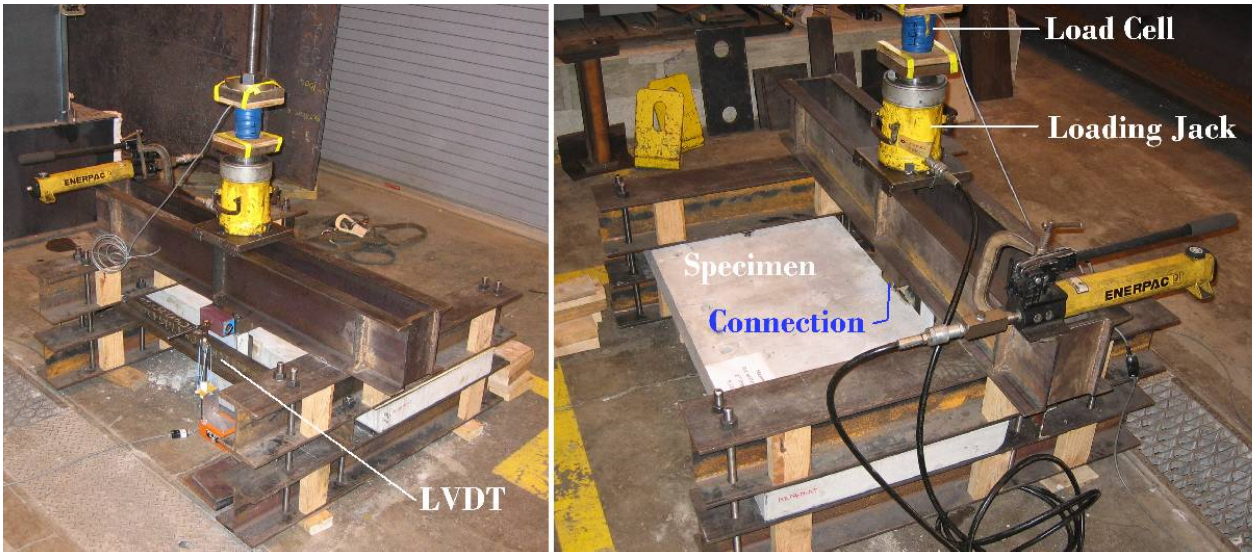


Figure 6: Out-of-plane test setup

Out-of-plane Loading Protocol

The out-of-plane monotonic shear tests are conducted to evaluate the connector response under vertical pure shear deformation. The test represents the joint condition where the panels are shearing vertically. The test provides an estimate of average connector yield, peak strength, and the deformation capacity. Monotonic shear protocol consisted of three cycles to 0.01-in. to estimate initial stiffness and verify equipment operation. Afterwards, the specimens were loaded monotonically to failure (Figure 4).

Load was applied through a loading block to the slab. The loading block was pulled up via a threaded rod passing through a hydraulic jack and load cell. The loading mechanism sat on the C channels that spanned across the W6 sections. Rotation of the loading block as it was pulled was restrained by a C channel on the opposite side of the block as the slab. Friction between the loading block and channel was minimized by a Teflon sheet affixed to the loading block. A hand pump was used to slowly increase the pressure and the resulting uplift force to the slab plate. The vertical displacement was measured using an LVDT. The load and displacement were recorded five scans per second on a Campbell Scientific CR5000 data logger.

MATERIAL PROPERTIES

The properties of the steel and concrete used in the experimental subassemblies are included in this section of the report.

Concrete Properties

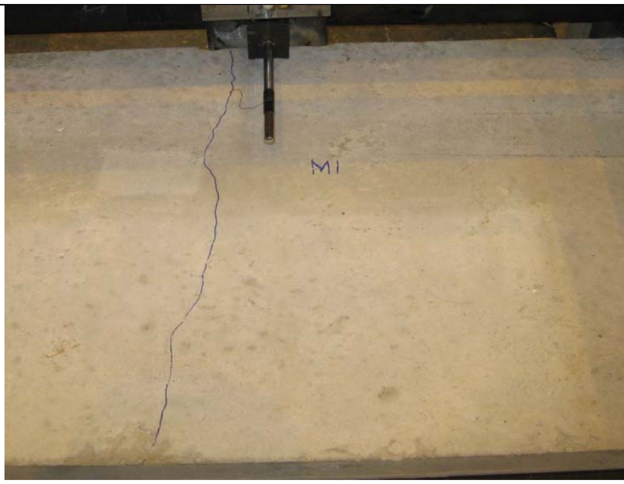
The base 2-in. precast panels were fabricated using ready mix concrete with design 28-day strength of 5000 psi. The concrete compressive strength was measured in accordance with ASTM C39-05 using 4 in. by 8 in. cylinders. The measured compressive strength was 8880+/-508 psi.

Reinforcement Properties

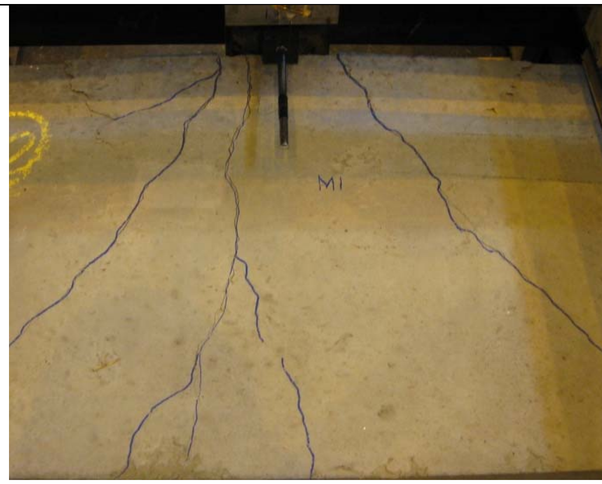
The C-Grid reinforcement used in the panels was spaced at 4 in. on center and consisted of C50 fibers with an approximate tensile strength of 800lbs each. Carbon strands were oriented perpendicular to the connector face and held in place using non-carbon strands oriented parallel to the connector face. The supplemental reinforcement conformed to ASTM A615 specifications. The slugs and connectors were fabricated from ASTM A36 steel plate properties were not available.

TEST OV1: MINI MC CONNECTION UNDER MONOTONIC OUT-OF-PLANE SHEAR

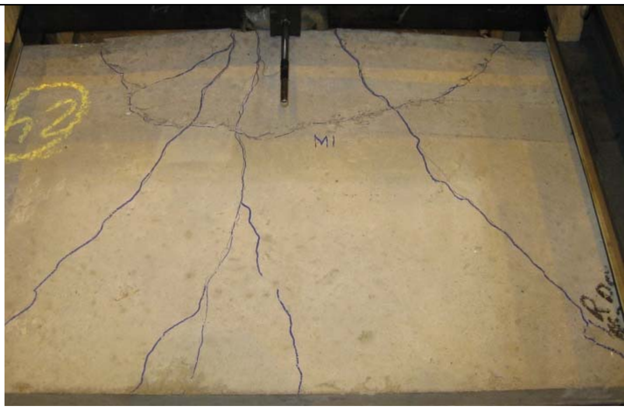
The performance of the mini MC connection subject to monotonic, out-of-plane shear is presented in this section. The connector was subjected to shear displacement in the vertical direction with the in plane shear and tension displacements restrained. The performance of the panel was characterized by cracking and spalling in the area where the connector legs are embedded. Failure occurred when the connector legs had been pulled free of the surrounding concrete. The observed key events and the corresponding displacement level are presented in Table 1. The photos of the damage are presented in Figure 7 and Figure 8. The global force deformation response and backbone curve are presented in Table 2 and Figure 9.



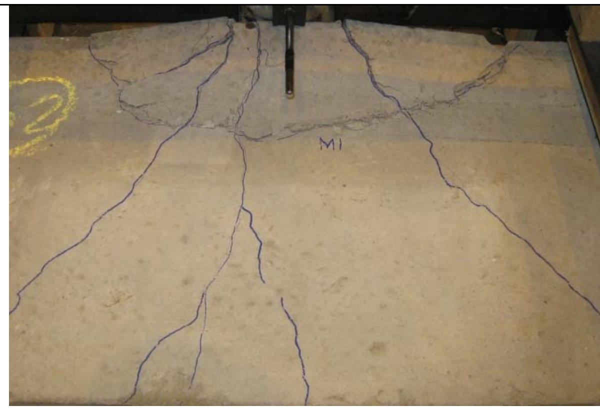
a) 0.12-in.



b) 1.03-in.



c) 1.41-in.



d) 2.13-in

Figure 7: Damage state at various out-of-plane shear deformations OV1

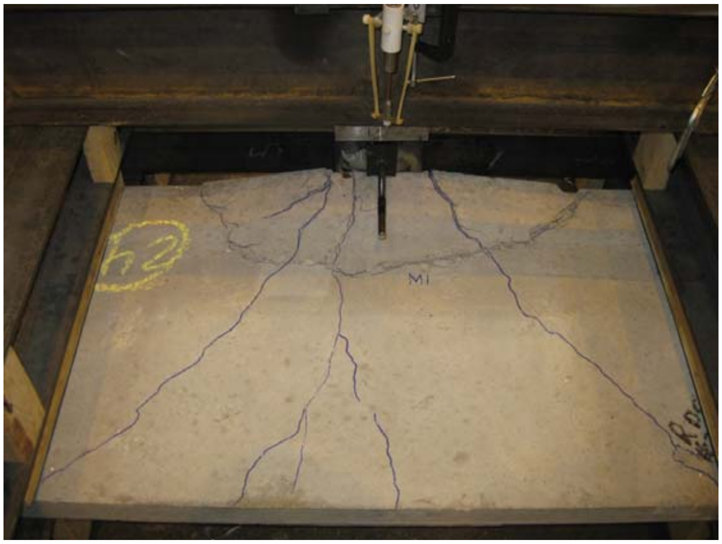


Figure 8: Damage at end of test OV1

Table 1: Key Test Observations (Out-of-plane shear) OV1		
Event #	Shear Δ Step [in.]	Event Description
1	0.12	First perpendicular crack formed on the panel
2	0.54	Two more cracks formed on the panel
3	1.03	Concrete started spalling
4	1.41	Cracks around the connector formed
5	2.13	Connector sheared out of panel

Table 2: Experimental Results Backbone Curve (Out-of-plane shear) OV1		
Event	Shear Displacement [in.]	Shear Force [kips]
Peak Load	0.99	2.76
End of test	2.13	1.22

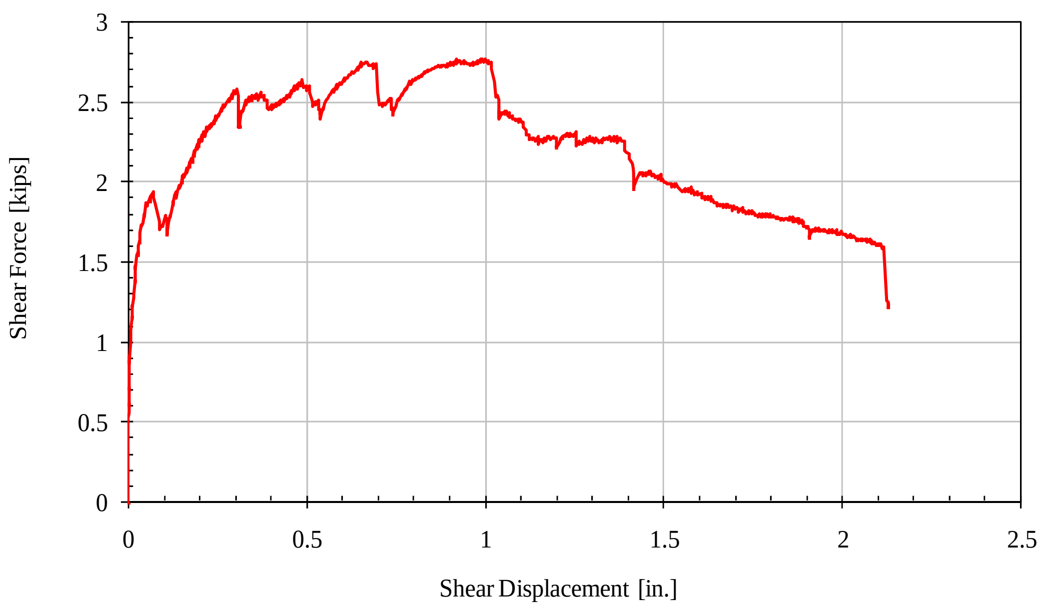
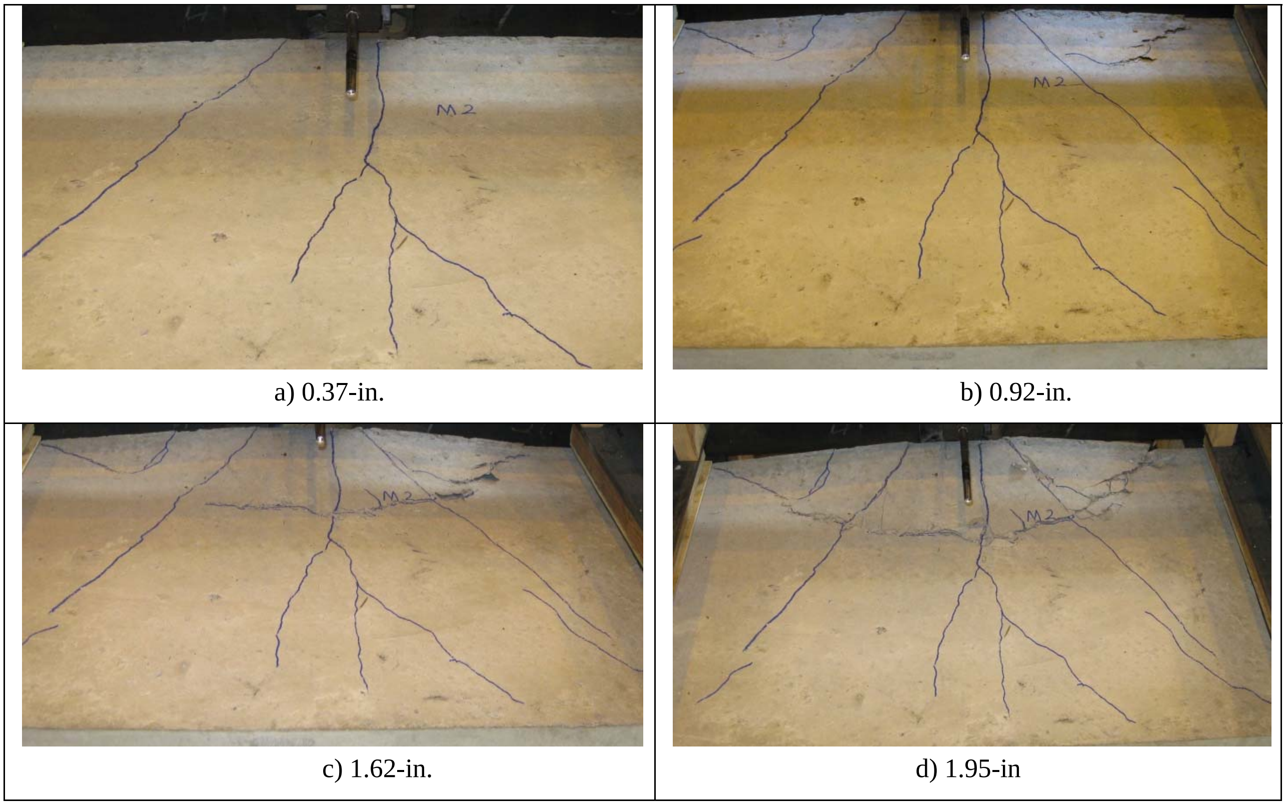


Figure 9: Shear force and displacement (Out-of-plane shear)

TEST OV2: MINI-MC CONNECTION UNDER MONOTONIC OUT-OF-PLANE SHEAR

The performance of the Mini-MC connection subject to monotonic, out-of-plane shear is presented in this section. The connector was subjected to shear displacement in the vertical direction with the in plane shear and tension displacements restrained. The performance of the panel was characterized by cracking and spalling in the area where the connector legs are embedded. Failure occurred when the connector legs had been pulled free of the surrounding concrete. The observed key events and the corresponding displacement level are presented in Table 1. The photos of the damage are presented in Figure 10 and Figure 11. The global force deformation response and backbone curve are presented in Table 2 and Figure 12.



a) 0.37-in. b) 0.92-in.

c) 1.62-in. d) 1.95-in

Figure 10: Damage state at various out-of-plane shear deformations OV2

Figure 11: Damage at end of test OV2

Table 3: Key Test Observations (Out-of-plane shear) OV2		
Event #	Shear Δ Step [in.]	Event Description
1	0.37	Diagonal cracks formed on the panel
2	0.58	More cracks formed on the panel, existing cracks progressed
3	0.72	Concrete started spalling
4	1.62	Cracks around the connector formed
5	1.95	Connector sheared out of panel

Table 4: Experimental Results Backbone Curve (Out-of-plane shear) OV2		
Event	Shear Displacement [in.]	Shear Force [kips]
Peak Load	0.56	2.73
End of test	1.95	0.72

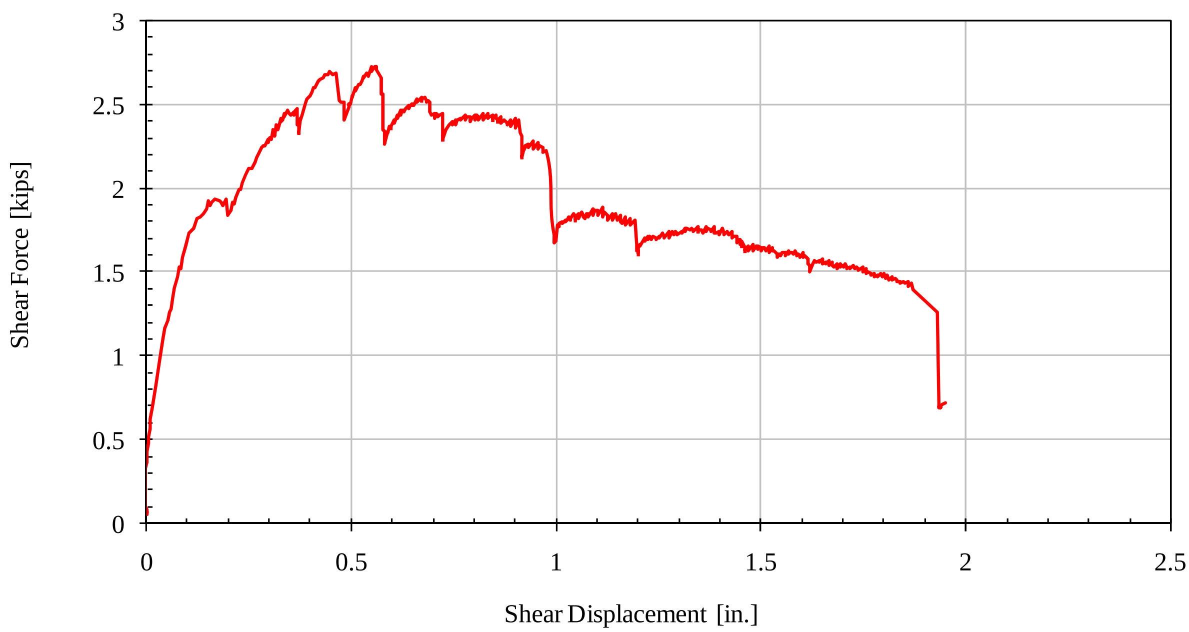


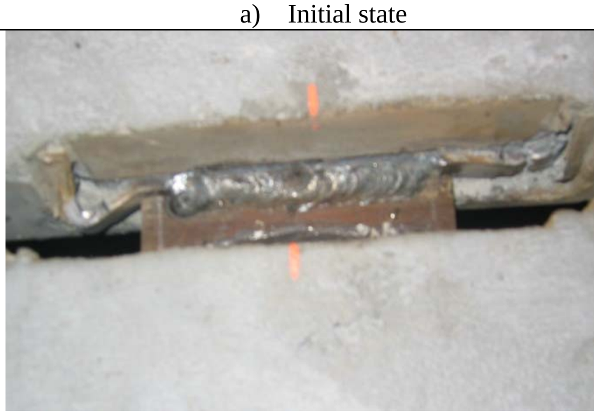
Figure 12: Shear force and displacement (Out-of-plane shear)

TEST CV1: MINI-MC CONNECTION UNDER CYCLIC IN-PLANE SHEAR

The performance of the Mini-MC connection subject to cyclic in-plane shear is presented in this section. The connector was subjected to cyclical shear with the joint opening restrained at its initial spacing. A reference shear deformation of 0.10 was used for the test. The performance of the connector was characterized by bending and plastic deformation of the legs near where they become embedded in the concrete. Failure of the connector was due to low cycle fatigue fracture of the connector legs in the region of plastic deformation. The observed key events and the corresponding displacement level are presented in Table 5. The photos of the damage are presented in Figure 13 and Figure 14. The global force deformation response and backbone curve are presented in Table 6 and Figure 15.

a) Initial state


b) 0.15-in.


c) 0.30-in.


d) -0.30-in.

Figure 13: Damage state at various shear deformations CV1


Figure 14: Damage at end of test

Table 5: Key Test Observations (Cyclic In-Plane Shear) CV1		
Event #	Shear Δ Step [in.]	Event Description
1	0.15	The compression legs embed in panel B bent
2	0.30	One leg of connector fractured
3	-0.30	The other leg of connector fractured ,connector failed

Table 6: Experimental Results Backbone Curve (Cyclic In-Plane Shear) CV1		
Event	Shear Displacement [in.]	Shear Force [kips]
Peak Load	-0.07	-8.57
End of test	-0.30	-1.20

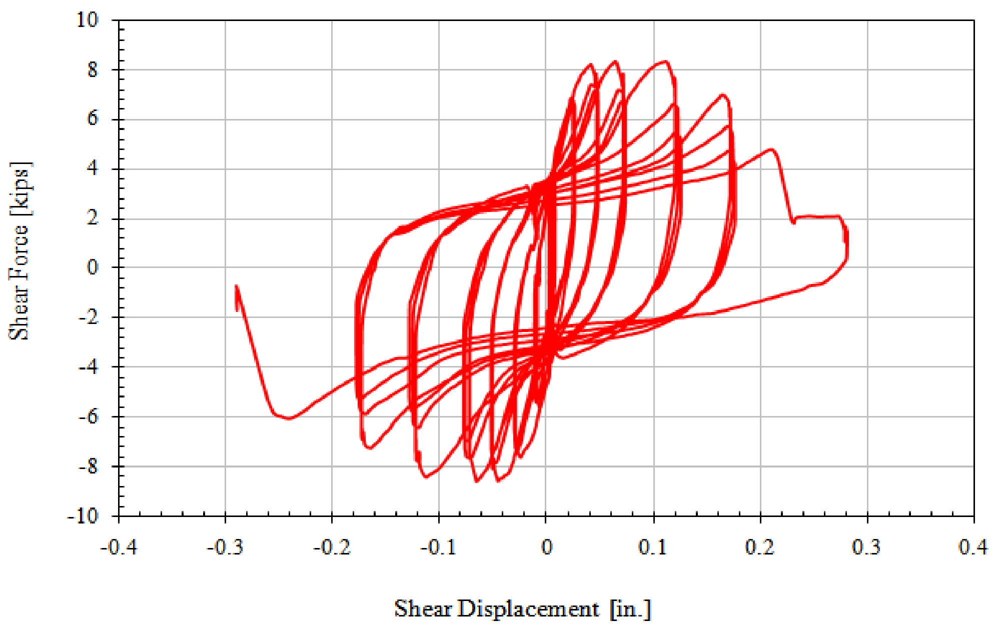


Figure 15: Shear force and displacement (Cyclic In-Plane Shear) CV1

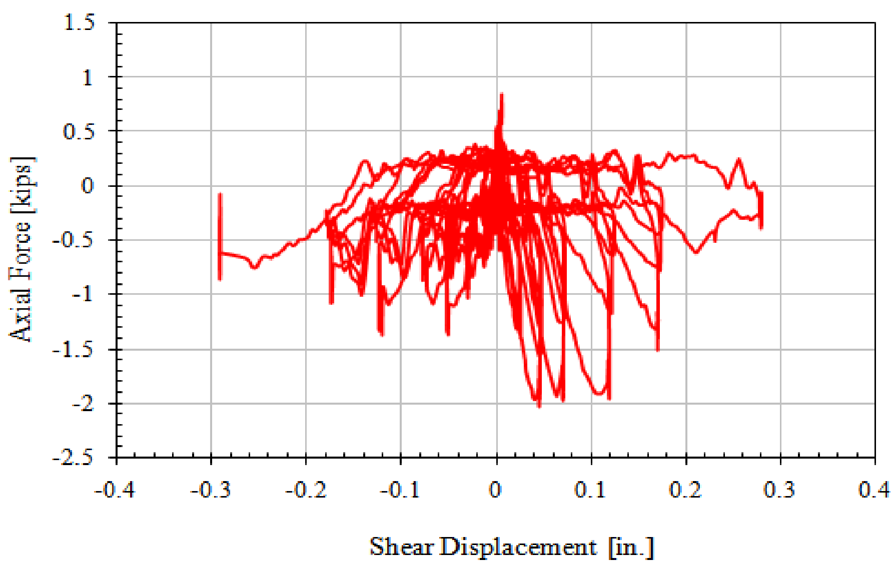
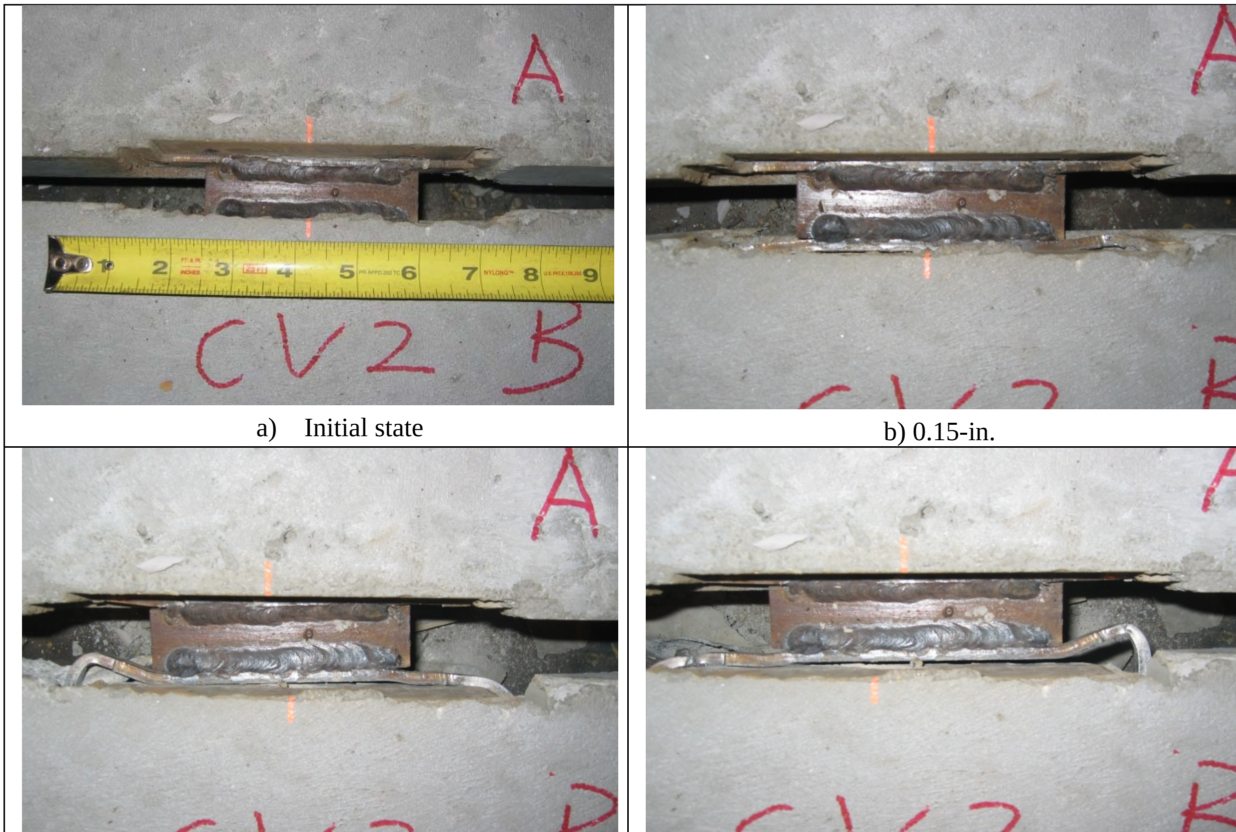


Figure 16: Axial force and shear displacement (Cyclic In-Plane Shear) CV1

TEST CV2: MINI-MC CONNECTION UNDER CYCLIC IN-PLANE SHEAR

The performance of the Mini-MC connection subject to cyclic in-plane shear is presented in this section. The connector was subjected to cyclical shear with the joint opening restrained at its initial spacing. A reference shear deformation of 0.10 was used for the test. The performance of the connector was characterized by bending and plastic deformation of the legs near where they become embedded in the concrete. Failure of the connector was due to low cycle fatigue fracture of the connector legs in the region of plastic deformation. The observed key events and the corresponding displacement level are presented in Table 7. The photos of the damage are presented in Figure 17 and Figure 18. The global force deformation response and backbone curve are presented in Table 8 and Figure 19.



a) Initial state

b) 0.15-in.

c) -0.30-in.

d) 0.30-in.

Figure 17: Damage state at various shear deformations CV2

Figure 18: Damage at end of test

Table 7: Key Test Observations (Cyclic In-Plane Shear) CV2		
Event #	Shear Δ Step [in.]	Event Description
1	0.15	The compression legs embed in panel B bent
2	-0.30	One leg of connector fractured
3	0.30	The other leg of connector fractured ,connector failed

Table 8: Experimental Results Backbone Curve (Cyclic In-Plane Shear) CV2		
Event	Shear Displacement [in.]	Shear Force [kips]
Peak Load	0.05	8.27
End of test	0.28	0.12

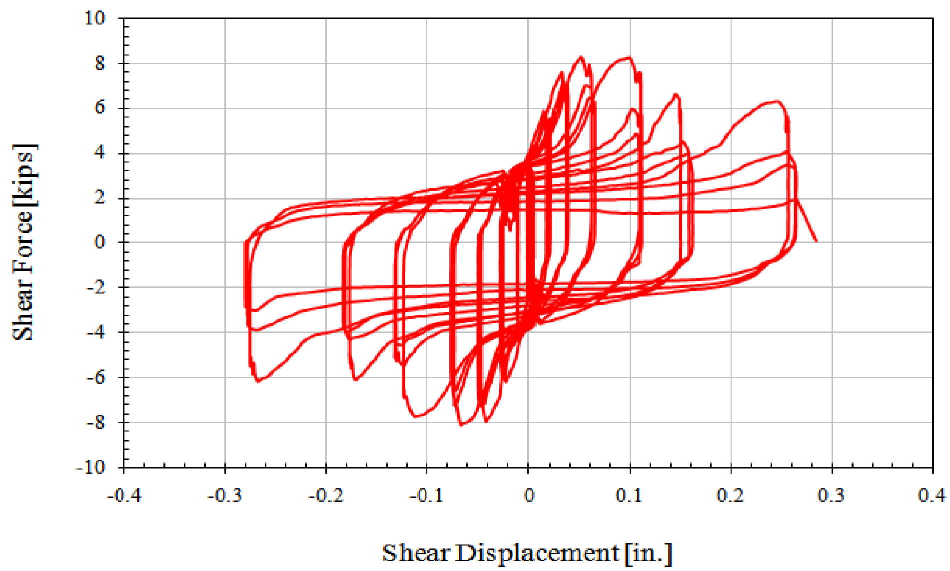


Figure 19: Shear force and displacement (Cyclic In-Plane Shear) CV2

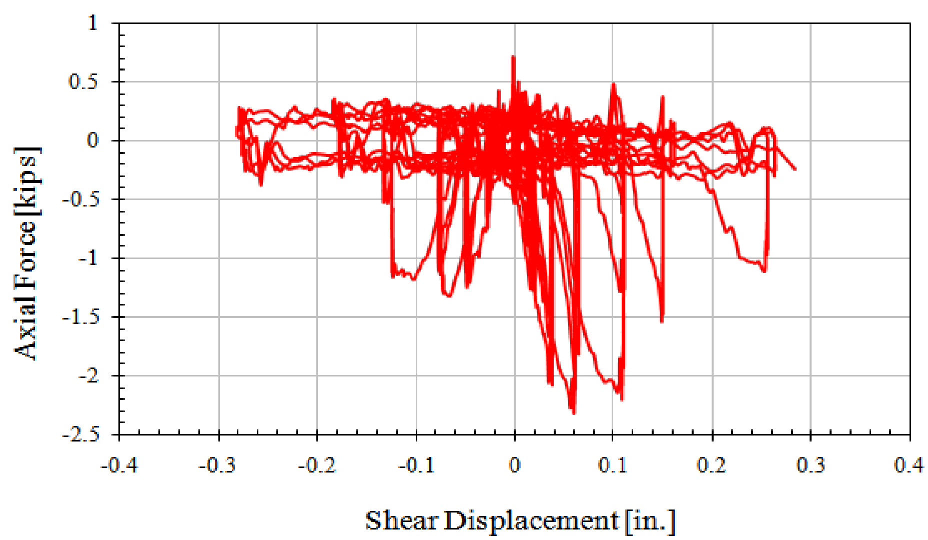
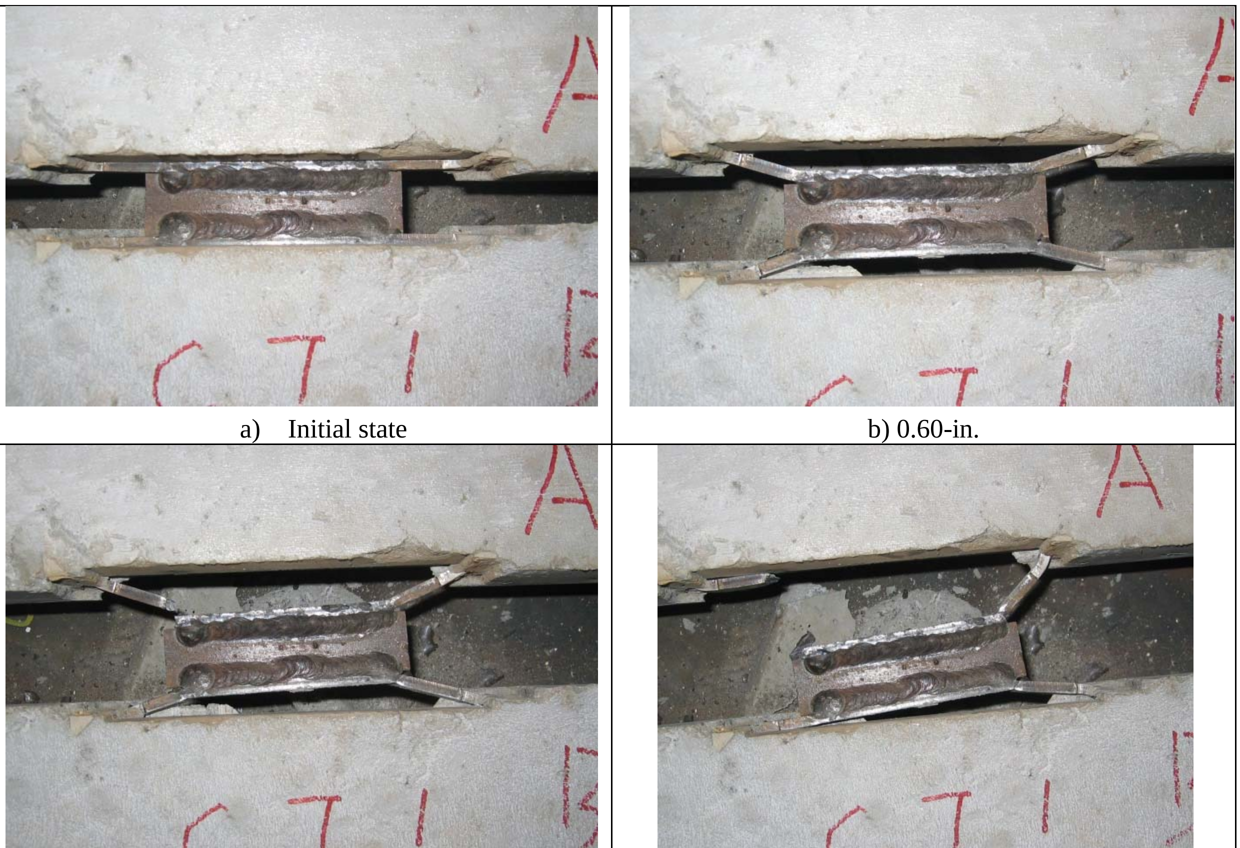


Figure 20: Axial force and shear displacement (Cyclic In-Plane Shear) CV2

TEST CT1: MINI-MC CONNECTION UNDER CYCLIC IN-PLANE TENSION NO SHEAR FORCE

The performance of the Mini-MC connection subject to cyclic tension/compression is presented in this section. The connector was subjected to cyclical tension/compression displacement with the shear force unrestrained, Fv =0. The compression cycle consisted of a closing displacement of 0.01-in. A reference tension deformation of 0.10 was used for the test. The performance of the connector was characterized by bending and permanent deformation of the legs near where they become embedded in the concrete. No significant damage occurred in the concrete surrounding the connector. Connector bending of the faceplate region became apparent after a tension displacement of 0.20 inches. Failure of the connector was characterized by low cycle fatigue fracture of the faceplate in the end region of the slug weld. The observed key events and the corresponding displacement level are presented in Table 9. The photos of the damage are presented in Figure 21 and Figure 22. The global force deformation response and backbone curve are presented in Table 10 and Figure 23.



a) Initial state
b) 0.60-in.
c) 1.0-in.
d) 1.40-in.

Figure 21: Damage state at various shear deformations CT1

Figure 22: Damage at end of test

Table 9: Key Test Observations (Cyclic In-Plane Tension) CT1		
Event #	Tension Δ Step [in.]	Event Description
1	0.15	Small gap formed between faceplate and panels
2	0.20	Faceplate bent
2	1.00	Faceplate fractured in the region of weld tip during the loading
3	1.60	The other side of faceplate fractured ,connector failed

Table 10: Experimental Results Backbone Curve (Cyclic In-Plane Tension) CT1		
Event	Tension Displacement [in.]	Tension Force [kips]
Peak Load	0.73	3.65
End of test	1.50	0.25

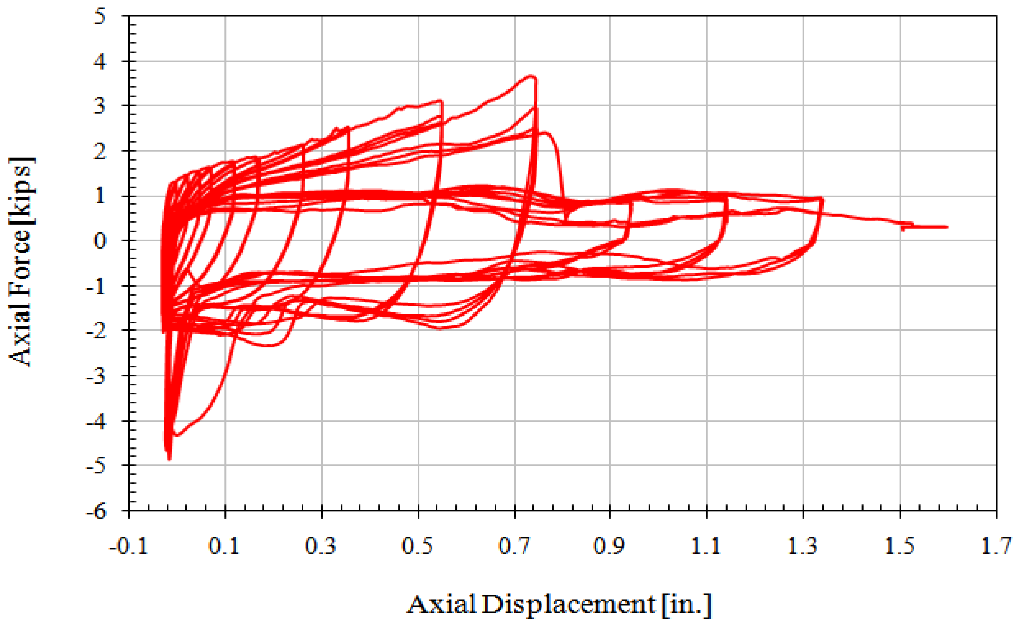


Figure 23: Axial force and displacement (Cyclic In-Plane Tension) CT1

TEST CT2: MINI-MC CONNECTION UNDER CYCLIC IN-PLANE TENSION NO SHEAR FORCE

The performance of the Mini-MC connection subject to cyclic tension/compression is presented in this section. The connector was subjected to cyclical tension/compression displacement with the shear force unrestrained, Fv =0. The compression cycle consisted of a closing displacement of 0.01-in. A reference tension deformation of 0.10 was used for the test. The performance of the connector was characterized by bending and permanent deformation of the legs near where they become embedded in the concrete. No significant damage occurred in the concrete surrounding the connector. Connector bending of the faceplate region became apparent after a tension displacement of 0.20 inches. Failure of the connector was characterized by low cycle fatigue fracture of the faceplate in the region of weld tip. The observed key events and the corresponding displacement level are presented in Table 11. The photos of the damage are presented in Figure 24 and Figure 25. The global force deformation response and backbone curve are presented in Table 12 and Figure 26.

a) Initial state

b) 0.60-in.

c) 1.0-in.

d) 1.40-in.

Figure 24: Damage state at various shear deformations CT2

Figure 25: Damage at end of test

Table 11: Key Test Observations (Cyclic In-Plane Tension) CT2		
Event #	Tension Δ Step [in.]	Event Description
1	0.15	Small gap formed between faceplate and panels
2	0.20	Faceplate bent
2	1.00	Faceplate fractured in the region of weld tip during the loading
3	1.40	The other side of faceplate fractured ,connector failed

Table 12: Experimental Results Backbone Curve (Cyclic In-Plane Tension) CT2		
Event	Tension Displacement [in.]	Tension Force [kips]
Peak Load	0.79	3.51
End of test	1.40	0.26

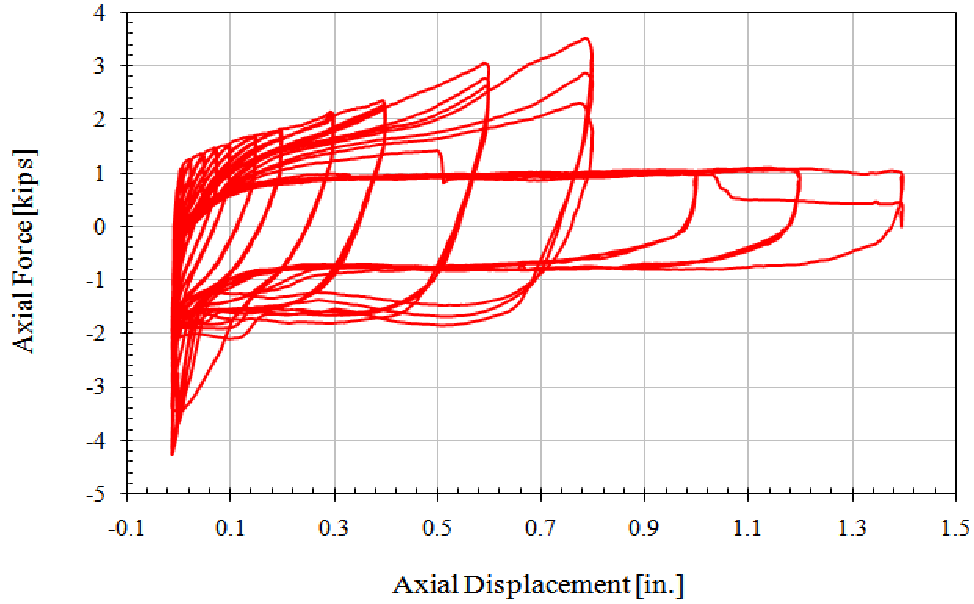


Figure 26: Axial force and displacement (Cyclic In-Plane Tension) CT2

MINI-MC SUMMARY

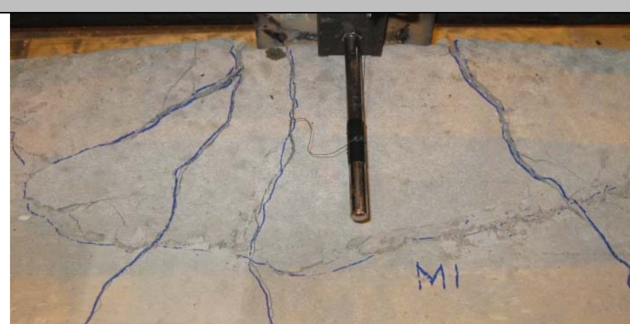
The Mini-MC flange connector produced by Metromont Corporation was tested under a series of in-plane and out-of-plane demands. The following table summarizes the results of the experimental program. The connectors were tested under three loading configurations, namely (1) Out-of-plane Shear, (2) Cyclic In-plane Shear, and (3) Cyclic In-plane Tension. For each test configuration, the peak load, corresponding deformation, and max design load are presented in Table 13. The max design load represents the largest load that the connector can reliably resist. No factors of safety have been applied to this value. The max design value represents the average of the two tests when the higher value does not exceed the lower value by more than 5 percent and the lower value when the test results vary by more than 5%.

Table 13: Mini-MC Summary Results

Description	ID	Loading Protocol	Maximum Load [kips]	Corresponding Deformation [in.]	Max Design Load [kips]
Mini-MC Flange Connector	OV1	Out-of-Plane Shear	2.76	0.99	2.75
	OV2	Out-of-Plane Shear	2.73	0.56	
	CV1	Cyclic In-Plane Shear	8.57	0.07	8.42
	CV2	Cyclic In-Plane Shear	8.27	0.05	
	CT1	Cyclic In-Plane Tension	3.65	0.73	3.58
	CT2	Cyclic In-Plane Tension	3.51	0.79	

The failure modes of each experiment are summarized in Table 14. The Out-of plane shear tests were controlled by concrete breakout. In-plane shear and tension failure modes were controlled by fracture of the legs and faceplate of connector.

Table 14: Failure Modes

Specimen	ID	Loading Protocol	Failure Modes
Mini-MC	OV1	Out-of-Plane Shear	
Mini-MC	OV2	Out-of-Plane Shear	

Mini-MC	CV1	In-Plane Shear	
Mini-MC	CV2	In-Plane Shear	
Mini-MC	CT1	In-Plane Tension	
Mini-MC	CT2	In-Plane Tension	

Out-of-Plane Shear Response

The measured load and displacement of the connectors subject to out-of-plane shear is summarized in Figure 27. The connectors were evaluated through two experiments. . The connector exhibited a consistent response between the tests. They all had a measured out-of-plane capacity greater than 2500 lbs. The failure mode of these connections was a result of concrete breakout above the connector. Due to the failure mode of these connectors the use of a topping slab above the connectors used in the 2in. thick panels would significantly enhance the out-of-plane capacity.

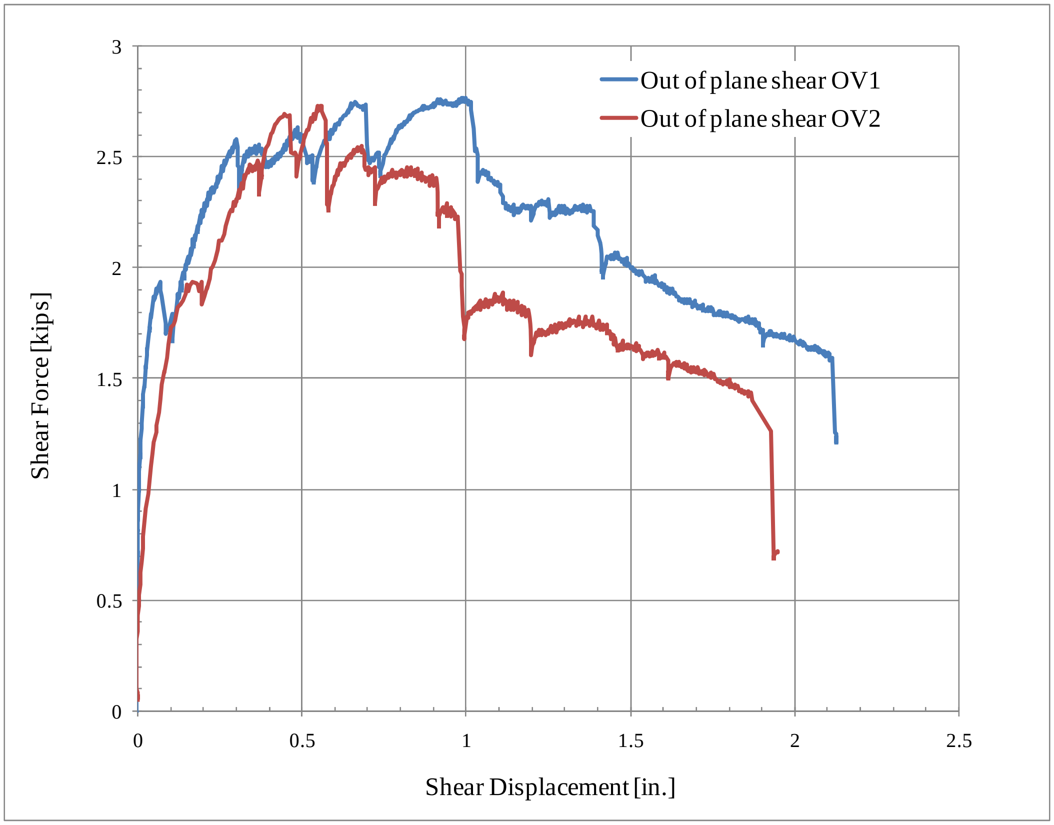


Figure 27: Out-of-plane shear response

In-Plane Shear Response

The measured load and displacement of the connectors subject to cyclic in-plane shear is summarized in Figure 28.The connectors were evaluated through two experiments. The connector exhibited a consistent response between the tests. In general the connections exhibited yielding and bending of the faceplate. The ultimate failure modes were controlled by fracture of the faceplate near where they become embedded in the concrete panels.

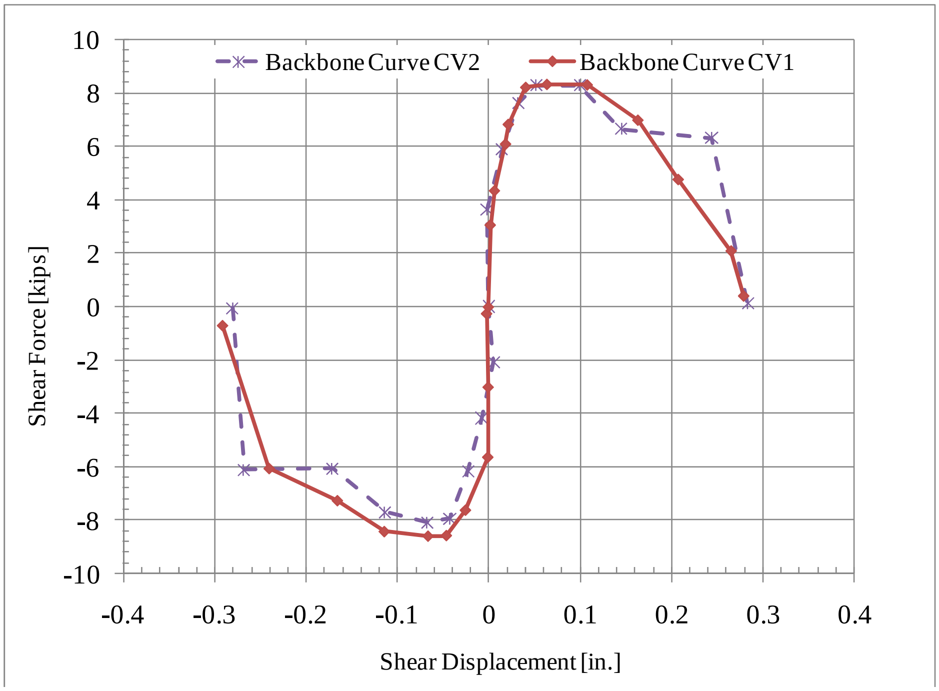


Figure 28: In-plane cyclic shear response

In-Plane Tension Response

The measured load and displacement of the connectors subject to cyclic in-plane tension is summarized in Figure 29.The connectors were also evaluated through two experiments. The connector exhibited a consistent response between the tests. In general the connections exhibited yielding and bending of the faceplate. The ultimate failure modes were controlled by fracture of the faceplate adjacent to the weld. All connectors reached their peak resistance prior to an opening of 0.80 in.

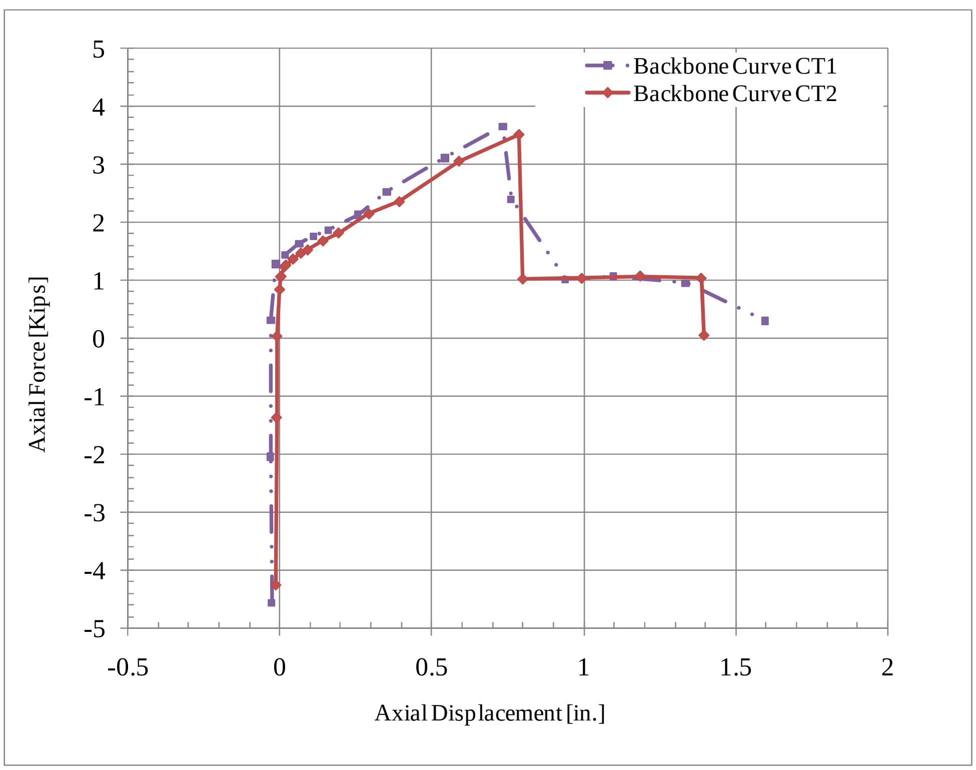


Figure 29: In-plane cyclic tension response