



College of Engineering and Applied Science
Department of Civil Engineering and Mechanics

Structural Engineering Laboratories

JW Vector Connector for Precast Double-Tee Members

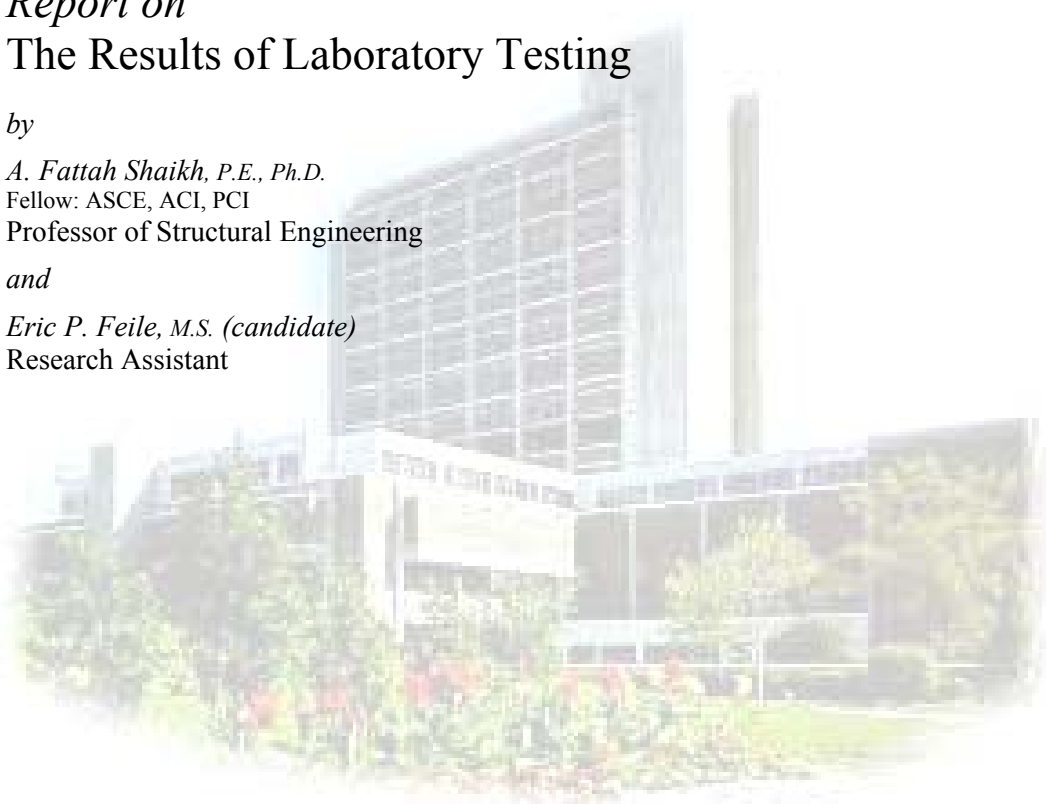
Report on
The Results of Laboratory Testing

by

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Testing of JVI Vector Connector

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Background and Executive Summary

Recognizing the need for better shear connections, JVI introduced a new shear connector, the Vector Connector, in 1999. Comprehensive tests on this connection were carried out at the University of Wisconsin-Madison under the supervision of Prof. Michael Oliva. The results were reported in June 2000. This report can be found on the JVI web site at www.jvi-inc.com.

The Vector Connector has gained good acceptance in the precast industry and JVI has undertaken further development of it in response to the experiences gained with its use.

Recently, JVI implemented minor changes to the Vector Connector. JVI changed the faceplate height from 2 ½" to 2" with proportionate changes to the returns. In addition, the directions of the bent leg tips were reversed. A photograph of the revised Vector Connector can be seen in Figure 1. JVI engaged the University of Wisconsin-Milwaukee (UWM) to carry out tests similar to those conducted on the original connector. The UWM tests were carried out in August-September, 2002. The results are given in this report. For simplicity of reference, this revised connector is labeled as VC-R to distinguish it from the original Vector Connector, VC-O.

Shear connections are primarily used to transfer forces that transmit horizontally through a precast joint. These connectors also can provide force transfer between tees as well as to enable double tee roofs and floors to function as diaphragms. Typically, these connections include a faceplate with tail leg at each end bent at some angle to the faceplate and embedded in the flange concrete. The faceplates of the connectors in two adjacent double tees are field-welded through a plug insert to complete the connection. These connections have generally performed well, although periodic concern has been noted relating to concrete cracking and spalling in the connection area. Performance of precast double tee diaphragms in recent earthquakes, in particular the 1994 Northridge Earthquake, has shown deficiencies in overall diaphragm design including these flange-to-flange connections. This has led to considerable discussion and some new research.

As noted above, testing of the VC-O served as the basis for design of the VC-R tests. Thus, test protocols for testing of the VC-R have intentionally mimicked the VC-O tests as far as practicable to allow for comparison between the results of the two test programs. Tests on the VC-R were performed under monotonic and cyclic horizontal shear loads with and without tension, tension only, and vertical shear only. Load and corresponding deformation readings were electronically obtained and stored and also viewed in real time to monitor test progress. A summary of the test procedures and the obtained results are given in the body of this report while detailed data is included in Appendix B.

The results show good consistency between identical tests among the various test types suggesting validity of the test program. Test results are also proportionally similar to the results of tests on the VC-O, mutually validating the two test programs.

Detailed conclusions based on this test program are given on page 29. A table comparing the results of the two studies is given in Appendix A.

Objective and Scope

The primary objective of the tests was to determine the strength of JVI's Vector Connector under various types of loads. Another important objective of the testing was to measure deformation of the connection to evaluate ductility. Tests included in this study measured the performance of the connection under the following applied loads:

- Monotonically applied horizontal shear force
- Cyclically applied horizontal shear force
- Monotonically applied horizontal shear force with applied tension
- Cyclically applied horizontal shear force with applied tension
- Monotonically applied tension force
- Monotonically applied downward vertical shear force.

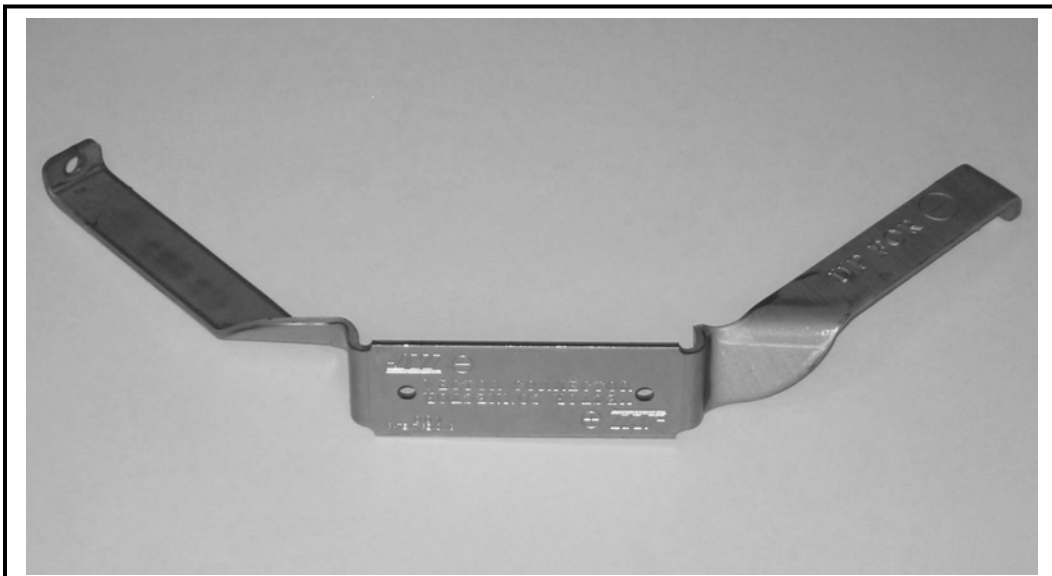


Figure 1: JVI Vector Connector

Test Setups

All tests for this study were conducted in the Structural Engineering Laboratory at the University of Wisconsin-Milwaukee from August 20 through September 9, 2002. The flange connectors used for this study were embedded in 4' x 4' x 4" concrete slabs intended to simulate the conditions experienced in a 4" thick double tee flange. Specimens were fabricated by PBM Concrete of Rochelle, Illinois. For ease of testing, each specimen had a rectangular slug and a 5/8" thick steel plate welded to the connector. All welding was done in the PBM plant by certified welders and witnessed by a representative of the UWM research team. Additional details of the specimens used for this study are discussed later in this report. Loads were applied using hydraulic jacks controlled by load or displacement depending on the type of test being conducted. Details of the load applications used for the various tests will be discussed in the "Test Procedures" section later in this report. The following pages describe the test station setup used for the various tests.

Horizontal Shear Test Setup

Diagrams and photos of the test setup employed for horizontal shear tests (including those with an initial tension force applied to the connection) are given in Figures 2 through 5. Each specimen was held in place using a 3-foot spreader beam that was anchored to the strong floor of the laboratory. The slabs were also braced on each side to prevent slab rotation due to the applied horizontal loads. Each specimen had a plate welded to the connection allowing for each specimen to be bolted to a custom-fabricated tube which was used to apply the necessary forces to the connection. The loading tube rested on rollers, allowing free movement when horizontal loads were applied. Rollers were also placed against the face of the tube at each end ensuring that there was no rotation of the tube due to the applied horizontal loads.

Horizontal loads were applied to the loading tube by a rod attached to two hydraulic jacks braced against a heavy frame anchored to the floor. Horizontal forces were applied by one of the two jacks at a time to create the intended push/pull force sequence. Prior to each test the hydraulic jacks were realigned to ensure pure axial loading to the tube. A tension force was applied to the connection by a rod attached to the tube with force provided by another hydraulic jack. The jack for applying the tension force was braced against a tower anchored to the floor. The connection between the tube and the tension rod was designed to allow for the horizontal displacement that would be experienced when horizontal loads were applied. The application of the tension force was lined up to be perpendicular to the center of the connector face. Tension force was applied using a hand-operated Enerpac hydraulic pump, allowing for the desired amount of displacement to be applied to the connection.

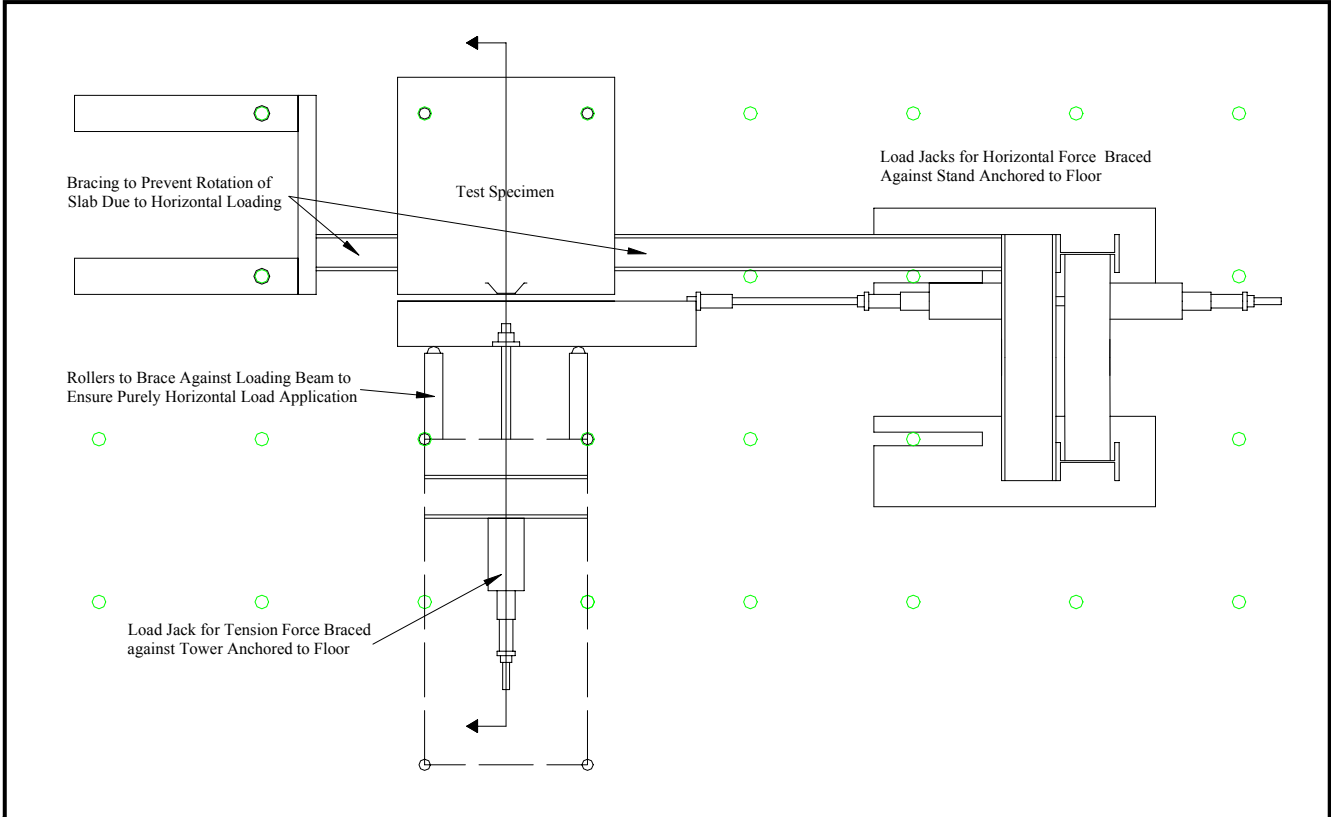


Figure 2: Plan View of Horizontal Shear Test Setup

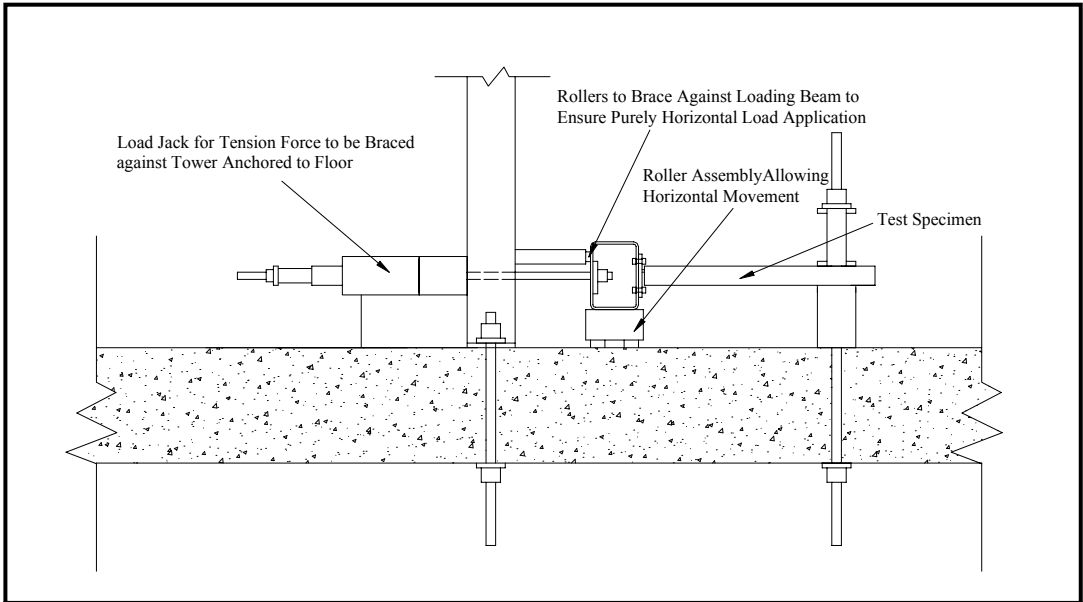
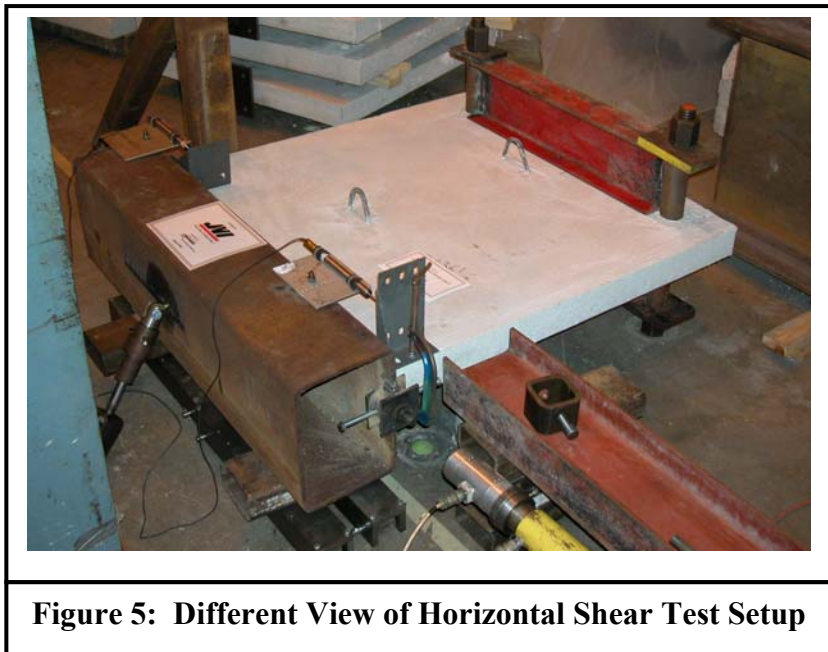
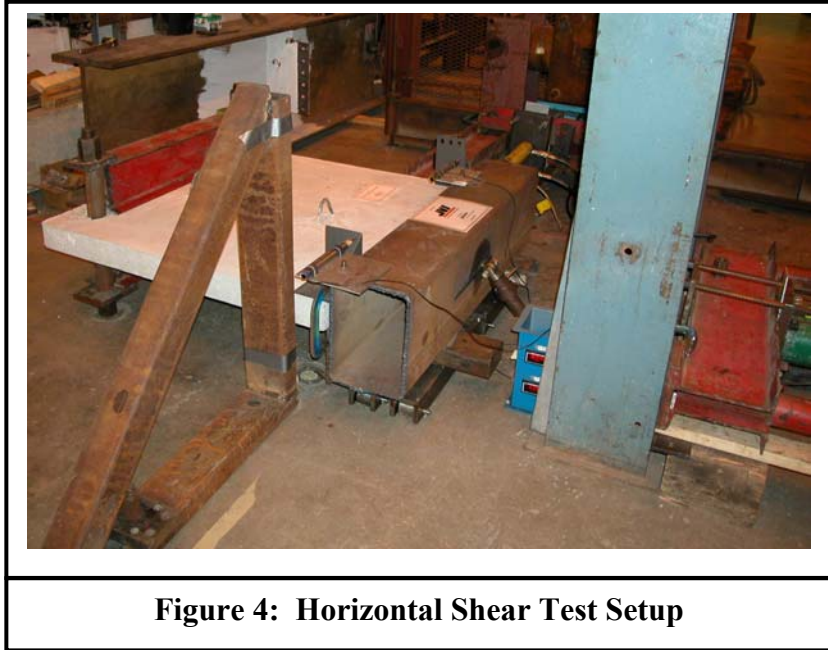


Figure 3: Section View of Horizontal Shear Test Setup



Tension Test Setup

A diagram and two photographs of the test setup employed for pure tension tests can be seen in Figures 6 through 8. The setup employed for these tests was very similar to the setup previously described for tension force application in the horizontal shear tests. Load was applied by a rod welded to a custom plate, which was bolted to the plate welded to the connection. Special attention was given to ensure that load was applied at the center of the connection. For pure tension tests, bracing was placed between the tower and the slab to prevent slipping of the slab due to the applied loads.

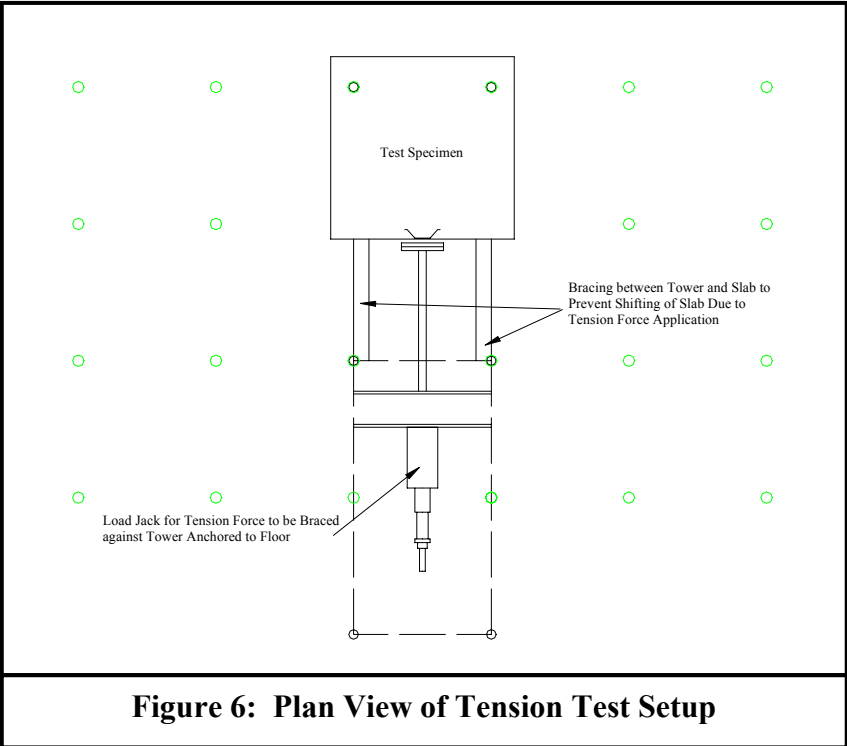




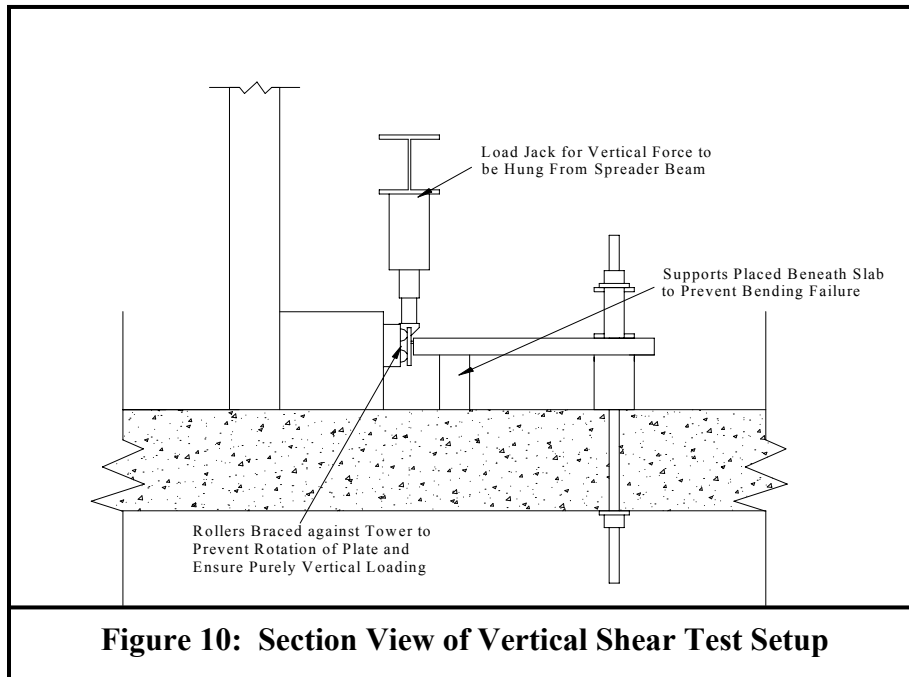
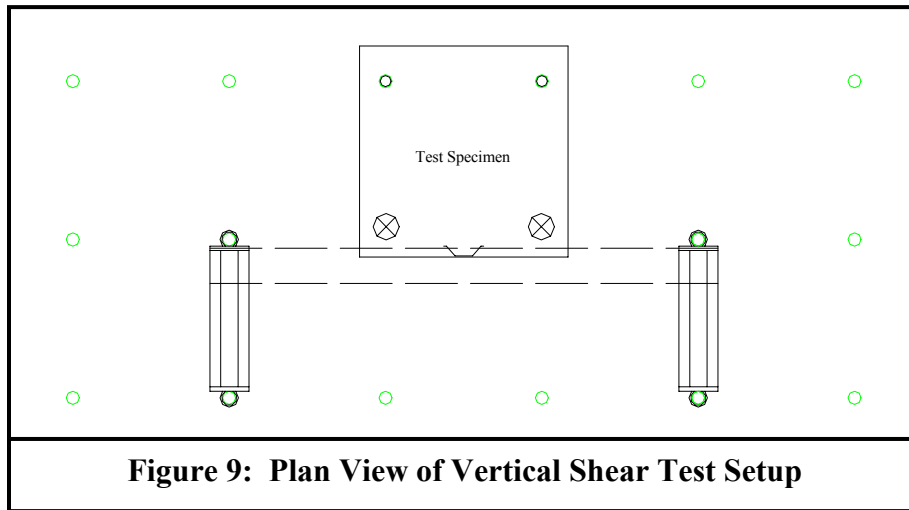
Figure 7: Tension Test Setup



Figure 8: Side View of Tension Test Setup

Vertical Shear Test Setup

Diagrams and photographs of the test setup employed for vertical shear tests can be seen in Figures 9 through 12. For vertical shear the slabs were again anchored to the floor as done in previously described tests. For vertical shear testing, supports were placed below the slab closer to the connection to prevent bending failures of the slab upon load application. For load application, a hydraulic jack was hung from a spreader beam over the connection. Special attention was given prior to each test to ensure that load was applied vertically at the center of the plate. A custom fixture was fabricated to apply the load to the plate. Rollers were also placed against the plate to prevent rotation and ensure application of a purely vertical force.



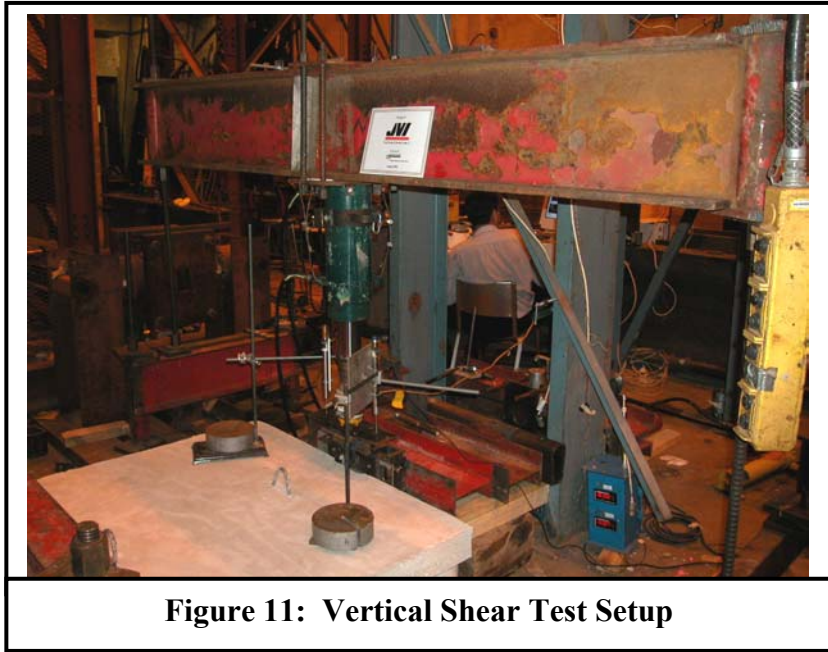


Figure 11: Vertical Shear Test Setup

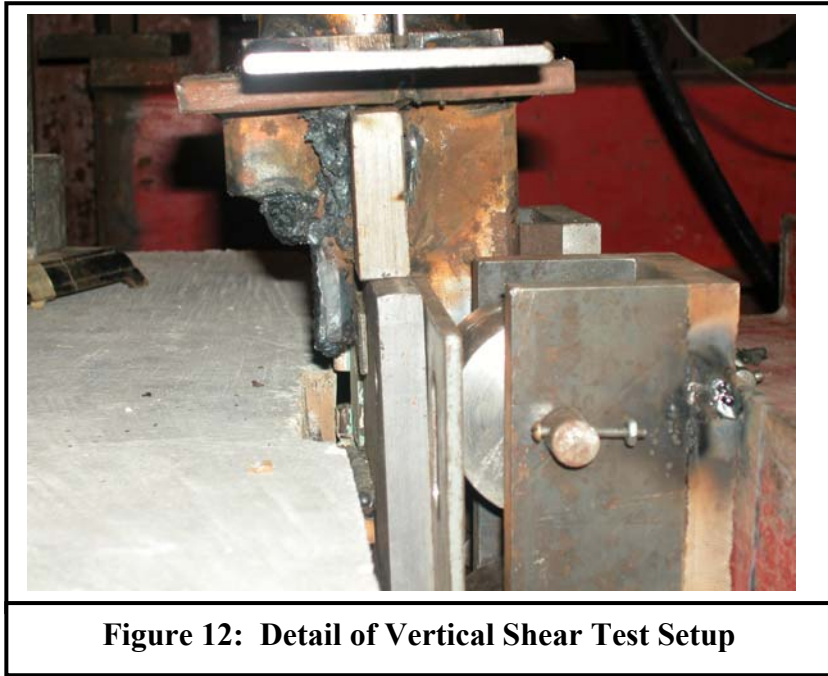


Figure 12: Detail of Vertical Shear Test Setup

Test Procedures

For each of the various types of test conducted, test procedures were kept similar to allow for true comparison of data between tests. The following description of each of the test procedures gives details of the load application and instrumentation setup; these and other test variables were kept the same to allow for consistency between tests.

Monotonic Horizontal Shear w/o Tension

For all of the test setups employed, load was applied gradually to allow for data readings to be taken at regular intervals and for specimen inspection while loading was taking place. For all variations of horizontal shear tests, Linear Variable Differential Transducers (LVDTs) were placed on both sides of the slab (see Figures 4 & 5 on page 7) to read relative slip between the slab and the loading beam. As mentioned previously, two LVDTs were employed for all tests for verification of data. Electronic readings of the load cell and LVDTs were stored for later use in analysis.

Cyclic Horizontal Shear w/o Tension

The test program utilized for cyclic tests was based on the program developed for the original JVI flange connector testing at the University of Wisconsin-Madison. Load application for this test setup was based on the results of the monotonic horizontal shear tests. The yield force and corresponding displacement for each type of steel were estimated and used as a basis for cyclic loading. For cyclic testing, the specimen was first cycled back and forth to a load of 75% of the yield force. Subsequent load cycles were applied in groups of three at displacement levels of 2, 3, 5, 8, and 12 times the yield displacement until connection failure.

Monotonic/Cyclic Horizontal Shear w/ Tension

Horizontal loads for these tests were applied in the same manner as previously described. However, for these tests the connection was initially loaded with a tension force to cause 0.1 in. of joint opening. This displacement of 0.1 in. was read from a dial gage mounted on the slab and placed against the plate near the connection (see Figure 13). This tension load was then held while the appropriate horizontal forces were applied.

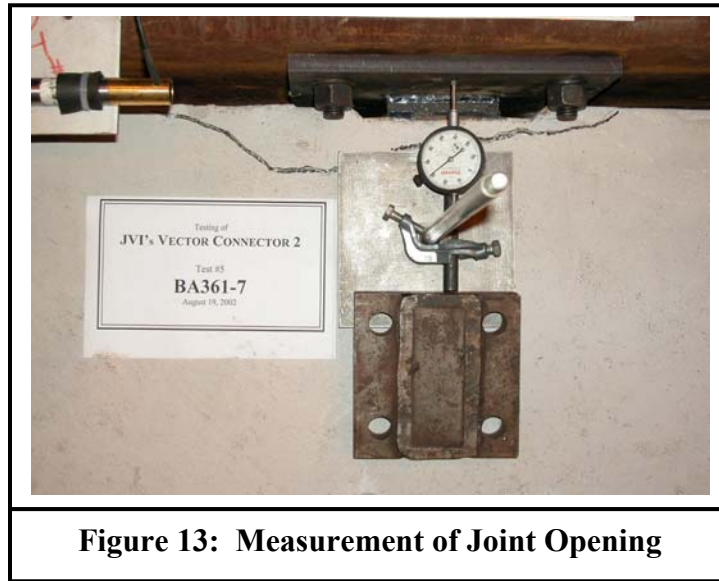


Figure 13: Measurement of Joint Opening

Tension

Tension loads for these tests were also applied gradually, allowing for data gathering of load as well as displacement. For tension tests also, two LVDTs, one on each side of the connection were employed. The LVDTs rested on the slab and measured the opening of the connection relative to the slab.

Vertical Shear

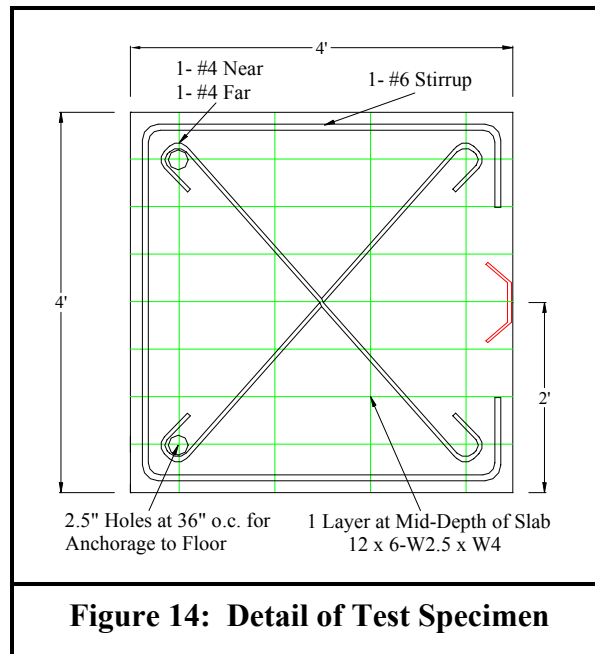
As previously mentioned, vertical loads were applied monotonically from a hydraulic jack hung from a spreader beam anchored to the floor. LVDTs measured the vertical displacement of the plate relative to the slab.

Instrumentation

All loads were applied using either an electric Enerpac hydraulic pump or a hand-operated Enerpac hydraulic pump. All load cells, as well as the LVDTs were calibrated prior to testing. The load cells and LVDTs were connected to a Hewlett-Packard Data Acquisition Unit programmed to scan all transducers at a 10-second interval. All data was displayed and graphed in real-time during testing as well as saved for subsequent use.

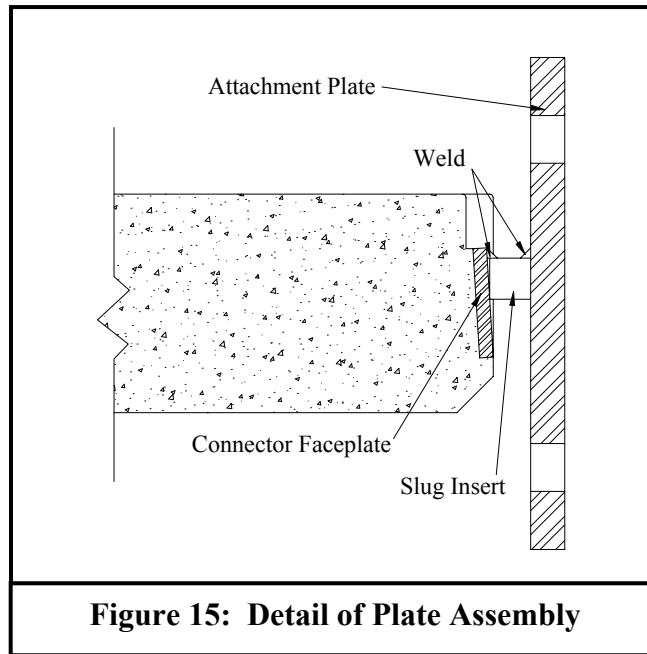
Test Specimens

All specimens were cast by PBM Concrete of Rochelle, Illinois. Each slab specimen had a Vector Connector placed at the midpoint of the slab. A detail of slab dimensions and reinforcement can be seen in Figure 14. Note that two 2.5" diameter holes 36" apart were cast into the slabs for anchorage to the floor. Upon receiving the test specimens, the UWM research team conducted a thorough inspection of all specimens, noting any irregular conditions in the slab as well as the placement of the connector in the concrete. Notes from this initial inspection have been included in Appendix C to this report. All welds were examined to check for cracking, however no cracks were observed.



Each specimen had a 5/8" thick steel plate welded to a rectangular bar, which in turn was welded to the flange connector. All welding was conducted by certified welders in the PBM plant and witnessed by a member of the UWM research team. A custom fixture was fabricated at UWM to aid in this welding process and ensure consistency between test specimens. The use of these plates was done to speed the testing process at later stages. A detail of the plate/connector configuration is shown in Figure 15. The following details were used for this configuration:

- 3/4" x 3/4" x 4" rectangular slugs (A36/A304 stainless)
- the top of the slugs were positioned 1/4" below the top of the connector
- the slug to connector weld was made with a 1/4" throat by 4" long fillet weld using 7018 electrodes with the A36 steel and 309 electrodes with the stainless steel.



Material Tests

The following paragraphs detail material tests conducted on the concrete and the flange connector steels used in this study.

Concrete

Concrete testing was performed by PBM in their Quality Control Department. Test cylinders (6" x 12") were cast at the time of slab fabrication and were tested at different dates throughout the testing process to obtain an estimate of concrete strength at time of specimen testing. Concrete strengths for each specimen are listed in the results table later in this report. All specimens tested had a concrete strength ranging from 5100 psi to 5400 psi.

Steel

Tension tests were conducted for both types of steel used to construct the Vector Connector. All tension testing was conducted at UWM. The tension test coupons were fabricated out of flange connectors from the same batch as those cast in the test specimens. Results of coupon testing can be seen in Figure 16. Yield stress was determined using 0.2% offset.

COUPON TEST RESULTS		
Specimen #	Yield Stress (ksi)	Ultimate Stress (ksi)
A36 #1	62.2	71.5
A36 #2	60.3	73.9
Stainless #1	52	97
Stainless #2	50.9	96.7

Figure 16: Coupon Test Results

Test Schedule

The following table lists the types of tests conducted and labeling notation used for each test.

SCHEDULE OF TESTS			
Test Type	Specimen Number	Test Label	
		A36 Steel	Stainless Steel
Monotonic Horizontal Shear w/o Tension	1	BA361-1	BSS1-1
	2	BA361-2	BSS1-2
Cyclic Horizontal Shear w/o Tension	3	BA361-3	BSS1-3
	4	BA361-4	BSS1-4
Monotonic Horizontal Shear w/ Tension	7	BA361-7	BSS1-7
	8	BA361-8	BSS1-8
Cyclic Horizontal Shear w/ Tension	9	BA361-9	BSS1-9
	10	BA361-10	BSS1-10
Monotonic Tension	5	BA361-5	BSS1-5
	6	BA361-6	BSS1-6
Vertical Shear - 4" Slab	11	xxx	BSS1-11
	12	BA361-12	BSS1-12
	13	BA361-13	BSS1-13
	14	xxx	BSS1-14
Vertical Shear - 6" Slab	1	xxx	6" Slab - 1
	2	xxx	6" Slab - 2

Figure 17: Schedule of Tests

Test Results

The following figures show the results of all tests conducted for this study. More detailed descriptions of specific test results can be found on the following pages.

RESULTS OF JVI VECTOR CONNECTOR TESTING -- A36 STEEL					
Test Type	Specimen Number	f _c (age in days) (psi)	Cracking Load (lb)	Ultimate Load (lb)	Failure Mechanism
Monotonic Horizontal Shear w/o Tension	BA361-1	5167 (19)	14000	18613	tension leg pullout
	BA361-2	5167 (19)	15000	20723	tension leg pullout
Cyclic Horizontal Shear w/o Tension	BA361-3	5123 (23)	18000	21433	connector faceplate rupture
	BA361-4	5123 (23)	18000	20203	connector faceplate rupture
Monotonic Horizontal Shear w/ Tension	BA361-7	5167 (19)	4000	13183	tension leg pullout
	BA361-8	5167 (19)	8400	13120	tension leg pullout
Cyclic Horizontal Shear w/ Tension	BA361-9	5462 (37)	14800	14802	connector faceplate rupture
	BA361-10	5462 (37)	14500	15573	connector faceplate rupture
Monotonic Tension	BA361-5	5123 (23)	6300	6293	weld failure
	BA361-6	5123 (23)	5500	7513	weld failure
Vertical Shear - 4" Slab	BA361-11**	xxx	xxx	xxx	xxx
	BA361-12	5462 (37)	5000	5876	spalling of bottom surface
	BA361-13	5462 (37)	5200	5500	spalling of bottom surface
** Test BA361-11 failure not due to connection, results neglected					

Figure 18: A36 Steel Test Results

RESULTS OF JVI VECTOR CONNECTOR TESTING -- STAINLESS STEEL					
Test Type	Specimen Number	f _c (age in days) (psi)	Cracking Load (lb)	Ultimate Load (lb)	Failure Mechanism
Monotonic Horizontal Shear w/o Tension	BSS1-1	5167 (19)	14500	19523	tension leg pullout
	BSS1-2	5167 (19)	15000	21055	tension leg pullout
Cyclic Horizontal Shear w/o Tension	BSS1-3	5462 (37)	23000	23208	connector faceplate rupture
	BSS1-4	5123 (23)	22000	22306	connector faceplate rupture
Monotonic Horizontal Shear w/ Tension	BSS1-7	5123 (23)	14000	18187	tension leg pullout
	BSS1-8	5123 (23)	11000	15748	tension leg pullout
Cyclic Horizontal Shear w/ Tension	BSS1-9	5462 (37)	14000	17070	connector faceplate rupture
	BSS1-10	5462 (37)	18000	21508	connector faceplate rupture
Monotonic Tension	BSS1-5	5123 (23)	7300	11807	weld failure
	BSS1-6	5123 (23)	6000	11360	weld failure
Vertical Shear - 4" Slab	BSS1-11	5462 (37)	6000	6000	spalling of bottom surface
	BSS1-12	5462 (37)	6000	6000	spalling of bottom surface
	BSS1-13	5462 (37)	5989	5989	spalling of bottom surface
	BSS1-14	5462 (37)	5400	5400	spalling of bottom surface
Vertical Shear - 6" Slab	6" Slab - 1	5462 (37)	6000	6000	spalling of bottom surface
	6" Slab - 2	5462 (37)	6732	6732	spalling of bottom surface

Figure 19: Stainless Steel Test Results

ALL RESULTS OF JVI VECTOR CONNECTOR TESTING			
Test Type	Specimen	Ultimate Load (lb)	
		A36 Steel	Stainless Steel
Monotonic Horizontal Shear w/o Tension	1	18613	19523
	2	20723	21055
Cyclic Horizontal Shear w/o Tension	3	21433	23208
	4	20203	22306
Monotonic Horizontal Shear w/ Tension	7	13183	18187
	8	13120	15748
Cyclic Horizontal Shear w/ Tension	9	14802	17070
	10	15573	21508
Monotonic Tension	5	6293	11807
	6	7513	11360
Vertical Shear - 4" Slab	11	xxx	6000
	12	5876	6000
	13	5500	5989
	14	xxx	5400
Vertical Shear - 6" Slab	1	xxx	6000
	2	xxx	6600

Figure 20: Comparison of Selected Results for All Specimens

Monotonic Horizontal Shear w/o Tension

TEST RESULTS	A36 Steel		Stainless Steel	
	Specimen Number	Ultimate Load	Specimen Number	Ultimate Load
Monotonic Horizontal Shear w/o Tension	BA361-1	18613	BSS1-1	19523
	BA361-2	20723	BSS1-2	21055

Results of this series of tests were consistent between the two types of steel. As seen, the ultimate loads are similar between the two types of steel, as is the cracking load. The load-deformation behavior of the connection, however, varied significantly with steel type. The ductility of the stainless steel connectors was almost double the A36 connectors. All specimens tested under this load type had very similar failures; cracking of the concrete at approximately 14000 lbs, with pullout of the tension leg of the connector at 19000-20000 lbs. Typical cracking for this type of test included spalling directly above the flange connector, crushing of the concrete due to the connector bearing on the side opposite of load application, and splitting of the slab at failure due to the pulling out of the tension leg of the connector. Results of this series of tests were significant because as previously mentioned; they would serve as the basis for the program employed for all cyclic testing. The following values were estimated from this series of tests:

A36 Steel: Yield Force = 17300 lbs Yield Displacement = .045"
Stainless Steel: Yield Force = 15000 lbs Yield Displacement = .175"

Photos of a typical failure and a sample data graph for this type of test can be seen in Figures 21-23. Note that all data graphs, with the exception of cyclic data graphs, display two curves on the graph. These curves represent the data obtained from each of the LVDTs. Data graphs for all tests conducted in this study are included as Appendix B to this report.

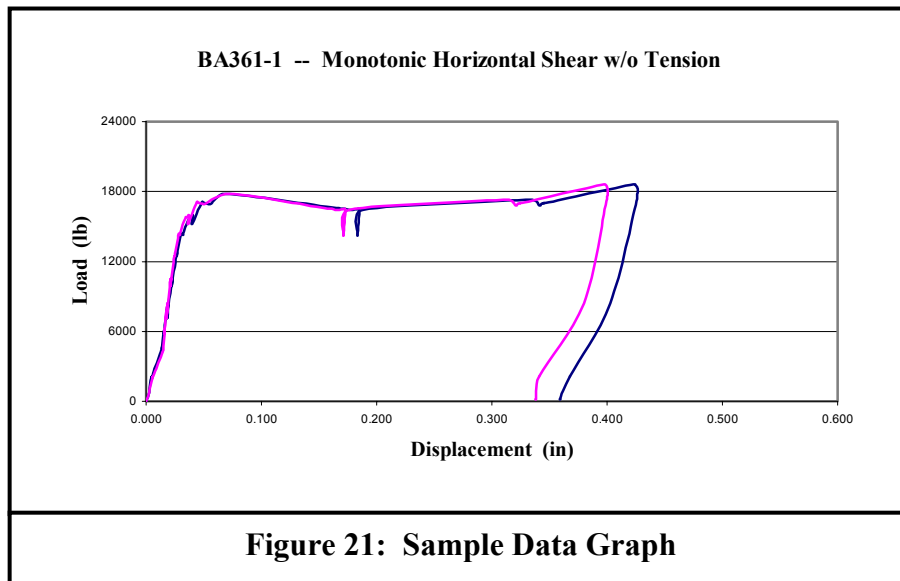




Figure 22: Typical Failure for Horiz. Shear w/o Tension

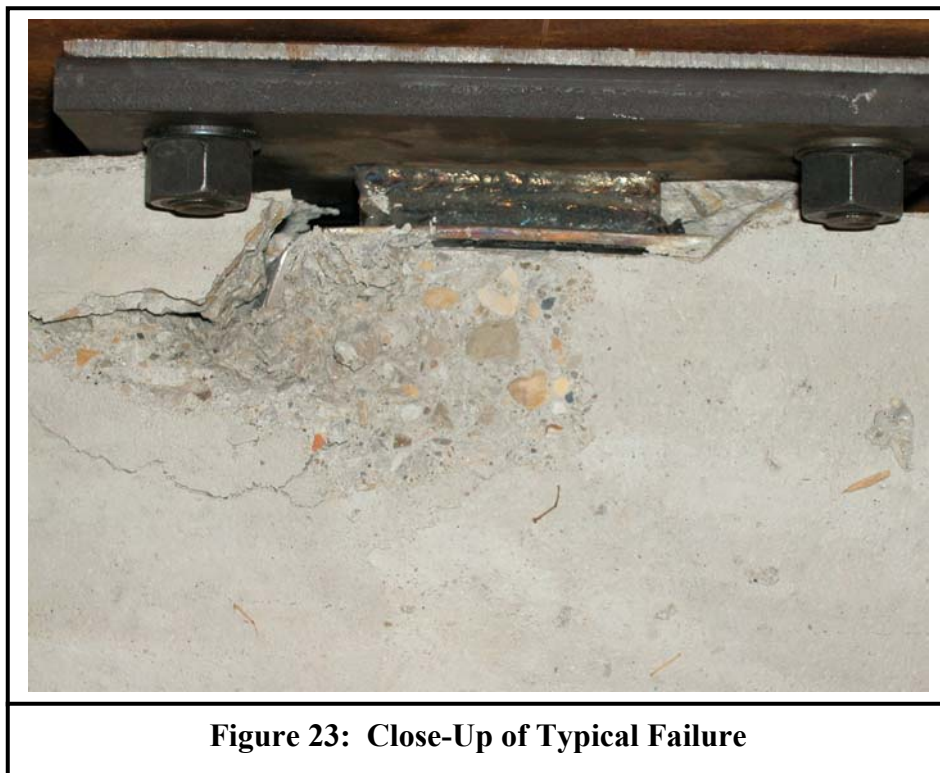


Figure 23: Close-Up of Typical Failure

Cyclic Horizontal Shear w/o Tension

TEST RESULTS	A36 Steel		Stainless Steel	
	Specimen Number	Ultimate Load	Specimen Number	Ultimate Load
Cyclic Horizontal Shear w/o Tension	BA361-3	21433	BSS1-3	23208
	BA361-4	20203	BSS1-4	22306

As noted previously, the program for all cyclic testing was based on the yield force and displacement obtained from the tests for monotonic horizontal shear w/o tension. Specimens were first cycled back and forth to a load of 75% of the estimated yield force. Specimens were then cycled in groups of three to displacements of 2, 3, 5, 8, and 12 times yield displacement until connection failure. The resulting cyclic programs for each type of steel were:

A36 Steel: cycle once to 13000 lbs, cycle three times each at .09", .135", .225", .360", and .540"

Stainless Steel: cycle once to 11250 lbs, cycle three times each at .350", and .525".

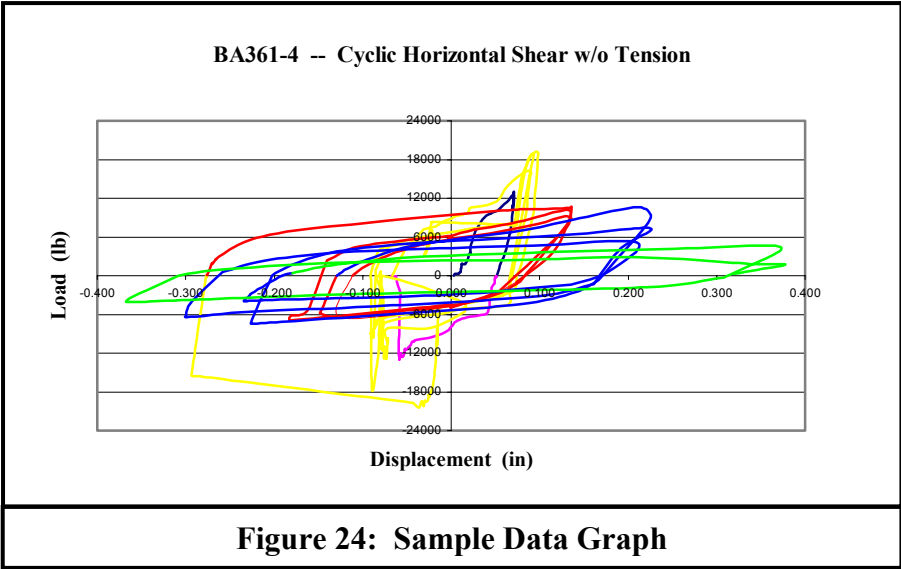
A36 Steel

Tests for A36 connectors displayed very similar ultimate loads at approximately 21000 lbs. Ductility varied greatly between the two tests, however. Test BA361-3 failed on its first cycle up to .225" while Test BA361-4 failed on its second cycle up to a displacement of .360". In comparing test observations, Test BA361-4 experienced cracking at a much later stage, accounting for the extended life of the connection. Failure for these, as well as all other cyclic tests, was the result of faceplate rupture. Typically concrete cracking occurred during the first displacement cycle, causing the concrete surrounding the faceplate to break away. This left the connection free to displace back and forth with the cycles. As higher displacements were reached, the faceplate began to tear on both sides. This tearing occurred at the first bend in the connector between the faceplate and the leg. Typically, once tearing had initiated, the connector still functioned for at least two more cycles.

Stainless Steel

Tests for Stainless Steel exhibited ultimate loads of approximately 22500 lbs. Ductility was the same for both Tests BSS1-3 and BSS1-4 failing on the first cycle down to .525". The failure process for these tests was similar to those previously described.

Photos of a typical failure and a sample data graph for this type of test can be seen in Figures 24-26. Data graphs for all tests conducted in this study are included as Appendix B to this report.



Monotonic Horizontal Shear w/ Tension

TEST RESULTS	A36 Steel		Stainless Steel	
	Specimen Number	Ultimate Load	Specimen Number	Ultimate Load
Monotonic Horizontal Shear w/ Tension	BA361-7	13183	BSS1-7	18187
	BA361-8	13120	BSS1-8	15748

For this series of tests, horizontal load was applied as previously mentioned. However, for these tests an initial tension force was applied to the connection. All failures for this series of test were again due to pullout of the tension leg as was seen in the same test without a tension force applied to the connection. The intended tension force to be applied to the connection was to cause a joint opening of 0.1". As will be discussed in the following paragraphs, for various reasons this was not always accomplished.

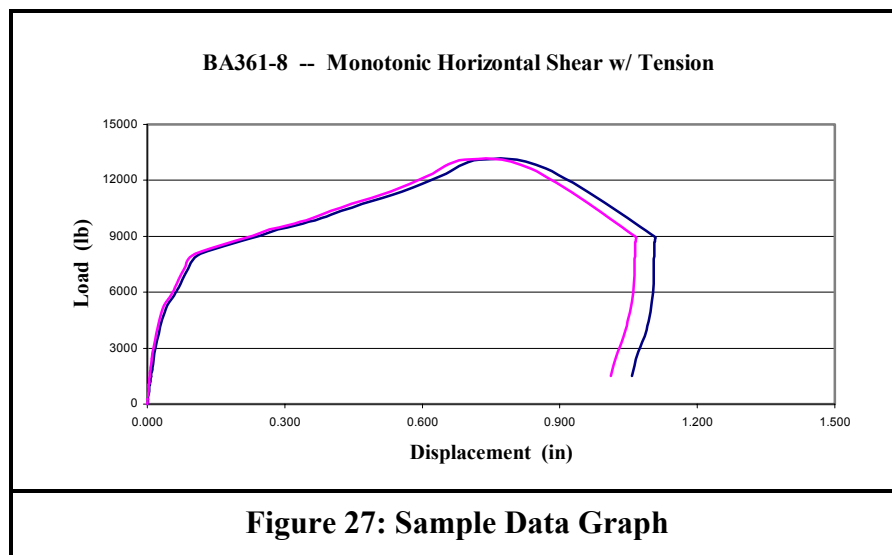
A36 Steel

Ultimate load (13000 lbs) as well as ductility for Tests BA361-7 and BA361-8 were nearly identical. For BA361-7, the tension load was applied to cause a joint opening of .1". As this load was applied, however, further deformation occurred causing a joint opening of .15". Tension load was released and a permanent deformation of more than .1" had occurred. A load was then reapplied to the connection to place it under tension and held while horizontal testing was initiated. For BA361-8, tension load was increased to cause a joint opening of .1", this load was then held and horizontal testing was initiated.

Stainless Steel

Differences in tension load explain the varying results between Tests BSS1-7 and BSS1-8. For Test BSS1-7, as tension load was applied, joint opening increased to .12" of permanent deformation. The load was then released and horizontal testing was carried out with no tension force applied to the connection. For Test BSS1-8 tension load was applied to cause .1" of joint opening. This force was then held while horizontal testing was conducted.

A sample data graph for this type of test can be seen in Figure 27. Photos of typical failures have not been included for this series since they are identical to tests done without tension applied to the connection.



Cyclic Horizontal Shear w/ Tension

TEST RESULTS	A36 Steel		Stainless Steel	
	Specimen Number	Ultimate Load	Specimen Number	Ultimate Load
Cyclic Horizontal Shear w/ Tension	BA361-9	14802	BSS1-9	17070
	BA361-10	15573	BSS1-10	21508

Results of this series of tests were again very consistent. For all tests in this series, a tension load was applied which resulted in 0.1” of joint opening. This load was then held while cyclic horizontal testing was conducted. Failure for these tests were identical to cyclic tests conducted with no tension force applied. Rupture at the ends of the faceplates was again the cause of failure.

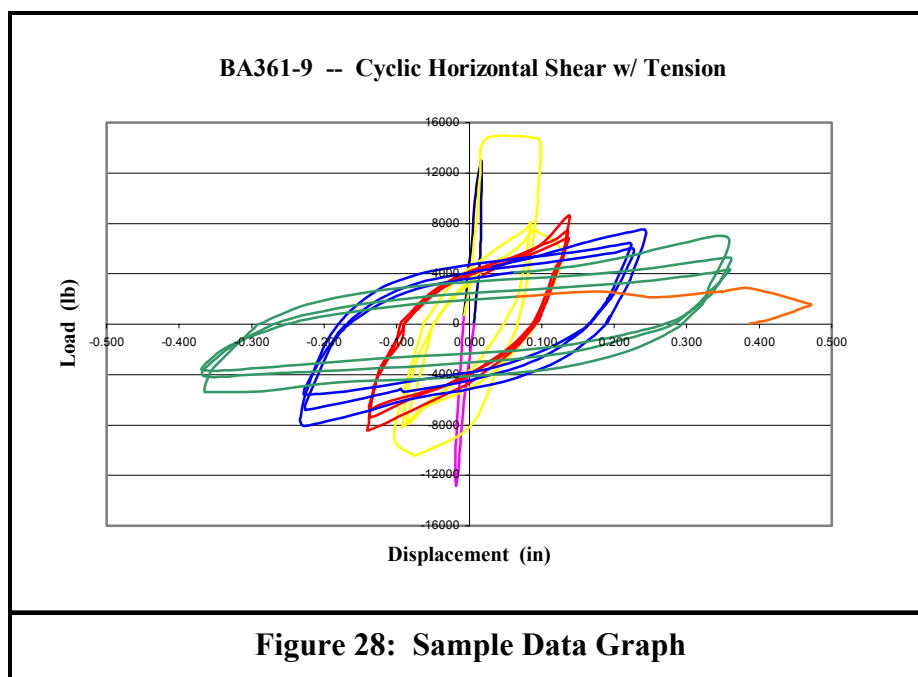
A36 Steel

As can be seen in the data graphs, ultimate loads as well as load-deformation behavior for Tests BA361-9 and BA361-10 were nearly identical. Test BA361-9 failed on its first cycle up to .540”. Test BA361-10 failed on its final cycle down to .360”. Ultimate loads for both tests were approximately 15000 lbs. For both tests, the tension load applied to produce 0.1” of joint opening was 4600 lbs.

Stainless Steel

Results for Tests BSS1-9 and BSS1-10 varied. Ultimate load ranged from 17000 lbs. to 21000 lbs. Ductility was comparable with Test BSS1-9 failing on its first cycle up to .525” and Test BSS1-10 failing on its first cycle down to .525”. For both tests, the approximate tension force applied to produce 0.1” of joint opening was 6400 lbs.

A sample data graph for this type of test can be seen in Figure 28. Photos of typical failures have not been included for this series of test since they are identical to tests done without tension applied to the connection.



Monotonic Tension

TEST RESULTS	A36 Steel		Stainless Steel	
	Specimen Number	Ultimate Load	Specimen Number	Ultimate Load
Monotonic Tension	BA361-5	6293	BSS1-5	11807
	BA361-6	7513	BSS1-6	11360

Results for this series of tests were again consistent. As the tension load was applied to the connection, concrete around the faceplate broke off and the faceplate began to fold downward. Once the faceplate reached an approximate angle of 30° compared to its original position, the weld began to tear from each end, propagating rapidly towards the center. This was the mode of failure for all monotonic tension tests.

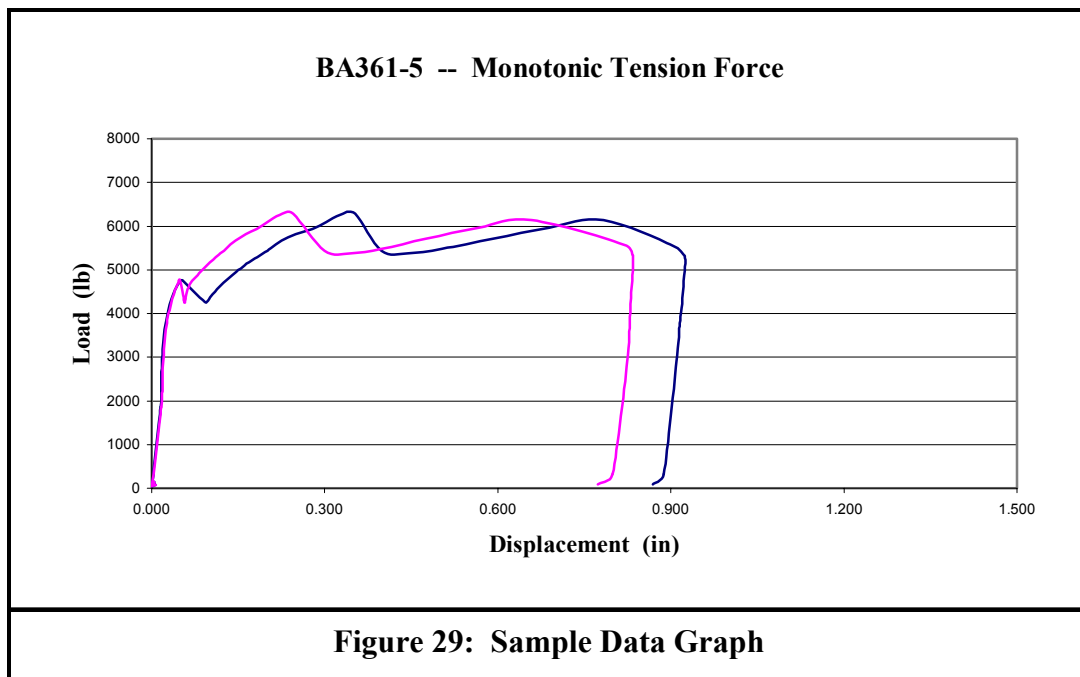
A36 Steel

Ultimate loads for Tests BA361-5 and BA361-6 ranged from 6300 lbs. to 7500 lbs. Load-deformation behavior was also very similar with cracking occurring at 6000 lbs. Later portions of the graphs appear to differ. However, for Test BA361-6, the LVDTs were removed to prevent possible damage due to failure of the connection.

Stainless Steel

Ultimate loads for Tests BSS1-5 and BSS1-6 were nearly identical at approximately 11500 lbs. Load-deformation behavior was also similar with cracking around 6000-7000 lbs.

Photos of a typical failure and a sample data graph for this type of test can be seen in Figures 29-32. Data graphs for all tests conducted in this study are included as Appendix B to this report.





Figures 30 through 32: Typical Failure for Tension Only Test

Vertical Shear

TEST RESULTS	A36 Steel		Stainless Steel	
	Specimen Number	Ultimate Load	Specimen Number	Ultimate Load
Vertical Shear - 4" Slab	xxx	xxx	BSS1-11	6000
	BA361-12	5876	BSS1-12	6000
	BA361-13	5500	BSS1-13	5989
	xxx	xxx	BSS1-14	5400
Vertical Shear - 6" Slab	xxx	xxx	6" Slab -1	6000
	xxx	xxx	6" Slab -2	6732

Vertical shear test results are remarkably consistent. All failures were due to spalling of the concrete on the bottom surface of the slab below the connector. All failures were brittle due to the failure of the concrete, thus the ultimate load was the same as the cracking load.

A36 Steel

Ultimate loads for Tests BA361-12 and BA361-13 ranged from 5500 lbs. to 5876 lbs.

Stainless Steel

Tests BSS1-11 through Test BSS1-13 were all performed on slabs with similar construction. Ultimate loads were 6000 lbs. for each test. Specimen BSS1-14 was constructed with the connector placed below the mesh. This is the probable cause for the reduction in ultimate load to 5400 lbs. Two tests were also conducted on 6" slabs. 6" Slab – 1 had an ultimate load of 6000 lbs. 6" Slab – 2 had $\frac{3}{4}$ " more concrete cover below the connector than the previous slab, a possible explanation for the increase in ultimate load to 6700 lbs.

Photos of a typical failure and a sample data graph for this type of test can be seen in Figures 33-35. Data graphs for all tests conducted in this study are included as Appendix B to this report.

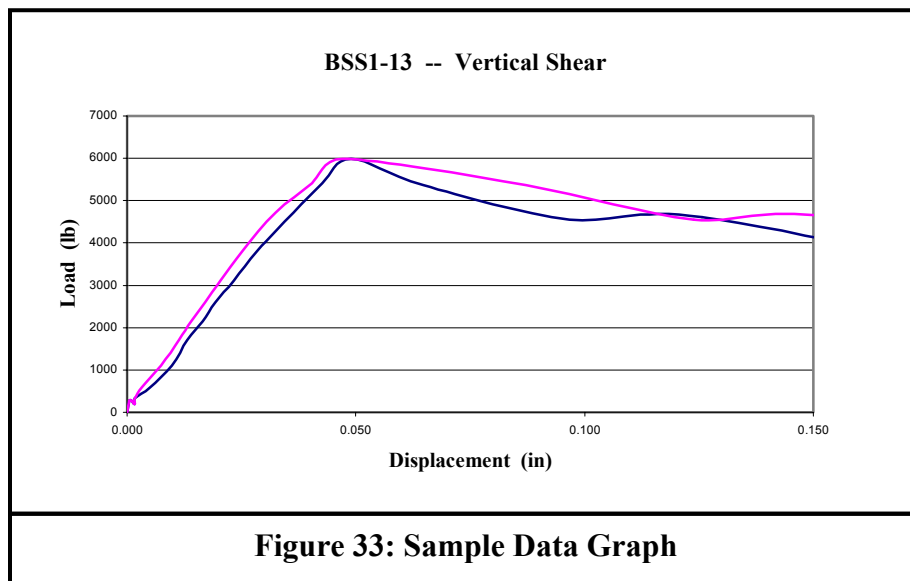




Figure 34: Front View of Slab



Figure 35: Bottom View of Slab

Summary and Conclusions

This report covers the results of testing of JVI's Vector Connector embedded in concrete slabs and exposed to various types of loading to simulate typical loads under service conditions. The loading conditions were:

- Monotonically applied horizontal shear force
- Cyclically applied horizontal shear force
- Monotonically applied horizontal shear force with applied tension
- Cyclically applied horizontal shear force with applied tension
- Monotonically applied tension force
- Monotonically applied downward vertical shear force.

Twenty-six tests were conducted on single connectors, each embedded in a 4' x 4' x 4" thick concrete slab. The remaining two tests were conducted on similar 6" thick slabs. The connector installation in the slabs modeled typical flanges of precast double-tee members. The connectors were made of two types of steel: A36 structural grade steel, and A304 Stainless steel. The specimens were fabricated at PBM and transported to Milwaukee and tested in the Structural Engineering Laboratory of the University of Wisconsin-Milwaukee during August – September, 2002.

Based on a review of the results of this testing, the following conclusions* are drawn:

- (1) The results of identical tests within each load category showed remarkable consistency, which should enable better predictability in the design process.
- (2) The horizontal shear strength with tension load across the joint was consistently about 70% of the corresponding strength without tension load.
- (3) In all cyclic horizontal shear tests, failure occurred due to rupture of the connector faceplate from the legs, demonstrating sufficient anchorage in concrete.
- (4) In the tension load only tests, the failure occurred due to rupture of the weld and thus the connector tension strength could not be achieved. Pretest visual examination of the specimens and welding did not reveal any obvious flaws or cracking in the weld zones.
- (5) Spalling of concrete at the bottom of the slab occurred in all vertical shear tests. Use of auxiliary reinforcement, such as welded wire mesh has been suggested to help against such spalling.

* In addition to these conclusions, the authors suggest reference to the conclusions and recommendations given in the "Oliva 2000" report (available at www.jvi-inc.com).

Appendix A

Comparison of Current and Previous JVI Test Results

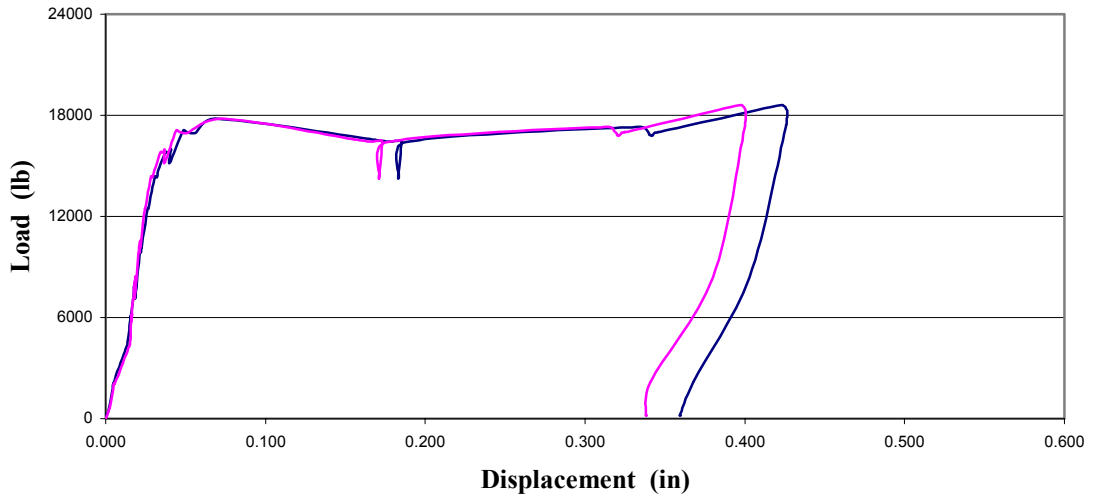
RESULTS OF CURRENT AND PREVIOUS JVI VECTOR CONNECTOR TESTS

Test Type	Specimen	Current Results		Results from Previous Testing	
		Ultimate Load (lb)		Ultimate Load (lb)	
		A36 Steel	Stainless Steel	A36 Steel	Stainless Steel
Monotonic Horizontal Shear w/o Tension	1	18613	19523	22300 (1B)	23100 (10B)
	2	20723	21055	20700 (2B)	22500 (11B)
Cyclic Horizontal Shear w/o Tension	3	21433	23208	21700 (3B)	18100 (7A)
	4	20203	22306	23100 (4B)	19100(12B)
Monotonic Horizontal Shear w/ Tension	7	14802	18187	19000 (5B)	13500(13B)
	8	15573	15748	16500 (6B)	19400 (14B)
Cyclic Horizontal Shear w/ Tension	9	13183	17070	16100 (7B)	12300 (8A)
	10	13120	21508	12400 (8B)	14300 (15B)
Monotonic Tension	5	6293	11807	7300 (4A)	10000 (9A)
	6	7513	11360	12700 (9B)	16200 (16B)
Vertical Shear - 4" Slab	11	xxx	6000	8600 (5A)	7000(17B)
	12	5876	6000	5600 (6A)	xxx
	13	5500	5989	xxx	xxx
	14	xxx	5400	xxx	xxx
Vertical Shear - 6" Slab	1	xxx	6000	xxx	xxx
	2	xxx	6600	xxx	xxx

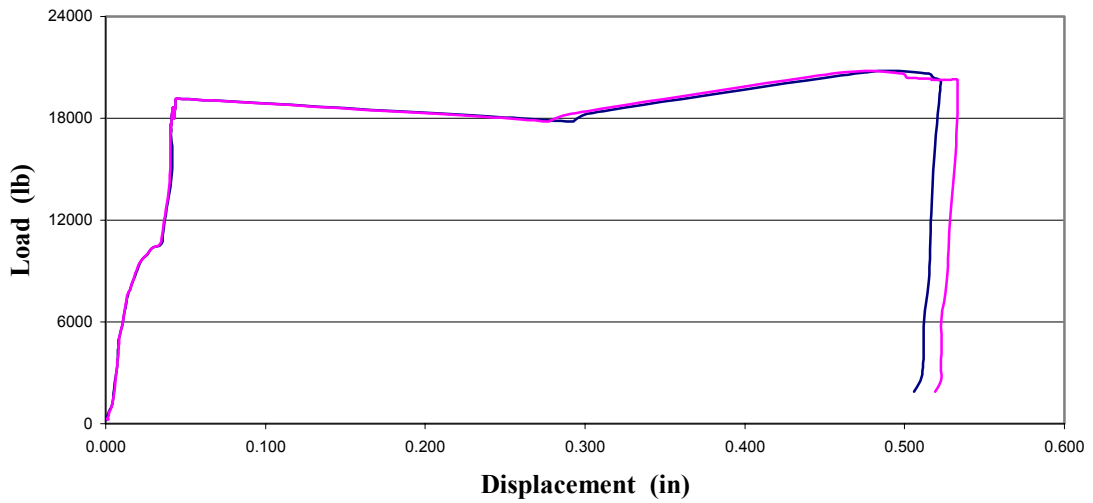
Appendix B

Test Data Graphs

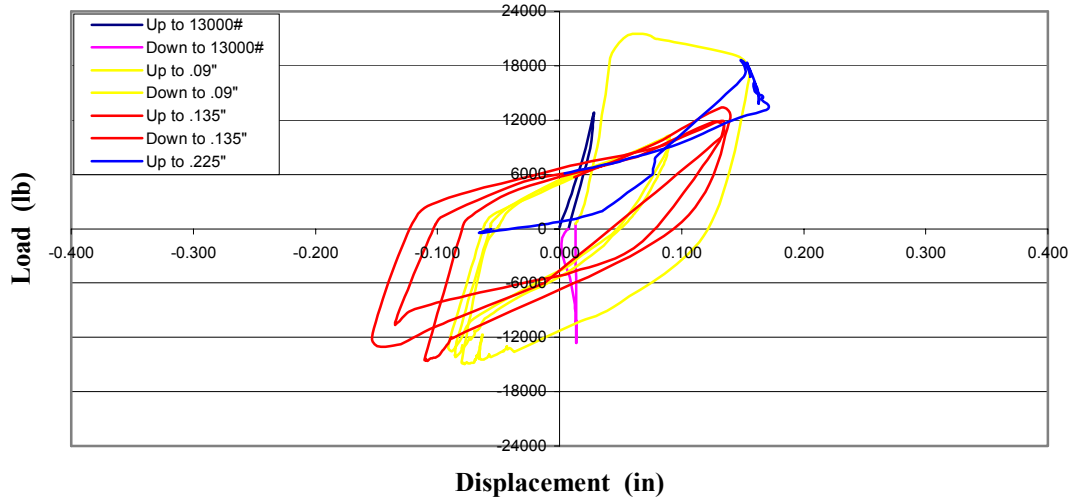
BA361-1 -- Monotonic Horizontal Shear w/o Tension



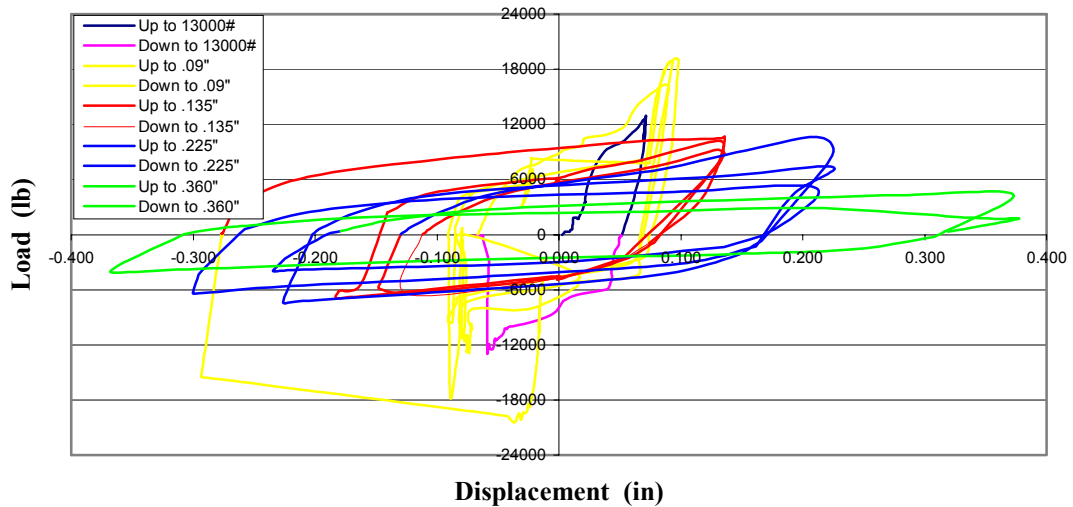
BA361-2 -- Monotonic Horizontal Shear w/o Tension



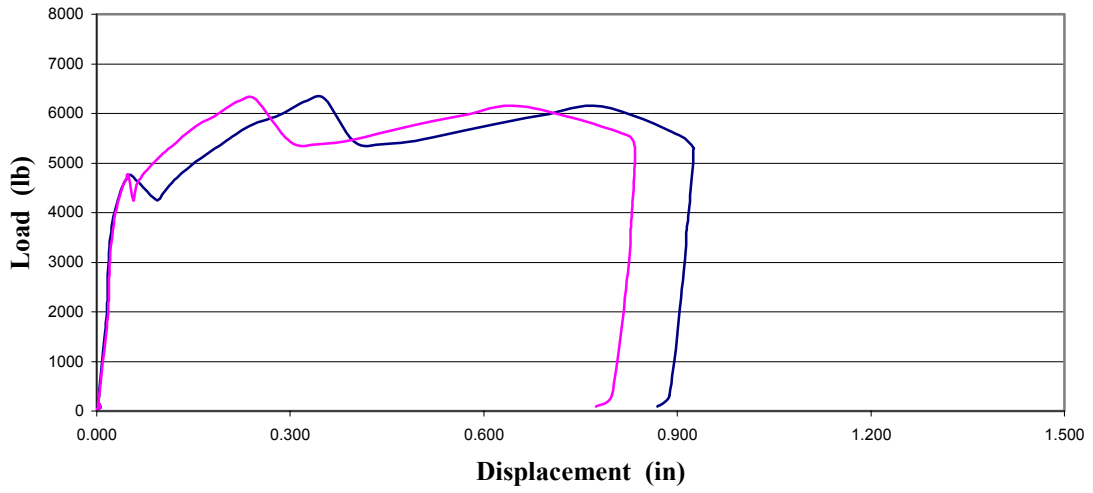
BA361-3 -- Cyclic Horizontal Shear w/o Tension



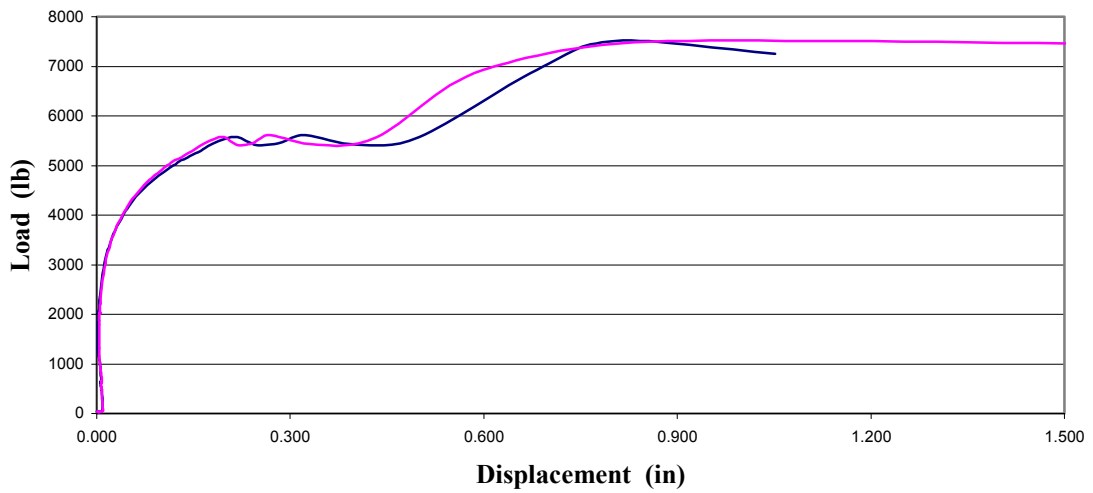
BA361-4 -- Cyclic Horizontal Shear w/o Tension



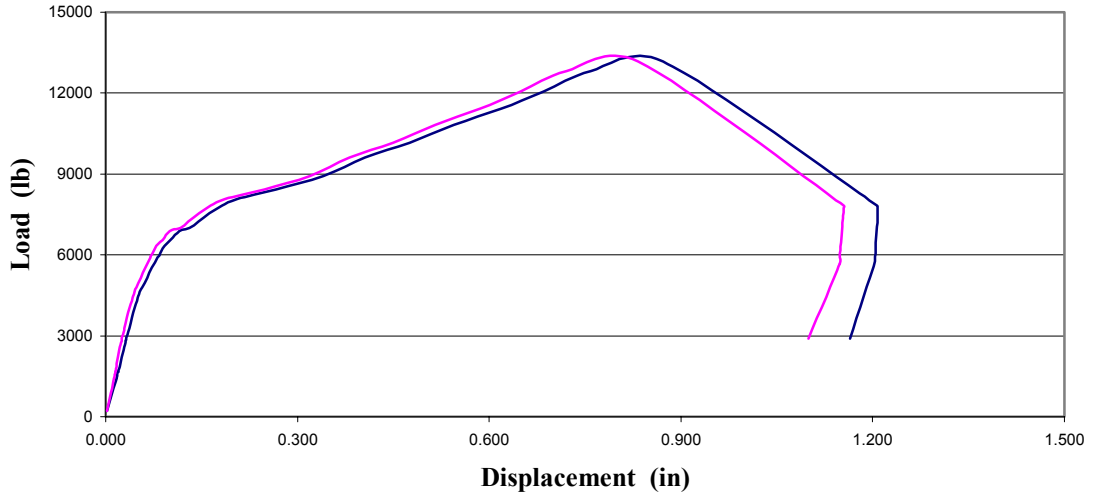
BA361-5 -- Monotonic Tension Force



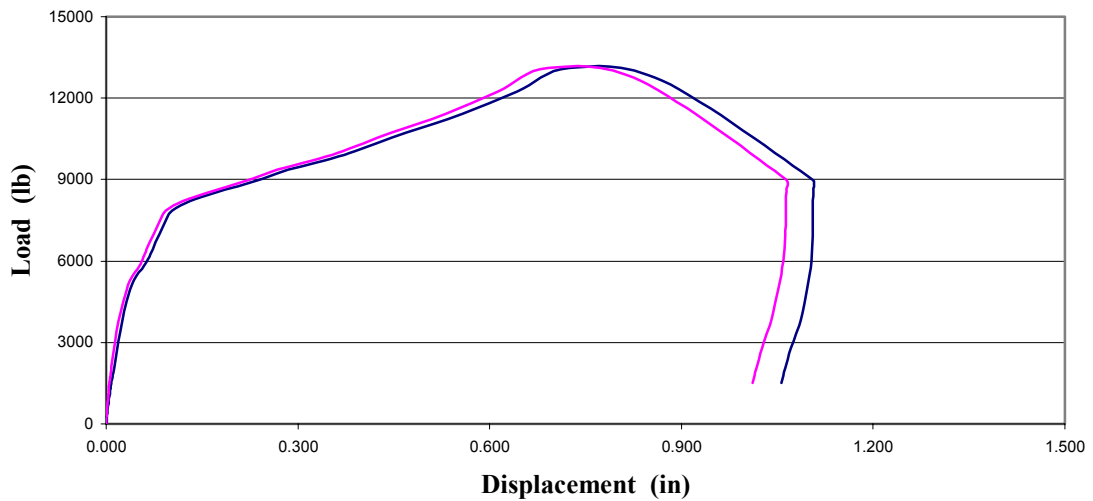
BA361-6 -- Monotonic Tension Force



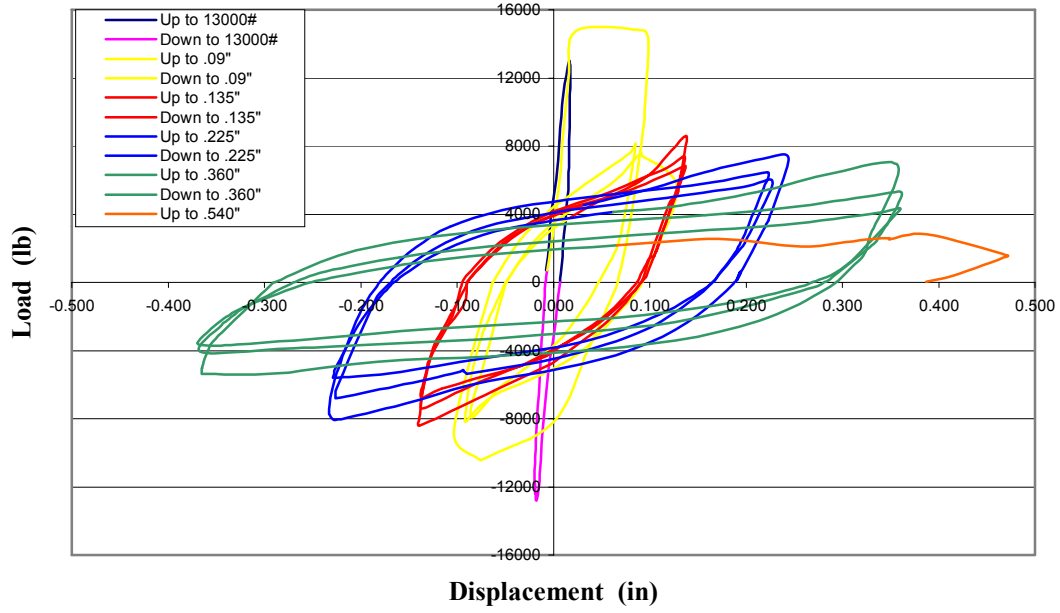
BA361-7 -- Monotonic Horizontal Shear w/ Tension



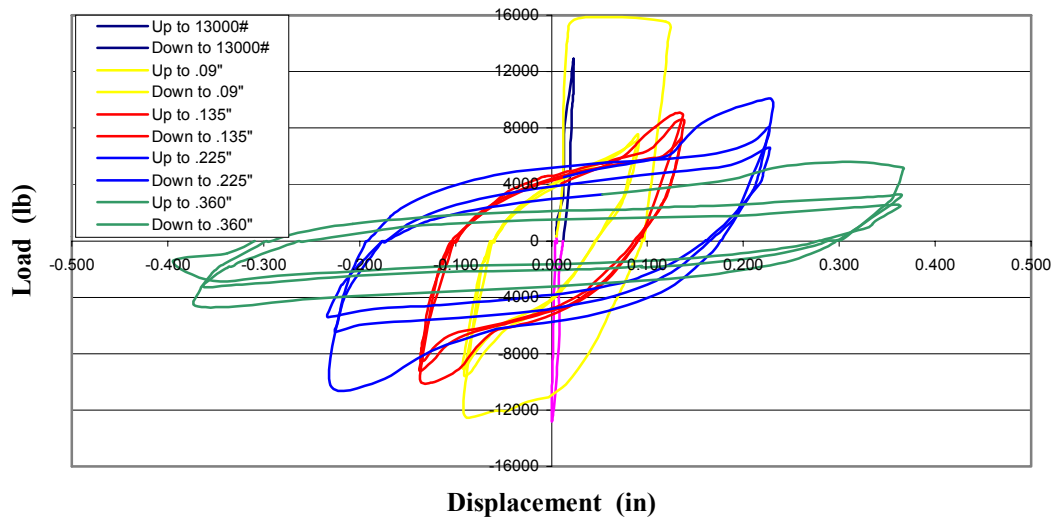
BA361-8 -- Monotonic Horizontal Shear w/ Tension



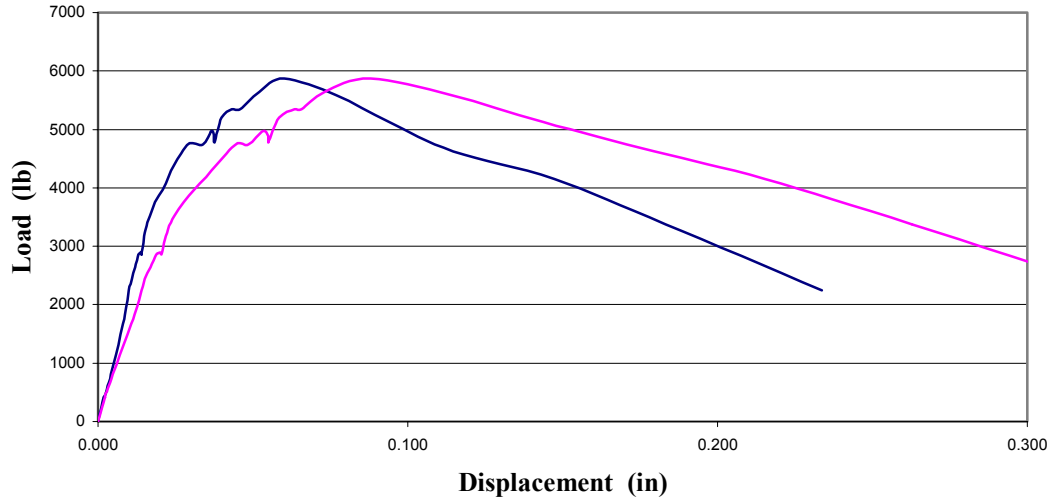
BA361-9 -- Cyclic Horizontal Shear w/ Tension



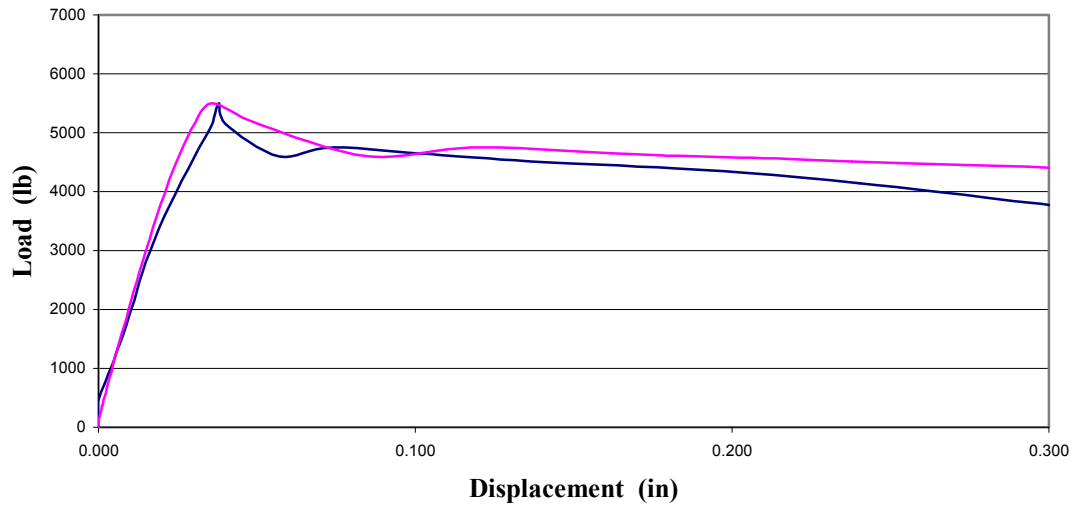
BA361-10 -- Cyclic Horizontal Shear w/ Tension



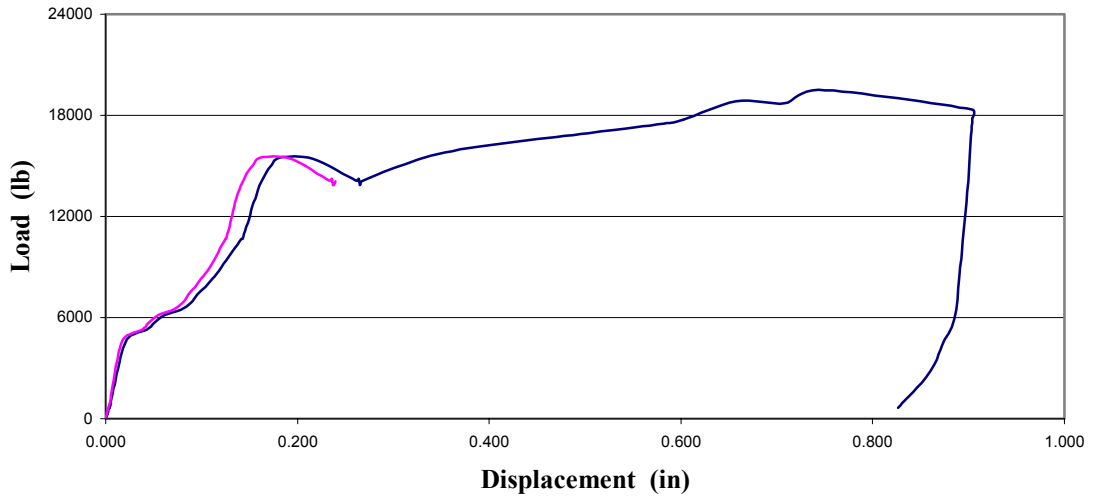
BA361-12 -- Vertical Shear



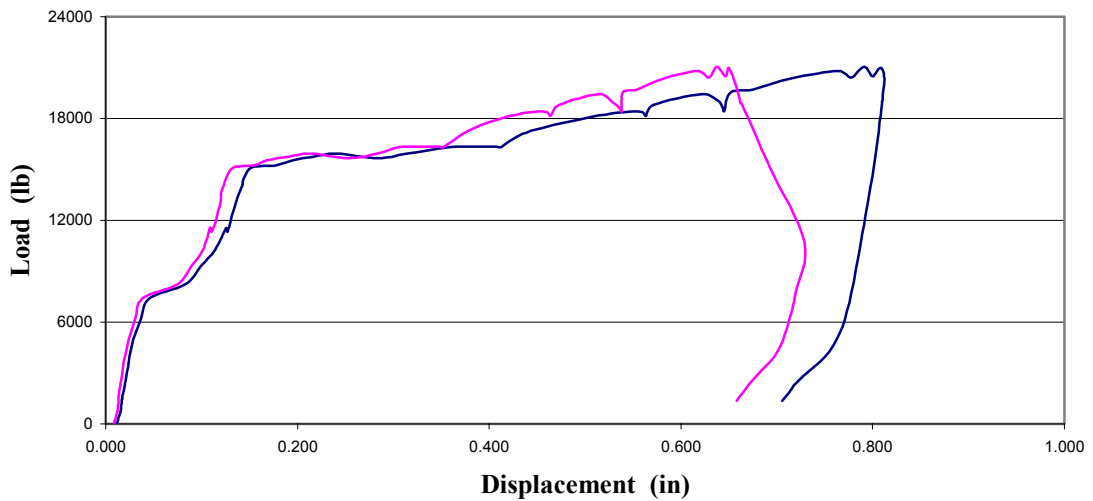
BA361-13 -- Vertical Shear



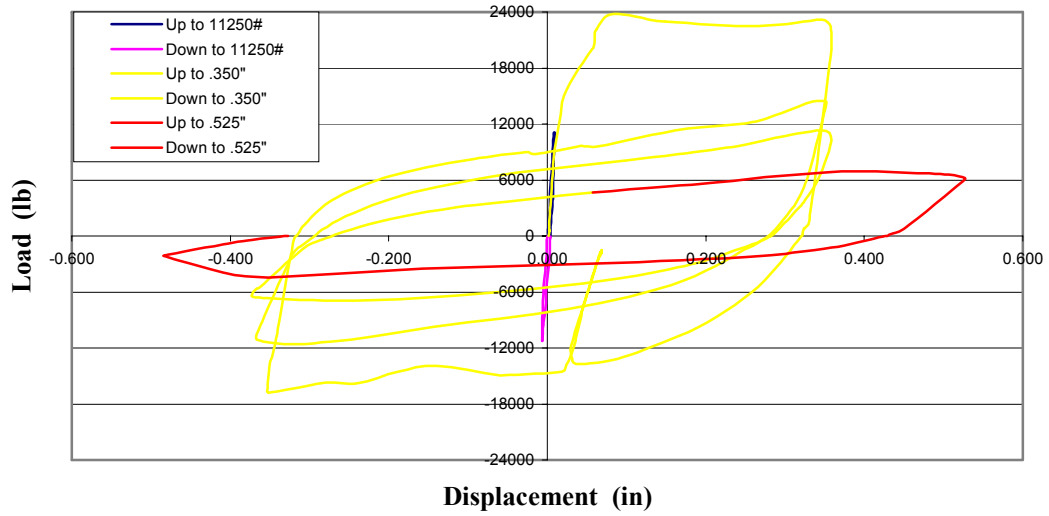
BSS1-1 -- Monotonic Horizontal Shear w/o Tension



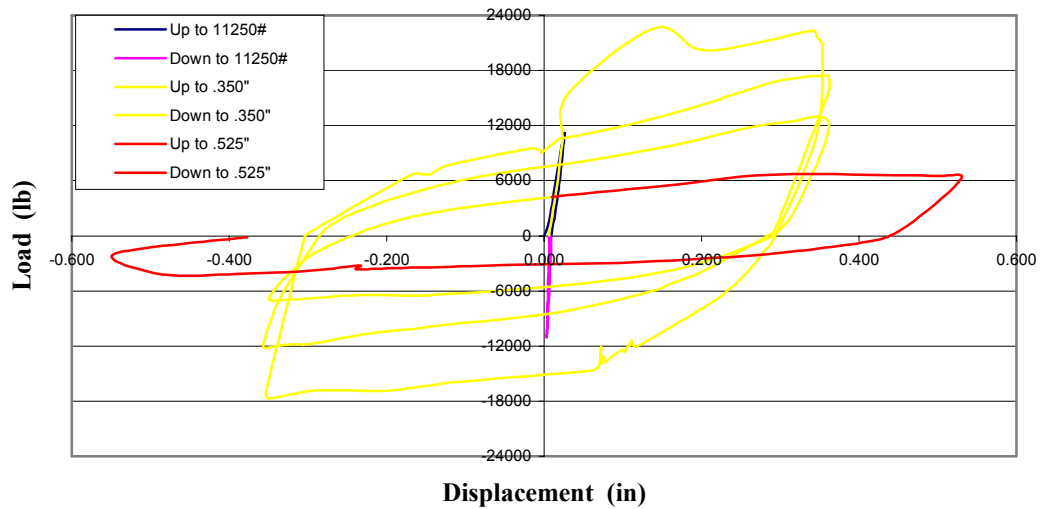
BSS1-2 -- Monotonic Horizontal Shear w/o Tension



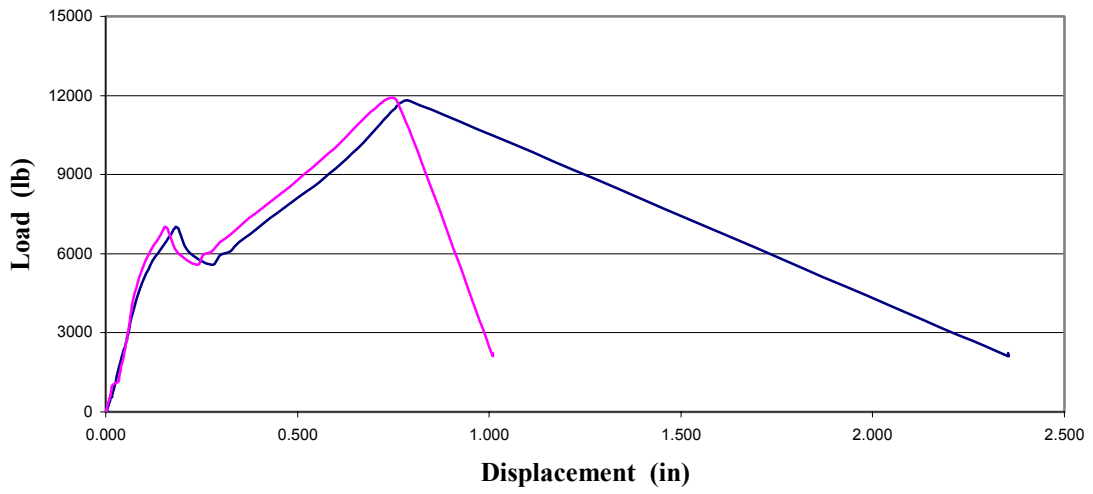
BSS1-3 -- Cyclic Horizontal Shear w/o Tension



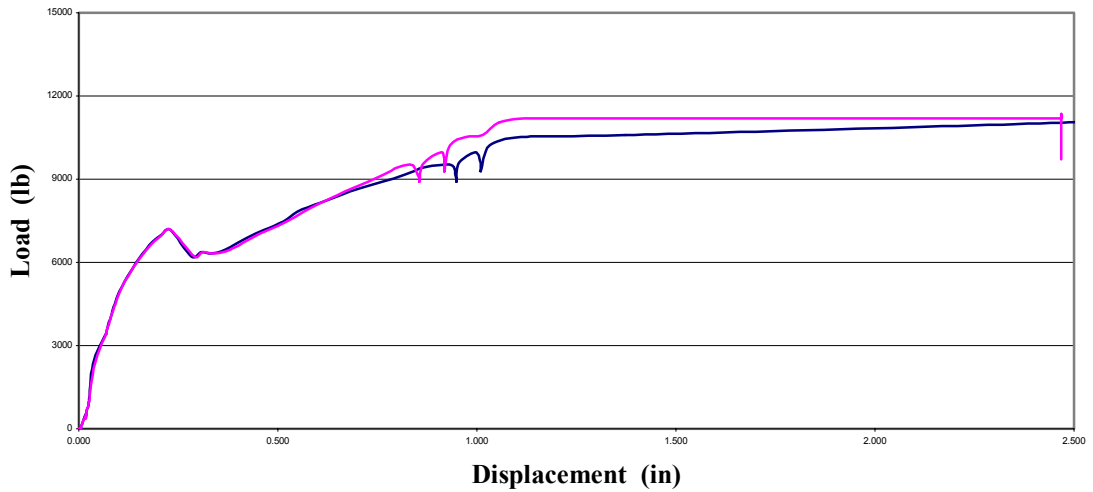
BSS1-4 -- Cyclic Horizontal Shear w/o Tension



BSS1-5 -- Monotonic Tension Force



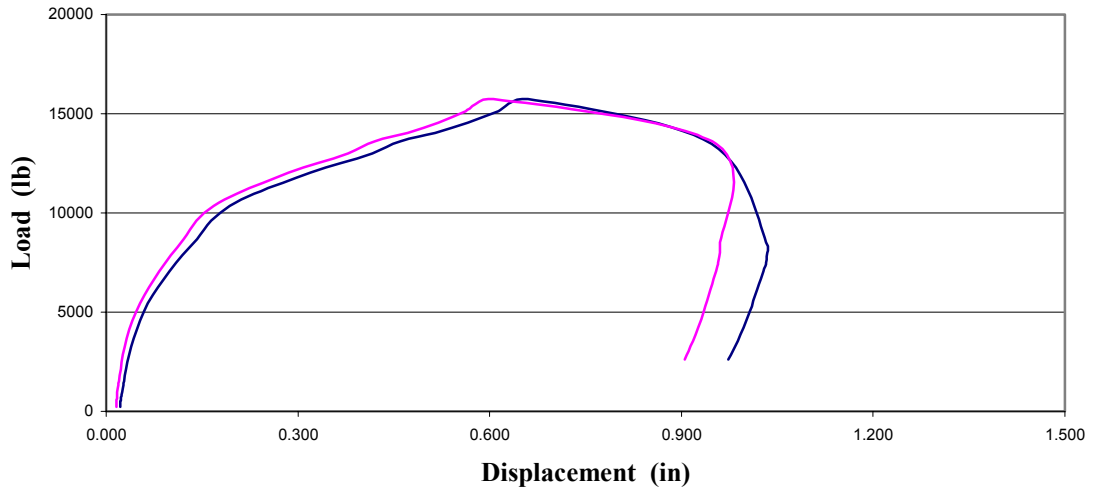
BSS1-6 -- Monotonic Tension Force



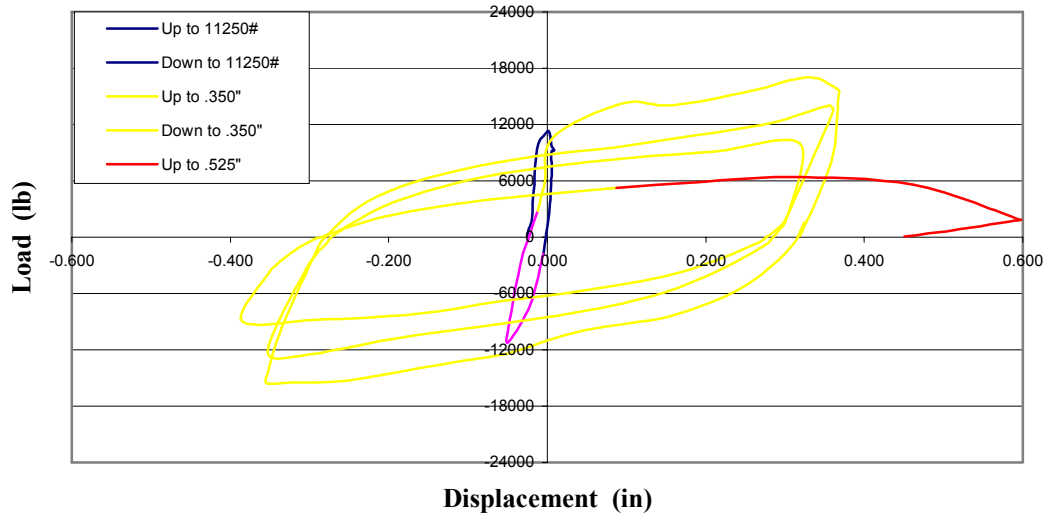
BSS1-7 -- Monotonic Horizontal Shear w/ Tension



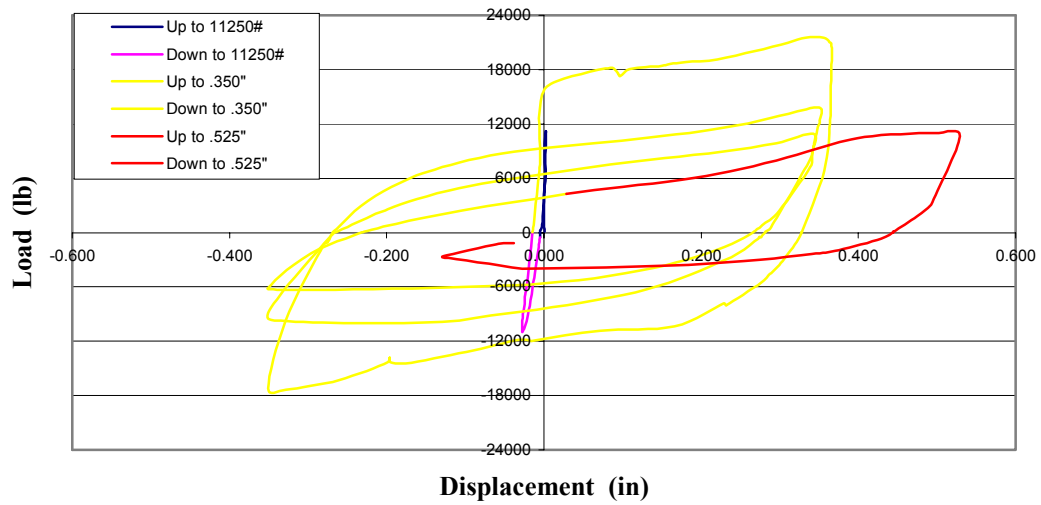
BSS1-8 -- Monotonic Horizontal Shear w/ Tension

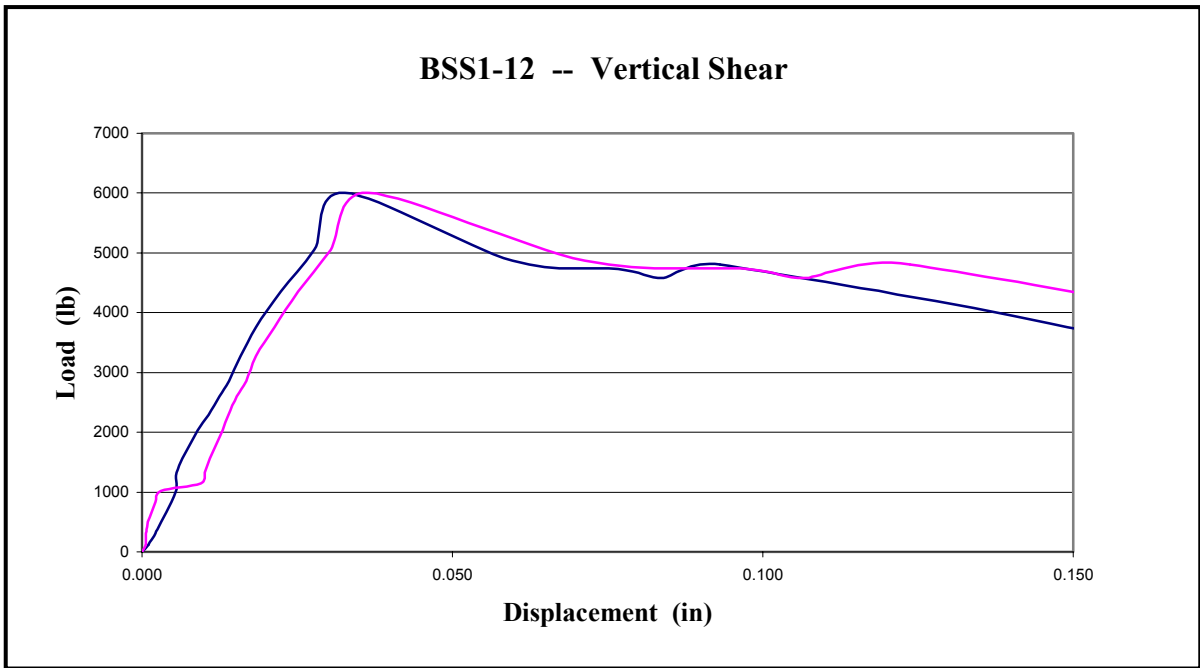
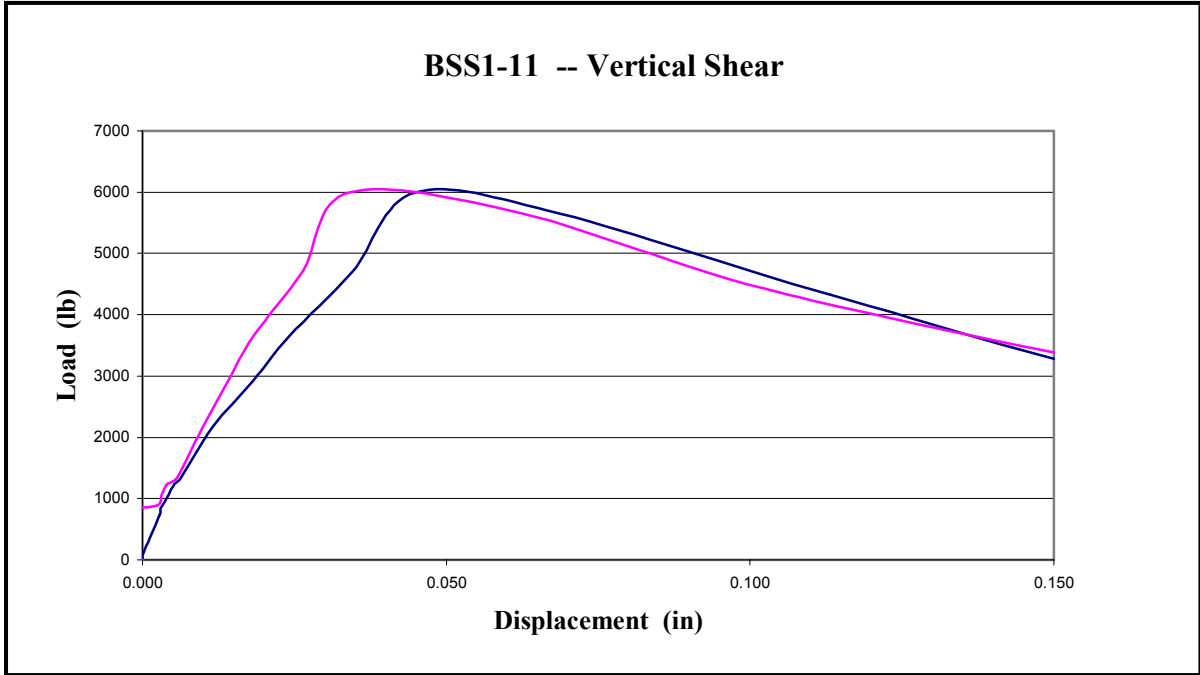


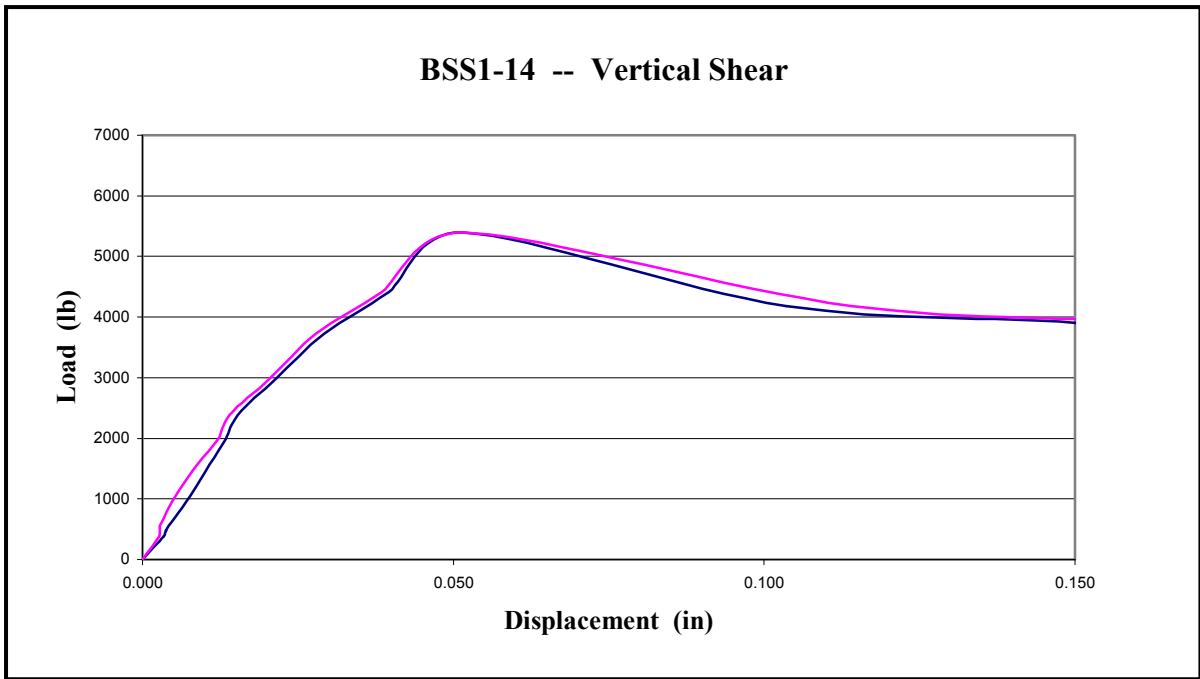
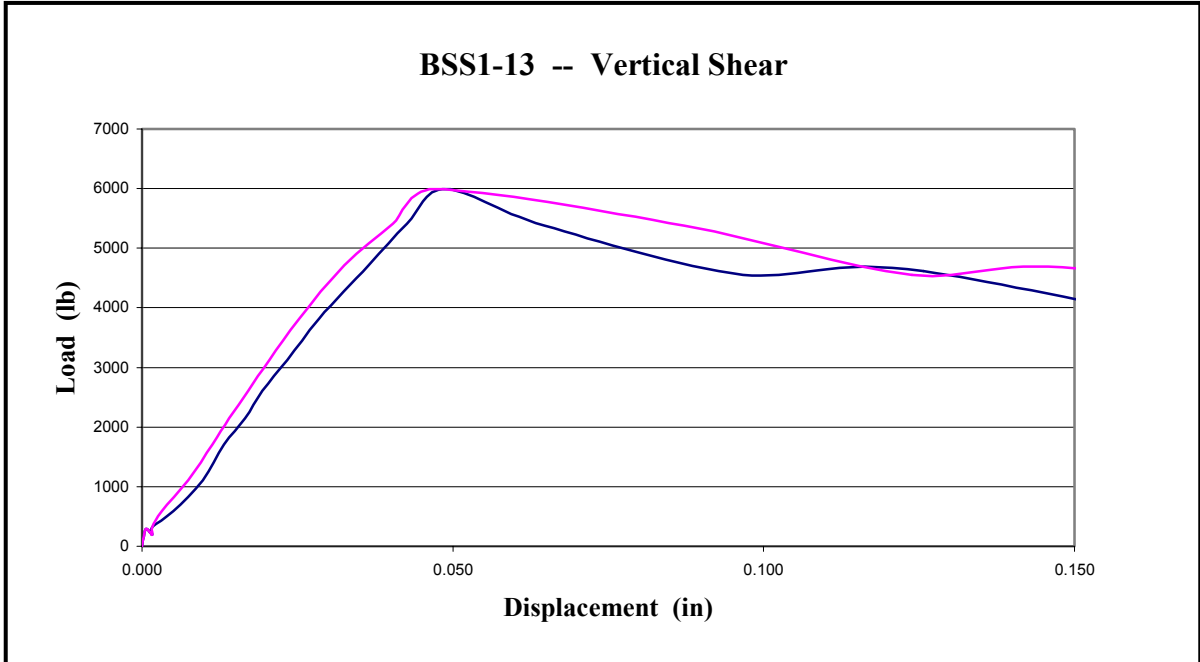
BSS1-9 -- Cyclic Horizontal Shear w/ Tension

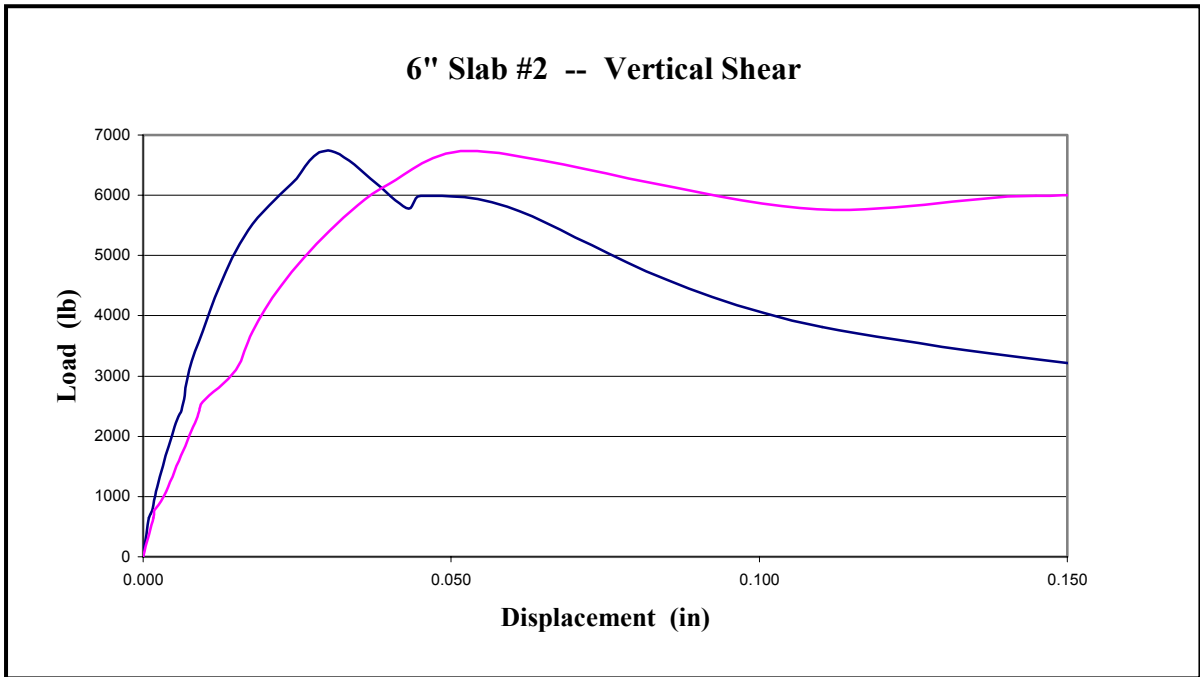
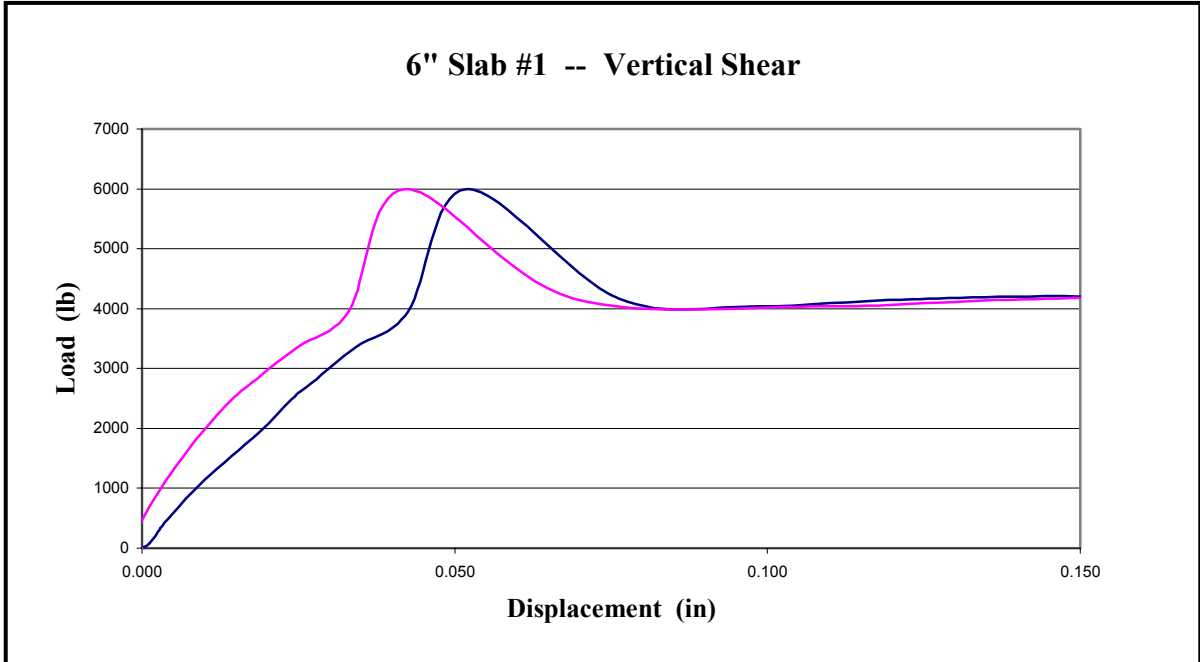


BSS1-10 -- Cyclic Horizontal Shear w/ Tension









Appendix C

Table of As-Received Specimen Condition

SUMMARY OF AS-RECEIVED SPECIMEN CONDITION

SUMMARY OF AS-RECEIVED SPECIMEN CONDITION				
Test Type	A36 Steel		Stainless Steel	
	Specimen #	Comments	Specimen #	Comments
Monotonic Horizontal Shear w/o Tension	BA361-1	1", connector rotated 1/4"	BSS1-1	3/4" from top of slab to top of conn.
	BA361-2	1" from top of slab to top of conn.	BSS1-2	1" from top of slab to top of conn.
Cyclic Horizontal Shear w/o Tension	BA361-3	1", connector rotated 1/8"	BSS1-3	1", connector rotated 3/16"
	BA361-4	1" from top of slab to top of conn.	BSS1-4	1", connector rotated 1/8"
Tension	BA361-5	1-1/4" from top of slab to top of conn.	BSS1-5	1", connector rotated 1/8"
	BA361-6	1-1/4" from top of slab to top of conn.	BSS1-6	1" from top of slab to top of conn.
Monotonic Horizontal Shear w/ Tension	BA361-7	1-3/8" from top of slab to top of conn.	BSS1-7	3/4" from top of slab to top of conn.
	BA361-8	1" from top of slab to top of conn.	BSS1-8	1", connector rotated 1/4"
Cyclic Horizontal Shear w/ Tension	BA361-9	1", connector rotated 1/4"	BSS1-9	1", connector rotated 1/8"
	BA361-10	1", connector rotated 1/4"	BSS1-10	1", connector rotated 1/8"
Vertical Shear - 4" Slab	xxxxx	xxxxxxx	BSS1-11	1" from top of slab to top of conn.
	BA361-12	1" from top of slab to top of conn.	BSS1-12	1" from top of slab to top of conn.
	BA361-13	1" from top of slab to top of conn.	BSS1-13	1", connector rotated 1/8"
	xxxxx	xxxxxxx	BSS1-14	3/4", mesh placed on top of VC2
Vertical Shear - 6" Slab	xxxxx	xxxxxxx	6" Slab - 1	2-3/4" from top of slab to top of conn.
	xxxxx	xxxxxxx	6" Slab - 2	2" from top of slab to top of conn.

Reference: “Report on the Results of Laboratory Testing: JVI Vector Connector”

Addendum: Additional Tension-Only Load Test

At the request of JVI, one additional tension-only load test was carried out subsequent to completion of the above referenced report. In the previous tension tests, the mode of failure was weld rupture. This one additional specimen (notated as BSS1-15x) was tested to determine the achievable connector strength by prevention of weld failure. For this purpose, additional welding was done on the bottom of the connection. Testing was carried out on September 27, 2002, using the same procedure as in previous tests. The result, as well as the results of previous tests, is given below:

TEST RESULTS	A36 Steel		Stainless Steel	
	Specimen Number	Ultimate Load	Specimen Number	Ultimate Load
Monotonic Tension	BA361-5	6293	BSS1-5	11807
	BA361-6	7513	BSS1-6	11360
	xxx	xxx	BSS1-15x	13855

Initial cracking for Test BSS1-15x occurred at an applied load of 8700 lbs. Failure for this test was similar to those described in the body of the report, however, the connector faceplate did not fold down as seen previously. Due to the symmetry caused by welds on the top and bottom, the faceplate remained vertical throughout testing. The ultimate load for Test BSS1-15x was 13855 lbs. Failure was due to pullout of one of the connector legs. The data graph for Test BSS1-15x is shown below.

