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EVALUATION OF DISCONNECT BOXES AND SIGNAL HEADS FOR HURRICANE RESISTANCE

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The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

METRIC CONVERSION TABLE

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
FORCE and PRESSURE				
kip	kilopound-force	4.45	kilonewtons	kN
lbf	pound-force	4.45	newtons	N
lbf/ft^2	pound-force per square foot	0.048	kilopascals	kPa

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16. Abstract

The objectives of this project were to quantify the maximum load requirements for disconnect boxes and signal heads and to develop test methods for product testing. Test programs for both flexure and tension were developed with the goal of producing repeatable test procedures.

Tests were performed on each of the disconnect box and signal products on the FDOT-approved product list, recording maximum load and failure mode of each product. Tests were then performed using retrofit reinforcement in order to determine the strength improvement achieved using available reinforcement methods. Finally, tests were performed on a combined signal and disconnect system to evaluate behavior of individual components as compared to the system. Results did not strongly indicate that the available reinforcement provided significant strength improvement. Results also showed that the behavior of each component during individual testing was consistent with the behavior of the system as a whole. The results of testing, along with a consideration of failure modes, were used to develop recommendations for improved hurricane resistance.

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EXECUTIVE SUMMARY

The performance of span wire traffic signal systems during hurricanes has demonstrated a need to improve the hurricane resistance of disconnect boxes and signal heads. Damage to span wire signals typically occurred in the hanger, top of the disconnect box, or the disconnect box-signal connection. The failures suggest a need for standardized load criteria and product testing methods for disconnect boxes and signal heads.

The project objectives were to quantify the maximum load requirements for disconnect boxes and signal heads and to develop test methods for product testing. Flexure and tension test programs were developed with the goal of creating repeatable test procedures. A total of 84 tests were performed, 42 in tension and 42 in flexure, and the failure load was recorded for each.

The tests performed included both flexure and tension test series for each of five disconnect boxes, four signal heads, and a combined signal-disconnect system. Additional tests using retrofit reinforcement were performed on a representative large disconnect box, small disconnect box, signal head, and combined disconnect-signal system. Results from testing showed:

- Signal heads and disconnect boxes have a similar range of maximum loads when compared in flexure and compared in tension
- Disconnect boxes most commonly fail in the corners, followed by adapter hub failure; signal heads most commonly fail at the top connection
- Results did not strongly indicate significant improvement provided by the reinforcement tested
- Combination tests of disconnect boxes and signals failed at the location and load of the worst performing component in that system.

This study provided data for determining load criteria for signal and disconnect box qualification. The ability of products to resist hurricane loads can be improved by requiring a higher maximum load of components than the strength exhibited during testing. Improvements can be achieved by considering the failure modes seen during testing and improving the weakest locations in the system. Locations shown to be weak during testing include the corners of disconnect boxes, adapter hubs, the top connection of disconnect boxes, and the top of signal heads. The study also provided methods for product testing in both flexure and tension. The implementation of the result of this test program will result in a standardized evaluation of product performance, as well as ultimately improve the performance of span wire traffic signal systems during hurricane events. Recommendations are provided regarding qualification requirements for improved hurricane resistance.

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CHAPTER 1: INTRODUCTION

1.1 Background

The damage to wire span traffic signal support systems as a result of high wind events has indicated a need for improvement in the connections associated with disconnect boxes. The damage to cable-supported traffic signals during Hurricane Andrew in 1992 spurred investigation into the cause of failure and evaluation of improvements. In 1994, a project funded by FDOT and conducted by Hoit et al. developed the Analysis of Traffic Lights and Signals (ATLAS) computer software for use in analysis and design of traffic signals (as cited in Cook and Johnson, 2007). A study done by the Florida Department of Transportation (FDOT) and the University of Florida (UF) in 1996 developed a test procedure and apparatus to test signals under simulated wind loads (Cook et al., 1996).

The damage to traffic signal support systems during the hurricane season of 2004 suggested that performance of signal systems during hurricanes could still be improved (Florida Department of Transportation [FDOT], 2005). An FDOT report presented the damage observed during the hurricane season and noted the main cause of damage was "bracket failure, with general span wire failure being a close second, and mast arm failure (i.e., failure of the structure itself) being a very distant third" (FDOT, 2005). Table 1-1 shows the damage reported in the categories of mast arm structural damage and other sustained damage, which encompasses failure of the span wire, bracket assembly, mast arm mounting hardware, or other components. It was observed in the same report that although mast arms are more effective in withstanding hurricane conditions, span wires can be repaired quickly at low cost compared to mast arms. Of the span wire damage, failure was noted to have occurred in hangers, clamps, and disconnect boxes (Cook et al., 1996). These observations prompted two more studies performed by FDOT and the University of Florida. The first compared dual wire and single wire support systems by performing full scale wind tests on each (Cook and Johnson, 2007). A subsequent project evaluated the performance of hangers to determine the best performing hanger for hurricane resistance (Cook et al., 2012). Of the reported span wire system failures during hurricanes, the disconnect box remained to be investigated.

Table 1-1. Traffic signal statistics for 2004 hurricane season (FDOT, 2005)

District	Total no. of signals district-wide	Total mast arm signals district-wide	Mast arm structural damage	Total span wire signals district-wide	Signalized intersections that sustained damage *
1	1,778	802	2	976	496
2	1,585	537	0	1,048	40
3	987	300	2	687	265
4	3,329	1,180	14	2,149	735
5	2,972	458	2	2,514	1,885
6	2,640	1,848	0	660	0
7	2,151	518	0	1,633	102
Sum	15,442	5,643	20	9,667	3,523

* Damage can be defined as signal loss due to failure of the span wire, bracket assembly, mast arm mounting hardware, or other components.

The purpose of a disconnect box is to house wiring and allow easy access for removal of the signal head, either for replacement or repair. Disconnect box related failures occur at either the top of the box near the messenger cable attachment or the bottom of the box at the signal head connection (Cook et al., 1996). The purpose of this research was to further investigate failure relating to the disconnect box by evaluating current disconnect box and signal breaking strength using static load tests. This project also considered the effect of available retrofit reinforcement in order to quantify improvements reinforcement provides to the system.

The current FDOT standards do not have a strength qualification or test standards for signal heads and disconnect boxes. Although a test procedure had been previously developed, it was not put into practice due to its use of cyclic loading which requires additional software and setup. The desire for this test program was to develop static load tests that can be carried out by manufacturers, test labs, or the FDOT.

1.2 Objectives

The primary objectives of this project were to quantify load criteria for disconnect box and signal head products, and to develop a repeatable test program for product testing. A test matrix was developed to perform flexure and tension static tests on each of the disconnect and signal head products on the FDOT approved product list (APL). Additional tests were performed on reinforced components and systems in order to determine the effect of the reinforcement currently available. In addition to developing test procedures and performing tests on currently approved products, a secondary objective was to develop recommendation for improved hurricane resistance based on test results.

Figure 1-1 below shows a disconnect box and signal head with relevant terminology which will be used throughout this report.

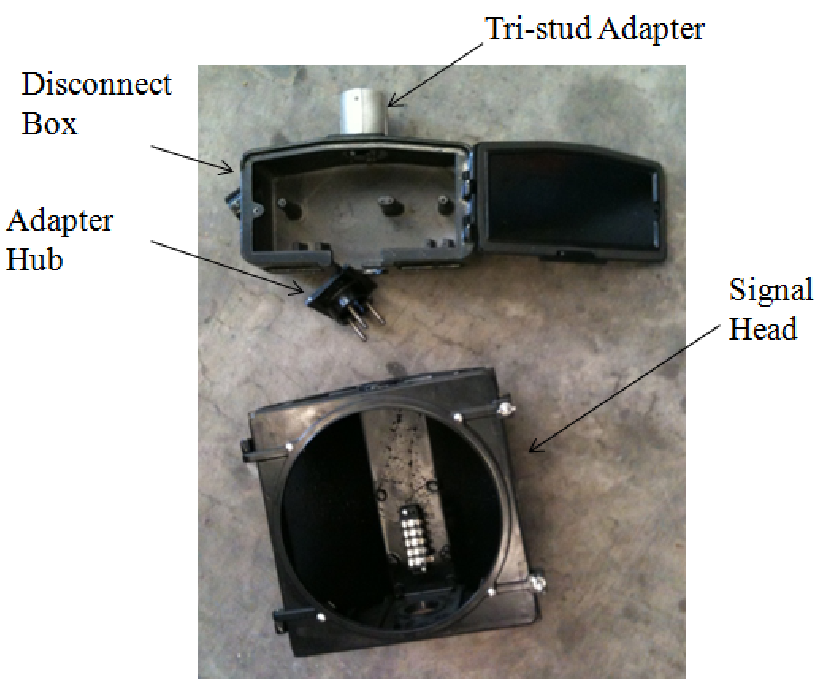


Figure 1-1. Terminology (photo courtesy of author)

CHAPTER 2: LITERATURE REVIEW

This project is the latest in a series of research projects funded by FDOT and performed by UF on the topic of wire span traffic support systems. The investigation into cable supported traffic signals was spurred by the amount of damage to the systems caused by hurricane Andrew in 1992 (Figure 2-1). Failures observed included damage to hangers and disconnect box connections.

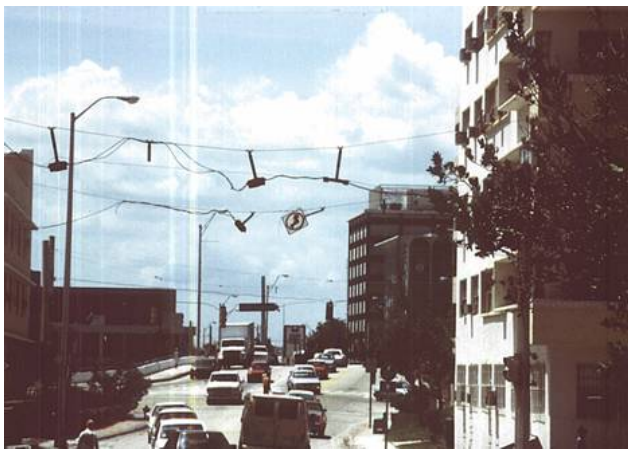


Figure 2-1. Failure of signals supported by dual cables during hurricanes (Photo courtesy of Ronald A. Cook)

Each of the previous projects investigated a different aspect of span wire failure observed during high velocity wind events. The first project in the series developed a traffic signal testing program for testing traffic signals and signs and their hardware using cyclic loading to simulate wind loads (Cook et al., 1996). The test frame designed and fabricated for the 1996 project was modified for the testing of disconnect boxes and signal heads for the current project. A subsequent research study focused on comparing dual cable and single cable systems with various sag, boxes, weights, and signal orientations in order to determine the forces in the signals, cables, and poles (Cook and Johnson, 2007). The results showed that forces in the cables of single cable systems do not appreciably increase as wind increases, in contrast to large increases in dual cable tensions. The results determined single cable systems were a better alternative to dual cable systems. The most recent project evaluated each of the dual cable signal support systems using full scale tests with the UF Hurricane Simulator. The test program compared five hanger systems, measuring signal rotation, cable tensions, and cable displacement. The results showed that "the systems that tend to have greater rotation under relatively low wind loads also reduce the increase in cable tension experienced under high wind loads." (Cook et al., 2012)

The current project is also related to existing standards for traffic signals and devices. Standards related to this project include the Minimum Specifications for Traffic Control Signals and Devices (MSTCSD) sections A650 and A659, FDOT Design Standards Index 17727, and ITE Specs Section 3.02. Although materials, assembly, and dimensions are specified, FDOT does not specify load requirements for manufacturers to meet.

MSTCSD A650 deals with vehicular traffic signal assembly, and specifies dimensions and hardware requirements for signals. Any traffic signal loading criteria developed as a result of this project will be published in this section. MSTCSD A659 specifies requirements for signal head auxiliaries, including disconnect box standards. Disconnect boxes are required to made of aluminum alloy 319.0 having a minimum tensile strength of 23 ksi (FDOT, 2010). Adapter hubs are required to be made of aluminum alloy Almag 35, having a tensile strength of 35 ksi (FDOT, 2010). They are secured in the disconnect box to restrict rotational movement and incorporate a hold down device to secure the adapter in place. Disconnect box load requirements that are developed as a result of this project will be published in MSTCSD A659.

The Institute of Transportation Engineers (ITE) Section 3.02 requires signal heads to be able to withstand a sustained wind load of 25 pound-force/ft^2 (psf) applied perpendicular to the front and rear of the signal (ITE, 1985). Applying this load over the area of a signal and disconnect box, the force requirement comes out to be a sustained load of approximately 110 pounds.

FDOT Design Standards Index 17727 shows installation details of cable hanging signals. Disconnect box and signal configurations are shown in Figure 2-2 (FDOT, 2012).

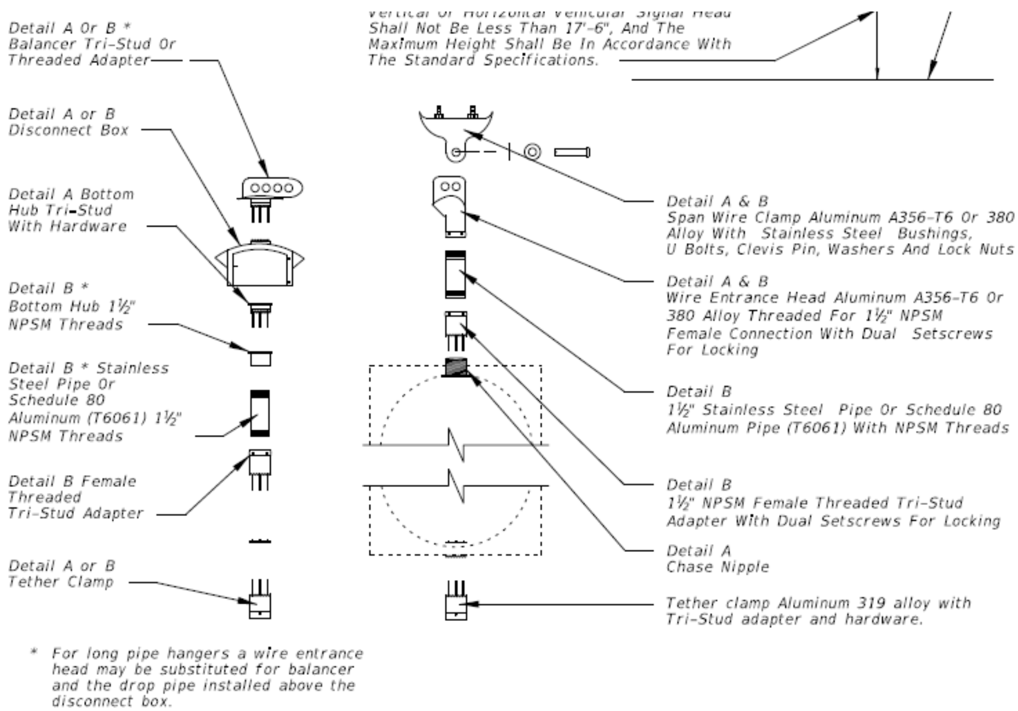


Figure 2-2. Disconnect box and signal assembly specification (FDOT, 2012)

CHAPTER 3: METHODOLOGY

In order to determine product breaking strength, static flexure and tension tests were performed on each of five disconnect boxes, four signal heads, and a combined signal-disconnect system. Additional tests using retrofit reinforcement were performed on a representative large disconnect box, small disconnect box, signal head, and combined system.

3.1 Test Matrix

The test program was implemented by developing the test matrix shown in below in Table 3-1.

Table 3-1. Test matrix

Test series no.	Reinforced or non-reinforced	Product	Signal component	Load direction	Replications
T1	Non-reinforced	DS1	Small disconnect	Front	3
T2	Non-reinforced	DS2	Small disconnect	Front	3
T3	Non-reinforced	DL1	Large disconnect	Front	3
T4	Non-reinforced	DL2	Large disconnect	Front	3
T5	Non-reinforced	DL3	Large disconnect	Front	3
T6	Non-reinforced	SH1	Signal head	Front	3
T7	Non-reinforced	SH2	Signal head	Front	3
T8	Non-reinforced	SH3	Signal head	Front	3
T9	Non-reinforced	SH4	Signal head	Front	3
T10	Non-reinforced	C1	Combination	Front	3
T11	Reinforced	RDS1	Small disconnect	Front	3
T12	Reinforced	RDL1	Large disconnect	Front	3
T13	Reinforced	RSH1	Signal head	Front	3
T14	Reinforced	RC1	Combination	Front	3
T15	Non-reinforced	DS1	Small disconnect	Tension	3
T16	Non-reinforced	DS2	Small disconnect	Tension	3
T17	Non-reinforced	DL1	Large disconnect	Tension	3
T18	Non-reinforced	DL2	Large disconnect	Tension	3
T19	Non-reinforced	DL3	Large disconnect	Tension	3
T20	Non-reinforced	SH1	Signal head	Tension	3
T21	Non-reinforced	SH2	Signal head	Tension	3
T22	Non-reinforced	SH3	Signal head	Tension	3
T23	Non-reinforced	SH4	Signal head	Tension	3
T24	Non-reinforced	C1	Combination	Tension	3
T25	Reinforced	RDS1	Small disconnect	Tension	3
T26	Reinforced	RDL1	Large disconnect	Tension	3
T27	Reinforced	RSH1	Signal head	Tension	3
T28	Reinforced	RC1	Combination	Tension	3

Product IDs have been used for reporting in order to maintain manufacturer result anonymity. DS stands for disconnect-small, DL for disconnect-large, SH for signal head, and C for the combination signal and disconnect system. Products used in reinforced test series are preceded with an R for reinforced. In all tests involving signal heads, only the top section of the signal was used, as the top connection was the point of concern.

3.2 Experimental Design

The objective while developing a test method was to design repeatable static load tests for both flexure and tension.

3.2.1 Flexure Test Design

Flexure tests made use of a signal testing frame developed for previous testing at UF in 1996, shown in Figure 3-1 (Cook et al., 1996). The original frame was constructed using steel tubing with overall dimensions of 6′-8″ width x 6′-0″ length x 10′-8″ height.

Figure 3-1. Original test frame (Cook et al., 1996)

Slight modifications were made to the existing test frame to accommodate this test program. The adaptations consisted of modifications to the hanger system and a new actuator and mounting system. The hanger used for this test program was a 6′ long 1 ½″ diameter steel pipe with a threaded end. The pipe was hung through the middle of the frame in order to simulate a pipe hanger connection as seen in the field. The pipe was mounted by welding a steel angle with four 3/8″ holes to the frame at both the 6′ level and top level. U-bolts were used to securely attach the pipe and create a pin connection, shown in Figure 3-2.

Figure 3-2. Pipe hanger connection (photos courtesy of author)

The actuator and mounting method is detailed in Figure 3-3 below. The actuator was mounted 44″ up from the bottom of the test frame in order to apply load horizontally at the center of area of a 3 section signal, which occurs 25″ down from the top of the disconnect box. The location of the actuator takes in to account that the test components are attached to a hanging pipe which extends 5″ below the bottom of the 6′ level. The actuator was mounted at the desired location using a ball joint piece attached to the frame, creating a moment free connection. A 1″ diameter threaded rod was threaded into the actuator rod on one end and the load cell receiver on the other. The rod was machined down to a ½-20 thread on the load cell end in order to thread into the load cell button. A mount was fabricated for the load cell to allow deformation of the load cell on one side with a $^5/_8$″ threaded rod extending from other side. The $^5/_8$″ rod was connected to a clevis piece which was pinned to the ball joint piece attached to a pipe hanging from the bottom of the signal component.

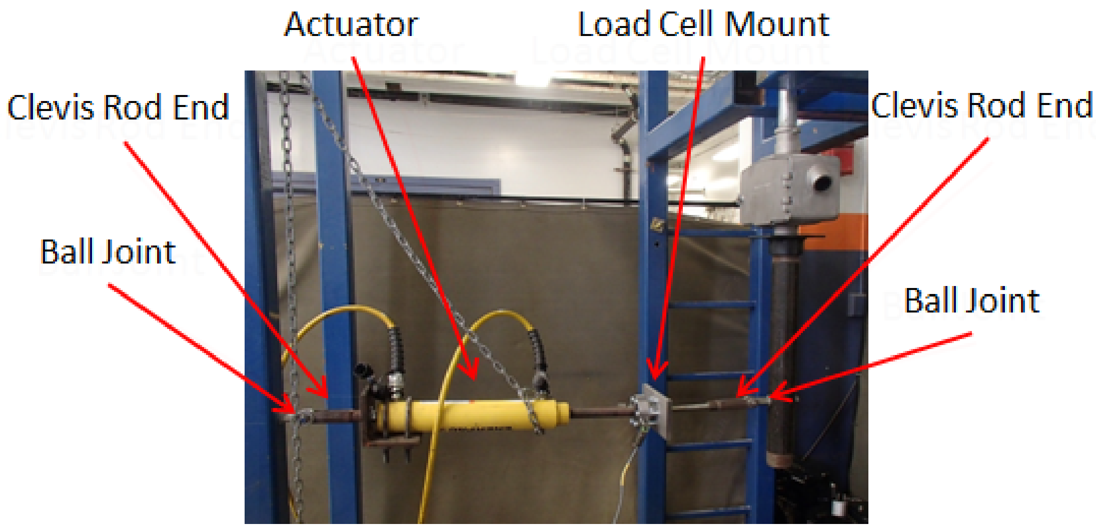


Figure 3-3. Actuator mounting system (photo courtesy of author)

The configuration of each flexure test changed slightly based on which signal component was being tested. Coupler pieces and modified connections were used for each type of component in order to consistently load samples at the center of area without moving the location of the actuator. Figure 3-4 shows the test configuration of disconnects, signals, and combinations, respectively.

Disconnect boxes were tested using a tri-stud adapter at the top and a fabricated connection to simulate a signal head at the bottom. A 2 ½″ pipe threads into the fabrication piece and had a ball joint connection at the location of the center of area. Signal heads were tested using a 7″ pipe as a spacer to simulate a disconnect box. The spacer was joined to the frame with a coupler and connected to the signal with a tri-stud adapter. A tri-stud adapter was used at the bottom of each signal as well, allowing a 1 ½″ pipe to hang from the signal with a ball joint piece attached at the center of area of a signal. Combinations were tested using a tri-stud adapter at both the top of the disconnect box and bottom of the signal head. The same pipe was used at the bottom as was used during signal testing.

3-4a Disconnect 3-4b Signal 3-4c Combination

Figure 3-4. Test configuration of each component, flexure (photos courtesy of author)

3.2.2 Tension Test Design

Tension tests were performed using the Tinius Olsen 400 Super "L" machine at the University of Florida, shown in Figure 3-5 (Tinius Olsen, 2010). The machine was configured for tension testing by installing manually operated lever-type wedge grips that clamp onto pipe. A 1 ½″ pipe was connected to the top and bottom of each signal component to fit in the grips of the Tinius Olsen.

Figure 3-5. Tinius Olsen 400 Super "L" (Tinius Olsen, 2010)

As with flexure testing, each component type required different connections. The setup of each component is shown in Figure 3-6. Tri-stud adapters were used at the top of each disconnect to attach the pipe. The fabricated connection used to simulate a signal head was again used for tension at the bottom of each disconnect box. A reducing pipe bushing was used with the fabricated piece during tension testing to allow the pipe on the top and bottom to be the same size, 1 ½″. Both signal head and combination testing used tri-stud adapters at the top and bottom to connect the pipes. Reinforcement was used at the bottom of the signal during non-reinforced and reinforced combination tests in tension in order to effectively evaluate the signal-disconnect interaction. The connections at the top and the bottom of the signal were the same during tension testing, and so in order to isolate the signal-disconnect connection, the bottom of the signal-to-pipe connection was reinforced.

3-6a Disconnect 3-6b Signal 3-6c Combination

Figure 3-6. Test configuration of each component, tension (photos courtesy of author)

3.2.3 Reinforced Connections

Reinforced testing was completed similarly to non-reinforced testing, the only exception being the use of available reinforcement pieces. The available reinforcement was used in the top of large and small disconnect boxes, the bottom of large and small disconnect boxes, and for signal head connections. The reinforcement fit over existing connections, fastening over the tri-stud connection between signal head and disconnect box. Figure 3-7 shows the reinforcement installed in a disconnect box, signal, and combination, respectively.

Figure 3-7. Reinforcement configuration (photos courtesy of author)

The top disconnect box reinforcement was modified for this testing to be used with tri-stud adapters as opposed to a single stud hanger. The bottom disconnect box reinforcement was attached by a 3/8″ diameter bolt through 25 washers, then the fabricated connection, adapter hub, and reinforcement, and secured with a washer and nut. The purpose of the washers was to maintain the proper connection length by modeling the height of signal reinforcement. Signal head reinforcement was connected using a 20 washers and a ¼″ thick steel washer in the tri-stud adapter to maintain the connection length. A bolt was fastened through the washers, the signal, and the reinforcement and secured by a washer and nut. Figure 3-8 shows the washers in use for reinforced disconnect box and signal head testing, respectively. Combinations were reinforced according to the reinforcement specifications with no modifications required.

Figure 3-8. Use of washers in reinforced disconnect and signal head testing (photos courtesy of author)

3.3 Instrumentation

The instruments used during testing included an actuator and pump system, a pancake-type load cell, a string potentiometer (string pot), and the Tinius Olsen 400 Super "L".

3.3.1 Flexure Instrumentation

The actuator used during testing was an Enerpac RR-1012 hydraulic cylinder with a 10 ton capacity and a 12″ stroke. It was attached to the test frame at 44″ up from the ground in order to apply a horizontal load on the signal components. The actuator was double acting, with the capability to both expand and contract at the operator's control. A 4-way valve hand pump was attached to the actuator by two hoses to make use of the double action feature of the cylinder.

An LCH-5K load cell was mounted to the end of the actuator between the actuator rod and signal component in order to record the force applied during testing. The load cell and mount is shown in Figure 3-9. The load cell measures deformation and converts the deformation into an electric signal which is then recorded as a force reading. The LCH-5K load cell has a 5000 pound capacity and was last calibrated in June 2012.

Figure 3-9. Load cell mount (photo courtesy of author)

A string pot was mounted to the frame to acquire displacement data for graphing purposes. It was mounted to the frame next to the actuator with the wire end attached to the load cell mount, as shown in Figure 3-10 below. The string pot was last calibrated in July 2012.

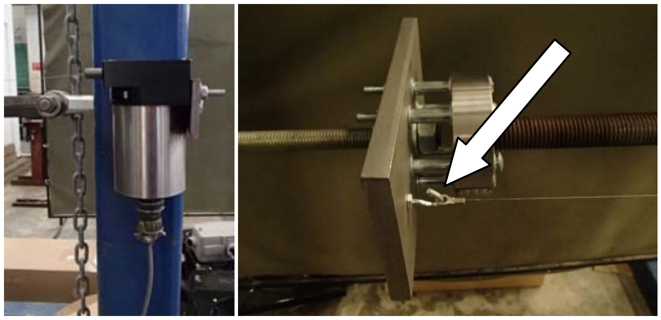


Figure 3-10. String pot mount (photos courtesy of author)

3.3.2 Tension Instrumentation

The Tinius Olsen 400 Super "L" machine at the University of Florida was the method used to perform tension tests. The Tinius Olsen has a load capacity of 400,000 lbf and an allowable maximum specimen size of 38″. It was last calibrated on July 6th, 2012. The machine is accompanied by a handheld controller and computer with Test Navigator Testing Software. The Navigator software can control load rate, failure definition, and specimen parameters as applicable. Data were shown in real time on the monitor during testing and stored as a .cvc file upon completion of a test.

3.4 Test Procedures

The first step for each test was to set up each component as described in Section 3.1.1, 3.1.2, and 3.1.3 for flexure, tension, and reinforcement as applicable. Once the appropriate configuration had been set up, the test procedures were uniform irrespective of the component being tested.

3.4.1 Flexure Procedures

Data acquisition software was initiated to begin the test. Load was then applied by depressing the handle of the hand pump at a constant rate of 20 seconds for one full depression, quickly raising the handle, and repeating until failure was reached in the specimen. Failure was determined by significant drop off in load, which can be defined as approximately 70% drop off, accompanied with visible cracking in the specimen. The actuator was returned to its starting position by reversing the valve toggle on the hand pump and pumping the handle.

Although flexure tests were performed using a specially designed test frame, the test can be completed without the use of specialized equipment. All that is required is a hanger system secured with two pin connections above the signal component and application of a static load at the center of area of the signal until failure.

3.4.2 Tension Procedures

The following tension procedure was performed using the Tinius Olsen 400 Super “L” at the University of Florida. However, tension tests can be performed using any similar materials testing machine given the machine has an appropriate capacity and height.

The test was begun by turning on the pump, then the computer, and loading the test settings. A program was used for signal and disconnect product testing specifying displacement rates and definition of failure. The test was programmed to load the specimen in two stages. The purpose of the first stage was to fully engage the grips, so an initial load rate of 0.125 in/sec was used from 0-100 lb. At 100 lb the load rate was decreased to 0.25 in/min for the remainder of the test. The test was set to run until specimen failure, defined in the program as 70% drop off in load.

To begin each test, the crosshead was returned to its home position after turning the pump on and before loading any samples. The mechanical head was lowered to allow room for the test specimen. The specimen was loaded by inserting the top pipe through the top grip and lowering the lever of the grip to clamp the pipe. For a secure grip, the specimen was loaded so that at least 1″ of pipe was visible above the top of the grip. The bottom lever was at its lowest position, allowing the bottom grips to remain open. The mechanical head was then raised until the bottom pipe slid through the grips and was visible at the bottom of the mechanical head. The bottom lever was then raised to clamp the grips onto the bottom pipe. Both the bottom and top pipes were extending beyond the respective grip 1″ or more without being in contact with the lever for a secure hold. Once the sample was in place, the instrumentation was zeroed and test was initiated by clicking “Test Now” on the monitor screen. Once failure was reached, the program automatically ended the test. At that point, the specimen was unloaded by returning the crosshead to its zero position and releasing the grip levers to remove the specimen.

CHAPTER 4: TEST RESULTS AND OBSERVATIONS

The results of interest during testing were the maximum load and failure mode of each product. Three repetitions of each test series were performed and the average maximum load of the three was reported as the failure load for the series. Raw data and pictures of failures for each test performed are shown in Appendix A.

4.1 Non-reinforced Component Tests

4.1.1 Test Results

The first stage was to determine the failure load of each product. Table 4-1 shows flexure test results of each product, reporting the average maximum load and the range of maximum loads for the three tests in each series. The average maximum load of all of the components tested in flexure was 343 lb with a 26% coefficient of variation.

Table 4-1. Average maximum load of components, flexure

Test series	Product	Component	Average maximum load (lb)	Range of maximum load (lb)
T1	DS1	Small disconnect box	337	319-356
T2	DS2	Small disconnect box	376	358-386
T3	DL1	Large disconnect box	351	333-378
T4	DL2	Large disconnect box	437	310-546
T5	DL3	Large disconnect box	250	207-292
T6	SH1	Signal head	451	421-512
T7	SH2	Signal head	300	166-462
T8	SH3	Signal head	237	185-282
T9	SH4	Signal head	350	337-364

The failure mode of each test was also documented, and an example of each failure mode is shown below. Of the disconnect boxes tested in flexure, five failed in the top corners, four failed in the bottom corners, three failed in the attachment hardware, two failed in the adapter hub, and one failed from cracking at the top connection. Figure 4-1 shows an example of each of these failure modes. Figure 4-2 shows signal head failures, eleven of which failed by cracking in the top connection during flexure tests, and one of which failed by a break off of the top surface.

4-1a Top corner 4-1b Bottom corner 4-1c Attachment hardware

4-1d Adapter hub 4-1e Top connection

Figure 4-1. Disconnect box failure modes, flexure

4-2a Top connection 4-2b Top surface

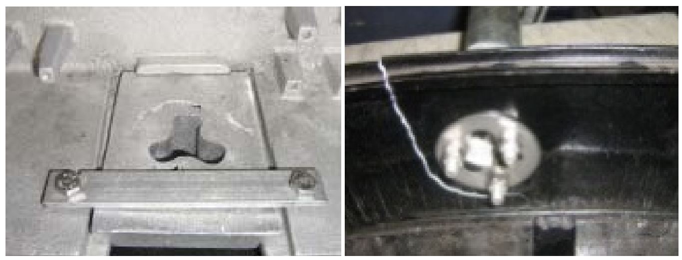
Figure 4-2. Signal head failure modes, flexure

Table 4-2 shows the average maximum load of each product tested in tension and the range of maximum loads for each series. Products DS1 and DL2 failed at higher loads compared to the other products tested and were treated as outliers while calculating averages. The average maximum load of the components tested in tension, excluding the two products with the highest results, was 3690 lb with a 20% coefficient of variation.

Failure modes of disconnect boxes are shown in Figure 4-3. Five failed in the adapter hub, four at the top connection, three cracked around the bottom, and three cracked in the top corner. Six signal heads failed by cracking at the top connection and six failed by cracking around the top surface, examples of which are shown in Figure 4-4.

Table 4-2. Average maximum load of components, tension

Test series	Product	Component	Average maximum load (lb)	Range of maximum load (lb)
T15	DS1	Small disconnect box	5970	5770-6350
T16	DS2	Small disconnect box	4887	4490-5540
T17	DL1	Large disconnect box	3330	3060-3370
T18	DL2	Large disconnect box	7283	6020-7940
T19	DL3	Large disconnect box	3373	2260-4270
T20	SH1	Signal head	3860	3610-4300
T21	SH2	Signal head	3220	2290-3400
T22	SH3	Signal head	3150	3110-3170
T23	SH4	Signal head	4310	4290-4330



4-3a Adapter hub 4-3b Top connection

4-3c Top corner 4-3d Around bottom

Figure 4-3. Disconnect box failure modes, tension

4-4a Top connection 4-4b Around top surface

Figure 4-4. Signal head failure modes, tension

4.1.2 Test Observations

Flexure results of disconnect boxes and signal heads showed a similar range of failure values. Disconnect boxes failed in the range of 250 to 437 lb while signal heads failed in the range of 237 to 451 lb. Therefore, depending on the combination of products used, failure could occur in either the disconnect box or the signal head. The most common failure modes seen were cracking in the corners of the disconnect box and cracking at the top of the signal head.

The range of tension testing was more spread out. Disconnect boxes failures occurred between 3330 to 7283 lb. The range of failure loads for signal heads in tension was 3150 to 4310 lb. This would suggest the signal head is the weak link; however, excluding the two disconnect box products with higher failure loads, the values were again within a similar range. The most common failure modes were cracking in the adapter hub followed by cracking at the top connection for disconnect boxes. Signal heads failed equally between cracking at the top connection and failing around the top surface.

4.2 Reinforced Component Tests

Tests using available retrofit reinforcement were performed on a representative small disconnect, large disconnect, signal, and combination in order to evaluate the effect of the reinforcement on maximum load. The results from individual tests, series T1-T9 for flexure and T15-T23 for tension, were used to determine which components would be used for combination and reinforced testing. The weakest of the large disconnect box and signal head products were chosen for reinforced testing in order to evaluate the maximum effect of reinforcement. Of the large disconnect boxes, product DL3 failed at the lowest load in flexure and close to the lowest load in tension and was therefore chosen for combination and reinforced testing. Signal head SH3 failed at the lowest load for both flexure and tension. Product DS2 was used for reinforced testing of small disconnects owing to the failure mode seen during non-reinforced testing. Two out of three repetitions of DS2 in flexure failed in the adapter hub, and it was chosen in order to record the effect of reinforcement on the adapter hub failure. Reinforced product IDs and corresponding non-reinforced product IDs are shown in Table 4-3 for reference.

Table 4-3. Product IDs for reinforced testing

Reinforced product ID	Non-reinforced product ID
RDS1	DS2
RDL1	DL3
SH3	SH3
C1	DL3 and SH3
RC1	DL3 and SH3

4.2.1 Test Results

Table 4-4 shows results of reinforced flexure tests, reporting average maximum load and the range of maximum load for each test series. Reinforced disconnect boxes failed during flexure tests by beginning to crack in the top corner and then continuing to crack around the reinforcement, an example of which is shown in Figure 4-5. All three reinforced signal heads cracked at the top connection in flexure, as shown in Figure 4-6.

Table 4-4. Average maximum load of reinforced components, flexure

Test series	Product	Component	Average maximum load (lb)	Range of maximum load (lb)
T11	RDS1	Reinforced small disconnect	418	385-453
T12	RDL1	Reinforced large disconnect	187	169-208
T13	RSH1	Reinforced signal head	299	273-318

Figure 4-5. Reinforced disconnect box failure mode, flexure

Figure 4-6. Reinforced signal failure mode, flexure

Table 4-5 shows results of reinforced tension tests. During tension tests, large disconnect boxes failed by cracking around the top reinforcement while small disconnect boxes failed by cracking in the top corners as shown in Figure 4-7. Each of the three reinforced signal heads cracked at the back edge of the reinforcement in tension, as shown in Figure 4-8.

Table 4-5. Average maximum load of reinforced components, tension

Test series	Product	Component	Average maximum load (lb)	Range of maximum load (lb)
T25	RDS1	Reinforced small disconnect	6273	5770-7270
T26	RDL1	Reinforced large disconnect	4053	3000-4600
T27	RSH1	Reinforced signal head	3900	3850-3980

Figure 4-7. Reinforced disconnect box failure modes, tension

Figure 4-8. Reinforced signal failure mode, tension

4.2.2 Test Observations

Reinforced tests were performed in order to evaluate the available methods for strength improvement. Table 4-6 shows the percent difference of reinforced to non-reinforced results for both flexure and tension. The average percent increase of maximum load provided by reinforcement during flexure tests was 8%.

Table 4-6. Reinforced to non-reinforced ratio of maximum load

Product	Percent difference in failure load, flexure	Percent difference in failure load, tension
RDS1	11	28
RDL1	-25	20
RSH1	26	24
RC1	20	16

Results of reinforced and corresponding non-reinforced flexure results are shown graphically in Figure 4-9. The results did not show a strong indication that reinforcement significantly improves the maximum load resisted by components. The results did show that a discussion of failure modes is important while considering the effect of reinforcement. In flexure, the most common failure modes of disconnect boxes was failure in either the top or bottom corners. The available reinforcement did not extend to those areas, having little effect on maximum load. The tested reinforcement should, however, affect the adapter hub and top connection failure modes. Non-reinforced components that failed in the adapter hub failed in the corners during reinforced testing, but at only slightly increased loads. Signal heads saw more of a punching action and still failed at the top connection around the back of the reinforcement.

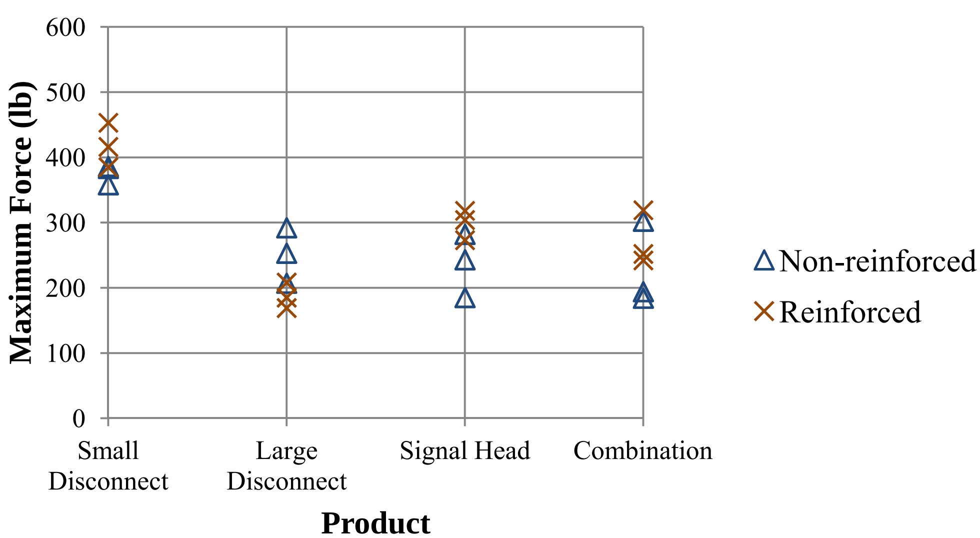


Figure 4-9. Comparison of reinforced to non-reinforced results, flexure

A comparison of reinforced and corresponding non-reinforced tension results are presented in Figure 4-10. As with flexure, there was no strong indication that reinforcement had an appreciable effect on component strength. Disconnect box failure modes observed during reinforced tension testing were less varied than with non-reinforced testing. Failures occurred around the top reinforcement and in the top corners. However, non-reinforced failure modes such as adapter hub and cracking in the bottom were seen mostly in products that were not used during reinforced testing, so the testing was not able to evaluate the effect of reinforcement on all failure modes. Signal heads failed around the back of the top reinforcement.

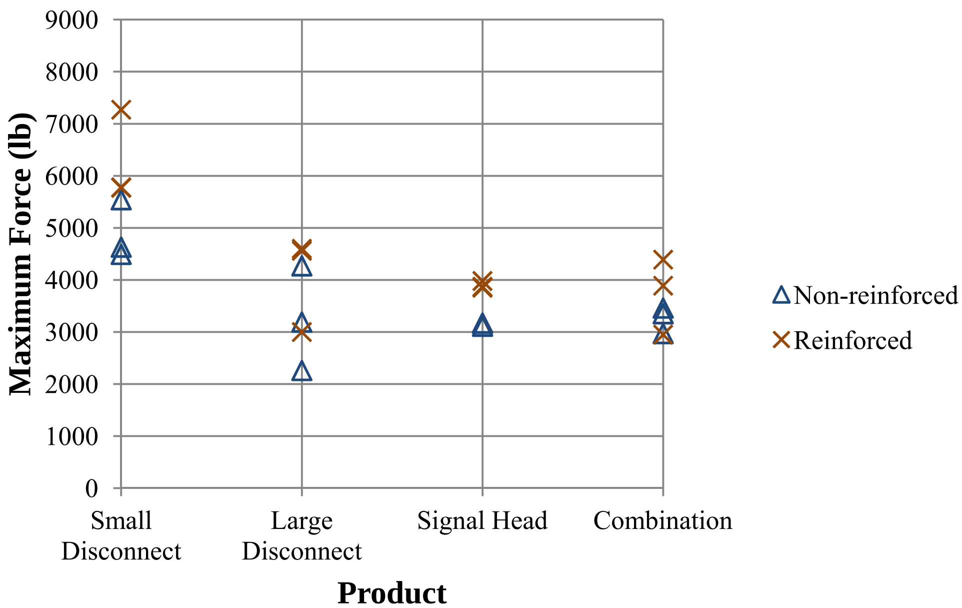


Figure 4-10. Comparison of reinforced to non-reinforced results

4.3 Non-reinforced and Reinforced Combination Tests

Combination tests were performed in both flexure and tension in order to verify that components behave the same in a system as during individual testing. Products DL3 and SH3 were used in order to compare combination results to the weakest components from individual testing and to compare reinforced to non-reinforced combination results.

4.3.1 Test Results

Results of both non-reinforced and reinforced combination tests in flexure are shown in Table 4-7, along with corresponding individual component results for comparison. Combination test series T10 corresponds to component test series T5 and T8. T14 corresponds to T12 and T13. Two non-reinforced combinations failed at the top of the disconnect in flexure, and one failed at the top of the signal head. Reinforced combinations failed at the top of the disconnect box in flexure. Examples of these failure modes are shown below in Figure 4-11 and Figure 4-12.

Table 4-7. Average maximum load of combinations, flexure

Test series	Product	Component	Average maximum load (lb)	Range of maximum load (lb)
T5	DL3	Large disconnect box	250	207-292
T8	SH3	Signal head	237	185-282
T10	C1	Combination	226	184-302
T12	RDL1	Reinforced large disconnect	187	169-208
T13	RSH1	Reinforced signal head	298	273-318
T14	RC1	Reinforced combination	271	242-319

Figure 4-11. Combination failure modes, flexure (photos courtesy of author)

Figure 4-12. Reinforced combination failure mode, flexure (photo courtesy of author)

Table 4-8 shows both non-reinforced and reinforced combination results in tension, along with corresponding individual product results for comparison. Test series T24 corresponds to T19 and T22 while test series T28 is the combination of components used in T26 and T27. Each repetition of non-reinforced combinations failed at the top of the signal in tension, as shown in Figure 4-13. Reinforced combinations failed in the signal head, as shown in Figure 4-14.

Table 4-8. Average maximum load of combinations, tension

Test series	Product	Component	Average maximum load (lb)	Range of maximum load (lb)
T19	DL3	Large disconnect box	3373	2260-4270
T22	SH3	Signal head	3150	3110-3170
T24	C1	Combination	3260	2970-3460
T26	RDL1	Reinforced large disconnect	4053	3000-4600
T27	RSH1	Reinforced signal head	3900	3850-3980
T28	RC1	Reinforced combination	3743	2950-4390

Figure 4-13. Combination failure mode, tension (photo courtesy of author)

Figure 4-14. Reinforced combination failure mode, tension (photo courtesy of author)

4.3.2 Test Observations

The goal of combination testing was to verify that individual products behave as they would in a system during testing. It was expected that the weakest of the components from individual testing fails in a system at an equivalent load during combination testing.

Non-reinforced combination testing in flexure resulted in two different failure locations at an average load of 226 lb. Two combinations failed at the top of the disconnect while one failed at the top of the signal. The individual product failure loads for disconnects and signals were very close, disconnects being 250 lb and signals being 237 lb, demonstrating that the results of combination testing agree with individual testing.

Reinforced combinations failed in flexure in the top of the disconnect box. That was shown to be the weakest link during individual reinforced testing. The combination failed at a slightly higher load than the disconnect box alone, averaging 271 lb to 187 lb, respectively, but can be considered within an acceptable range when considering the scatter of RDL1 data.

All three repetitions of non-reinforced combinations in tension failed at the top of the signal head, which was the weakest link during individual component testing. Signals in combinations showed very similar cracking patterns as individual signal heads.

Each of the repetitions of reinforced combinations tested in tension failed in the signal head. The average of the individual product failure loads were statistically identical, signal heads failing at 3900 lb and disconnect boxes at 4053 lb. The combination failed at an average of 3740 lb which is within the expected range based on individual testing.

By comparing combination results to component results of both non-reinforced and reinforced systems, it was concluded that the behavior of the system as a whole was consistent with the behavior of each component during individual testing. It is reasonable to impose a test standard on each component type and expect the individual improvements to translate to the system. Product results showed that signals and disconnect boxes generally failed at similar loads, so improvement of one part of the system is not enough. The performance of the signal system will only be improved if the capacity of both components is improved.

4.4 Summary of Test Results and Observations

A total of 84 tests were completed to determine the strength of non-reinforced disconnect boxes, signal heads, and sample reinforced components. Tests on a combined system were also completed to verify the assumption that individual components will act as they do in a system. Tests were performed in both flexure and tension with 3 replications per test series. Points of interest during testing were failure loads of individual products, behavior of components as compared to combinations, and the effect of reinforcement on performance of signals and disconnect boxes.

The results of non-reinforced flexure component tests are shown graphically in Figure 4-15. Results showed that signal heads and disconnect boxes have a similar range of maximum load in flexure. The average maximum load of components in flexure was 343 lb with a 26% coefficient of variation. Disconnect boxes most commonly failed in the corners in flexure; signal heads most commonly failed at the top connection.

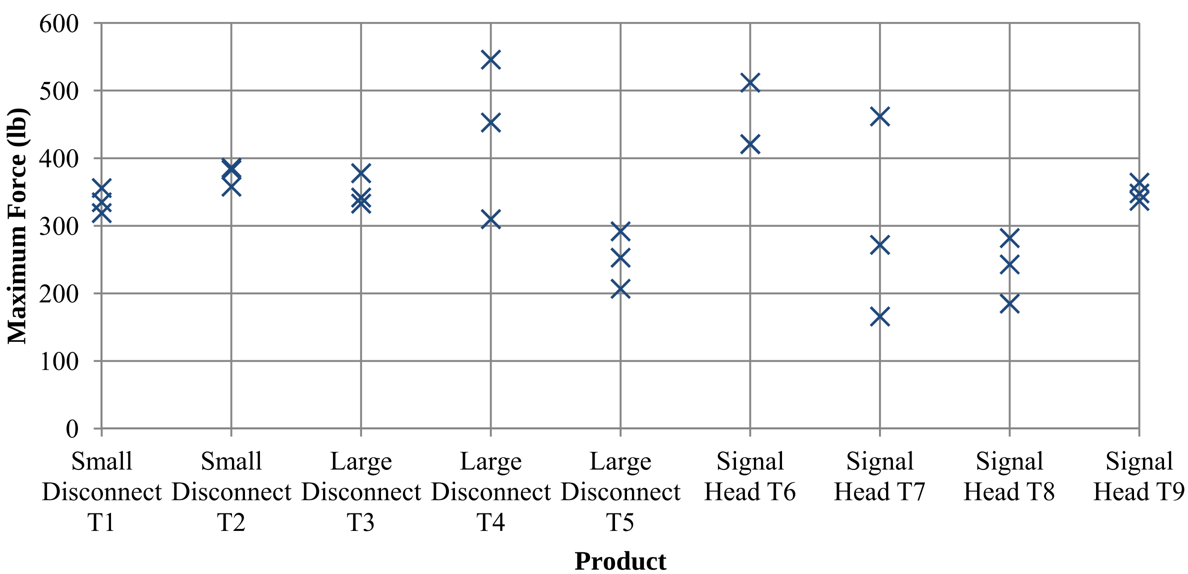


Figure 4-15. Non-reinforced component results, flexure

Figure 4-16 below shows a summary of the results of each non-reinforced component test performed in tension. With the exception of two disconnect box products which had larger maximum loads, signal heads and disconnect boxes again had a similar range of maximum load in tension. The average maximum load of components in tension was 3690 lb with a 20% coefficient of variation, excluding the two highest valued test series. Disconnect boxes most commonly failed in the adapter hub in tension; signal heads failed equally between the top connection and a break around the top surface.

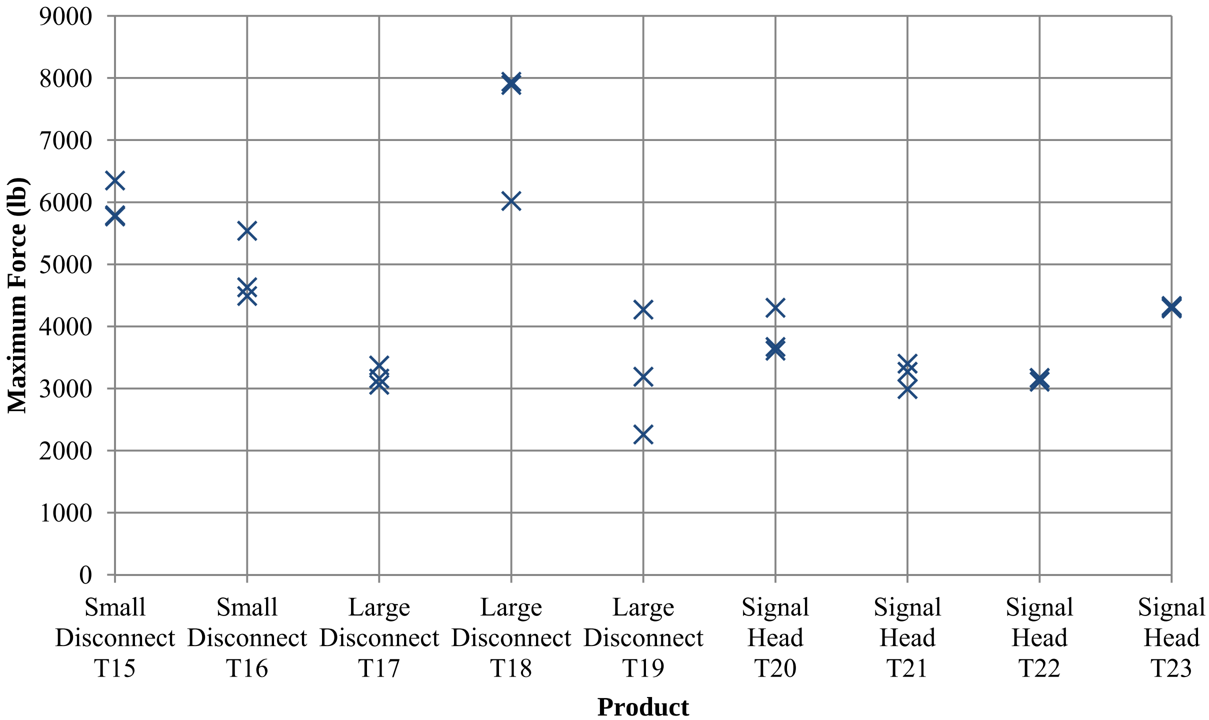


Figure 4-16. Non-reinforced component results, tension

For both test types, results did not indicate that reinforcement provided significant increases in strength performance of components. Finally, results showed that combinations failed at the location and general load of the weakest component from individual testing.

CHAPTER 5: RECOMMENDATIONS

Objectives of this report include assessing test options for product evaluation testing and developing recommendations on breaking strength criteria for improved hurricane resistance.

5.1 Advantages and Disadvantages of Testing Options

Test options for product evaluation include requiring flexure tests, tension tests, or both. In order to assess the test options, the benefits and drawbacks of each are presented in the following sections.

5.1.1 Flexure

Advantages: The benefit of flexure tests is that the prying action at the top of each component is captured. The weakness of the top corners of the disconnect box was apparent during flexure tests.

Disadvantages: The drawback to testing in flexure alone is that some failure modes will not be represented. Disconnect boxes failed in the adapter hub most often in tension while that failure mode was not common in flexure. Signal heads in flexure saw almost exclusively the failure mode of cracking at the top connection, not accounting for the failure of a break off of the whole top surface. Also, the benefits of alternative methods of strengthening, such as the use of a cable or rod through the system, may not be quantified in flexure while providing significant increase in tensile strength.

5.1.2 Tension

Advantages: The benefits of tension tests are that they allow for the evaluation of the adapter hub failure mode better than flexure tests. Tension tests also resulted in an even amount of failures between the top connection and a break off of the top surface in signal heads. They can also be performed in any test lab with a universal testing machine.

Disadvantages: The most common failure of cracking in the top corners during flexure was the least common seen failure mode during tension. Also, although a loose correlation between flexure and tension test results exists, the products DS1 and DL2 were shown to be significantly stronger than comparable products in tension while showing slightly below and slightly above average results, respectively, in flexure. Tension testing alone would show these products to be superior, but when loaded in flexure that would not be the case.

5.1.3 Ratio of Tension to Flexure

One aspect of the discussion is the potential of a correlation between flexure and tension results. The ratios of the maximum tension load to maximum flexure load for each product are presented below in Table 5-1. The average ratio was 13 with a coefficient of variation of 22%. The data suggests that there was a correlation between tension and flexure strength; however this ratio is not the only consideration when determining what tests are most effective. Failure modes should also be considered, as well as the ability of each test to represent loads for each type of signal support system.

Table 5-1. Ratio of maximum tension load to maximum flexure load

Product	Ratio of Tension to Flexure
DS1	17.7
DS2	13.0
DL1	9.5
DL2	16.7
DL3	13.5
SH1	8.6
SH2	10.7
SH3	13.3
SH4	12.3

5.2 Testing Recommendations

Based on observations of failure modes made during testing, it is recommended that both flexure and tension tests be required for product qualification. Recommendations for load criteria were determined by considering AASHTO design wind loads on traffic signals and the dynamic effects felt by the system.

5.2.1 AASHTO Wind Load Determination

Design procedures in AASHTO 2009 were used to determine an estimate design wind load for traffic signals. AASHTO's "Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals" Section 3 gives a procedure for determining design pressures from wind velocities using the equation (5-1)

$$P_z = 0.00256\, K_z G V^2 I_r C_d \tag{5-1}$$

where K_z is a height and exposure factor, G is a gust effect factor, V is design velocity, I_r is the importance factor, and C_d is the drag coefficient. The code provides methods for determining each of these factors. K_z, the height and exposure factor, was obtained from Table 3-5 of AASHTO 2009. The gust effect factor, G, accounts for the dynamic nature of the effect of wind on a structure. G was taken as 1.14, as the minimum recommendation in the document. The design velocity is based on basic wind speed maps; 150 mph was used as a worst case wind speed in Florida for Occupancy Category II as provided in AASHTO 2009. The importance factor relates to design life of the structure and will be 1.0 for this case. AASHTO recommends a drag coefficient of 1.2 according to Table 3-6; however, according to Cook et al. (2012), 0.45 can be used as a conservative drag coefficient for span wire traffic signals. Using these factors in equation 5-1, the design pressure was determined to be 26.6 psf.

Applying the AASHTO design pressure over the total area of a 5-section disconnect, signal, and backplate system with an area of approximately 14 ft^2, the resulting design force on a signal becomes 370 lb. The design value is slightly larger than the 343 lb average of results from flexure tests indicating that failures would certainly be expected in high wind events.

5.2.2 Dynamic Effects

There is potential for dynamic effects on signal components during a hurricane, and so a dynamic amplification factor was considered in order to try to account for movement of traffic signals under high velocity wind loading. In dynamic applications, a 100% load amplification is the upper limit of a rigid object subjected to a constant dynamic load, neglecting the dynamics of oscillation of the entire structure (Tedesco et al., 1999). The full dynamic factor of 2.0 is recommended as a conservative value for signal components, however, the dynamics of the full system are complex, and this factor may not take into account the movement or damping of the entire system. Recommended load criterion for flexure was determined by applying the dynamic factor to the AASHTO wind load of 370 lb, resulting in a requirement of 740 lb for flexure. Although a tension design load cannot be determined directly from AASHTO procedures, a comparison of the flexure design load to the average of the test results suggests that average test results approximated the design loads. Based on this relationship, the average of the tension test results was used as an estimate to determine a tension criterion. A dynamic amplification factor of 2.0 was also used for tension requirements to be consistent for dynamic behavior of the system. Applying the dynamic amplification factor to the average of the tension test results produced a recommended load requirement of 7400 lb for tension.

5.3 Suggestions for Possible Improvements

The goal of FDOT is to improve public safety by enhancing the performance of span wire signals during and after hurricanes. One approach may be to consider the distinction between ultimate limit state and serviceability limit state. The ultimate limit state is reached when failures result in collapse of the structure. In the case of span wire signals, damage to a signal severe enough to result in a nonoperational intersection would be past its ultimate limit state. The serviceability limit state occurs when a structure has been damaged but is still considered useful to preserve life safety. Based on observations during testing, it may be useful to consider serviceability of traffic signals. For example, a design incorporating a cable or threaded rod through the middle of the disconnect box may allow for structural damage to occur in the signal or disconnect box while maintaining the operational function of the signal until it is able to be repaired. This design, or similar approach, would allow higher rotations to occur after the outer structure has failed resulting in decreased visibility, but could maintain the function of a signalized intersection.

5.4 Summary of Recommendations

To improve the performance of span wire traffic signal support systems, the suggested load qualification for signals and disconnect boxes is 740 lb in flexure and 7400 lb in tension. These values were determined by determining wind loads using AASHTO 2009 procedures and considering the dynamic effects of wind. Product testing should be performed using both tension and flexure tests in order to evaluate common failure modes for each respective loading. Finally, failure modes observed during testing should be considered while determining possible improvements to the system. Targeted improvement of proven weaker areas may result in significant improvement in the performance of traffic signals under hurricane wind loading.

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APPENDIX A: TEST RESULTS AND FAILURE MODES FOR EACH TEST

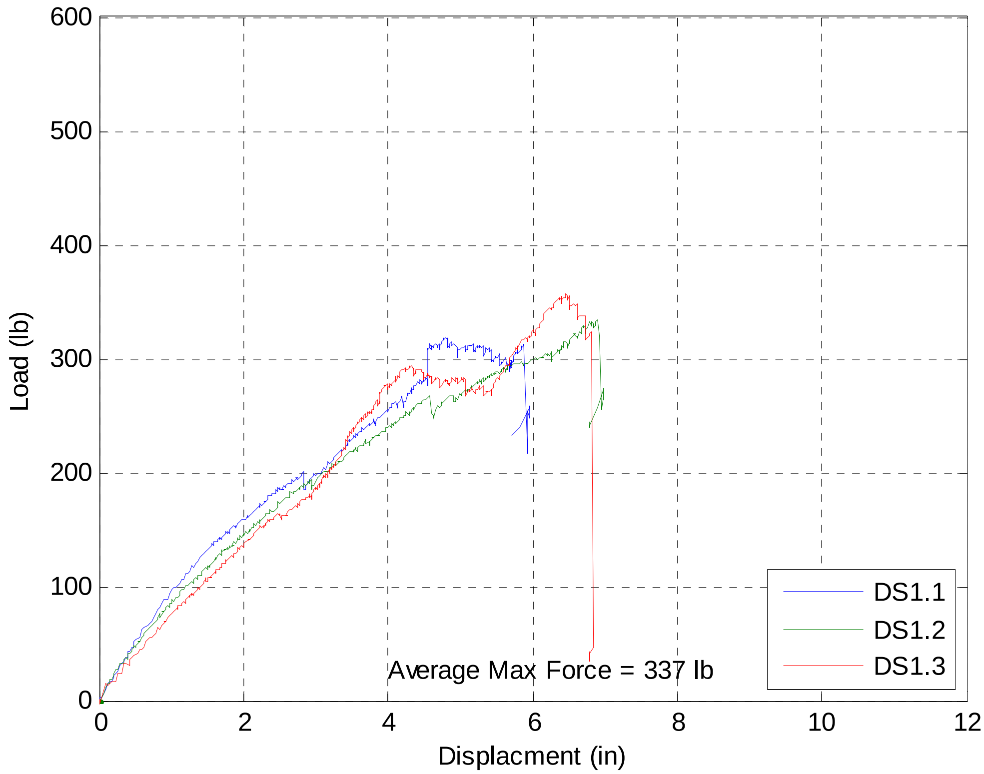

Figure A-1. Test series 1: DS1 in flexure

Figure A-2. DS1.1 failure mode, crack in bottom corner

Figure A-3. DS1.2 failure mode, crack in bottom corner

Figure A-4. DS1.3 failure mode, crack in bottom corner

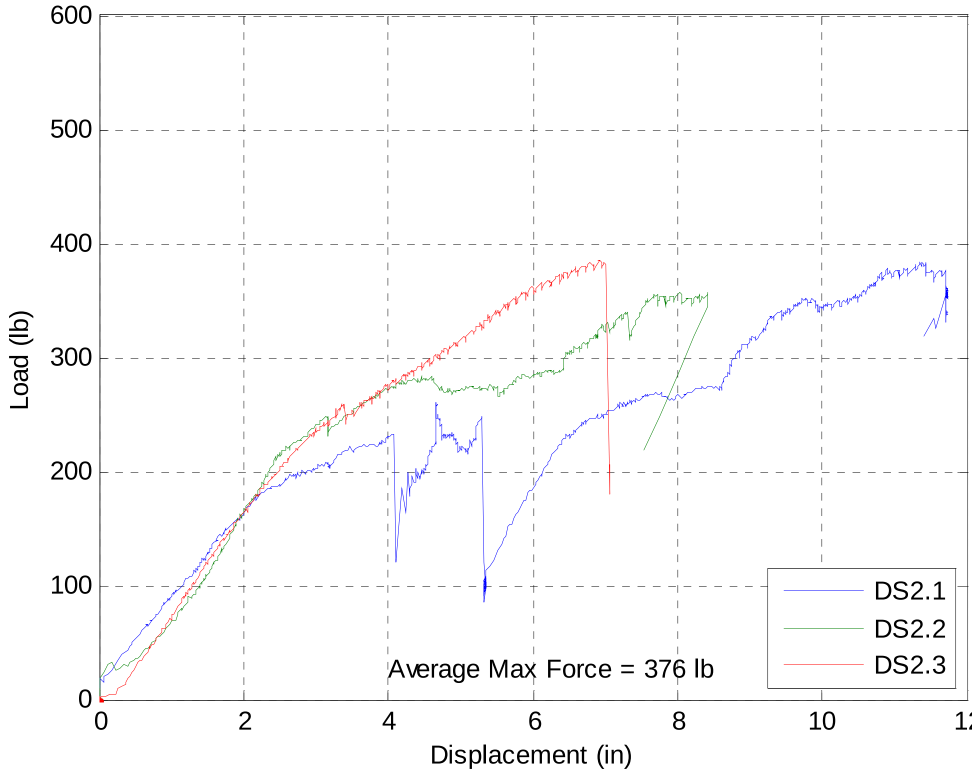

Figure A-5. Test series 2: DS2 in flexure

Figure A-6. DS2.1 failure mode, adapter hub failure

Figure A-7. DS2.2 failure mode, adapter hub failure

Figure A-8. DS2.3 failure mode, crack in top corner

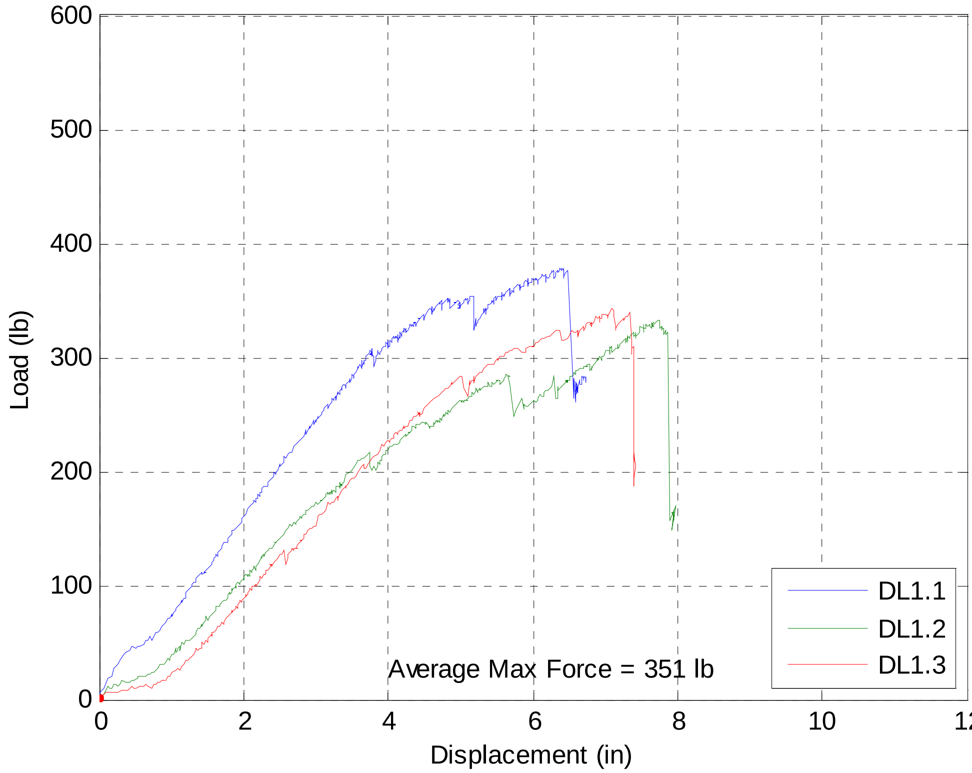

Figure A-9. Test series 3: DL1 in flexure

Figure A-10. DL1.1 failure mode, crack in bottom corner

Figure A-11. DL1.2 failure mode, crack in top corner

Figure A-12. DL1.3 failure mode, crack in top corner

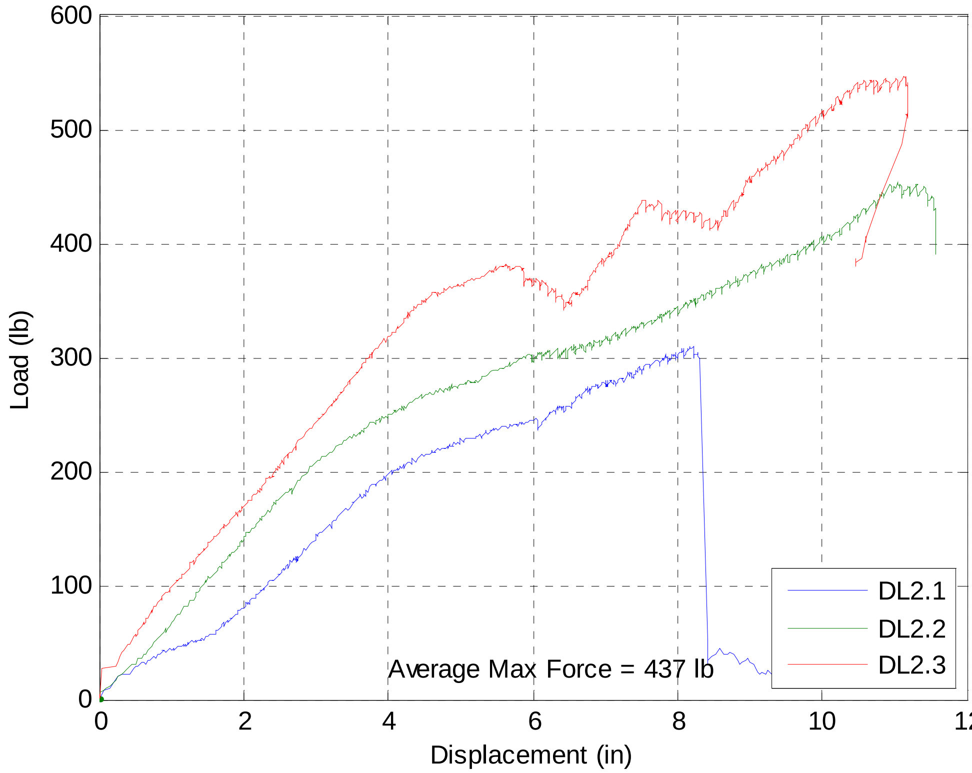

Figure A-13. Test series 4: DL2 in flexure

Figure A-14. DL2.1 failure mode, attachment hardware

Figure A-15. DL2.2 failure mode, attachment hardware

Figure A-16. DL2.3 failure mode, attachment hardware

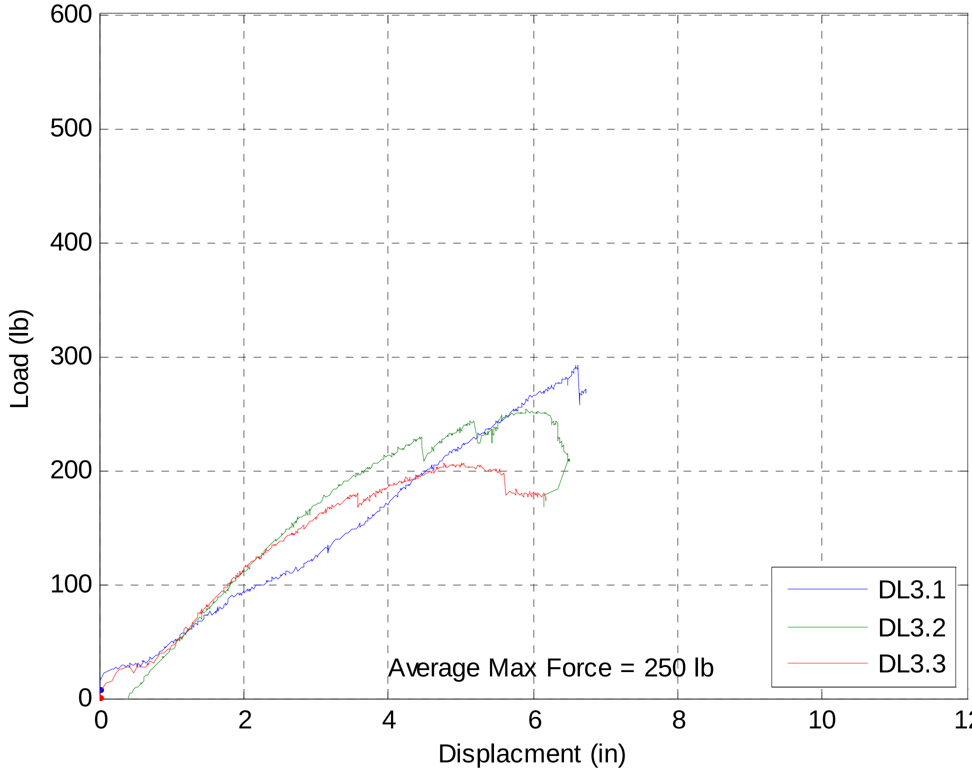

Figure A-17. Test series 5: DL3 in flexure

Figure A-18. DL3.1 failure mode, crack at top connection

Figure A-19. DL3.2 failure mode, crack in top corner

Figure A-20. DL3.3 failure mode, crack in top corner

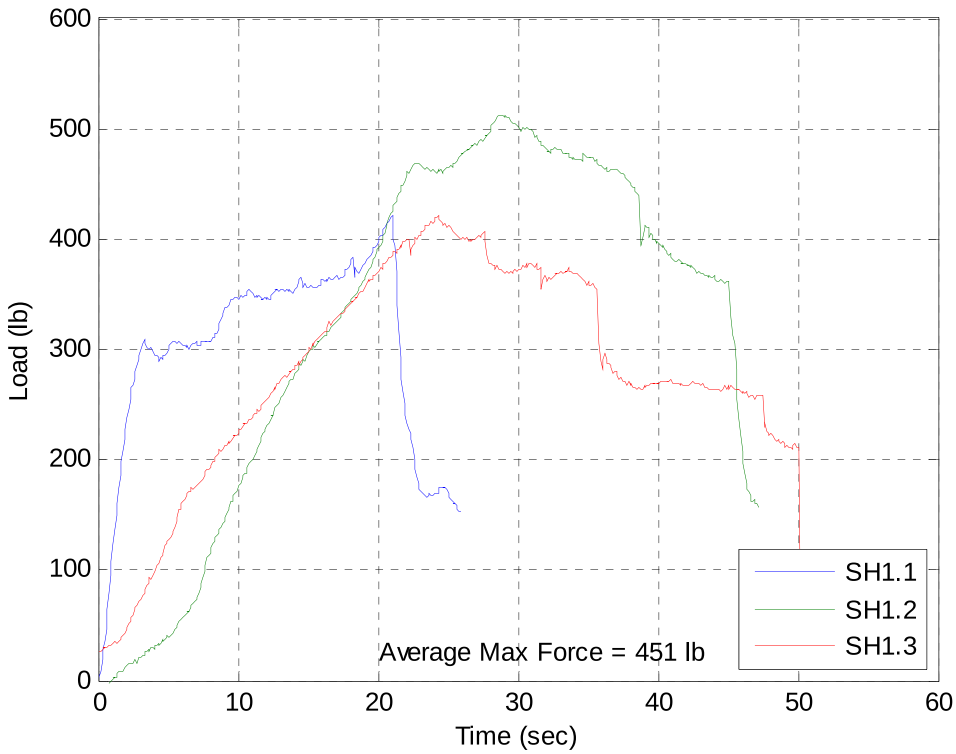

Figure A-21. Test series 6: SH1 in flexure*

*Tests completed prior to string pot set up; results shown with respect to time instead of displacement

Figure A-22. SH1.1 failure mode, crack at top connection

Figure A-23. SH1.2 failure mode, crack at top connection

Figure A-24. SH1.3 failure mode, crack at top connection

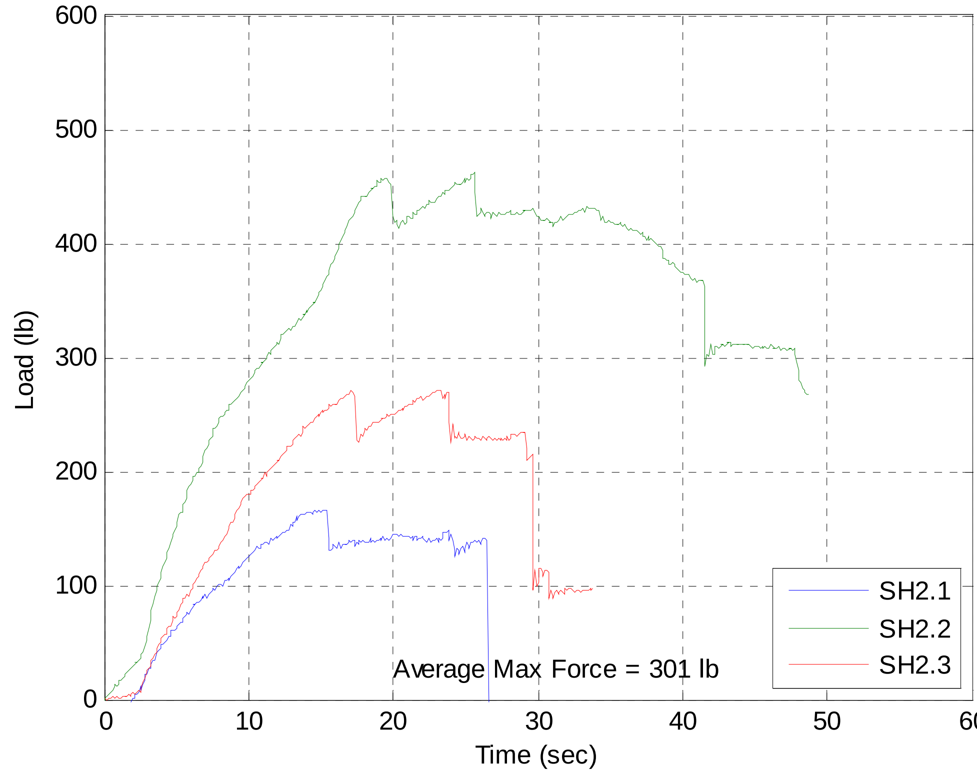

Figure A-25. Test series 7: SH2 in flexure*

*Tests completed prior to string pot set up; results shown with respect to time instead of displacement

Figure A-26. SH2.1 failure mode, crack at top connection

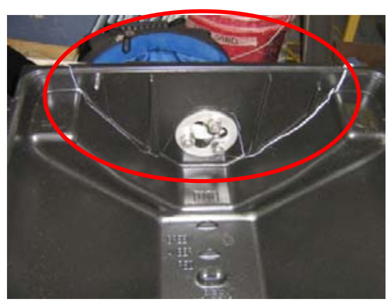

Figure A-27. SH2.2 failure mode, crack at top

Figure A-28. SH2.3 failure mode, break off around top surface

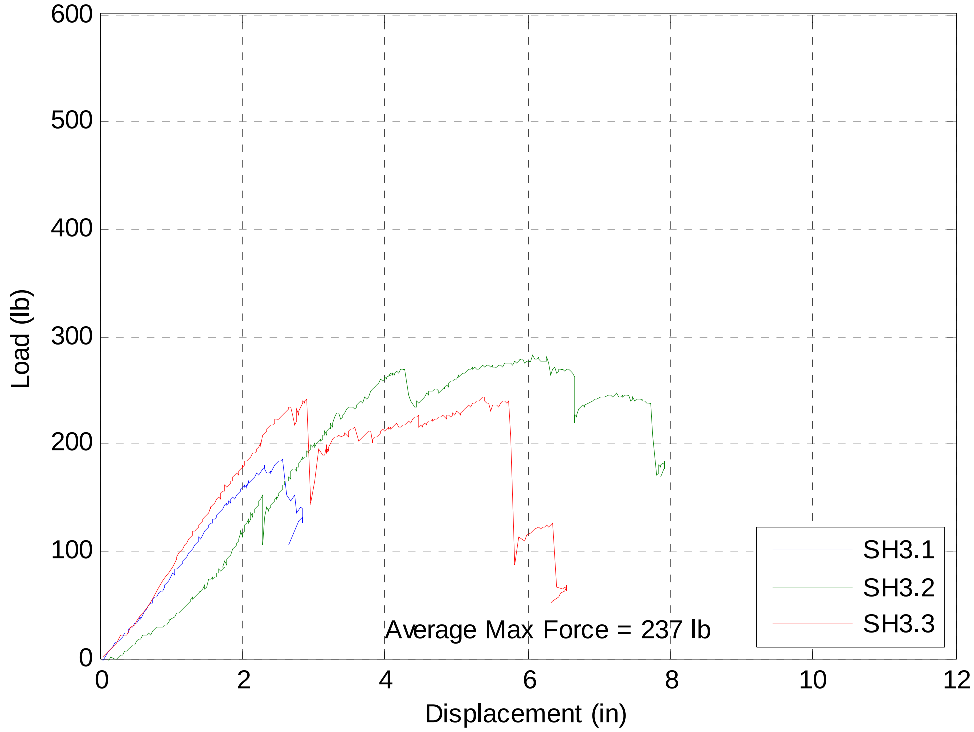

Figure A-29. Test series 8: SH3 in flexure

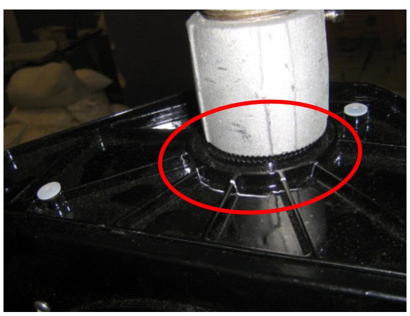

Figure A-30. SH3.1 failure mode, crack at top connection

Figure A-31. SH3.2 failure mode, crack at top connection

Figure A-32. SH3.3 failure mode, crack at top connection

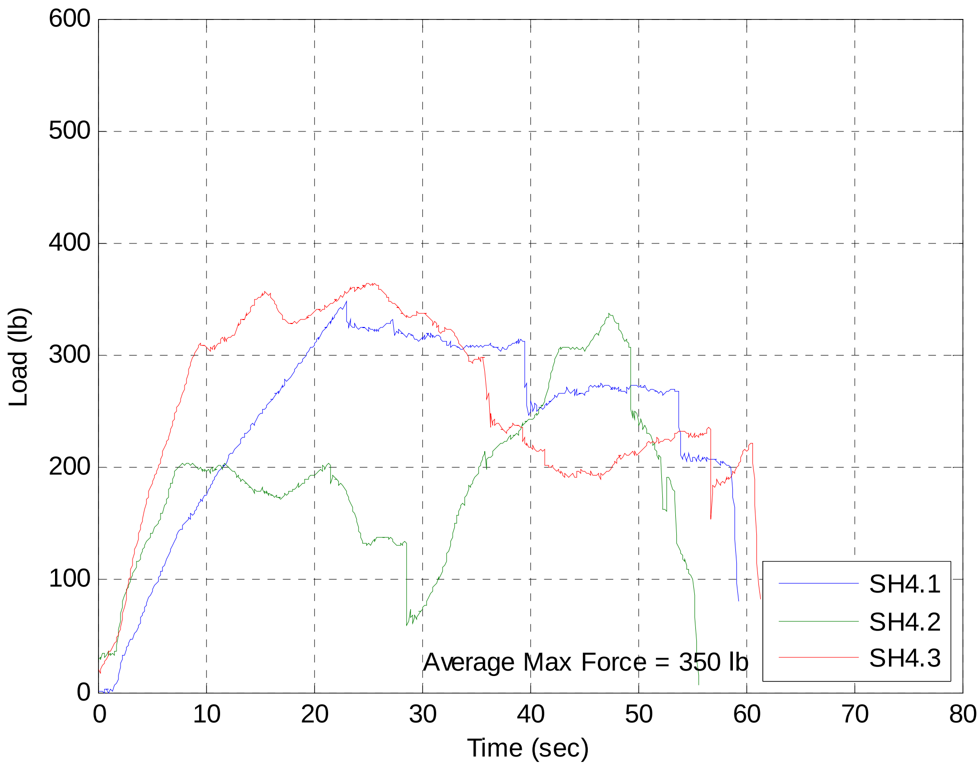

Figure A-33. Test series 9: SH4 in flexure*

*Tests completed prior to string pot set up; results shown with respect to time instead of displacement

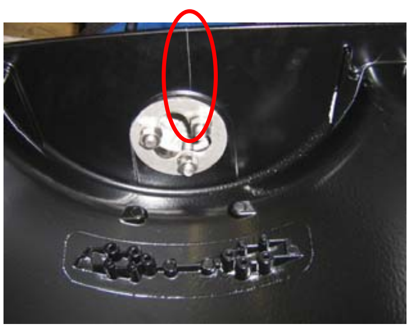

Figure A-34. SH4.1 failure mode, crack at top connection

Figure A-35. SH4.2 failure mode, crack at top connection

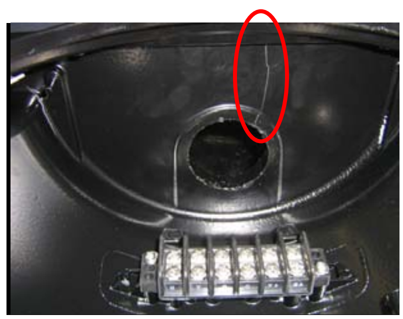

Figure A-36. SH4.3 failure mode, crack at top connection

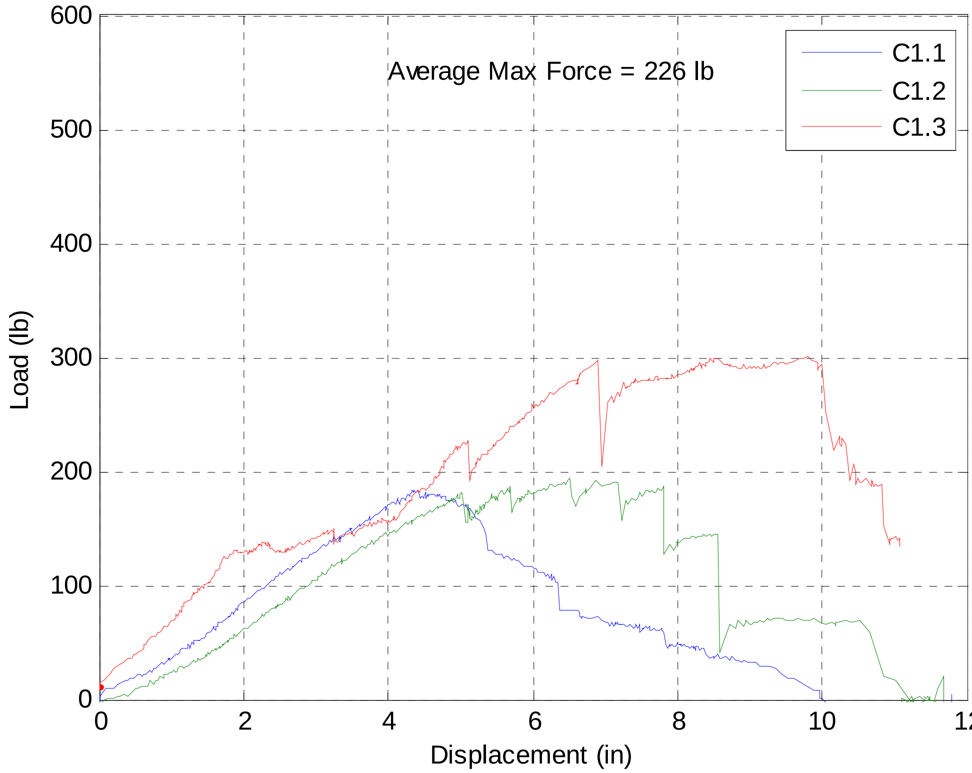

Figure A-37. Test series 10: C1 in flexure

Figure A-38. C1.1 failure mode, crack at top of disconnect

Figure A-39. C1.2 failure mode, crack around top of disconnect

Figure A-40. C1.3 failure mode, crack at top of signal

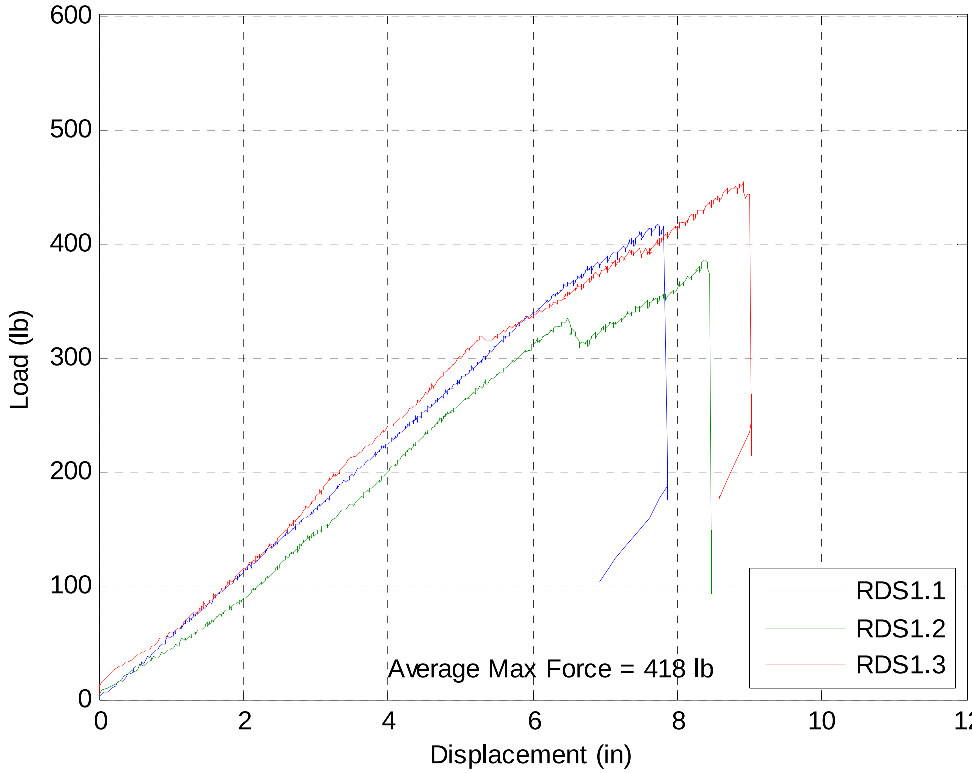

Figure A-41. Test series 11: RDS1 in flexure

Figure A-42. RDS1.1 failure mode, crack in top corner

Figure A-43. RDS1.2 failure mode, crack in top corner

Figure A-44. RDS1.3 failure mode, crack in top corner

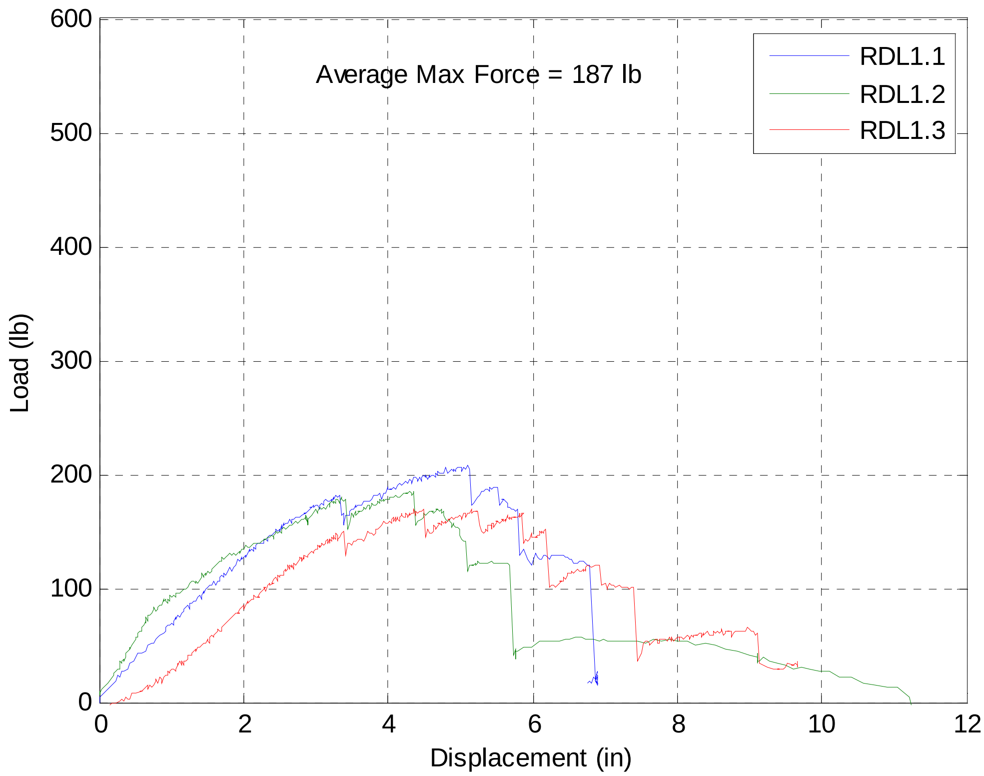

Figure A-45. Test series 12: RDL1 in flexure

Figure A-46. RDL1.1 failure mode, crack starting in top corner

Figure A-47. RDL1.2 failure mode, crack starting in top corner

Figure A-48. RDL1.3 failure mode, crack starting in top corner

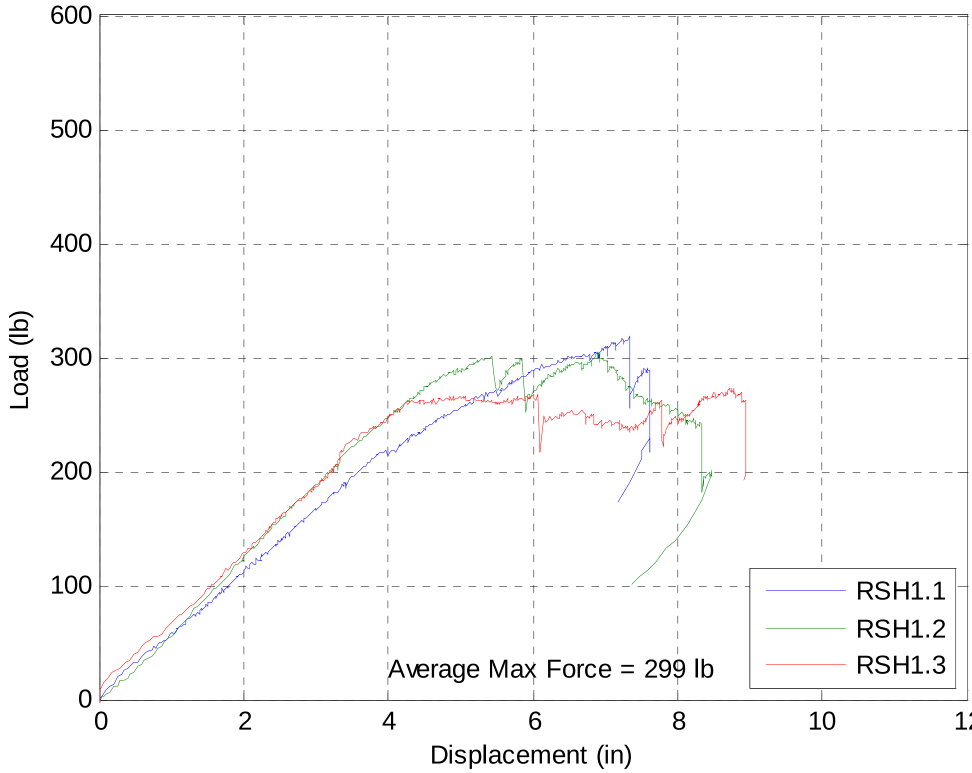

Figure A-49. Test series 13: RSH1 in flexure

Figure A-50. RSH1.1 failure mode, punching at top connection

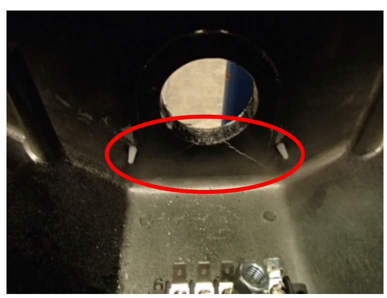

Figure A-51. RSH1.2 failure mode, cracking in top connection

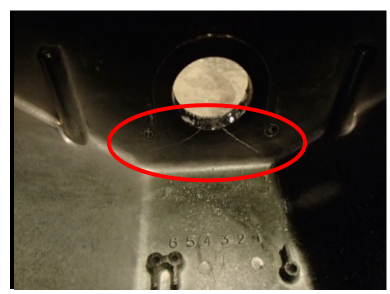

Figure A-52. RSH1.3 failure mode, cracking in top connection

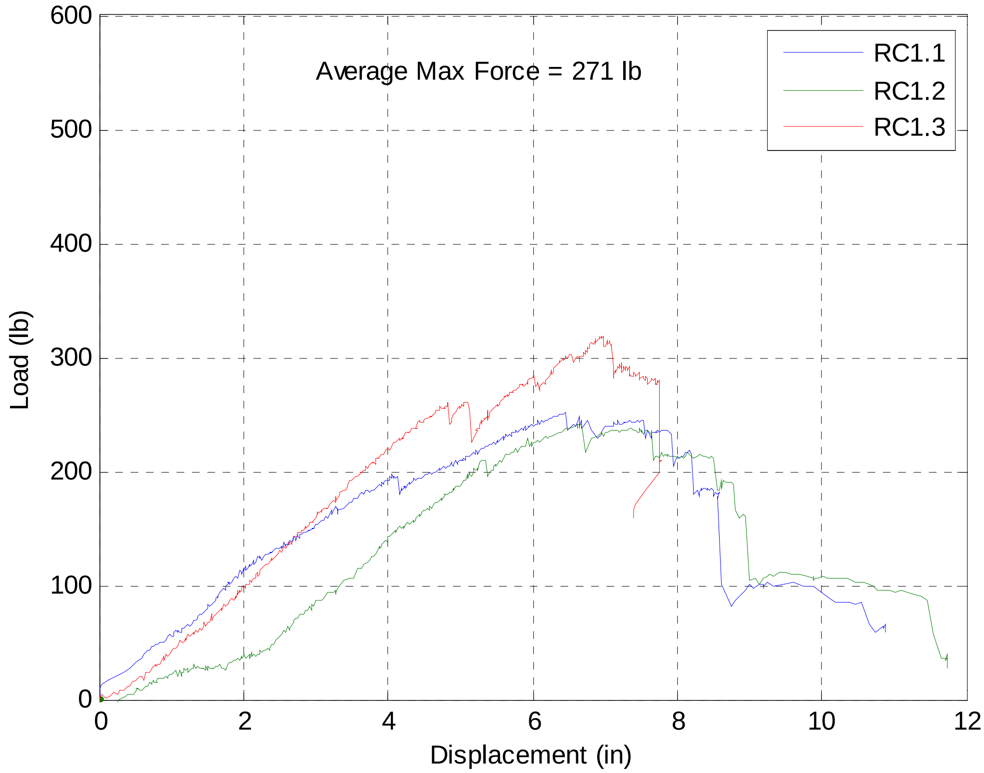

Figure A-53. Test series 14: RC1 in flexure

Figure A-54. RC1.1 failure mode, crack around top

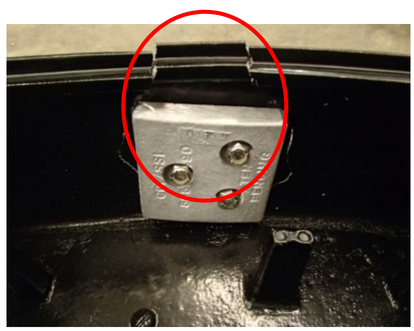

Figure A-55. RC1.2 failure mode, crack around top reinforcement

Figure A-56. RC1.3 failure mode, crack around top reinforcement

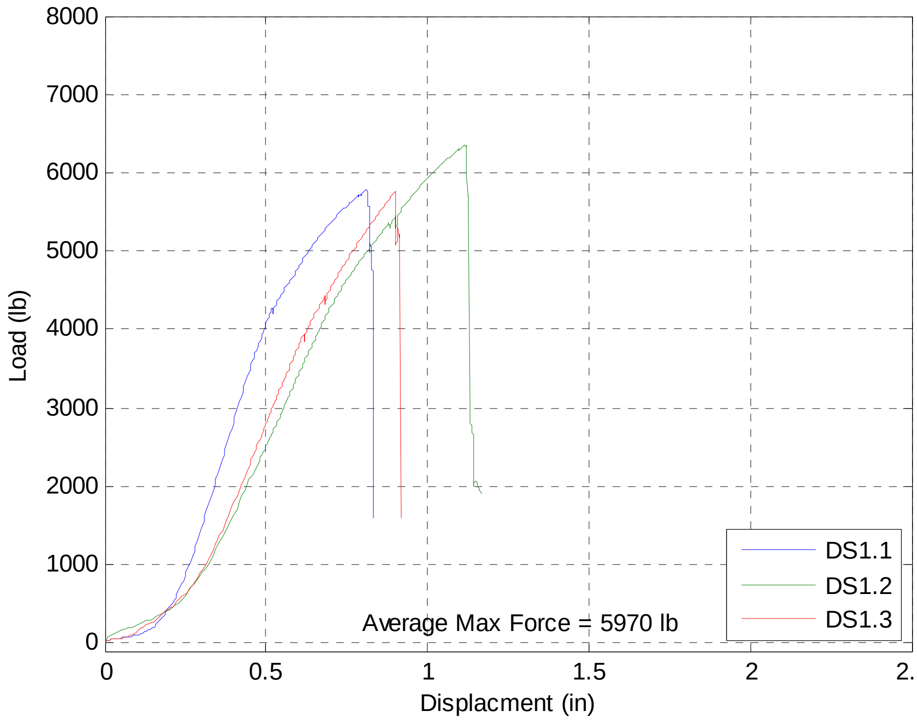

Figure A-57. Test series 15: DS1 in tension

Figure A-58. DS1.1 failure mode, crack around bottom

Figure A-59. DS1.2 failure mode, crack around bottom

Figure A-60. DS1.3 failure mode, crack around bottom

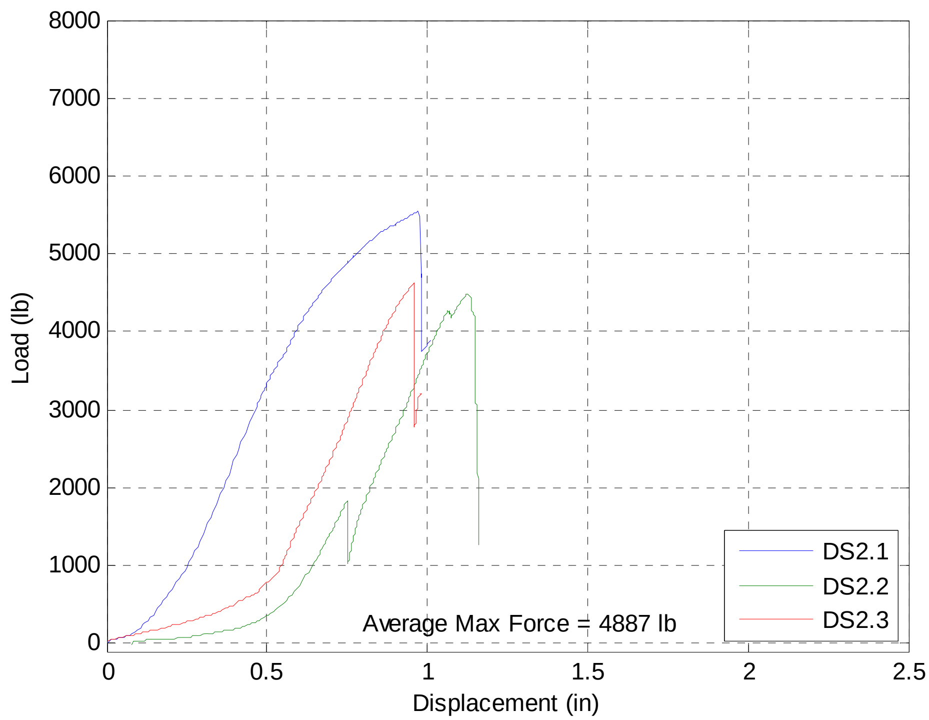

Figure A-61. Test series 16: DS2 in tension

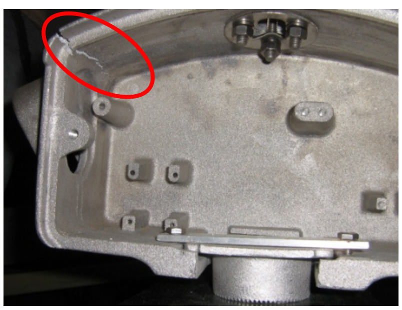

Figure A-62. DS2.1 failure mode, crack in top corner

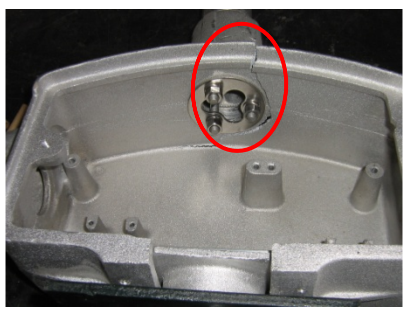

Figure A-63. DS2.2 failure mode, crack at top connection

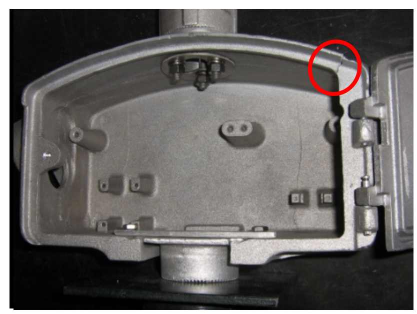

Figure A-64. DS2.3 failure mode, crack at top corner

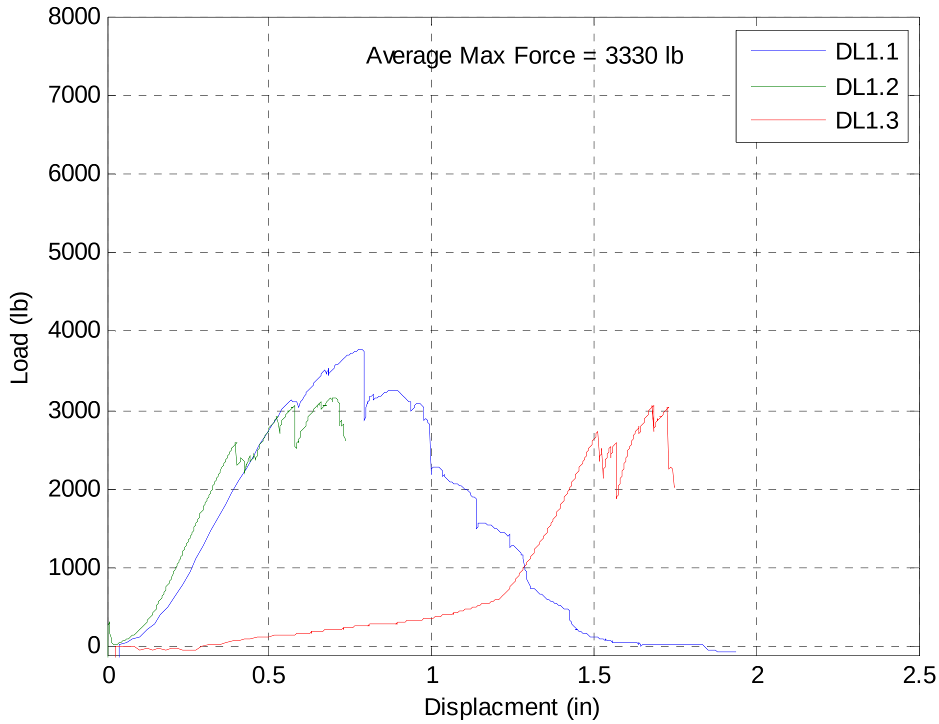

Figure A-65. Test series 17: DL1 in tension

Figure A-66. DL1.1 failure mode, adapter hub, crack around bottom

Figure A-67. DL1.2 failure mode, crack in bottom corner

Figure A-68. DL1.3 failure mode, crack in bottom corner

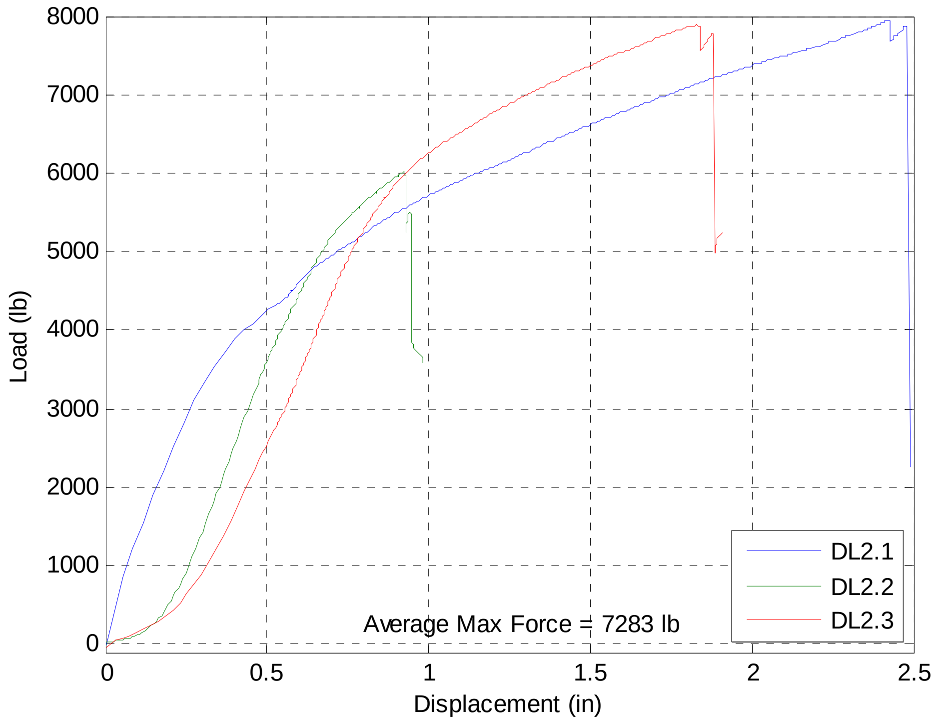

Figure A-69. Test series 18: DL2 in tension

Figure A-70. DL2.1 failure mode, crack in top corner

Figure A-71. DL2.2 failure mode, adapter hub failure

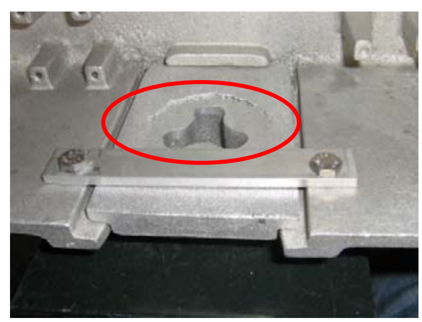

Figure A-72. DL2.3 failure mode, adapter hub failure

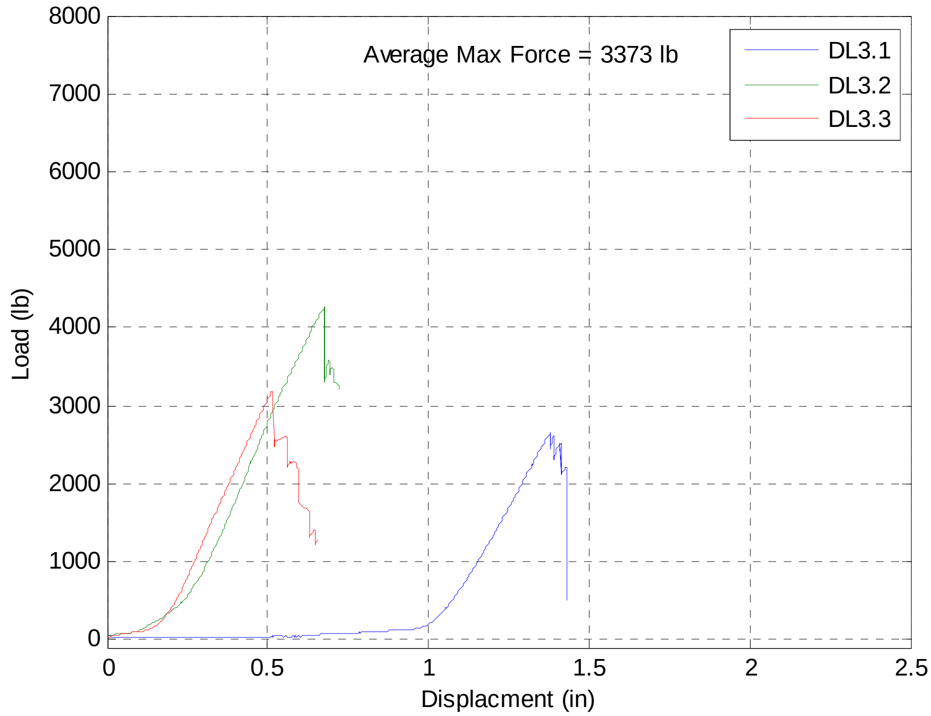

Figure A-73. Test series 19: DL3 in tension

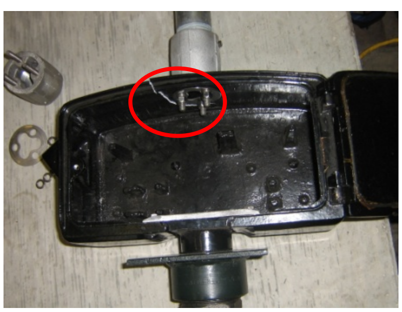

Figure A-74. DL3.1 failure mode, crack at top connection

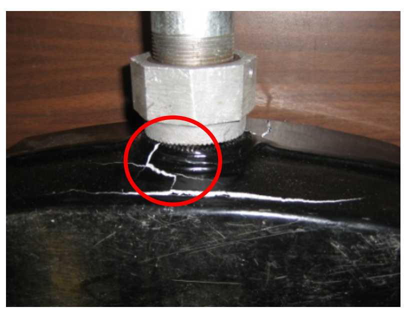

Figure A-75. DL3.2 failure mode, crack at top connection

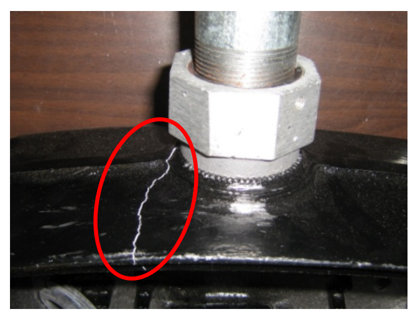

Figure A-76. DL3.3 failure mode, crack at top connection

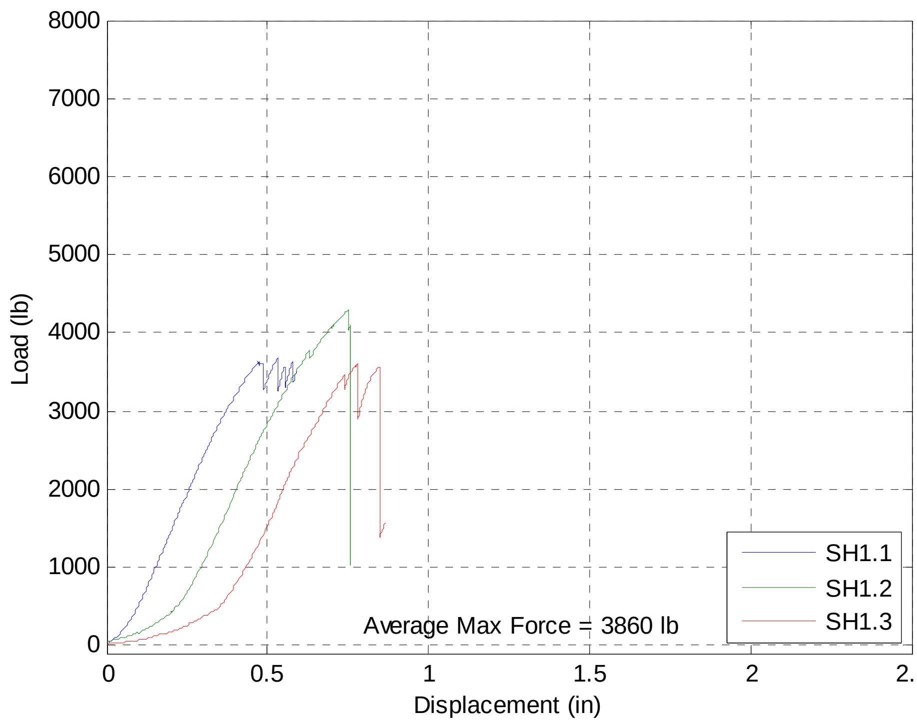

Figure A-77. Test series 20: SH1 in tension

Figure A-78. SH1.1 failure mode, crack at top connection

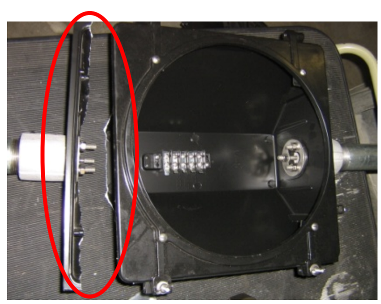

Figure A-79. SH1.2 failure mode, crack around top surface

Figure A-80. SH1.3 failure mode, crack at top connection

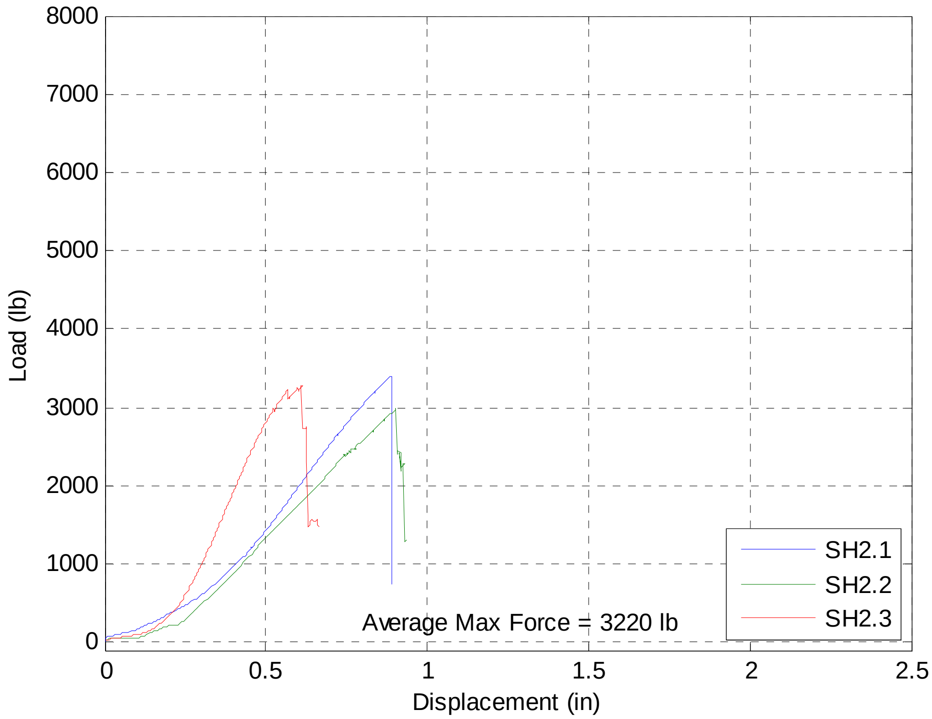

Figure A-81. Test series 21: SH2 in tension

Figure A-82. SH2.1 failure mode, crack around back of signal

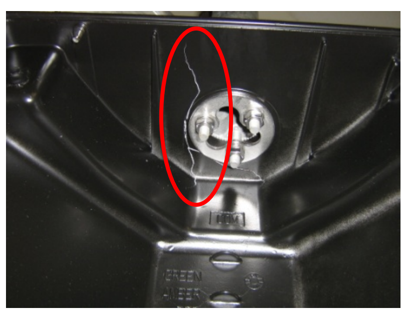

Figure A-83. SH2.2 failure mode, crack at top connection

Figure A-84. SH2.3 failure mode, crack at top of connection

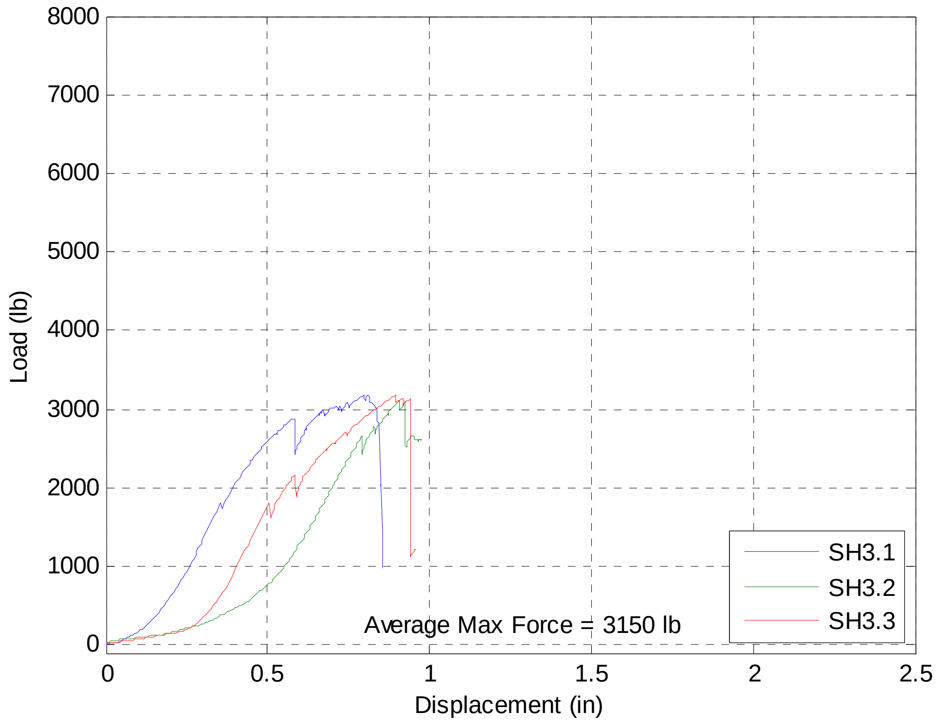

Figure A-85. Test series 22: SH3 in tension

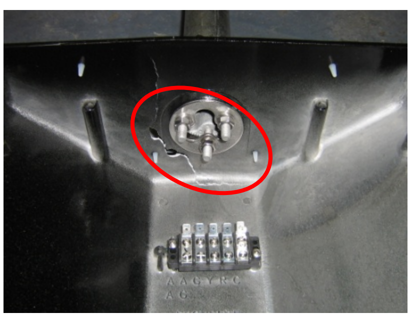

Figure A-86. SH3.1 failure mode, crack at top connection

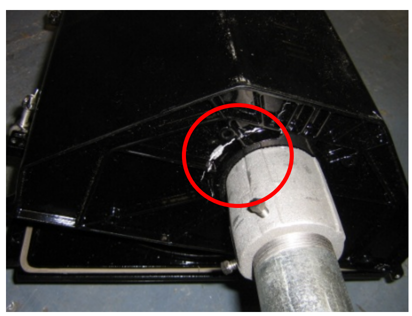

Figure A-87. SH3.2 failure mode, crack at top connection

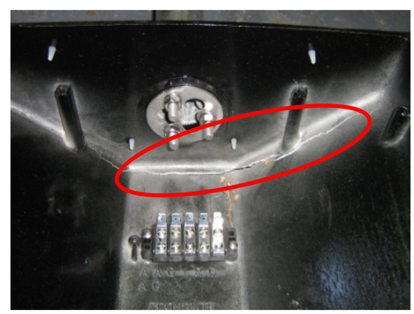

Figure A-88. SH3.3 failure mode, crack around top surface

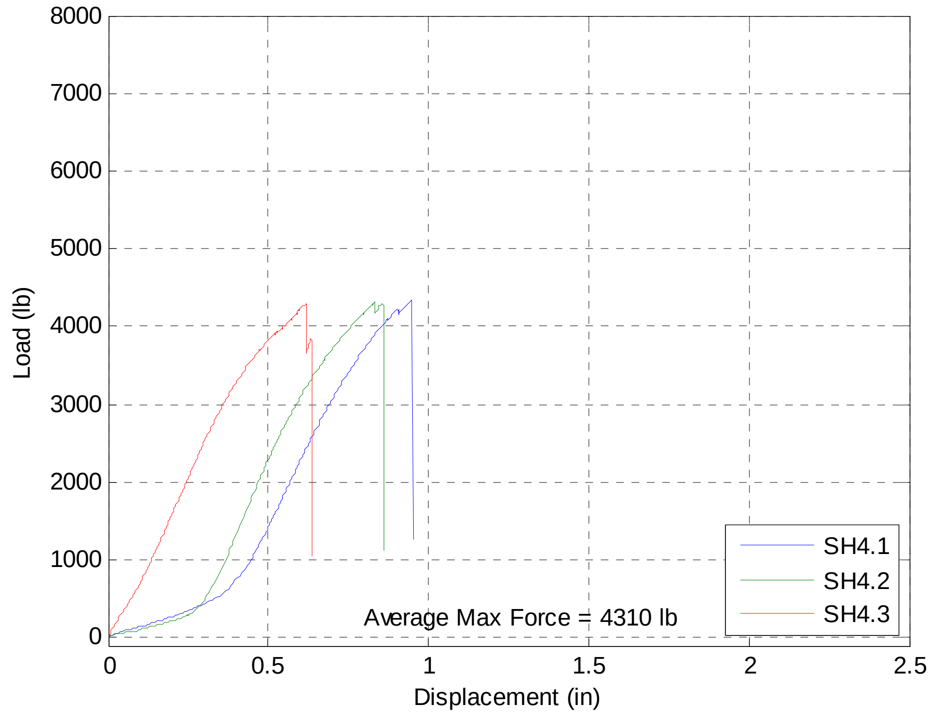

Figure A-89. Test series 23: SH4 in tension

Figure A-90. SH4.1 failure mode, crack around top surface

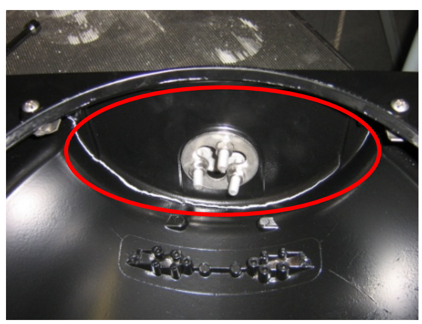

Figure A-91. SH4.2 failure mode, crack around top surface

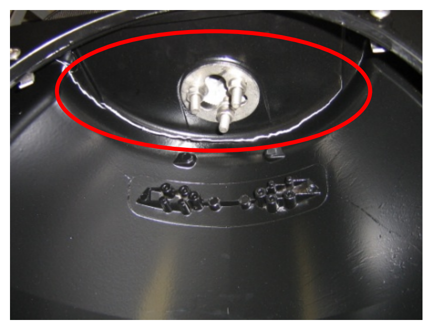

Figure A-92. SH4.3 failure mode, crack around top corner

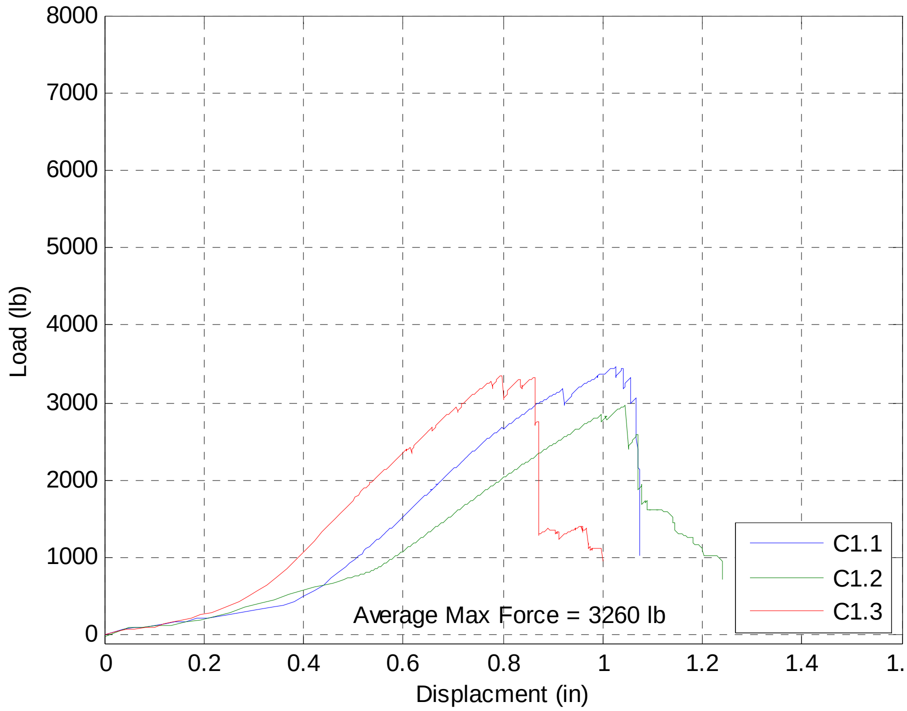

Figure A-93. Test series 24: C1 in tension

Figure A-94. C1.1 failure mode, crack at top of signal

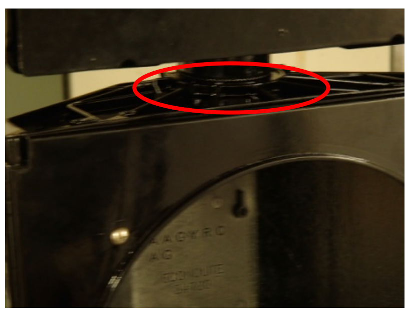

Figure A-95. C1.2 failure mode, crack at top of signal

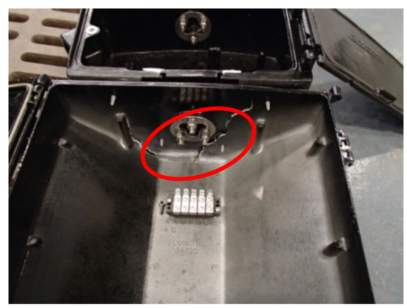

Figure A-96. C1.3 failure mode, crack at top of signal

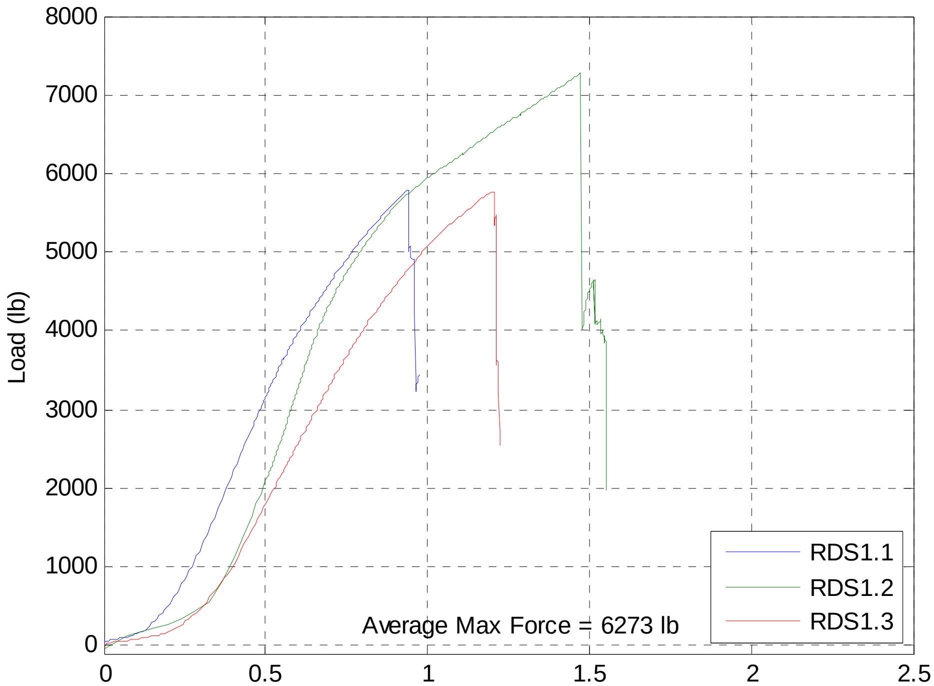

Figure A-97. Test series 25: RDS1 in tension

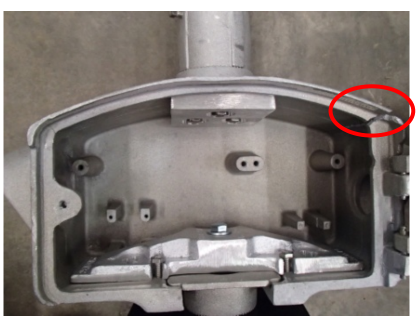

Figure A-98. RDS1.1 failure mode, crack in top corner

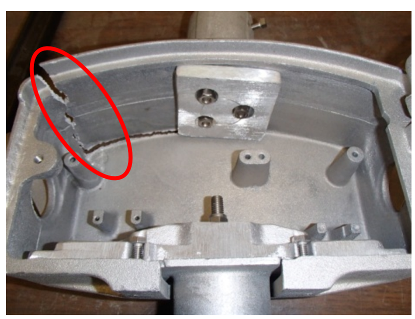

Figure A-99. RDS1.2 failure mode, crack in top corner

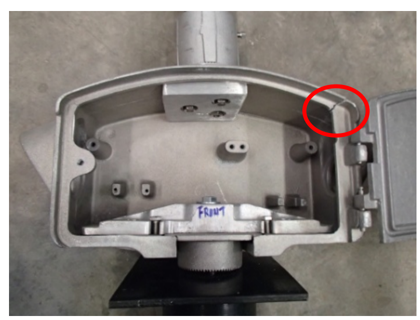

Figure A-100. RDS1.3 failure mode, crack in top corners

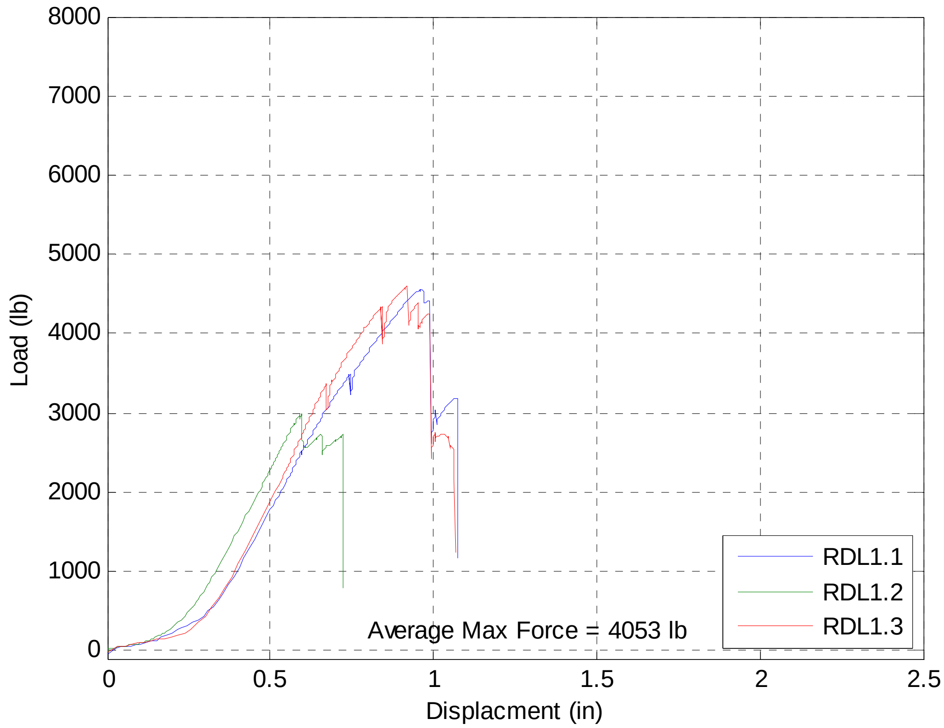

Figure A-101. Test series 26: RDL1 in tension

Figure A-102. RDL1.1 failure mode, crack around top reinforcement

Figure A-103. RDL1.2 failure mode, crack around top reinforcement

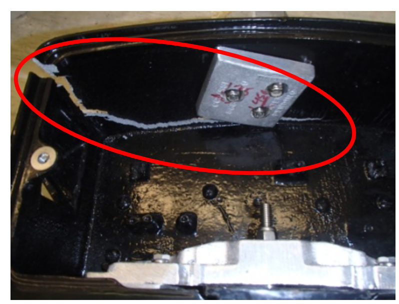

Figure A-104. RDL1.3 failure mode, crack around top reinforcement

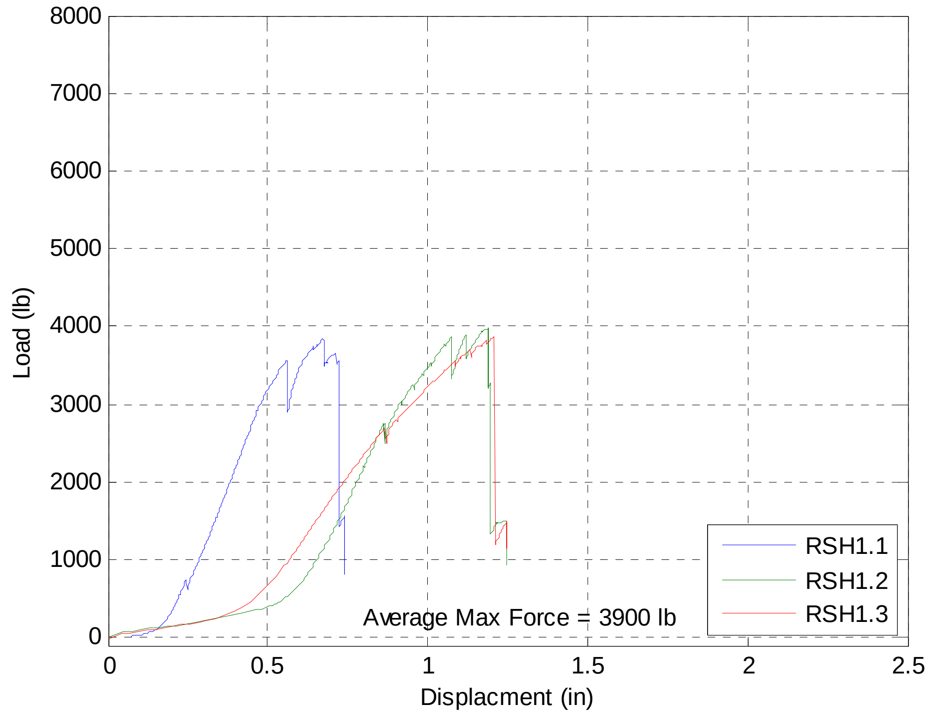

Figure A-105. Test series 27: RSH1 in tension

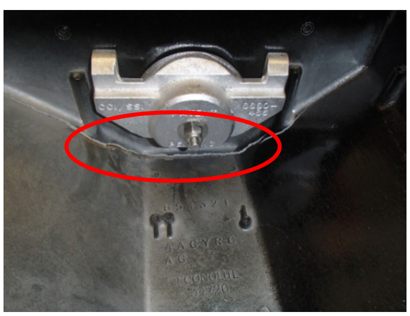

Figure A-106. RSH1.1 failure mode, crack in top of signal

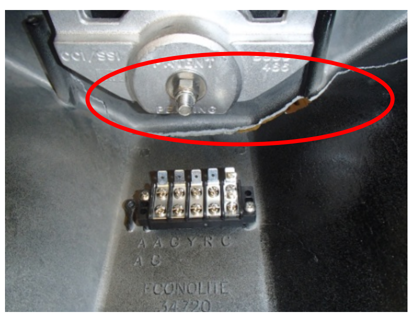

Figure A-107. RSH1.2 failure mode, crack in top of signal

Figure A-108. RSH1.3 failure mode, crack in top of signal

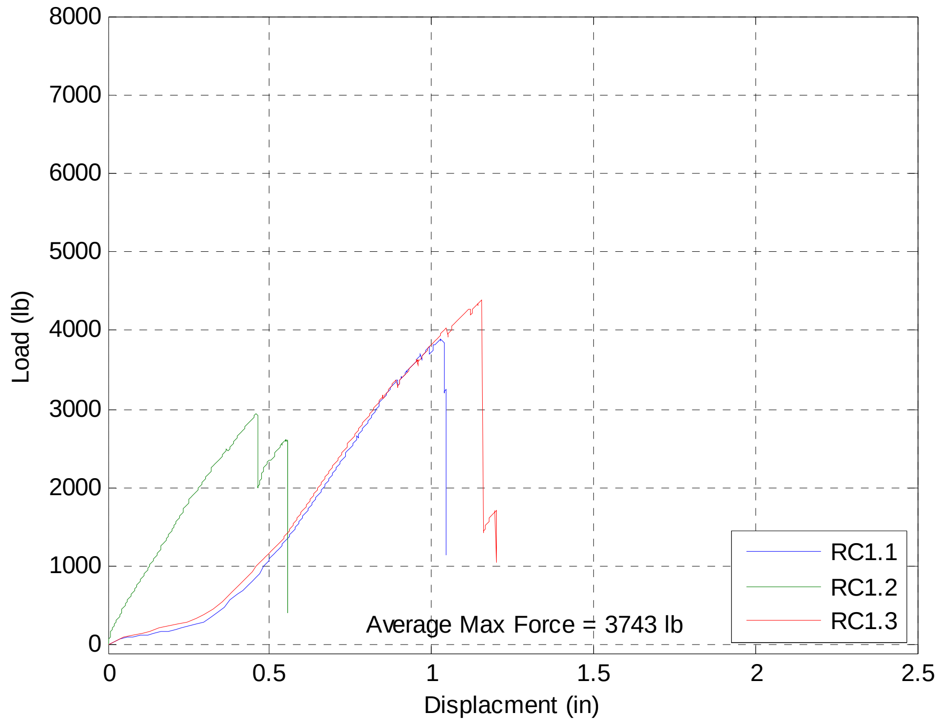

Figure A-109. Test series 28: RC1 in tension

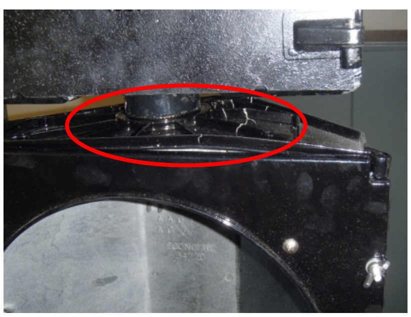

Figure A-110. RC1.1 failure mode, crack in top of signal

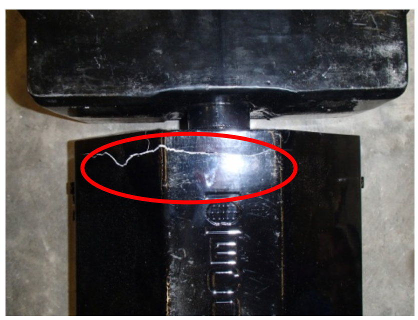

Figure A-111. RC1.2 failure mode, crack in top of signal

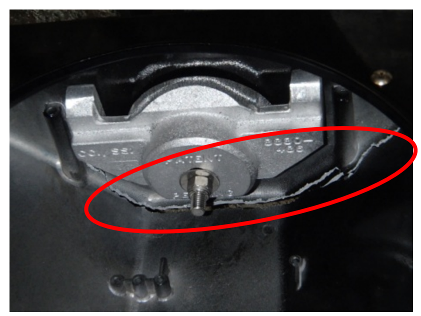

Figure A-112. RC1.3 failure mode, cracking in signal

APPENDIX B: LIST OF PARTS USED


Figure B-1. 12 inch aluminum signal head


Figure B-2. Disconnect box


Figure B-3. Tri-stud adapter with attachment hardware


Figure B-4. 1 ½″ steel pipe


Figure B-5. 2 ½″ steel pipe


Figure B-6. Tri-stud to pipe adapter for bottom of disconnect box


Figure B-7. 2 ½″ to 1 ½″ reducing bushing


Figure B-8. 1 ½″ steel pipe, 12″ long

Figure B-9. 1 ½″ steel pipe, 7″ long

Figure B-10. Top disconnect reinforcement

Figure B-11. Large disconnect reinforcement, bottom

Figure B-12. Small disconnect reinforcement, bottom

Figure B-13. Signal reinforcement

Figure B-14. Reinforcement attachment hardware

Figure B-15. Steel washer for reinforcement connections