Washington State University | Composite Materials and Engineering Center
VOILAND COLLEGE OF ENGINEERING AND ARCHITECTURE

Report No. CMEC 16-018
Test Evaluation of Tree Anchor Bolts

Prepared

for

Nelson Treehouse and Supply
PO box 1135
Fall City, WA 98024

By

Composite Materials and Engineering Center
Washington State University

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PO Box 645815, Pullman, WA 99164-5815
509-335-2262 | cmec@wsu.edu | www.cmec.wsu.edu

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Introduction

The Composite Materials and Engineering Center (CMEC), at Washington State University in Pullman, WA, performed a series of tests on several tree anchor systems provided by Nelson Treehouse and Supply. There were two sizes of the treehouse attachment bolts (TAB) evaluated, the standard limb (SL) and the heavy limb (HL). In addition to the TAB testing, each size of tab was also evaluated with a 3/8" cable backup system. (Figure 1). The testing was conducted between October 11 and October 17, 2016. The tests conducted were selected to demonstrate the typical loading experienced in service, gravity load – parallel to grain of tree, wind load – perpendicular to the grain of the tree and withdrawal from the tree.

Standard limb TAB (1¼-in diameter) | Heavy Limb TAB (1¾-in diameter) | Cable backup (3/8-in diameter)

Figure 1. Nelson Treehouse products

Test Materials

Standard and heavy treehouse attachment bolts and cable backup systems were provided by Nelson Treehouse and Supply for testing. These products were tested in both Western Red Cedar and Douglas Fir logs that were harvested within the state of Washington. The dimensions of all specimens were measured and recorded prior to testing. Moisture content of the logs near the location where the bolt was inserted for testing was determined after the testing was complete for each log.

Test Methods

The two TAB sizes were tested in three distinct directions relative to the grain direction in a log: Parallel to the longitudinal axis/grain direction of the tree, perpendicular to the longitudinal axis/grain direction of the log (tangential to the curvature of the log), and parallel to the short axis/radial direction of the log (withdrawal). The parallel to grain direction test (longitudinal) was selected to simulate the in-service occupancy load of the treehouse due to gravity. The perpendicular to grain direction (tangential) was selected to simulate wind and or seismic loading of the treehouse. The withdrawal test was selected to also simulate wind or seismic loading of the treehouse. A typical setup for a longitudinal TAB test (parallel to the grain) is shown in Figure 2. A typical setup for a tangential TAB test (perpendicular to the grain) is shown in Figure 3. A typical setup for a withdrawal TAB test is shown in Figure 4.

Figure 2. Typical parallel to grain test setup.

Figure 3. Typical perpendicular to grain test setup

Figure 4. Typical withdrawal test setup

The longitudinal loading was conducted with two different methods. The primary method was a step type of loading where a load was applied and then released and then the load was incremented until 0.50 inches per minute actuator motion throughout the testing.

The second type of loading that was employed was a cyclic loading using the CUREE protocol. The CUREE protocol is based on the American Society for Testing Materials (ASTM) test method E2126-11 *Standard Test Method for Cyclic (Reversed) Load Test for Shear Resistance of Vertical Elements of the Lateral Force Resisting Systems for Buildings*, Test Method C. This is a loading procedure that involves incrementally increasing displacement cycles grouped in phases. The limits of the phases are based on a reference deformation determined from the 80% of the post-peak maximum deformation observed during a monotonic test. The reference deformation used for this testing was 4.927 inches, and was based on the deflection recorded during the step loading used in the perpendicular to grain test of the tabs in a western red cedar log. The testing was conducted using a constant rate of crosshead rate motion of 0.50 inches per minute. A plot of the loading protocol is shown in Figure 5; the vertical line represents the expected failure displacement.

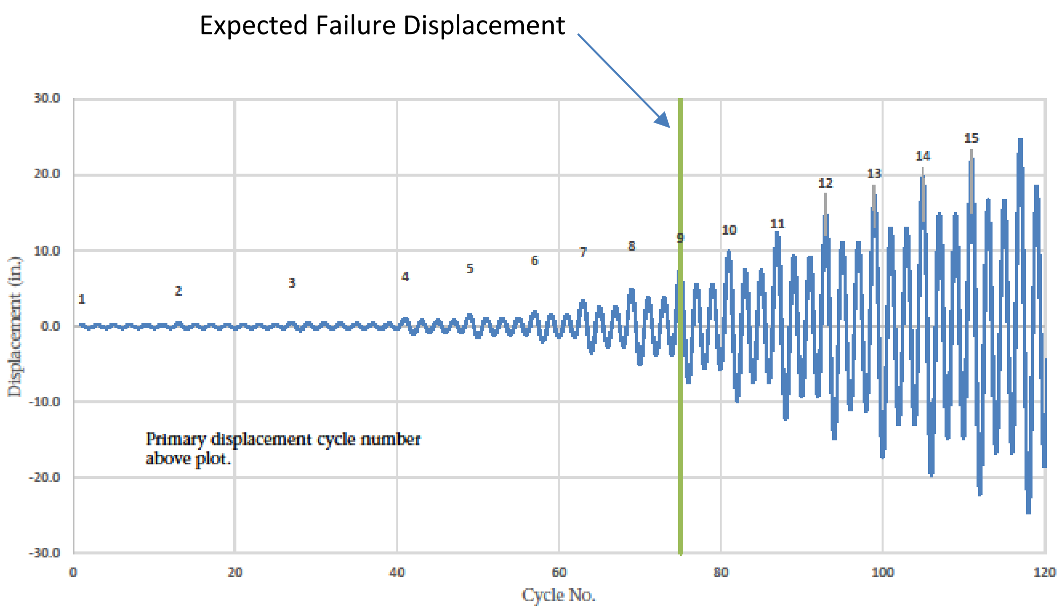

Figure 5. CUREE loading protocol for cyclic loading of TABs

The withdrawal testing was conducted at a constant rate throughout the test. The rate was initially set at 0.15 inches per minute, but was increased to 0.25 inches per minute after the first test due to the failure occurring in almost 20 minutes for the first specimen. The increase resulted in a time to failure of about 10 minutes.

Movement of the TAB was monitored in several different ways, depending on the type of test that was being conducted. Most often, the movement was monitored and recorded using a displacement transducer (potentiometer), an alternative method was use the movement of the actuator as the movement of the TAB. Figure 6 shows the typical location of two displacement transducers used to measure movement during a perpendicular to grain test. Transducer T1 was used to measure movement of the boss portion of the TAB (and the log). Transducer T2 was used to measure movement (roll) of the log. During analysis of the data, the rigid body movement of the log was removed from the movement of the TAB and the log, to provide the relative movement of the TAB.

Figure 6. Displacement transducer locations-perpendicular test setup

The typical setup for a parallel to grain test with a backup cable attached and two distance transducers being used to measure movement of different components is shown in Figure 7. Transducer T1 was used to measure movement of either boss around the backup lag screw or the lag screw directly. Transducer T2 was used to measure movement of the boss portion of the TAB. When the cable backup was not tested only transducer T2 was used.

Figure 7. Displacement transducer locations-parallel to grain test setup

Table 1 lists all of the tests conducted, which type of log was used, the test orientation and the TAB size.

Table 1. TAB testing matrix

Test ID	Log Type and Number	Log Orientation	TAB Size[1]
Para-1	Douglas Fir #1	Parallel	SL
Para-2	Western Red Cedar #3	Parallel	HL
Perp-3	Western Red Cedar #3	Perpendicular	SL
Para-4	Douglas Fir #1	Parallel	HL with backup cable
Para-5	Douglas Fir #1	Parallel	SL with backup cable
Para-6	Douglas Fir #2	Parallel	SL
Para-7	Douglas Fir #2	Parallel	HL
Perp-8	Douglas Fir #1	Perpendicular	SL
Perp-9-Cyclic	Douglas Fir #1	Perpendicular	SL
Perp-10-Cyclic	Western Red Cedar #3	Perpendicular	SL
Withdrawal-1	Douglas Fir #1		SL
Withdrawal-2	Douglas Fir #1		SL
Withdrawal-3	Douglas Fir #1		HL
Withdrawal-4	Douglas Fir #1		HL
Withdrawal-5	Western Red Cedar #3		HL
Withdrawal-6	Western Red Cedar #3		SL
Withdrawal-7	Western Red Cedar #3		Paddle TAB

[1] Tab Size: SL = Standard limb, HL = Heavy limb

Results

The two primary pieces of information desired from this testing were the ultimate load for each test as well as the load when there was a permanent displacement of no more than 0.030 inches. Additional information that can be determined from the testing would include a design load (whether calculated directly from the peak load based on a safety factor of 2.5 or from the yield load when determining a five percent offset of the linear region of the load deflection curve). Table 2 presents the peak load, the load at 0.030 inches of deflection, the safety factor design load and the 5% offset design load. A typical plot showing the determination of the 5% offset load is shown in Figure 8. All of the graphs for the load versus displacement for the determination of the 5% offset design load and the cyclically loaded TABs are shown in Appendix B.

Table 2. Test results from TAB testing

Test ID	Peak Load (lbf)	Load at 0.030" deflection (lbf)	Safety Factor Design Load	5% Offset Design Load
Para-1	16,044	11,062	6,417	11,063
Para-2	22,499	15,058	9,000	13,042
Perp-3	8,046	3,018	3,218	4,009
Para-4	50,514	18,139	20,206	24,124
Para-5	30,054	7,088	12,021	18,029
Para-6	24,130	9,038	9,652	10,030
Para-7	33,000	11,130	13,200	14,037
Perp-8	8,011	4,039	3,205	5,022
Perp-9-Cyclic	11,385	2,433	4,554	3,376
	-5,732	-3,676	2,293	3,676
Perp-10-Cyclic	10,893	2,363	4,357	1,442
	-5,422	-3,675	2,169	5,060
Withdrawal-1	11,624		4,650	
Withdrawal-2	10,505		4,202	
Withdrawal-3	17,357		6,943	
Withdrawal-4	18,956		7,582	
Withdrawal-5	14,975		5,990	
Withdrawal-6	9,419		3,768	
Withdrawal-7	10,513		4,205	

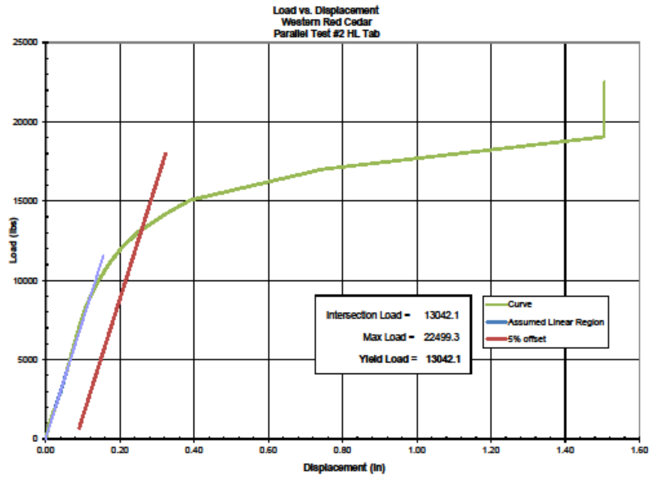

Figure 8. Typical load vs. displacement curve for TAB testing

Failure was considered when the TAB, or the system, could no longer sustain an increase in load. This typically resulted in a withdrawal of the TAB from the log. When testing was perpendicular to the grain (long axis) the failure was most often seen with splitting of the log. This may not happen in a tree due to the ability of the tree to move freely (i.e. twist) when under the increased stresses imposed during testing as well as the increased length of the tree relative to the tested logs. When a backup cable was installed the failure was either fracture of the cable or yielding of the steel in the TAB. Pictures of typical failures are shown in Appendix A.

Testing conducted by Robert Duncan and Scott R. Lewis

Report prepared by:

Robert Duncan
Research Coordinator
CMEC Quality Manager

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Appendix A

Typical failures of Treehouse Attachment Bolts

Figure A1. Parallel to grain (long axis) failure in Douglas Fir

Figure A2. Parallel to grain (long axis) failure in Western Red Cedar

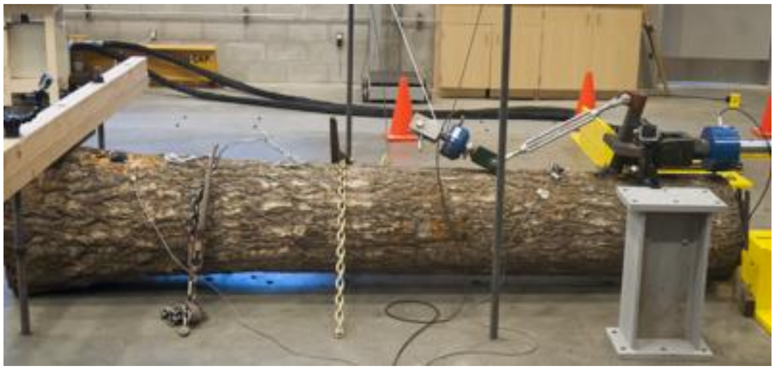

Figure A3. Parallel to grain (long) axis failure in Douglas Fir with cable backup

Figure A4. Parallel to grain (long axis) failure in Douglas Fir with cable backup

Figure A5. Parallel to grain (long axis) failure in Douglas Fir with cable backup

Figure A6. Parallel to grain (long axis) failure in Douglas Fir with cable backup

Figure A7. Perpendicular to grain (long axis) failure in Douglas Fir

Figure A8. Perpendicular to grian (long axis) failure in Western Red Cedar

Figure A9. Perpendicular to grain (long axis) failure in Western Red Cedar after cyclic testing

Figure A10. Perpendicular to grain (long axis) failure in Western Red Cedar after cyclic testing

Figure A11. TAB with minimal damage after testing

Figure A12. TAB with heavy damage after testing

Appendix B
Plots of load versus displacement for TAB testing

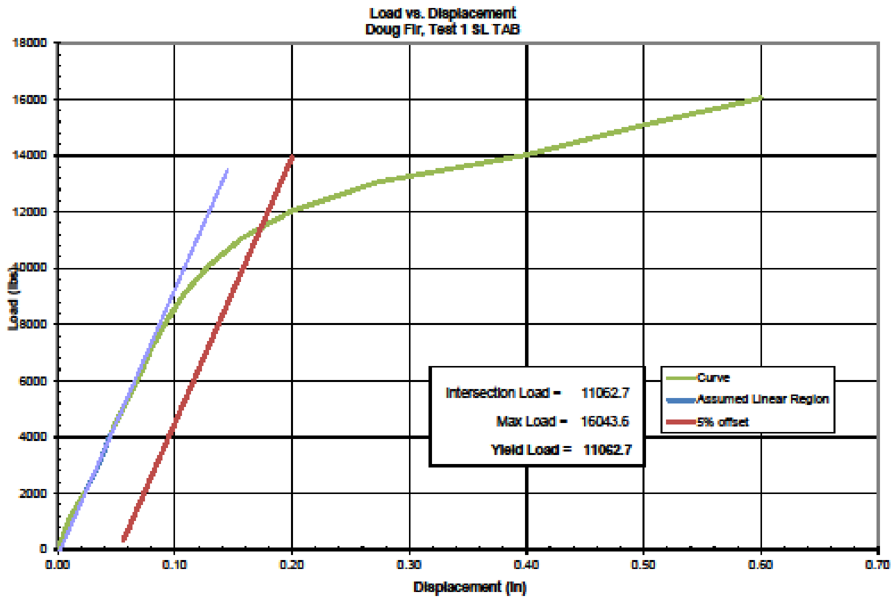

Figure 1B. Test 1

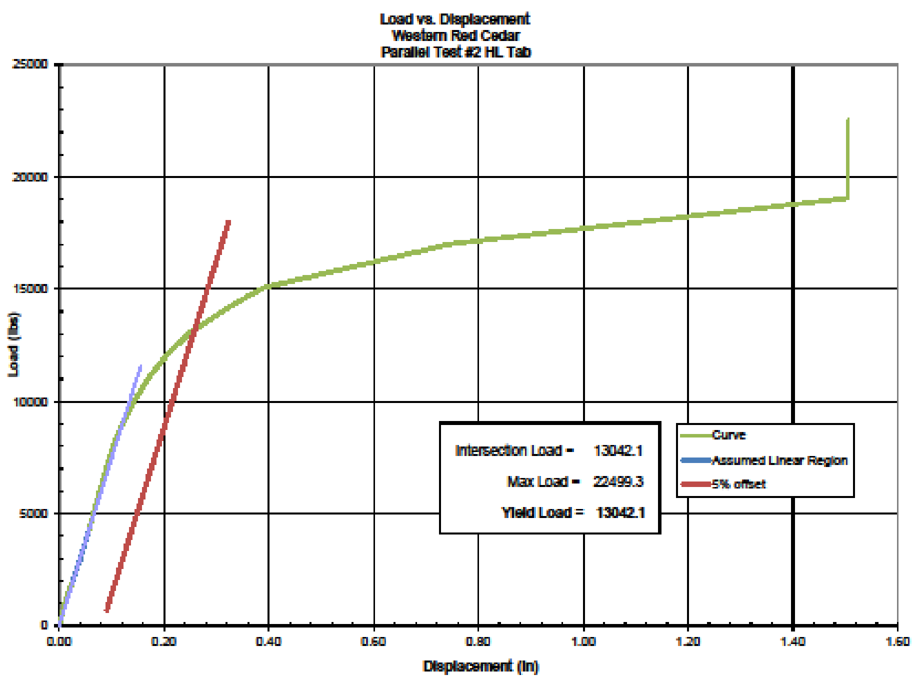

Figure 2B. Test 2

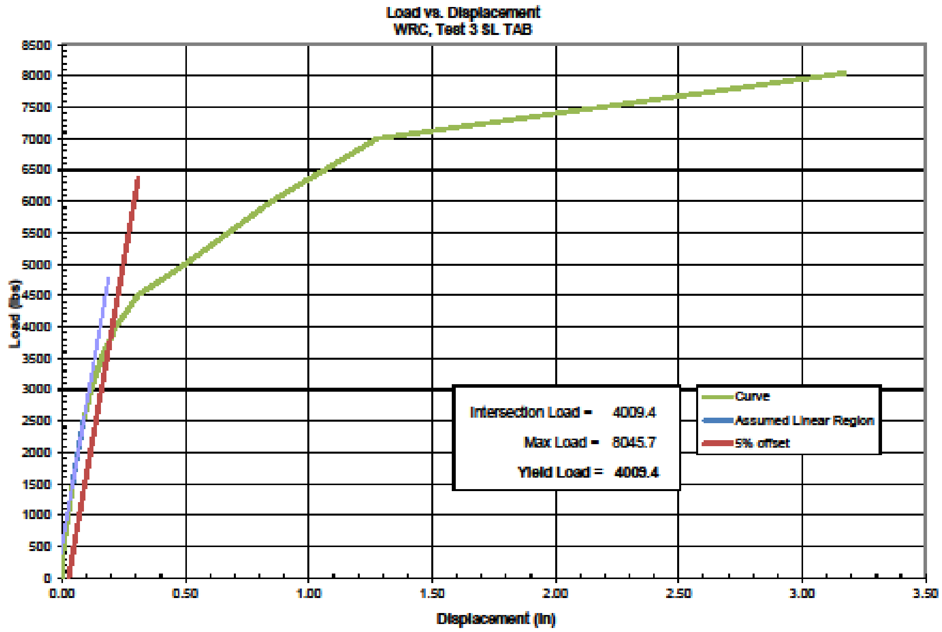

Figure 3B. Test 3

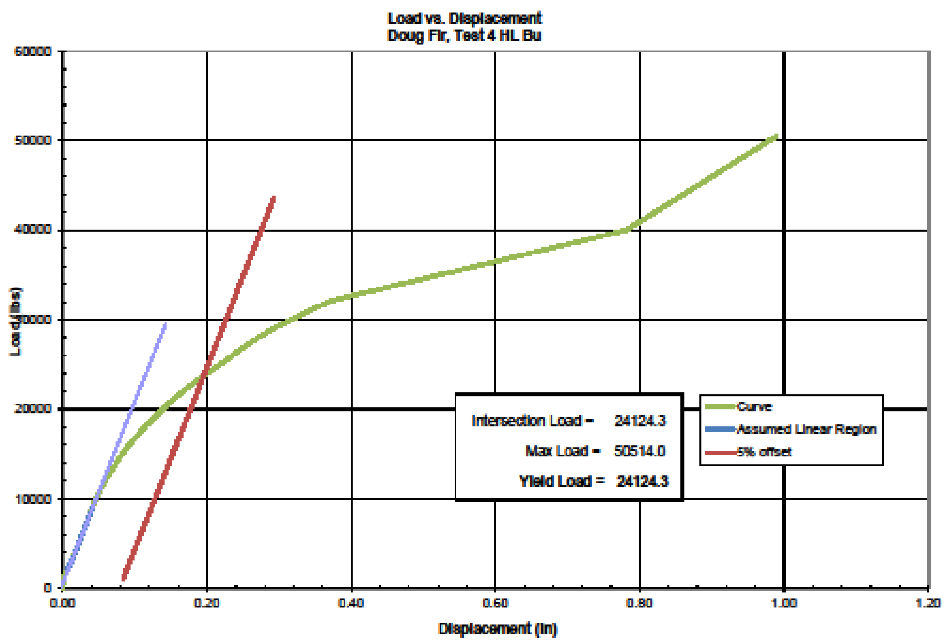

Figure 4B. Test 4

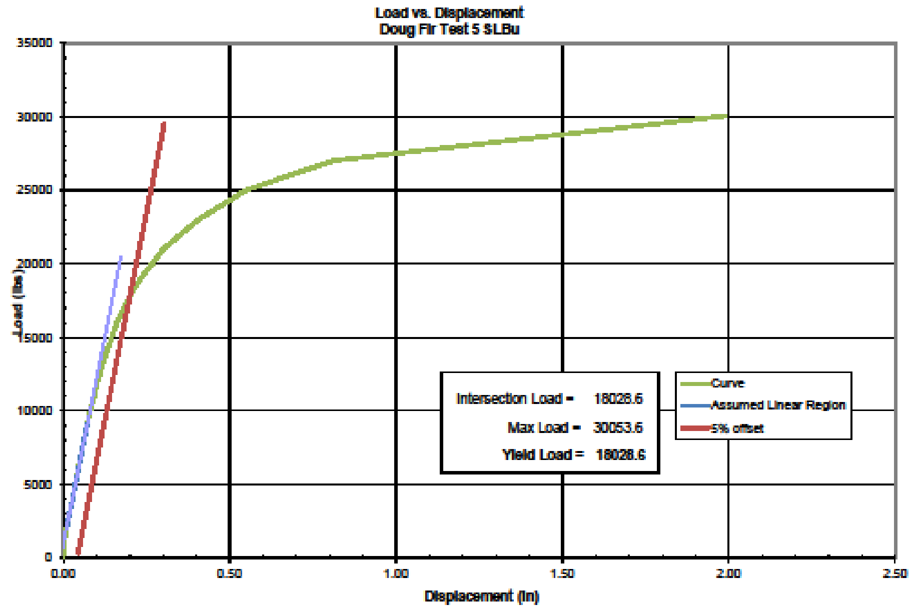

Figure 5B. Test 5

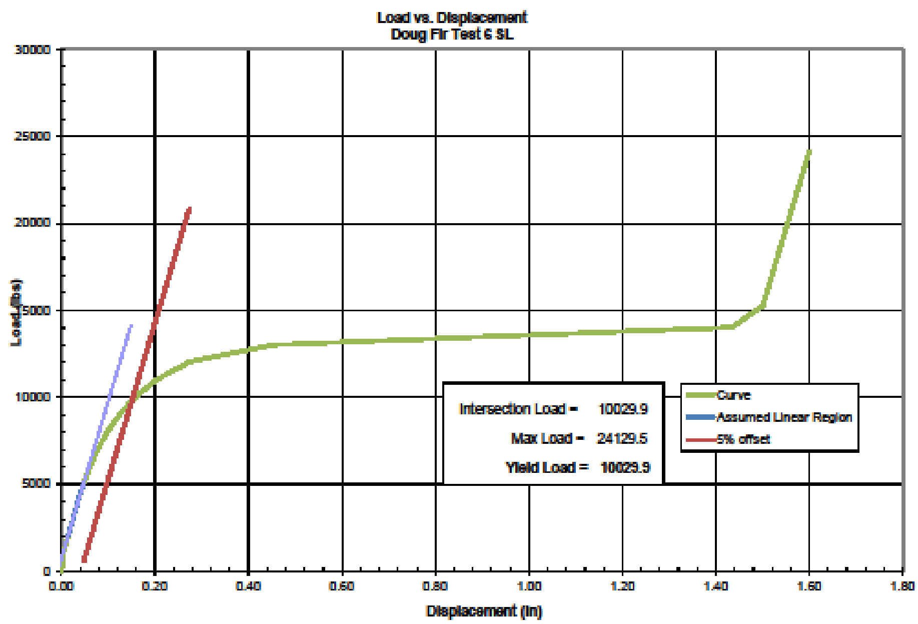

Figure 6B. Test 6

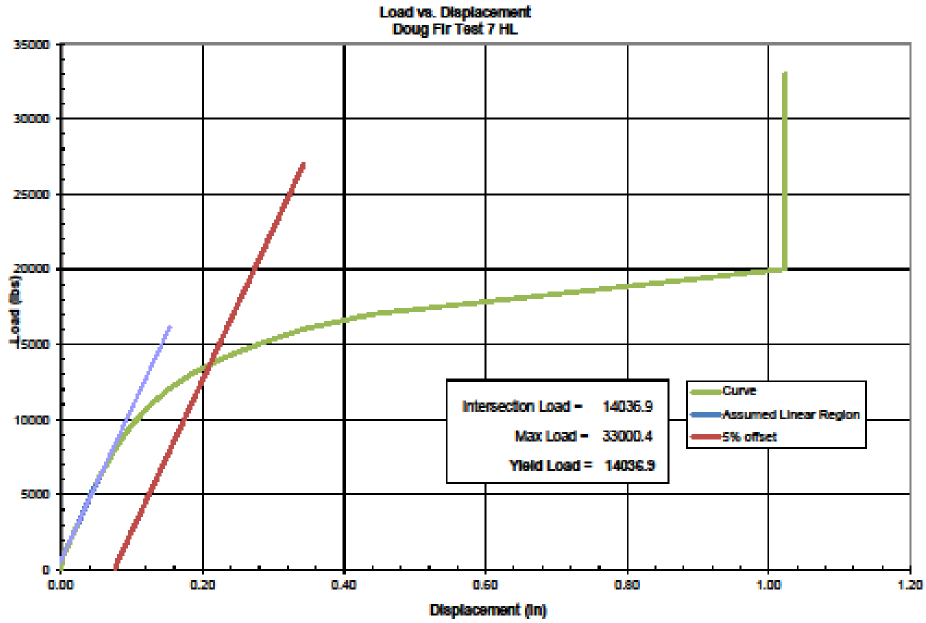

Figure 7B. Test 7

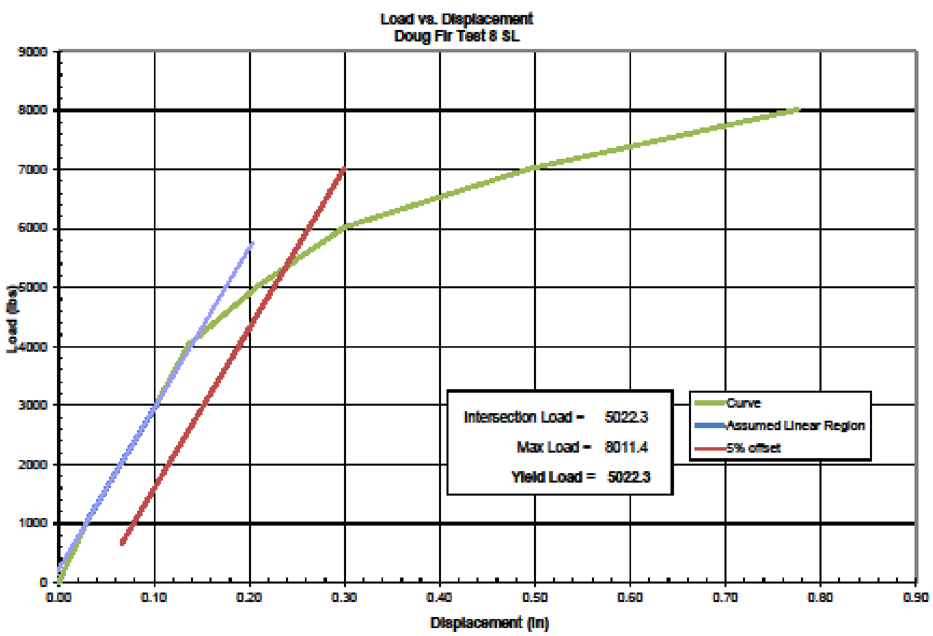

Figure 8B. Test 8

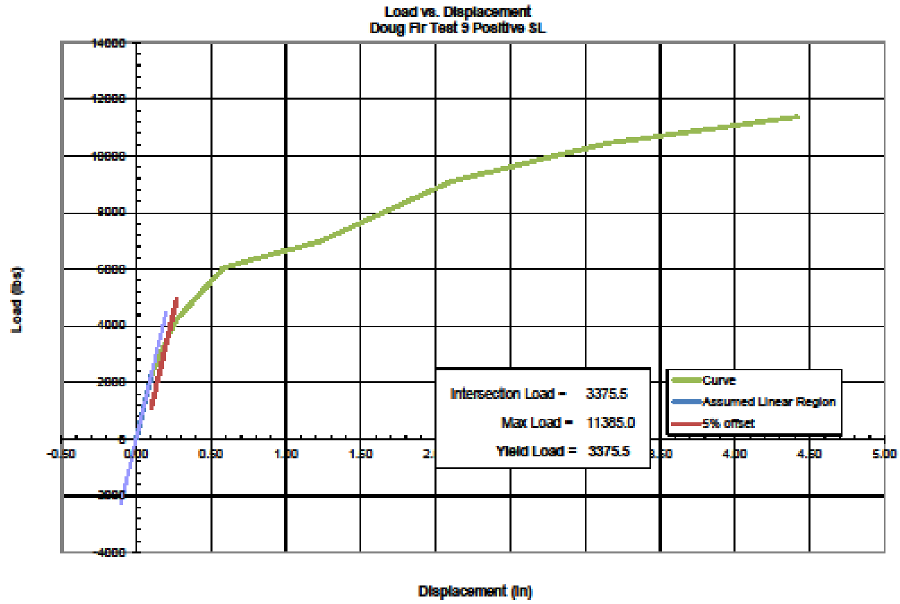

Figure 9B. Test 9, positive direction

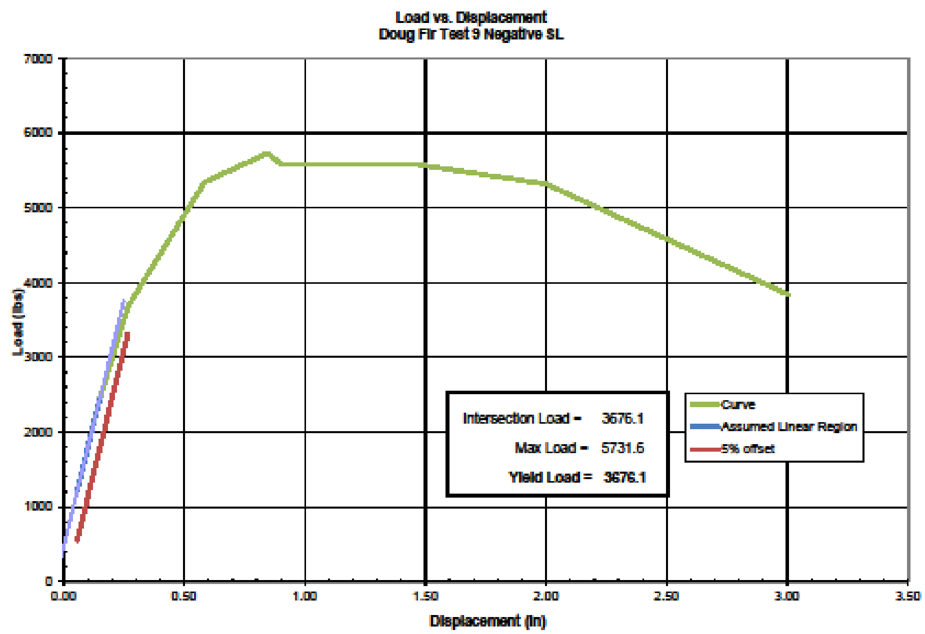

Figure 10B. Test 9, negative direction

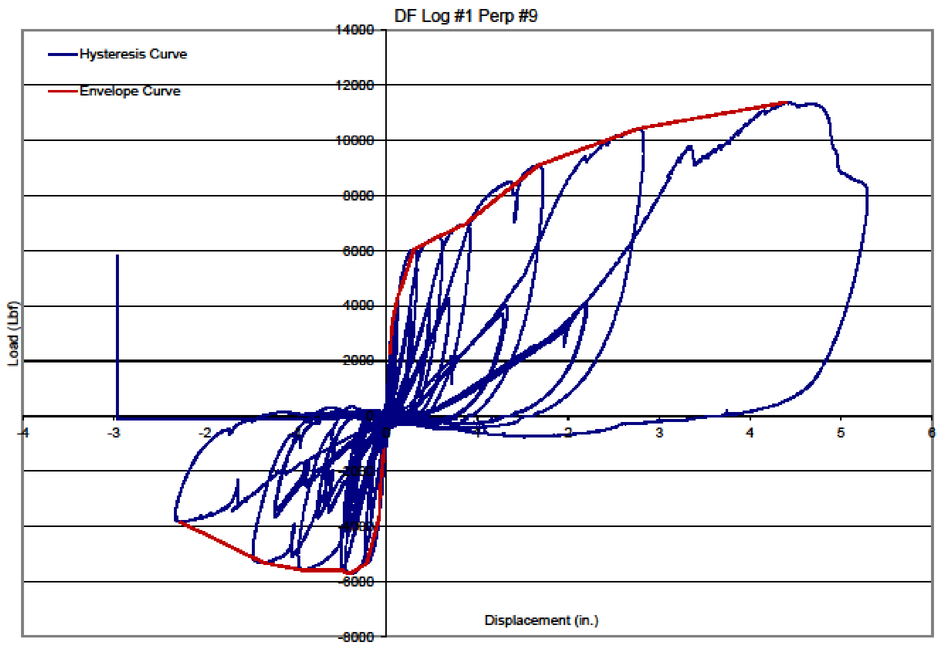

Figure 11B. Test 9, cyclic loading

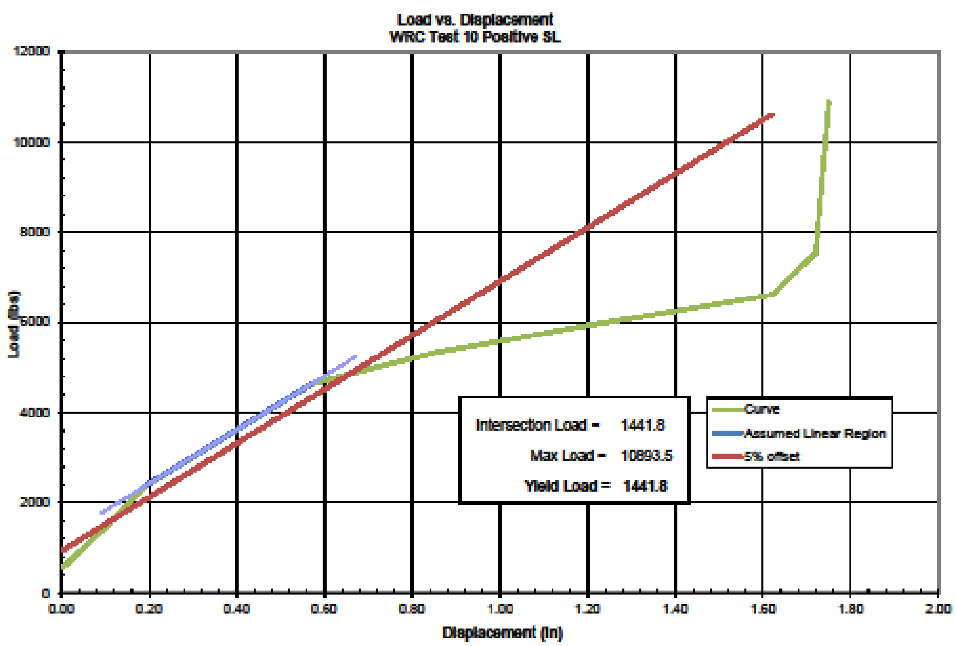

Figure 12B. Test 10, positive direction

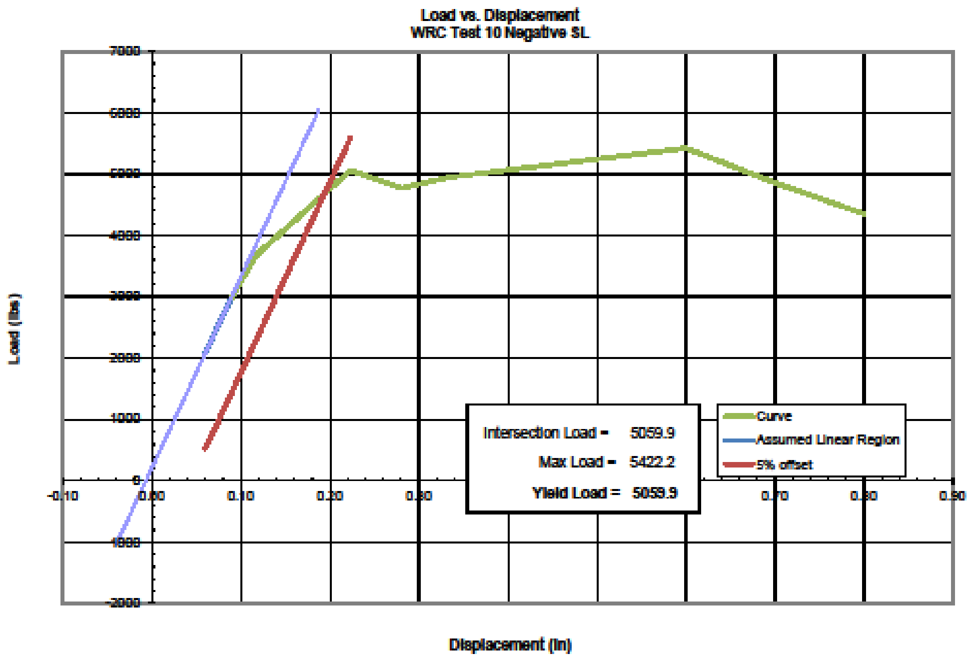

Figure 13B. Test 10, negative direction

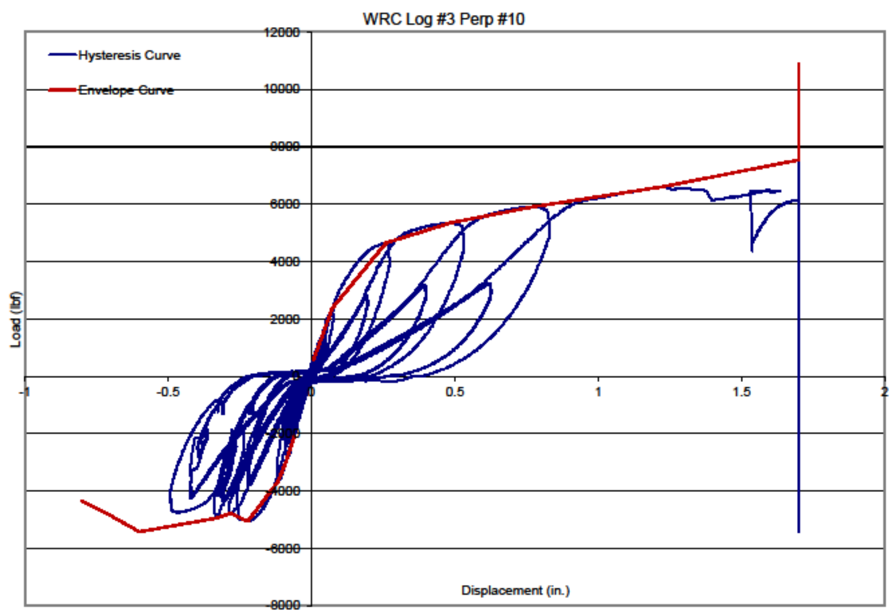

Figure 14B. Test 10, cyclic loading