April 9, 2007

Ms. Amy Starr
Research Engineer
Nebraska Department of Roads
Midwest States Regional Pooled Fund Program
1400 Highway 2
Lincoln, NE 68509

Subject: Letter report documenting dynamic component testing of potential alternative anchors for the F-shape temporary concrete barrier steel strap tie-down system.
TRP-03-182-07
RPFP-06-06

Dear Ms. Starr:

In 2002, the Midwest Roadside Safety Facility developed a tie-down system for temporary concrete barriers when installed on concrete bridge decks (1-2). This tie-down system, as shown in Figure 1, consisted of a retrofit, steel strap, tie-down design for use with Iowa's F-shape temporary concrete barriers. The steel strap was a 3.0-in. wide x 0.25-in. thick x 36-in. long piece of ASTM A36 steel that was bent at four points along the strap to form a trapezoidal shape. A 0.875-in. diameter hole, punched 2 in. from each end of the plate, was used to accommodate two Red Head 0.75-in. diameter, Red Head drop-in anchors and the 0.75-in. diameter x 1.75-in. long, Grade 5 bolts which constrained the strap. In addition, 3.0-in. wide x 0.25-in. thick x 3.25-in. long steel plates with identically sized holes were welded to the strap at the hole locations to reinforce the strap. A third 1.375-in. diameter hole was also punched in the center of the strap to accommodate the vertical pin used to connect the barrier segments. The center hole in the plate was reinforced by a 3.0-in. wide x 0.5-in. thick x 3.25-in. long ASTM A36 steel plate. The new tie-down design was then installed in combination with sixteen F-shape barriers and crash tested according to NCHRP Report No. 350 test designation 3-11. The results showed that the vehicle was safely redirected, and the test was judged acceptable according to the NCHRP Report No. 350 criteria. Barrier deflections for the system were reduced, and all of the barriers in the system were safely restrained on the bridge deck.

While this system has performed as designed, there has been some concern over the anchors used to constrain the steel straps to the bridge deck surface. The anchors used in the system are commonly known as "drop-in" anchors, as shown in Figure 2. These anchors consist of a steel sleeve that is placed into a drilled hole within the concrete surface. The sleeve generally has some form of internal wedge that is expanded inside the narrow base of the sleeve to lock the sleeve into the concrete. A bolt is then threaded into the sleeve to complete the anchorage.

In recent years, screw-in anchors have gained wide acceptance as an economical replacement for drop-in anchors. These devices are less expensive, have comparable capacity, and are easier to install and remove than drop-in designs. Several companies offer screw-in anchor designs that have rated capacities near that of the drop-in anchors used in the original crash testing program. A typical screw-in mechanical concrete anchor is shown in Figure 3.

The goal of this research study was to examine the capacity of existing screw-in anchors to determine whether they would be acceptable substitutes for the drop-in anchors used in the steel strap tie-down design. It was also desired that the screw-in anchors remain as short as possible to limit their embedment into the bridge deck.

METHODOLOGY AND COMPONENT TESTING

This study proposed to compare the anchors through a series of dynamic component tests. These tests would compare the structural capacities of the anchors through relatively inexpensive dynamic component tests, thus eliminating the need for full-scale crash testing. Component testing would be conducted on both the original drop-in anchor as well as alternative screw-in anchors. Comparison of the test results would indicate whether or not the screw-in anchors had sufficient capacity to be used for this application.

Review of Potential Anchor Designs

Screw-in anchor alternatives were selected by examining data from currently available anchors and identifying anchors with tensile and shear ratings similar to that of the drop-in design. Approximate values for the tensile and shear capacities of the 0.75-in. diameter, Red Head drop-in anchor were determined during the development of the steel strap tie-down. Limited testing and review of manufacturer test data of the drop-in anchors conducted during the development of the steel strap tie-down found that the 0.75-in. diameter, Red Head drop-in anchor had an ultimate tensile capacity of 17.3 kips. The shear capacity was not determined through testing during the development of the steel strap tie-down, but its ultimate shear capacity was determined to be approximately 14 kips based on the manufacturer’s reported test data.

A review of existing screw-in anchor designs was conducted to find anchors with similar shear and tensile capacity. Results from this review are shown in Table 1. The search was limited to 0.75-in. diameter anchors that could be accommodated in the existing, steel strap tie-down holes. Table 1 displays 0.75-in. diameter screw-in anchors from Hilti, Red Head, and Simpson along with the corresponding ultimate shear and tensile capacities for the anchors based on concrete strength and embedment depth. Capacities are based on published values from the manufacturer websites.

Review of the tabulated manufacturer data for the screw-in anchors found that several of the screw-in anchors had the potential to be used in the steel strap tie-down system. Tensile capacity data showed that anchors from all three manufacturers would meet the 17.3-kip tensile capacity requirement as long as the anchor embedment was approximately 4.5 in. Similarly, the manufacturer data suggested that all the anchors with an embedment depth of at least 3 in. would meet the desired 14-kip shear capacity. The published shear and tensile capacities for the screw-in anchors were determined based on static load tests. The researchers believed that the behavior of the screw-in anchors under dynamic impact loading might change significantly. Thus, it was decided that the screw-in anchor designs needed to be tested dynamically to be considered for the tie-down application.

A final note should be added regarding the capacities listed above for the 0.75-in. diameter, Red Head drop-in anchor developed previously. Review of the manufacturer's listed ultimate shear and tensile capacities for Red Head drop-in anchors found that the published ultimate tensile and shear capacities had changed significantly from those values published at the time of the development of the steel strap tie-down. This change occurred as a result of revised testing procedures for concrete anchors beginning in the late 1990's. The design of the anchor itself did not change. This discrepancy in published capacities and the fact that the shear capacity of the drop-in anchor was not tested during the development of the steel strap tie-down made it difficult to determine the proper capacity for the drop-in anchor. Therefore, it was decided to test both the original drop-in anchor as well as alternative screw-in anchors from all three manufacturers in order to provide a accurate comparison of the anchor capacities.

Component Testing

Evaluation of the alternative screw-in anchors was accomplished through a series of twenty dynamic component tests. Component tests were conducted at the Midwest Roadside Safety Facility's Outdoor Test Site. The concrete surface at the test site has a 28 day compressive strength of slightly more than 4,000 psi (which was believed to be similar or slightly lower in strength than the concrete bridge deck surfaces the tie-down anchors would be installed on in the field). Component test setups for independently determining shear and tensile capacity were developed, as shown in Figure 4 through Figure 7. A summary of the test results are compiled in Table 2. Results from individual tests are shown in Figure 8 through Figure 27.

Component testing started with shear and tensile tests on the original 0.75-in. diameter, Red Head drop-in anchor to determine its baseline capacities. A pair of tests were conducted for both shear and tension on the original drop-in anchor and averaged to develop baseline capacities that the alternative anchors would be required to meet in order to be retrofitted in the steel strap tie-down. It should be noted that the original shear testing fixture did not function properly in test no. CAT-1. Thus, tensile testing of the baseline anchors and several alternative anchors was conducted while the shear test fixture was modified to function properly.

The initial alternative screw-in anchors selected for testing were chosen based on the manufacturer load data presented in Table 1. Subsequent alternative anchor tests were then conducted in order to find the screw-in anchors that would meet the shear and tensile load capacities of the original drop-in anchor while keeping anchor embedment to a minimum. Results from all of the anchor testing will be discussed in the next section.

Discussion of Results

Results from the component testing of the drop-in and screw-in mechanical concrete anchors revealed a great deal about their performance as well as their comparative strengths and weaknesses. The first important results to note were the baseline capacities of the drop-in anchors used in the steel strap tie-down design. The tension tests of the drop-in anchor displayed an average peak load of 18.7 kips. This value was within ten percent of the 17.3-kip peak tension load found for the anchors during the development of the steel strap tie-down system. Shear testing of the drop-in anchor revealed that the anchors developed an average peak shear load of

25.6 kips. This value of the peak shear load was much higher than previously believed based on the manufacturers' published data. The peak tension and shear loads also suggested that the drop-in anchor had the capacity to generate a larger combined load capacity than was determined in the original steel strap tie-down research. Thus, any of the alternative screw-in anchors needed to meet a peak tensile load of 18.7 kips and a peak shear load of 25.6 kips in order to be considered an acceptable retrofit for the 0.75-in. diameter, Red Head drop-in anchor.

Results from the tensile tests of the screw-in anchors found that the screw-in anchors performed well under dynamic tensile loading. Peak tensile loads for the screw-in anchors were generally higher than the manufacturers published values. All of the tested screw-in anchors were also found to develop equal or higher tensile loads than the 0.75-in. diameter, Red Head drop-in anchor. This result would seem to make sense given the slightly higher embedment of the screw-in anchors and the more effective mechanical engagement between the threads of the screw-in anchor and the concrete as opposed to the press fit engagement of the drop-in anchors.

The screw-in anchors did not perform as well with regards to the shear testing. The peak dynamic shear loads for the screw-in anchors were generally lower than those for the drop-in anchors, especially when considering the shallow embedment of the drop-in anchor. In addition, there were two distinct failure modes observed during shear testing of the anchors. The first failure mode for the shear testing was concrete crush and subsequent pullout of the anchor from the concrete. This failure mode was observed for all of the screw-in anchors with embedment of 3.5 in. or less (anchor lengths of 4.0 in. or less). The second failure mode observed was shear fracture of the anchor. This failure mode was observed for all of the tests with the drop-in anchors and all of the screw-in anchor tests with embedment of 4 in. or greater (anchor lengths of 4.5 in. or more). While, the cause for the lower screw-in anchor shear capacity and the two different failure modes cannot be exactly determined without more test data and analysis, there are two factors identified in this testing that may suggest a reason for the differences. First, the drop-in anchor sleeve has an outside diameter of approximately 1 in., while the diameter of the screw-in anchor bodies are only 0.75-in. The larger diameter of the drop-in anchor provides for increased bearing and compression on the concrete when loaded in shear which would tend to increase the shear capacity of the anchor. The second factor involves the materials used in the anchor. The bolt used in the drop-in anchor is a Grade 5 bolt with yield and tensile strengths of 92 ksi and 120 ksi, respectively. The screw-in anchors are manufactured from lower grade carbon steel and have lower strength than the Grade 5 bolt used in the drop-in. Thus, the higher grade steel in the drop-in anchor would tend to increase its shear capacity as compared to the screw in anchors.

Review of all of the screw-in anchor testing and comparison with the baseline 0.75-in. diameter, Red Head drop-in anchor shear and tensile capacity led to the identification of two suitable replacement anchors for the steel strap tie-down system. These two anchors were:

1. Red Head Large Diameter Tapcon (LDT) 0.75-in. diameter x 4.5-in. long
2. Simpson Titen HD 0.75-in. diameter x 5.0-in. long

It should be noted that these anchors represent the shortest 0.75-in. diameter screw-in anchors from Red Head and Simpson that can be safely substituted for the 0.75-in. diameter, Red Head drop-in anchor used in the steel strap tie-down system. Longer anchors with larger embedment depths would be acceptable as well.

SUMMARY AND CONCLUSIONS

Component testing was conducted on a series of concrete anchors with the goal of determining a safe, alternative screw-in anchor for use with the steel strap tie-down system for F-shape temporary concrete barriers. These component tests focused on determining the dynamic shear and tensile capacities of the 0.75-in. diameter, Red Head drop-in anchor used on the original tie-down design. Subsequent tests were conducted to evaluate the shear and tensile capacities of several screw-in type anchors to determine a safe alternative anchor. The screw-in anchor alternative was desired due to their ease of removal and low cost.

Results from the component testing found that two anchors were acceptable substitutes for the 0.75-in. diameter, Red Head drop-in anchor.

1. Red Head Large Diameter Tapcon (LDT) 0.75-in. diameter x 4.5-in. long
2. Simpson Titen HD 0.75-in. diameter x 5.0-in. long

The researchers recommend that only these two screw-in anchors be used as retrofits with the steel strap tie-down system at this time. It is possible that other, shorter length screw-in anchors, similar to those tested in this study, would function acceptably with the steel strap tie-down, but these anchors would have lower capacity than the original anchors used in the design. Thus, these lower capacity anchors would need to be tested with a full-scale vehicle crash test on a complete barrier system in order to evaluate their safety performance.

Please distribute this letter to the members of the Midwest Regional Pooled Fund Program. If you or any of the member states have any questions regarding this information, please feel free to contact me at your earliest convenience.

Respectfully,

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References

1. Bielenberg, B.W., Faller, R.K., Reid, J.D., Rohde, J.R., and Sicking, D.L., *Design and Testing of Tie-Down Systems for Temporary Barriers*, Paper No. 03-3146, Transportation Research Record No. 1851, Transportation Research Board, Washington D.C., November, 2003.

2. Bielenberg, B.W., Faller, R.K., Reid, J.D., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Development of a Tie-Down System for Temporary Concrete Barriers*, Final Report to the Midwest State's Regional Pooled Fund Program, Transportation Research Report No. TRP-03-115-02, Project No. SPR-3(017)-Year 9, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, August 16, 2002.

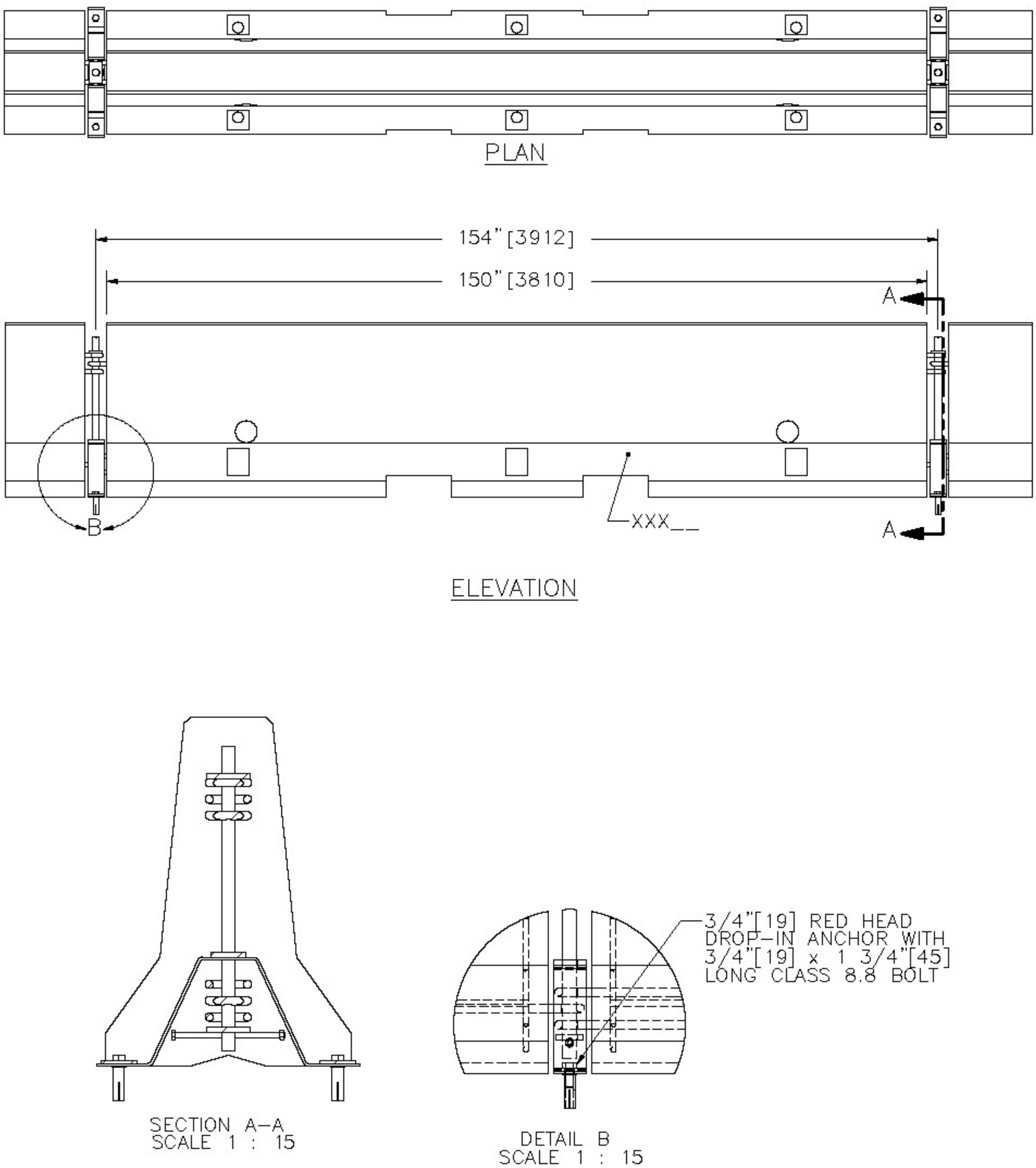


Figure 1. F-shape Steel Strap Tie-Down

Figure 2. Drop-In Anchor

Figure 3. Screw-In Anchor

Table 1. Review of Existing Anchor Designs

Manufacturer	Product Name	Embedment Depth (in.)	Ultimate Tension (lbs) f'c=4000 psi	Ultimate Tension (lbs) f'c=6000 psi	Ultimate Shear (lbs) f'c=4,000 psi	Ultimate Shear (lbs) f'c=6,000 psi	Anchor Material
Powers Fasteners	Wedge Bolt 3/4"	3.000	6480.0	8700.0	15340.0	18780.0	Zinc Plated Carbon Steel or Stainless Steel
		3.500	9320.0	11360.0	18780.0	20800.0	
		4.000	12140.0	14020.0	22200.0	22820.0	
		4.500	13580.0	16720.0	23320.0	23800.0	
		5.000	15020.0	19400.0	24440.0	24760.0	
		5.500	16460.0	22080.0	25560.0	25720.0	
		6.000	17900.0	24760.0	26680.0	26680.0	
Simpson	Titen HD 3/4"	2.750	6580.0	NA	11460.0	NA	Carbon Steel, Heat Treated
		4.625	17426.0	NA	24680.0	NA	
		5.750	18680.0	NA	24680.0	NA	
Red Head	Large Diameter Tapcon 3/4"	3.250	12636.0	NA	14316.0	NA	Hardened Carbon Steel and Zinc Plated
		4.500	18540.0	NA	20612.0	NA	
		5.500	23268.0	NA	25652.0	NA	

= Tensile Capacity > 17,400 lbs

= Shear Capcity > 14,000 lbs

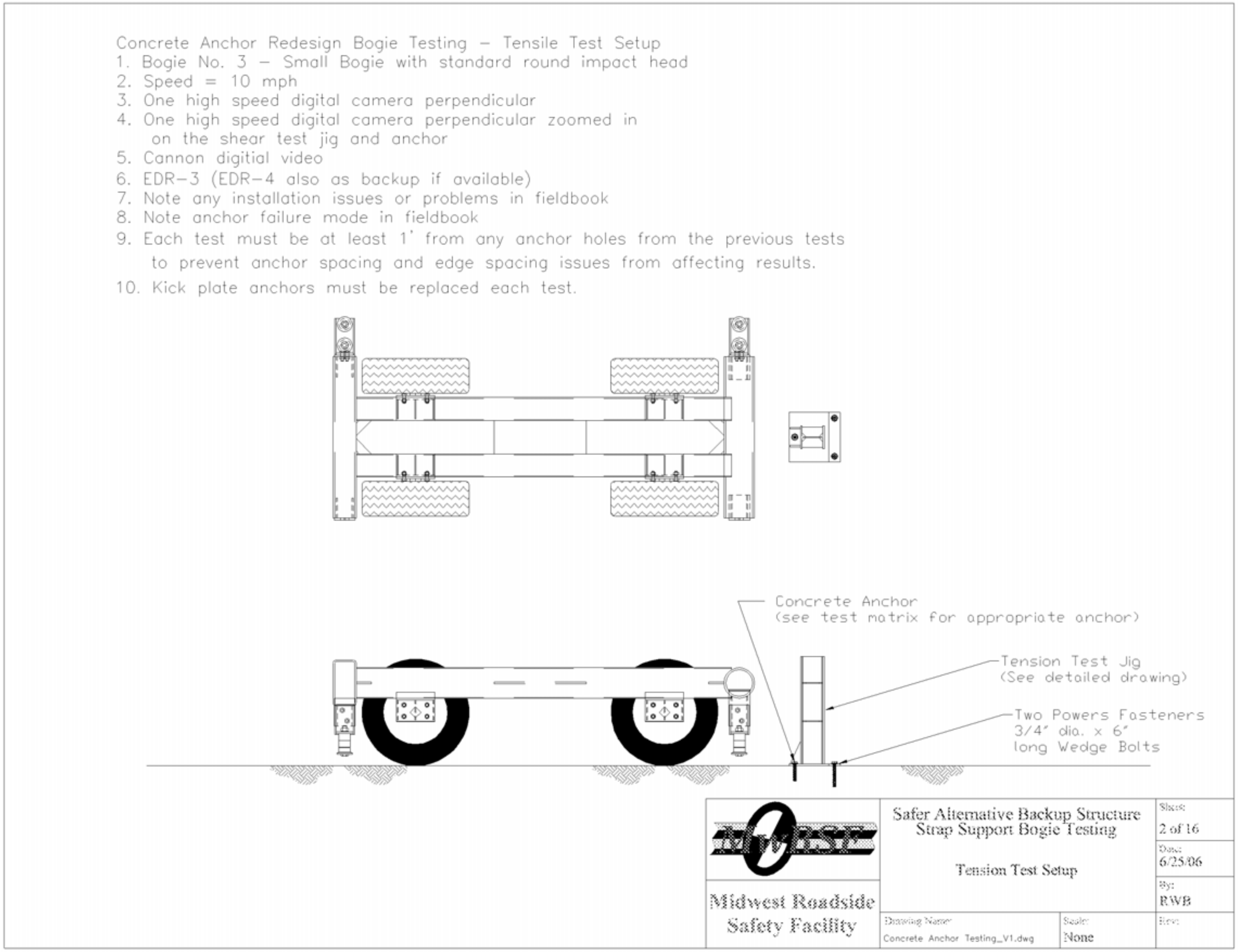


Figure 4. Tensile Test Setup Details

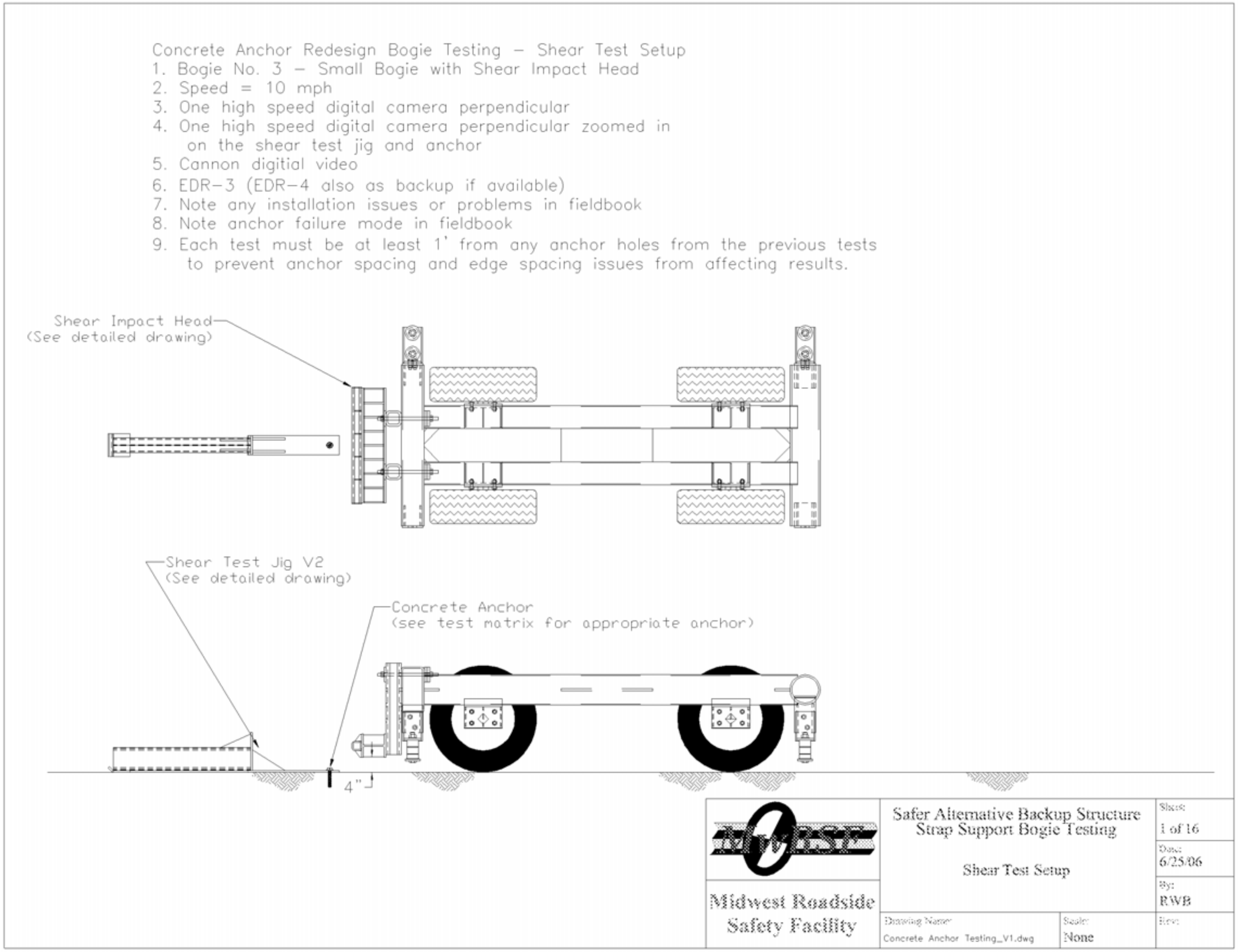


Figure 5. Shear Test Setup Details

Figure 6. Component Test Setup Photos

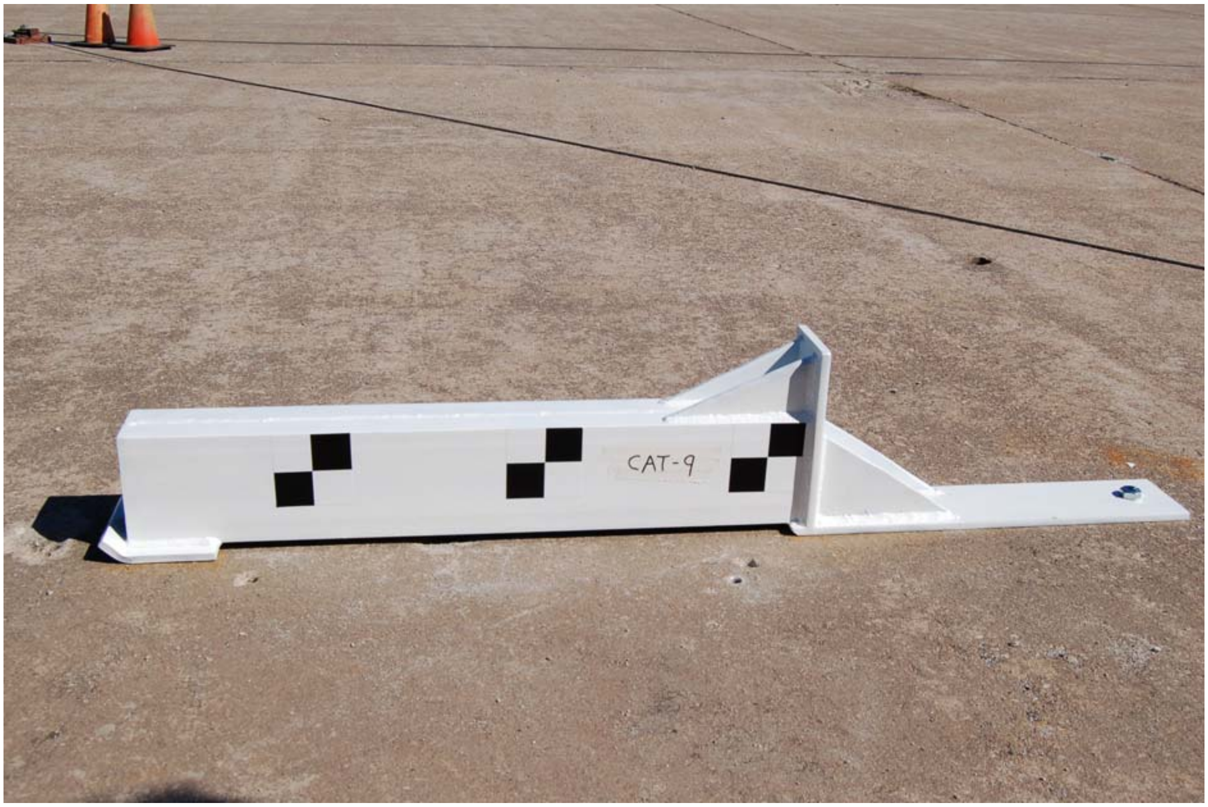


Figure 7. Component Test Setup Photos

Table 2. Anchor Testing Results

Test No.	Test Type	Anchor Type	Manufacturer Part No.	Speed	Peak Load (lbs)	Test Notes	
CAT-1	Shear	3/4" RedHead Multi-Set II Drop-In Anchor with 3/4" dia. x 1.75" long Grade 5 bolt	RM-34	10 mph	NA	Shear test Jig bent causing anchor pullout. Test jig was revised	
CAT-2	Tension	3/4" RedHead Multi-Set II Drop-In Anchor with 3/4" dia. x 1.75" long Grade 5 bolt	RM-34	10 mph	18,907.46	Anchor pulled out.	Average Load = 18,724.32
CAT-3	Tension	3/4" RedHead Multi-Set II Drop-In Anchor with 3/4" dia. x 1.75" long Grade 5 bolt	RM-34	10 mph	18,541.17	Anchor pulled out.	
CAT-4	Tension	Powers Fasteners 3/4" dia. x 4" long Wedge Bolt	07282	10 mph	22,368.59	Anchor pulled out.	
CAT-5	Tension	Powers Fasteners 3/4" dia. x 5" long Wedge Bolt	07284	10 mph	22,653.68	Anchor pulled out.	
CAT-6	Tension	Simpson Titen HD 3/4" dia. x 5" long Wedge Bolt	THD75500H	10 mph	22,403.60	Anchor pulled out.	
CAT-7	Tension	Simpson Titen HD 3/4" dia. x 5" long Wedge Bolt	THD75500H	10 mph	25,451.95	Anchor pulled out.	
CAT-8	Tension	RedHead 3/4" dia. x 5.5" long Large Diameter Tapcon (LDT)	LDT-3454	10 mph	19,550.42	Anchor pulled out.	
CAT-9	Shear	3/4" RedHead Multi-Set II Drop-In Anchor with 3/4" dia. x 1.75" long Grade 5 bolt	RM-34	10 mph	23,943.33	Peak load = 23.9 kips Bolt sheared off at ground line.	Average Load = 25,570.54
CAT-10	Shear	3/4" RedHead Multi-Set II Drop-In Anchor with 3/4" dia. x 1.75" long Grade 5 bolt	RM-34	10 mph	27,197.74	Peak load = 27.2 kips Drop-in fractured and broke below the ground line	
CAT-11	Tension	Simpson Titen HD 3/4" dia. x 4" long Wedge Bolt	THD75400H	10 mph	18,116.36	Anchor pulled out.	
CAT-12	Tension	RedHead 3/4" dia. x 4.5" long Large Diameter Tapcon (LDT)	LDT-3444	10 mph	19,516.12	Anchor pulled out.	
CAT-13	Tension	Simpson Titen HD 3/4" dia. x 4" long Wedge Bolt	THD75400H	10 mph	21,441.89	Anchor pulled out.	
CAT-14	Tension	Powers Fasteners 3/4" dia. x 3" long Wedge Bolt	7280	10 mph	19,035.72	Anchor pulled out.	
CAT-15	Shear	Powers Fasteners 3/4" dia. x 3" long Wedge Bolt	7280	10 mph	20,981.53	Anchor yielded and pulled out.	
CAT-16	Shear	Powers Fasteners 3/4" dia. x 4" long Wedge Bolt	07282	10 mph	16,582.47	Anchor pulled out and fractured	
CAT-17	Shear	RedHead 3/4" dia. x 4.5" long Large Diameter Tapcon (LDT)	LDT-3444	10 mph	25,950.08	Anchor sheared and fractured at groundline	
CAT-18	Shear	Simpson Titen HD 3/4" dia. x 4" long Wedge Bolt	THD75400H	10 mph	21,594.94	Anchor yielded and pulled out.	
CAT-19	Shear	Simpson Titen HD 3/4" dia. x 5" long Wedge Bolt	THD75500H	10 mph	34,276.73	Anchor sheared and fractured at groundline	
CAT-20	Shear	Powers Fasteners 3/4" dia. x 5" long Wedge Bolt	07284	10 mph	18,910.35	Anchor fractured below ground line	

= Baseline Drop-In Anchor Tests

= Meets Baseline Shear Capacity

= Meets Baseline Tensile Capacity

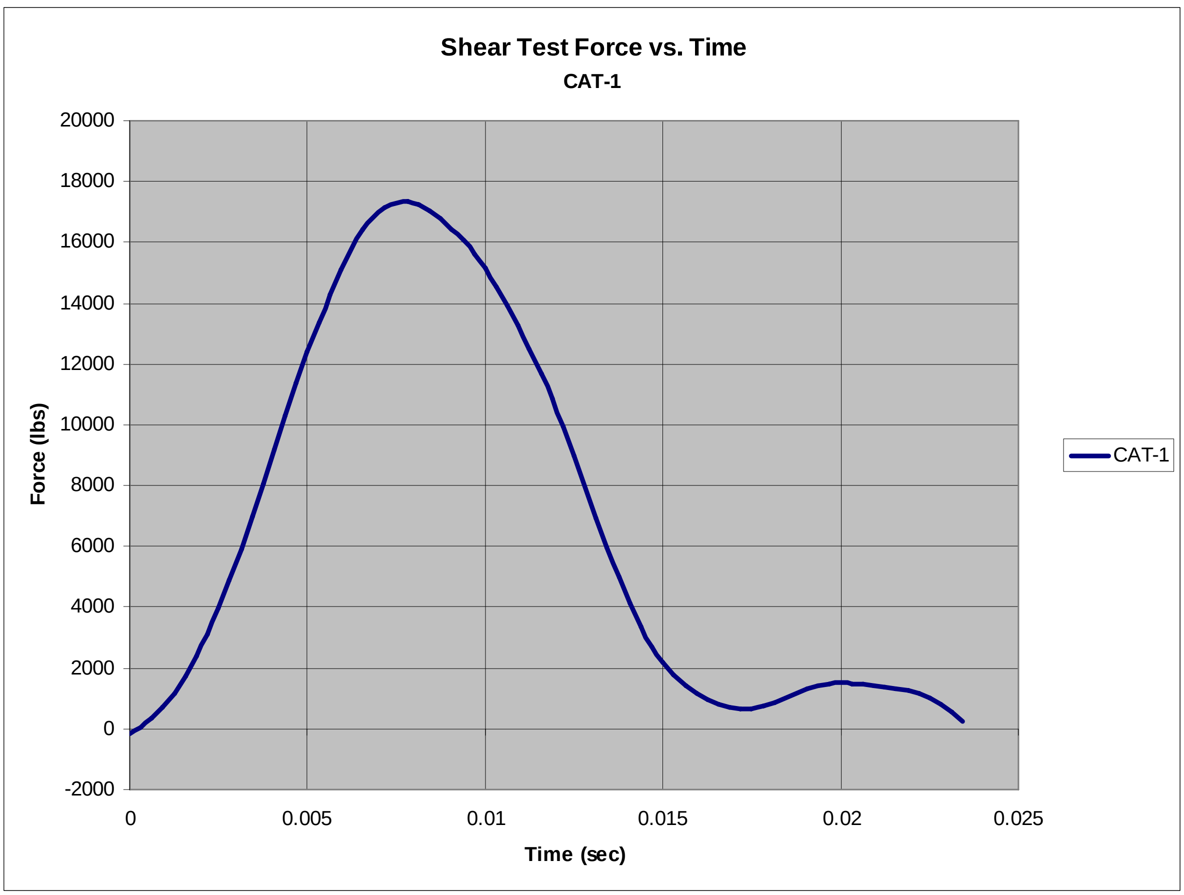
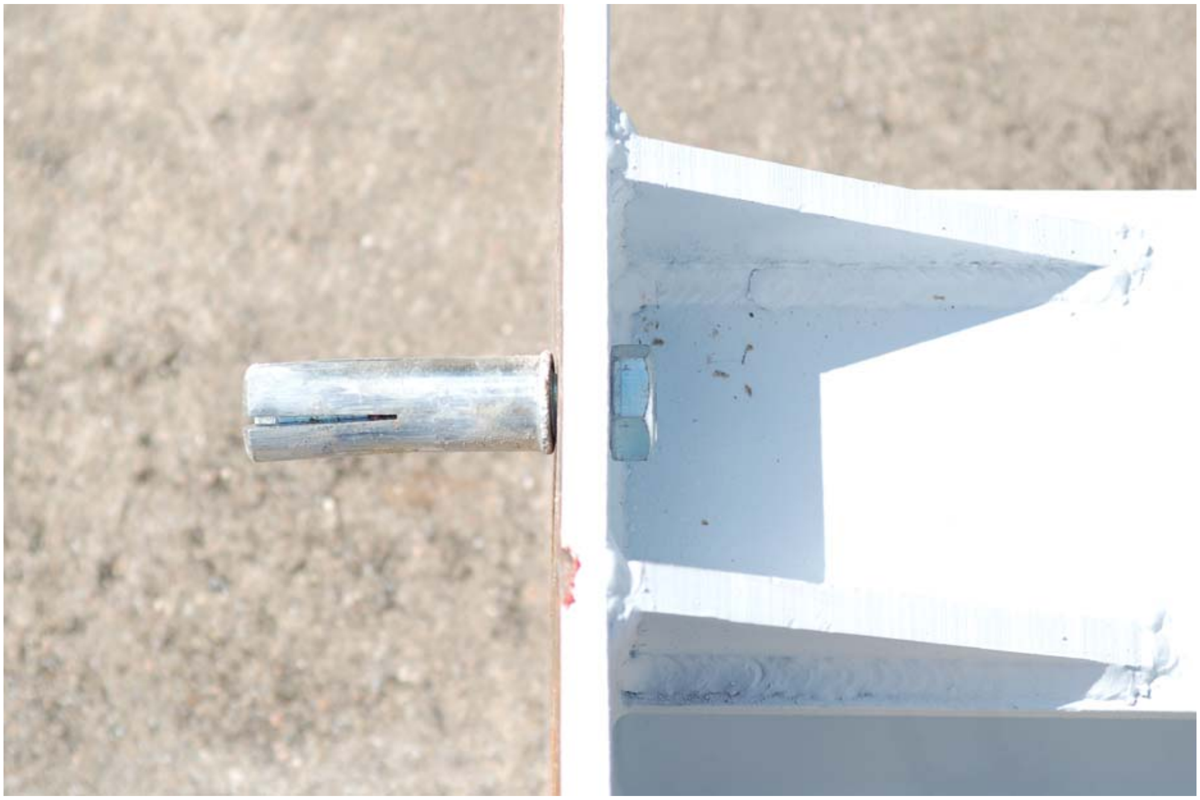


Figure 8. Component Test Results, CAT-1



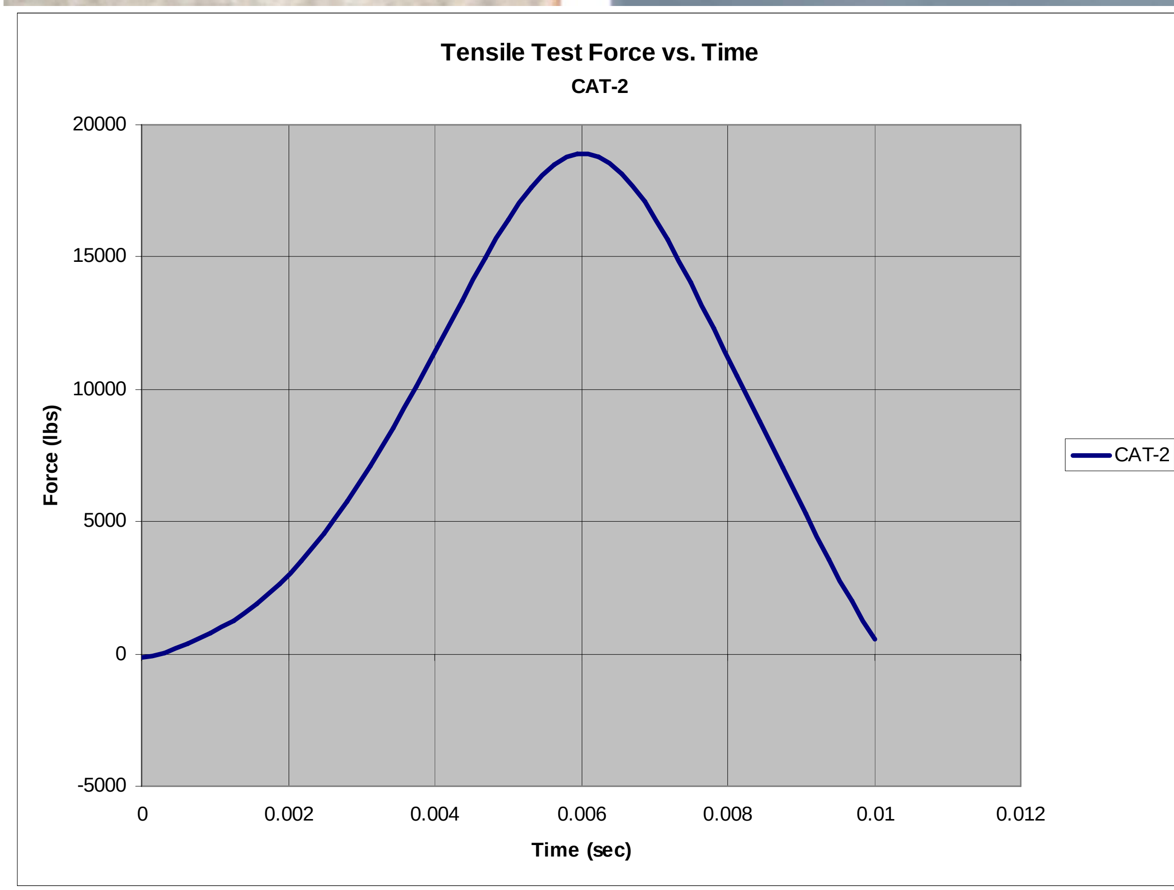
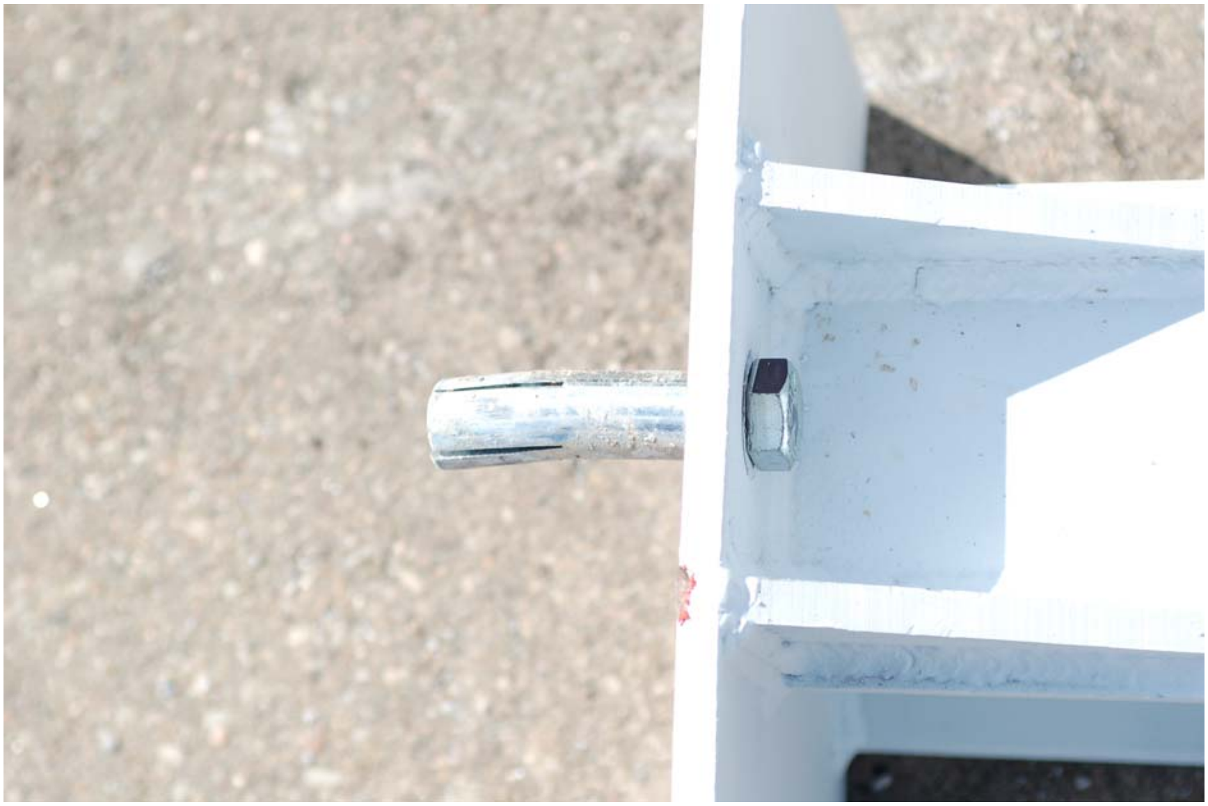


Figure 9. Component Test Results, CAT-2



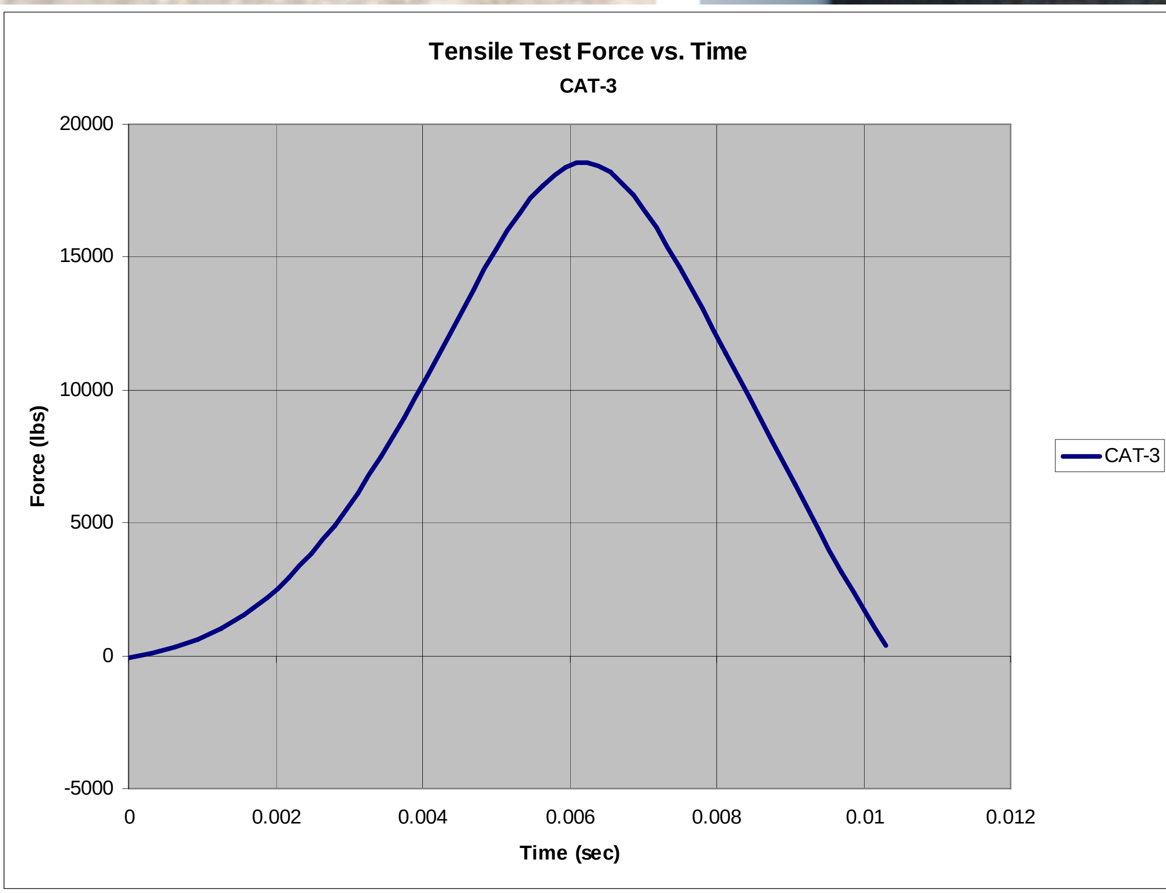
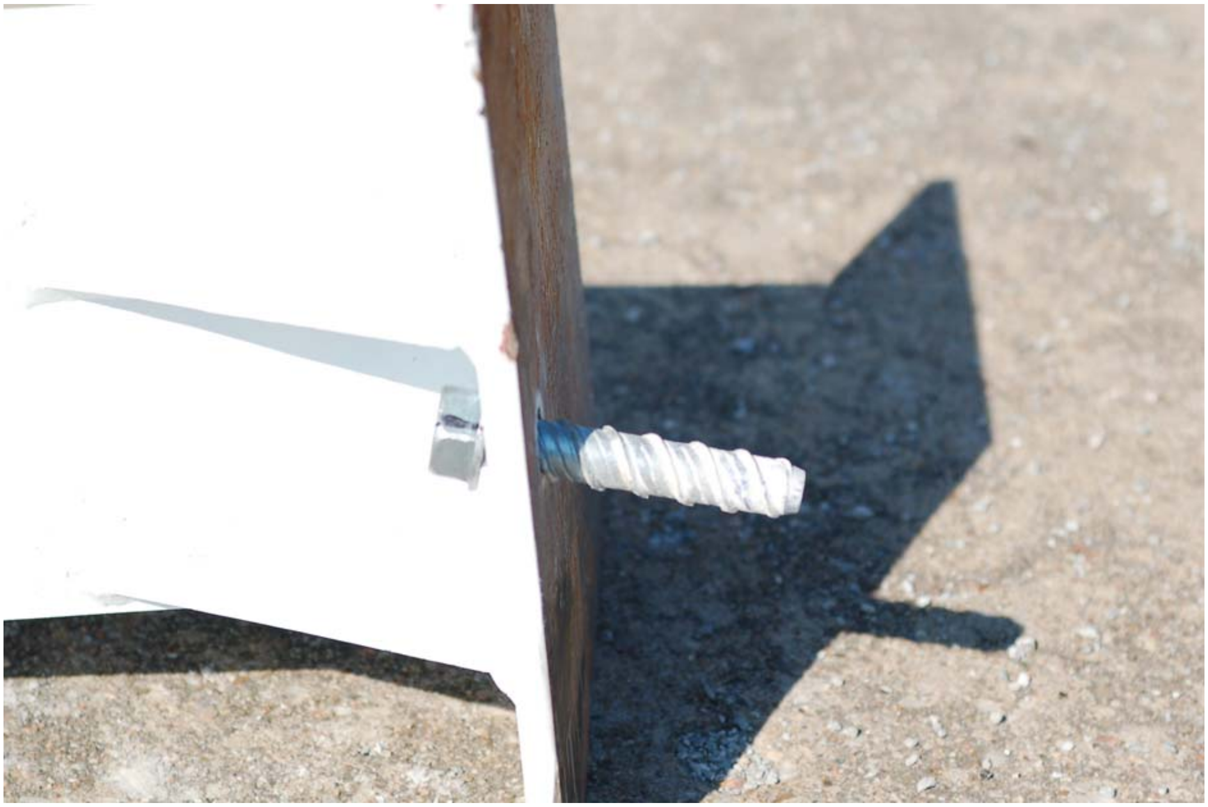


Figure 10. Component Test Results, CAT-3



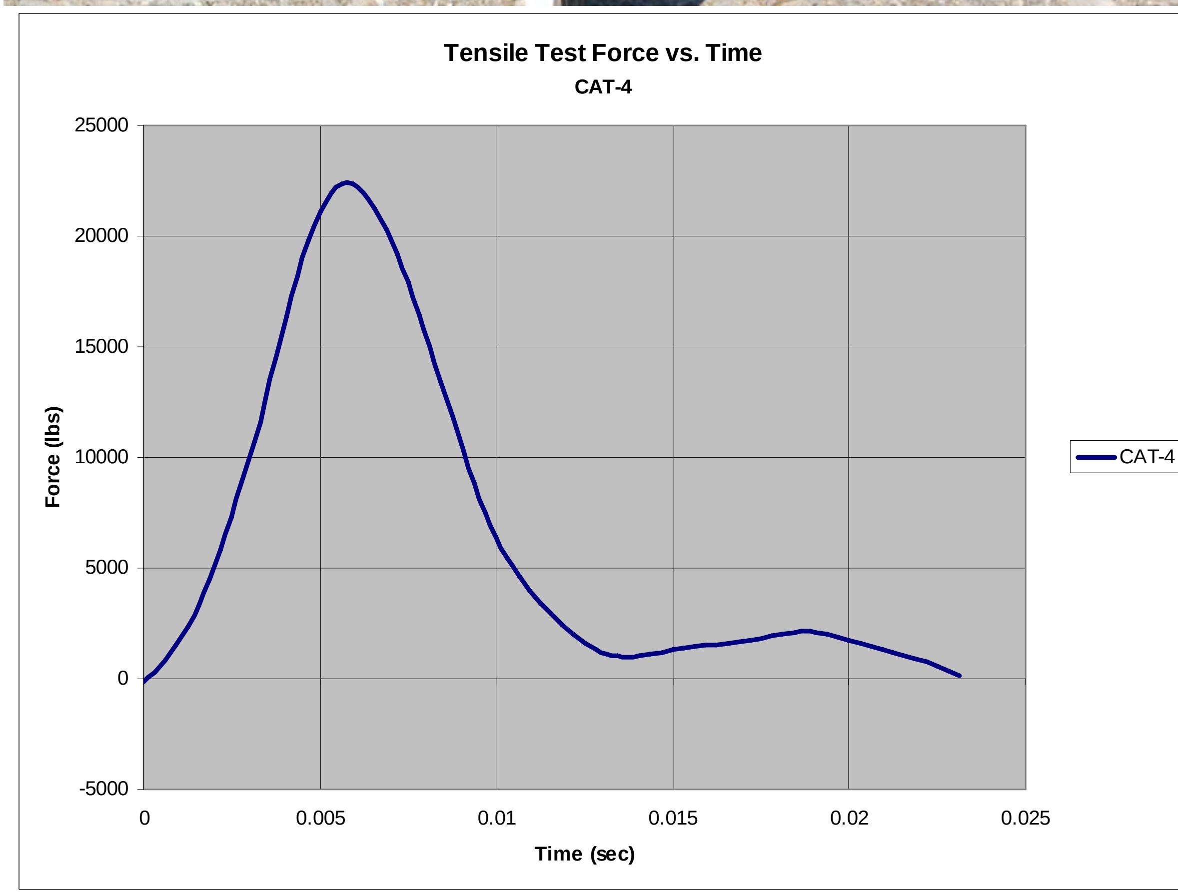


Figure 11. Component Test Results, CAT-4

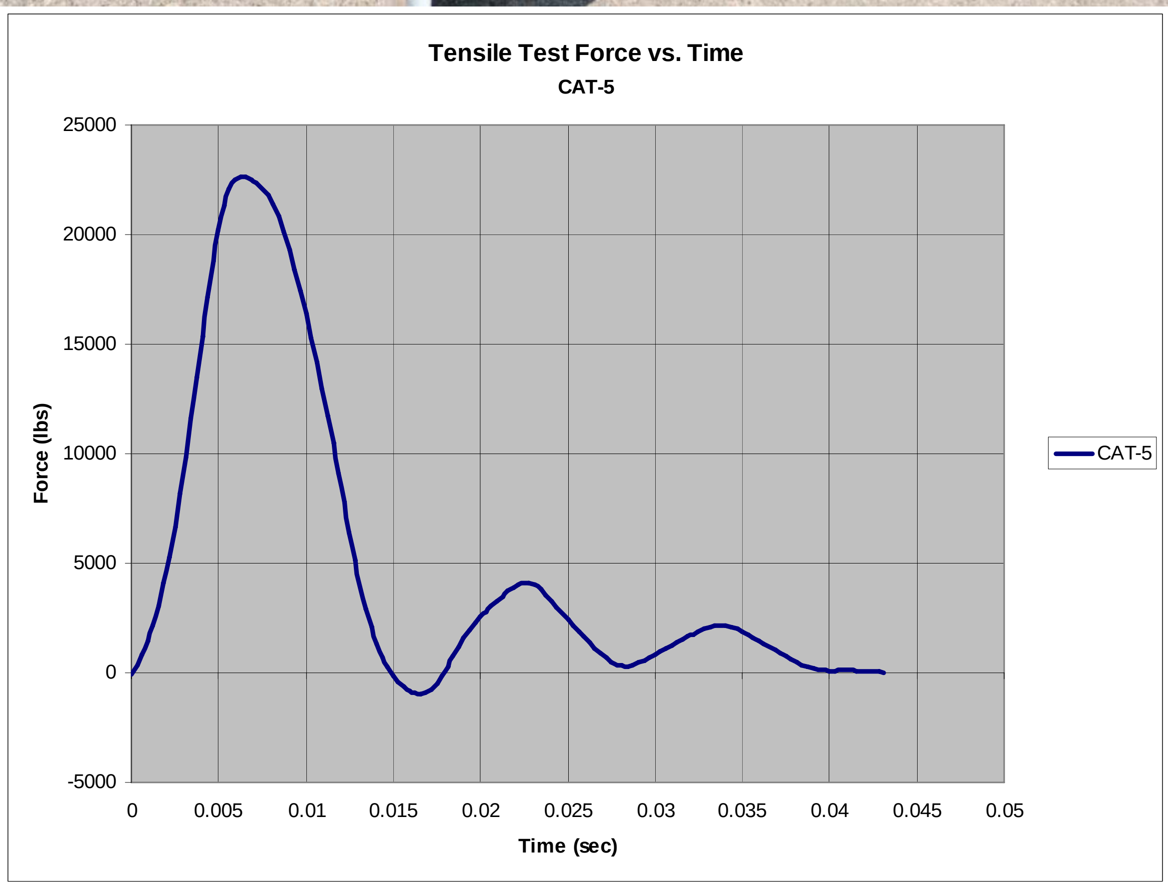
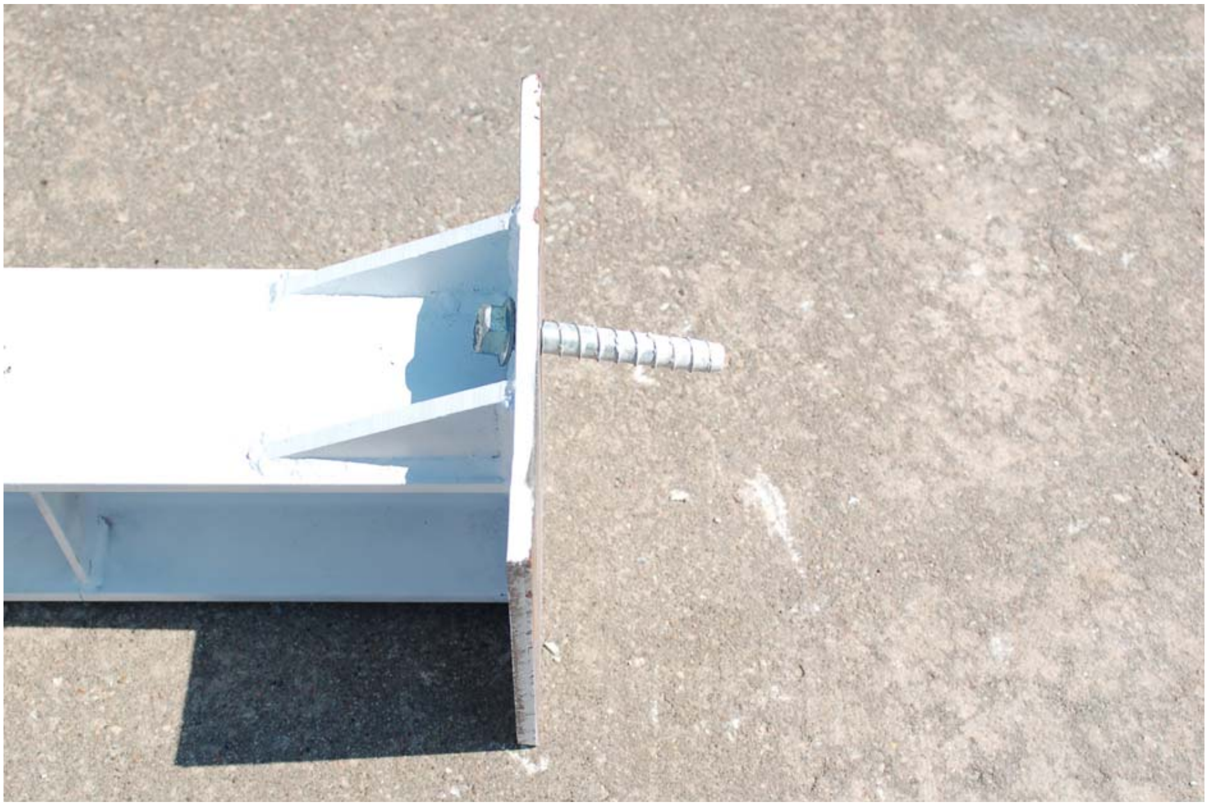


Figure 12. Component Test Results, CAT-5



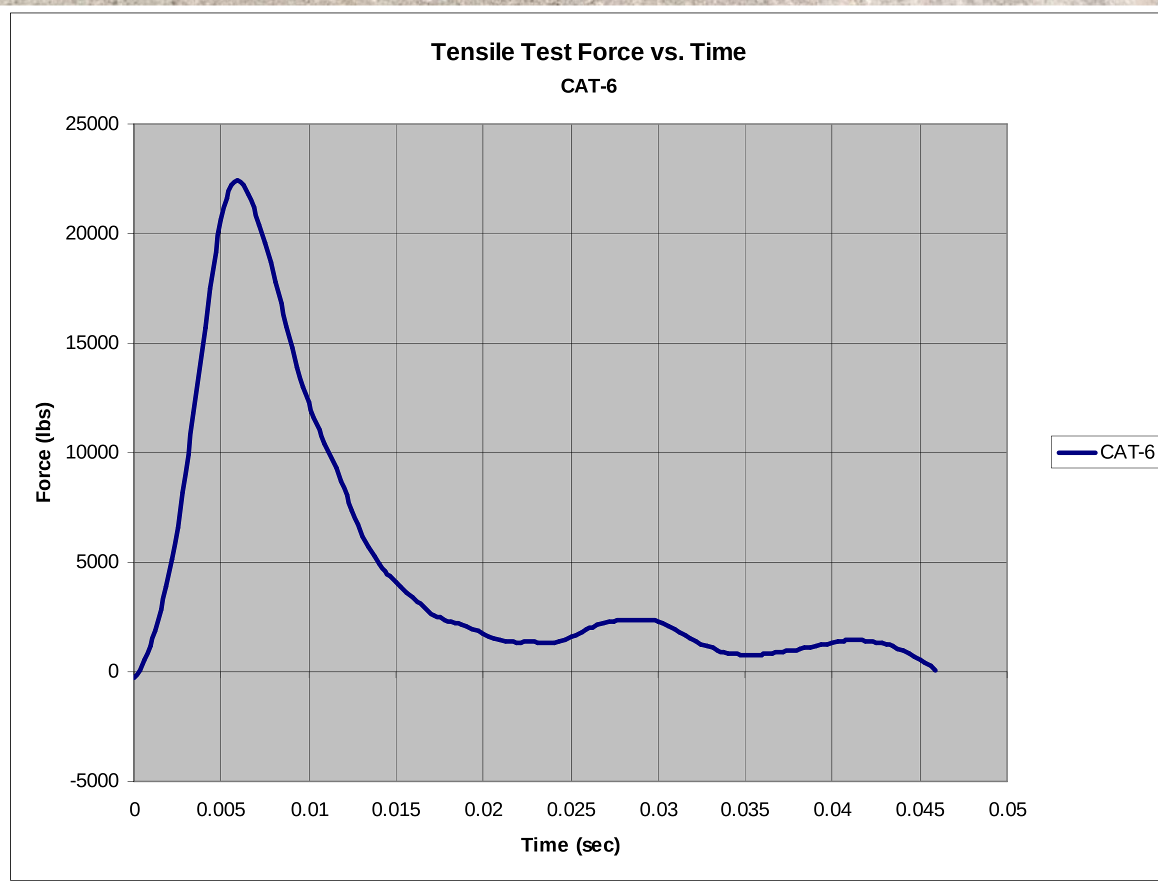
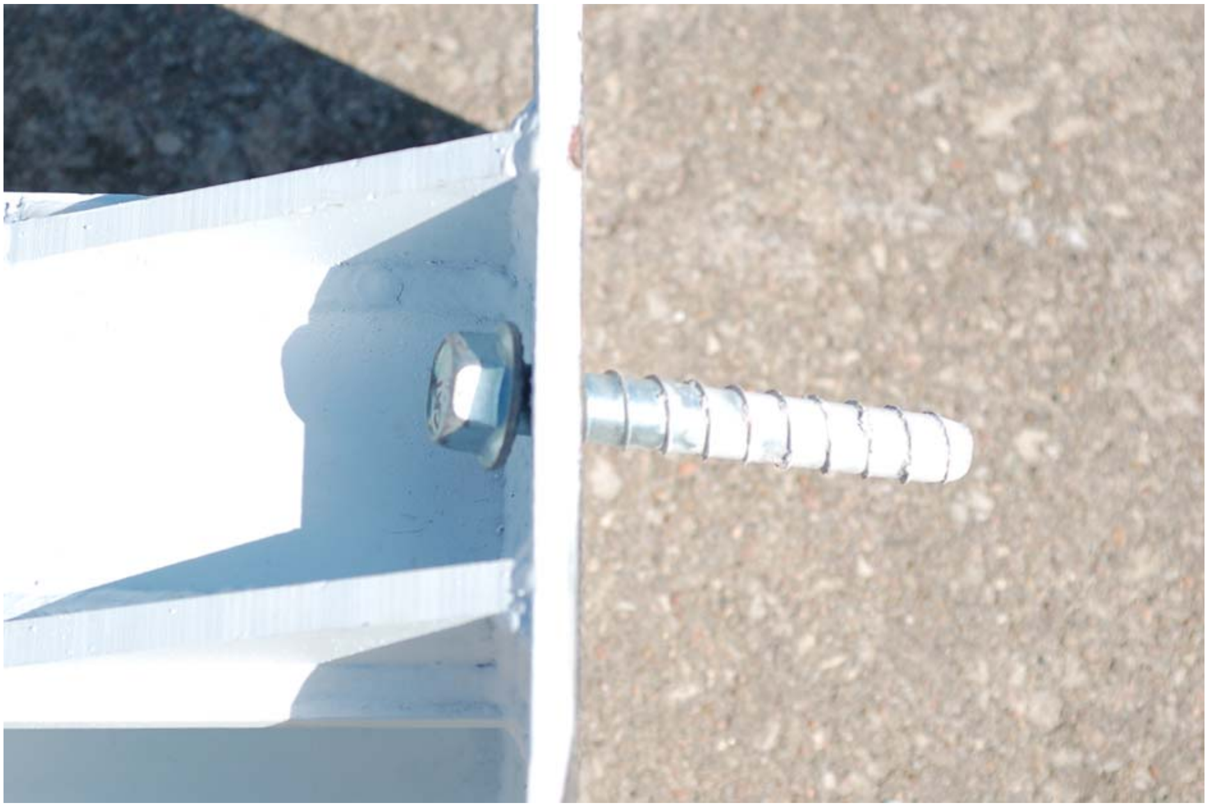


Figure 13. Component Test Results, CAT-6



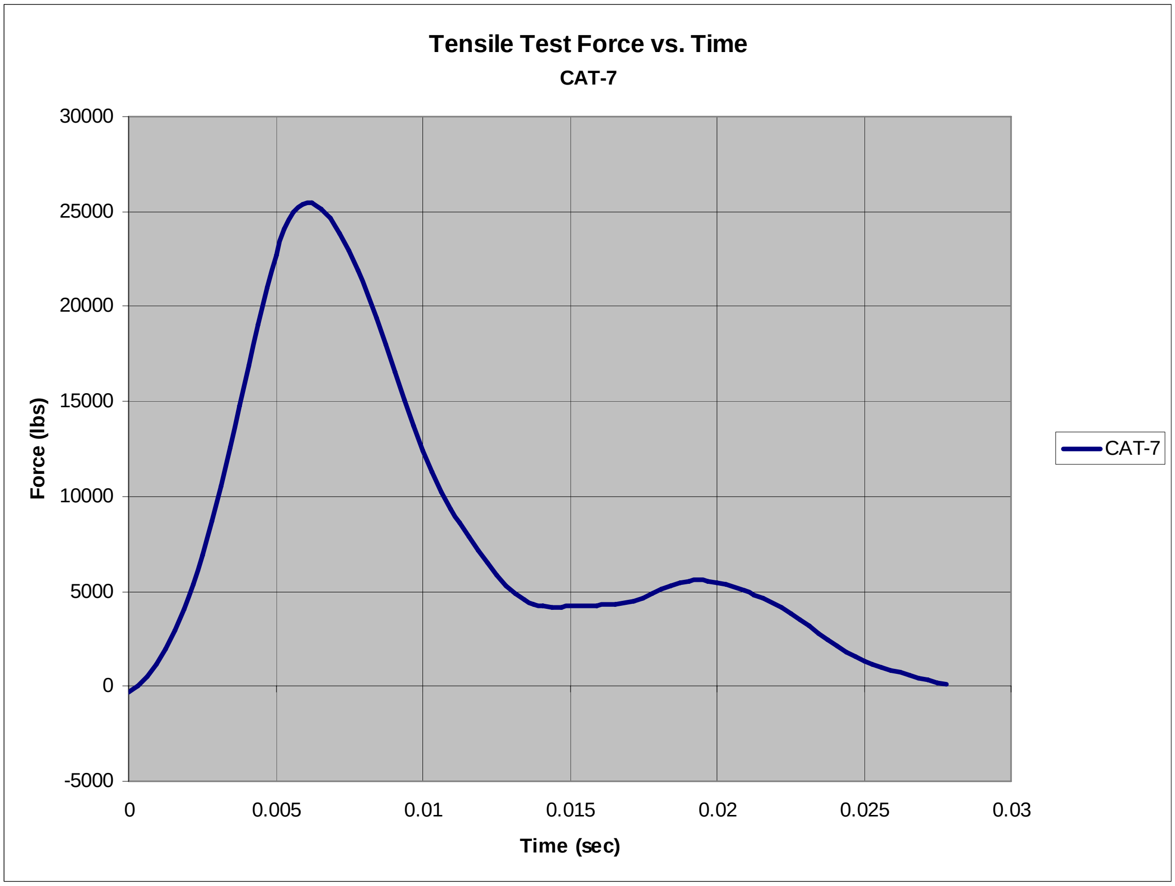
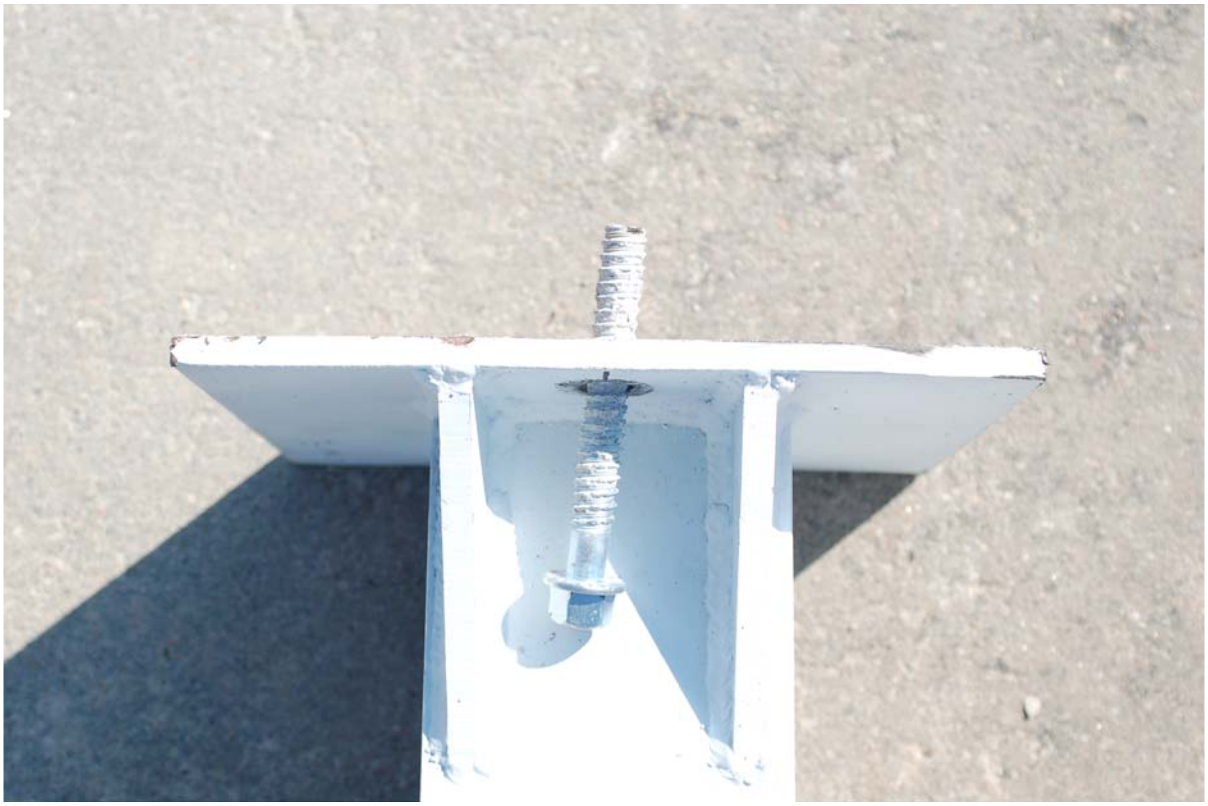


Figure 14. Component Test Results, CAT-7



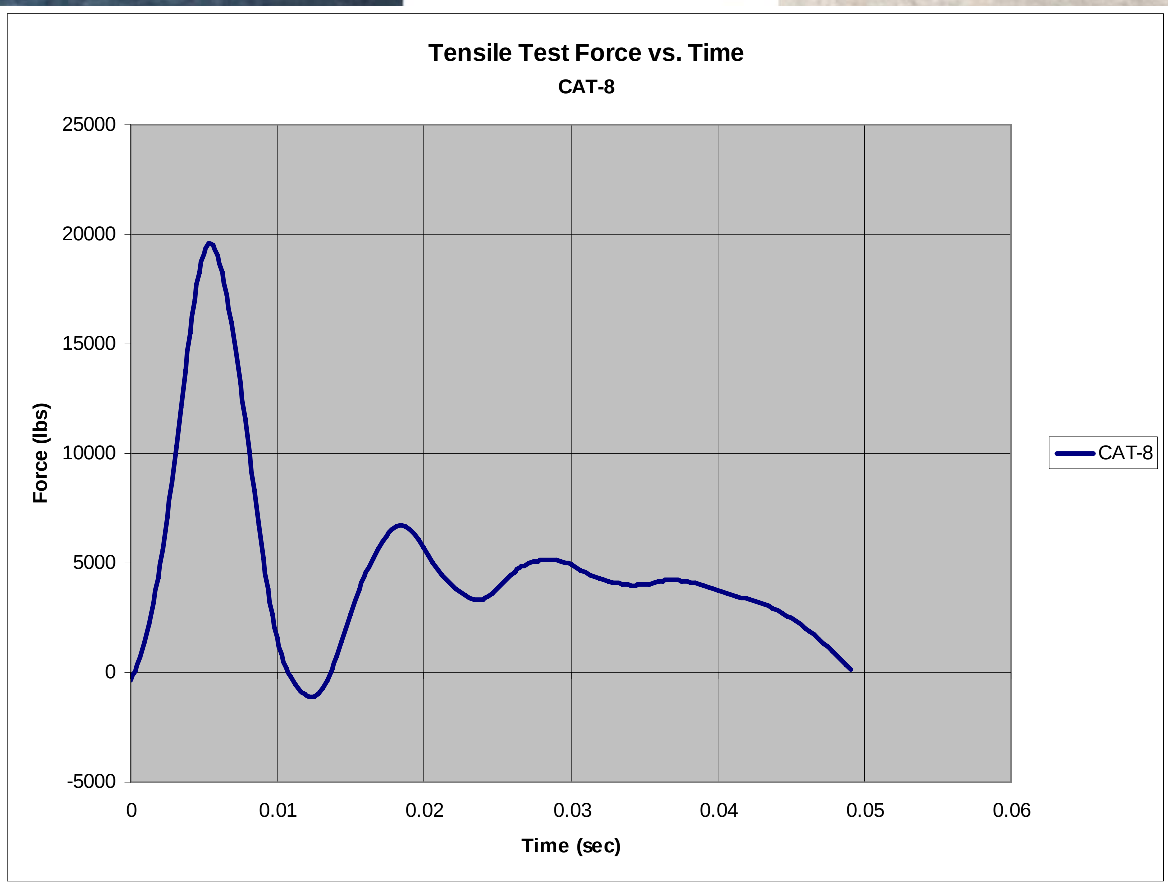


Figure 15. Component Test Results, CAT-8

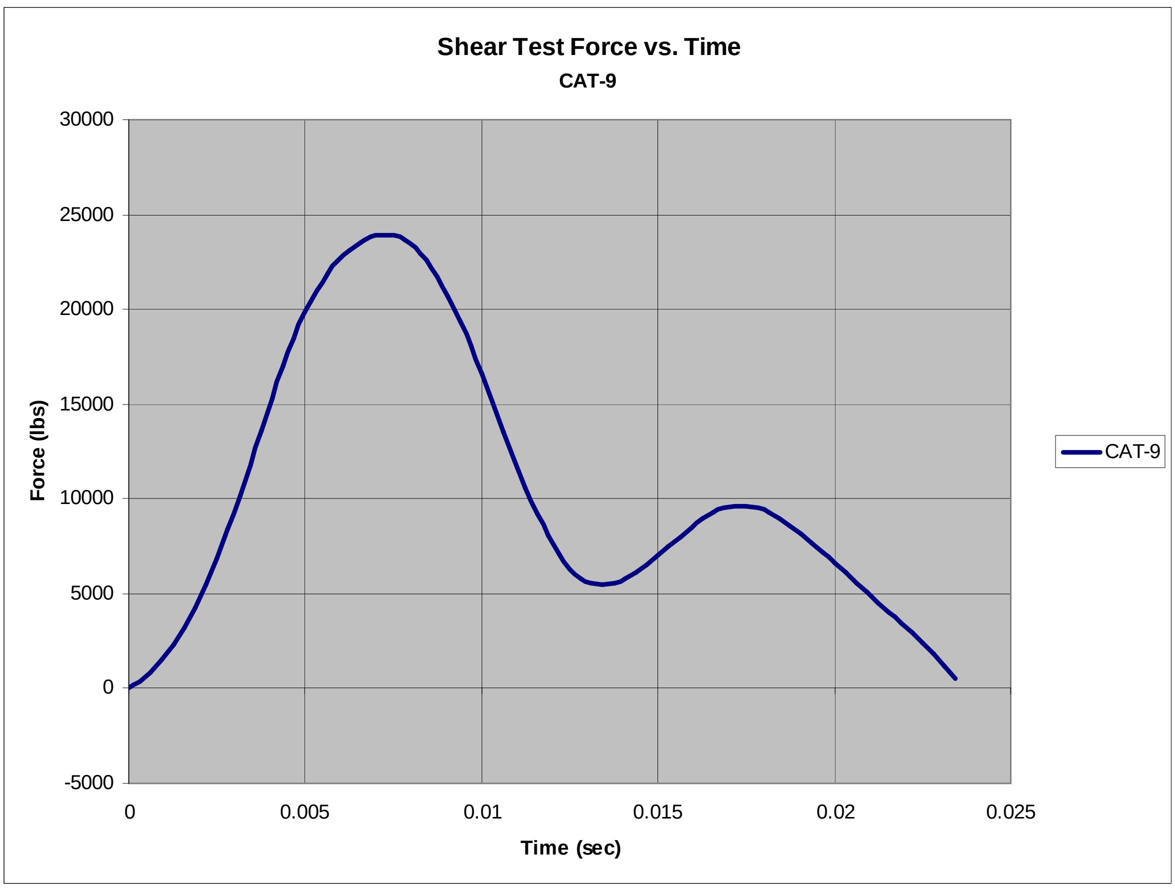


Figure 16. Component Test Results, CAT-9

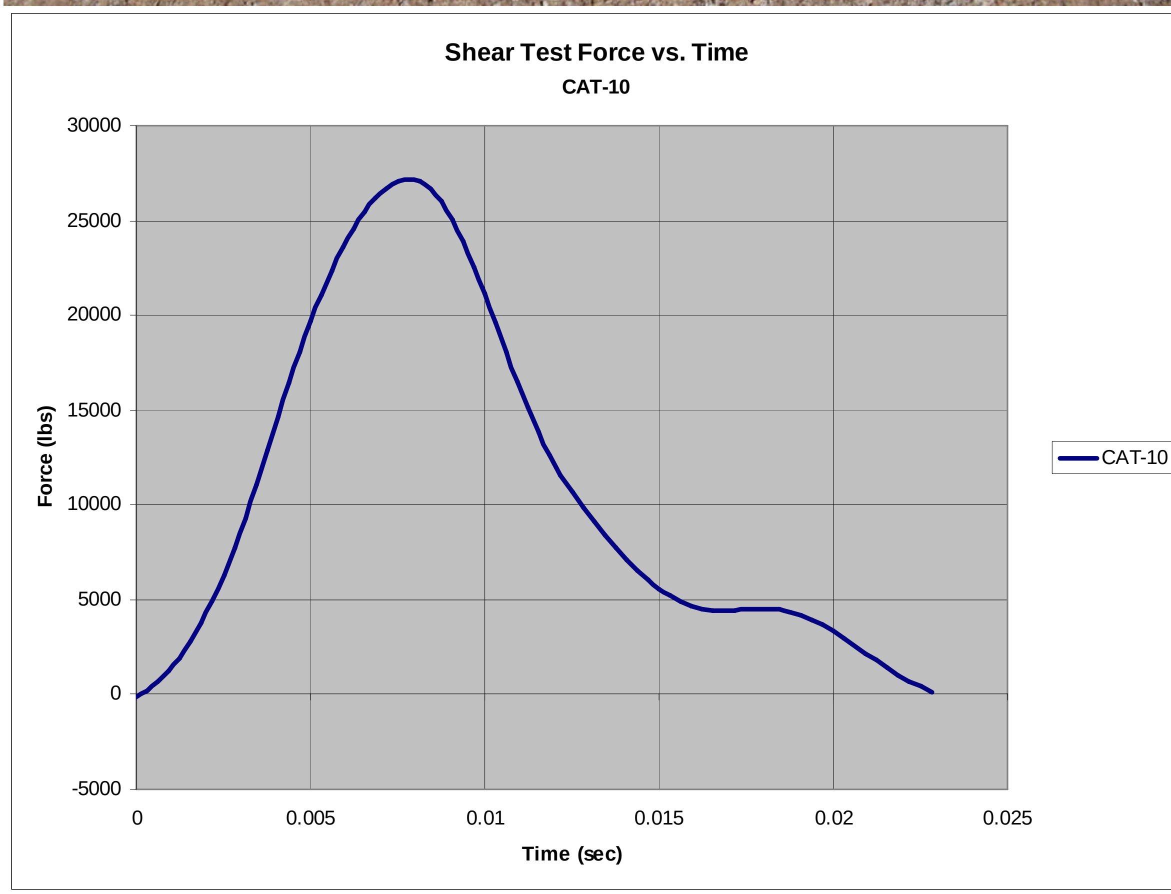


Figure 17. Component Test Results, CAT-10

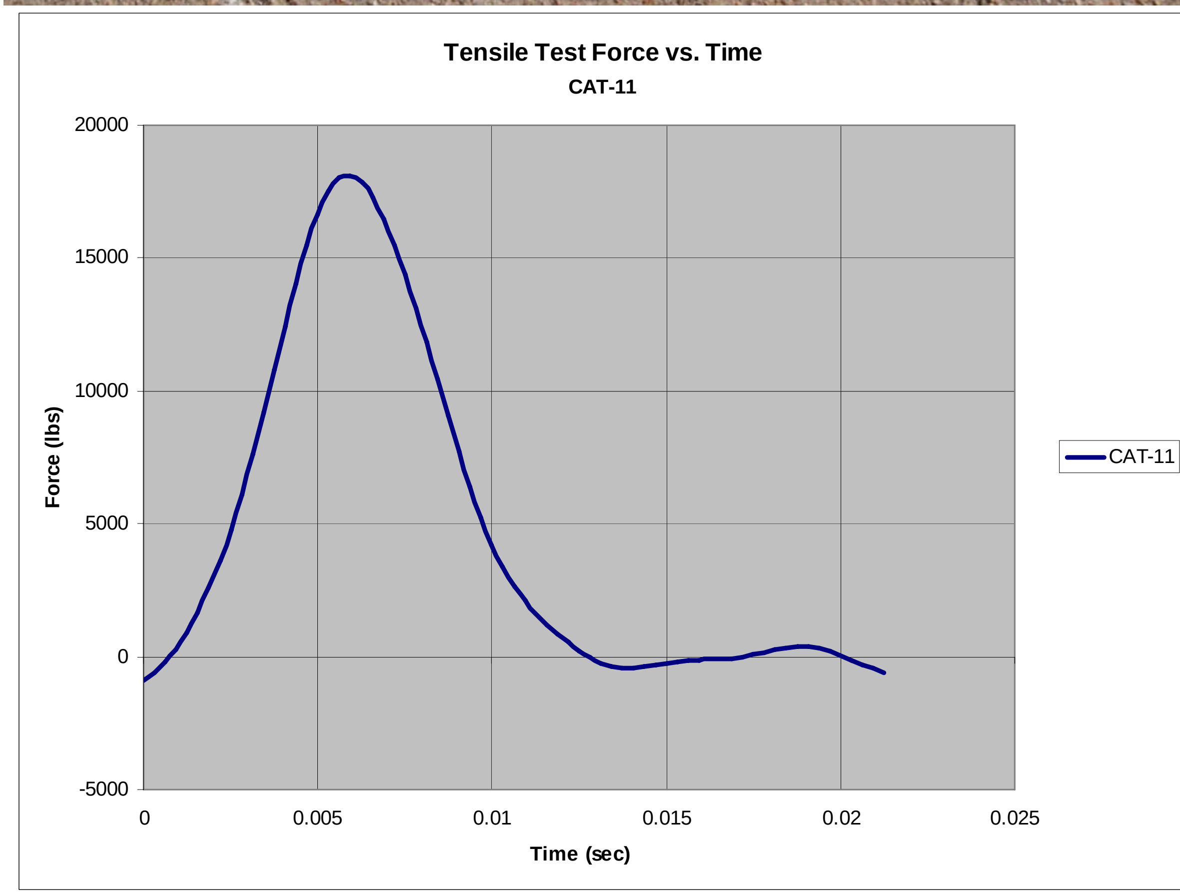


Figure 18. Component Test Results, CAT-11

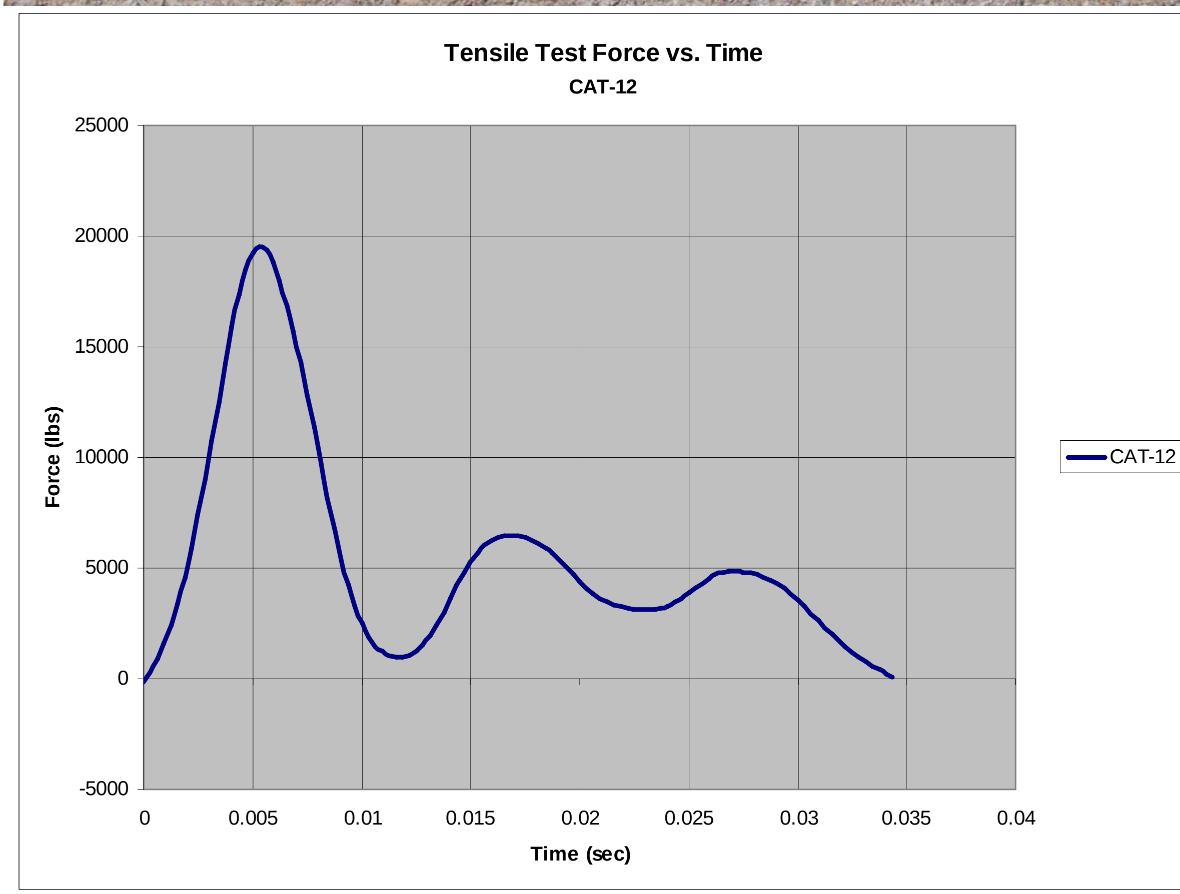


Figure 19. Component Test Results, CAT-12

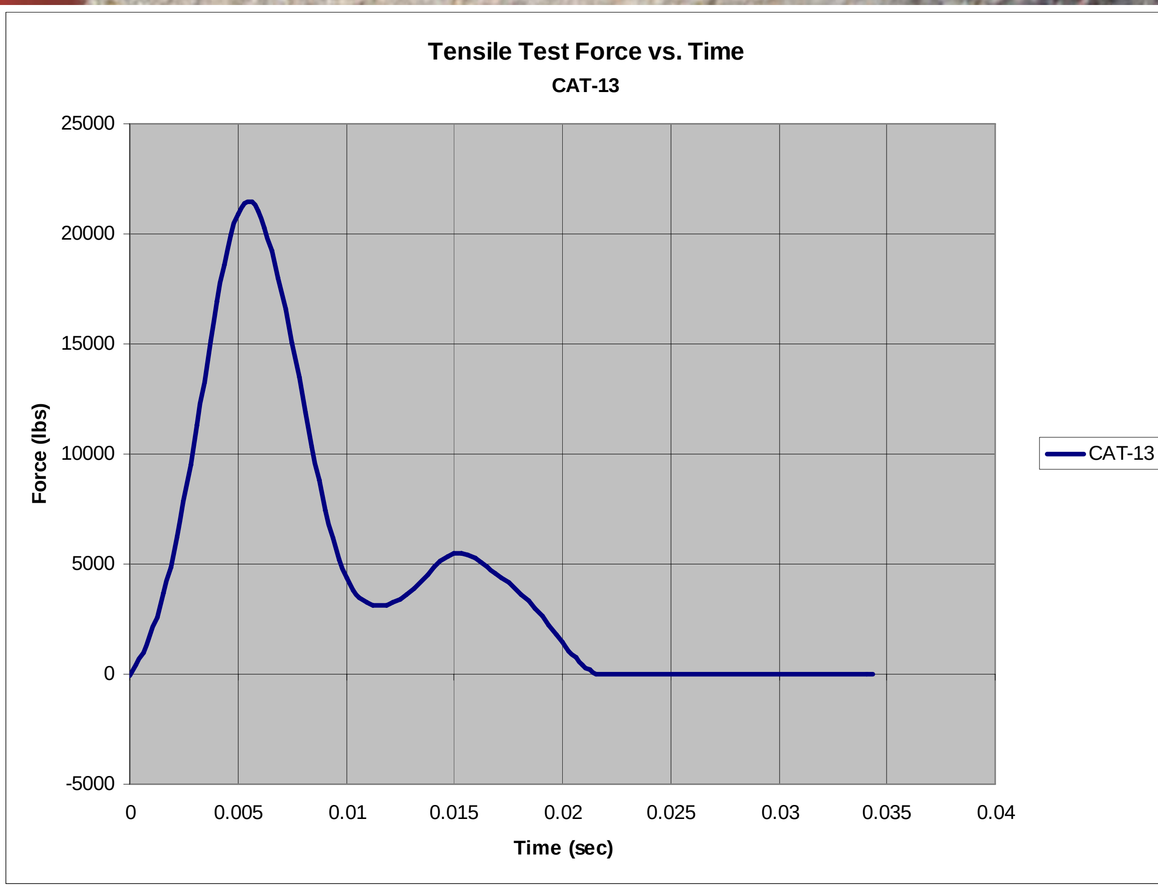


Figure 20. Component Test Results, CAT-13

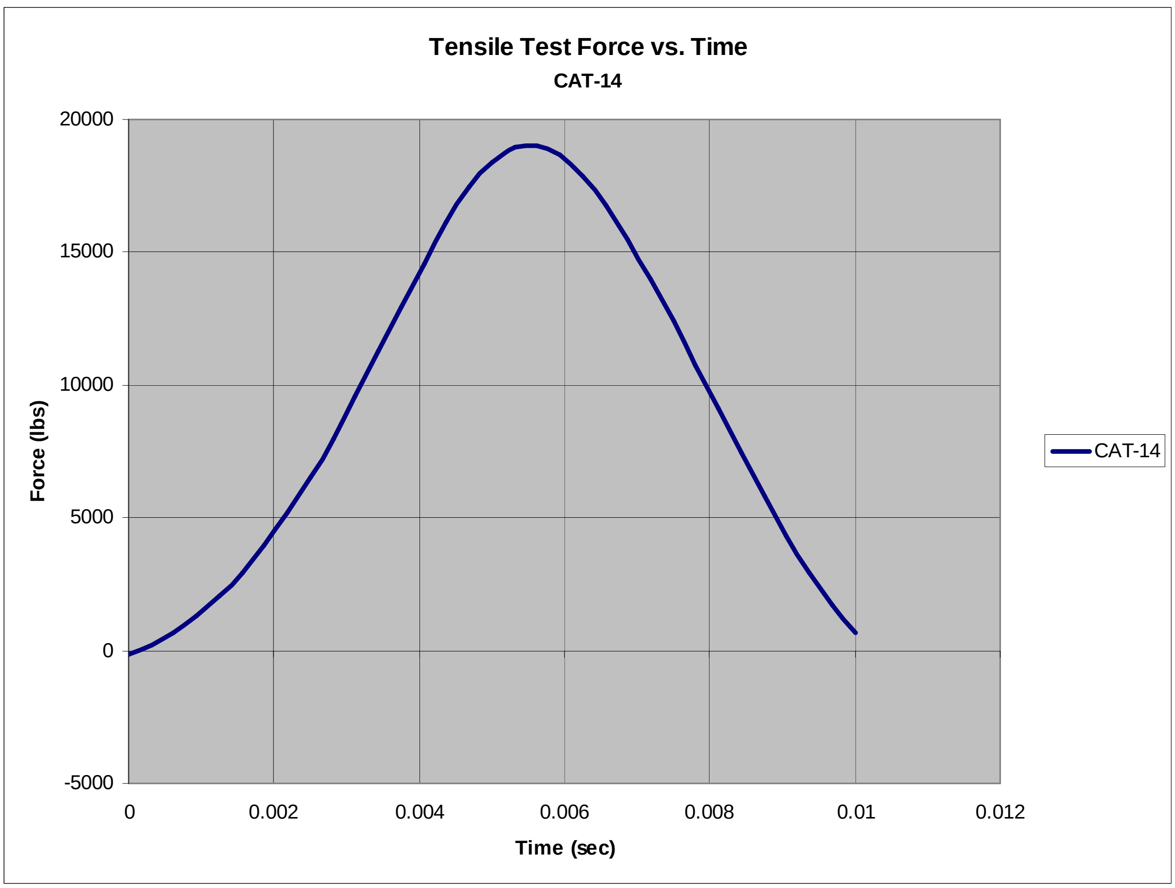


Figure 21. Component Test Results, CAT-14

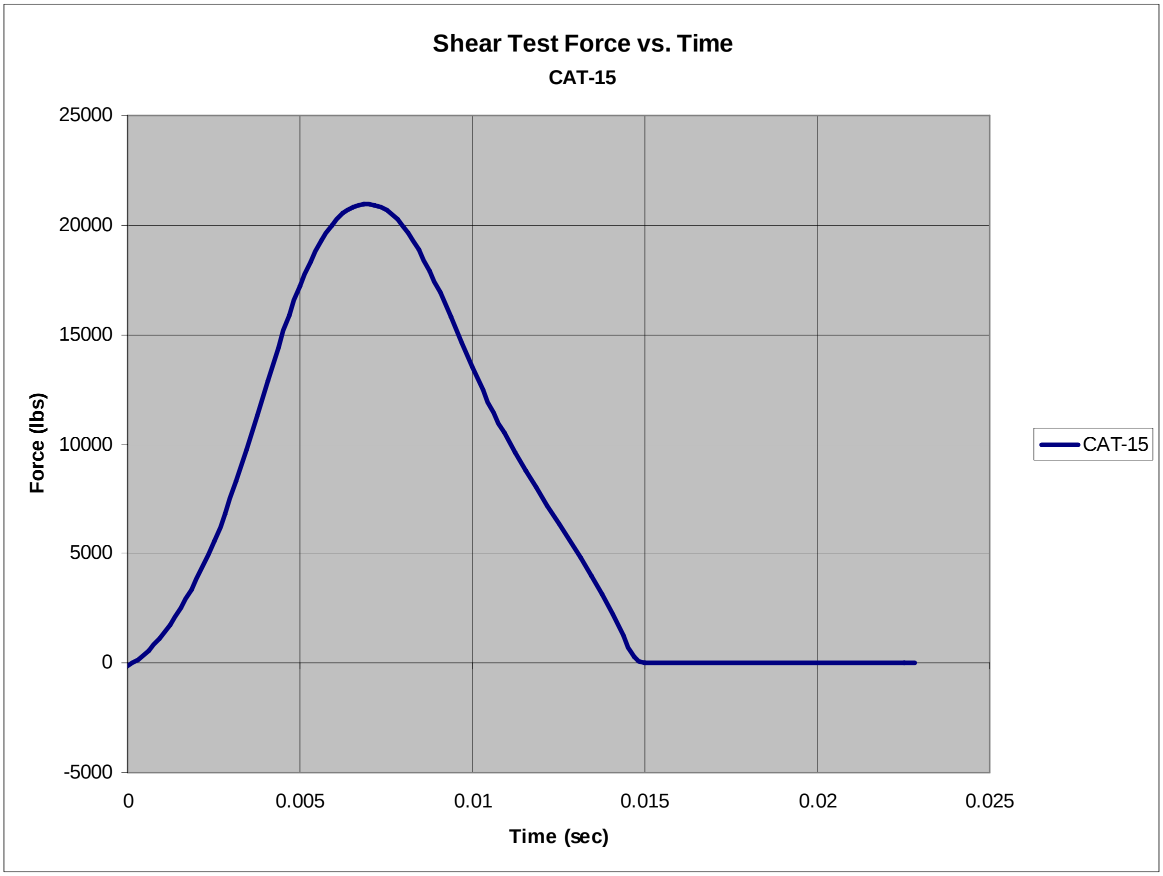


Figure 22. Component Test Results, CAT-15

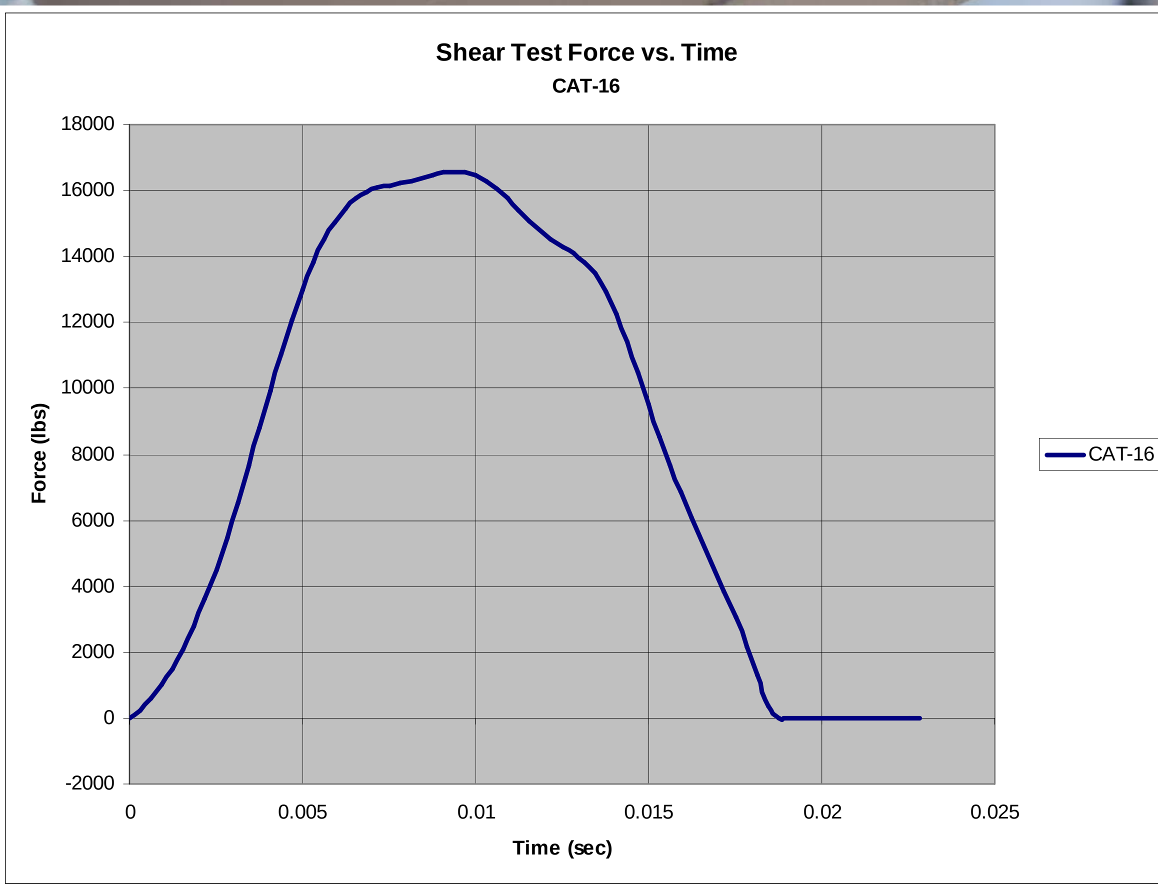


Figure 23. Component Test Results, CAT-16

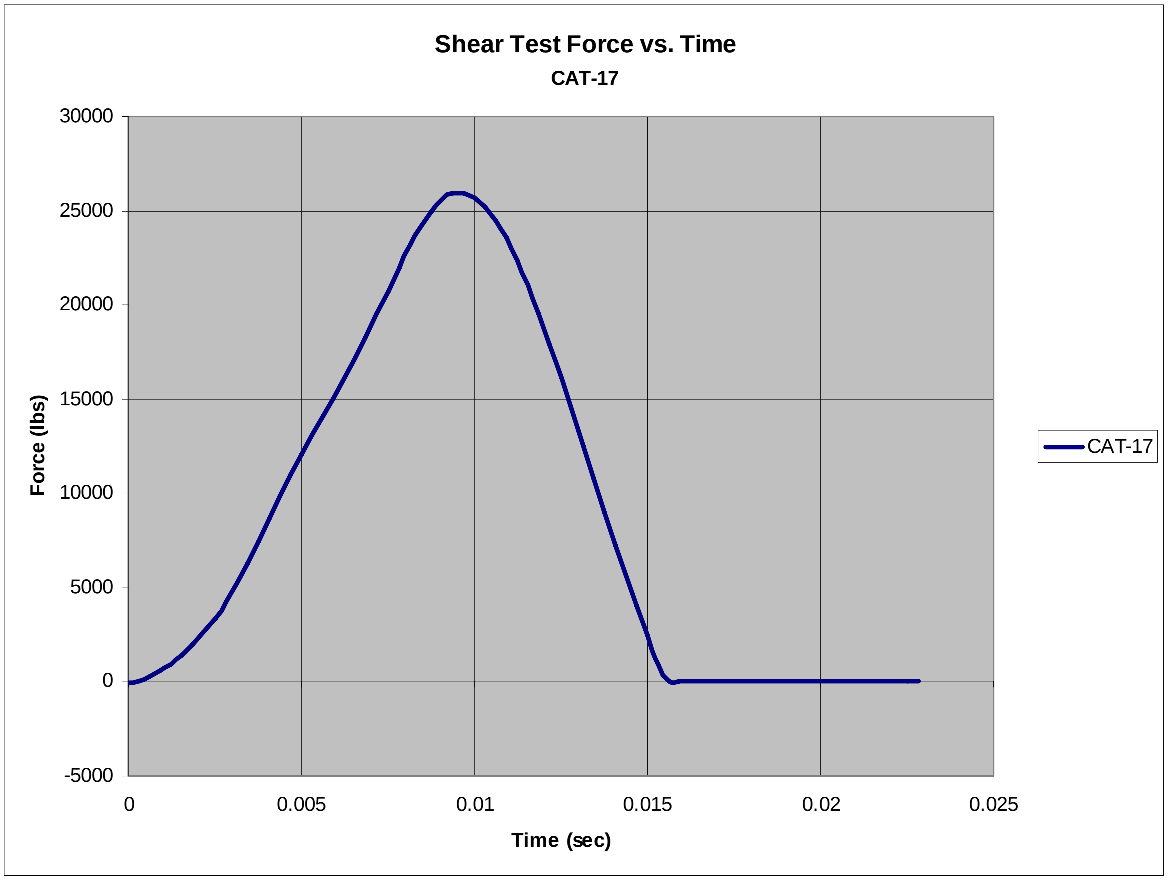


Figure 24. Component Test Results, CAT-17

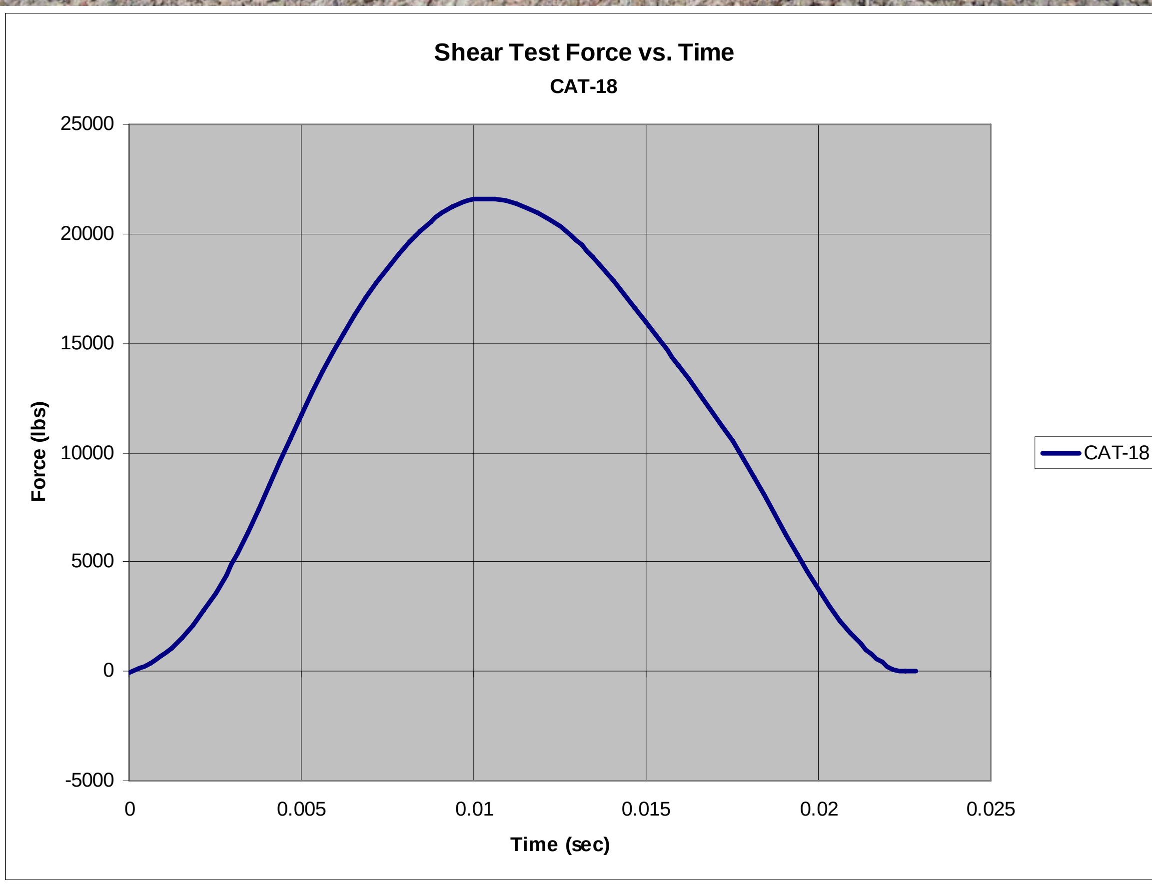


Figure 25. Component Test Results, CAT-18

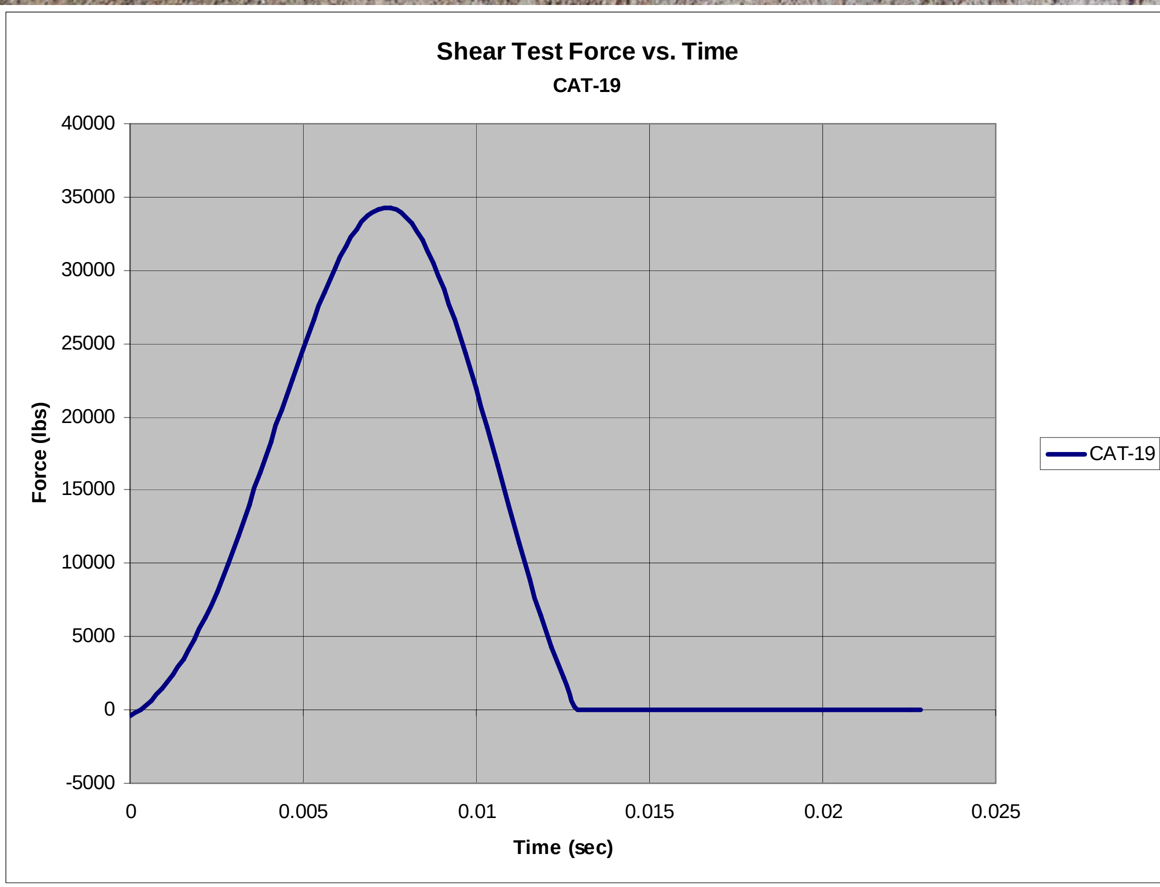
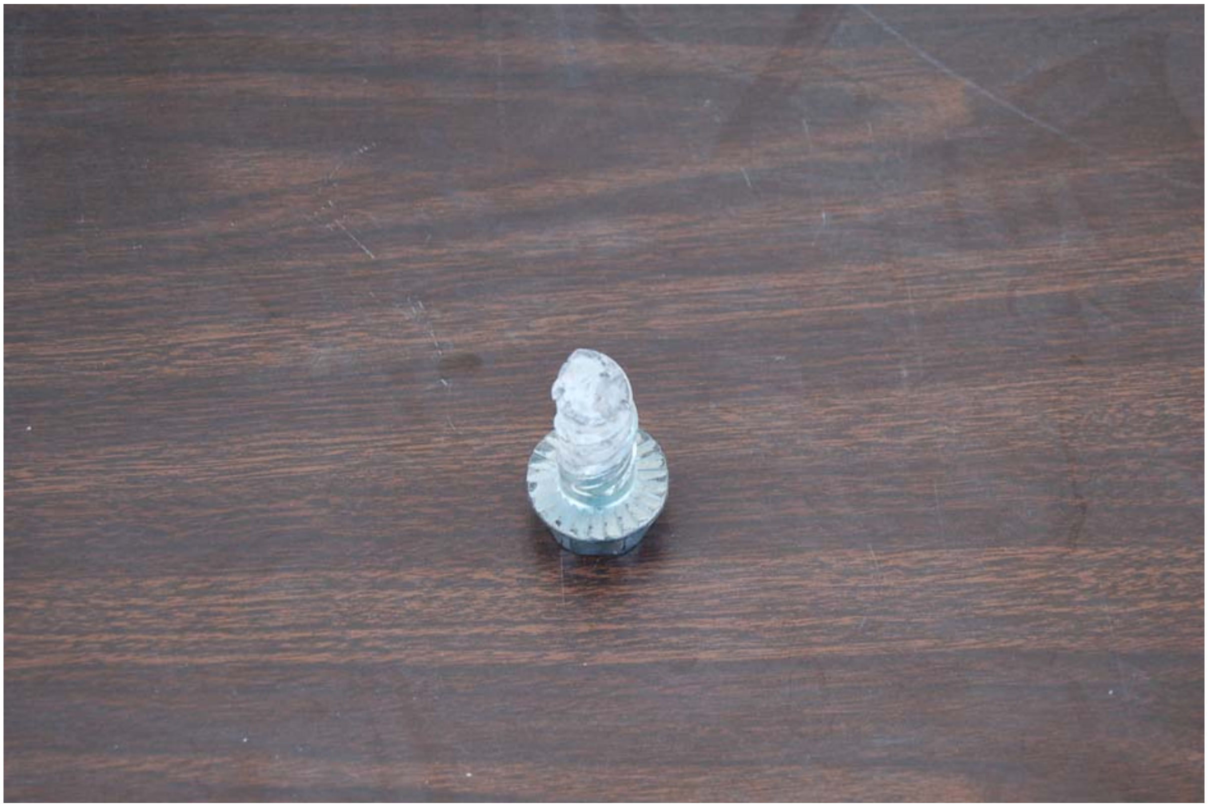


Figure 26. Component Test Results, CAT-19



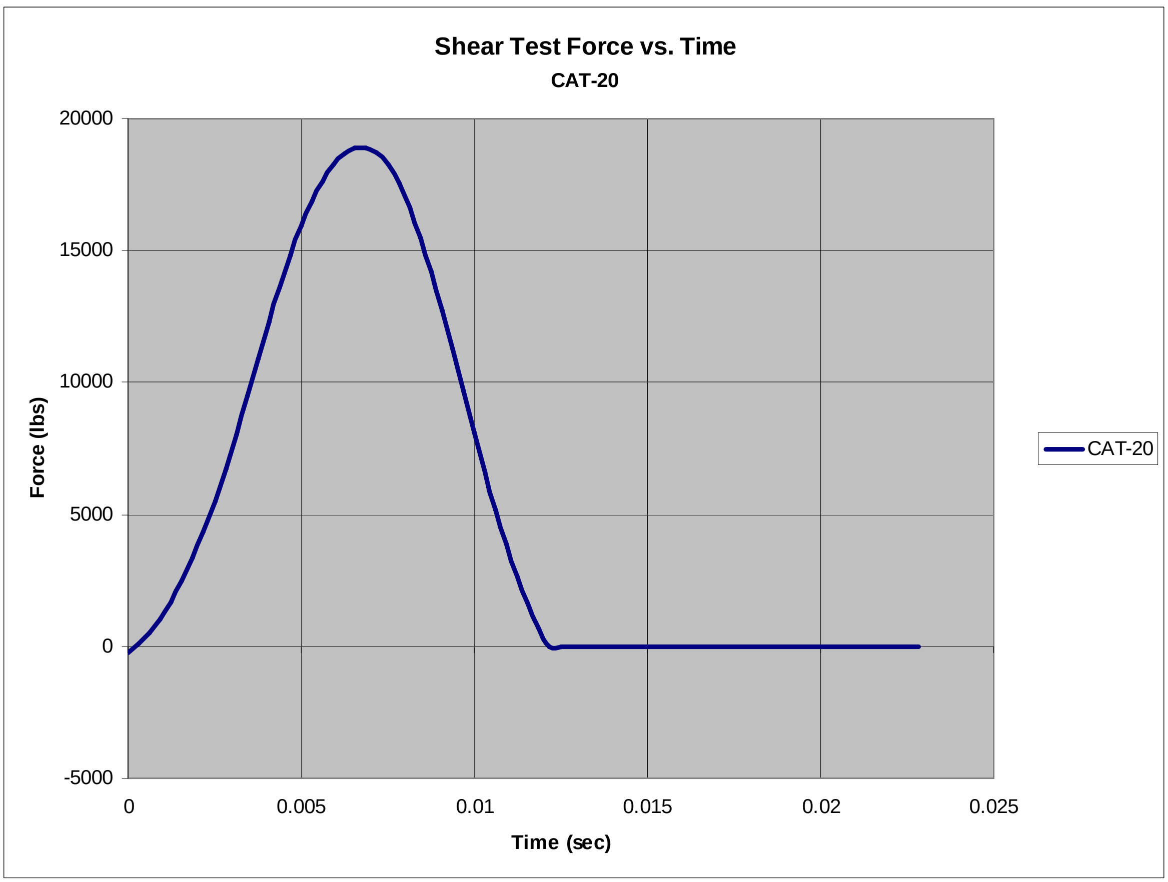


Figure 27. Component Test Results, CAT-20