Test Report for Removable Adhesive Anchors

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**Overview:**
The Structures Research Center is investigating the possibility of modifying the adhesive anchors for the Type-K Temporary Barrier System (Design Standards Index No. 414). The reason for the modification is to examine a more simplistic method of anchor removal as opposed to the current core drilling method. The objective is to be able to screw out the anchor with a minimum amount of effort, while maintaining the current pull-out criteria.

A series of tests were completed to investigate the modification. Initial tests were performed to test a variety of methods, with follow up tests on the superior method to ensure confidence and consistency. Tests were completed using the current standards so that a comparative analysis could be performed.

**Current Standards:**
The current Design Standards call for a 1¼ inch diameter adhesive-bonded anchor. The anchor shall be a fully threaded rod in accordance with ASTM F1554 Grade 36. The depth of embedment shall be 7½ inches into concrete. The adhesive bonding material is Type HSHV, FDOT Specification Section 937, and shall be installed in accordance with FDOT Specification Section 416. The installation specification requires that the hole diameter be established by the adhesive manufacturer, or as a minimum, be not less than 105% or greater than 150% of the bar diameter. The Design Standard installation is shown in Figure 1.

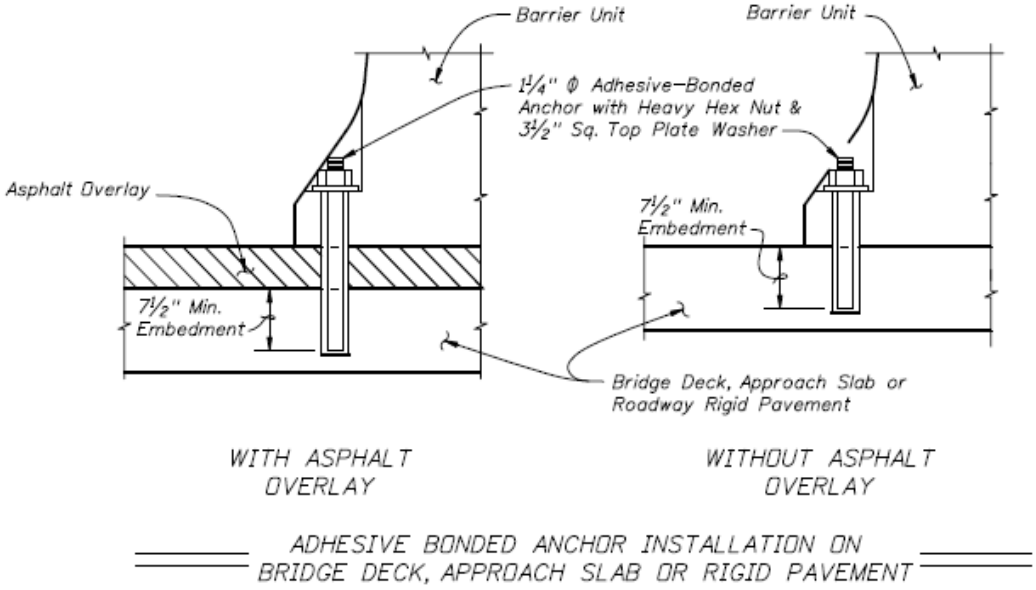


**Figure 1: Design Standard (Index No. 414)**

**Initial Testing:**
The initial testing of the anchor bolt entailed the removal method of the anchor bolt and not the conformance to the pull-out criteria. Several methods were tested for anchor removal including, plain threads, lubricated threads, PTFE (Teflon tape) wrapped threads, and couplers. The plain thread was tested to check if removing the anchor is achievable in its current setup. A higher grade, smaller diameter bar was tested using the coupler system. The smaller bar was to ensure that coupler could be installed in the same diameter hole as required by the 1¼" anchor bolt.

The results of the initial testing indicated that the PTFE coated threads reduced the effort needed to remove the anchor bolt. An extreme amount of force was needed to move the plain and lubricated threads and once movement occurred binding of the threads prevented further removal. Using the coupler with the smaller diameter bar allowed for easy removal of the anchor however, the installation and preparation was more time consuming and as a result was inferior to the PTFE coated threads.

**Pull-out Test Setup:**
Secondary testing was performed to verify whether the chosen method, PTFE (Teflon tape) threads, could meet the requirements of the *Structures Design Guidelines* based on pull-out. A series of confined tension tests were performed following AC308 – 07, *Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements*. Two unconfined tensions tests were also completed in accordance with ASTM E 1512-01. The test setup for the confined and unconfined tension tests is shown in Figures 2 and 3, respectively.

An additional modification to the Design Standard was made in the test setup by reducing the embedment depth of the anchor to 7 inches as opposed to 7½ inches. This is to reduce the possibility of concrete bursting on the reverse side of the drilled hole. The installation of the adhesive bonded anchor was in accordance with the FDOT Standard Specifications Section 416, using a 1½ inch drilled hole for the 1¼ inch threaded anchor. The adhesive epoxy used was Redhead Epcon G5 which is listed on the Qualified Products List (QPL).

For a comparative study, the testing was completed using both PTFE wrapped threads and non-wrapped threads, per current Index 414. The PTFE wrapped threads used two different methods to simulate normal wrapping and over-wrapping. The normal wrapping utilized 2 layers of Teflon tape, while the over-wrapping used 4 layers. Choosing the different layers provided an understanding of the effect the wrapping has on the capacity of the adhesive anchors. The idea behind the wrapping technique was to keep the tape taut enough so that the threads on the anchor are exposed as much as possible. The wrapping is shown in Figures 4 and 5.

The loading rate of the confined and unconfined tests was approximately 0.5 kips/sec until failure of the specimen or a load of 90 kips was reached. The 90 kip limit was based on safety and the required bond stress per FDOT Standard Specification Section 937.

Design Standards call for an ASTM F1554 Grade 36 anchor rod, however for testing purposes and to focus the test on the bond, an ASTM A193 B7 rod was used. The ultimate capacity of the B7 rod is 150 ksi (≈185 kips), which ensured the bond failure mechanism was exceeded before steel failure. Load and displacement was recorded throughout the test.

**Figure 2: Confined Tension Test**

**Figure 3: Unconfined Tension Test**


**Figure 4: 2 Layers of PTFE Tape**

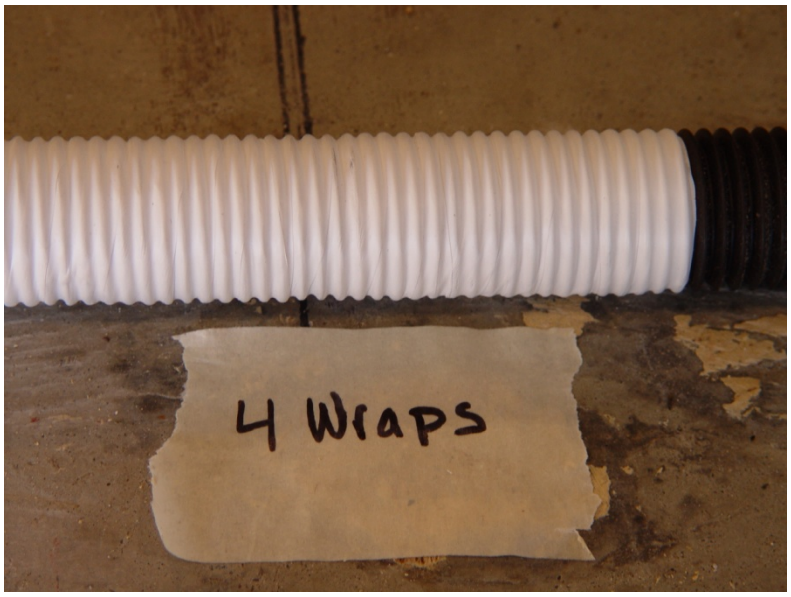


**Figure 5: 4 Layers of PTFE Tape**

**Pull-out Test Results:**

The results from the pull-out tension tests, confined and unconfined, are shown in Figure 6 with the average values in Figure 7. A tabulated form of the results is given in Table 1. Analyses of the results indicate a reduction in load capacity of the adhesive anchor when wrapped with PTFE tape. The average decrease in capacity is 25% and 60% for the 2 layers and 4 layers of PTFE tape, respectively. The unconfined test with 2 layers reveals a 24% reduction in capacity. A 4-layer unconfined test was not performed. It should be noted that Test B1, the non-wrapped confined test, was not considered in the averaging or the decrease in capacity calculations since it did not fail. Test B4 was not included with the other data based on lack of knowledge about the wrapping. However, from observation and data it appears it was over-wrapped. The failed specimens are shown in Figure 9.

Load and displacement graphs are given in Figures 10, 11, and 12 depicting the displacement response of the various tests that were performed. The results of the curves imply similar behavior between the 2-layer wrapped and non-wrapped anchors. The slope of the curves is comparable beyond the 10 kip initial loading stage. Within the initial loading stage the wrapped specimens show inconsistency or softening. This softening is obvious in Figure 11 with the unconfined tests. The PTFE tape creates a soft layer between the adhesive and the steel and until the PTFE tape is compressed and the steel engages the adhesive, the response is affected. Test S2 is not displayed because of equipment malfunction; the displacement gage shifted initially and disrupted the data. The graphs for the over-wrapped specimens are shown in Figure 12. The curves are incomparable due to the inconsistency. The phenomenon stated earlier, on the affect of the wrapping, is more predominant with this case and is likely the cause of the erratic displacement data.

Analyzing the failure mechanisms shows a slight difference between the methods. The wrapping technique indicates a pure mechanical type of failure with the epoxy adhesive

shearing at the anchor threads face. This is observed for the 2- and 4-layer wraps and is shown in Figures 9 and 13. The higher number of wraps, the smaller the area exposed at the thread face which reduces the capacity of the anchor rod. Testing of the non-wrapped specimens, which are in the current specifications, implies a combination of mechanical and bond failures. Shearing at the anchor threads face and bond failure between the concrete and the epoxy adhesive is apparent, see Figure 14. The failure mechanisms demonstrate the importance of exposing the threads when wrapping the PTFE tape. The possible reason for a more pronounced mechanical failure in the non-wrapped anchors is the size of the drilled hole. The product manufacturer recommends using a 1⅜" drilled hole, however a 1½ inch drilled hole was used for testing. The 1½ inch drilled hole was used based on the Department's Standard Specifications which allows a range from 105% to 150% larger than the diameter of the anchor rod.

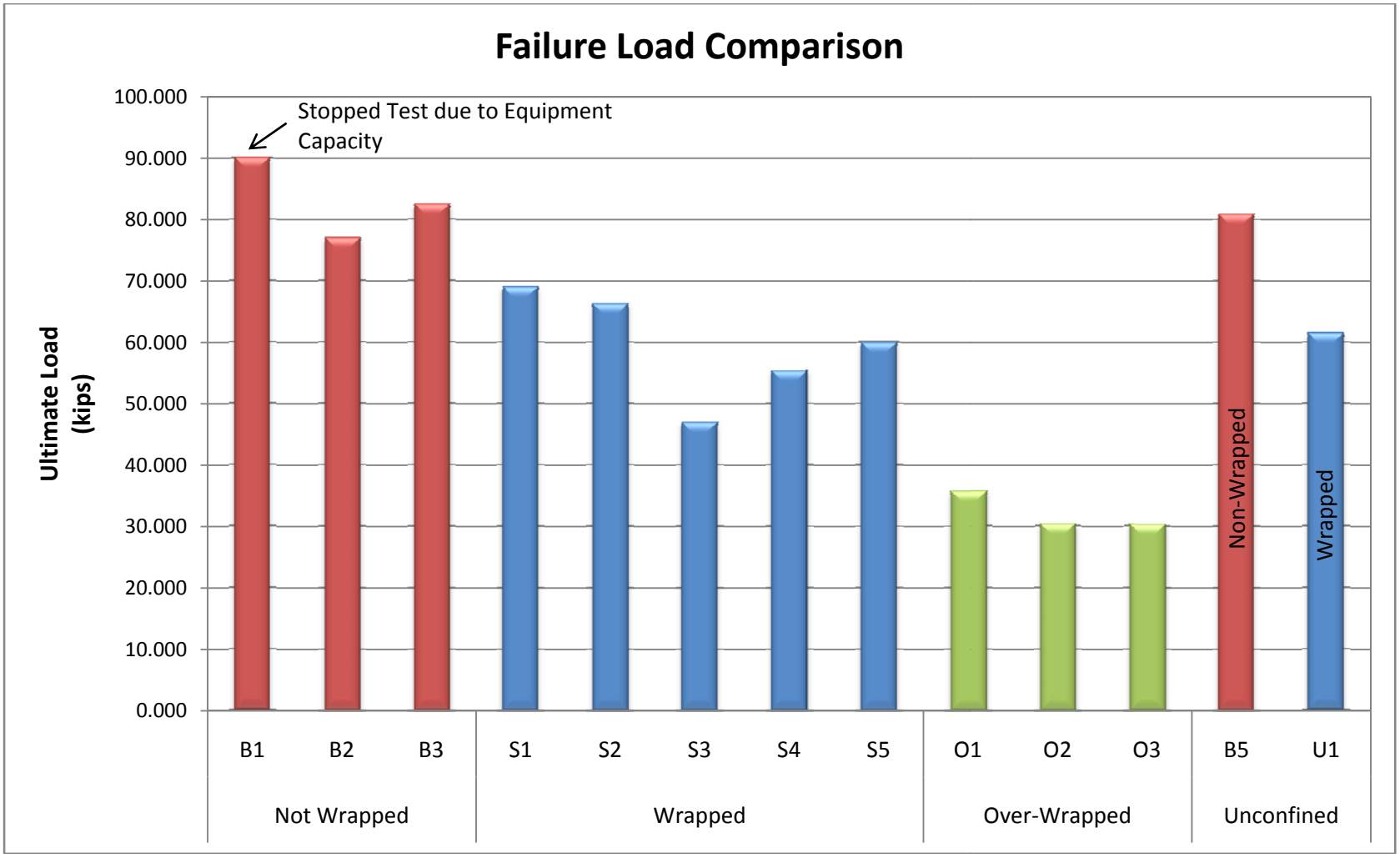


**Figure 7: Individual Test Results**

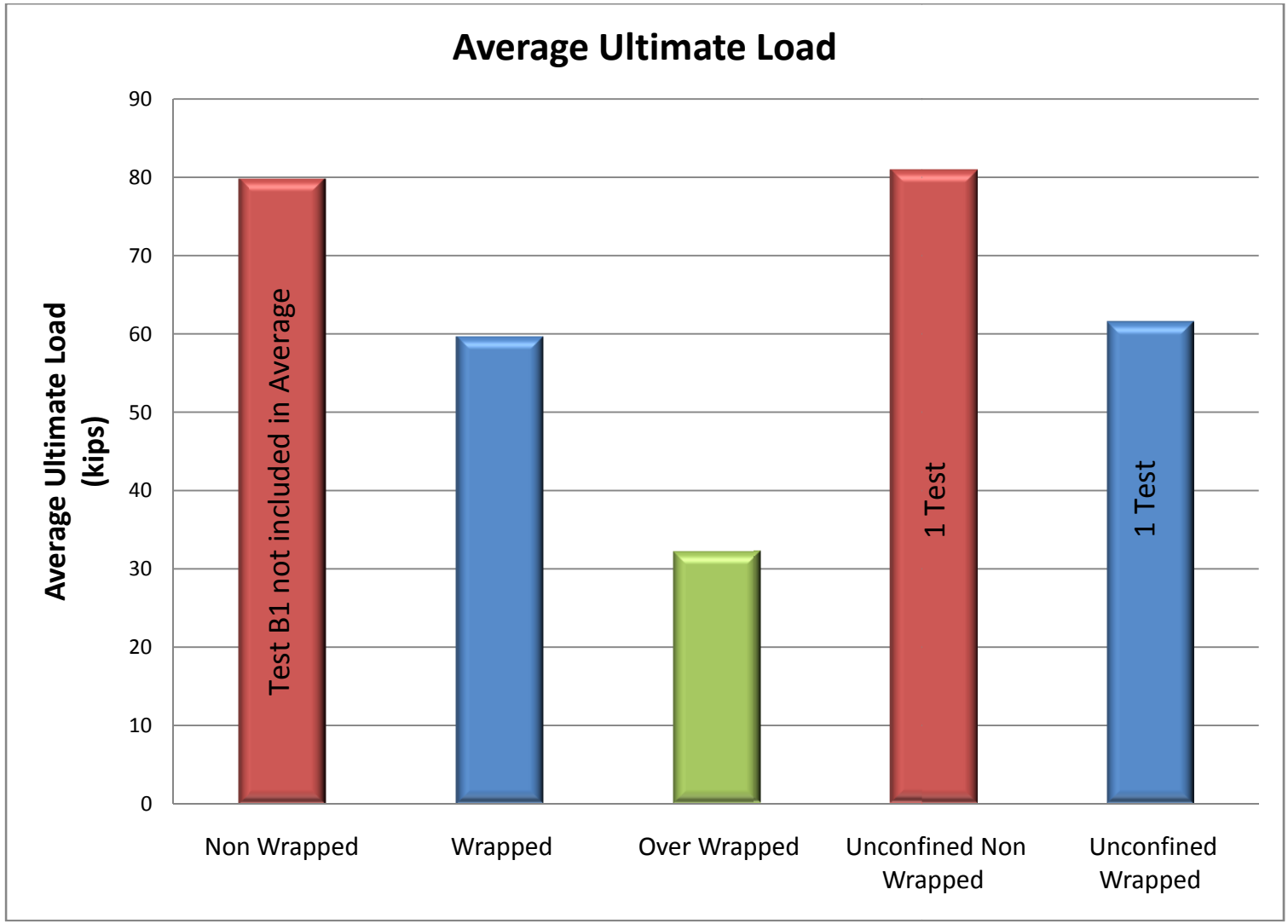


**Figure 8: Average Ultimate Load**

| | Non Wrapped | | | Wrapped | | | | | Over-Wrapped | | | | Unconfined | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test** | B1* | B2 | B3 | S1 | S2 | S3 | S4 | S5 | O1 | O2 | O3 | B4 | B5 | U1 |
| **Ultimate Load (kips)** | 90.18 | 77.07 | 82.56 | 69.10 | 66.35 | 47.05 | 55.46 | 59.95 | 35.77 | 30.45 | 30.45 | 30.692 | 81.00 | 61.58 |
| **Mean** | 79.81 | | | 59.58 | | | | | 32.22 | | | NA | NA | NA |
| **Standard Deviation** | 3.88 | | | 8.81 | | | | | 3.07 | | | NA | NA | NA |
| **Coefficient of Variation** | 4.87% | | | 14.79% | | | | | 9.54% | | | NA | NA | NA |
| **Average Percent Reduction in Ultimate Load** | NA | NA | NA | 25.35% | | | | | 59.63% | | | 61.55% | NA | 0.24 |
| *Did not fail | | | | Compared to Not Wrapped | | | | | | | | | | To B5 |

**Table 1: Test Results**

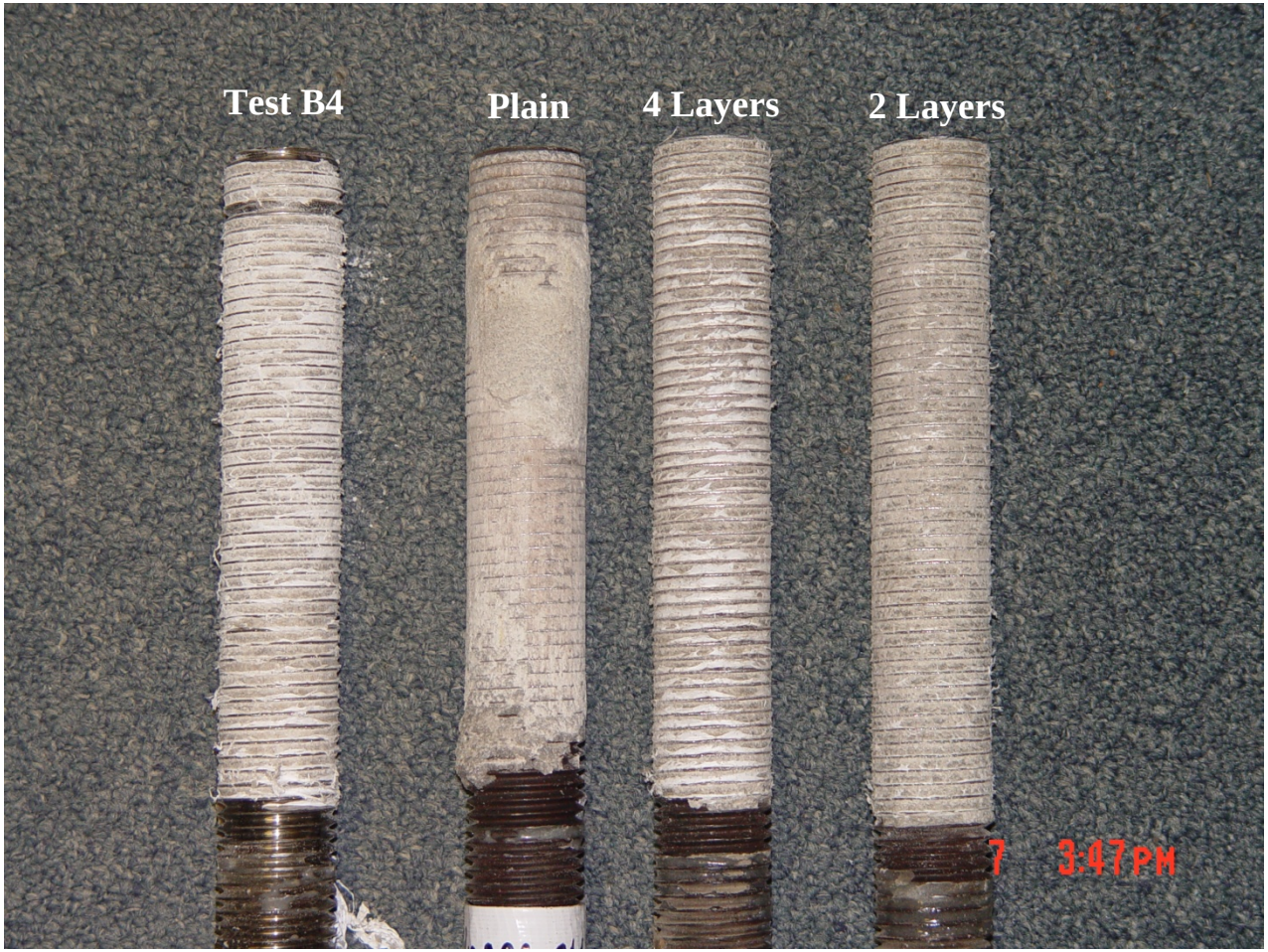


**Figure 9: Failed Specimens (All methods)**

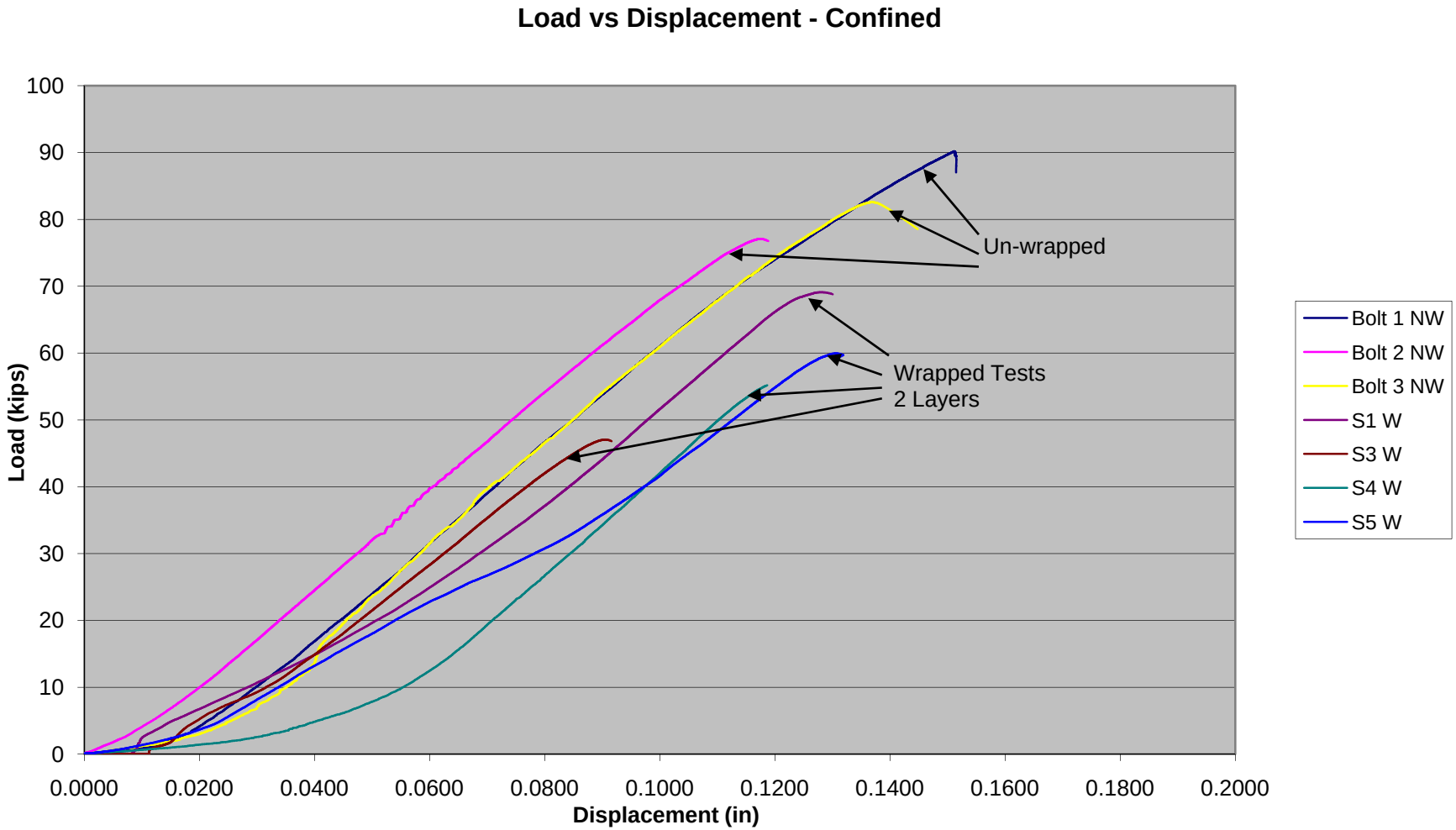


**Figure 10: Load/Displacement for Confined Tests**

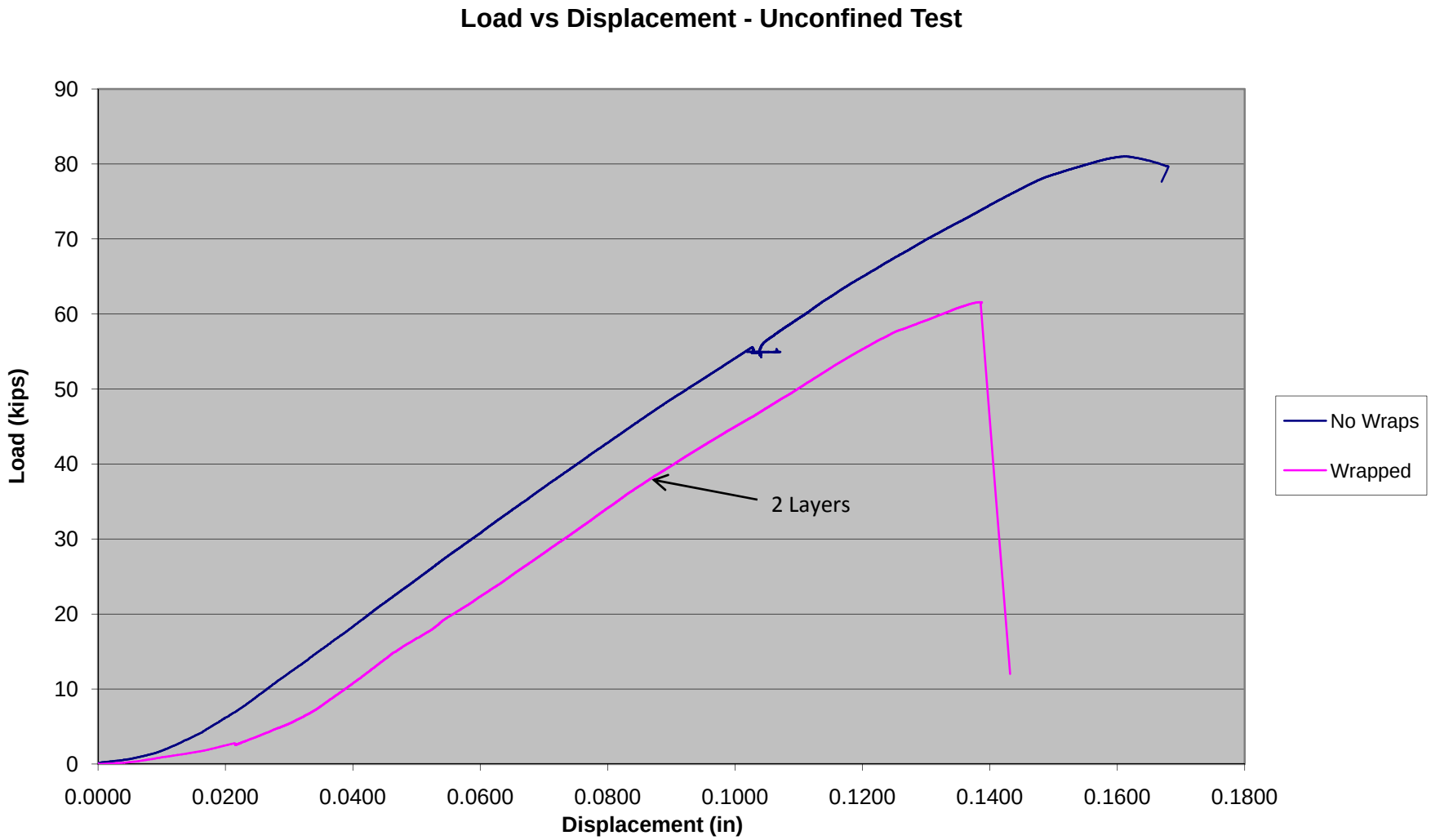


**Figure 11: Load/Displacement for Unconfined Tests**

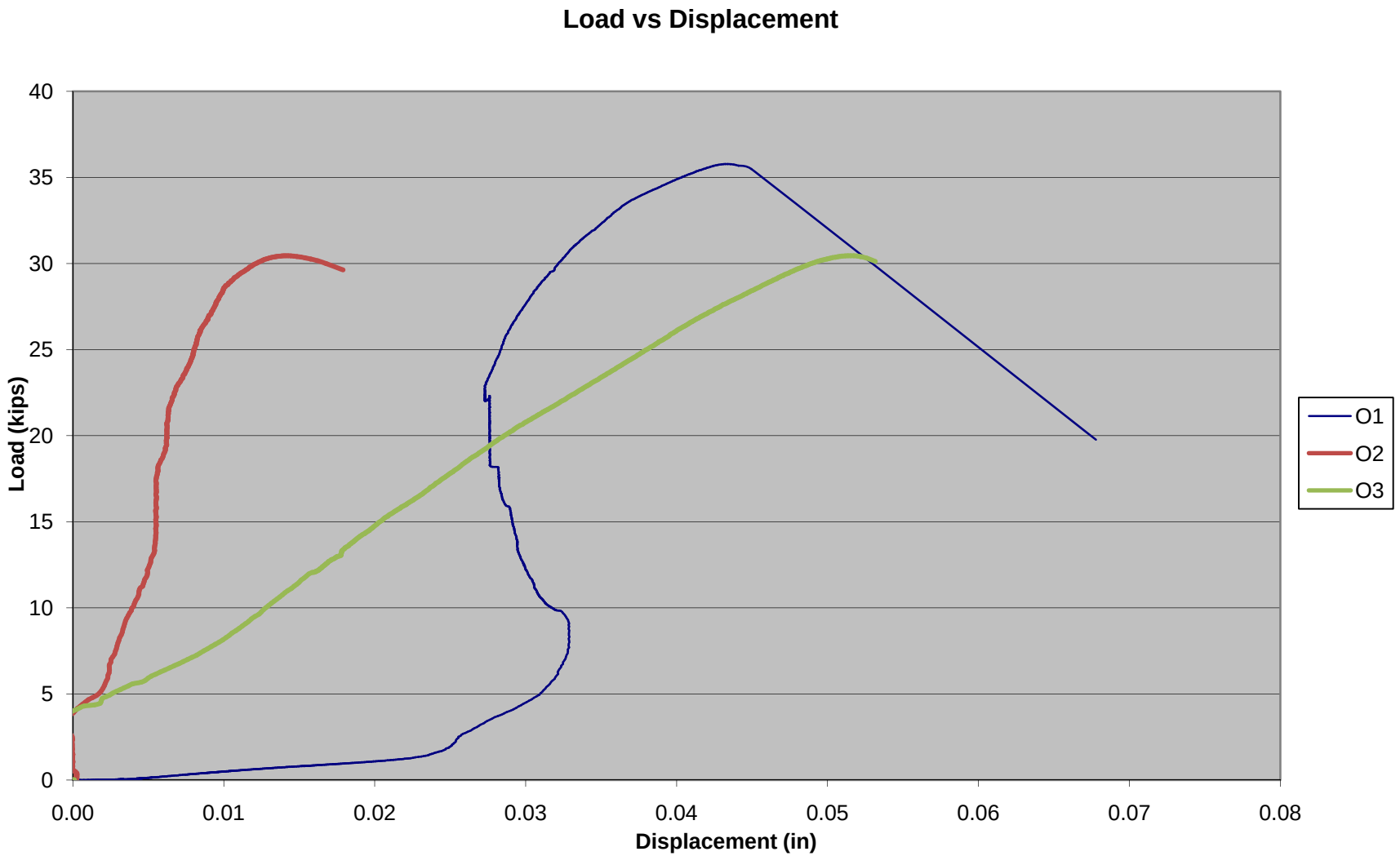


**Figure 12: Load/Displacement for Over-wrapped, Confined Tests**

**Figure 13: Mechanical Failure – Wrapped Specimens**


**Figure 14: Combination of Mechanical and Bond Failure – Non-Wrapped**

**Conclusion:**
The main requirement to achieve acceptability of the modified installation is that the pull-out capacity needs to be at least 125% of the yield strength of the anchor. For a 1¼" diameter Grade 36 anchor this value is 41.4 kips, assuming an effective area of 75% the nominal area for a threaded anchor. The design strength, based on the *Structures Design Guidelines* and including the φ-factor, is 37.4 kips. The results of the 2-layer PTFE wrapped anchors indicates that all 6, including the unconfined test, specimens either met or exceeded the requirement of 125% yield (41.4 kips). Compared to the design strength, 37.4 kips, all 2-layer wrapped anchors substantially exceeded the requirement. The over-wrapped specimens, 4 layers, did not meet any of the above requirements.

The design minimum pull-out strength from the *Structures Design Guidelines* based on bond strength is 42.76 kips, including φ-factor. This calculation is based on the bond strength being 1.83 ksi. However, when using the specified bond strength, 3.06 ksi, from Section 937 in the *Standard Specifications* the strength of the anchor is calculated as 84.1 kips, excluding the φ-factor. All 2-layer wrapped anchors exceeded the design requirement of 42.76 kips; however, none had 84.1 kips of capacity. Only one non-wrapped specimen met the higher bond strength requirement which could be a result of the oversized hole as mentioned earlier.

The results of the testing indicate that the 2 layers of PTFE wrapping meet the strength requirements necessary for pull-out in addition to having the capability of being removed. The over-wrapping technique proves that additional tape significantly reduces the capacity of the anchor and should be avoided.

**Recommendations:**
If PTFE tape is used to ease the removal process of the anchors, then guidelines need to be made to ensure proper wrapping of the tape. A maximum of 2 layers should be permitted. A description of the wrapping technique is given in figure 15, assuming the maximum 2 layers are used. As stated before, the intent is to keep the tape tight as it is wrapped to ensure the maximum amount of thread depth is attained. It is recommended that 1 layer of PTFE tape be used with slight overlapping, if possible. Also, the drilled hole diameter should strictly follow the manufacturer's recommendation, otherwise use the *Standard Specifications* range. Test anchors, with taping detail, should be performed as per *Design Standards Index No. 414* to ensure adequacy.

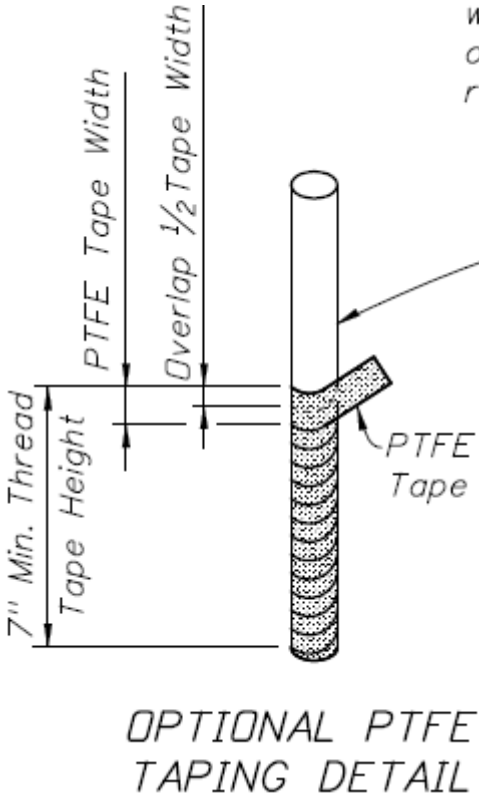


**Figure 15: Wrapping Technique**