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Investigation of Standard Penetration Torque Testing (SPT-T) to Predict Pile Performance

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INVESTIGATION OF STANDARD PENETRATION TORQUE TESTING (SPT-T) TO PREDICT PILE PERFORMANCE

FINAL REPORT

BY

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SUBMITTED TO THE WISCONSIN DEPARTMENT OF TRANSPORTATION

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16. Abstract

Soil/pile set-up is a time-dependant increase in pile capacity. Incorporation of soil/pile set-up in pile design often has considerable economic benefits, resulting from reduction in pile section, length, and/or size of driving equipment.

A number of in-situ tests have been developed to measure set-up that can be performed within a subsurface exploration program. One such test, the SPT-Torque (SPT-T) test, is considered to offer the most-favorable combination of applicability of results, ease and simplicity of performing the test, and equipment cost. However, instrumentation has not been formally developed for commercial application, research correlating SPT-T test results to measured soil/pile set-up is limited, and no documented research has involved Wisconsin soils. In addition, previous SPT-T research concentrated on performing tests spanning from several hours to several weeks. Considerably shorter time intervals (on the order of one hour or less) will likely be required if the SPT-T test is to be included in a typical exploration program.

The primary objective of this research was to perform short-term SPT-T tests and correlate results to long-term measured soil/pile set-up. The results indicate that there does not appear to be any correlation between set-up values from short-term (1 hour or less) SPT-T tests and unit set-up values obtained from long-term restrikes of test pile installation. Negative set-up (relaxation) exhibited in may short-term SPT-T tests followed by positive set-up also contributes skepticism to using this procedure as a tool to estimate set-up. Therefore, short-term SPT-T testing does not appear to be a practical, economical exploration-phase method to predict soil/pile set-up.

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Piles, pile capacity, pile design, pile testing, soil/pile set-up, SPT-T test, SPT-Torque test, in-situ set-up determination, in-situ testing, exploration phase testing

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Executive Summary

Project Summary / Purpose

Soil/pile set-up is a time-dependant increase in pile capacity. Set-up has long been recognized, and can contribute significantly to long-term pile capacity. Its incorporation into pile design can offer substantial economic benefits, including reducing pile lengths, sections, and/or size of driving equipment.

Within the public transportation sector, use of set-up in design is typically limited to relatively large projects, where benefits from including set-up in the design outweigh the testing costs incurred from reasonably predicting set-up (usually through performing a full-scale pile test program). If it were possible to accurately predict set-up during a typical subsurface exploration program, economic benefits could be realized on medium and small projects as well.

The research presented herein was designed to evaluate the ability to predict set-up through incorporation of a field test method, the SPT-Torque (SPT-T) test, into a typical subsurface exploration program. This research is based on recommendations presented in a precursor report (Komurka et al., 2003).

The result of this research will provide the WisDOT with the basis to make an informed decision on whether further investigation into using the SPT-T test to estimate design soil/pile set-up is warranted and appropriate.

Background

The majority of transportation structures designed by the Wisconsin Department of Transportation ("WisDOT") are supported on deep foundations consisting of driven piles. For construction lettings in calendar year 2001, the WisDOT installed over 230,000 linear feet of piles on its projects. With typical pile costs ranging from $15 to $19 per linear foot, piles represent a significant annual dollar expenditure.

Soil/pile set-up is a time-dependant increase in pile capacity, and can contribute significantly to long-term pile capacity. Incorporation of set-up into pile design often results in smaller pile sections, shorter pile lengths, and/or reduction of the size of installation equipment; all of which result in less-expensive foundation cost.

Empirical relationships correlating soil/pile set-up to common geotechnical tests are limited in application due to the interdependence of back-calculated or assumed variables, the complexity of mechanisms contributing to set-up, and combination of shaft and toe resistance. The most-accurate method of estimating set-up is through a full-scale, site-specific, pile test program. The cost of pile test programs make their application economically unattractive on medium and small projects.

Efforts have been made in recent years to develop soil/pile set-up estimation methods/tests which could be incorporated into the initial subsurface exploration program. Such tests include the SPT-Uplift test, SPT-Torque (SPT-T) test, piezocone test, dilatometer test, and vane shear test. Of these, the SPT-T test has been demonstrated in previous research to offer the most-favorable combination of applicability of results, ease and simplicity of performing the test, and equipment cost.

The SPT-T test is a fairly simple exploration-phase field test which can be performed using typical subsurface exploration equipment. The SPT-T test is performed on a split-spoon sampler after driving, and measures the side shear torsional strength of soil. The test is conducted by turning the drill rods and split-spoon sampler from the surface and recording the required torque and angle of rotation. By performing the test at different times after SPT sampler penetration, peak, residual, and time-dependant torque values can be determined.

However, the instrumentation required for the SPT-T test has not been formally sustained (i.e., has not been formally maintained for use, nor developed for commercial application). Accordingly, SPT-T test results which have been correlated to measured soil/pile set-up are very limited, and no SPT-T testing had been performed in Wisconsin prior to this research. In addition, previous research has concentrated on SPT-T tests with time durations ranging from several hours to several weeks. Such time requirements would likely preclude incorporation of the SPT-T test into a typical subsurface exploration program.

Process

The objective of the research presented herein is to further assess the ability to predict soil/pile set-up by incorporating the SPT-T test into a typical subsurface exploration program.

This research project included:

1. Development of SPT-T equipment that is durable, compatible with existing WisDOT drilling equipment, available for reasonable cost, and requires minimal training. Equipment was produced by the WisDOT and GRL Engineers, Inc.

2. Selection of a site for SPT-T testing, taking into account accessibility, proximity to existing test pile site, quality of previous test pile data, and stratigraphy.

3. Design of an SPT-T test program/schedule. The test program was designed to correlate SPT-T results to pile test results for each major soil stratum at the test site. The test program also was designed to evaluate the effects of plugged (constant volume displacement) versus unplugged (variable volume displacement) sampler, and staged (frequent torque application) versus unstaged (initial and one subsequent torque application) testing.

4. Performance of, along with WisDOT personnel, SPT-T tests at one site.

5. Reduction of SPT-T data and comparison to soil/pile set-up data from previous pile tests.

6. Discussion of results with the WisDOT's Technical Oversight Committee (TOC).

7. Formulation of conclusions and report production.

This research project started in October 2003. Field SPT-T testing was performed in November 2003. Data was discussed with the TOC in February 2004. The draft report was submitted to the TOC in May 2005. Comments were received from the TOC in August 2005, and this final report was issued in September 2005.

Findings and Conclusions

There does not appear to be any correlation between set-up values from short-term (1 hour or less) SPT-T tests and unit set-up values obtained from long-term restrikes of test pile installations. Negative set-up (relaxation) exhibited in many short-term SPT-T tests followed by positive set-up also contributes skepticism to using this procedure as a tool in set-up estimation. Therefore, short-term SPT-T testing does not appear to be a practical, economical method to use in exploration-phase testing to predict soil/pile set-up.

Secondary objectives yielded somewhat better results; the plugged and unplugged samplers exhibited different behavior, the staged and unstaged tests exhibited similar behavior. The mechanical equipment improved on equipment described in other SPT-T test research by providing a more-constant rate of rotation, lessening the potential for introducing bending in the SPT rod, and maintaining positioning of the entire assembly. The electronic equipment made it possible to determine not only torque, but also angular rotation. The combination of the mechanical and electronic equipment yielded what could be considered the most-precise method of torque application and data collection developed for the SPT-T test to-date.

Although not directly pertinent to the purpose of this test program, trends in the data obtained in this test program may provide additional insight into set-up behavior over very short time intervals (specifically short-term relaxation preceding set-up). Given the apparent lack of correlation between results from SPT-T testing and the test pile program, additional analysis and discussion was beyond the project scope.

Recommendations for Further Action

After consultation with the TOC, it was concluded that no meaningful correlation exists between short-time-interval torque measured as part of the SPT-T test and data obtained from the previous pile test. Consequently, no further action is recommended.

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INVESTIGATION OF THE USE OF SHORT-TERM STANDARD PENETRATION TEST TORQUE (SPT-T) TESTING TO EVALUATE SOIL/PILE SET-UP

BACKGROUND AND PROJECT OBJECTIVE

It is well known that driven pile capacity often increases with time after installation. This time-dependant capacity increase, referred to as “set-up,” has been the subject of numerous investigations. Set-up can be significant, with magnitudes of 12 times initial pile capacity documented (Titi and Wathugala, 1999). Not surprisingly, incorporation of set-up in pile design is becoming more common in recent years. Inclusion of set-up in design has several potential economic benefits, such as shorter piles, smaller pile sections, higher allowable pile loads, fewer piles, and/or reduced installation hammer size.

Several methods have been used to estimate set-up magnitude, including empirical relationships, static analyses, and project-specific pile testing (dynamic testing and/or static pile load testing). These methods are discussed in detail in the preceding report, Komurka, et al., (2003), hereafter referred to as the “precursor report”.

The most-accurate method is through a project-specific pile test program, containing dynamic monitoring and/or static testing. Test programs involving installation of even relatively few potential pile sections can be costly, and may not be economically attractive on smaller projects. For this reason, considerable research into alternate (i.e., less-costly) methods to predict set-up has been undertaken in recent years. The Marchetti Dilatometer, piezo-electric cone, vane shear, and the common Standard Penetration Test (“SPT”) split-barrel sampler have all been used in recent research. A summary regarding the application of these methods and their demonstrated ability to predict set-up is contained in the precursor report.

Given ease of inclusion into a typical subsurface exploration program, methods utilizing a split-barrel sampler have been the focus of considerable research. The most-commonly researched method using a SPT split-barrel sampler is the SPT-torque (“SPT-T”) test. This test involves applying torque to an SPT sampler at multiple time intervals after sampler penetration. The change in peak torque over time has been compared to set-up determined from static and dynamic testing of nearby test pile installations. Correlations between SPT-T test results and data obtained through production-scale pile test programs have been established in many investigations, including Rausche, et al. (1996), McVay, et al. (1999), Bullock (1999), and Bullock and Schmertmann (2003). A similar method including torquing driven steel rods in lieu of the SPT split-barrel sampler was investigated by Axelsson and Westin (2000).

Although correlations established in the above-referenced research show promise in prediction of soil/pile set-up, the time between sampler penetration and the second SPT-T test were on the order of, or greater than, 1 day. Such time intervals would not be easily incorporated into the timeline of a typical subsurface exploration program, thus have significantly decreased economic appeal.

Given the above background, the primary research objective of this study was to evaluate the ability to predict soil/pile set-up from SPT-T testing performed in time periods conducive to the execution of a standard subsurface exploration program. This research program is a follow-up to recommendations presented in the precursor report.

The primary objective also included development of sensitive, accurate and rugged SPT-T testing equipment. Secondary objectives included investigating the effect of multiple "staged" testing and sample recoveries on SPT-T test results.

This research was funded by, and performed under the auspices of, the Wisconsin Department of Transportation's ("WisDOT's") Wisconsin Highway Research Program. WisDOT technical oversight was provided by Mr. Jeffrey D. Horsfall, P.E.

REPORT OVERVIEW

This report details the development of an SPT-T testing program, means and methods of execution, data reduction, comparison to soil/pile data obtained from a nearby pile test site, and conclusions.

SITE SELECTION

The SPT-T test site was in downtown Milwaukee, Wisconsin, west of North 2nd Street, just south of I-794, as shown in Figure A-1. The site was selected for the presence of thick (massive) soil layers, proximate location to both a previously drilled and sampled soil boring and a pile test site (where dynamic monitoring of multiple piles was performed), and drill rig accessibility. The previous soil boring (P1421-02), and test pile locations are presented in Figure A-2.

EXISTING INFORMATION

Soil Conditions

Boring P1421-02 was previously drilled and sampled by others; its log is presented in Figure A-3. The boring encountered three relatively thick and uniform soil strata extending to the test-pile termination depths. Organic clay was encountered from 11 to 58 feet (Elevation 577[1] to 530), inorganic silty clay from 61 to 122 feet (Elevation 527 to 466), and silty sand from 122 to 155 feet (Elevation 466 to 433). The organic clay had water contents ranging from 50 to 70 percent, and calibrated penetrometer values from less than 0.25 ton per square foot (tsf) to 1.5 tsf. The silty clay had water contents

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[1] Unless noted otherwise, all elevations referred to in this report are positive, in units of feet, and with respect to NGVD-29 datum.

ranging from 10 to 20 percent, and calibrated penetrometer values ranging from 1.5 to 4.0 tsf, generally increasing with depth. The silty sand had SPT "N" values generally ranging from 30 to 50.

Pile Test Program

Location and Scope

The SPT-T test location is adjacent to Site SLT-F of the pile test program performed during the design phase of the Marquette Interchange (I-94/I-43/I-794) project. Six piles were installed at the site; one of the piles was statically load tested in axial compression. The configuration of the piles and their proximity to the SPT-T test location is shown in Figure A-2. With the exception of the static load test pile, all piles were restruck at three different times after installation. Installation and restriking of all piles was dynamically monitored by GRL Engineers, Inc. ("GRL") of Arlington Heights, Illinois. CAse Pile Wave Analysis Program ("CAPWAP®") analyzes were performed by GRL on a representative blow from all end-of-initial-drive ("EOID") and beginning of restrike ("BOR") events.

Soil/Pile Unit Set-Up Determination and Presentation

Soil/pile unit set-up at a given elevation was calculated as the difference between pile unit shaft resistance at BOR minus pile unit shaft resistance at EOID. When analyzing unit shaft resistances from EOID and BOR events, it is necessary to note whether the pile was sufficiently moved by each blow (i.e., had sufficient set per blow) to mobilize the full capacity of the pile. Non-mobilization at either EOID or BOR can lead to either underprediction or overprediction of unit shaft resistance, and therefore can affect set-up determination (Komurka, 2004). For purposes of our analysis, an equivalent maximum penetration resistance of 120 blows per foot delineates a "mobilized" pile from a "not fully mobilized" pile. Table 1 in the Appendix illustrates the mobilization of each event and its effect on set-up determination.

A review of Table 1 indicates that, with the exception of SLT-F-12-6C, all piles had a fully-mobilized EOID blow evaluated by CAPWAP. The second restrike (BOR2) on all piles did not fully mobilize pile capacity; therefore the set-up recorded during the second restrike on all piles is likely underreported (with the possible exception of SLT-F-12-6C, where the set-up is indeterminate).

Unit set-up distributions for each BOR event evaluated by CAPWAP are presented in Figures B-1 through B-6. A comparison among the last BOR unit set-up distribution for every pile, and the average unit set-up distribution, is presented in Figure B-7. The average set-up presented in Figure B-7 was calculated sans SLT-F-14-5, since the last restrike on that pile exhibited considerably higher unit set-up values than the other piles, and is considered an anomaly.

Low unit set-up values, both short-term (approximately 2 hours after installation) and long-term (30 days or more after installation), were typically exhibited in the organic clay. Short-term unit set-up in the organic clay was typically similar to, or slightly less than, what was exhibited in the immediately underlying cohesive soils. Long-term set-up in the organic soils was lower than any other stratum. Based on our experience, these unit set-up values are typical of weak fine-grained soils, such as the organic clay encountered in Boring P1421-02.

The silty clay stratum typically had short-term unit set-up less than 500 psf. Long-term unit set-up was on the order of 500 psf above Elevation 490 (henceforth referred to as the “upper portion” of the silty clay stratum), and 2,000 to 5,000 psf below approximate Elevation 490 (henceforth referred to as the “lower portion” of the silty clay stratum). Soil conditions documented in the log for Boring P1421-02 did not indicate markedly different soil properties between the upper and lower portions of the silty clay stratum.

The silty sand stratum typically had short-term unit set-up less than 700 psf. Long-term unit set-up was considerably higher, similar to the long-term unit set-up of the lower portion of the silty clay stratum.

Regarding set-up rate, an average “aggregate” unit set-up was calculated for each principal strata, for each pile, for each BOR event. These data are presented in Figures B-8 through B-8c. Since long-term set-up magnitudes in the silty clay stratum were observed to be markedly different above and below Elevation 490, data from this stratum were further divided into these (lower and upper) layers. From these figures, the set-up rate appears to be highest in the silty sand and the lower portion of the silty clay strata. Although data scatter from the silty sand strata is considerably greater than data from the lower silty clay layer, logarithmic trend lines through each of these datasets had similar slopes (i.e., set-up rates). The organic clay and the upper portion of the silty clay strata had similar set-up rates, with the upper portion of the silty clay strata marginally higher.

SPT-T TESTING

Equipment

Equipment selection was based on cost, speed of acquisition and configuration, and accuracy in measuring and recording torsional resistance and rotation angle. A picture of the equipment used to measure torsional resistance and rotation angle is provided in Figure C-1.

Electronic portions of the test equipment were configured, calibrated, and supplied to WKG[2] by Pile Dynamics, Inc. (“PDI”) of Cleveland, Ohio. Torque was determined using a section of AW drill rod outfitted with a Wheatstone bridge comprised of foil strain gages. A linear potentiometer, with wire wrapped around the drill rod (connected to the drill rod by Velcro®) was used to determine rotation angle. Electronic data acquisition equipment and software, including a laptop computer (all provided by PDI), was used to activate these instruments and record data.

The mechanical portions of the test equipment were developed and produced by WisDOT. The instrumented AW rod section was secured to an apparatus using two bearing collars to minimize misalignment. The linear potentiometer was also secured to the apparatus using steel plates. The apparatus was designed to be held by the drill rig's "table" clamp. Torque was applied manually using a handle connected to a worm gear, which was also developed by WisDOT. This enabled the sampler to be rotated at a low and relatively uniform rate.

Although the electronic equipment used for measuring and recording torque and rotation angle was based on that used by Rausche, et al., (1996), it likely that improvements in torque application, lateral support of the drill rod, and rotation angle measurement made this apparatus more accurate for conducting SPT-T Tests than other documented investigations.

Test Methodology

The primary focus of the test program was to evaluate the relationship between SPT-T test results and soil/pile set-up. In addition, the relationship between staged testing (in which more than two torque trials were performed) and unstaged testing (in which only two torque trials were performed), and the relationship between using a plugged SPT sampler (maintaining uniform soil displacement) and a standard (unplugged) SPT sampler, would be investigated. These relationships were addressed by performing SPT-T testing in sets, each typically consisting of two SPT-T tests separated by one foot. Each test consisted of multiple torque applications (trials) at various times after sampler penetration, and each set of tests was designed to compare either staged vs. unstaged testing, or plugged sampler vs. unplugged sampler type.

Torque trials in staged tests were generally performed at 4, 8, 15, 30, 60, and 120 minutes after penetration, and with one exception (Test 4B) were performed with a plugged sampler. Unstaged tests generally had torque trials performed at 4 and 60 minutes after penetration, and included both plugged and unplugged samplers. The 60-minute trial was common to all tests since it is considered to be the longest time interval that could be incorporated into a standard subsurface exploration program. Overnight trials were performed every morning on whichever test was being performed last the previous day. Torque trials generally lasted 1 to 2 minutes, with total sampler rotation ranging from 200 to 250 degrees (i.e., from approximately 1/2 to 2/3 revolution).

A total of 21 SPT-T tests (divided into 10 sets) were performed. Test elevations/depths, designations, time intervals, and sampler type are provided in Table 2 in the Appendix. A graphical illustration of the test locations relative to elevation/depth and stratigraphy is provided in Figure C-2.

Test sets were divided among the three principal soil strata. The upper two test sets (1 and 2) were in the organic clay; the middle five test sets (3, 4, 5, 6, and 7) were in the silty clay; and the lower three test sets (8, 9, and 10) were in the silty sand.

Field work was performed between Monday, November 10 and Friday, November 14, 2003, inclusive, and consisted of drilling one boring approximately 11 feet away from the nearest existing test pile (Figure A-2). The boring was drilled using a CME-550 drill rig, using mud-rotary methods.

Sampler penetration was achieved using an automatic hammer. Samplers were driven 18 inches, with blow counts recorded in six-inch increments. Soil samples were measured, classified, stratified, and logged by a geotechnical engineer. Portions of the obtained samples were placed into jars and sealed. A log documenting conditions encountered in the SPT-T boring is contained in Figure A-4. Recovered samples were generally similar to soils documented in the log for Boring P1421-02.

The linear potentiometer (used to determine angular displacement) was reset after each torque trial. The potentiometer was reset by “unwrapping” the extended wire from around the drill rod, and recoiling the wire back into the potentiometer.

The borehole was abandoned using grout after completion of the testing.

SPT-T TEST DATA RECORDING AND REDUCTION

A laptop computer recorded torque in pound-feet (lb-ft), and sampler rotation in degrees during each SPT-T trial, with sampling intervals of approximately 0.1 second. Torque was subsequently converted to SPT split-barrel sampler unit shaft resistance in pounds per square foot (psf). For all tests, the area used for shaft determination was the outside area of the embedded portion of the split-barrel sampler (113 square inches).

Correction for Residual Torque

After the 120-minute trial in Test 3A, it was realized that the wormdrive often did not release torque between trials. Therefore, this residual (relatively constant) torque was often maintained between trials in tests prior to, and including, Test 3A.

When data collection equipment was put on stand-by (between many, but not all of the staged tests), this residual torque was likely the zero measurement when the data collection equipment was restarted (i.e., subsequently recorded torque reflected incremental torque, not total torque).

After the 120-minute trial on 3A, the wormdrive was disengaged (allowing the drill rod to freely rotate), reengaged, and a 125-minute torque trial was performed. The residual torque measured in the 125-minute test was between 60 and 68 ft-lbs, which was significantly higher than the 28 to 32 ft-lbs measured five minutes prior – evidence of residual torque. In addition, the existence of residual torque may also explain the very small, and often negative, resistances in the uncorrected data for the 8-, 15-, 30-, and 60- minute trials on Test 3A.

The data from Test 3A was corrected to account for the above-described residual torque. The procedure used to adjust torque readings on the 8-, 15-, 30-, 60-, and 120-minute trials on Test 3A was by averaging the last few (residual) torque readings recorded by the computer for the previous test, and adding that value to the torque readings of the subsequent test. When the data was corrected in this fashion, the residual torque at the 120- and 125-minute trials showed good correlation.

The data for Tests 1A through 2B were examined to see if similar corrections were warranted. The original data for the 60-minute trials on Tests 1B and 2B had similar initial torque magnitudes as the last torque readings on the 4-minute trial, and therefore no correction was necessary. The data for Tests 1A and 2A were found to be similar to that described in Test 3A, and were therefore similarly corrected.

Residual torque was eliminated on all future trials (Tests 3B and later) by removing the wormdrive assembly immediately after the end of each trial.

Data Collection Issues

Two additional torque trials encountered problems during data collection. The linear potentiometer on the 970-minute trial on Test 4A was not properly connected. Therefore, rotation angle values are not available for this trial. During the 4-minute trial on Test 4B, the computer was not configured properly to read data from the linear potentiometer; therefore, the rotation angle data obtained is not considered representative, and is not included in this report.

SPT-T TEST RESULTS

For each test, the data obtained for each torque trial are presented graphically in Figures D-1 through D-10. Four figures are presented for each test:

(a) SPT sampler unit shaft resistance versus rotation angle. These plots illustrate the variation of resistance (both peak and residual) related to angular movement. Relative movement (in inches) between the outside sampler surface and the adjacent soil can be obtained by multiplying the rotation angle by 0.01745.

(b) SPT sampler unit shaft resistance versus strain (defined as the relative soil/sampler movement divided by split-barrel sampler outside diameter). These plots are provided as per instructions from the WisDOT oversight committee.

(c) Rotation angle versus time. These plots illustrate the uniformity of rotation rate during a given trial and among trials.

(d) SPT sampler unit shaft resistance versus time. These plots incorporate data presented in figures (a) and (c) to provide an illustration of resistance variation over time during sampler rotation.

The total number of blows required for 18-inch penetration, sampler condition (unplugged/plugged), sample recovery (if applicable), and test depth/elevation are also noted on the plots.

Peak unit shaft resistances were determined for each SPT-T trial, and are presented, along with calculated set-up in Table 3 in the Appendix. Peak unit shaft resistances are plotted versus the logarithm of time in Figure D-11. Figures D-11a, D-11b, and D-11c illustrate peak unit shaft resistances versus time for tests performed in each soil stratum. Since staged tests have more data points than non-staged tests, comparisons between the two can be difficult. For this reason, Figure D-12 illustrates peak unit shaft resistances for plugged-sampler tests for only 4-minute and 60-minute trials (the only trials common to both staged and unstaged tests), thus eliminating intermediate trials, and unplugged tests. Peak unit shaft resistance comparing unplugged/plugged samplers is presented in Figure D-13. Peak unit shaft resistance of tests comparing staged/unstaged tests is presented in Figure D-14.

Unit set-up versus logarithm of time is presented for each SPT-T test in Figure D-15. Unit set-up is calculated by subtracting the peak unit shaft resistance determined for the 4-minute trial (the first trial subsequent to penetration) from the peak unit shaft resistance determined from a subsequent trial. A decrease in peak unit shaft resistance is relaxation; an increase is set-up.

OBSERVATIONS AND DISCUSSION

SPT Values in SPT-T Test Boring versus Boring P1421-02

A comparison of SPT values from Boring P1421-02 and values from the SPT-T boring is presented in Figure E-1. It should be noted that different drill rigs (and consequently different SPT hammers) were used for each boring. Also, recoveries varied, with most samples in Boring P1421-02 having recoveries ranging from 12 to 18 inches, compared with the SPT-T boring, where unplugged samples typically had 18-inch recoveries, and all plugged samples had zero recovery. Comparing only the SPT tests in the SPT-T boring using unplugged samplers with SPT tests at corresponding elevations in Boring P1421-02, the SPT “N” values corresponded well, with 5 of the 6 tests having less than 10 percent deviation.

SPT-T Test Data

This section discusses trends within the SPT-T test data, comparing SPT-T data by soil type, plugged versus unplugged samplers, and testing frequency (i.e., staged versus unstaged). The relationship between angular rotation and peak shaft resistance is also discussed.

General

Twelve tests showed set-up in the first two hours after penetration. Of these, eight tests (Tests 1A, 2A, 3A, 6A, 6B, 8A, 9A, and 9B) had set-up of 500 psf or greater, with two tests (Tests 8A and 9A) having set-up greater than 1000 psf. The remaining nine tests (Tests 3B, 4A, 4B, 4C, 5B, 7A, 7B, 10A, and 10B) had relaxation, with five tests (Tests 4B, 4C, 5B, 7A, and 10A) exhibiting relaxation greater than 200 psf.

In reviewing a plot of unit shaft resistances versus time on a semi-log graph (Figure D-11) unit shaft resistances of tests containing more than two data points typically followed a curvilinear path; unit shaft resistance first decreased, then increased (i.e., the plot is concave upward). This behavior was also exhibited in corresponding unit set-up data (Figure D-15). Since soil/pile set-up is seldom determined by restrike testing performed two hours or less after EOID, our experience has not indicated such curvilinear unit pile shaft resistance and unit soil/pile set-up behavior. The literature search performed for the precursor report reported no such trend identified in the literature. The precursor report does discuss the likelihood of unusual (and perhaps unpredictable) changes in pore pressure (and corresponding changes in unit shaft resistance and unit set-up) in relatively short time periods after pile installation. The observed curvilinear trends may likely substantiate that discussion.

All four tests having overnight (approximately 1000-minute) trials (Tests 1A, 4A, 6A, and 9A) showed long-term set-up. The addition of data from the overnight trial created a curvilinear trend when plotted on a semi-log graph (Figure D-11). However, these three tests were all unstaged, and therefore only had three data points. The remaining test (Test 1A), which was staged, had a somewhat linear shape, including the overnight trial. Tests 4A, 6A, and 9A had similar rates of both unit shaft resistance and unit set-up increase between the 60-minute and overnight trials; Test 1A had a somewhat slower rate.

Comparisons by Soil Type

As discussed in the background section, set-up is typically considered to be greatly affected by soil type. Trends in the SPT-T test data among soil types are discussed below.

Organic Clay - Given the low SPT blow counts in organic clay (which ranged from 0 to 2 blows per 18 inches), low shaft resistances would be expected from SPT-T testing. However, initial (4-minute) peak unit shaft resistances were considerable, varying from 950 to 1,400 psf. These magnitudes are similar to, and in some instances considerably greater than, tests performed in the denser/stronger soils of the upper silty clay strata (Figure D-11).

Unit set-up measured at the 60-minute trial ranged from 393 to 553 psf (excluding Test 1A, which exhibited an apparent anomaly at the 60-minute reading). These magnitudes were typically higher than the values measured by most SPT-T tests performed in underlying native inorganic soils.

Silty Clay - Unit shaft resistance is typically expected to increase with soil strength. Given the general increase in SPT “N” and unconfined compressive strength values with depth in Boring P1421-02, corresponding increases in initial (4-minute) SPT-T test unit shaft resistances could be expected. This trend was not apparent in data from most SPT-T tests performed in cohesive soils (Figure D-11b). Initial peak unit shaft resistances (sans Tests 6B and 7B) ranged from 703 to 1238 psf, which was generally slightly higher than what was encountered in the organic clay, and slightly to much lower than what was encountered in the underlying granular soils. No significant differences in initial unit shaft resistance were observed between the upper and lower portions of the silty clay stratum.

As discussed in the precursor report, cohesive soils typically exhibit relatively high unit set-up values, especially when compared to granular and organic soils. Unit set-up from SPT-T tests in cohesive inorganic soils at the 60-minute trial ranged from -495 to 877 psf, with the range of tests sans 6B ranging from -495 to 166 psf. These values are typically less than unit set-up measured in most tests in granular and organic soils.

Silty Sand - Peak initial unit shaft resistances in tests performed in silty sand varied considerably, from 966 to 4,382 psf (Figure D-11c). Considering blow counts (required for 18-inch sampler penetration) ranged from 11 to 59, such variability could be expected. Although it could be expected that initial shaft resistances in granular soils typically increase with SPT “N” value, this trend was not apparent in the SPT-T test data.

Unit set-up in SPT-T tests in granular soils (Tests 8 through 10) varied widely, varying from -163 to 1348 psf; however, most unit set-up values were typically higher than in cohesive soils.

The only test to realize significant unit set-up was 8A (which had 1,500 psf unit set-up over 60 minutes). However, Test 8A appears to be an anomaly, considering uniformity of results from nearby tests (7A, 7B, 9A, 9B, and 10A), which had similar blow counts, and were located in relatively high (as evidenced from the test pile program) set-up soils.

Plugged versus Unplugged Sampler

Tests 2, 4, 6, 8, and 10 compared the effect of plugged/unplugged samplers on both unit shaft resistance and unit set-up; this comparison is illustrated in Figure D-13. As would be expected, SPT blow counts were higher in tests using a plugged sampler than companion tests using an unplugged sampler, attributable to differences in the volume of displaced soil.

Initial (4-minute) unit shaft resistances for tests using an unplugged sampler were typically higher than the companion test using a plugged sampler. This may be attributable to plugged samplers displacing and disturbing more soil, resulting in greater excess porewater pressure and lower effective stress, compared to an unplugged sampler. However unit set-up was mixed, with plugged sampler tests having higher set-up than their companion tests in Tests 2, 4, and 6 (performed in the organic clay and silty clay strata), and unplugged sampler tests showing higher set-up in Tests 8 and 10 (performed in the silty sand stratum).

Staged versus Unstaged Testing

Net changes in unit shaft resistance over the first 60 minutes were similar between the staged and companion unstaged tests, as illustrated in Figure D-14.

Relationship Between Angular Rotation and Unit Peak Shaft Resistance

Unit shaft resistance typically reached a “peak” at relatively low rotation angles (typically under 10 degrees), afterwhich “residual” resistance was encountered. The initial (4-minute) trial unit shaft resistance typically peaked at a greater rotation angle than subsequent trials. Subsequent trials (2 hours and under) tended to have peak resistances at progressively lower rotation angles. Trials subsequent to the second trial typically peaked at increasing, albeit variably small, rotation angles. This behavior was seen in all tests except Tests 3B, 5B, 7A, 7B (where no peaks were apparent in most, or all, trials). Overnight tests performed on Tests 1A, 4A, 6A, and 9A all showed peak strengths occurring at rotation angles greater than the previous (including the initial) trial.

Peaks were typically more-pronounced over time. This trend is particularly evident in the staged tests. In some cases where short-term trials did not exhibit a definite peak, peaks were evident in longer-term trials. This is evident in Test 3B, where the absence of a peak in the 4-minute trial was followed by a peak in the 60-minute trial. Similar behavior was evident in Tests 3A, 6B, and 7A. It should be noted that the 4-, 8-, 15-, and 30-minute trials in these tests did not have a pronounced peak, but the 60- and 120-minute trials both did.

Comparison of SPT-T Test and Test Pile Unit Set-Up

Magnitude

Unit set-up from the SPT-T test 60-minute trial, and each test pile’s long-term set-up, versus elevation are presented in Figure E-2. Figure E-3 presents the correlation between the unit set-up from each SPT-T test (60-minute trial) and long-term unit set-up from each test pile at each SPT-T test elevation. Figure E-4 presents a comparison between unit set-up for the 60-minute trial for each SPT-T test and the average long-term unit set-up at each SPT-T elevation from the test pile program. Figure E-4 also identifies these data points by soil strata.

Figure E-2 indicates that the peak unit set-up from the SPT-T tests consistently underestimates soil/pile set-up. However, there does not appear to be any reasonable correlation throughout the data. This scatter is more apparent in Figure E-3. Trends within soil strata (Figure E-4) suggest relatively good correlation within the organic clay stratum; however the unit set-up magnitudes are relatively low, and may be influenced by the precision of testing and data reduction methods. Figure E-4 also suggests a negative correlation (decreasing soil/pile unit set-up with increasing SPT-T unit set-up) for the silty sand stratum, which is counterintuitive. The relationships illustrated within the silty clay stratum are relatively vertical, with a wide range of soil/pile unit set-up corresponding to negative or nominal set-up.

Time Rate

Some time of decreasing unit shaft resistance, followed by some time of increasing unit shaft resistance, was common in most staged SPT-T tests. Similarities in unit set-up values between staged and companion unstaged tests suggests that similar behavior exists for the unstaged tests as well. Since the time intervals between the SPT-T test and test pile program are considerably different, it is unclear if test piles exhibited similar behavior. Regardless, the decreasing/increasing trend exhibited in the SPT-T test data cannot be correlated to longer-term soil/pile set-up. Consequently, further analysis into the relationship between set-up rates from the SPT-T test and test pile programs was not performed.

CONCLUSIONS

The goal of this study was to assess the correlation of data from short-term unit set-up from SPT-T tests and long-term soil/pile set-up. There does not appear to be any correlation between unit set-up values from short-term (1 hour or less) SPT-T tests and unit set-up values obtained from long-term restrikes of test pile installations. The negative set-up exhibited in many short-term SPT-T tests followed by positive set-up also contributes skepticism to using this procedure as a tool in set-up estimation. Therefore, short-term SPT-T testing does not appear to be a practical, economical method to use in exploration-phase testing to predict soil/pile set-up.

Secondary objectives yielded somewhat better results; the plugged and unplugged samplers exhibited different behavior, the staged and unstaged tests exhibited similar behavior. The mechanical equipment improved on equipment described in other SPT-T test research by providing a more-constant rate of rotation, lessening the potential for introducing bending in the SPT rod, and maintaining positioning of the entire assembly. The electronic equipment made it possible to determine not only torque, but also angular rotation. The combination of the mechanical and electronic equipment yielded what could be considered the most-precise method of torque application and data collection developed for the SPT-T test to-date.

Although not directly pertinent to the purpose of this test program, trends in the data obtained in this test program may provide additional insight into set-up behavior over very short time intervals (specifically short-term relaxation preceding set-up). Given the apparent lack of correlation between results from SPT-T testing and the test pile program, additional analysis and discussion was beyond the project scope.

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TABLES AND APPENDICES

Tables

Appendices

Table 1. Relationships Between EOID and BOR Capacity Mobilization and Set-Up Determination.

		Beginning of Restrike (BOR)	
		Mobilized	Not Fully Mobilized
End of Initial Drive (EOID)	Fully Mobilized	SLT-F-16F-1 BOR1, BOR3 SLT-F-16P-2 BOR1, BOR3, BOR4 SLT-F-12-3S BOR1 SLT-F-14-4 BOR1, BOR3, BOR4 SLT-F-14-5 BOR1*, BOR4 SET-UP CONSIDERED ACCURATE	SLT-F-16F-1 BOR2 SLT-F-16P-2 BOR2 SLT-F-14-4 BOR2 SLT-F-14-5 BOR1*, BOR2, BOR3 SET-UP LIKELY UNDERREPORTED
	Not Fully Mobilized	SLT-F-12-6C BOR3, BOR4 SET-UP LIKELY OVERREPORTED	SLT-F-12-6C BOR1, BOR2 SET-UP INDETERMINATE

* Equivalent penetration resistance of 120 blows per foot (borderline condition).

Table 2. Depths, Elevations, Time Intervals, and Sampler Type for SPT-T Testing

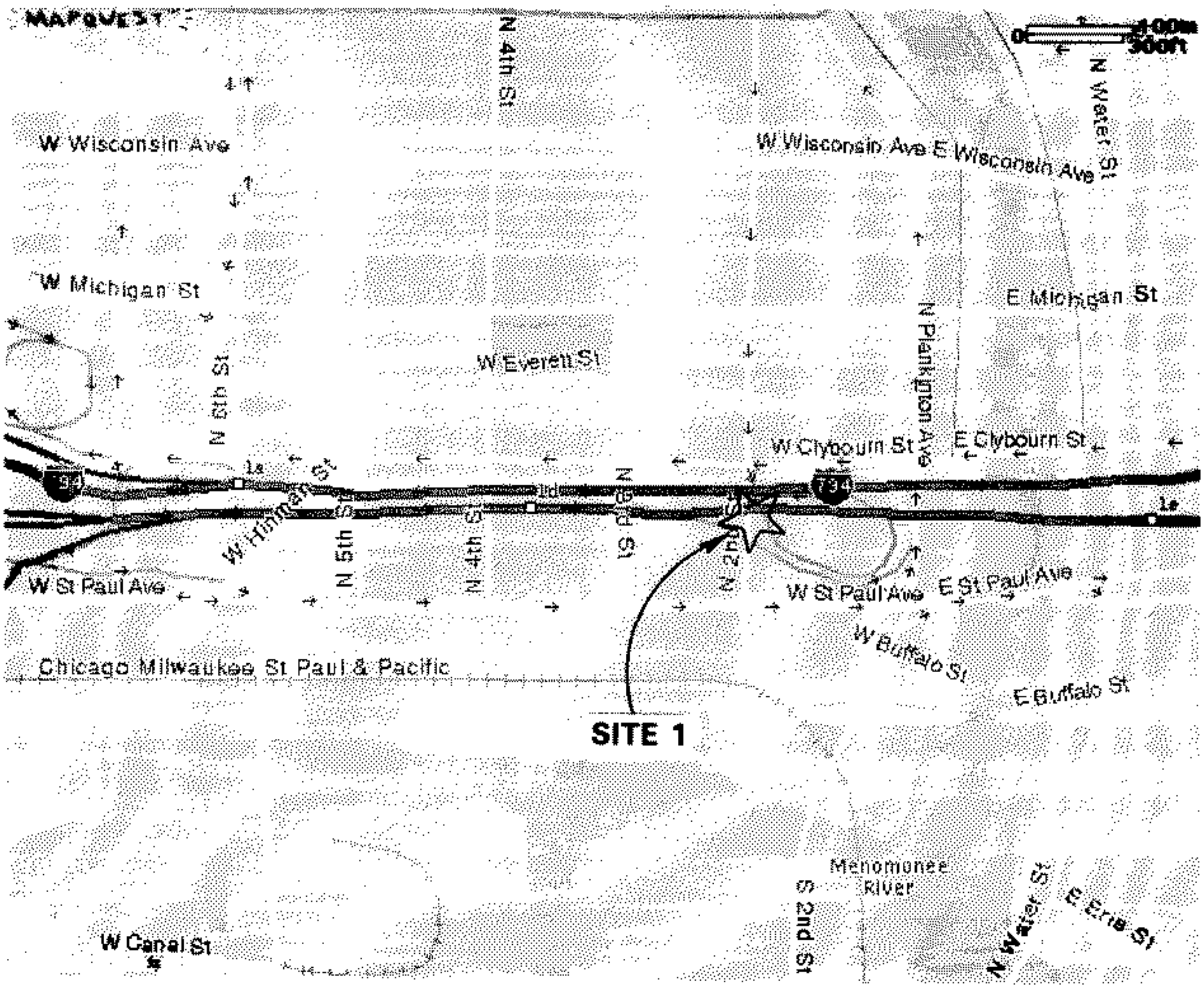
Test ID	Depth, feet (Elevation, feet)	Torque Trial Time, minutes after penetration	Sampler Type
1A	27.5-29.0 (560.5-559.0)	4, 8, 15, 30, 60, 120, 959	Plugged
1B	30.0-31.5 (558.0-556.5)	4, 60	Plugged
2A	42.0-43.5 (546.0-544.5)	4, 60	Plugged
2B	44.5-46.0 (543.5-542.0)	4, 60	Unplugged
3A	69.0-70.5 (519.0-517.5)	4, 8, 15, 30, 60, 120	Plugged
3B	71.5-73.0 (516.5-515.0)	4, 60	Plugged
4A	79.0-80.5 (509.0-507.5)	4, 60, 970	Plugged
4B	81.5-83.0 (506.5-505.0)	4, 6, 10, 60	Unplugged
4C	84.0-85.5 (504.0-502.5)	4, 60	Unplugged
5A	89.0-90.5 (499.0-497.5)	4, 8, 15, 30, 60, 120	Plugged
5B	91.5-93.0 (496.5-495.0)	4, 60	Plugged
6A	100-101.5 (488.0-486.5)	4, 60, 1007	Plugged
6B	102.5-104.0 (485.5-484.0)	4, 60	Unplugged
7A	111.0-112.5 (477.0-475.5)	4, 8, 15, 30, 60, 120	Plugged
7B	113.5-115.0 (474.5-473.0)	4, 60	Plugged
8A	124.0-125.5 (464.0-462.5)	4, 60	Plugged
8B	126.5-128.0 (461.5-460.0)	4, 60	Unplugged
9A	132.0-133.5 (456.0-454.5)	4, 60, 890	Plugged
9B	134.5-136.0 (453.5-452.0)	4, 8, 15, 30, 60, 120	Plugged
10A	140.0-141.5 (448.0-446.5)	4, 60	Plugged
10B	142.5-144.0 (445.5-444.0)	4, 60	Unplugged

Table 3 – Summary of SPT-T Test Data

Test ID	Depth (Elevation), feet	Trial Time after SPT penetration, minutes	SPT Blows per 18 inches	Sampler Type and recovery (unplugged)	Peak Unit Shaft Resistance, psf	Unit Set-up, psf
1A	28.3 (560.3)	4	0	Plugged	1084	n/a
		8			950	-134
		15			1281	197
		30			1507	423
		60			1249	165
		120			1477	393
		959			1778	694
1B	30.8 (557.8)	4	1	Plugged	589	n/a
		60			1032	443
2A	42.8 (545.8)	4	2	Plugged	1030	n/a
		60			1583	553
2B	45.3 (543.3)	4	2	Unplugged (18-in rec)	1416	n/a
		60			1809	393
3A	69.8 (518.8)	4	12	Plugged	703	n/a
		8			509	-194
		15			461	-242
		30			565	-138
		60			869	166
		120			1450	747
		125			1173	470
3B	72.3 (516.3)	4	15	Plugged	906	n/a
		60			902	-4
4A	79.8 (508.8)	4	26	Plugged	1238	n/a
		60			1198	-40
		966			1947	709
4B	82.3 (506.3)	4	23	Unplugged (1-in rec)	910	n/a
		6			574	-336
		10			604	-306
		60			683	-227
4C	84.8 (503.8)	4	23	Unplugged (15-in rec)	1164	n/a
		60			882	-282
5A	89.8 (498.8)	4	26	Plugged	871	n/a
		8			643	-228
		15			568	-303
		30			634	-237
		60			787	-84
		120			946	75

Table 3 – Summary of SPT-T Test Data, con't

Test ID	Depth (Elevation), feet	Trial Time after SPT penetration, minutes	SPT Blows per 18 inches	Sampler Type and recovery (unplugged)	Peak Unit Shaft Resistance, psf	Unit Set-up, psf
5B	92.3 (496.3)	4	28	Plugged	1125	n/a
		60			897	-228
6A	100.8 (487.8)	4	21	Plugged	792	n/a
		60			817	25
		1007			1684	892
6B	103.3 (485.3)	4	7	Unplugged (18-in rec)	440	n/a
		60			1317	877
7A	111.8 (476.8)	4	32	Plugged	1743	n/a
		8			1352	-391
		15			1308	-435
		30			1313	-430
		60			1248	-495
		120			1485	-258
7B	114.3 (474.3)	4	48	Plugged	3100	n/a
		60			2977	-123
8A	124.8 (463.8)	4	39	Plugged	3803	n/a
		60			5151	1347
8B	127.3 (461.3)	4	11	Unplugged (18-in rec)	1387	n/a
		60			1635	248
9A	132.8 (455.8)	4	33	Plugged	1224	n/a
		60			1699	475
		898			2897	1673
9B	135.3 (453.8)	4	36	Plugged	966	n/a
		8			1244	278
		15			1174	208
		30			1288	322
		60			1560	594
		120			1565	599
10A	140.8 (447.8)	4	59	Plugged	3377	n/a
		60			2976	-401
10B	143.3 (445.3)	4	45	Unplugged (18-inch rec)	4382	n/a
		60			4219	-163



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SITE LOCATION MAP – SITE 1

SPT-T TEST INVESTIGATION - MILWAUKEE, WI

FIGURE NO. A-1

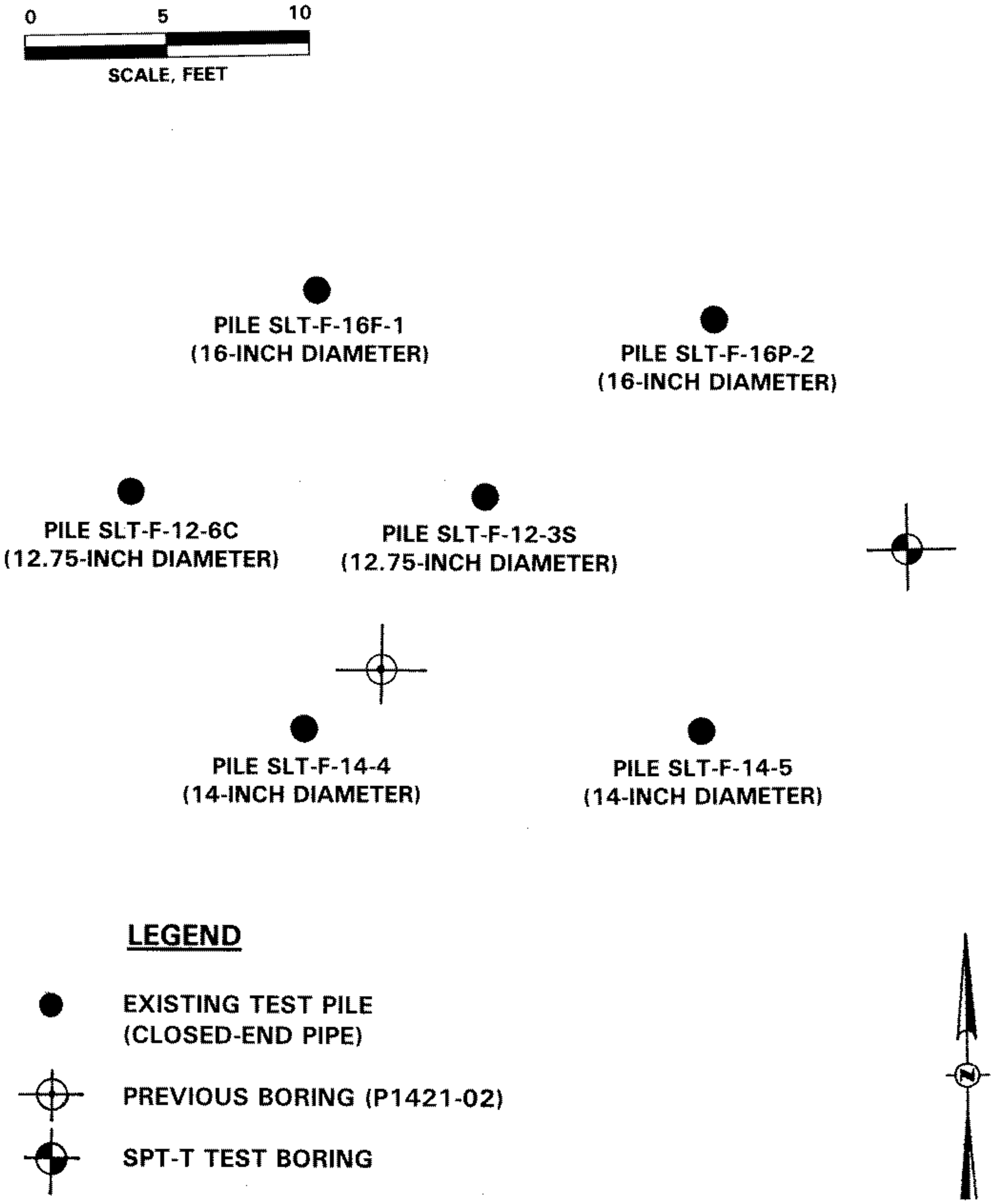
PROJECT NO. 03037

DATE 02-12-04

DRAWN BY RKM

CHECKED BY CJW

SCALE NONE



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SITE 1 - SOIL BORING AND PILE LOCATION DIAGRAM

SPT-T TEST INVESTIGATION - MILWAUKEE, WI

DATE 02-12-04	DRAWN BY RKM	CHECKED BY CJW	SCALE SHOWN

FIGURE NO. A-2

PROJECT NO. 03037

Milwaukee Transportation Partners

LOG OF TEST BORING

Page 1 of 7

acility/Project Name **Iarquette Interchange**
License/Permit/Monitoring Number
Boring Number **P1421-02**

Boring Drilled By: Name of crew chief (first, last) and Firm **SES – Steve Hunger**
Date Drilling Started **11 / 04 / 02** mm dd yy
Date Drilling Completed **11 / 08 / 02** mm dd yy
Drilling Method **Mud Rotary**

WI Unique Well No.
DNR Well ID No.
Well Name
Final Static Water Level ____ Feet MSL
Surface Elevation 588.50 Feet MSL
Borehole Diameter 7"

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☐
State Plane 298422 N, 604936 E S/C/N | Lat ___° ___' ___"
____1/4 of ____1/4 of Section ____, T ____ N, R ____ E/W | Long ___° ___' ___"
Local Grid Location
☐ N ☐ E
____ Feet ☐ S ____ Feet ☐ W

Facility ID
County **Milwaukee**
County Code **41**
Civil Town/City/or Village **Milwaukee, WI**

Sample									Soil Properties					
Number and Type	Length Recovered (in.)	Blow Counts	Depth in Feet (below ground surface)	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength Lab Qu is bold	% Moisture Content	Liquid Limit	Plasticity Index	P 200 (% silt / clay)	Moist / Dry Weight (pcf)
				1" BITUMINOUS	HF	▤								
1-2.5 SS-1	12	13	2	0.1' SILTY CLAY – stiff to medium stiff, brown, moist, trace fine sand and gravel	CL	▨		0.0						
3.5-5 SS-2	8	5	4					0.0	1.5	12.2	21	9		
			6											
6-7.5 SS-3	8	7						0.0	0.75					
			8											
8.5-10 SS-4	14	7	10					0.0		13.6				
11-12.5 SS-5	5	6	12	11.0' ORGANIC CLAY – soft, black to gray, moist, trace to some silt Loss On Ignition = 2.0%	OL	▦		0.0		19.3				
13.5-15 SS-6	8	2	14	With marl				0.0	0.25					
			16											
16-17.5 SS-7	NR	--						0.0	<0.25					
17.5-18.5 ST	NR	ST	18											
18.5-20 SS-8	18	WOH	20	Silty Loss On Ignition = 6.8%						60.4				
20-21 ST	16	ST		Gs=2.574; e_o=1.748; Pc=2500 psf; Cc=0.490; Cs=0.031						73.6 71.7				99.1/ 57.1 100.6/ 58.6
21-22.5 SS-9	18	WOH	22					0.0						
3.5-25 SS-10	18	WOH	24					0.0	<0.25					

Continued on page 2

Sample		Blow Counts	Depth in Feet (below ground surface)	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Soil Properties					Moist / Dry Weight (pcf)
Number and Type	Length Recovered (in.)								Compressive Strength Lab Qu Is bold	% Moisture Content	Liquid Limit	Plasticity Index	P 200 (% silt / clay)	
			26 28	ORGANIC CLAY continued from page 1	OL	▨								
28.5-30 SS-11	18	2	30			▨		0.0	0.25	57.8	52	14		
			32			▨								
33.5-35 SS-12	18	2	34			▨		0.0						
			36 38			▨								
38.5-40 SS-13	18	5	40			▨		0.0	0.25	63.1				
			42			▨								
43.5-45 SS-14	18	3	44			▨		0.0	1.5					
			46 48			▨								
48.5-50 SS-15	18	2	50	Loss On Ignition = 7.0%		▨		0.0		64.3				
			52			▨								
53.5-55 SS-16	18	3	54			▨		0.0						
			56			▨								
57.5-58.5 ST	15	ST	58	58.0'		▨				49.6 33.6	40	12		
58.5-60 SS-17	18	5	60	SILTY SAND – loose, greenish-gray, wet, medium to coarse grained, trace gravel	SM	░		0.0						

Continued on page 3

Sample										Soil Properties				
Number and Type	Length Recovered (in.)	Blow Counts	Depth in Feet (below ground surface)	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength Lab Qu is bolded	% Moisture Content	Liquid Limit	Plasticity Index	P 200 (% silt / clay)	Moist / Dry Weight (pcf)
				SILTY SAND continued from page 2	SM									
			62	61.0' SILTY CLAY – stiff to very stiff, gray, moist to wet, trace coarse sand	CL	▨								
63.5-65 SS-18	NR	23	64											
			66											
			68											
68.5-70 SS-19	15	15	70					0.0	1.25	13.1				
			72											
73.5-75 SS-20	14	12	74	Moist, trace to some sand				0.0	1.0					
			76											
			78											
78.5-80 SS-21	16	9	80					0.0	1.25	11.9				
			82											
83.5-85 SS-22	18	23	84					0.0	2.25					
			86											
			88											
88.5-90 SS-23	18	15	90					0.0	1.5	13.1	18	7		
			92											
93.5-95 SS-24	18	21	94					0.0	2.25					
			96											

Continued on page 4

Facility/Project Name: **Marquette Interchange**
Boring Number **P1421-02**

Sample									Soil Properties					
N and Type	Length Recovered (in.)	Blow Counts	Depth in Feet (below ground surface)	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength Lab Qu is bolded	% Moisture Content	Liquid Limit	Plasticity Index	P 200 (% silt / clay)	Moist / Dry Weight (pcf)
				SILTY CLAY continued from page 3	CL									
97.5-98.5 ST	12	ST	98						2.89	11.7				147.2/ 131.8
98.5-100 SS-25	18	20	100					0.0	1.5					
			102											
103.5-105 SS-26	18	7	104	Saturated silt seam				0.0	0.50	19.7				
			106											
			108											
108.5-110 SS-27	18	29	110	Some medium gravel				0.0	2.5					
			112											
113.5-115 SS-28	18	38	114					0.0	4.0					
			116											
			118											
118.5-120 SS-29	18	26	120	Wet sand seams				0.0	2.0					
			122	122.0'										
				SILTY SAND – dense to very dense, gray, wet, fine to medium grained	SM									
123.5-125 SS-30	12	34	124					0.0		16.6			19.6	
			126											
			128											
28.5-130 S-31	9	51	130	Fine grained				0.0						

Continued on page 5

Facility/Project Name: **Marquette Interchange**
Boring Number **P1421-02**

Sample		Blow Counts	Depth in Feet (below ground surface)	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Soil Properties					Moist / Dry Weight (pcf)
Number and Type	Length Recovered (in.)								Compressive Strength Lab Qu is bolded	% Moisture Content	Liquid Limit	Plasticity Index	P 200 (% silt / clay)	
			132	SILTY SAND continued from page 4	SM									
133.5-135 SS-32	12	48	134	Fine grained, some silt				0.0						
			136											
			138											
138.5-140 SS-33	16	51						0.0		13.2				
			140											
			142											
143.5-145 SS-34	12	41	144	Coarse sand with trace to some fine gravel				0.0						
			146											
			148											
148.5-150 SS-35	10	38						0.0						
			150											
			152											
153.5-155 SS-36	12	27	154					0.0						
				155.0'										
			156	SILTY CLAY – very stiff to hard, gray, moist, trace gravel, trace sand	CL									
			158											
158.5-160 SS-37	10	61		Silty sand Lenses – dense to very dense, gray, moist, fine grained				0.0	3.25	8.7				
			160											
			162											
163.5-165 SS-38	12	57	164	Continued on page 6				0.0						

Sample									Soil Properties					
Number and Type	Length Recovered (in.)	Blow Counts	Depth in Feet (below ground surface)	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength Lab Qu is bolded	% Moisture Content	Liquid Limit	Plasticity Index	P 200 (% silt / clay)	Moist / Dry Weight (pcf)
			166	SILTY CLAY continued from page 5	CL	▨								
			168											
168.5-170 SS-39	16	35						0.0	4.5+	24.7				
			170											
			172											
172.5-173.5 ST	12	ST								26.6	50	25		122.8/ 97.0
173.5-175 SS-40	18	25	174					0.0	3.6					
			176											
			178											
178.5-180 SS-41	18	30		No sand seams noted				0.0	4.0	26.7	43	23		
			180											
			182											
183.5-185 SS-42	12	56	184					0.0		17.2				
				184.5' SILTY SAND – very dense, gray, wet, fine to medium grained	SM-SP	⁙								
			186											
			188											
188.5-190 SS-43	<1"	100/1"		188.5' Dolomite rock		░								167.1
			190											
			192											
			194											
			196											
			198											
			200											

Continued on page 7

Facility/Project Name: **Marquette Interchange**
Boring Number **P1421-02**

Sample									Soil Properties					
No. and Type	Length Recovered (in.)	Blow Counts	Depth in Feet (below ground surface)	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength Lab Qu is bolded	% Moisture Content	Liquid Limit	Plasticity Index	P 200 (% silt / clay)	Moist / Dry Weight (pcf)
			202	Dolomite rock continued from page 6		▨								
				End of Boring @ 203.5 feet below grade Water emcountered @ 12.0 feet below grade										

WKG²
Wagner Komurka Geotechnical Group, Inc.

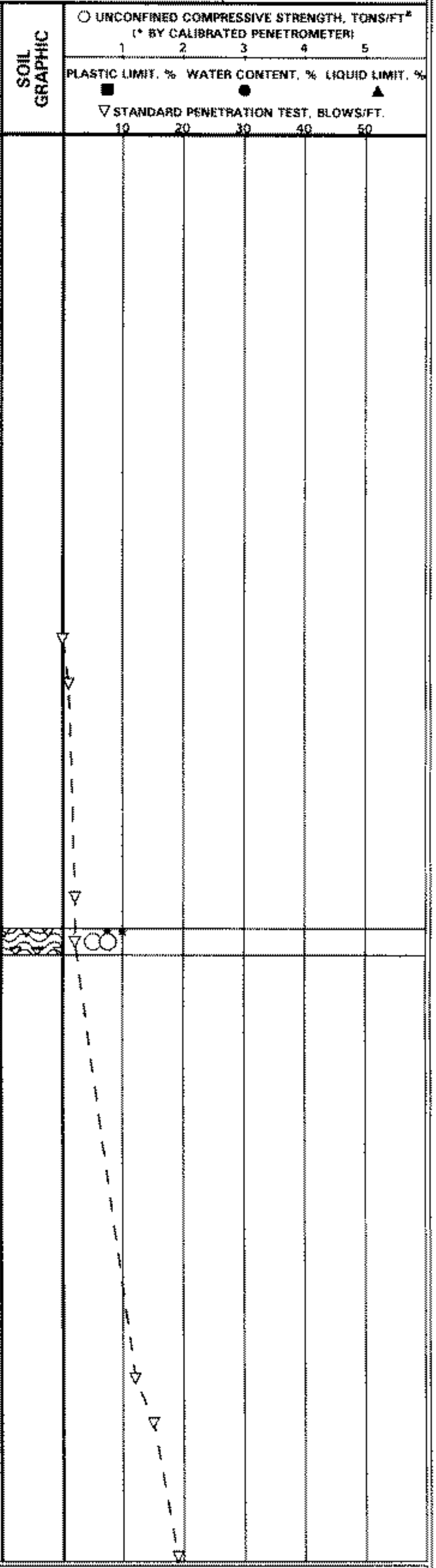
PROJECT NAME SPT-T Investigation	**SITE LOCATION** Milwaukee, Wisconsin	**BORING NO.** SPT-T
OWNER Wisconsin Department of Transportation	**ARCHITECT/ENGINEER**	**SHEET** 1 **OF** 2

STATION: **OFFSET:**
NORTHING: **EASTING:**
SURFACE ELEVATION: + 588.5 feet (NGVD-29 Datum)

SOIL/ROCK DESCRIPTION

ELEVATION/ DEPTH, FEET	SAMPLE NUMBER	SAMPLE TYPE	LENGTH	RECOV'RY	SOIL/ROCK DESCRIPTION
588.5 / 0					Plugged Sampler (no recovery)
	1A	SS			
	1B	SS			
	2A	SS			
544.0 / 44.5	2B	SS			Organic silt, little sand, with shells - gray - wet - very loose (ol)
542.5 / 46.0					Plugged Sampler (no recovery)
	3A	SS			
	3B	SS			

Elevation scale: 580, 570, 560, 550, 540, 530, 520, 510. Depth scale: 0, 10, 20, 30, 40, 50, 60, 70, 80.



THE STRATIFICATION LINES REPRESENT APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES; IN-SITU, THE TRANSITIONS MAY BE GRADUAL.

DRILLING COMPANY Wisconsin DOT	**RIG/HAMMER** CME 550/Auto	**FOREMAN** Joel	**BORING STARTED** 11-10-03	**BORING COMPLETED** 11-14-03
WATER LEVEL(S)		**INSPECTOR(S)** CJW	**APPROVED BY** CJW	**PROJECT NO.** 03037

WKG² Wagner Komurka Geotechnical Group, Inc.	PROJECT NAME SPT-T Investigation	SITE LOCATION Milwaukee, Wisconsin	BORING NO. SPT-T
	OWNER Wisconsin Department of Transportation	ARCHITECT/ENGINEER	SHEET 2 OF 2

SOIL/ROCK DESCRIPTION

STATION: OFFSET:
NORTHING: EASTING:

SURFACE ELEVATION: +588.5 feet (NGVD-29 Datum)

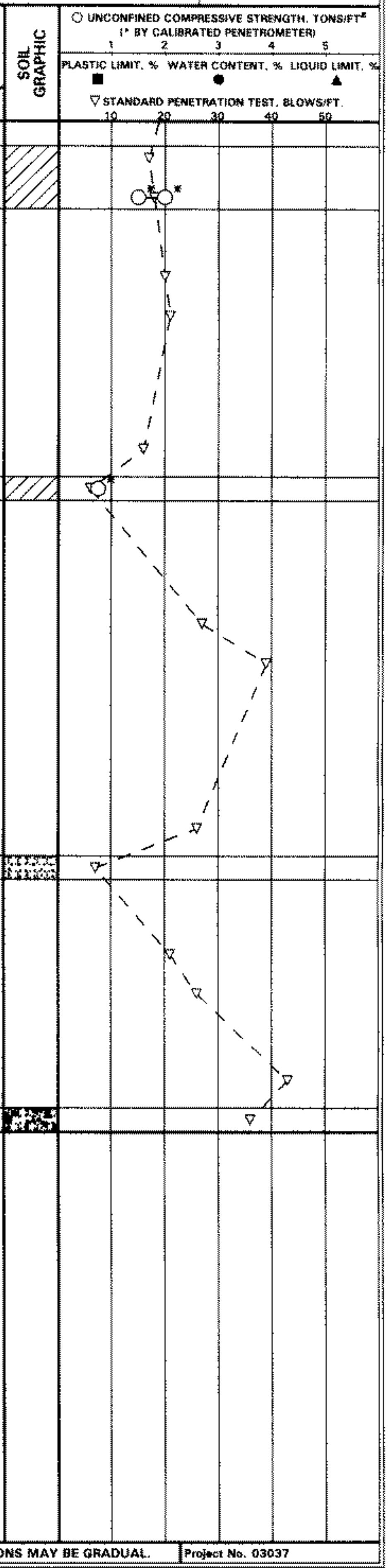
ELEVATION/ DEPTH, FEET	SAMPLE NUMBER	SAMPLE TYPE	SOIL/ROCK DESCRIPTION	Elevation	Depth
	4A	SS		507.0	81.5
	4B	SS	Silty clay, little sand, trace gravel - gray - stiff to very stiff (cl) **Note**: Sample 4B had stone in tip.		
	4C	SS		503.0	86.5
			Plugged Sampler (no recovery)		
500 / 90	5A	SS			
	5B	SS			
490 / 100	6A	SS		486.0	102.5
	6B	SS	Silty clay, little sand, trace gravel - gray - medium stiff (cl)	484.5	104.0
			Plugged Sampler (no recovery)		
480 / 110	7A	SS			
	7B	SS			
470 / 120	8A	SS		462.0	126.5
	8B	SS	Silty fine sand, trace clay - gray - wet - loose (sm)	460.5	128.0
460 / 130			Plugged Sampler (no recovery)		
	9A	SS			
	9B	SS			
450 / 140	10A	SS		446.0	142.5
	10B	SS	Silty sand and gravel - brownish gray - wet - dense (sm, gm)	444.5	144.0
440 / 150					
430 / 160					
420 / 170					

End of Boring.

Boring advanced to 10 feet using 4.25-inch-I.D. hollow- stem auger with center plug; boring advanced from 10 to 142.5 feet using 3.875-inch tri-cone rotary bit and recirculating drilling fluid.

10 feet of 4-inch-I.D. temporary steel casing installed.

Boring grouted upon completion.



THE STRATIFICATION LINES REPRESENT APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES; IN-SITU, THE TRANSITIONS MAY BE GRADUAL.

Project No. 03037

Figure B-1 - Unit Set-Up vs. Elevation - Test Pile SLT-F-16F-1

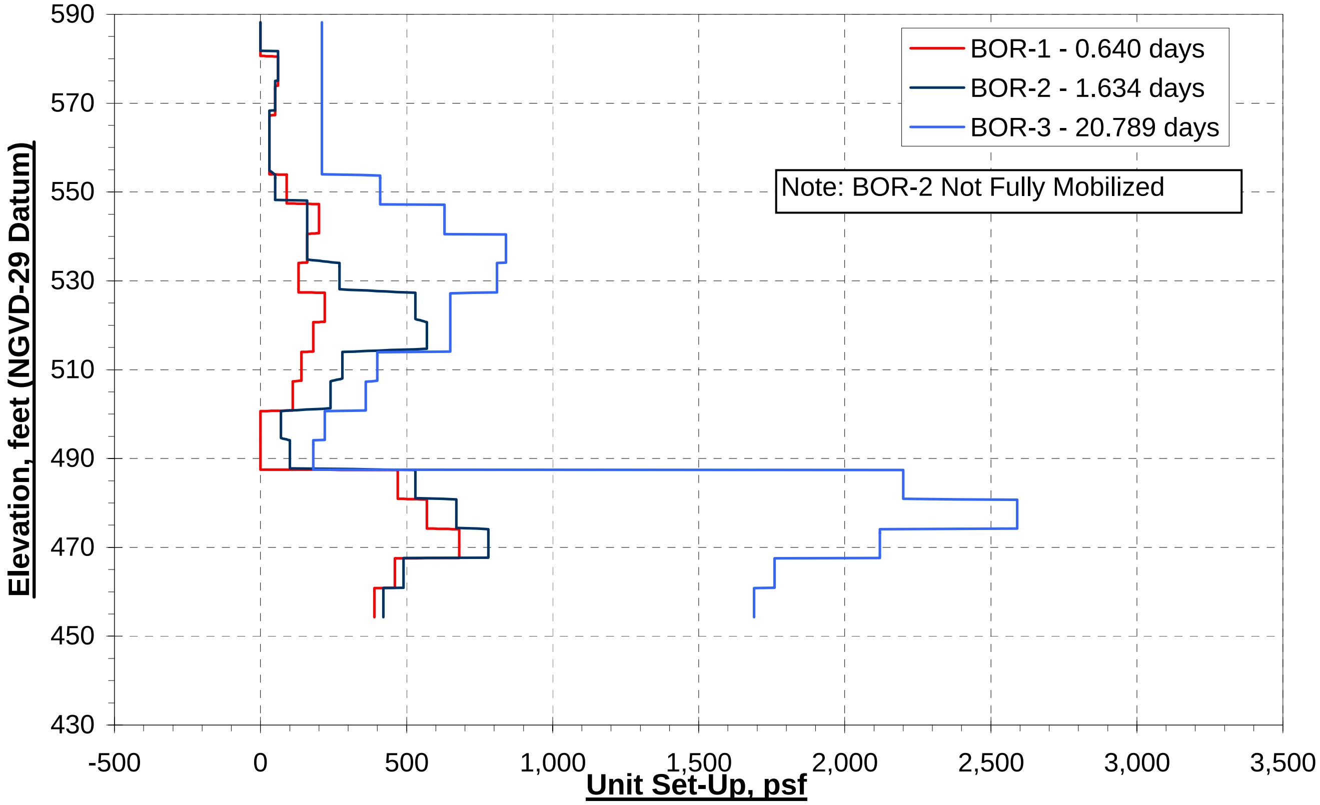


Figure B-2 - Unit Set-Up vs. Elevation - Test Pile SLT-F-16P-2

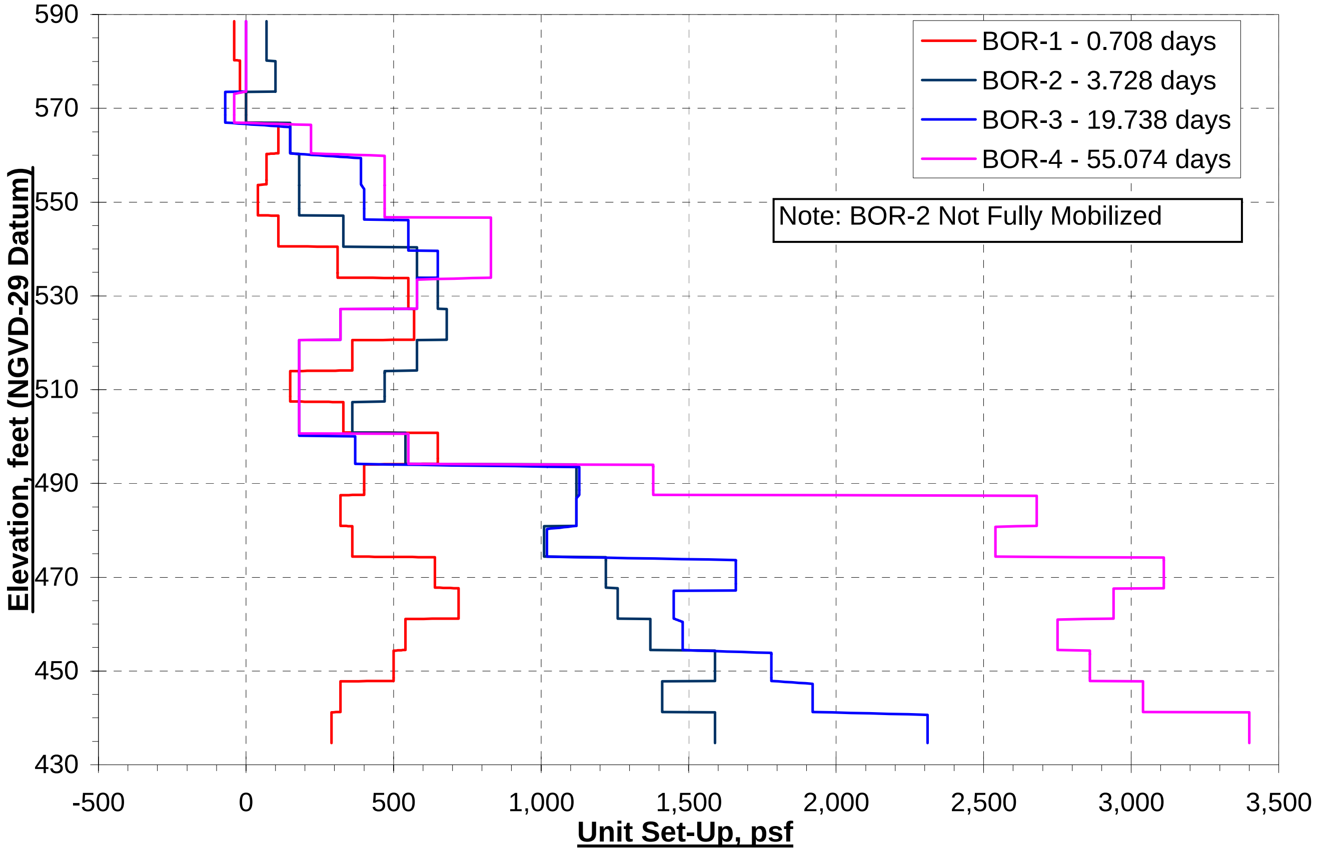


Figure B-3 - Unit Set-Up vs. Elevation - Test Pile SLT-F-12-3S

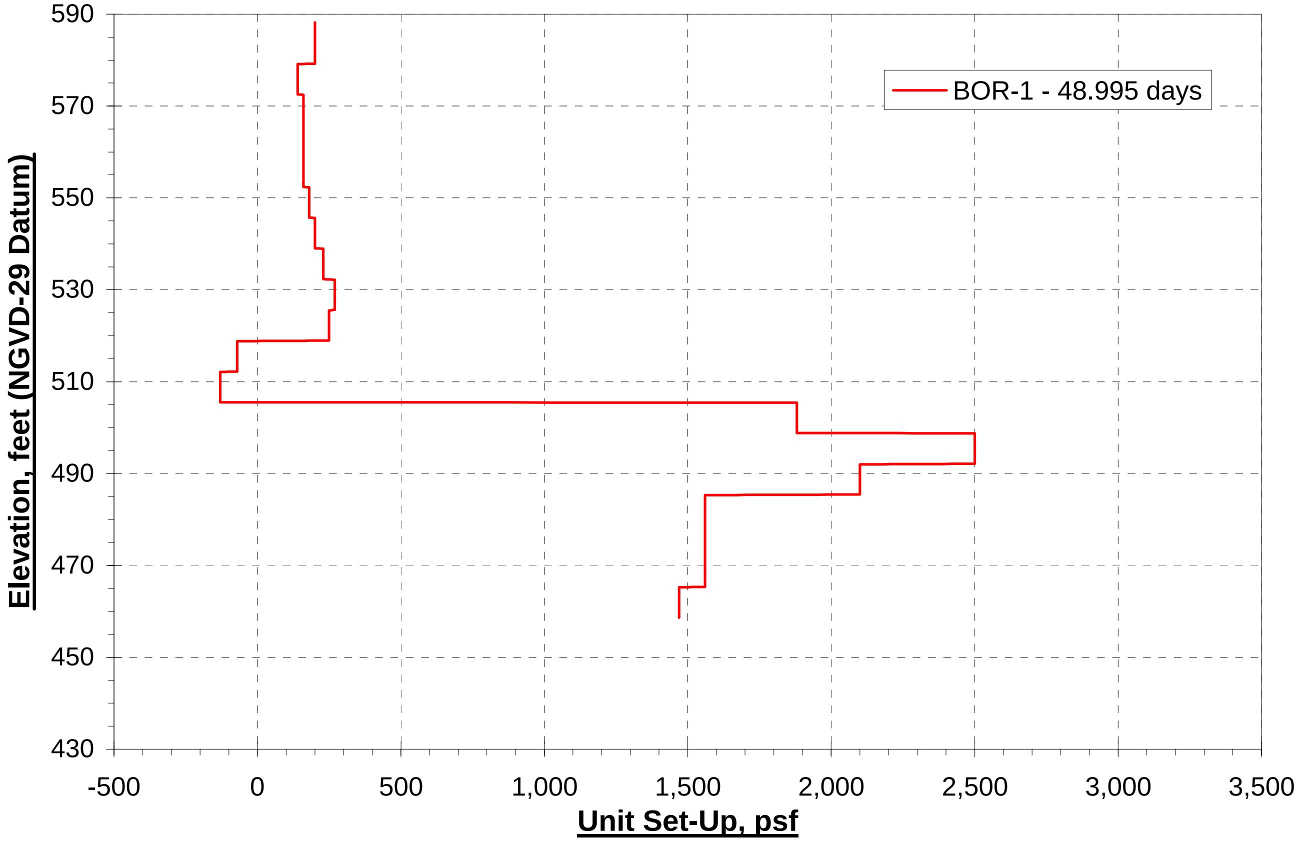


Figure B-4 - Unit Set-Up vs. Elevation - Test Pile SLT-F-14-4

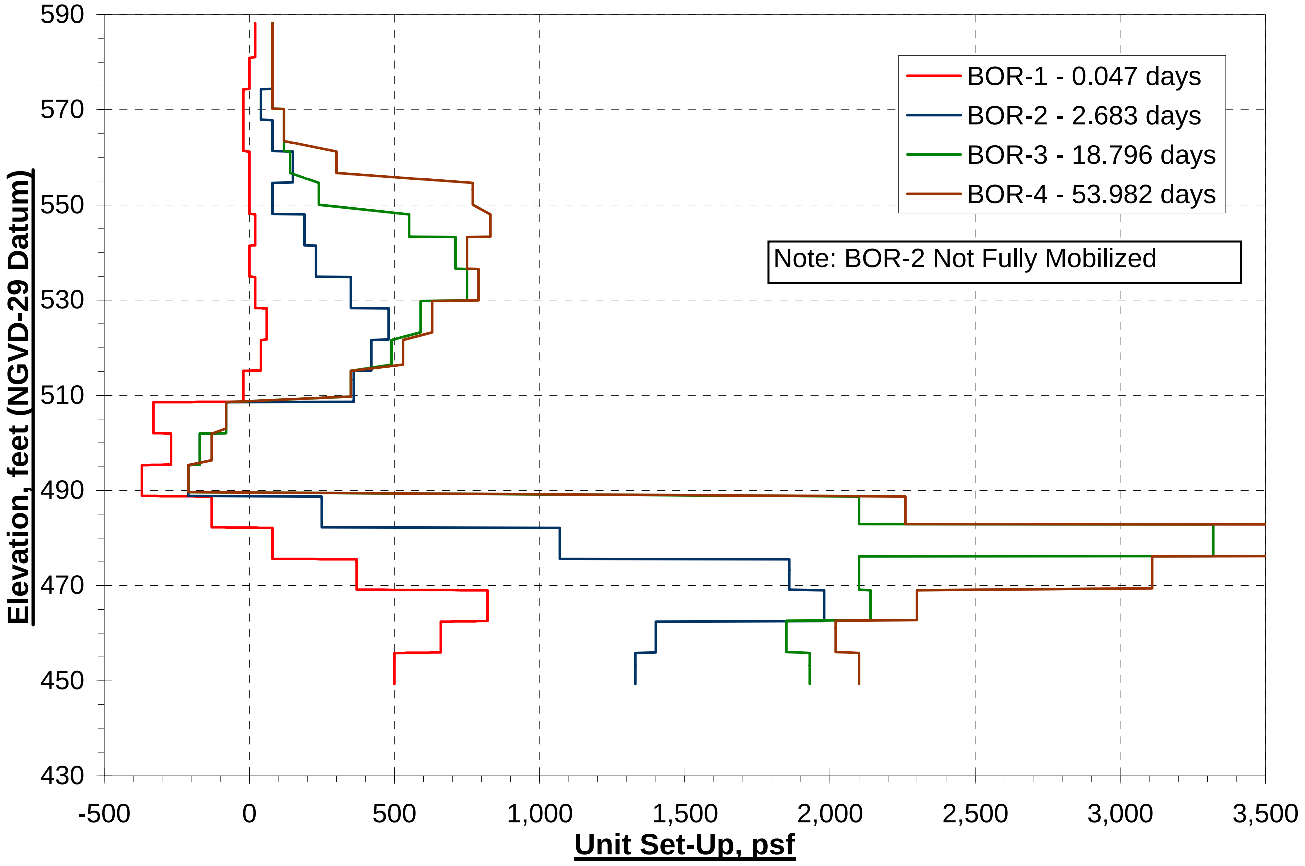


Figure B-5 - Unit Set-Up vs. Elevation - Test Pile SLT-F-14-5

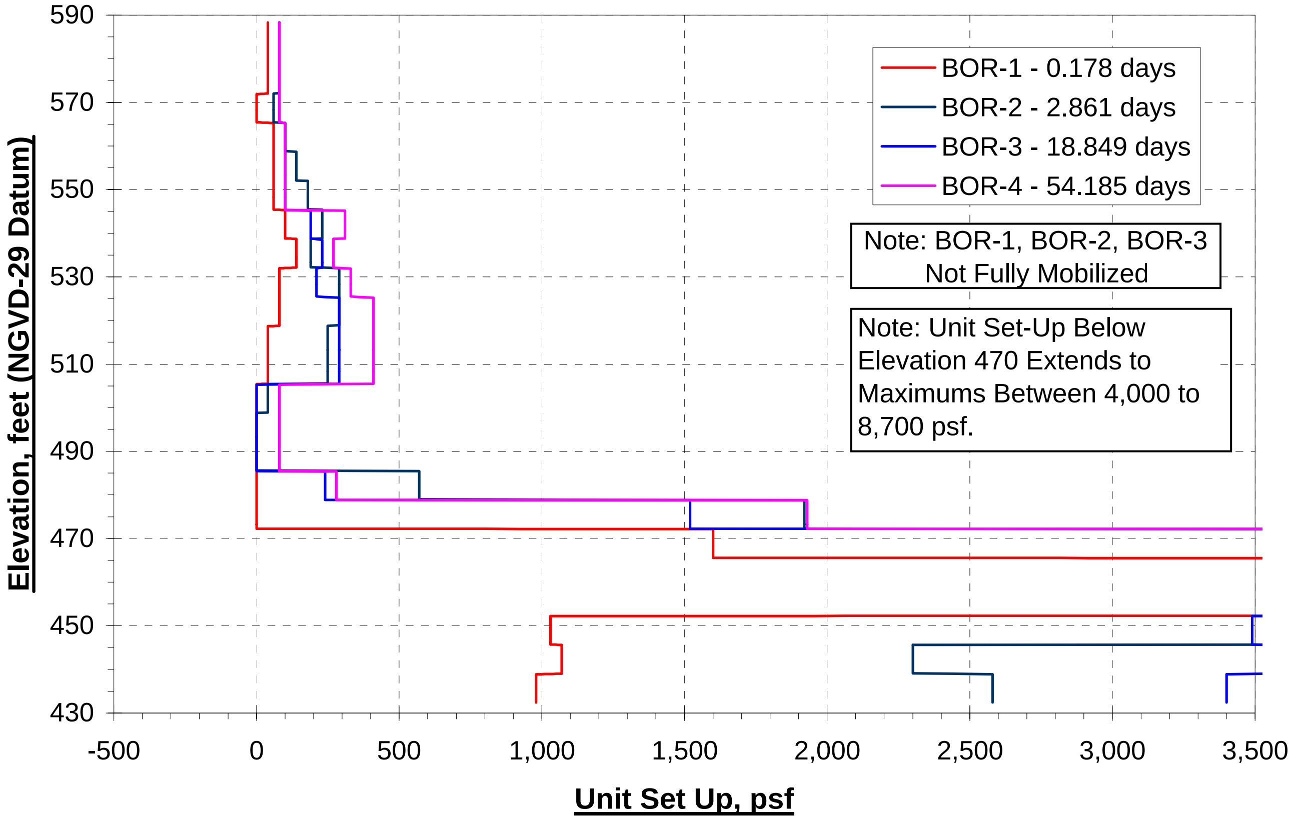


Figure B-6 - Unit Set-Up vs. Elevation - Test Pile SLT-F-12-6C

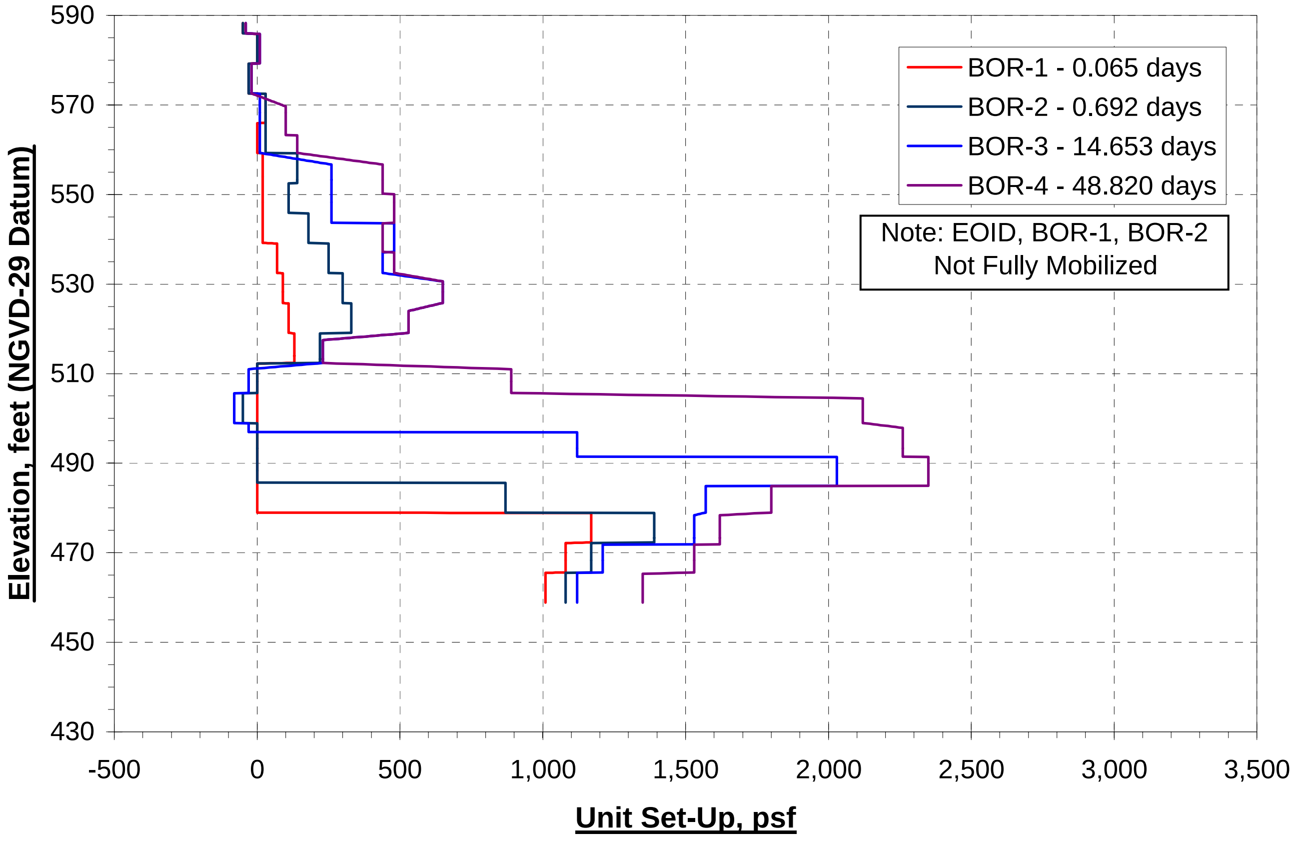


Figure B-7 - Last Restrike Unit Set-Up vs. Elevation - SLT-F Test Piles

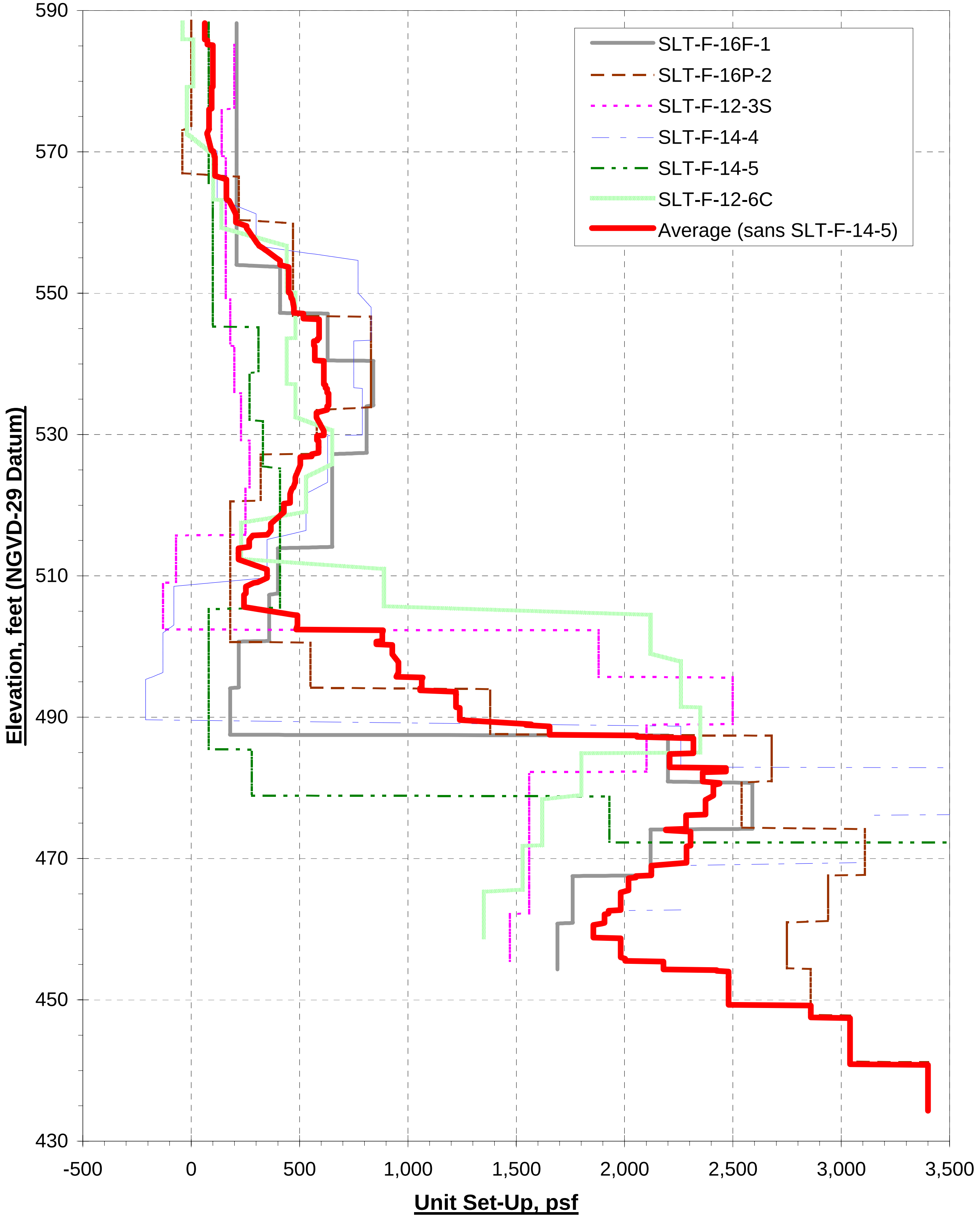


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Figure B-8 - Aggregate Unit Set-Up by Soil Type vs. Time

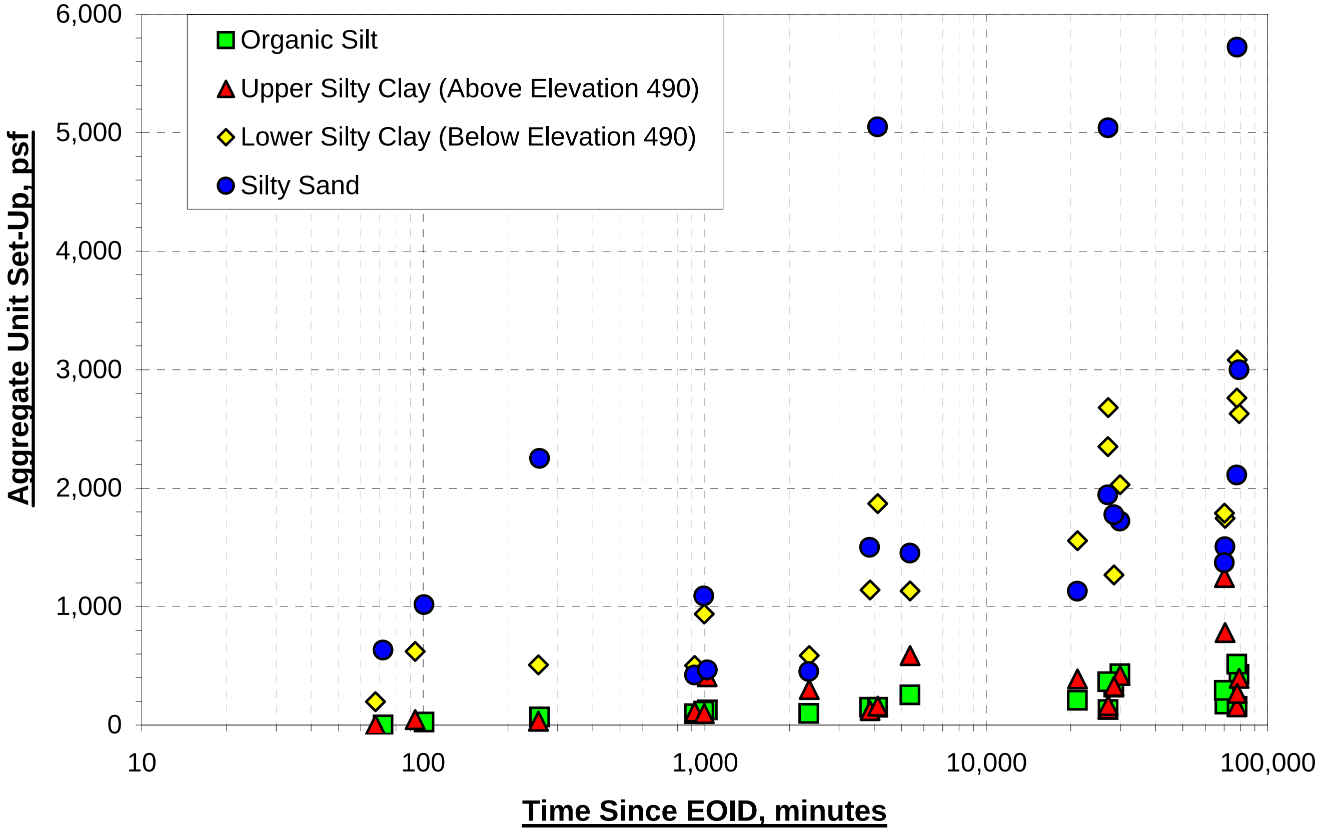

Figure B-8a - Average Aggregate Unit Set-Up vs. Time - Organic Silt

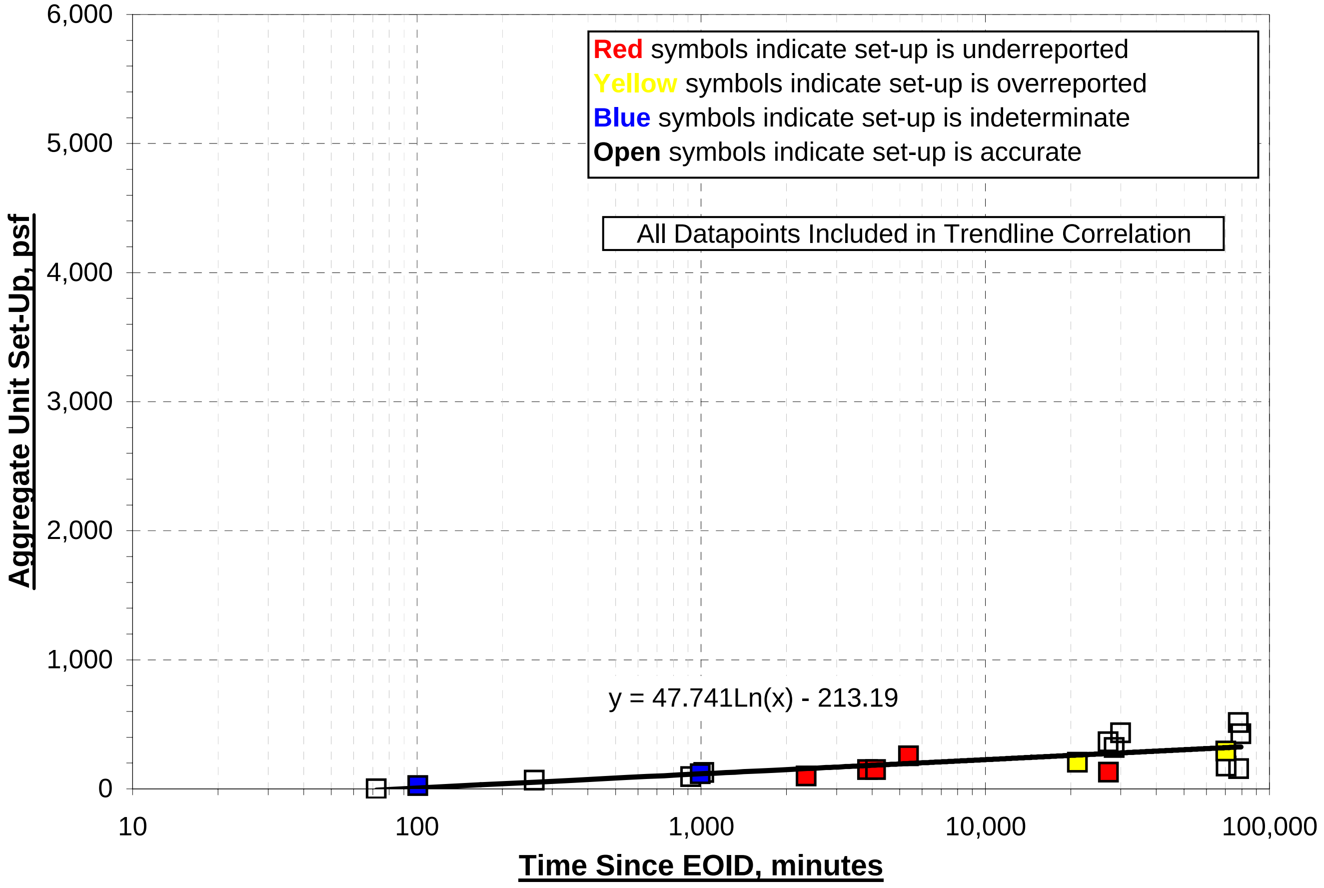

Figure B-8b - Average Aggregate Unit Set-Up vs. Time - Silty Clay

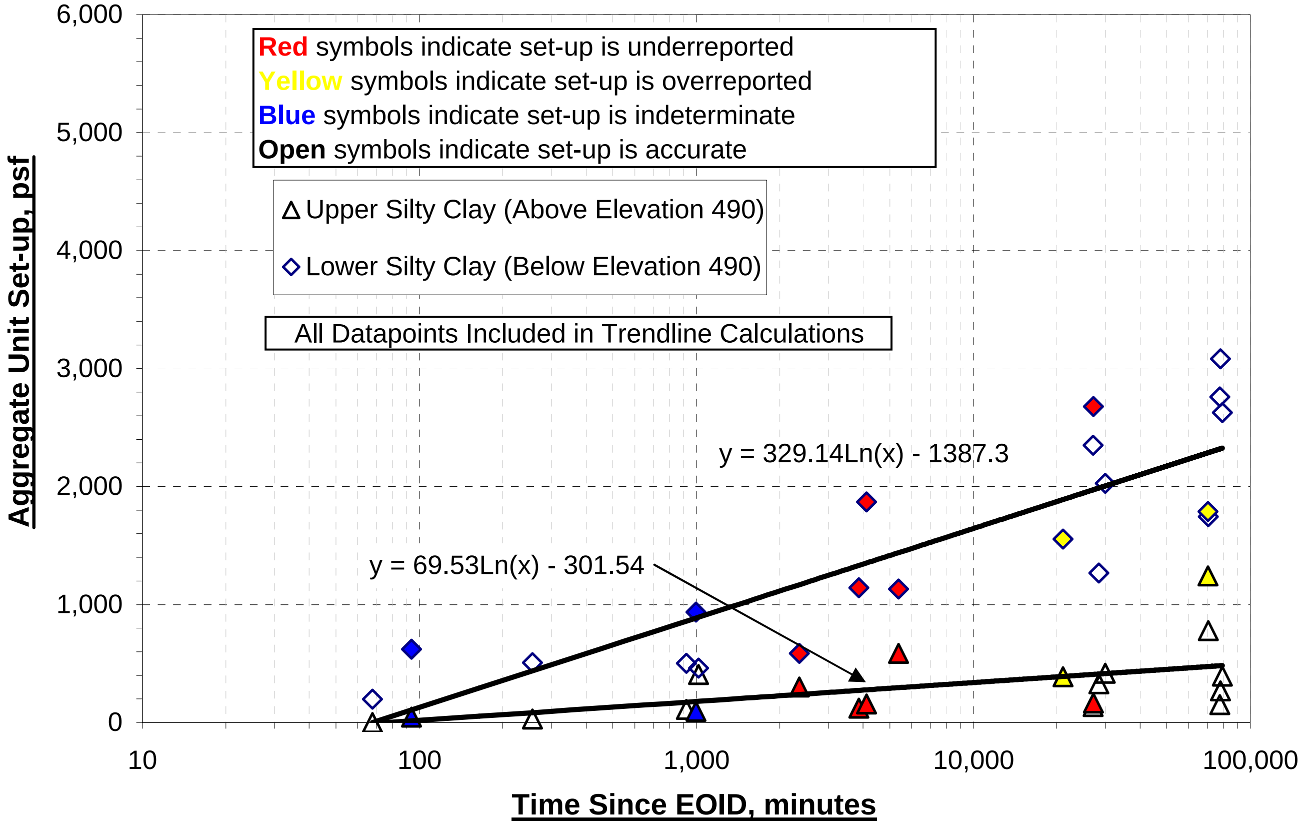

Figure B-8c - Average Aggregate Unit Set-Up vs. Time - Silty Sand

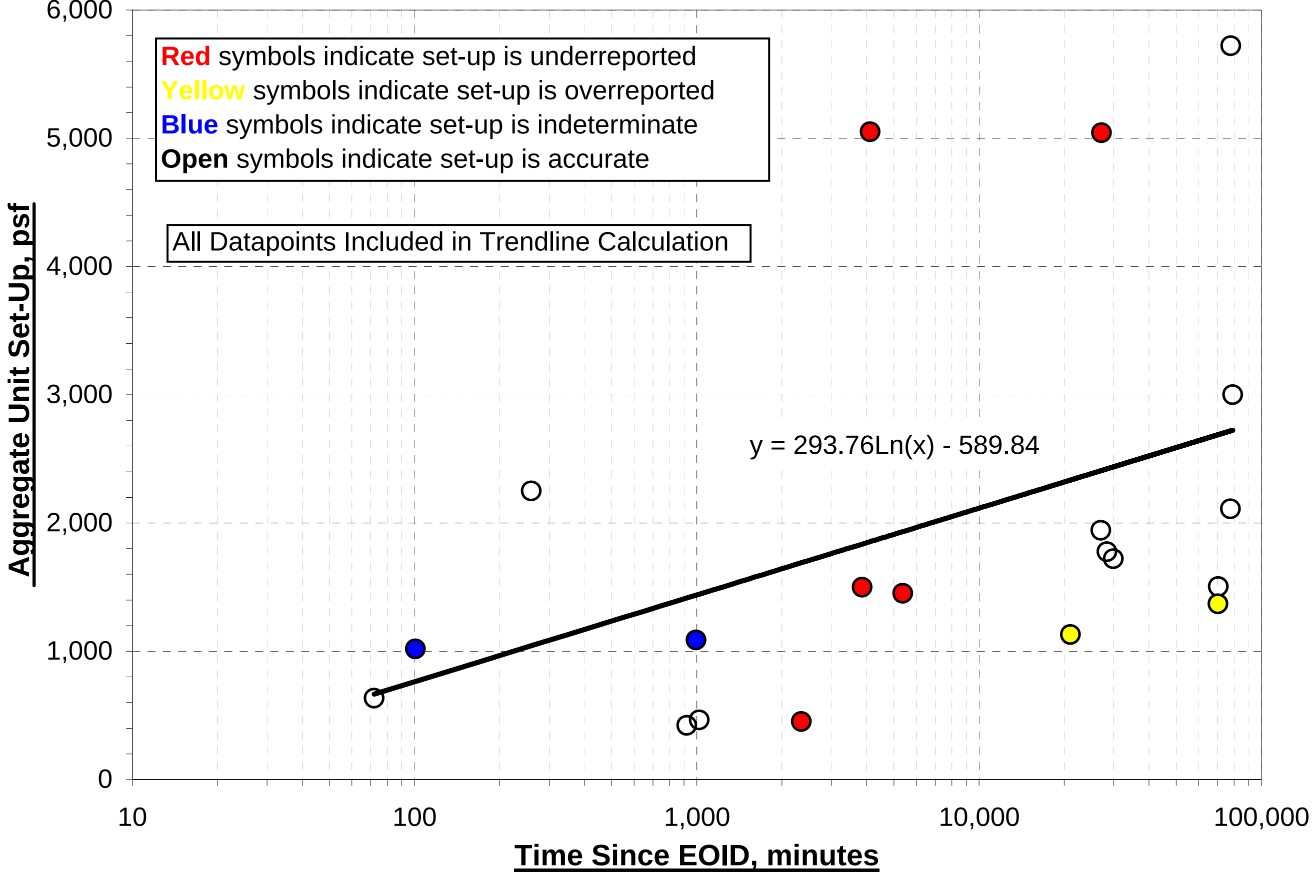

Figure C-1 – Picture of SPT-T Apparatus on Drill Rig

Figure C-2 - SPT-T Test Elevation and Soil Strata Delination

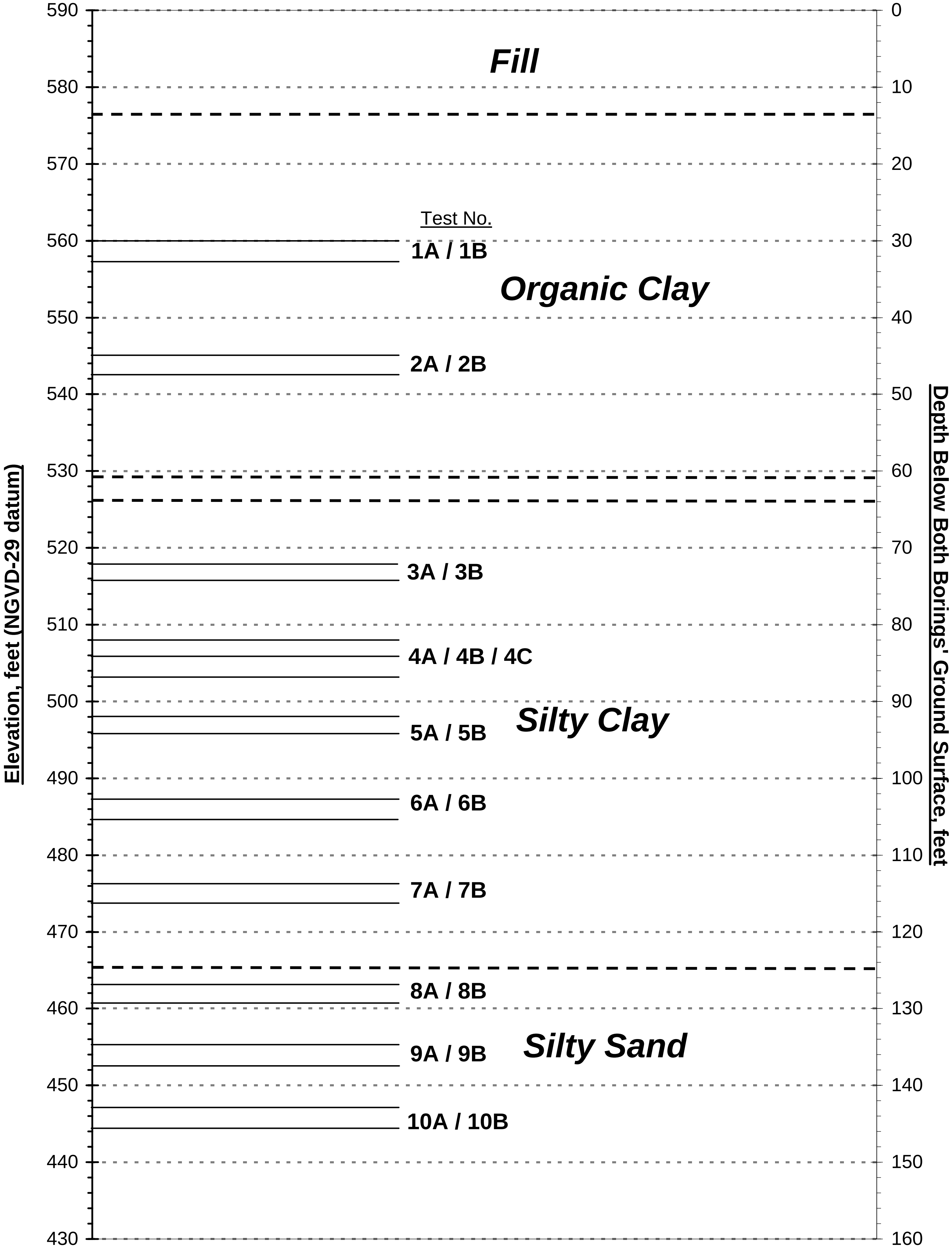

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Figure D-1A(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 1A

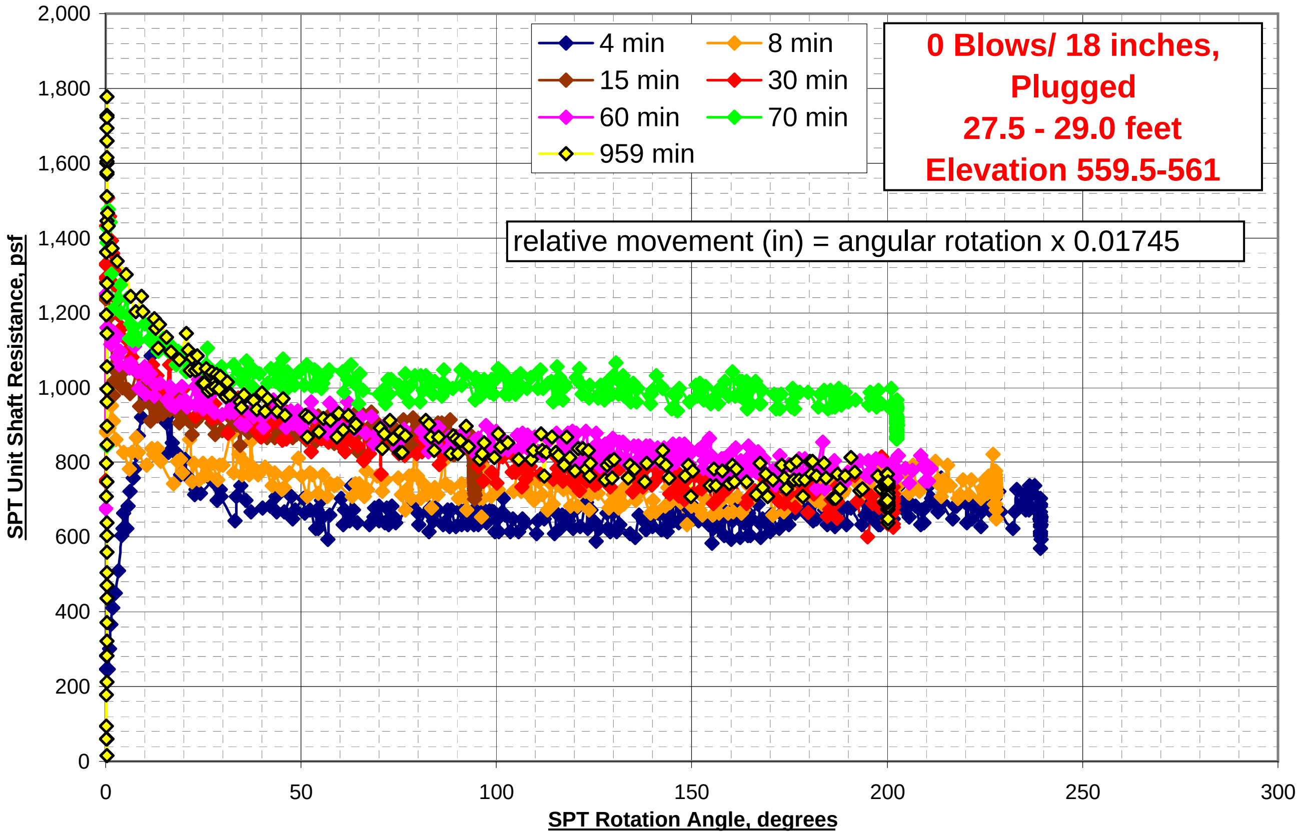

Figure D-1A(b) - SPT Unit Shaft Resistance vs. Strain, Test 1A

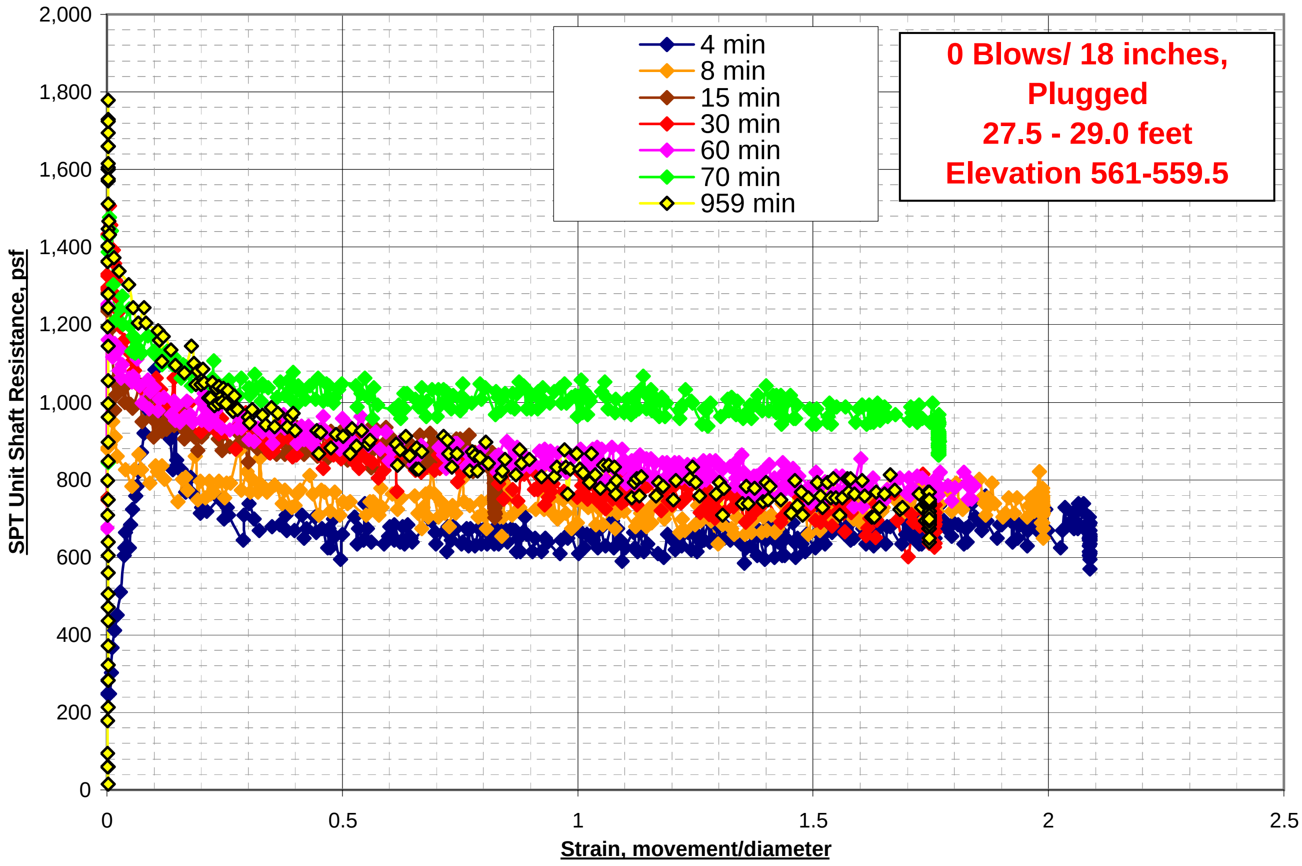

Figure D-1A(c) - Rotation Angle vs. Time, Test 1A

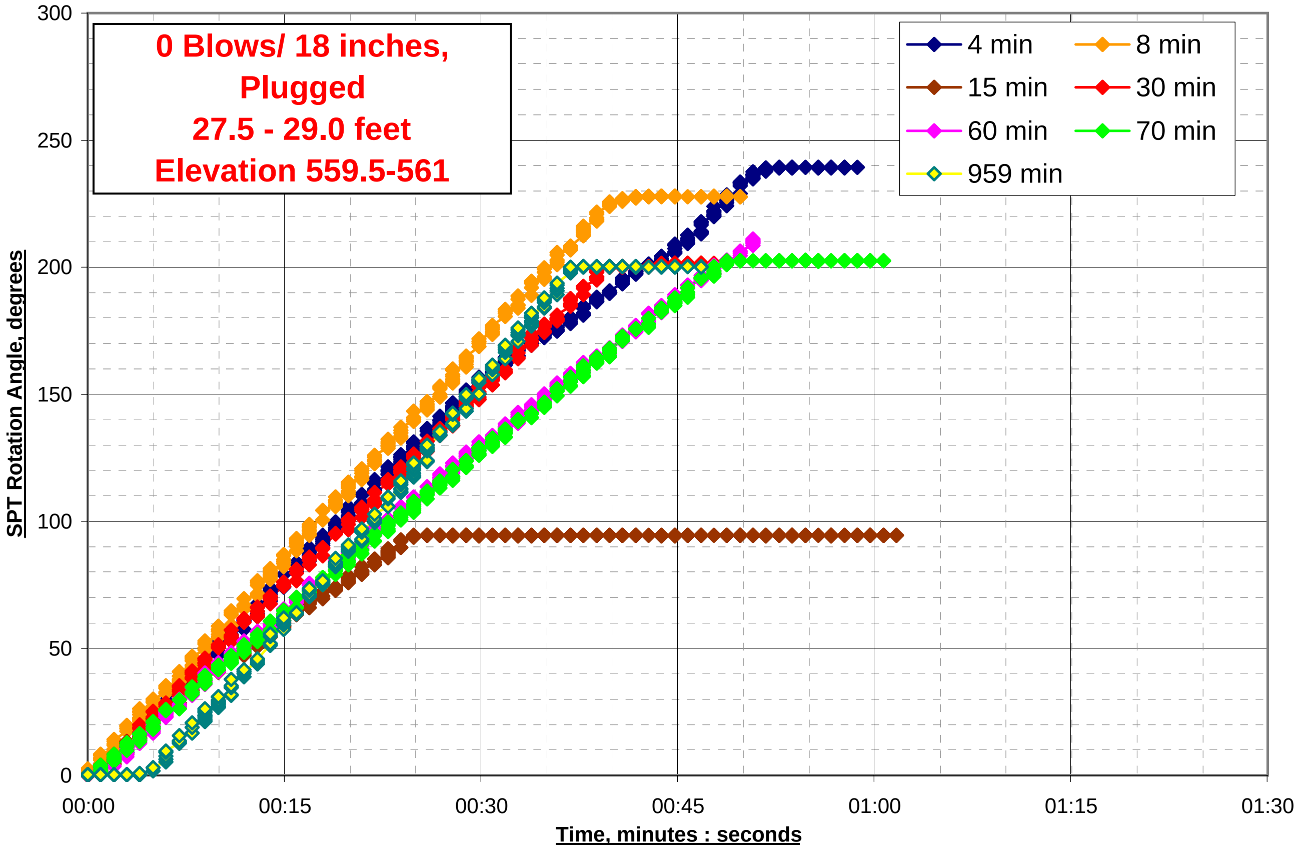

Figure D-1A(d) - SPT Unit Shaft Resistance vs. Time, Test 1A

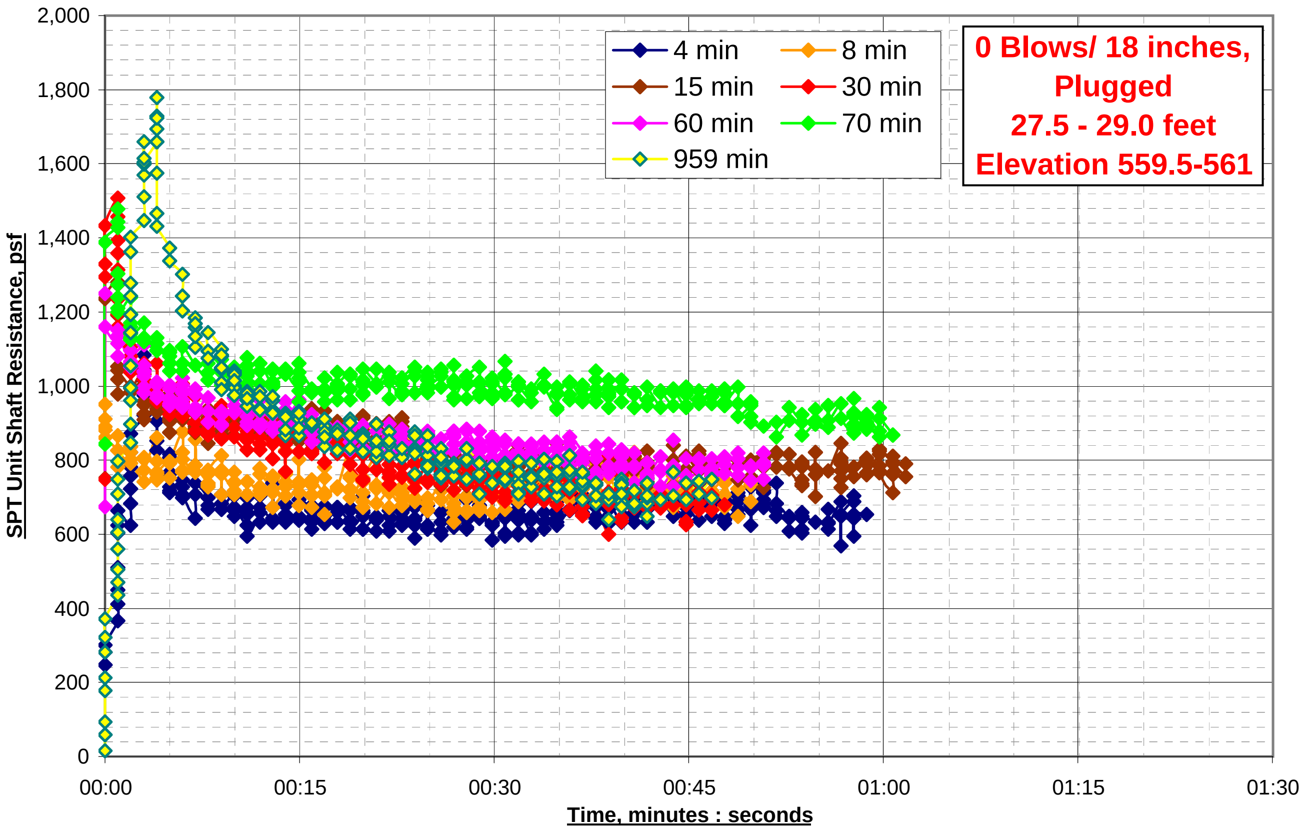

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Figure D-1B(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 1B

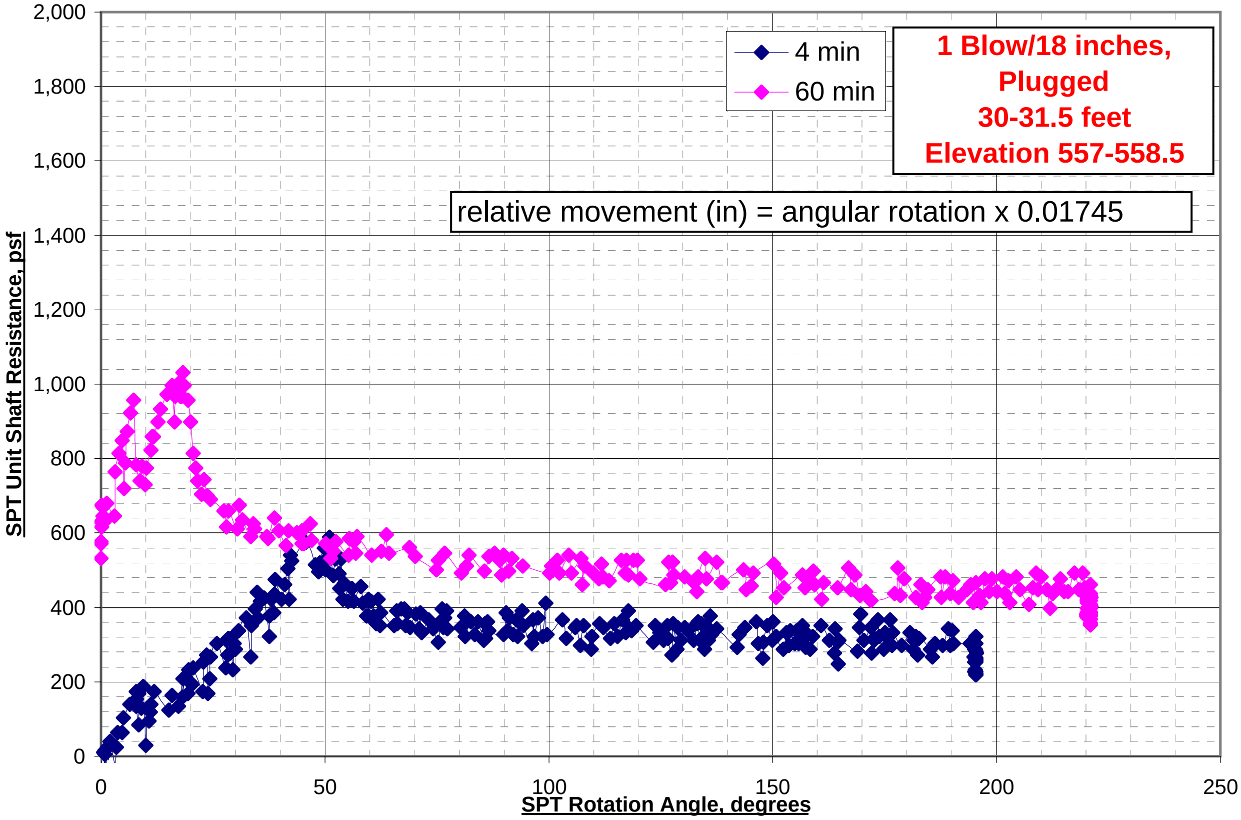

Figure D-1B(b) - SPT Unit Shaft Resistance vs. Strain, Test 1B

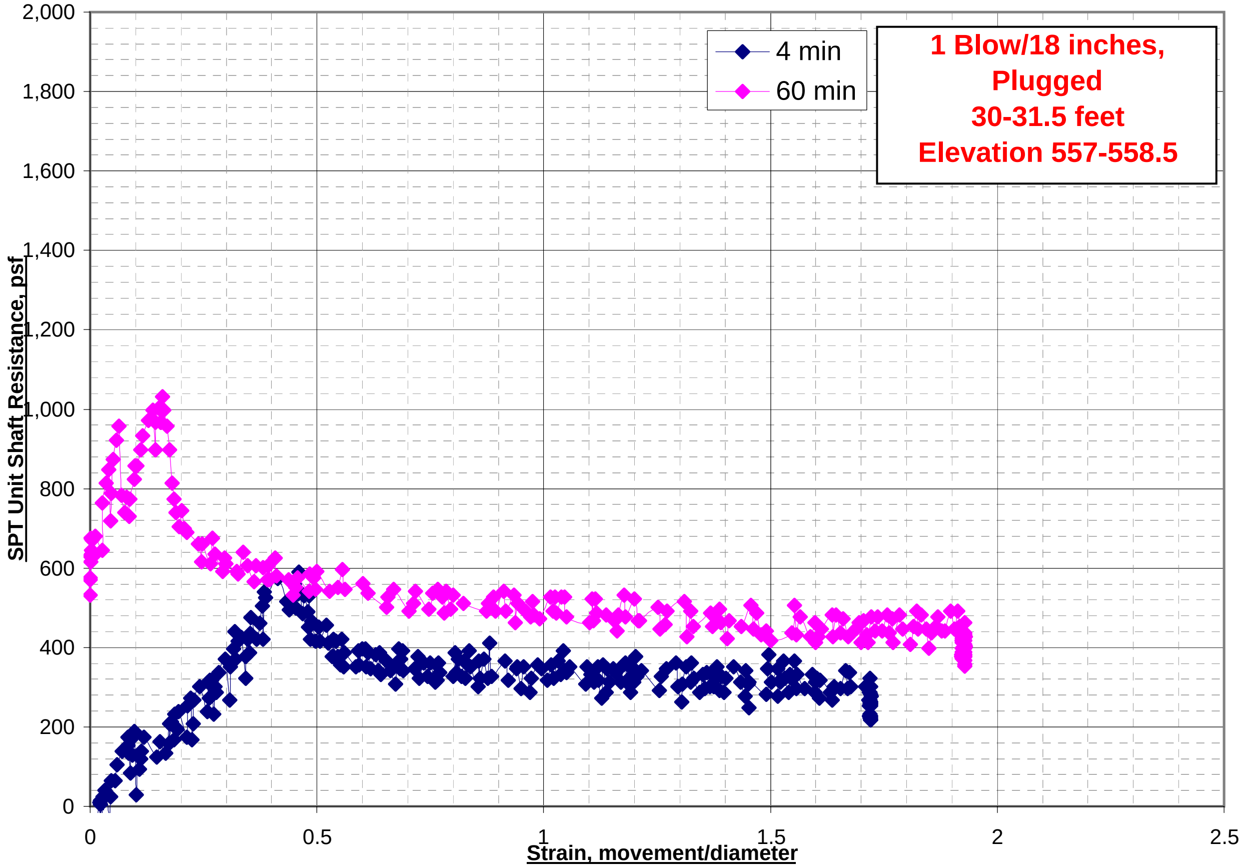

Figure D-1B(c) - Rotation Angle vs. Time, Test 1B

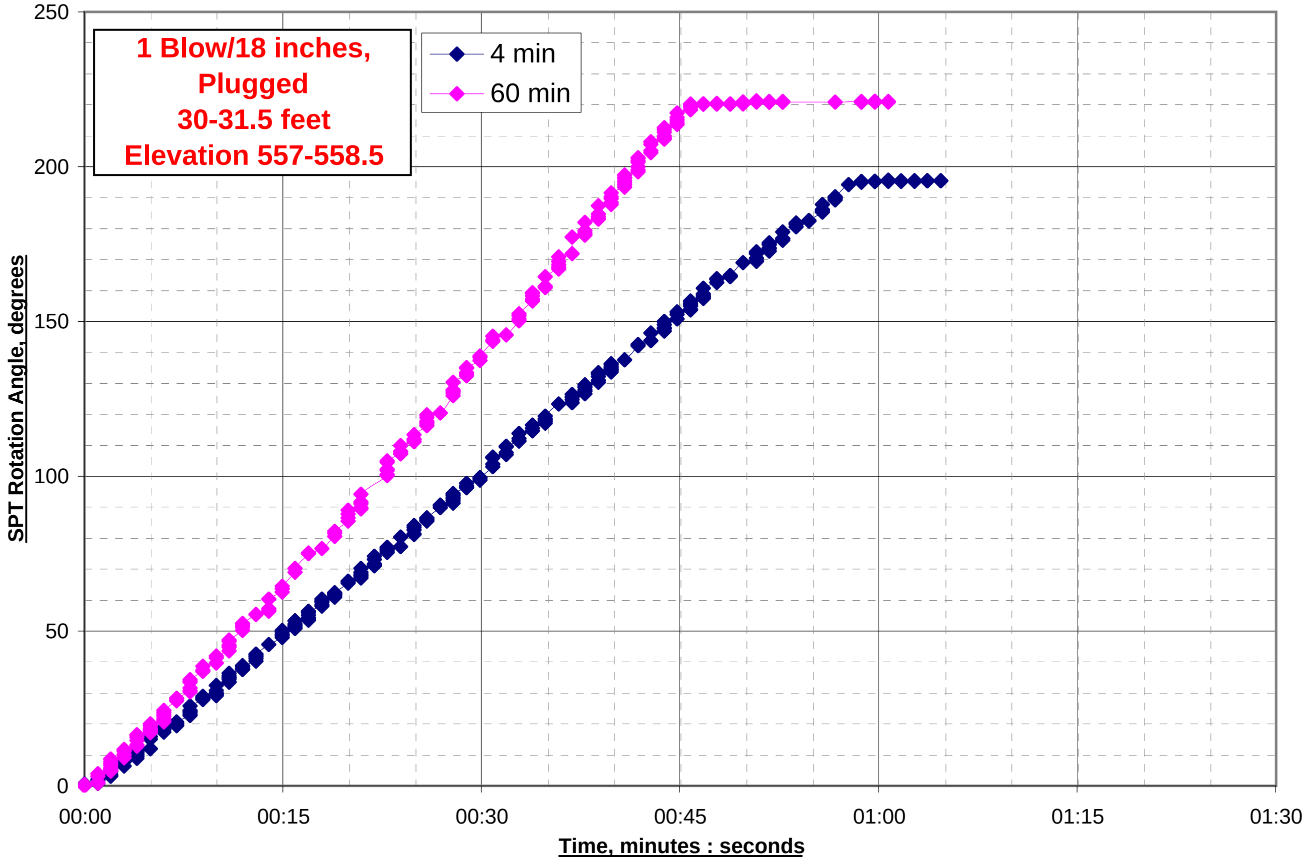

Figure D-1B(d) - SPT Unit Shaft Resistance vs. Time, Test 1B

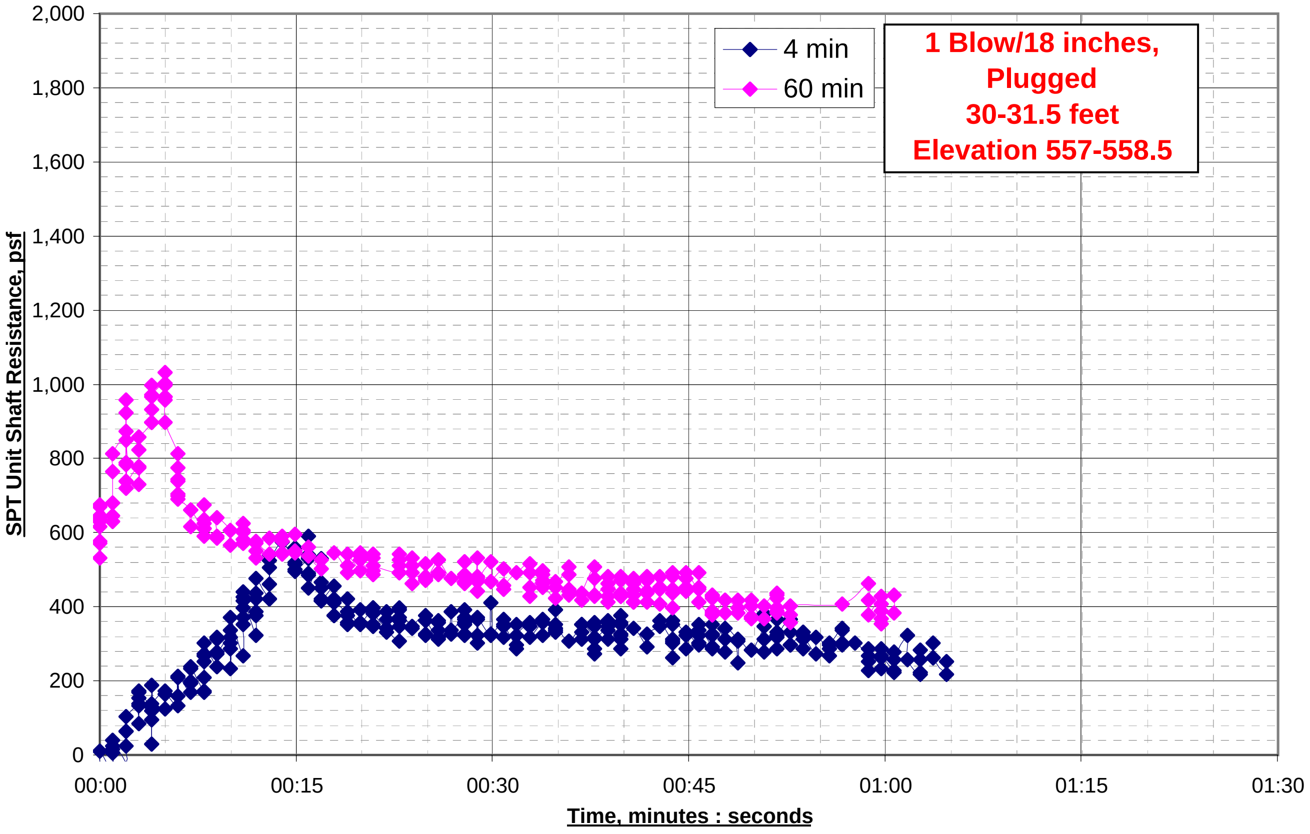

Figure D-2A(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 2A

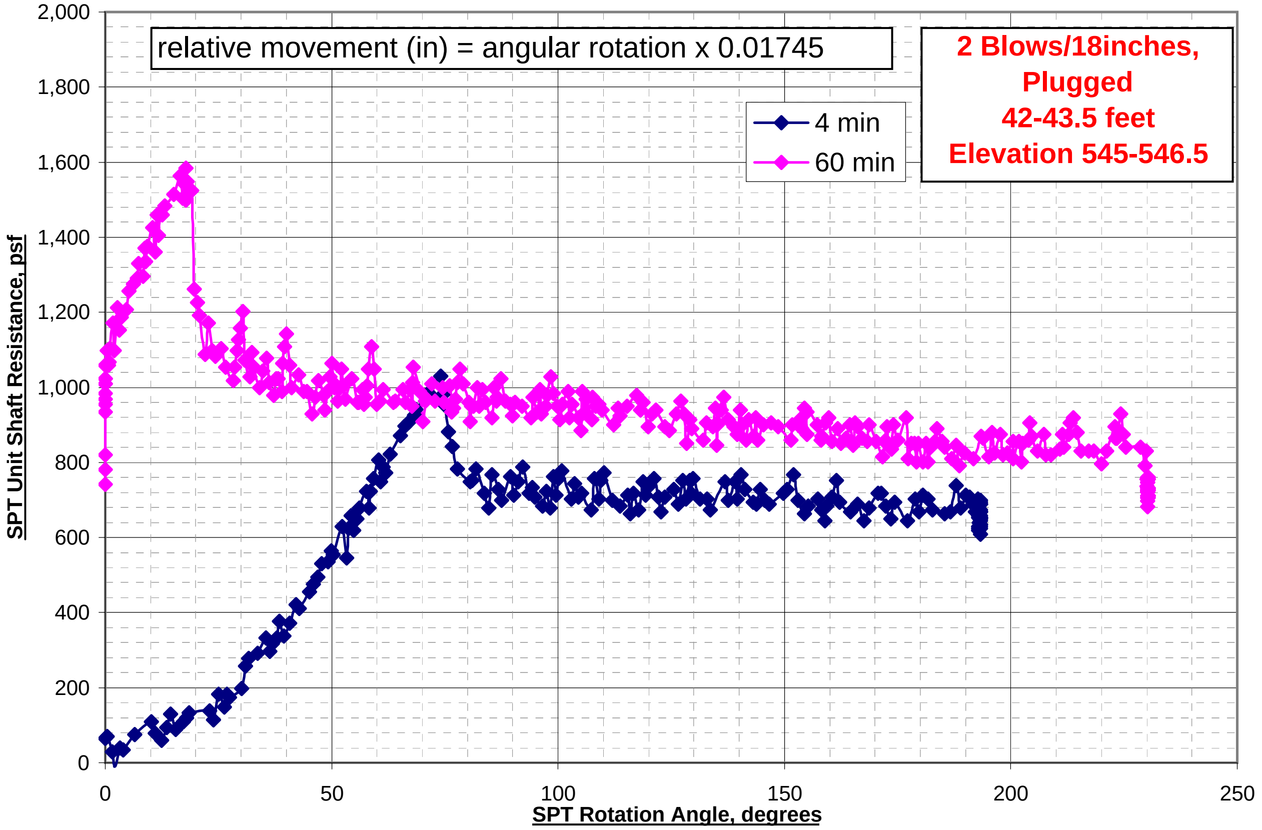

Figure D-2A(b) - SPT Unit Shaft Resistance vs. Strain, Test 2A

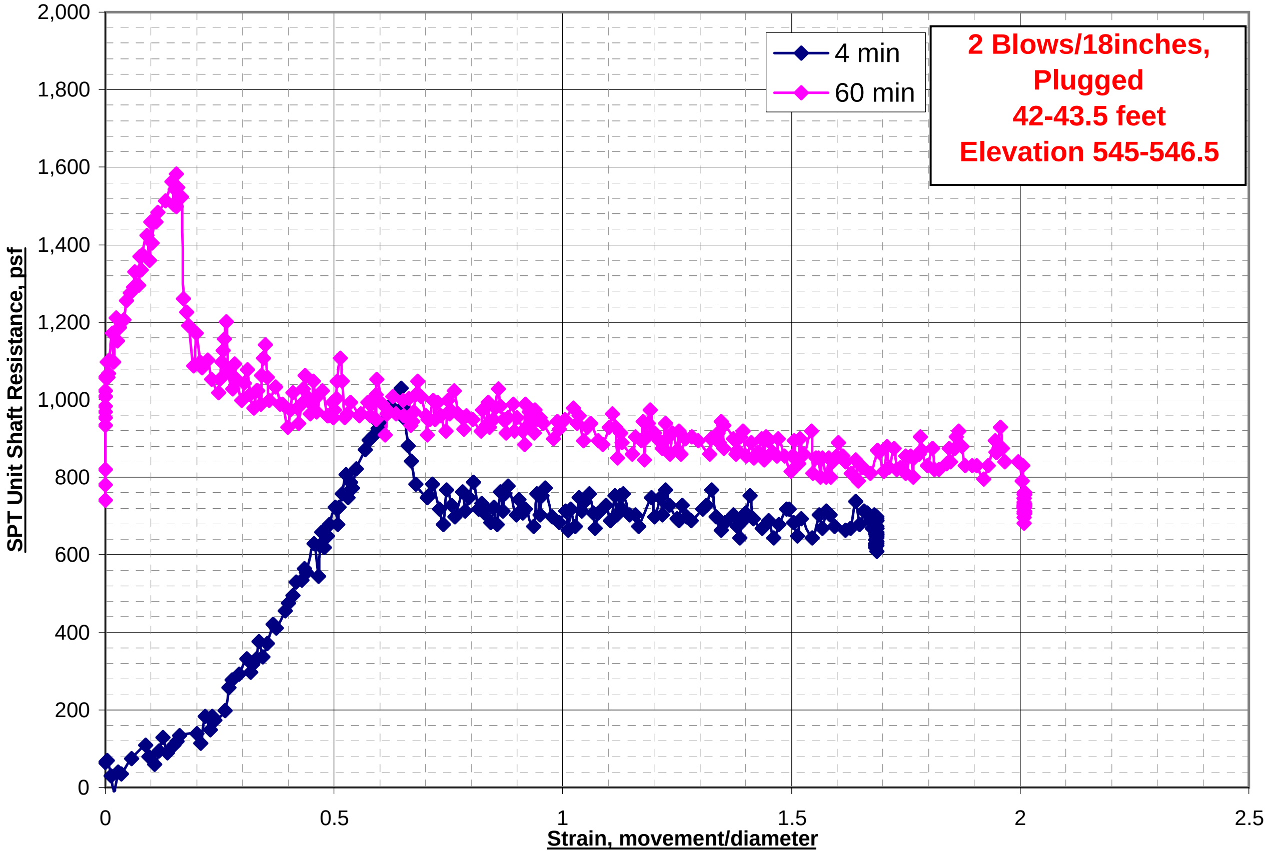

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Figure D-2A(c) - Rotation Angle vs. Time, Test 2A

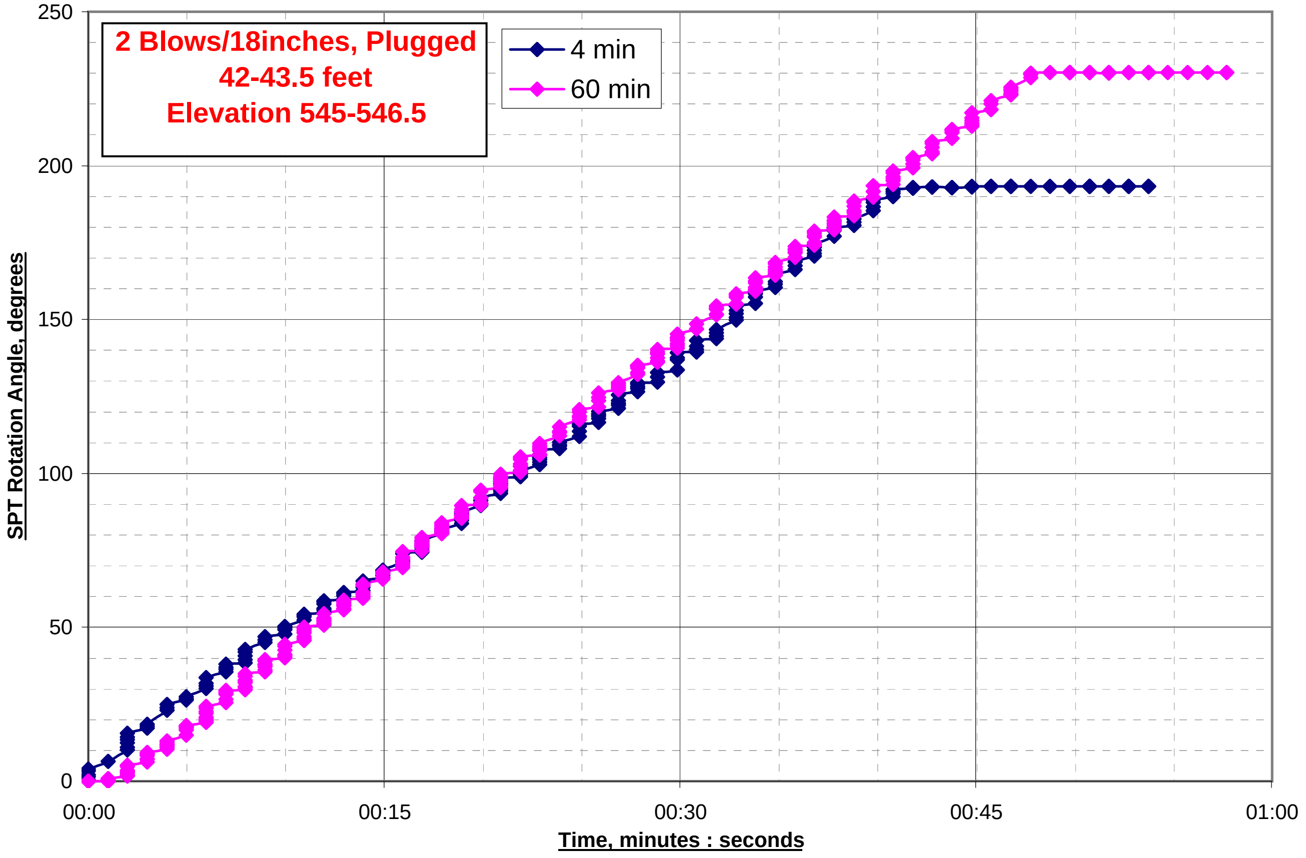


Figure D-2A(d) - SPT Unit Shaft Resistance vs. Time, Test 2A

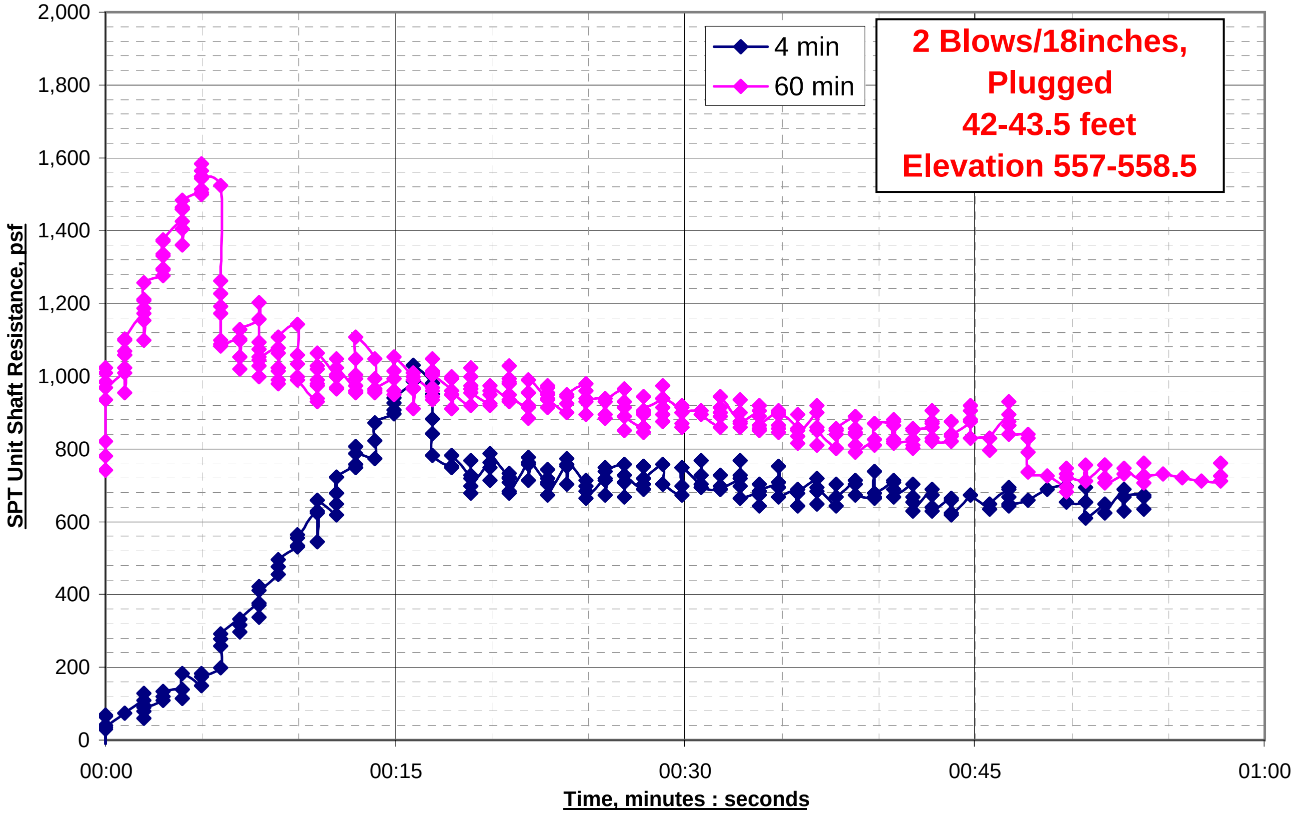
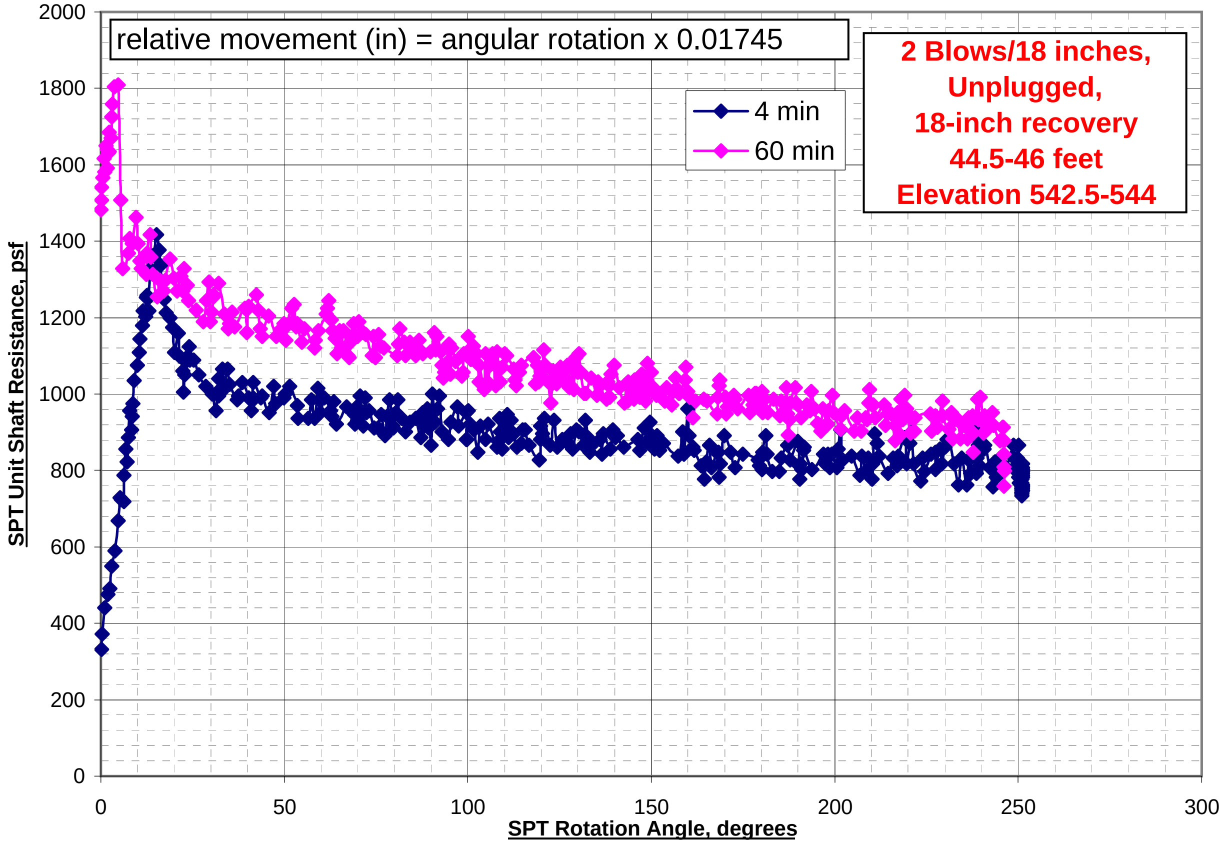


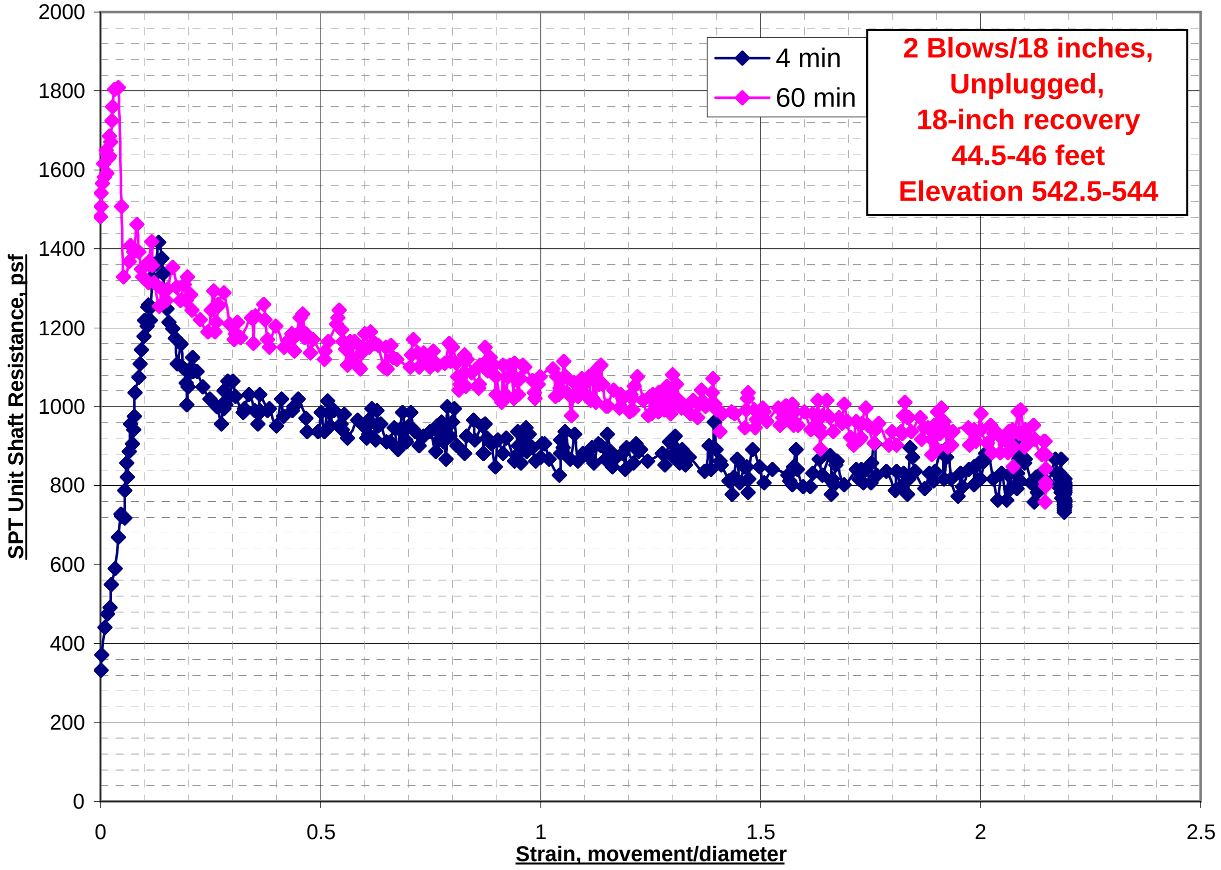
Figure D-2B(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 2B



relative movement (in) = angular rotation x 0.01745

2 Blows/18 inches,
Unplugged,
18-inch recovery
44.5-46 feet
Elevation 542.5-544

Figure D-2B(b) - SPT Unit Shaft Resistance vs. Strain, Test 2B



2 Blows/18 inches,
Unplugged,
18-inch recovery
44.5-46 feet
Elevation 542.5-544

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Figure D-2B(c) - Rotation Angle vs. Time, Test 2B

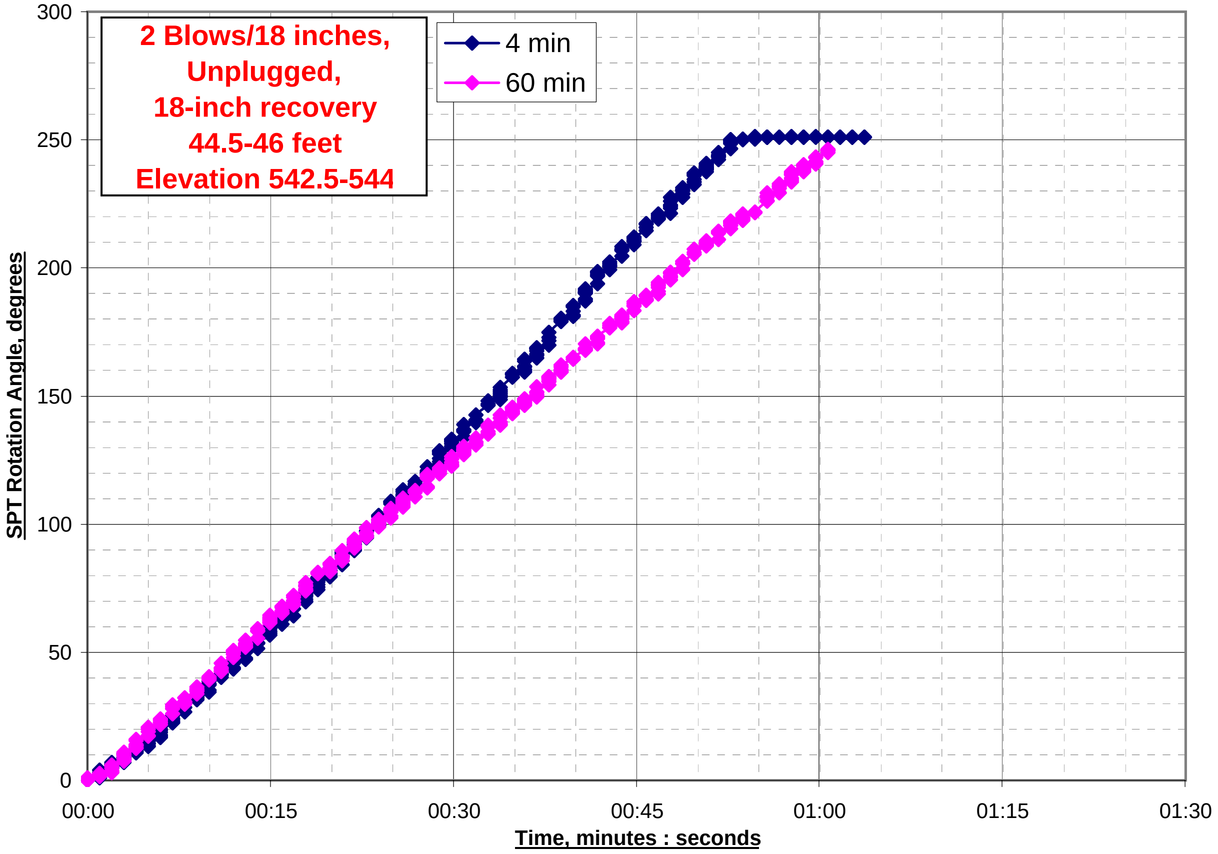


Figure D-2B(d) - SPT Unit Shaft Resistance vs. Time, Test 2B

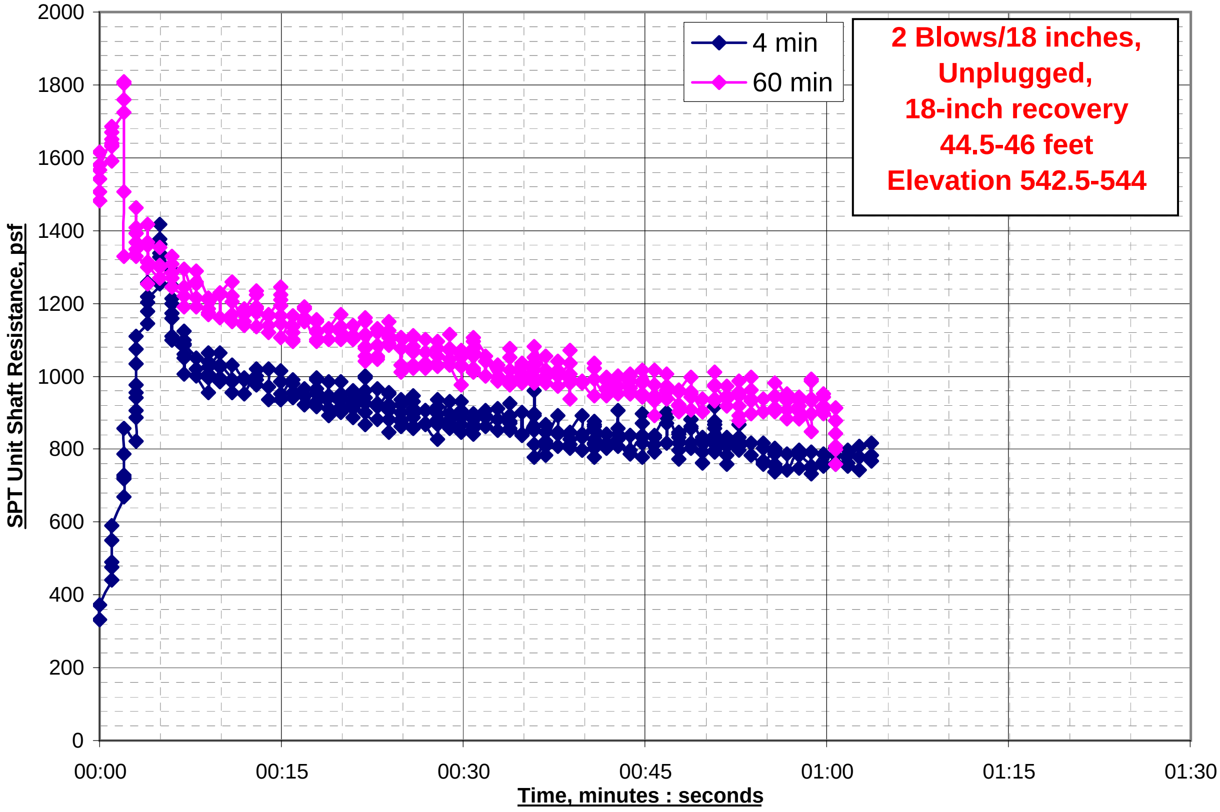


Figure D-3A(a) - SPT Unit Shaft Resistance vs. Rotation Angle, Test 3A

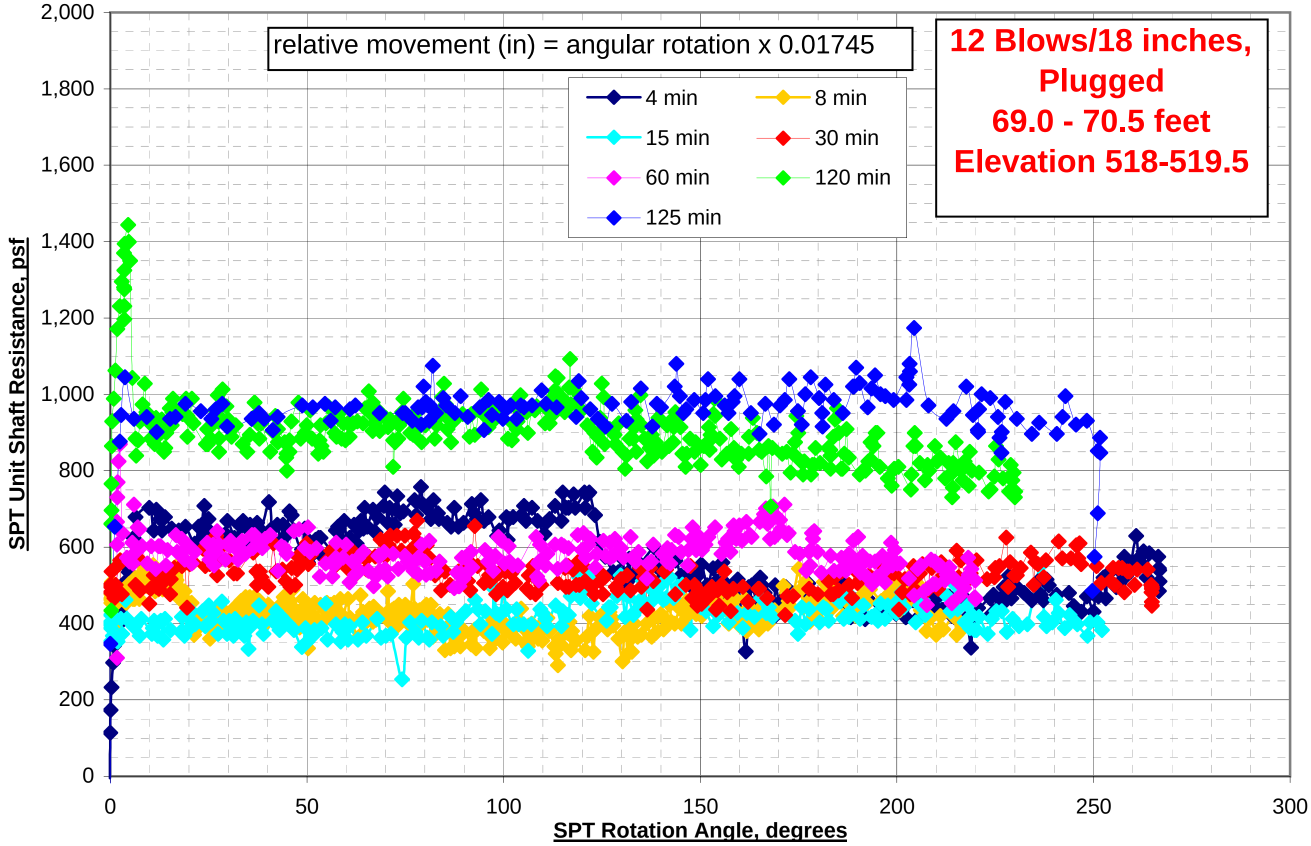


Figure D-3A(b) - SPT Unit Shaft Resistance vs. Strain, Test 3A

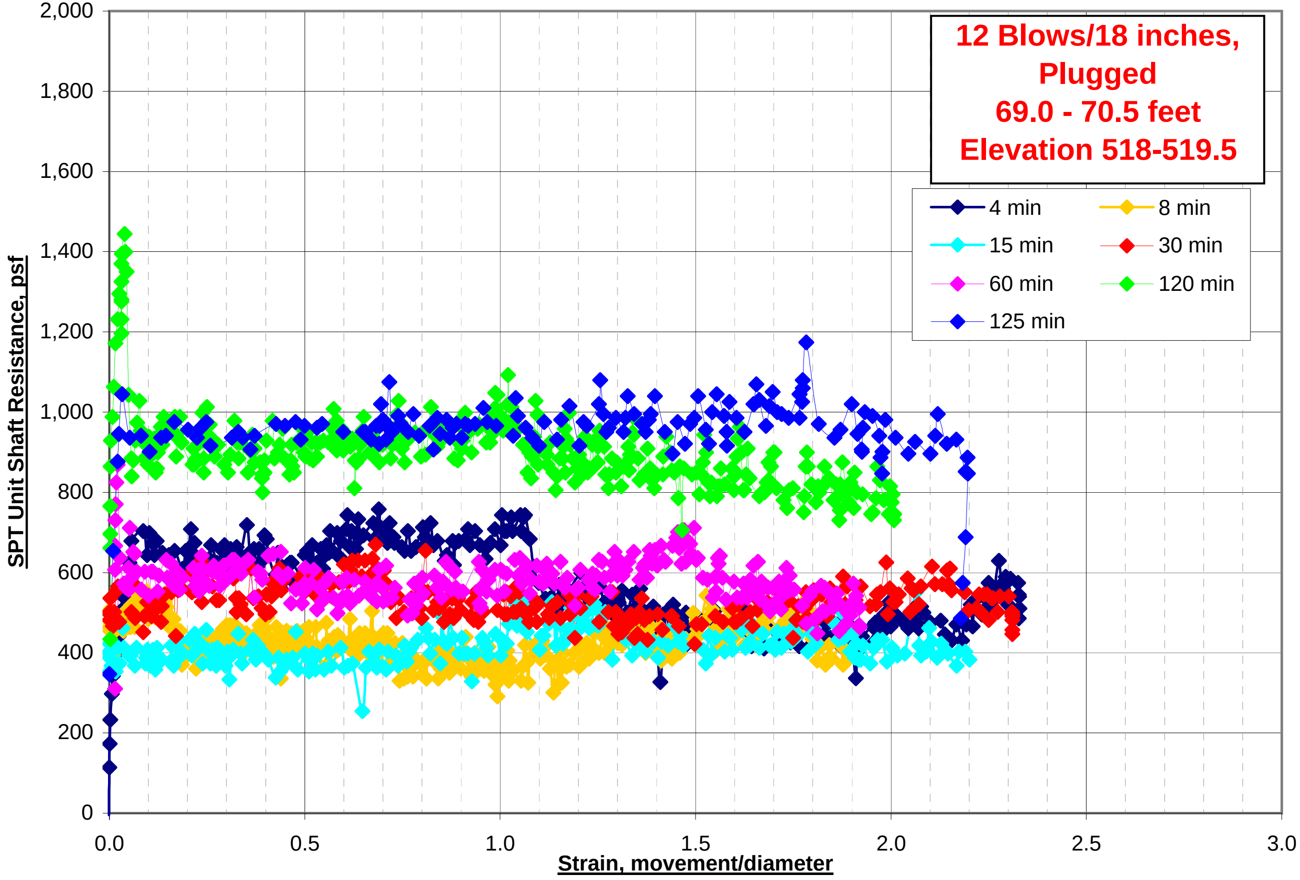


Figure D-3A(c) - SPT Rotation Angle vs. Time, Test 3A

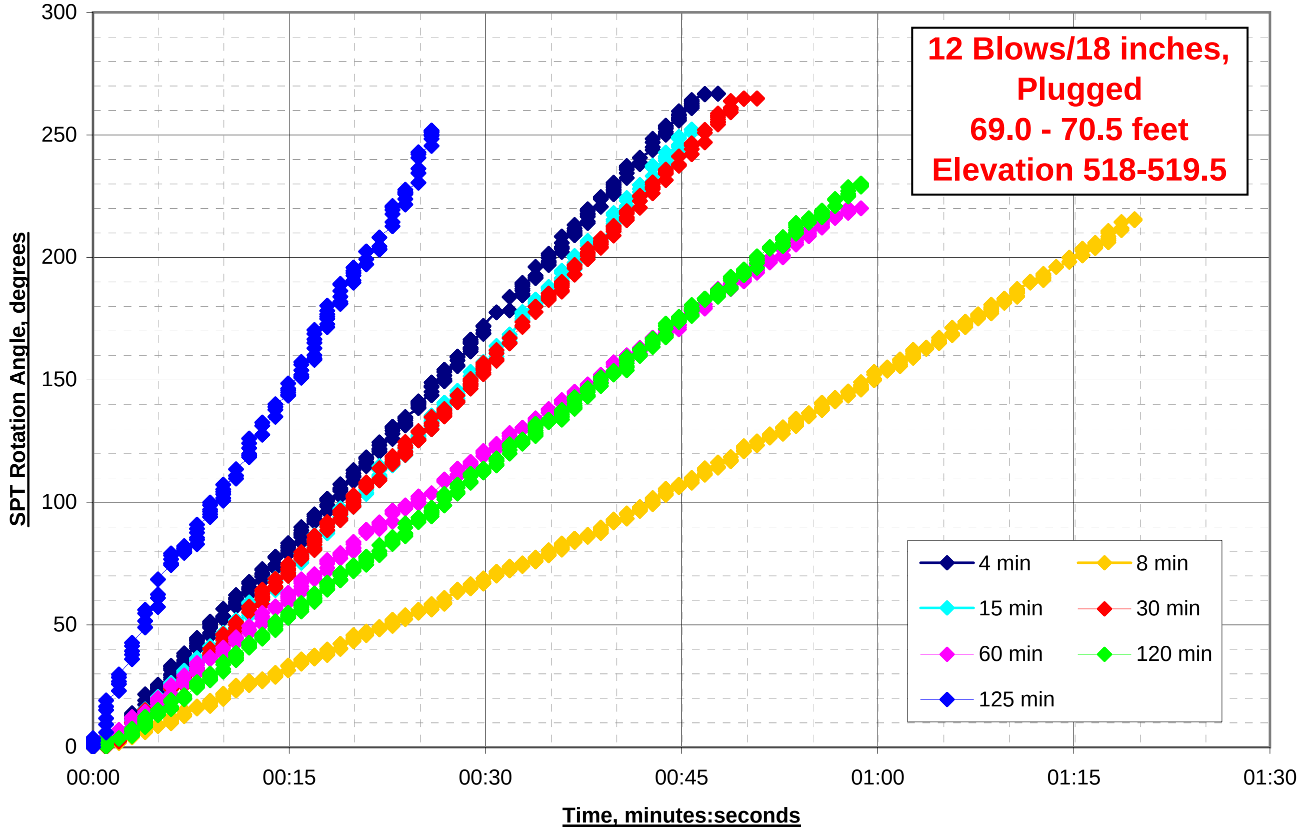


Figure D-3A(d) - SPT Unit Shaft Resistance vs. Time, Test 3A

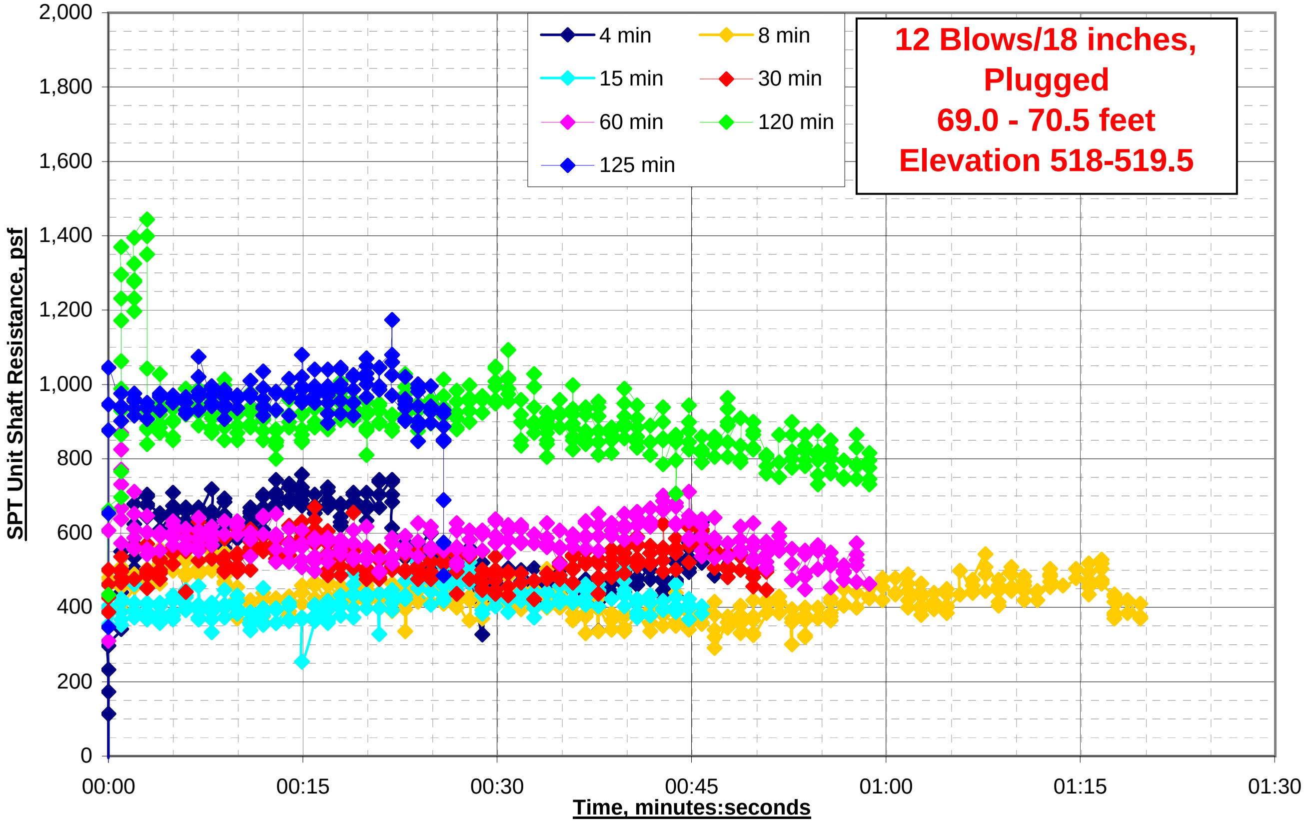


Figure D-3B(a) - SPT Unit Shaft Resistance vs. Rotation Angle, Test 3B

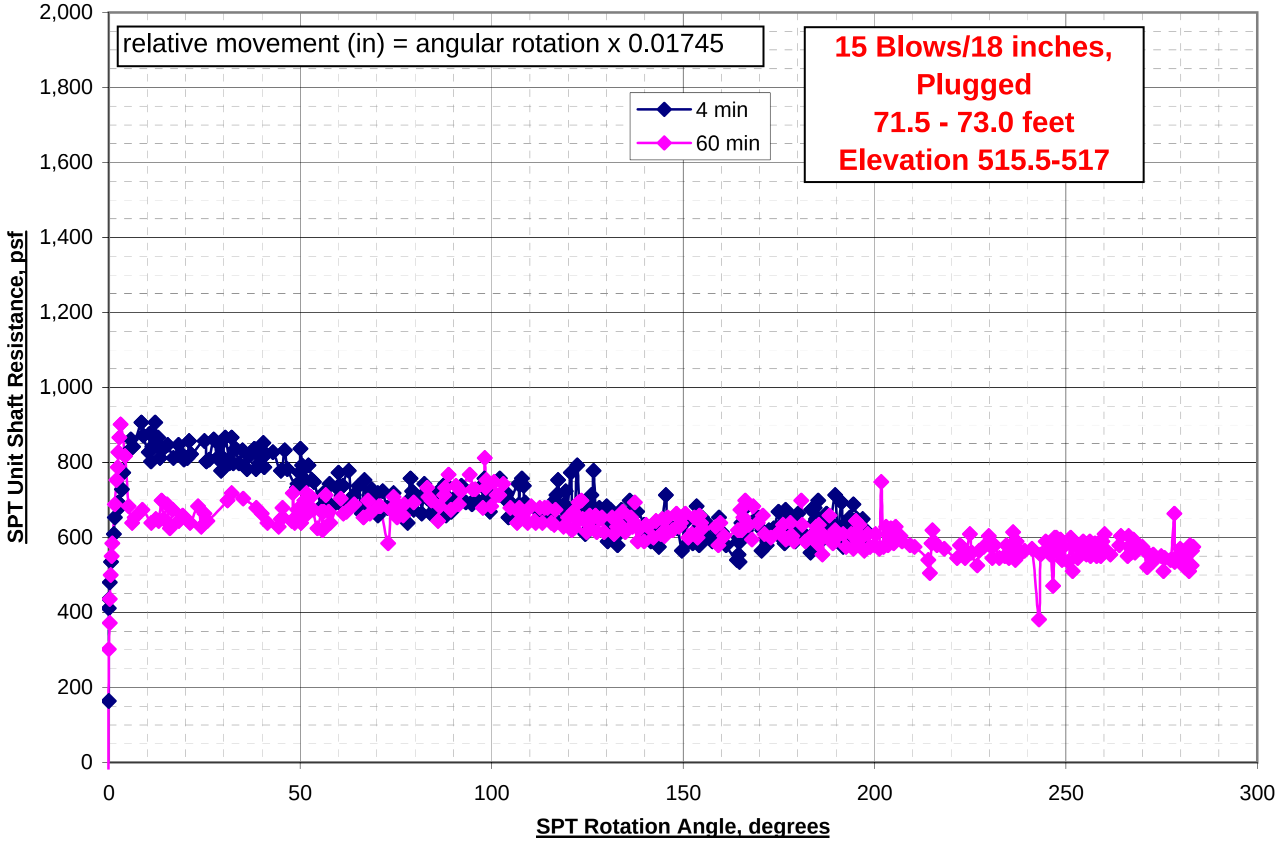


Figure D-3B(b) - SPT Unit Shaft Resistance vs. Strain, Test 3B

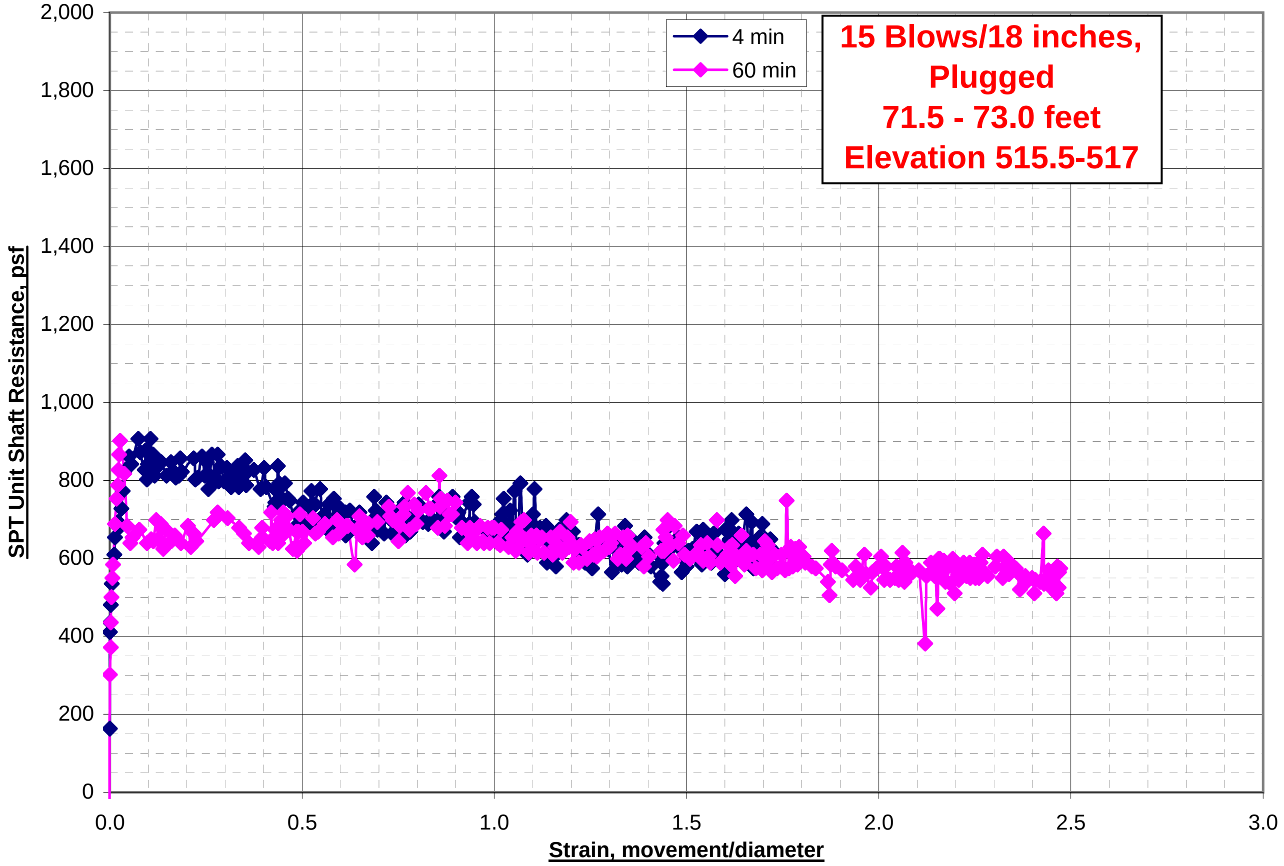


Figure D-3B(c) - SPT Rotation Angle vs. Time, Test 3B

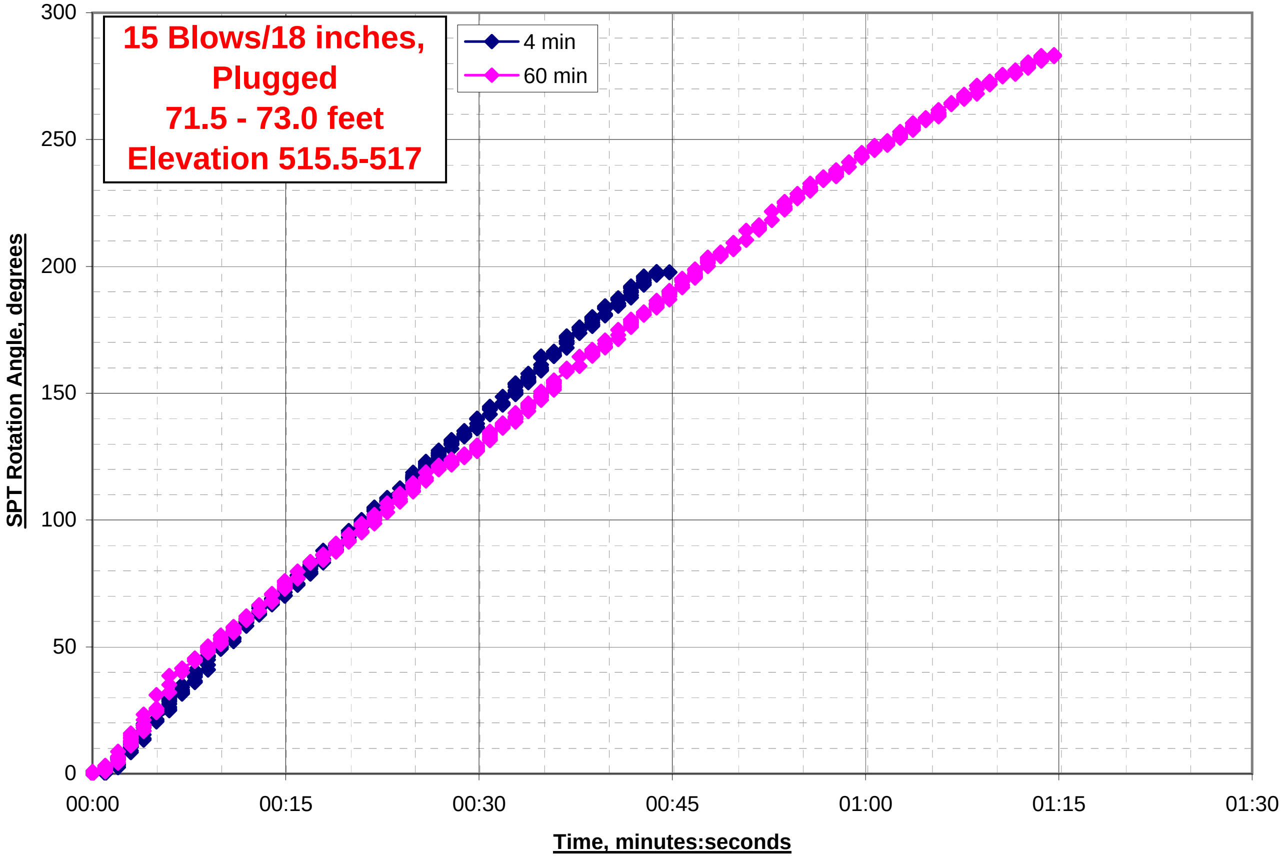


Figure D-3B(d) - SPT Unit Shaft Resistance vs. Time, Test 3B

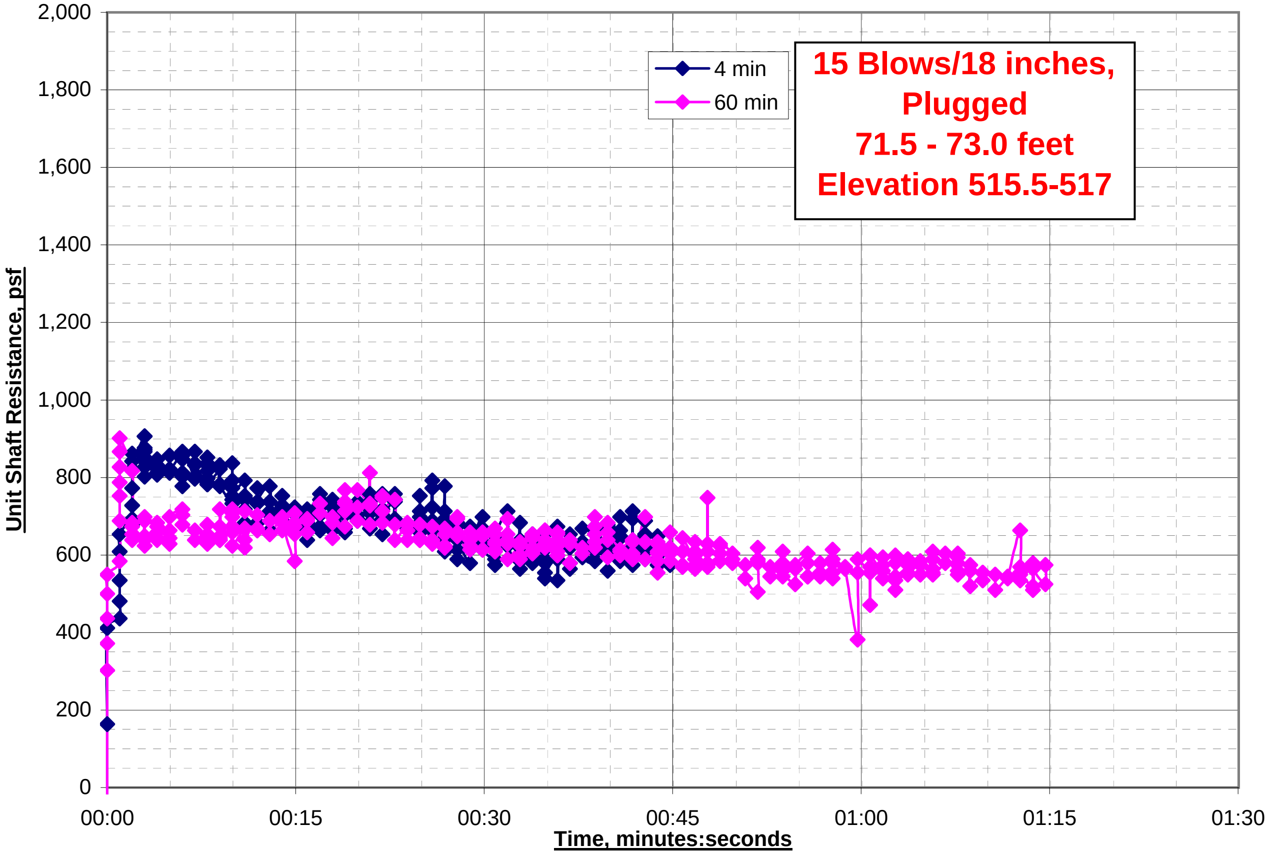
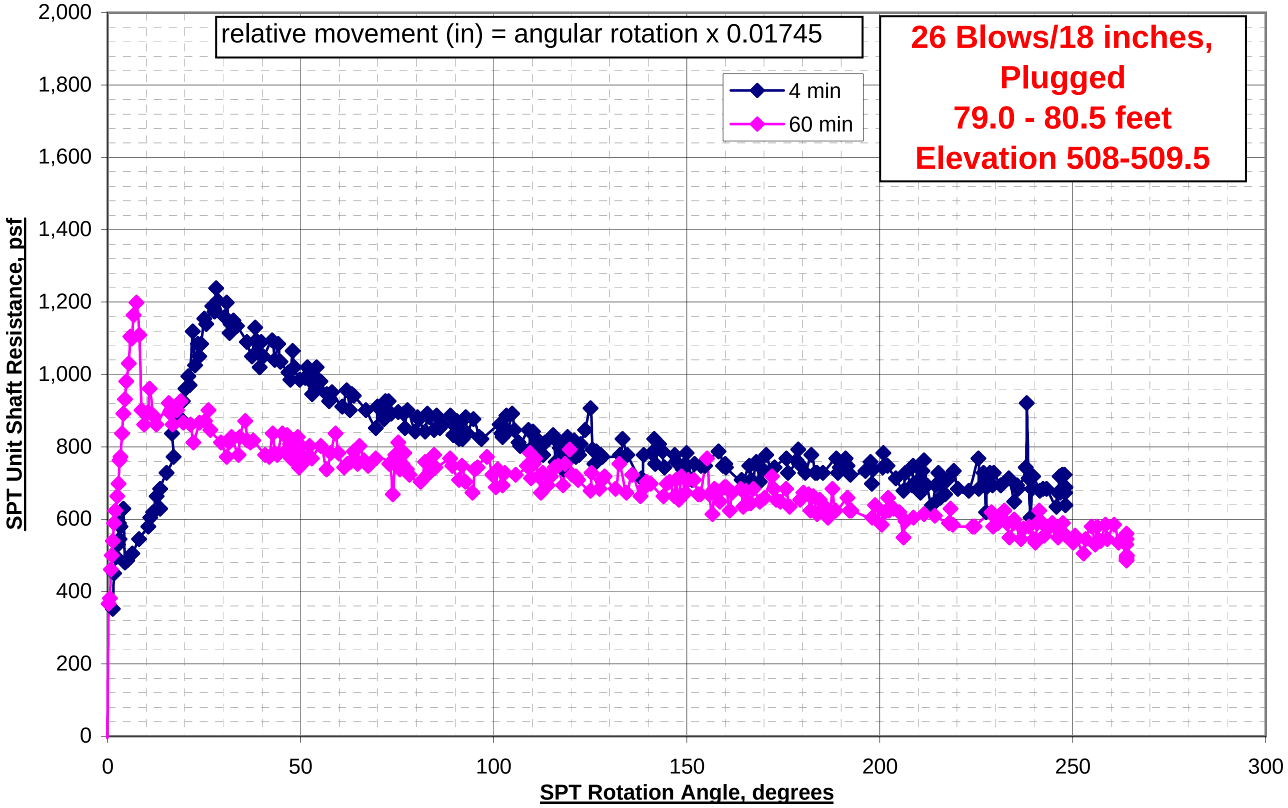
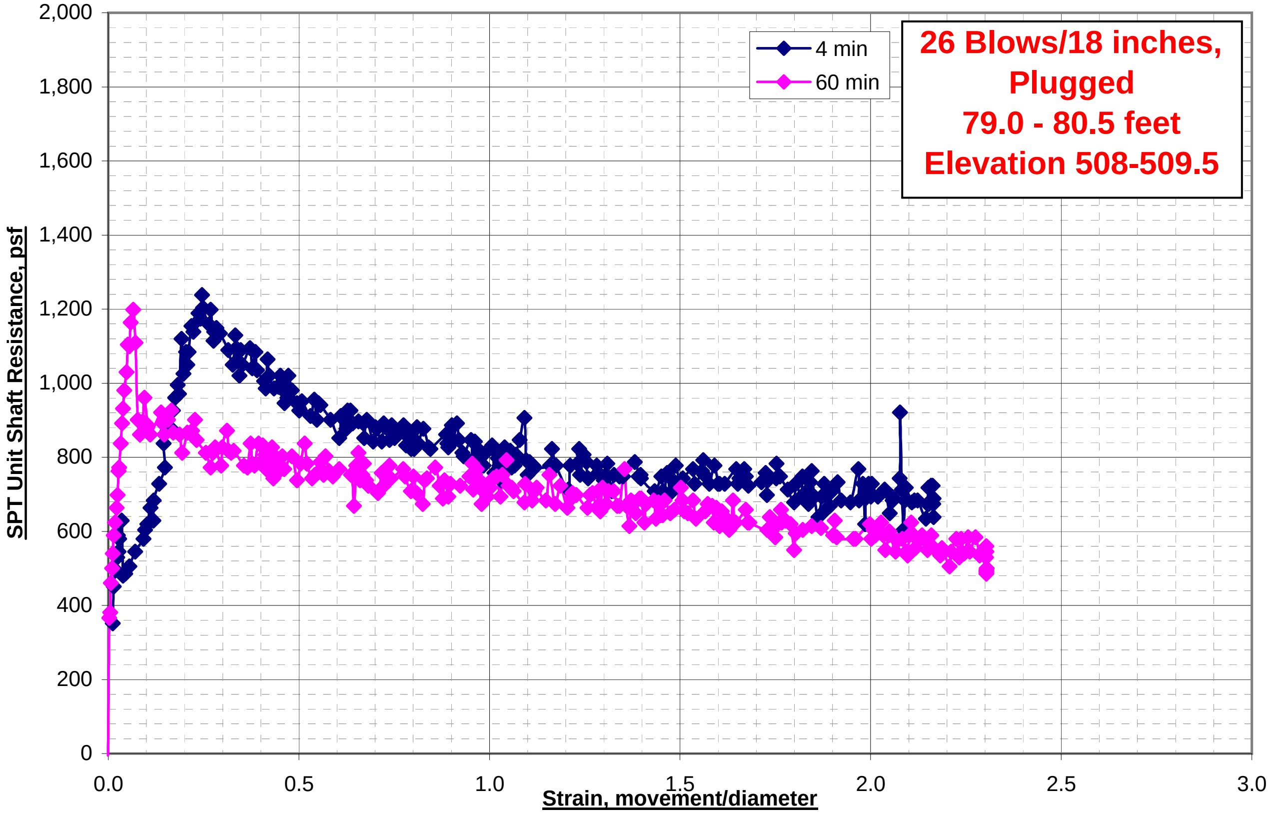


Figure D-4A(a) - SPT Unit Shaft Resistance vs. Rotation Angle, Test 4A



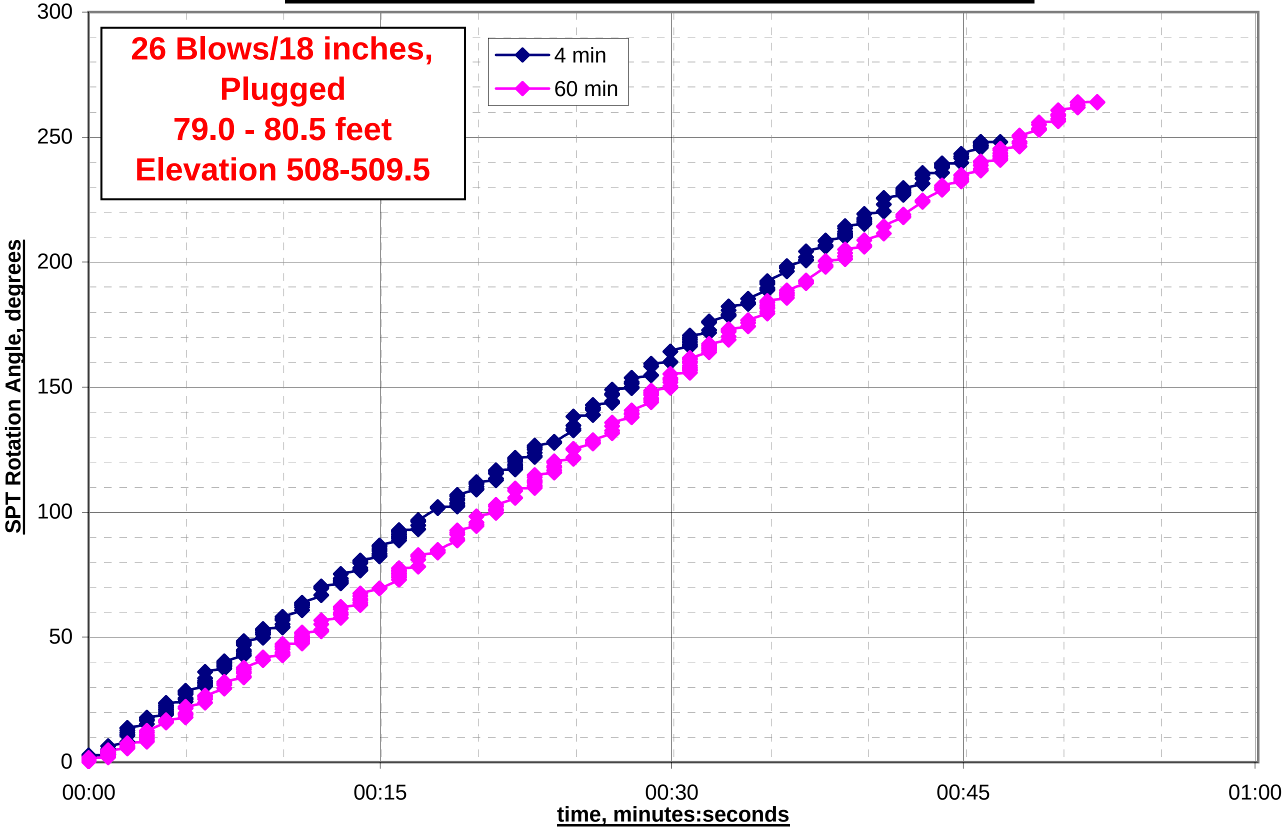
Note: Angle measurements not obtained in 966 min trial

Figure D-4A(b) - SPT Unit Shaft Resistance vs. Strain, Test 4A



Note: Angle measurements not obtained in 966 min trial

Figure D-4A(c) - SPT Rotation Angle vs. Time, Test 4A



Note: Angle measurements not obtained in 966 min trial

Figure D-4A(d) - SPT Unit Shaft Resistance vs. Time, Test 4A

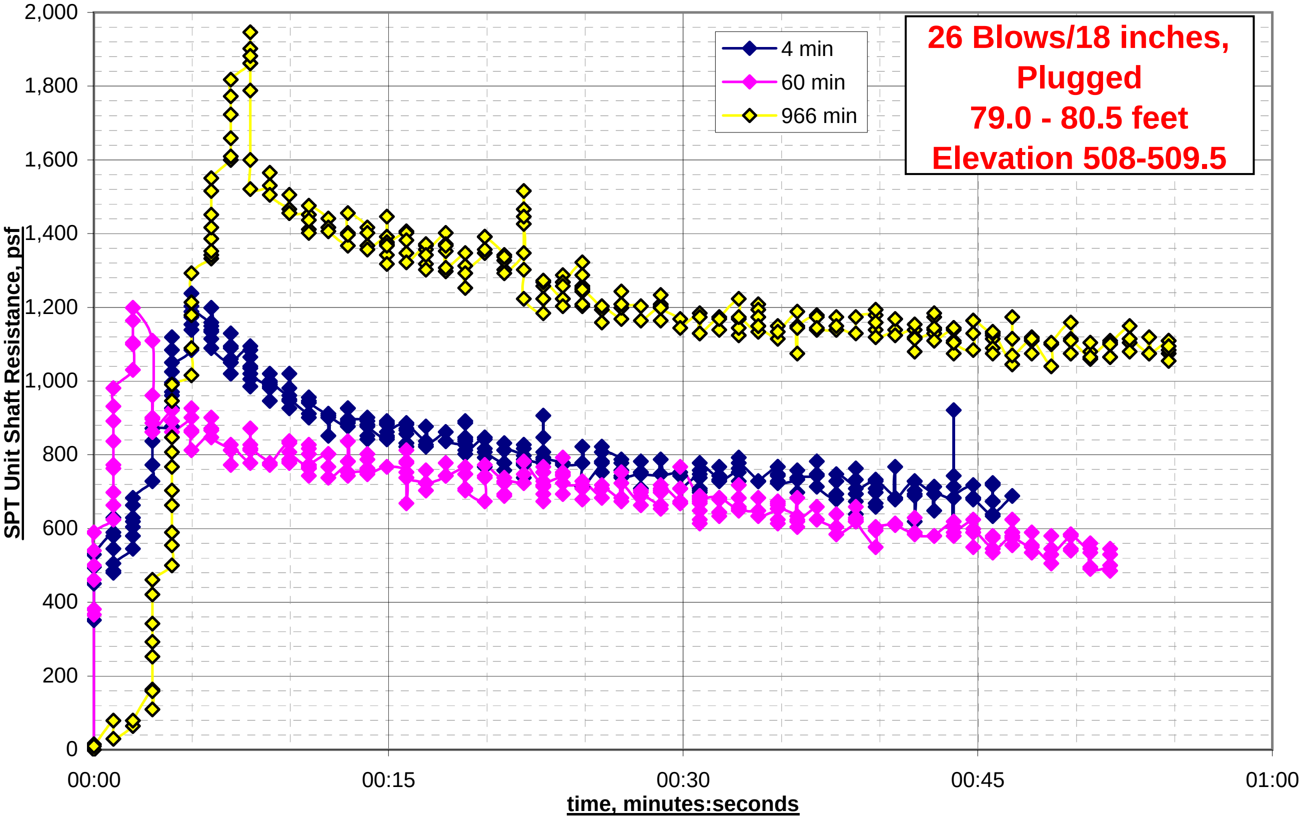


Figure D-4B(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 4B

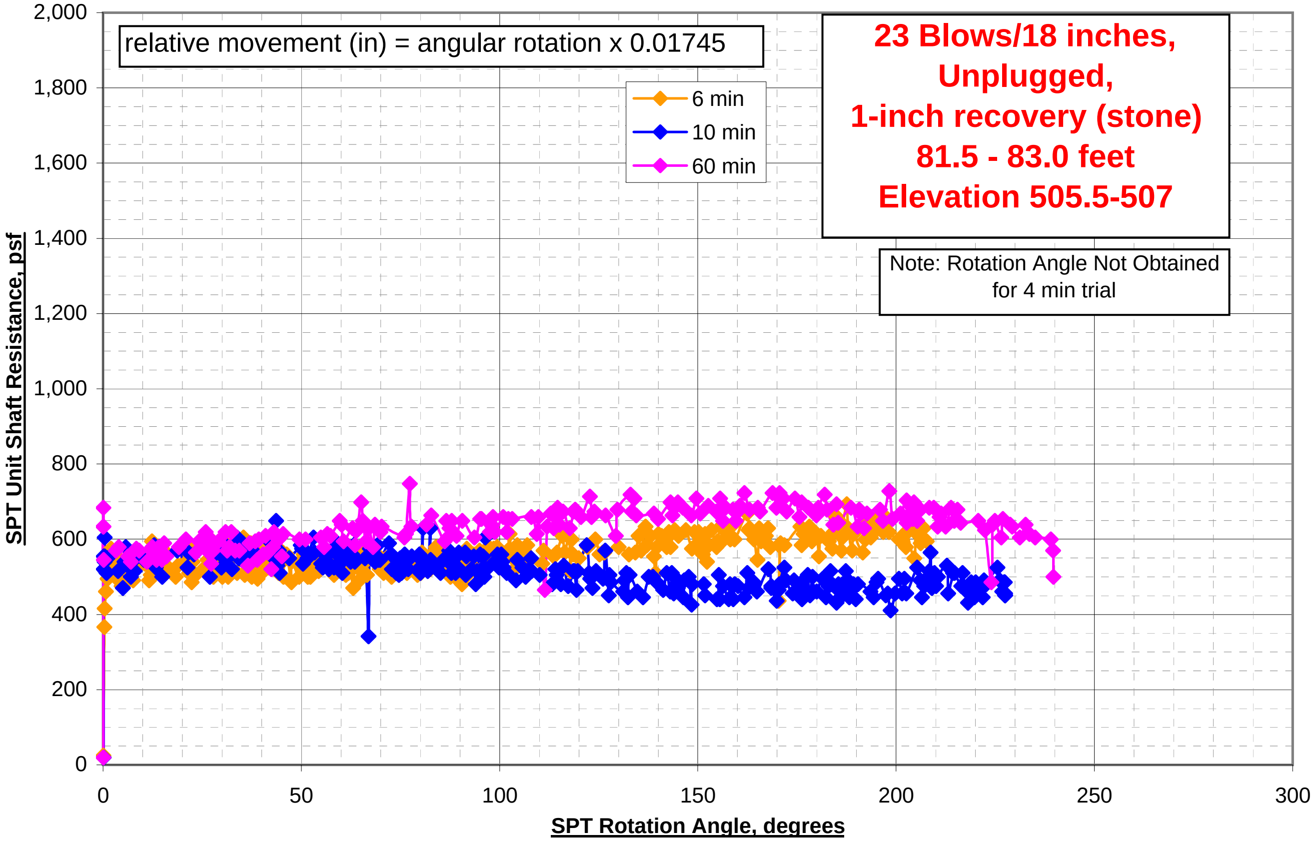


Figure D-4B(b) - SPT Unit Shaft Resistance vs. Strain, Test 4B

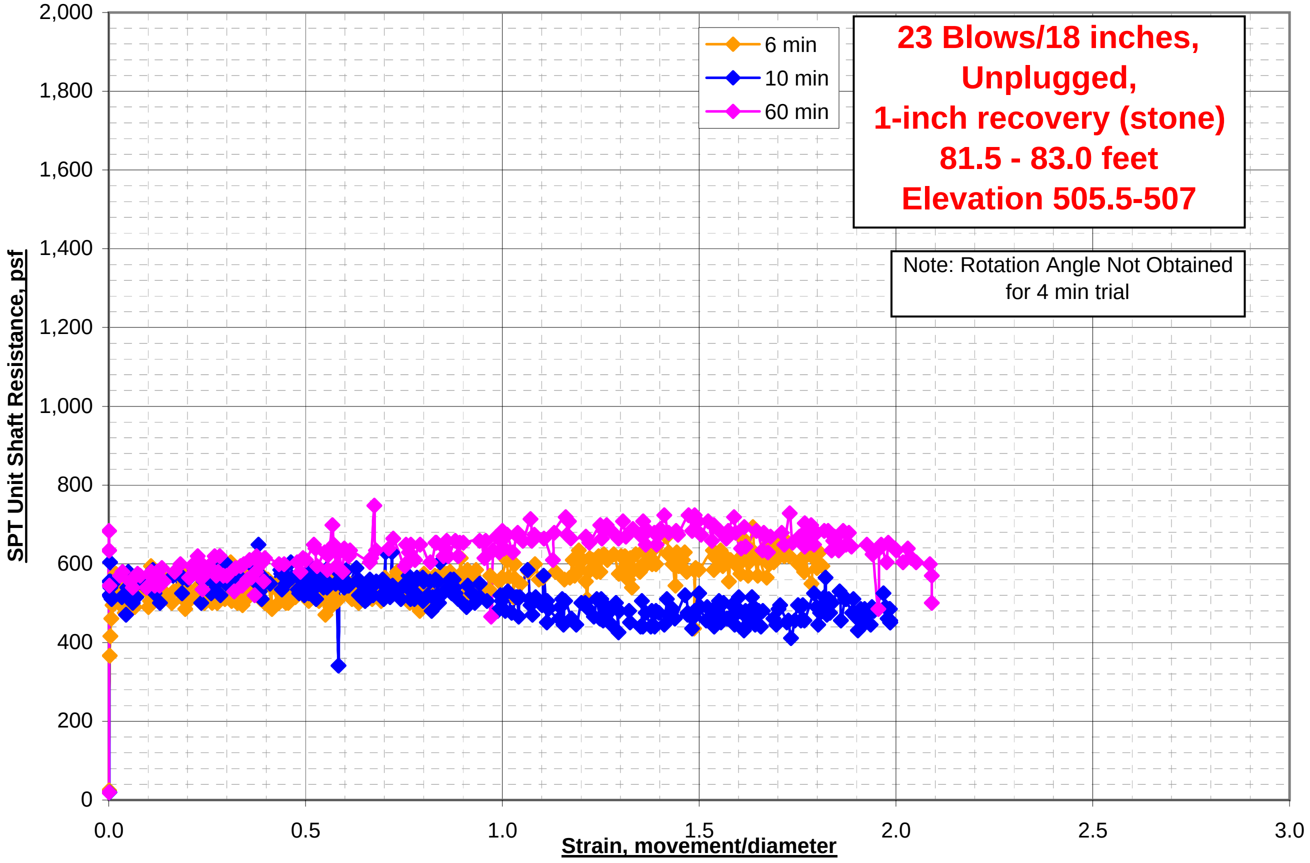
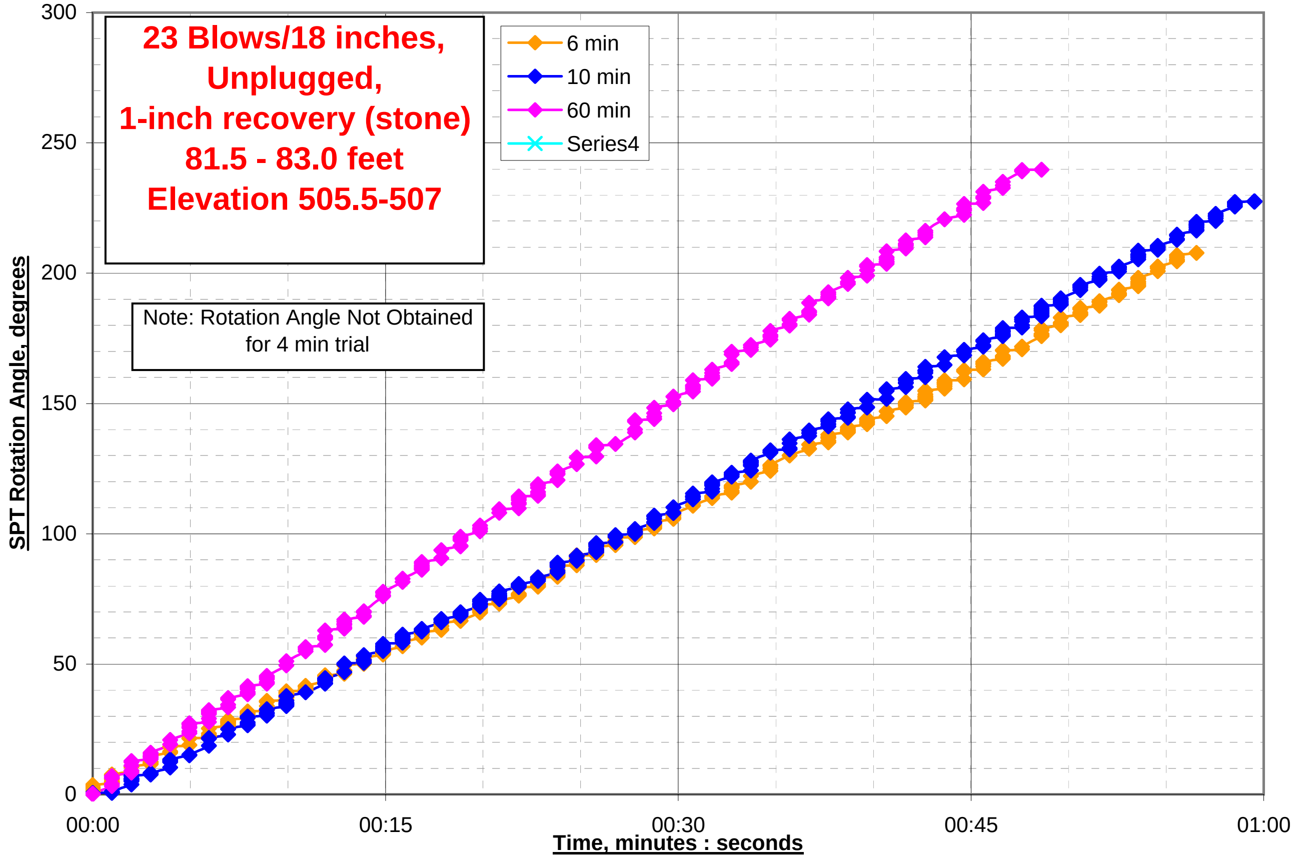


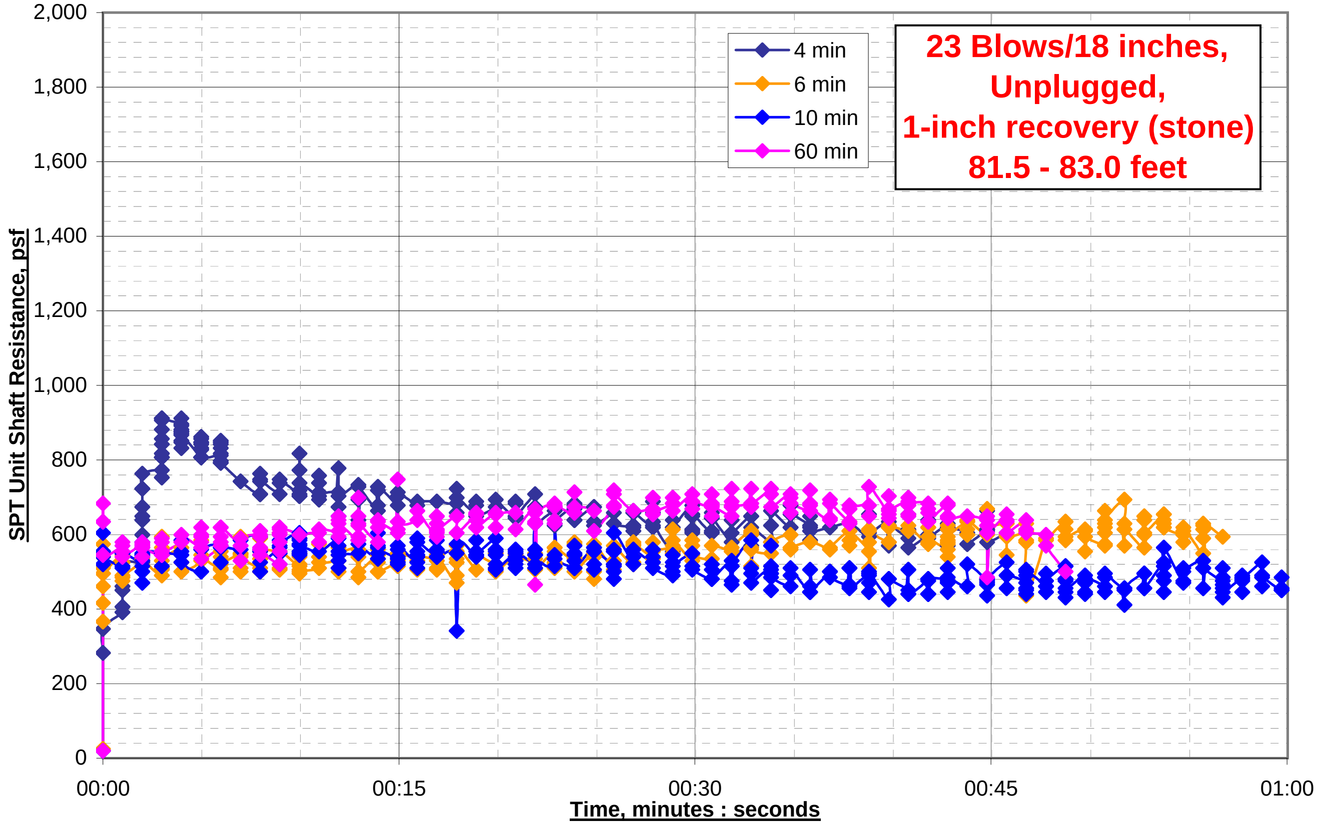
Figure D-4B(c) - SPT Rotation Angle vs. Time, Test 4B



23 Blows/18 inches,
Unplugged,
1-inch recovery (stone)
81.5 - 83.0 feet
Elevation 505.5-507

Note: Rotation Angle Not Obtained for 4 min trial

Figure D-4B(d) - SPT Unit Shaft Resistance vs. Time, Test 4B



23 Blows/18 inches,
Unplugged,
1-inch recovery (stone)
81.5 - 83.0 feet

Figure D-4C(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 4C

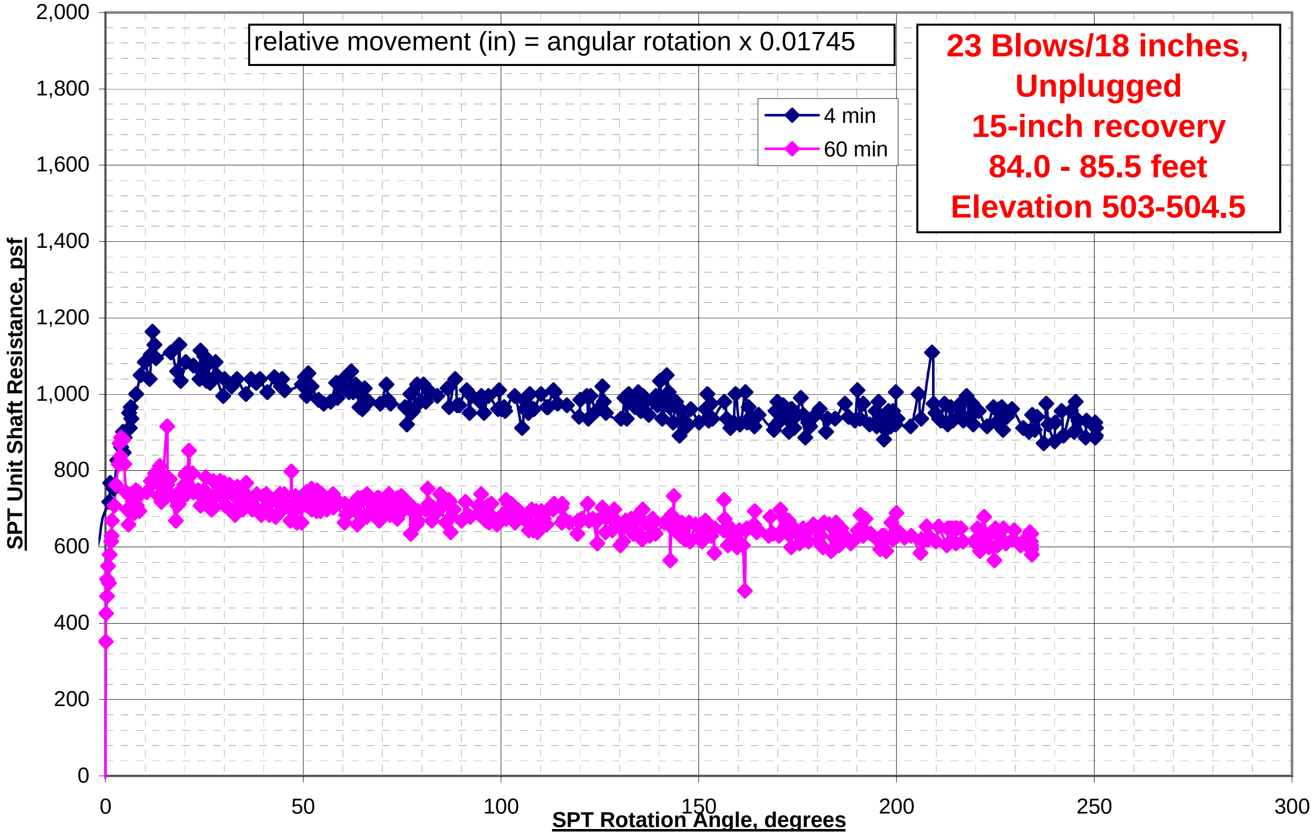


Figure D-4C(b) - SPT Unit Shaft Resistance vs. Strain, Test 4C

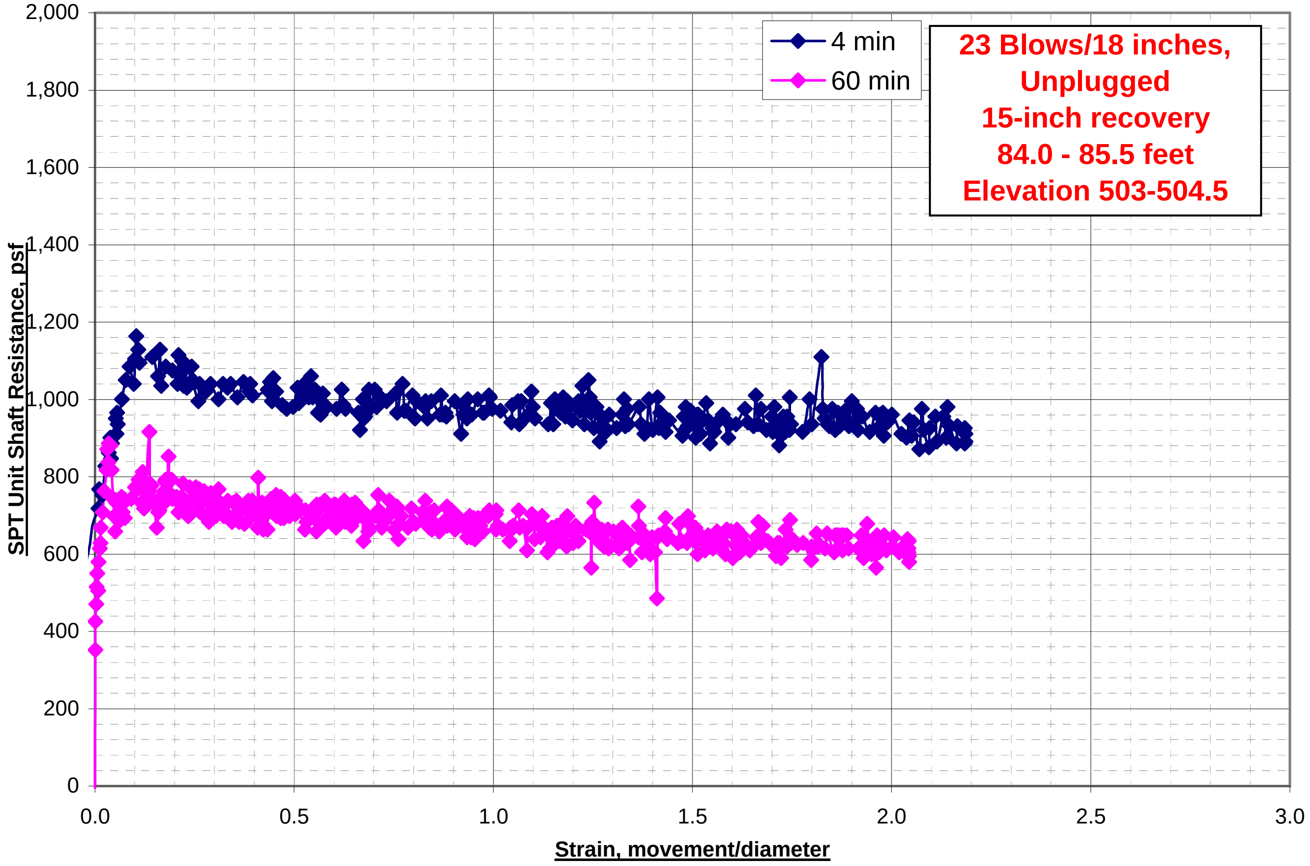


Figure D-4C(c) - SPT Rotation Angle vs. Time, Test 4C

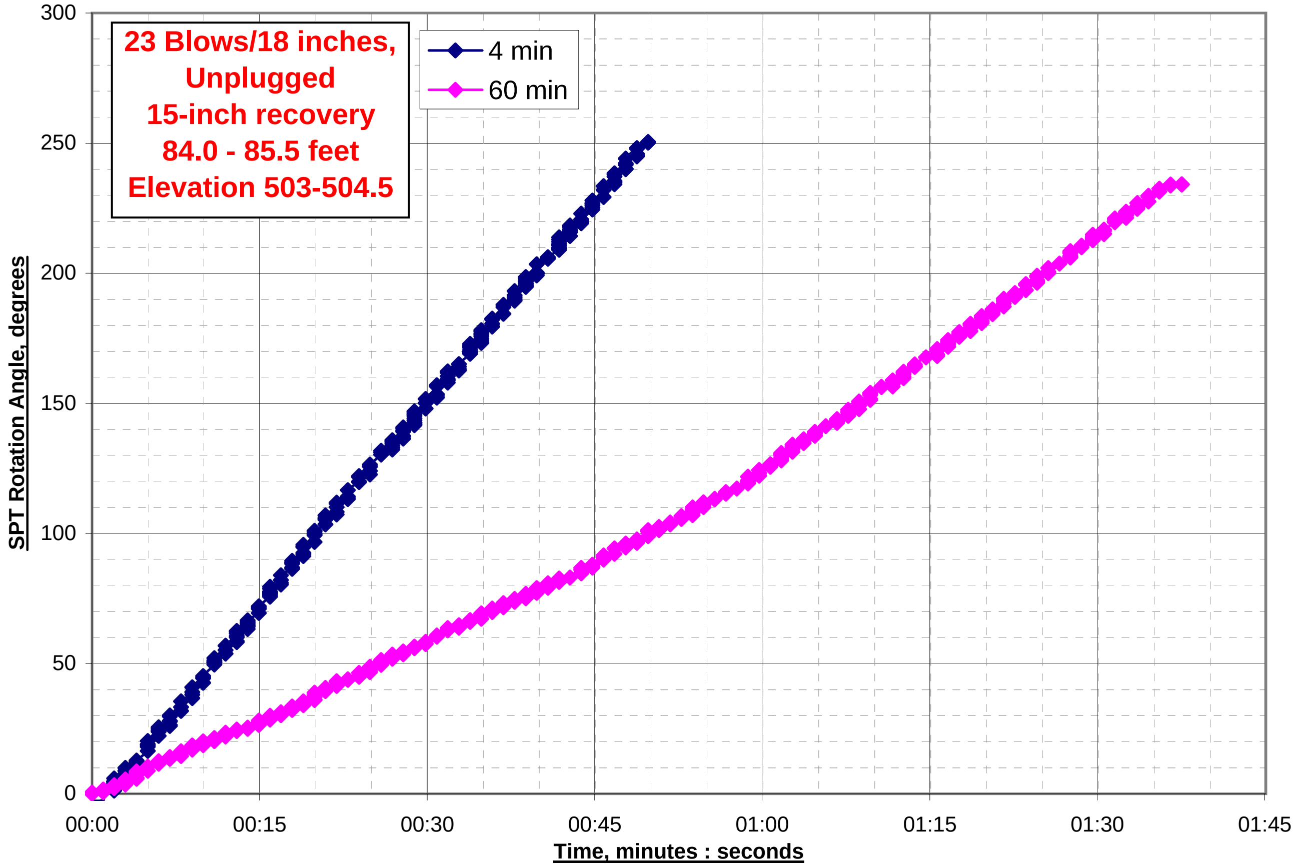


Figure D-4C(d) - SPT Unit Shaft Resistance vs. Angle, Test 4C

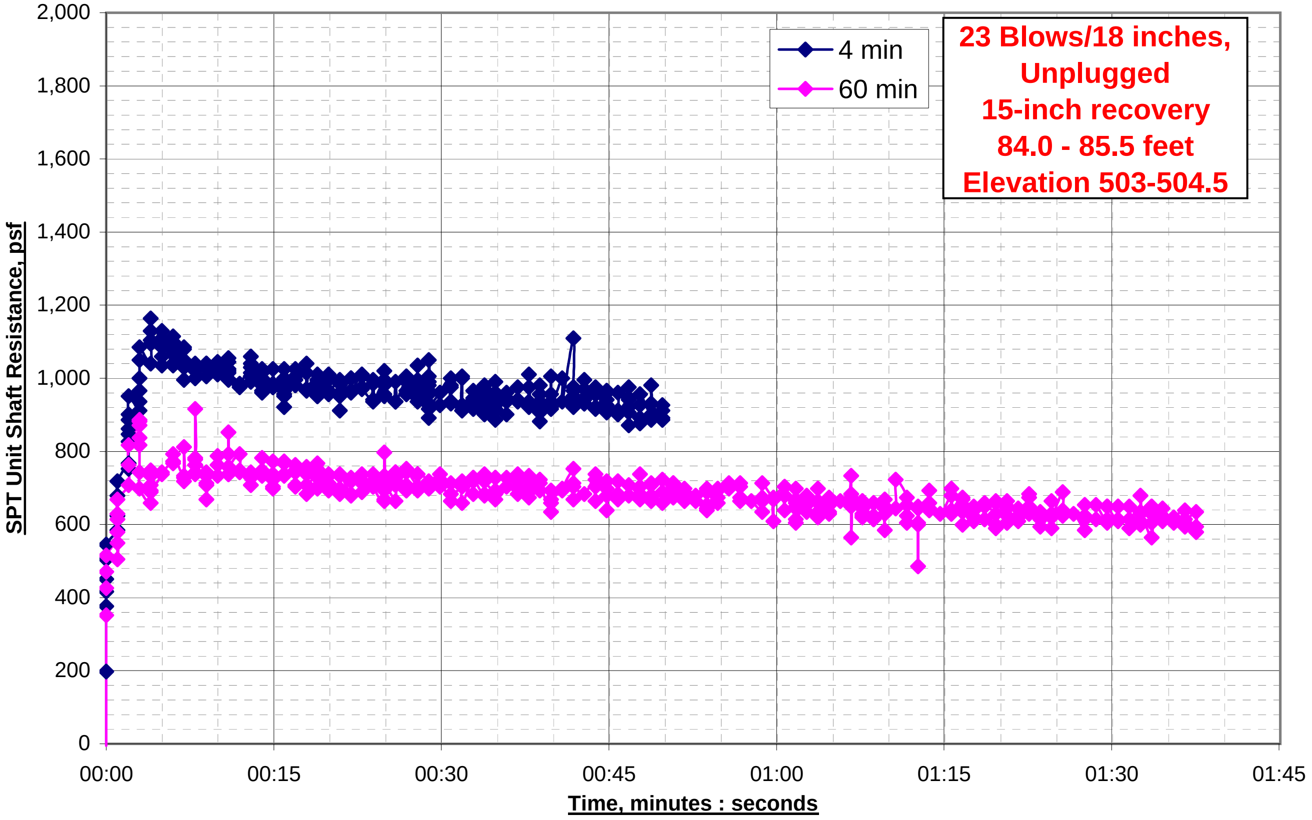


Figure D-5A(a) - SPT Unit Shaft Resistance vs. Rotation Angle, Test 5A

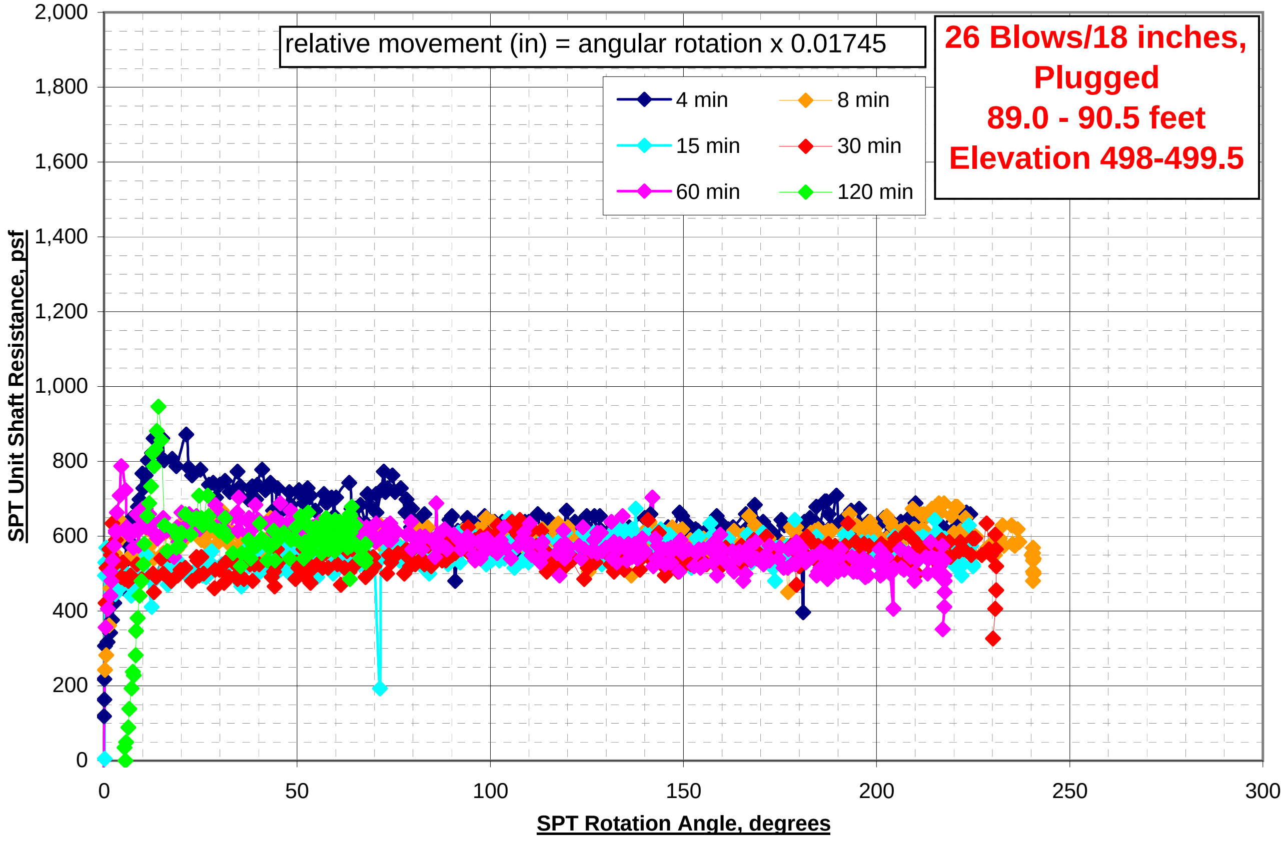


Figure D-5A(b) - SPT Unit Shaft Resistance vs. Strain, Test 5A

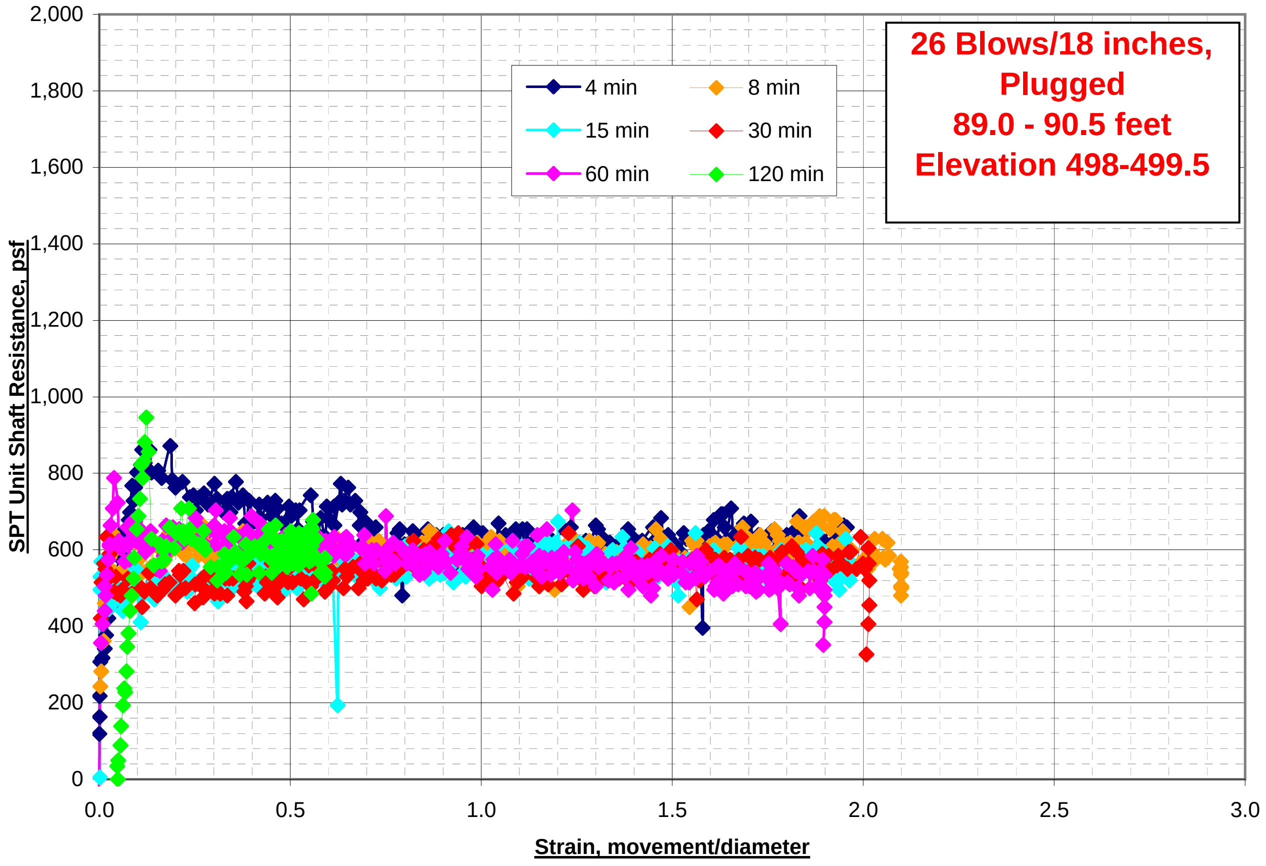


Figure D-5A(c) - SPT Rotation Angle vs. Time, Test 5A

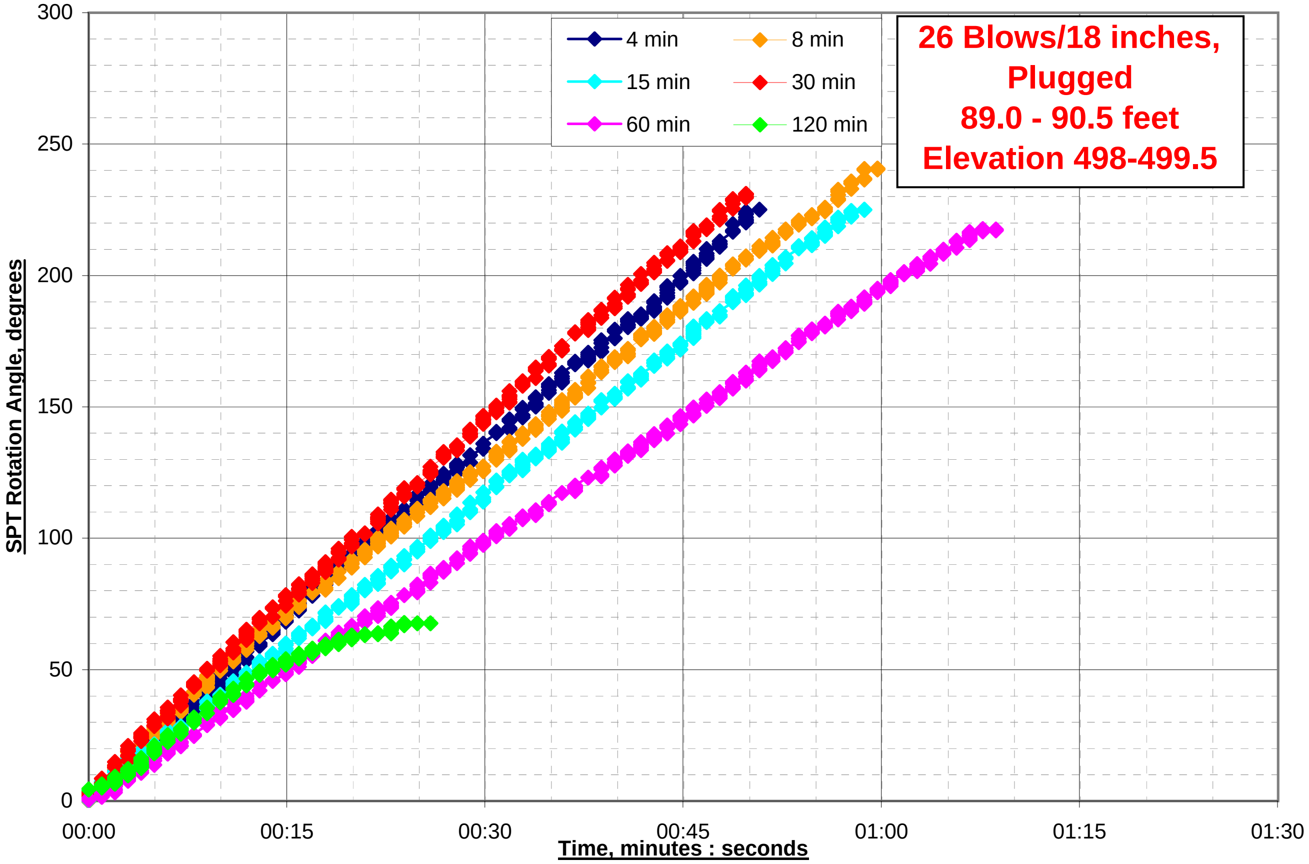


Figure D-5A(d) - SPT Unit Shaft Resistance vs. Time, Test 5A

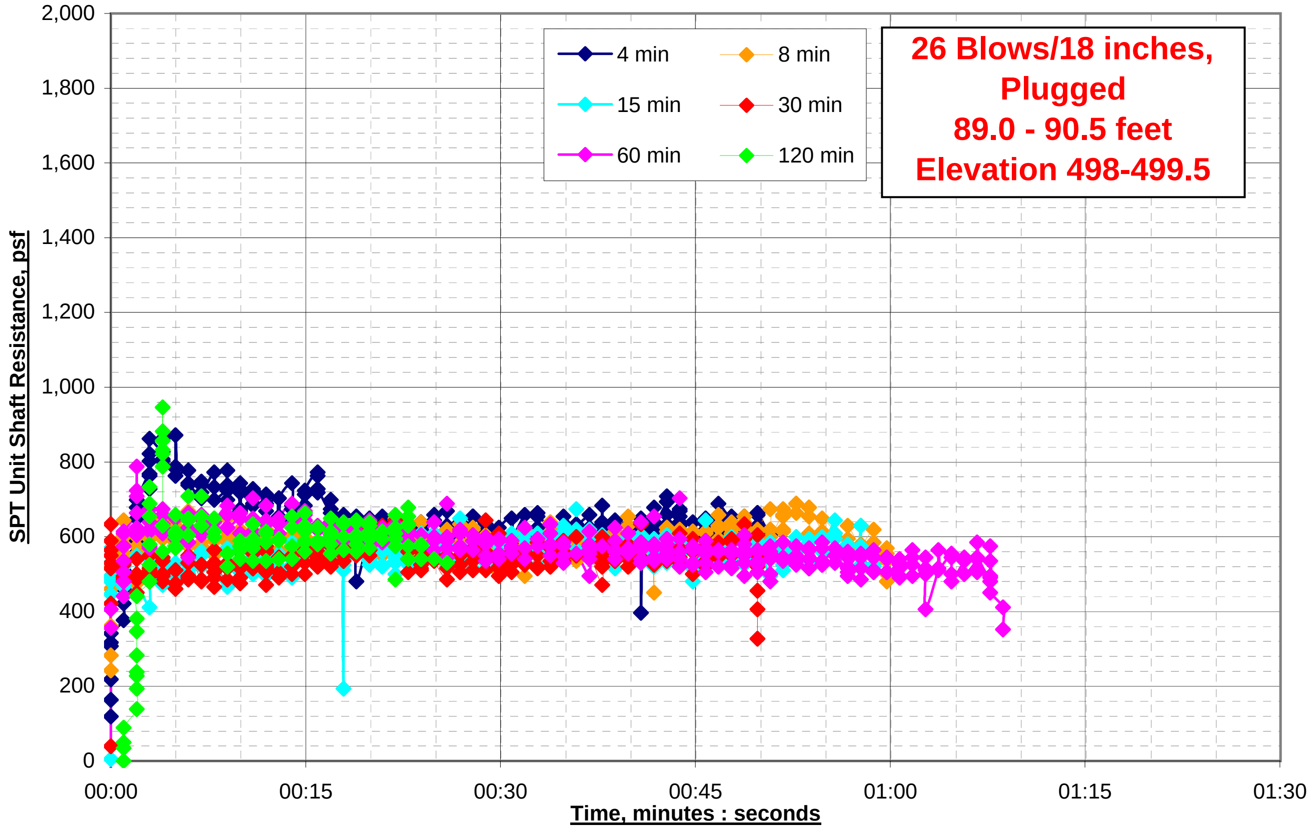


Figure D-5B(a) - Unit Shaft Resist. vs. Rotation Angle, Test 5B

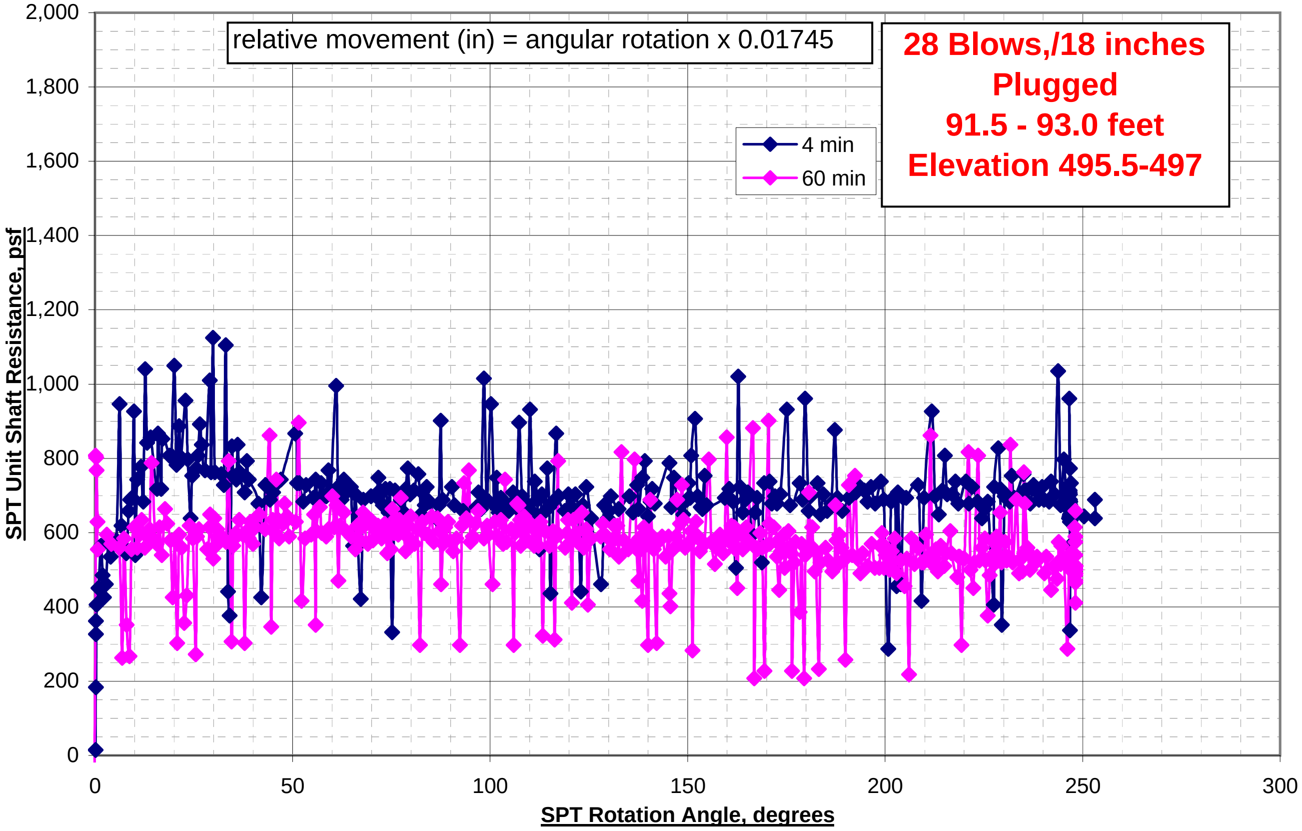


Figure D-5B(b) - Unit Shaft Resistance vs. Strain, Test 5B

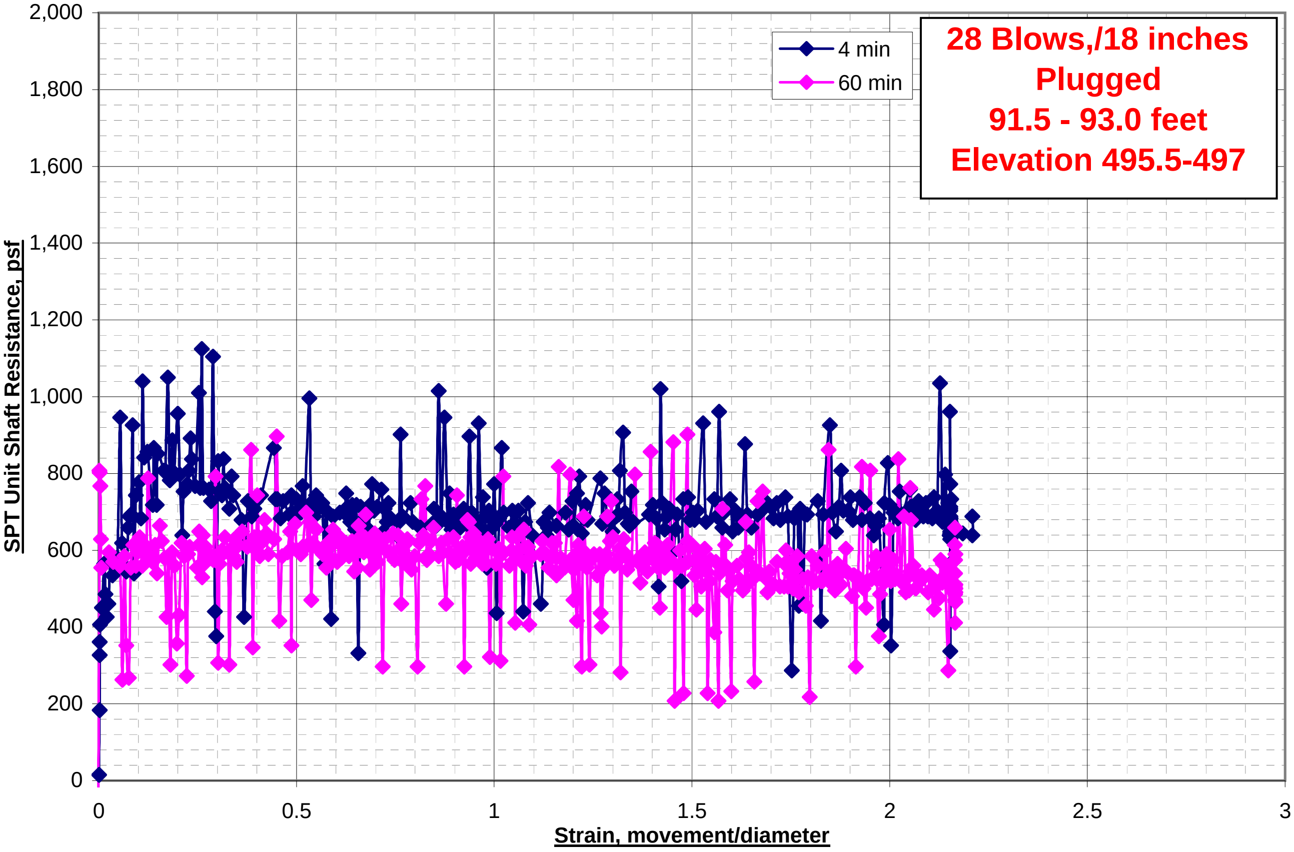


Figure D-5B(c) - SPT Rotation Angle vs. Time, Test 5B

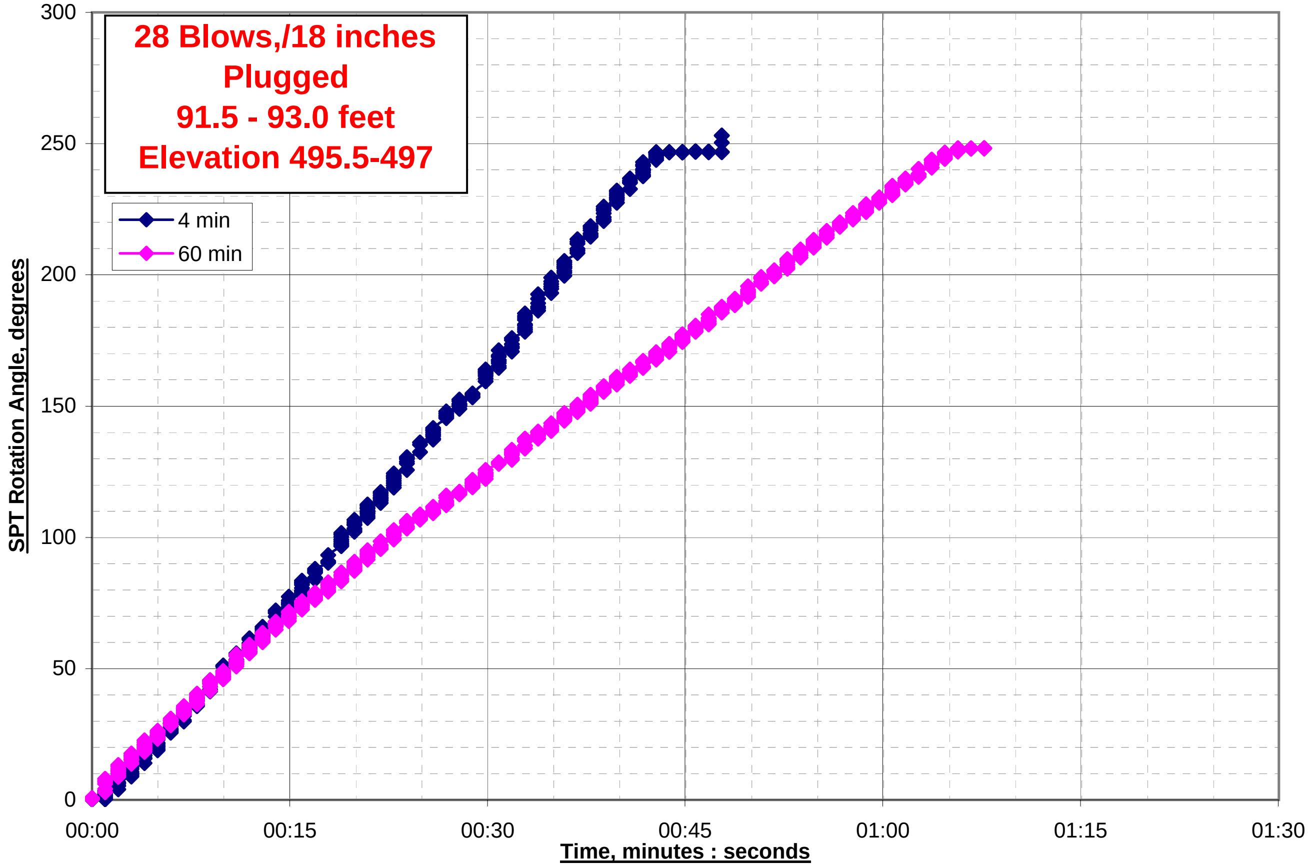


Figure D-5B(d) - Unit Shaft Resistance vs. Time, Test 5B

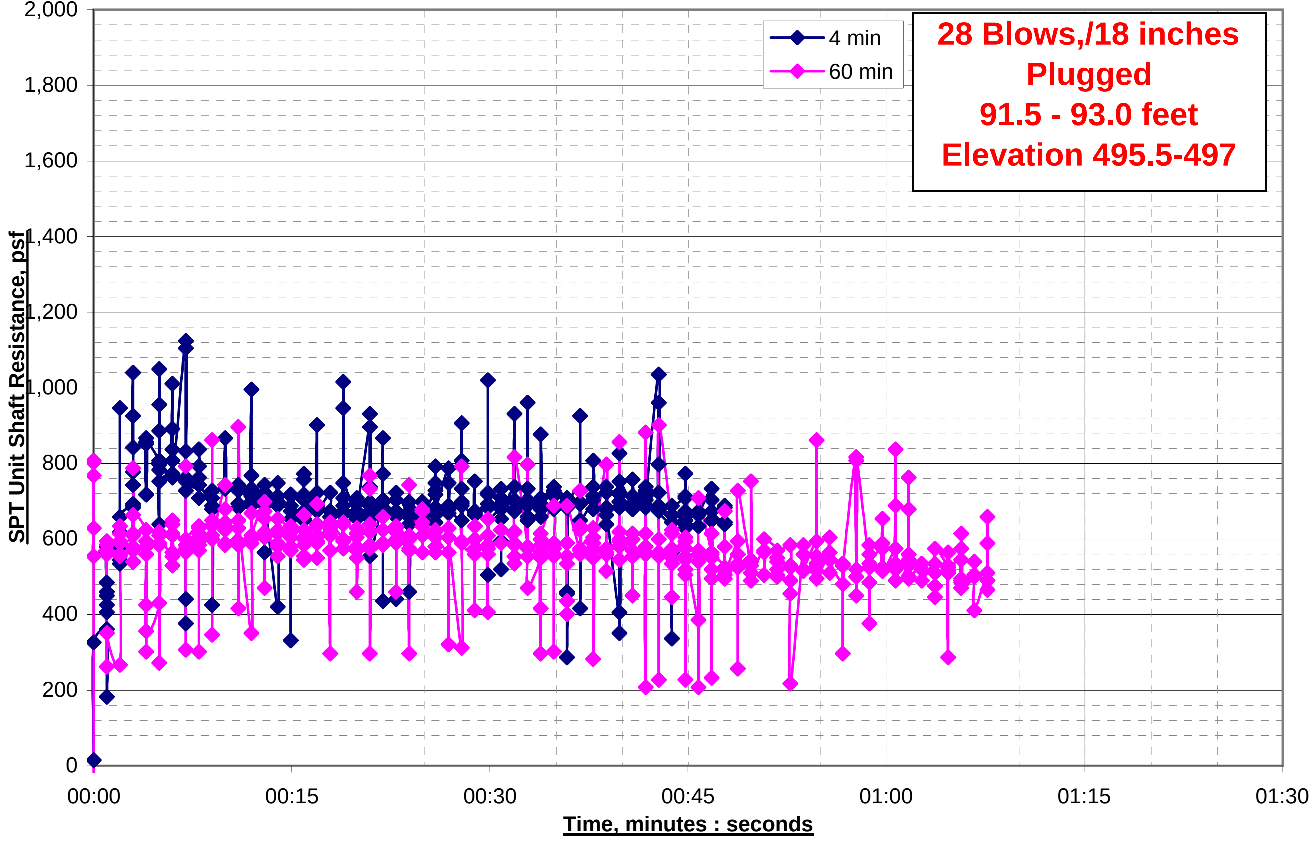


Figure D-6A(a) - SPT Unit Shaft Resistance vs. Rotation Angle, Test 6A

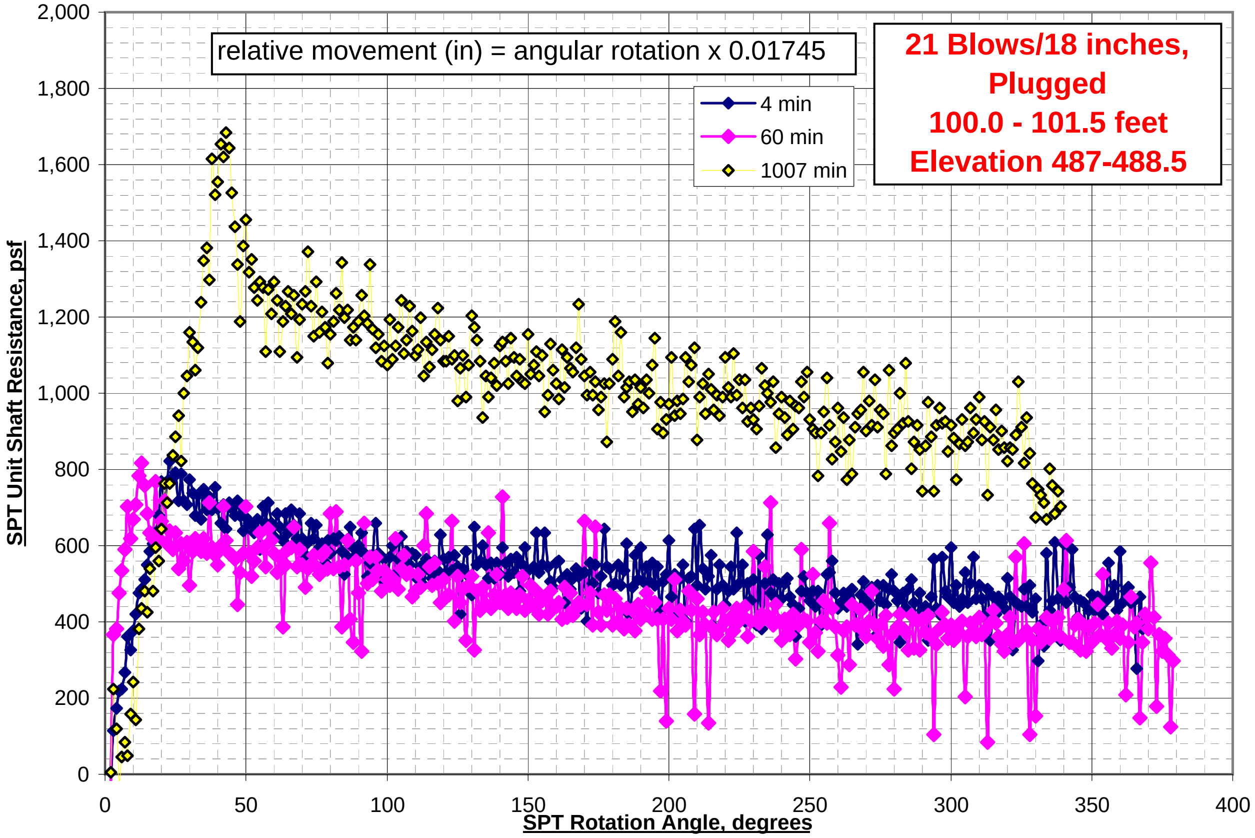


Figure D-6A(b) - SPT Unit Shaft Resistance vs. Strain, Test 6A

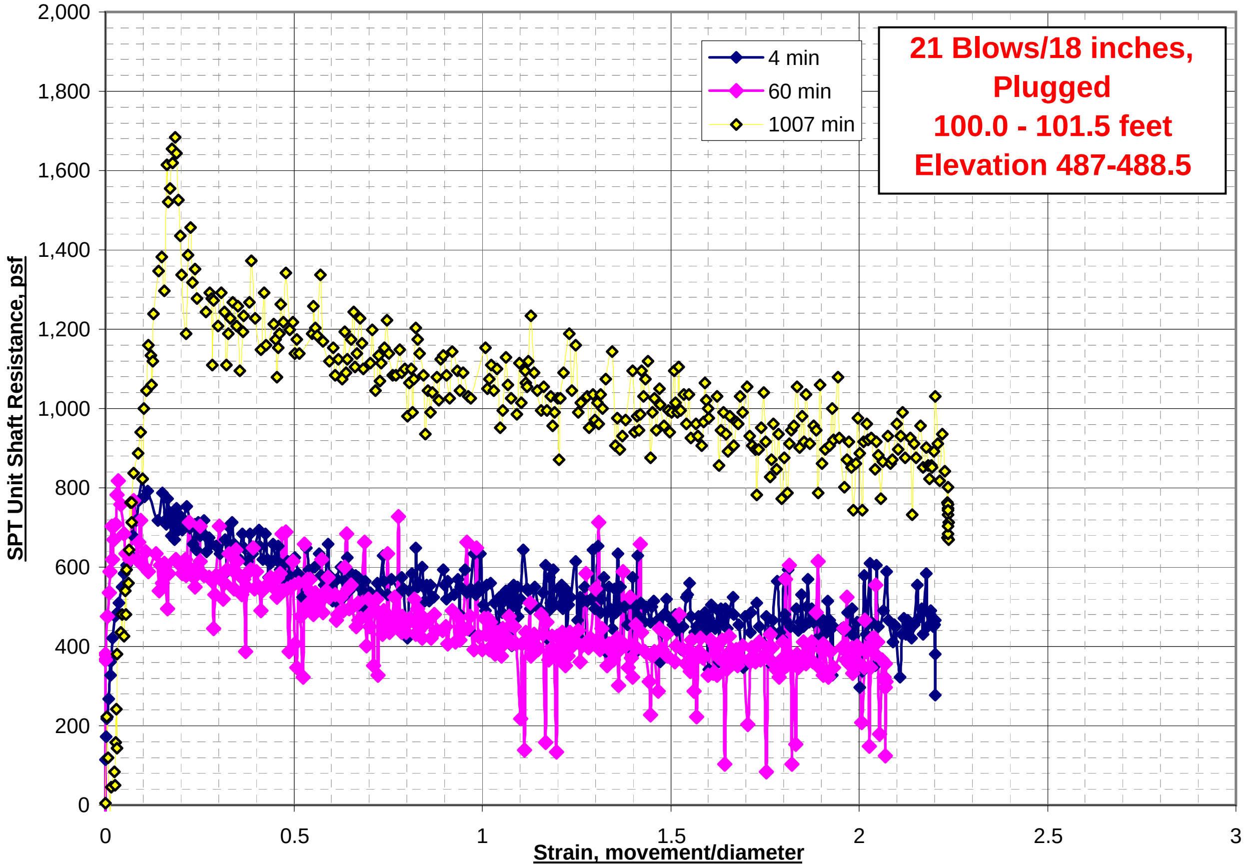


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Figure D-6A(c) - SPT Rotation Angle vs. Time, Test 6A

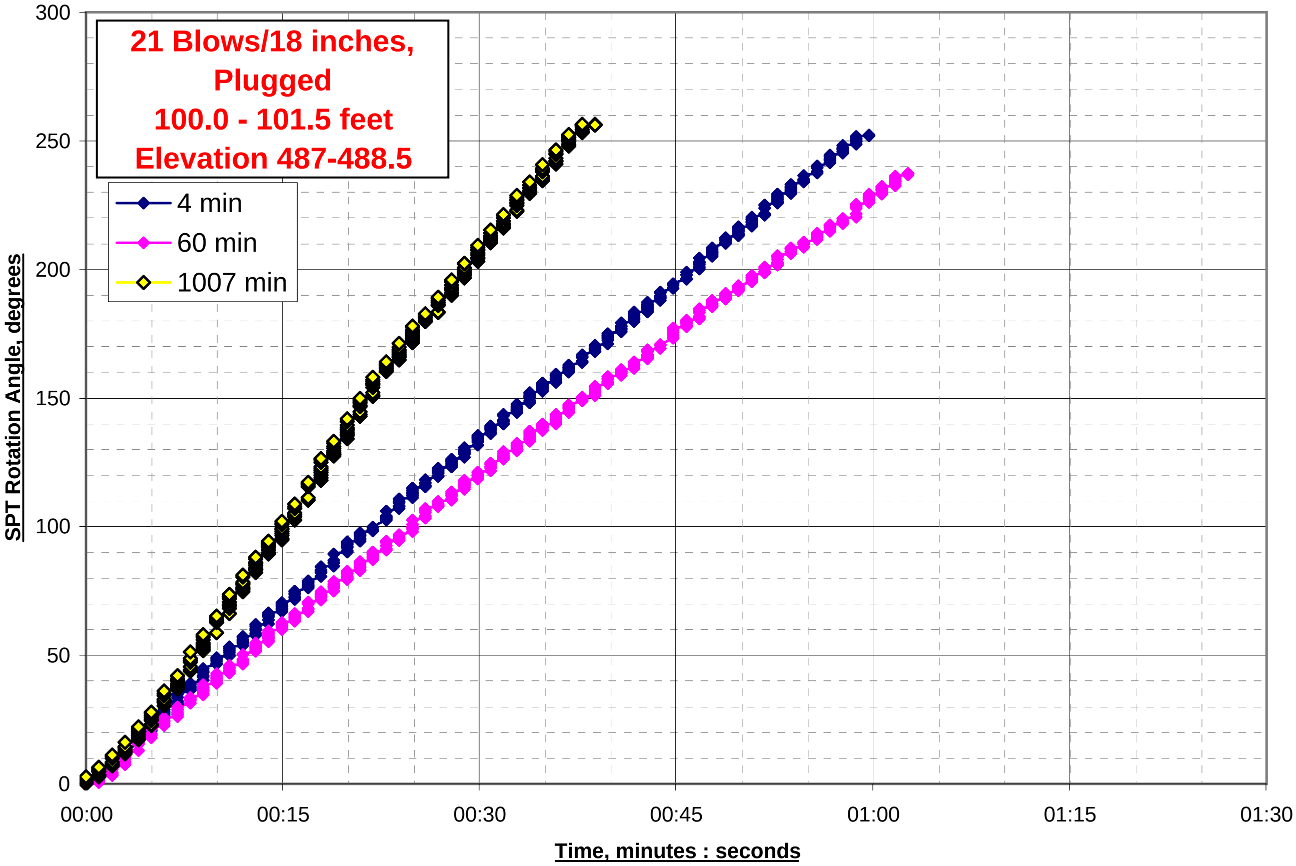

Figure D-6A(d) - SPT Unit Shaft Resistance vs. Time, Test 6A

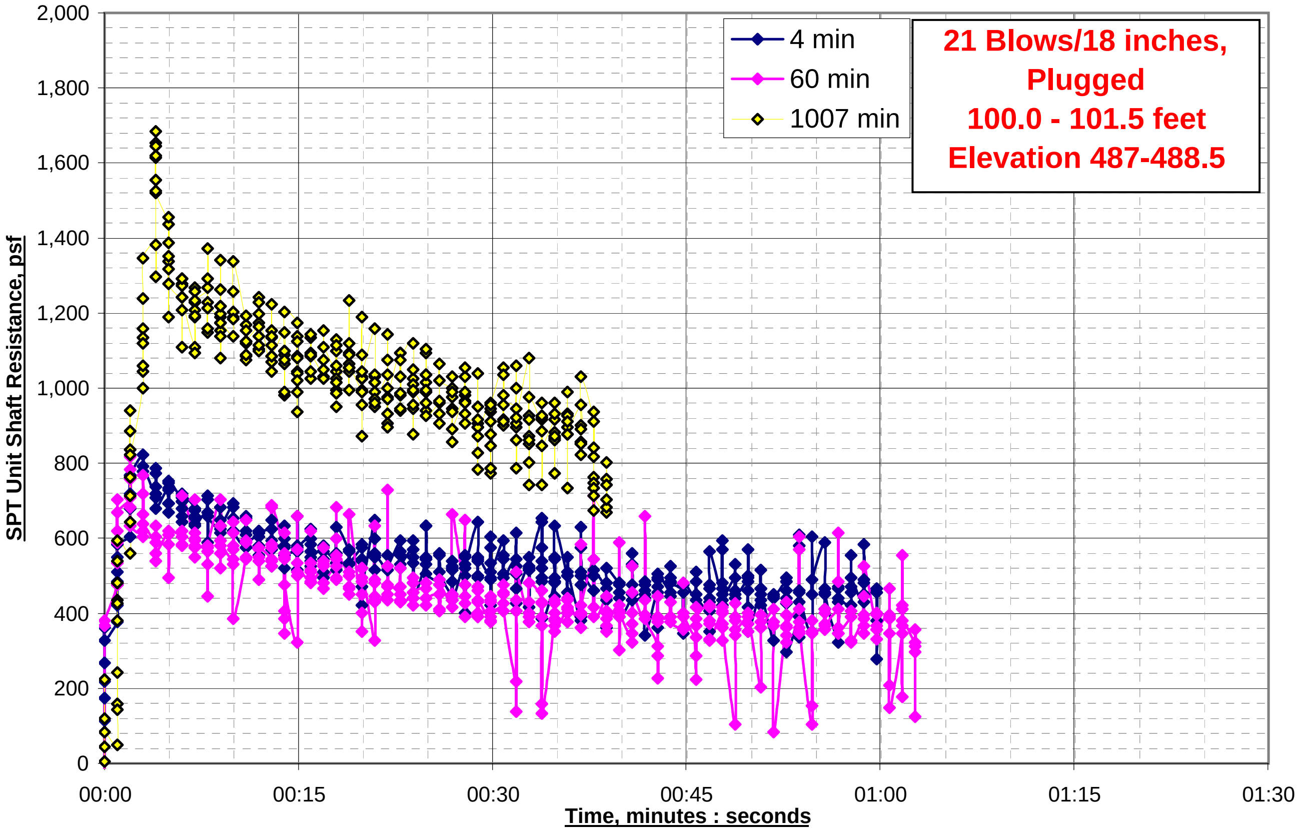

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Figure D-6B(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 6B

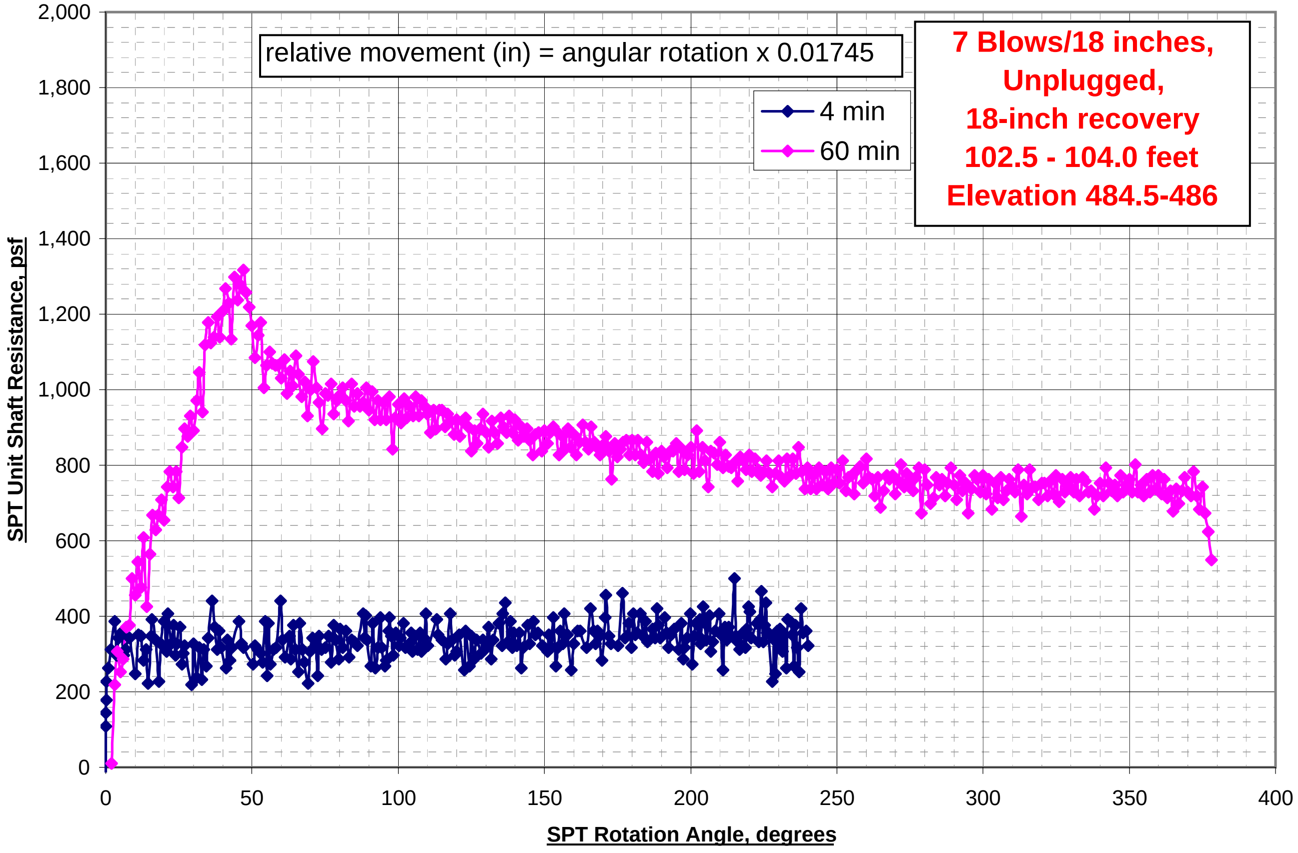

Figure D-6B(b) - SPT Unit Shaft Resistance vs. Strain, Test 6B

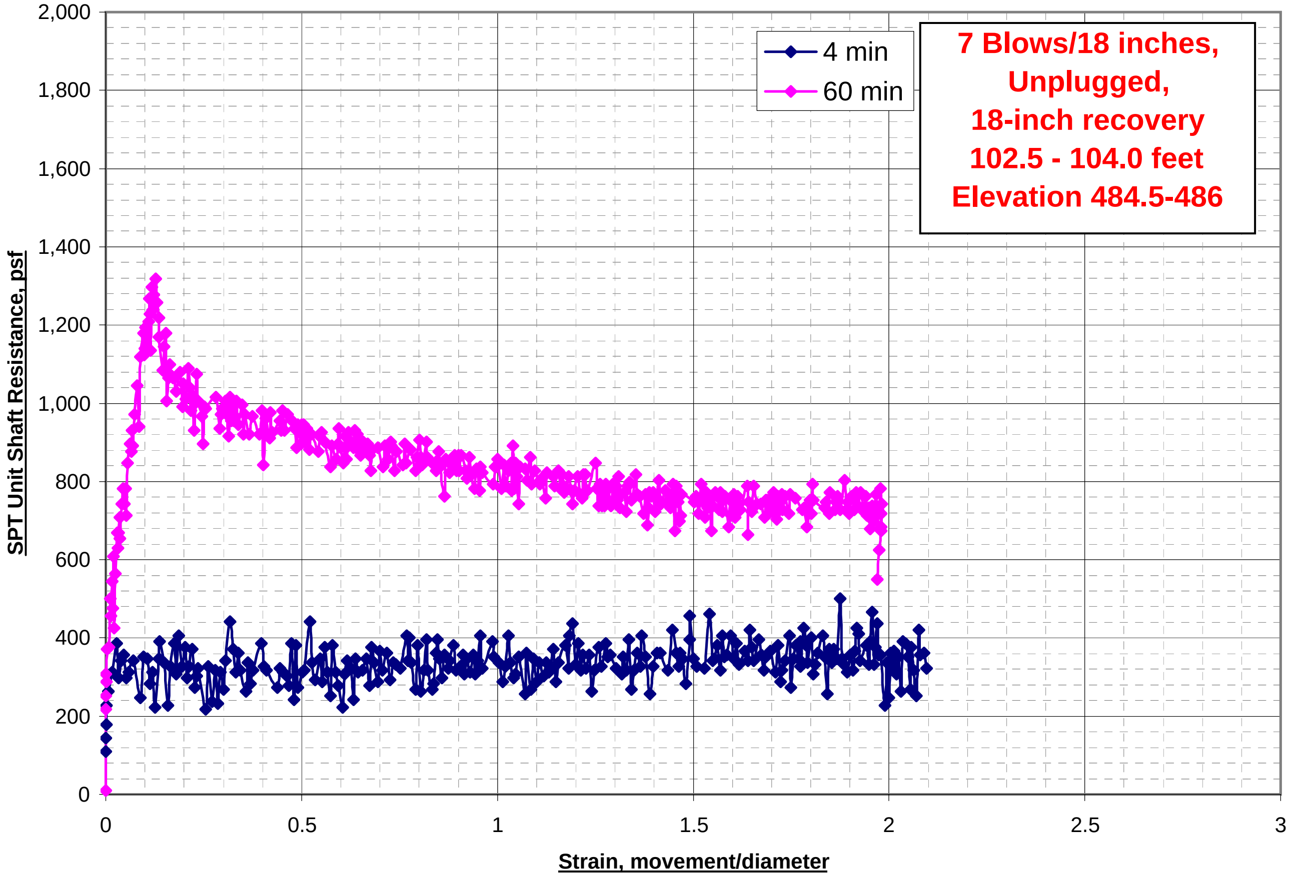

Figure D-6B(c) - SPT Rotation Angle vs. Time, Test 6B

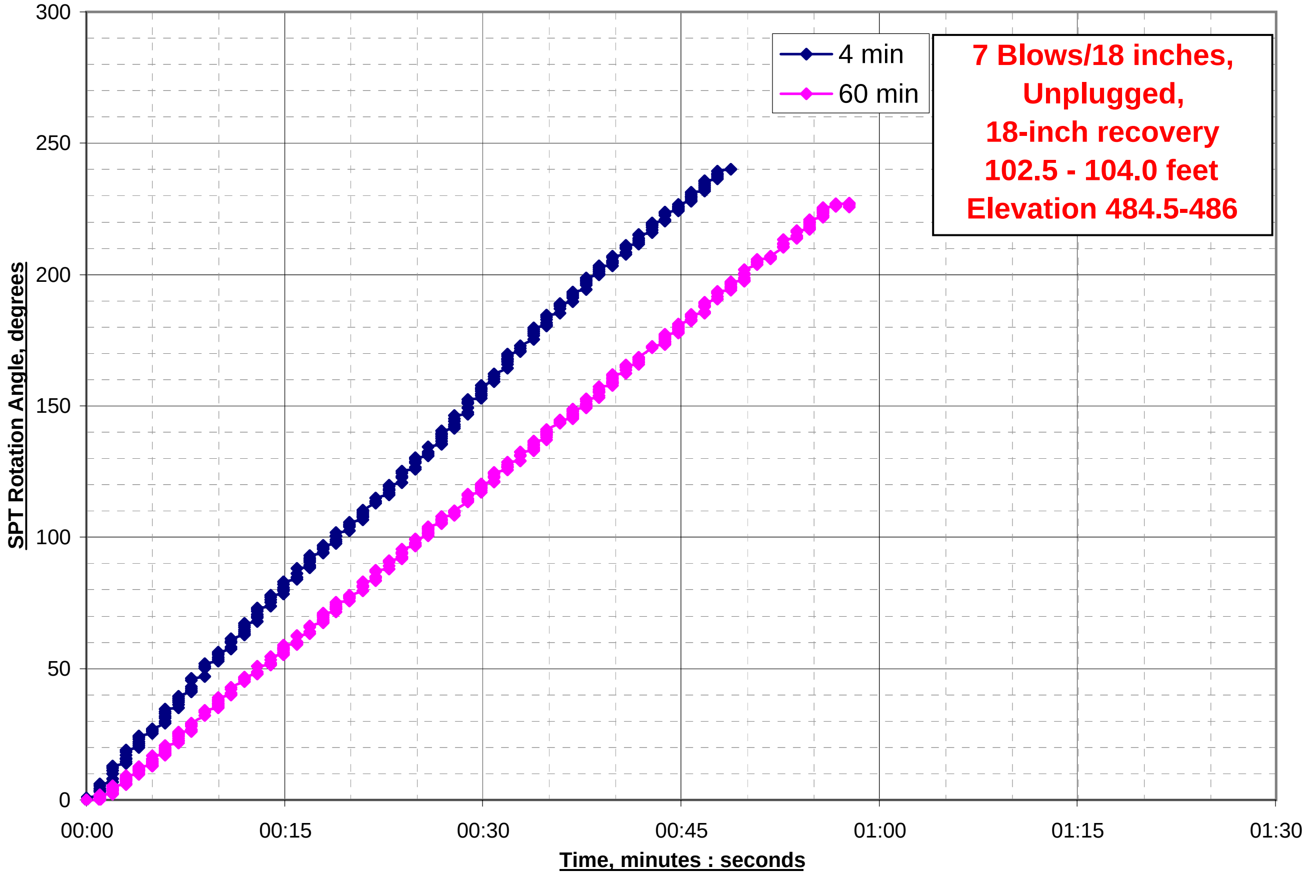

Figure D-6B(d) - SPT Unit Shaft Resistance vs. Time, Test 6B

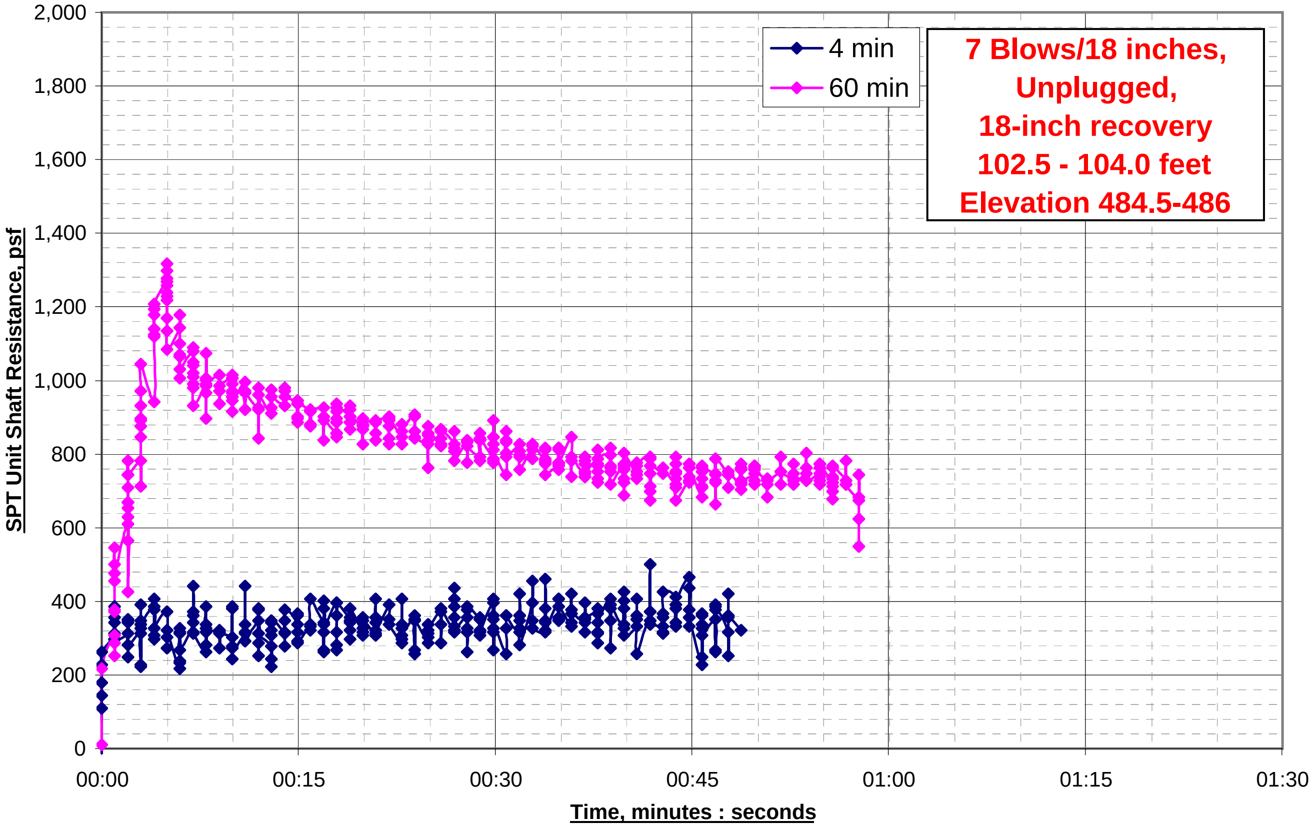

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Figure D-7A(a) - SPT Unit Shaft Resistance vs. Rotation Angle, Test 7A

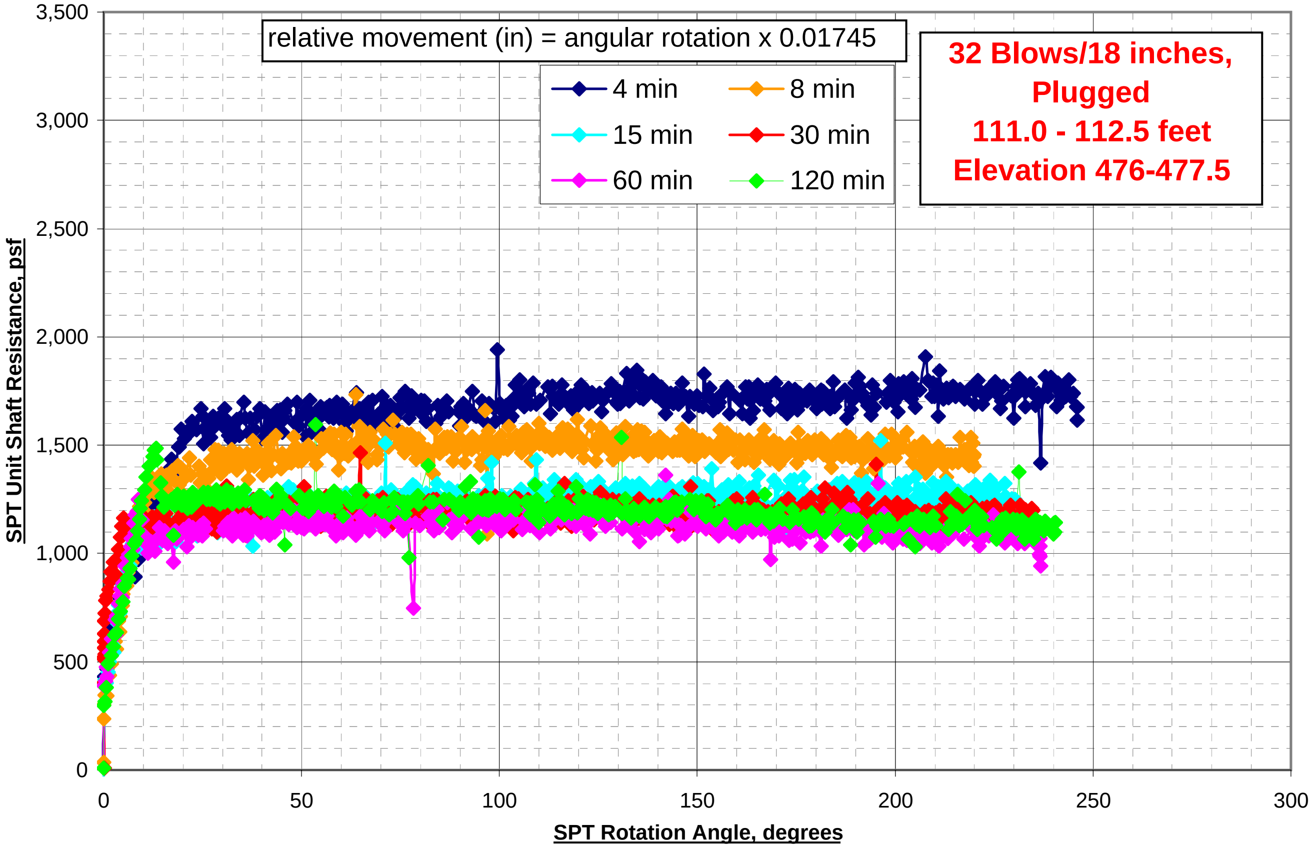

Figure D-7A(a) - SPT Unit Shaft Resistance vs. Strain, Test 7A

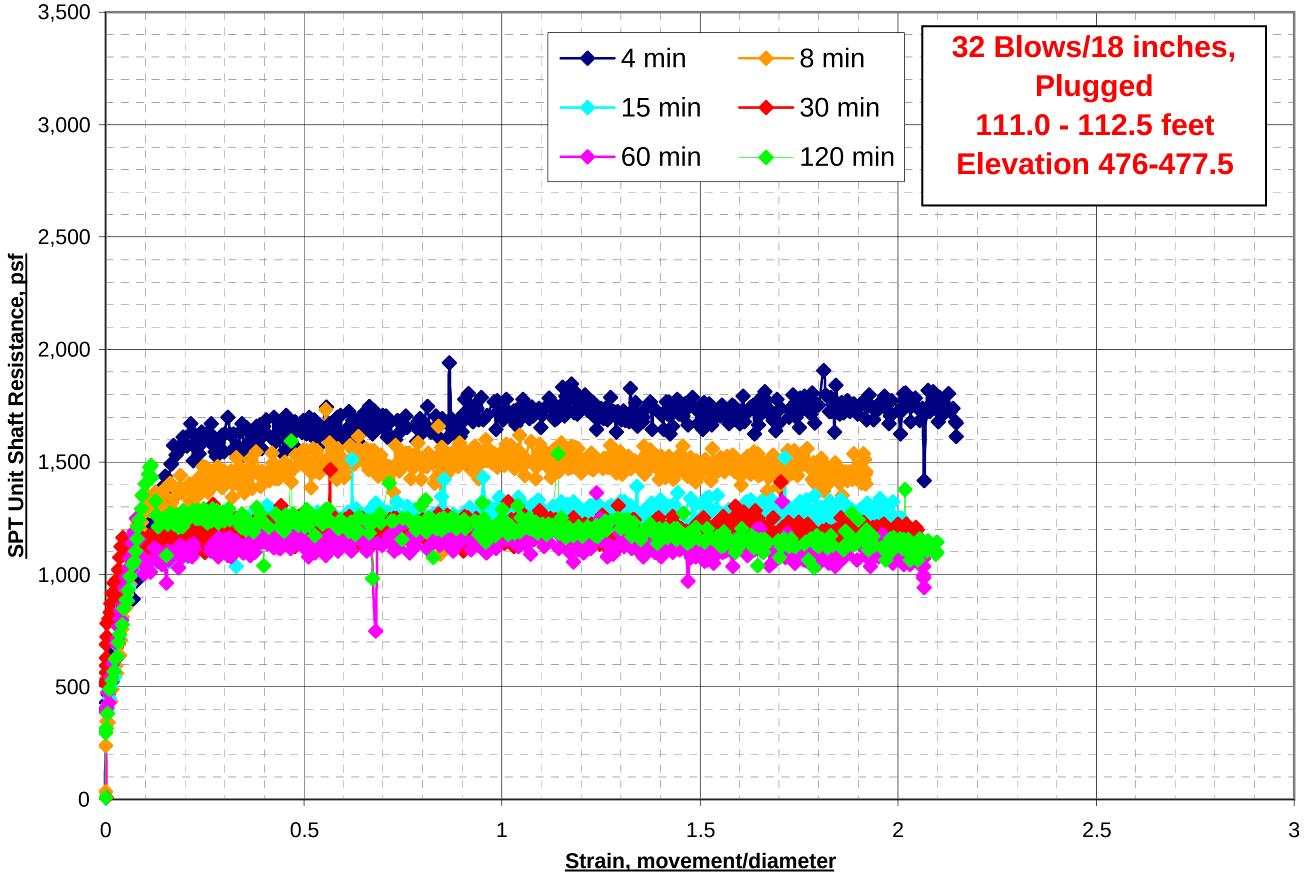

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Figure D-7A(c) - SPT Rotation Angle vs. Time, Test 7A

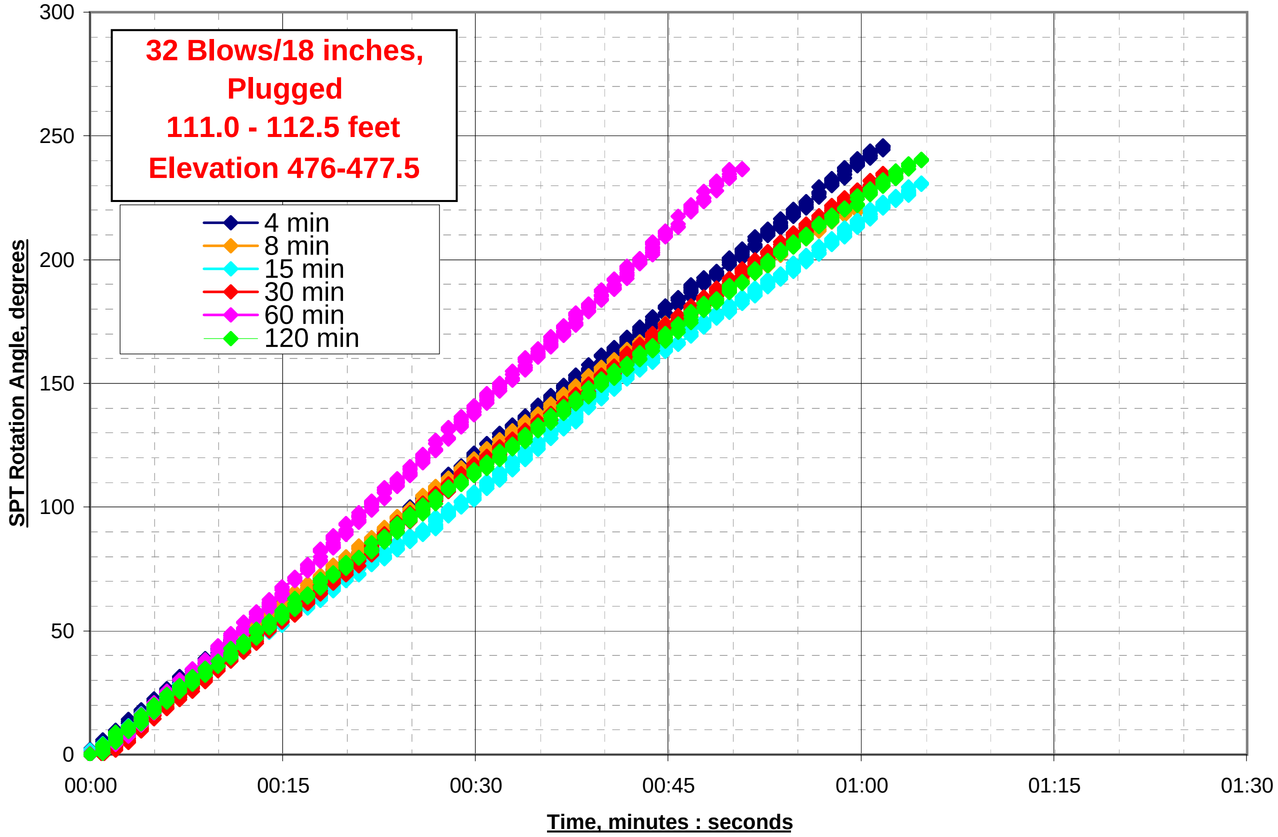

Figure D-7A(d) - SPT Unit Shaft Resistance vs. Time, Test 7A

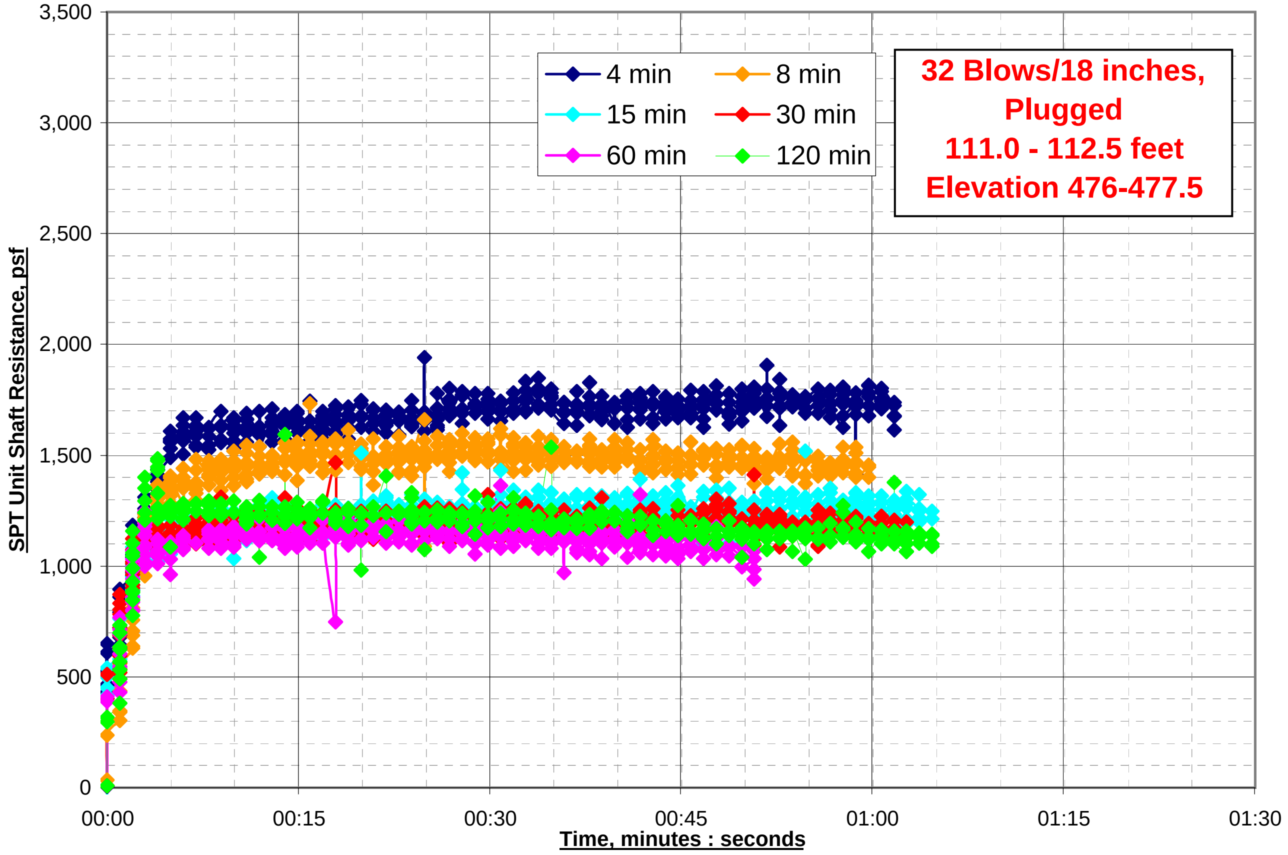

Figure D-7B(a) - SPT Unit Shaft Resistance vs. Angle, Test 7B

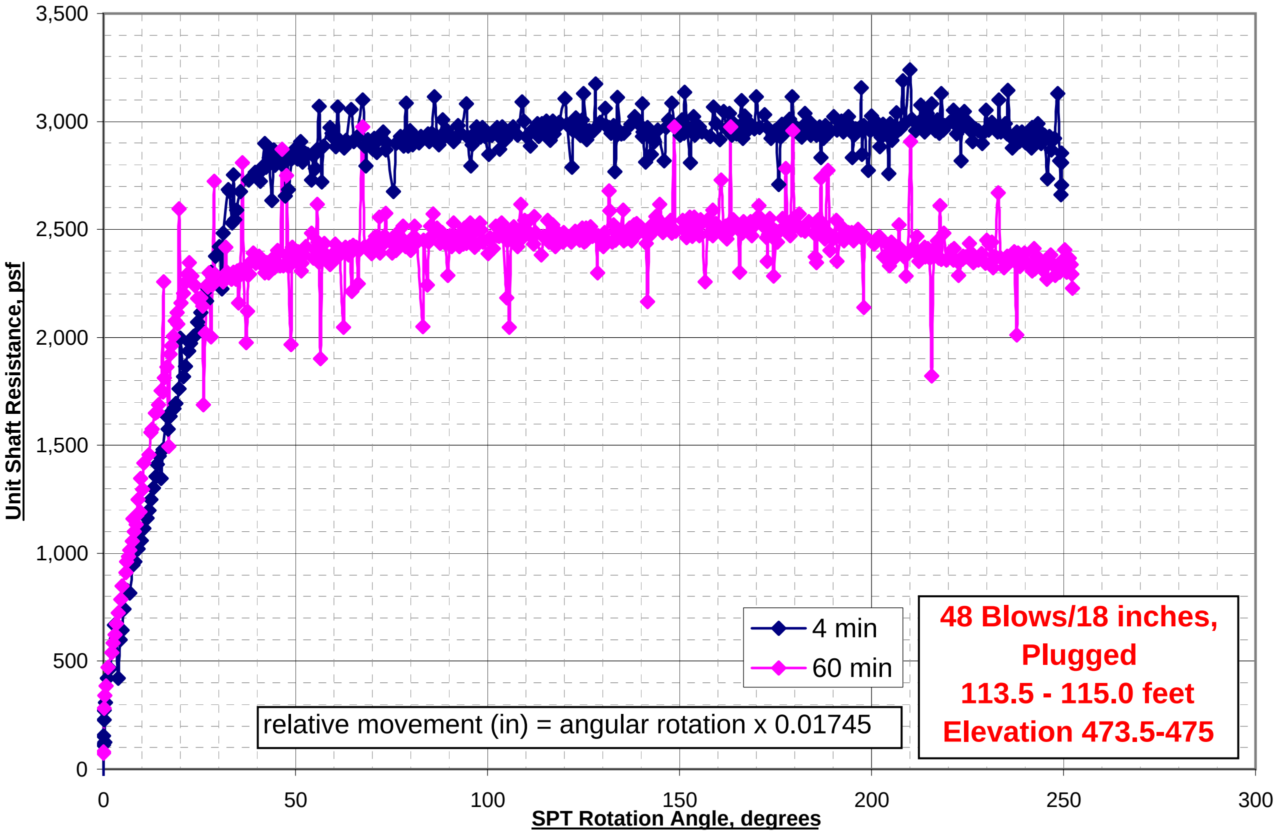

Figure D-7B(b) - SPT Unit Shaft Resistance vs. Strain, Test 7B

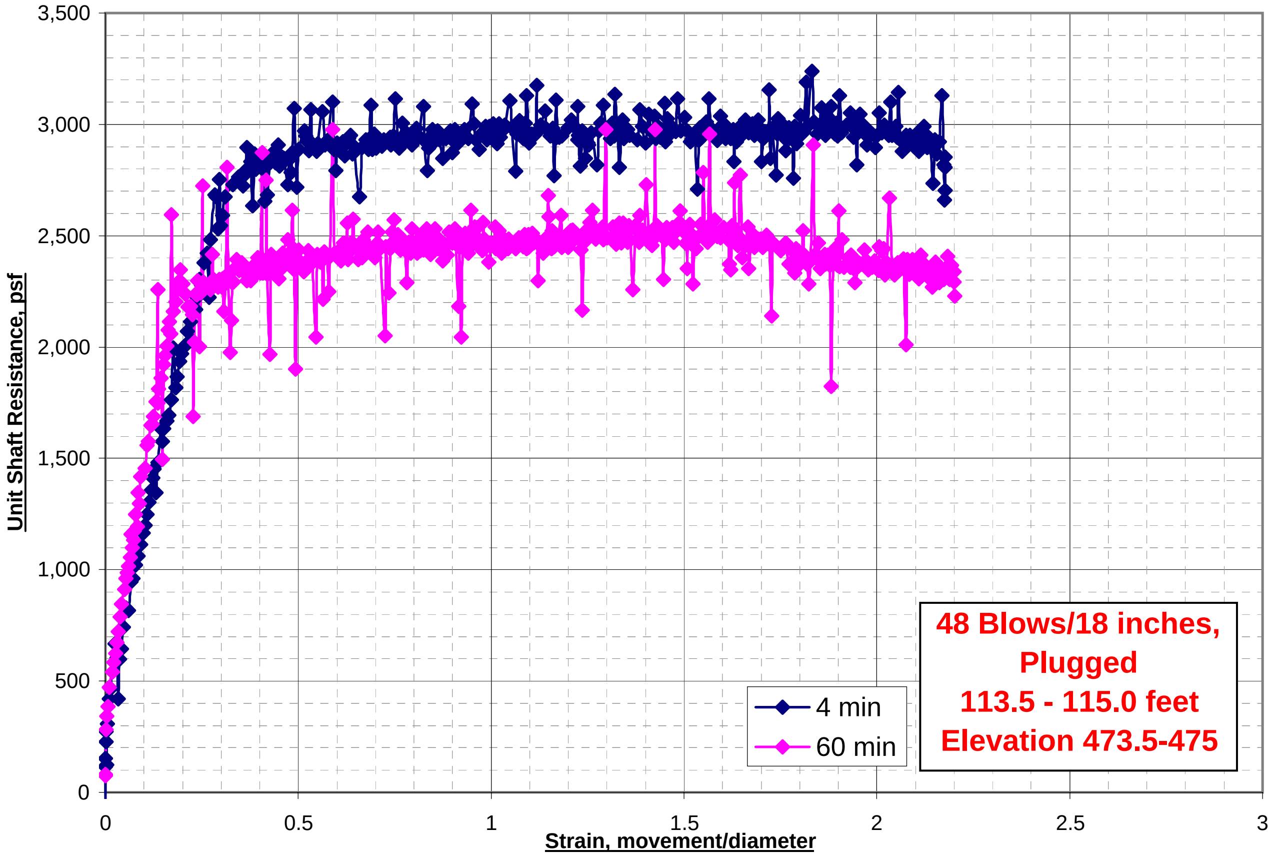

Figure D-7B(c) - SPT Rotation Angle vs. Time, Test 7B

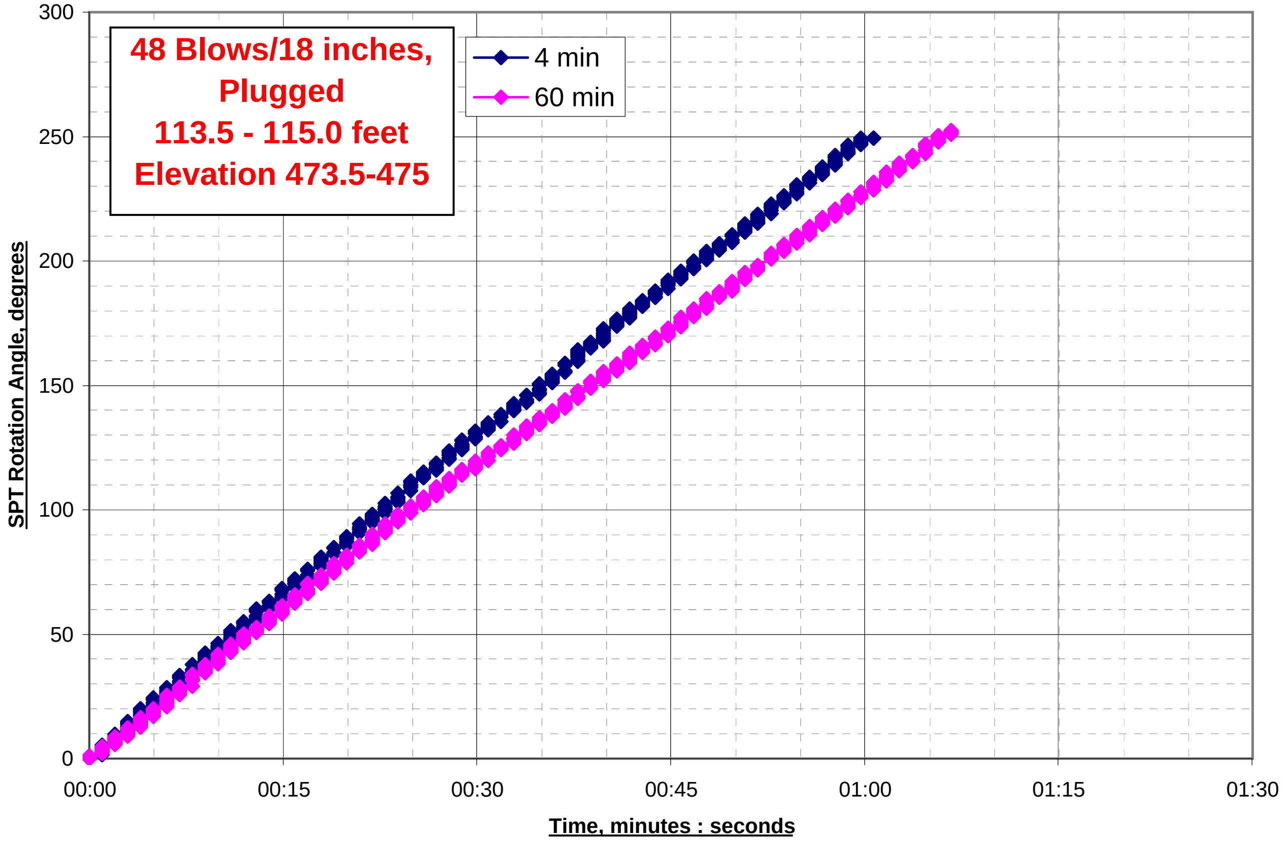

Figure D-7B(d) - SPT Unit Shaft Resistance vs. Time, Test 7B

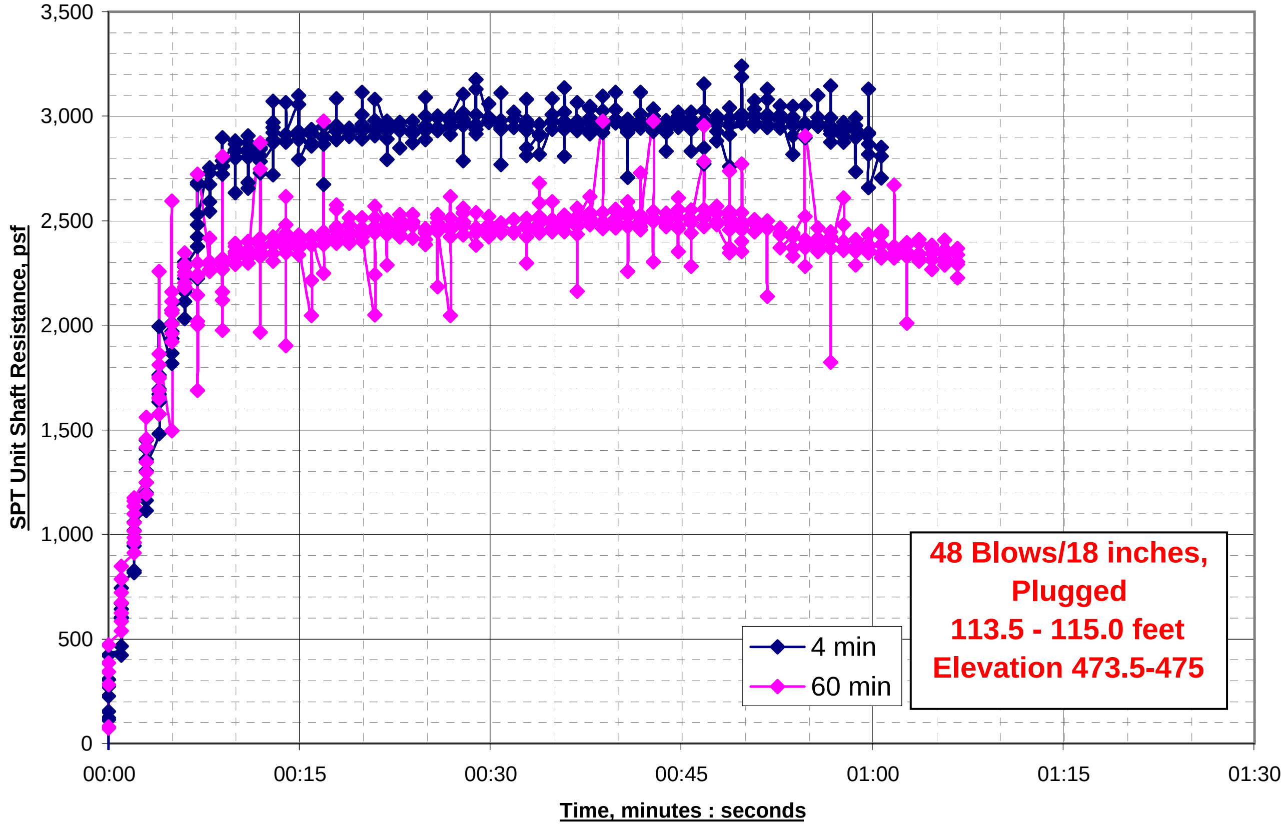

Figure D-8A(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 8A

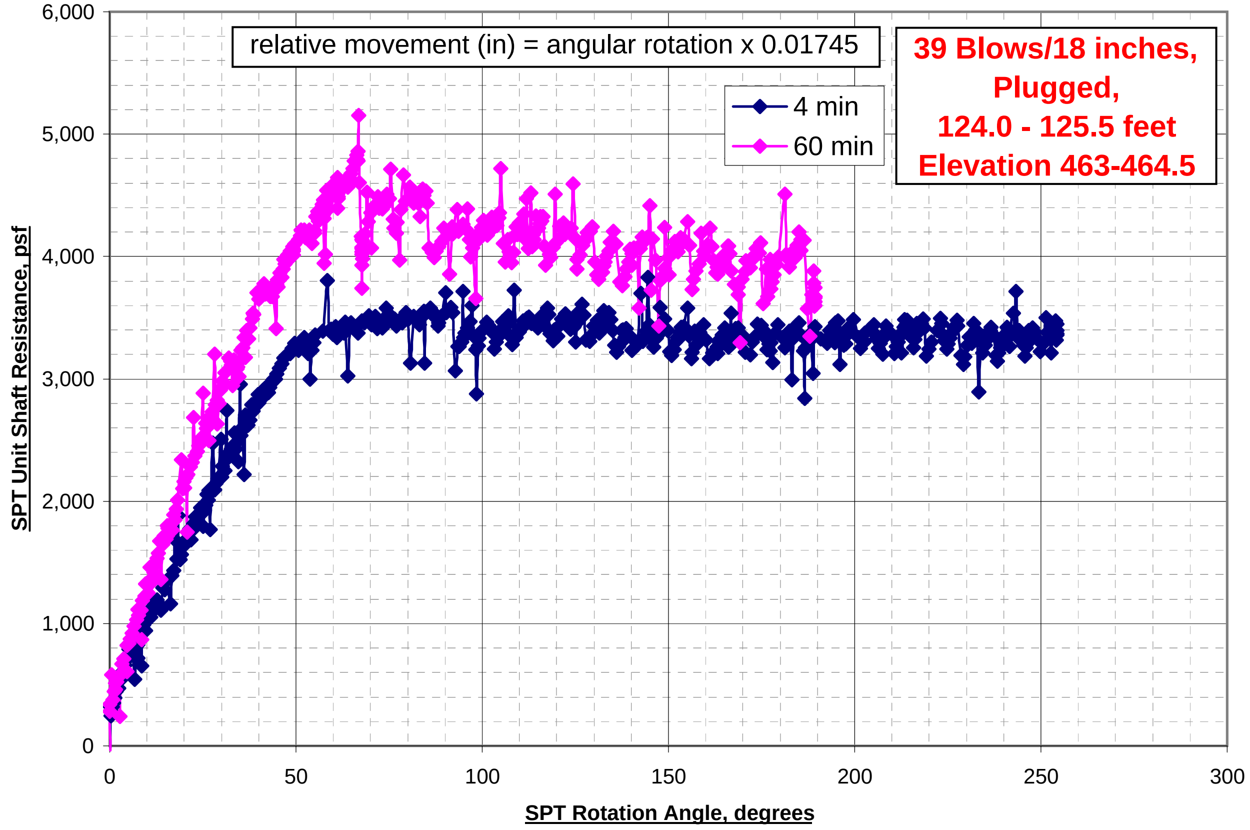

Figure D-8A(b) - SPT Unit Shaft Resistance vs. Strain, Test 8A

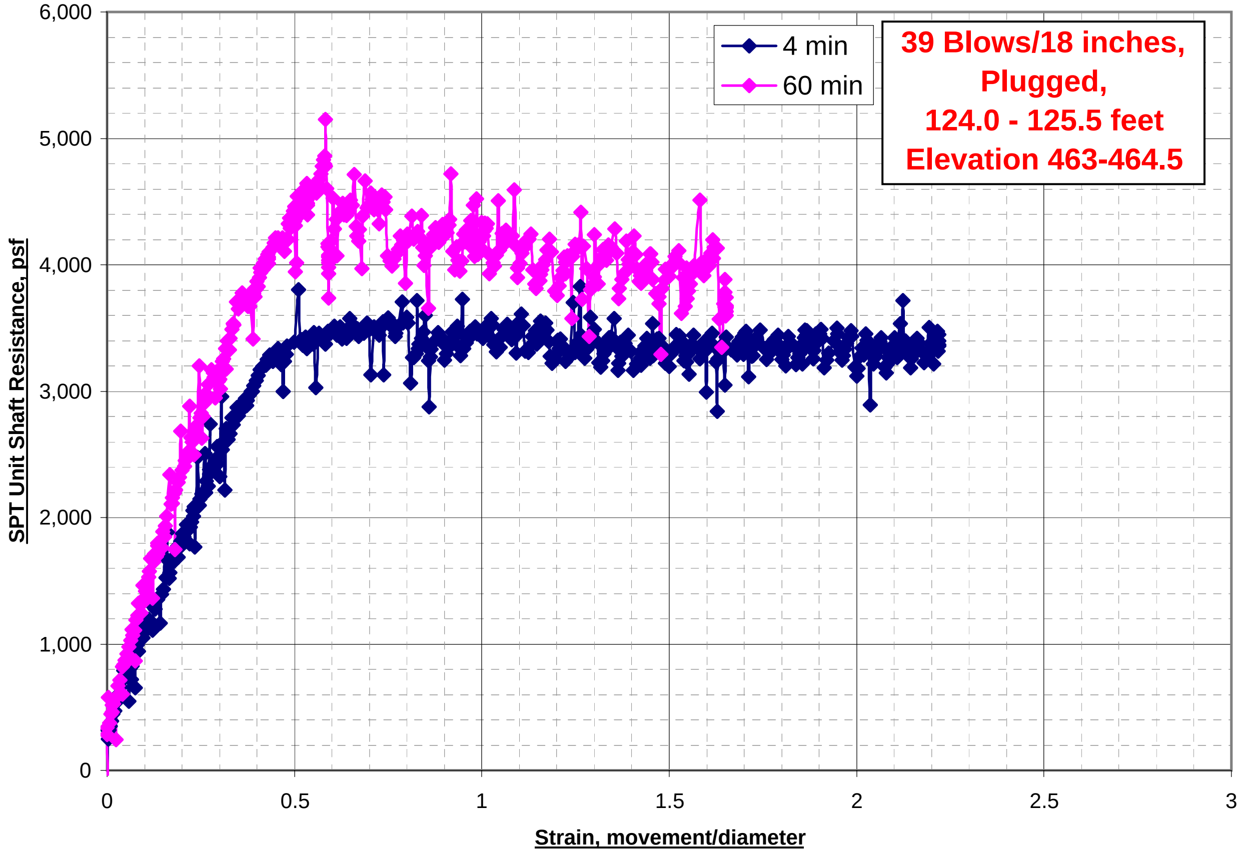

Figure D-8A(c) - SPT Rotation Angle vs. Time, Test 8A

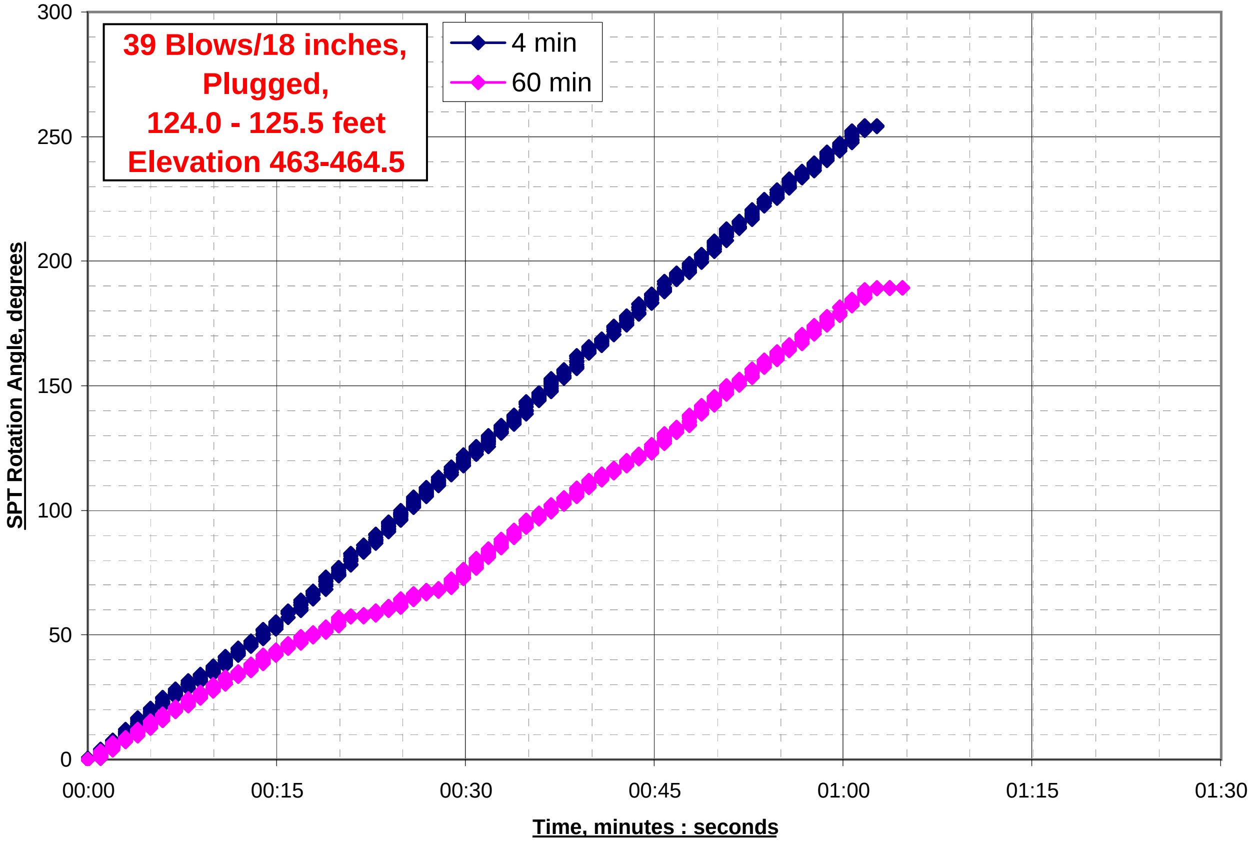

Figure D-8A(d) - SPT Unit Shaft Resistance vs. Time, Test 8A

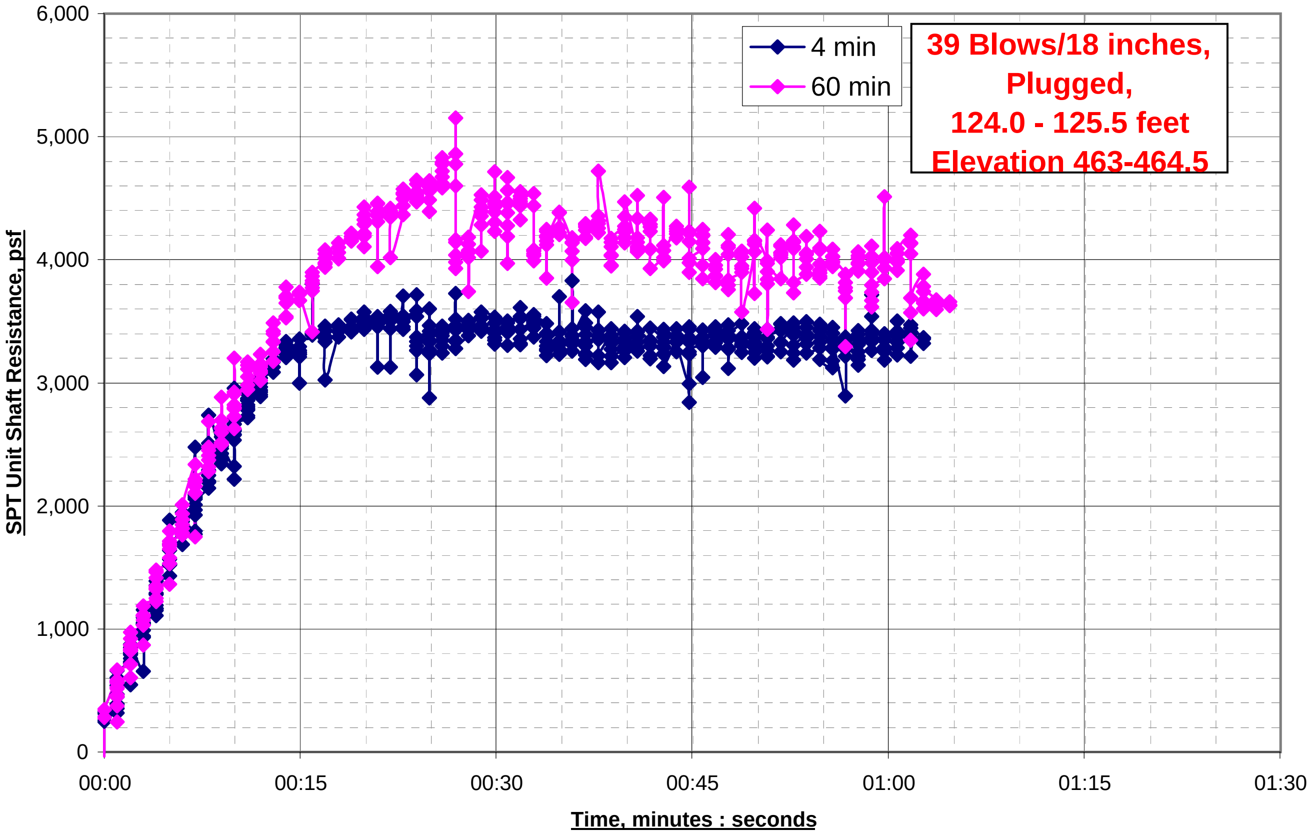

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Figure D-8B(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 8B

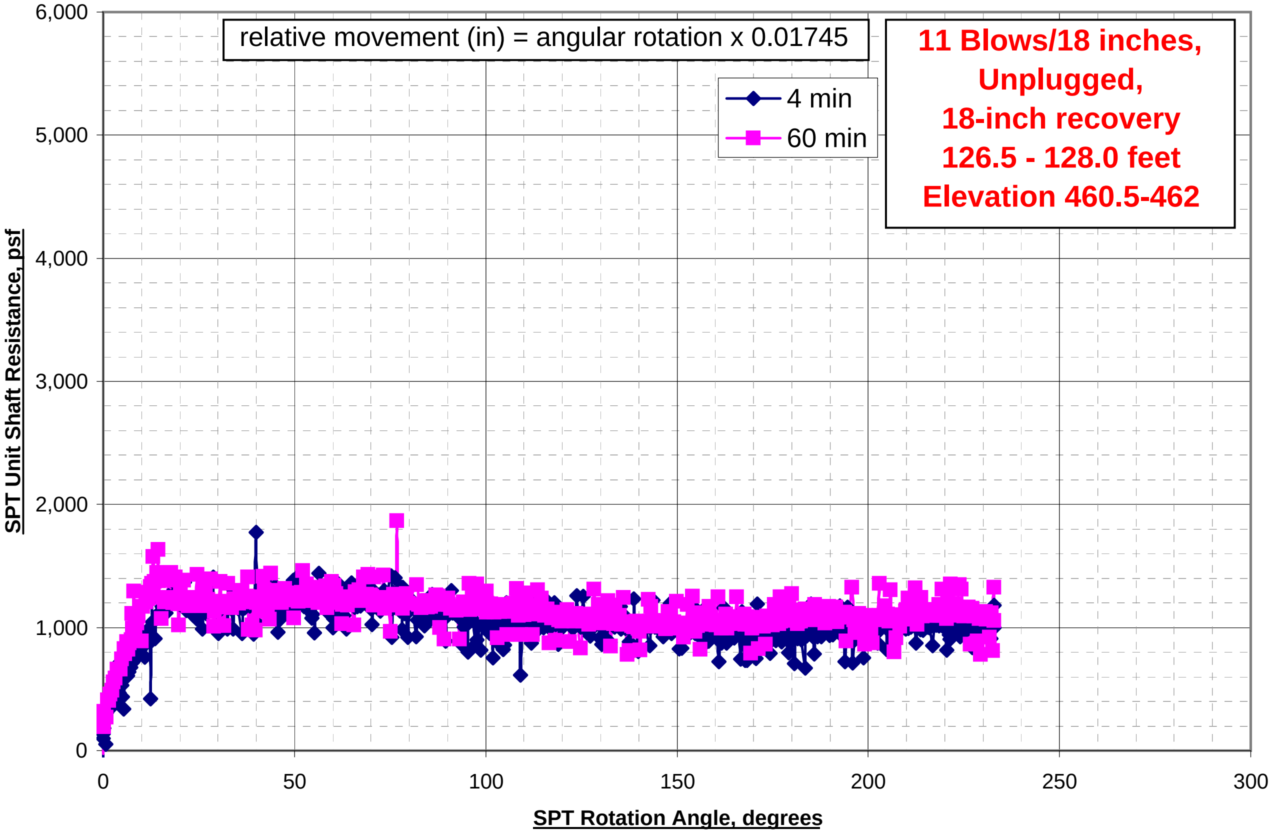

Figure D-8B(b) - SPT Unit Shaft Resistance vs. Strain, Test 8B

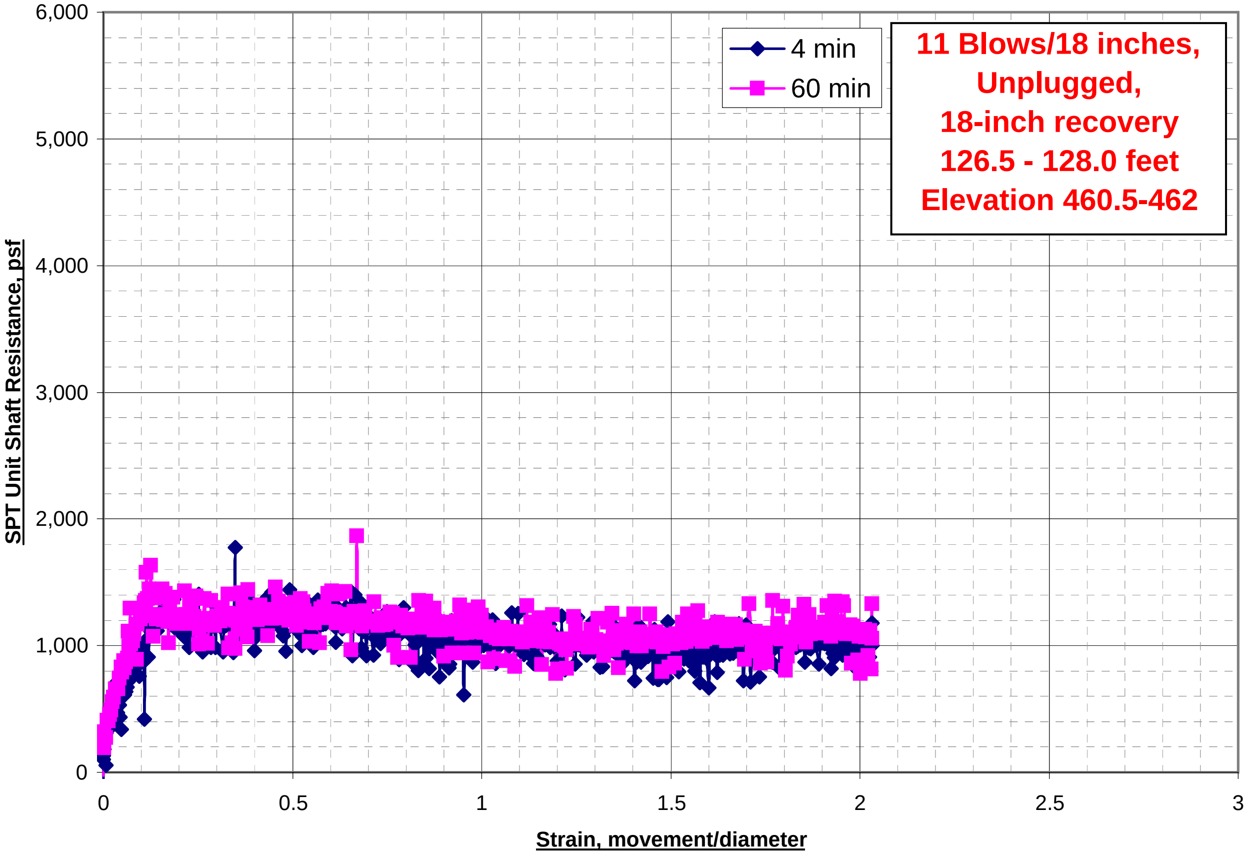

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Figure D-8B(c) - SPT Rotation Angle vs. Time,Test 8B

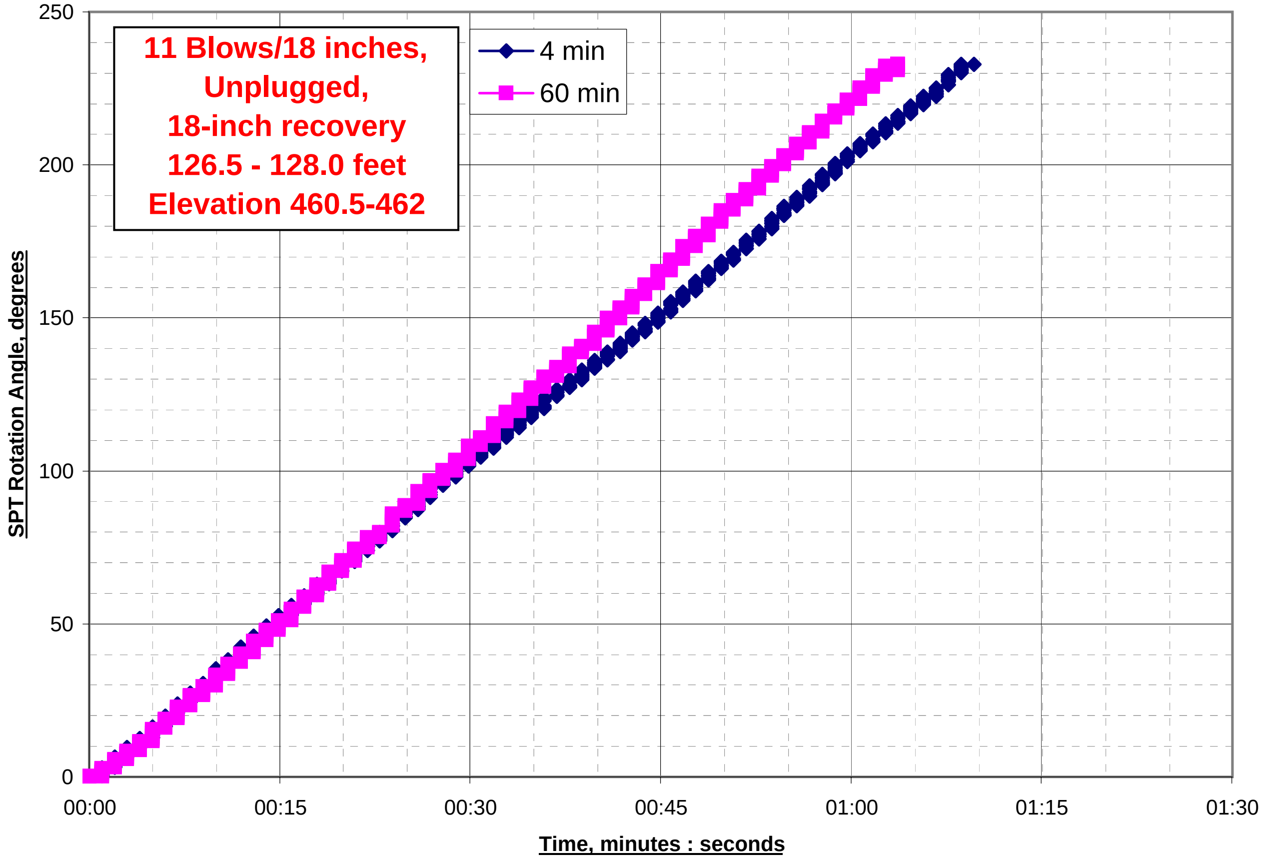

Figure D-8B(d) - SPT Unit Shaft Resistance vs. Time,Test 8B

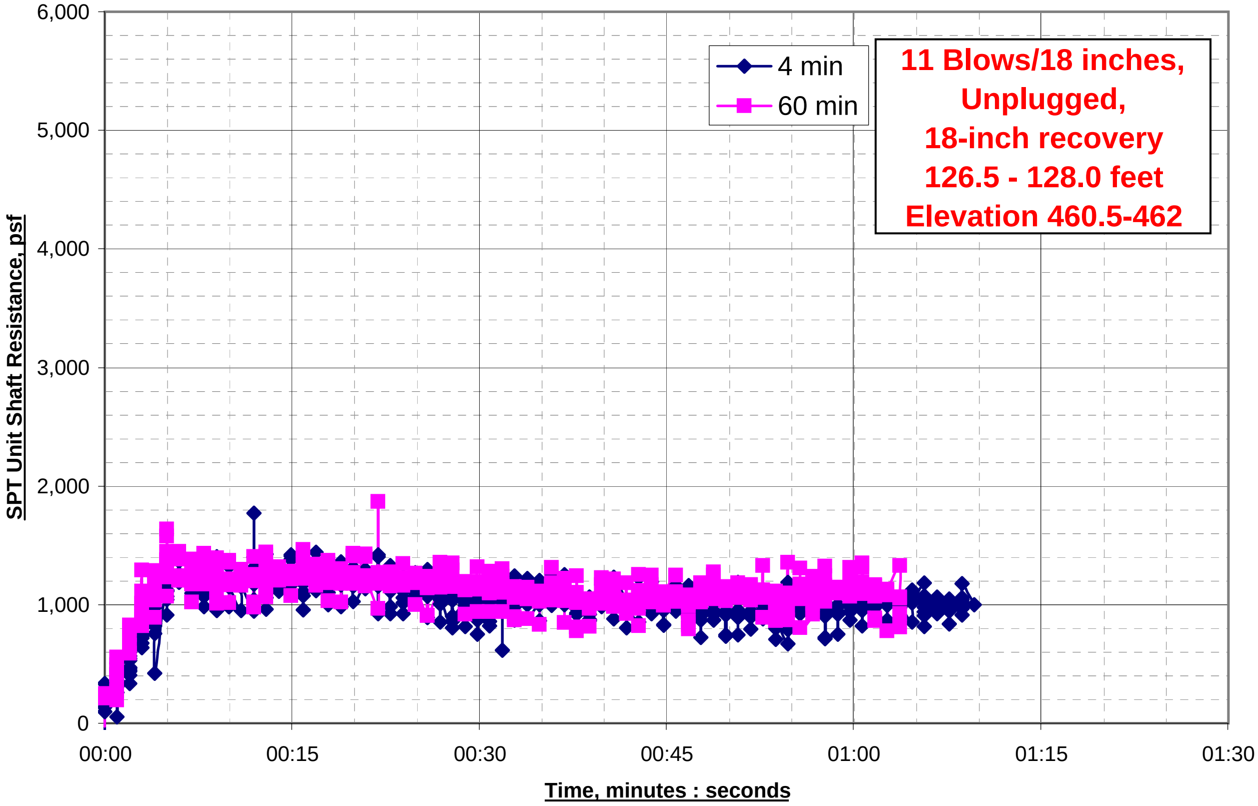

Figure D-9A(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 9A

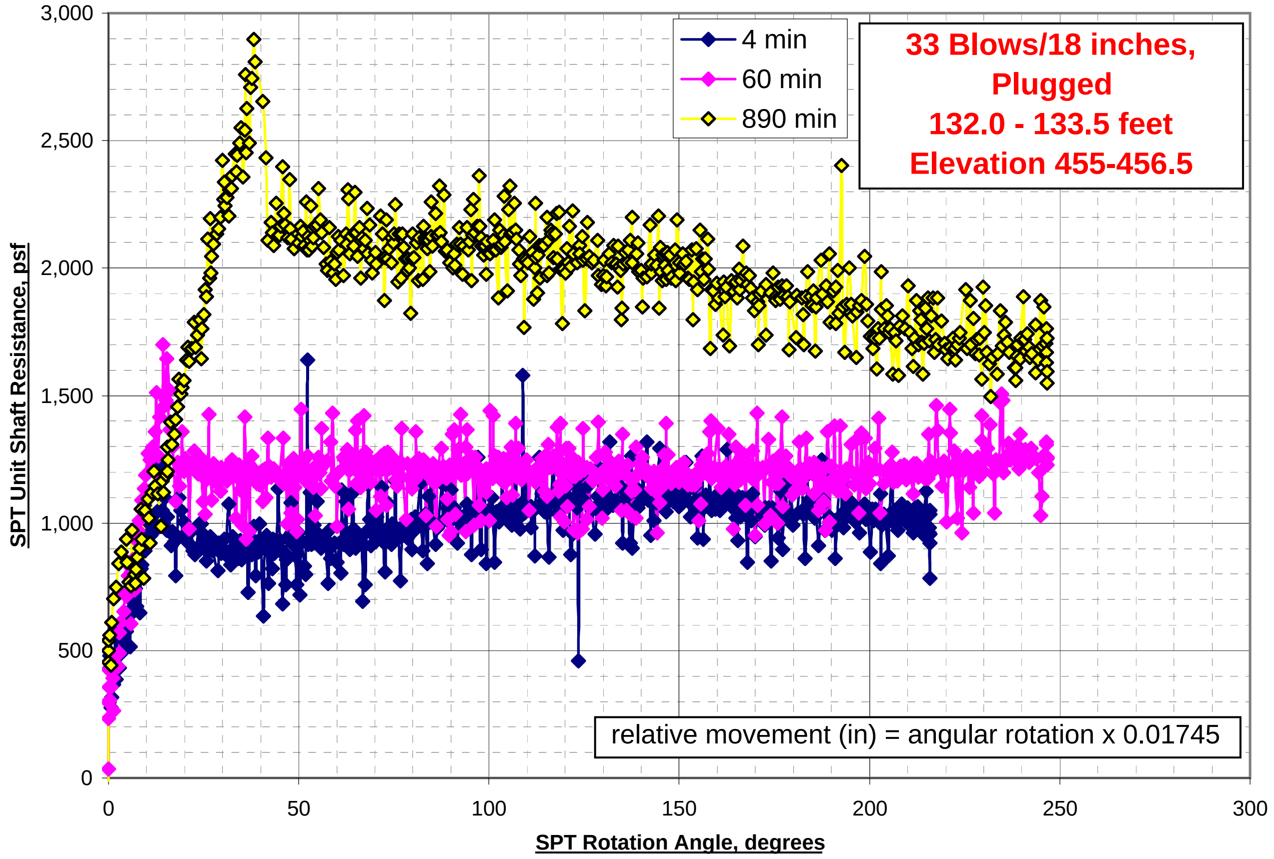

Figure D-9A(b) - SPT Unit Shaft Resistance vs. Strain, Test 9A

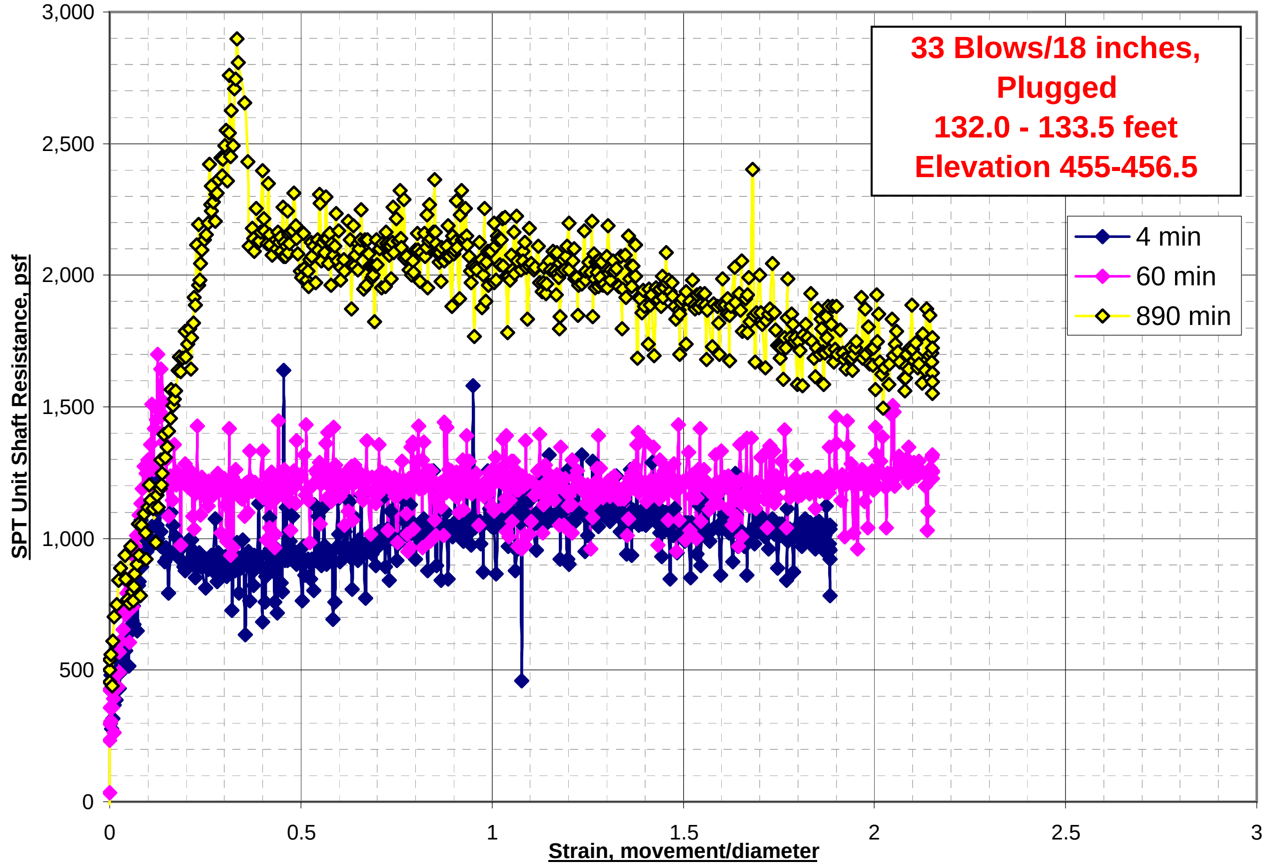

Figure D-9A(c) - SPT Rotation Angle vs. Time, Test 9A

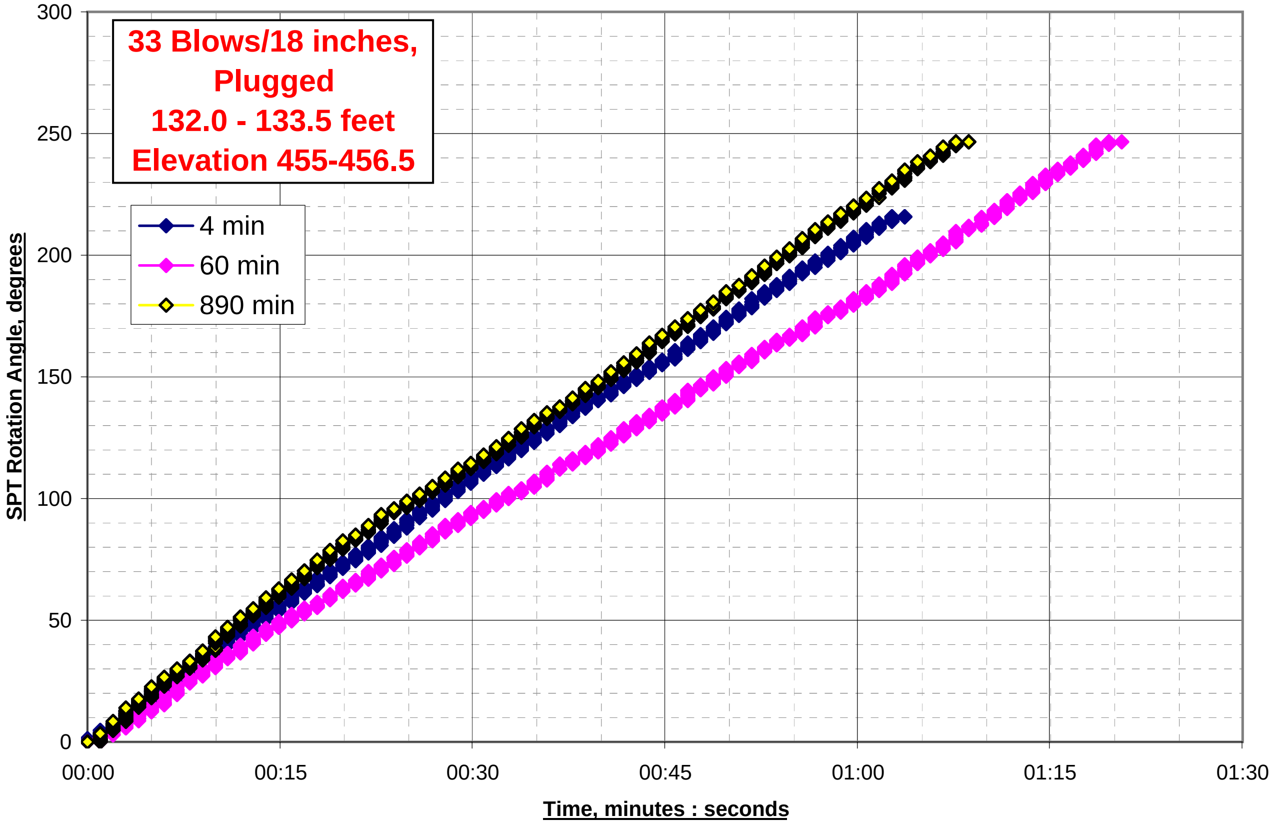

Figure D-9A(d) - SPT Unit Shaft Resistance vs. Time, Test 9A

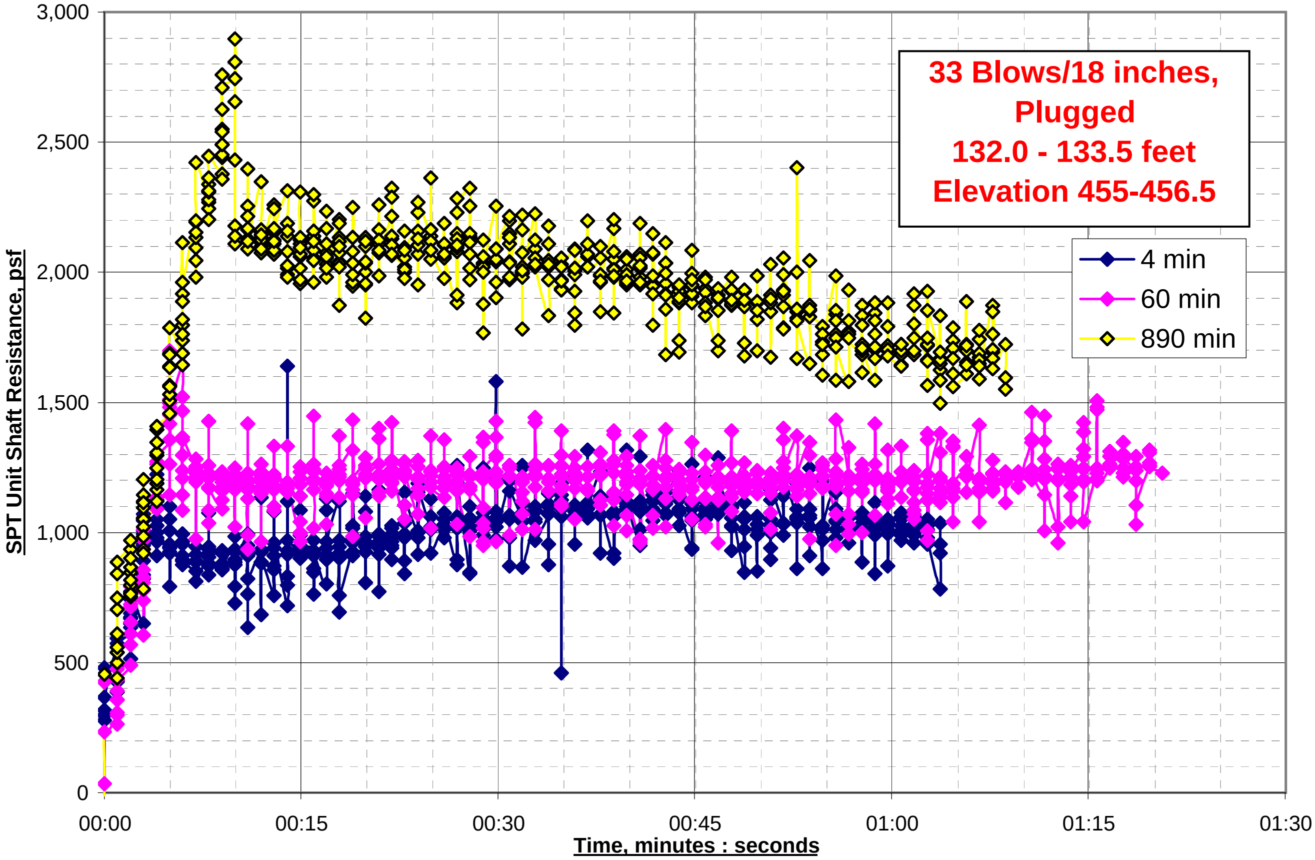

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Figure D-9B(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 9B

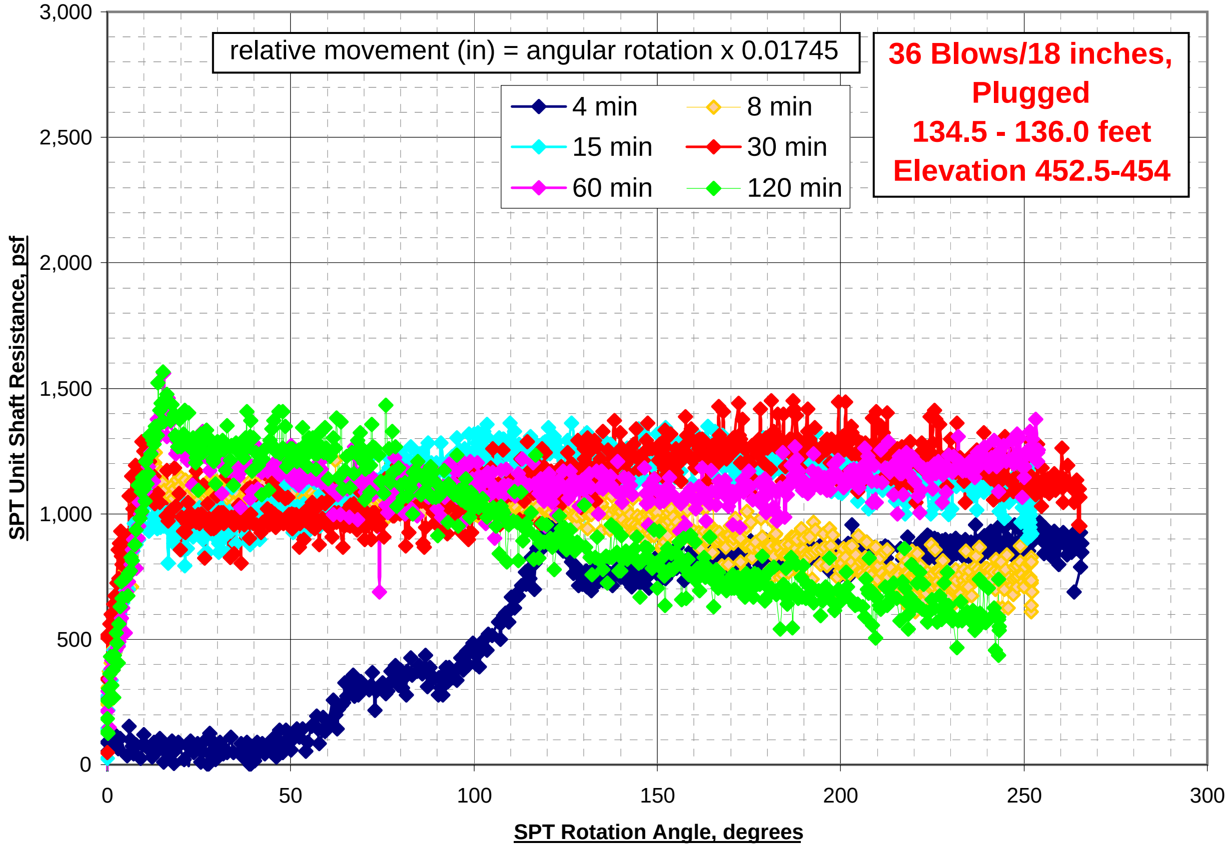

Figure D-9B(b) - SPT Unit Shaft Resistance vs. Strain, Test 9B

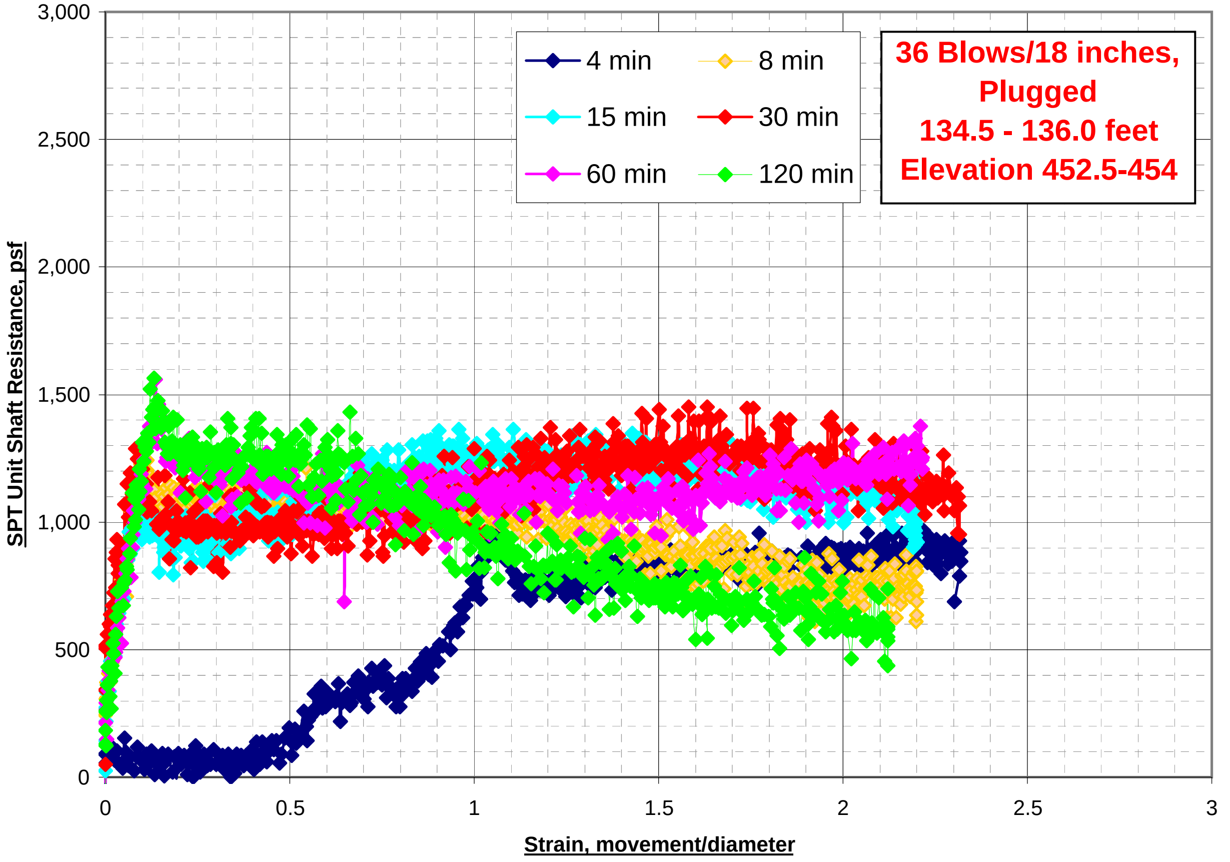

Figure D-9B(c) - SPT Rotation Angle vs. Time, Test 9B

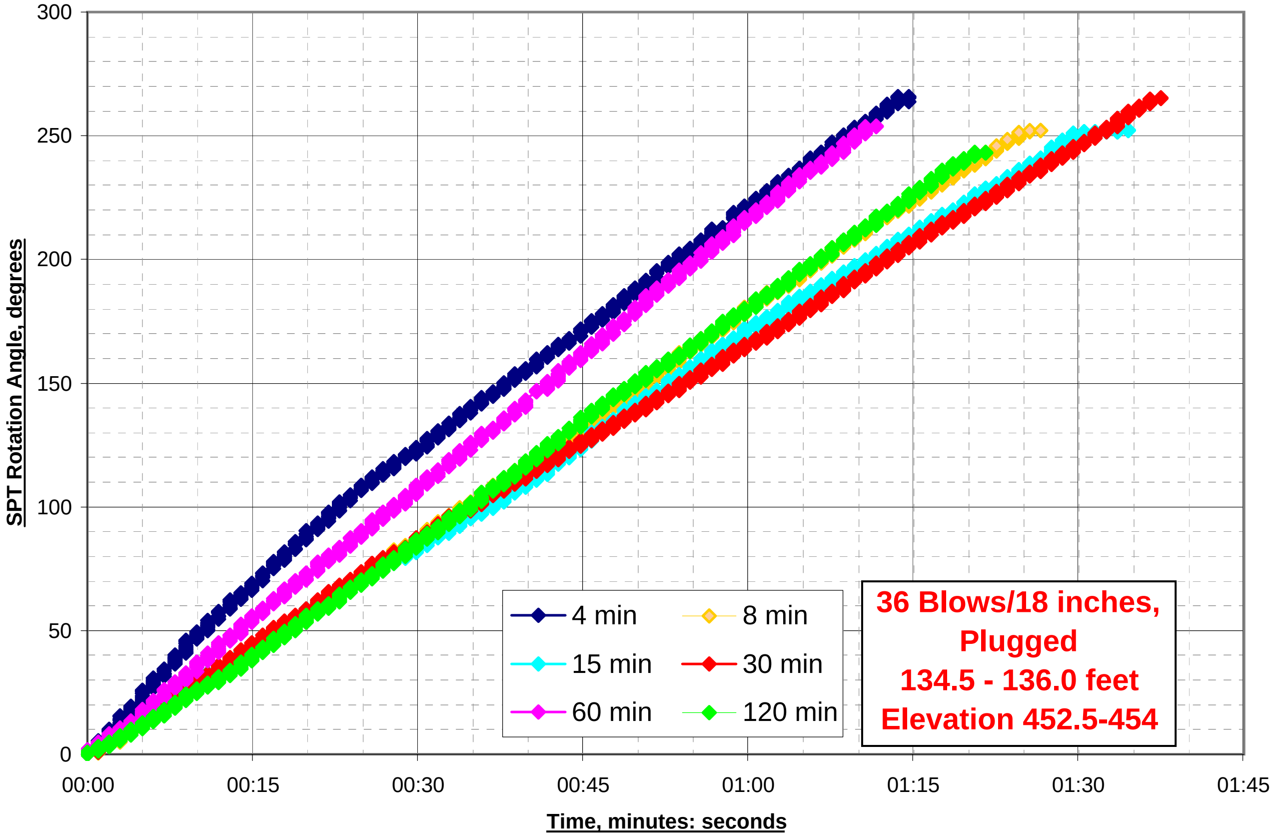

Figure D-9B(d) - SPT Unit Shaft Resistance vs. Time, Test 9B

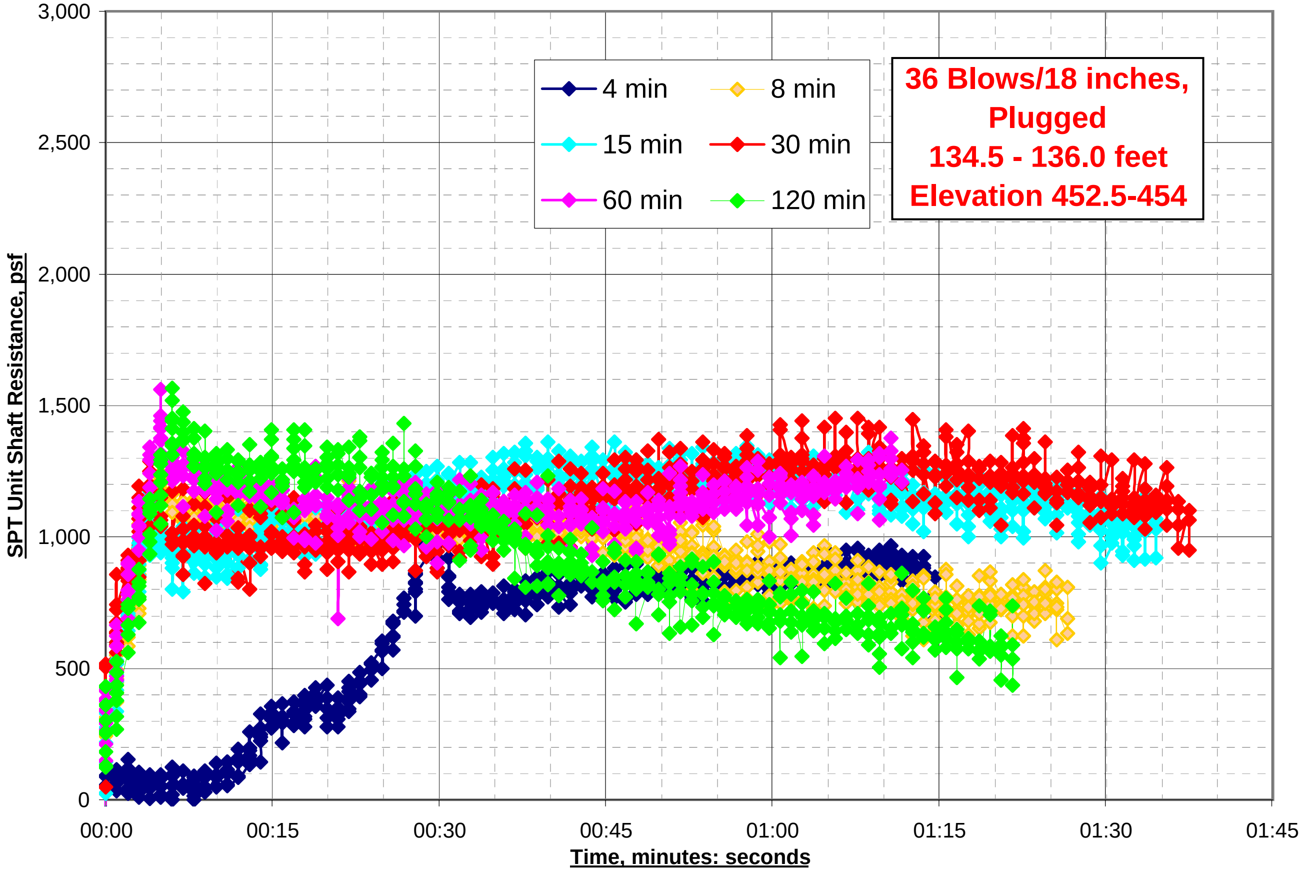

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Figure B-10A(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 10A

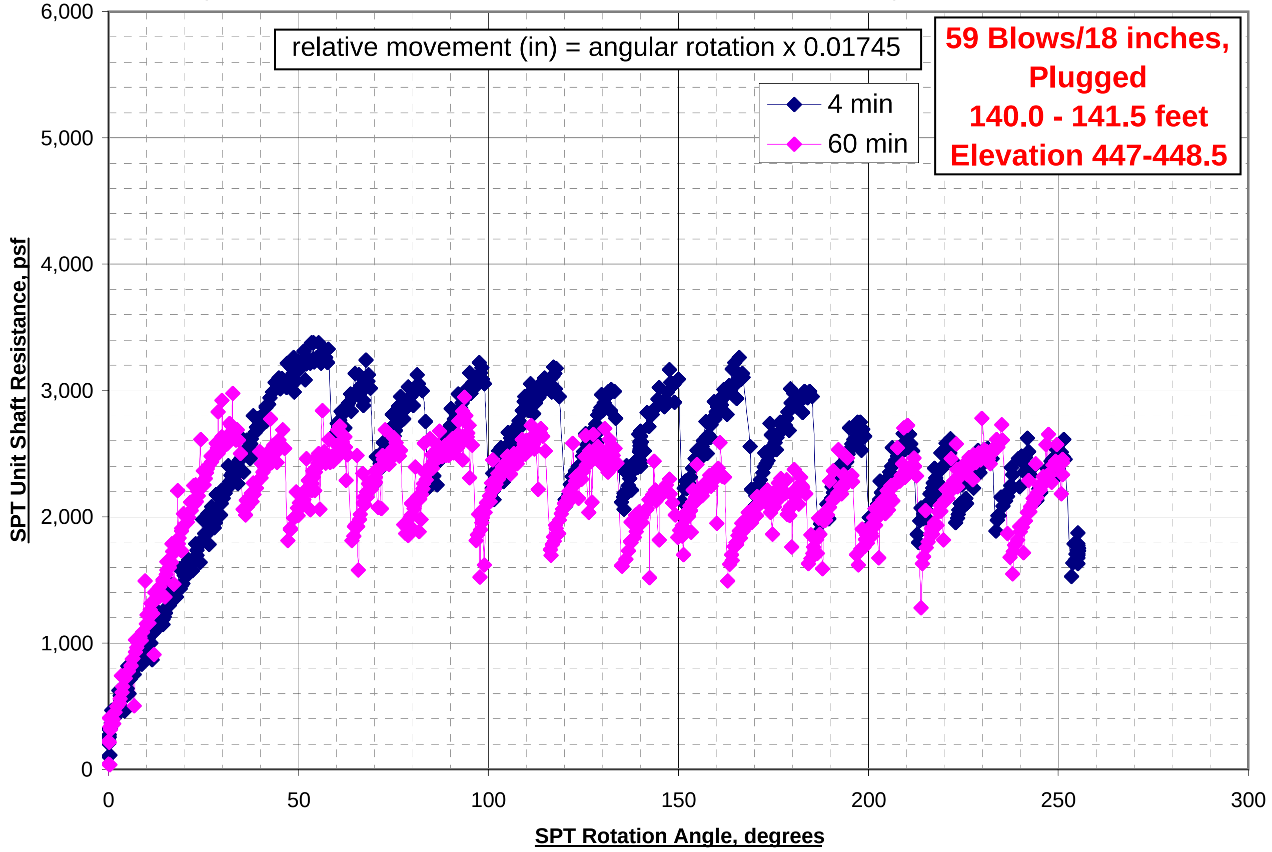

Figure D-10A(b) - Unit Shaft Resistance vs. Strain, Test 10A

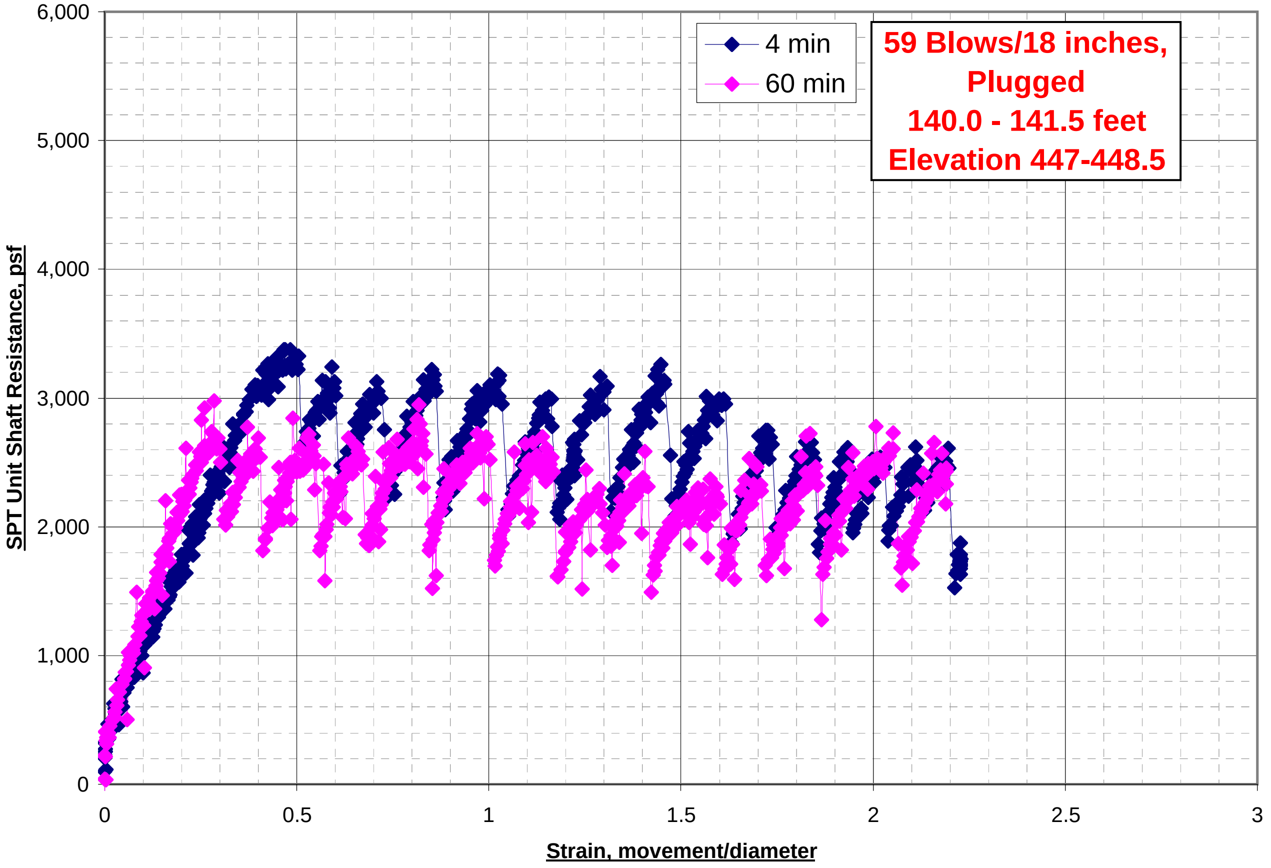

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Figure D-10A(c) - SPT Rotation Angle vs. Time, Test 10A

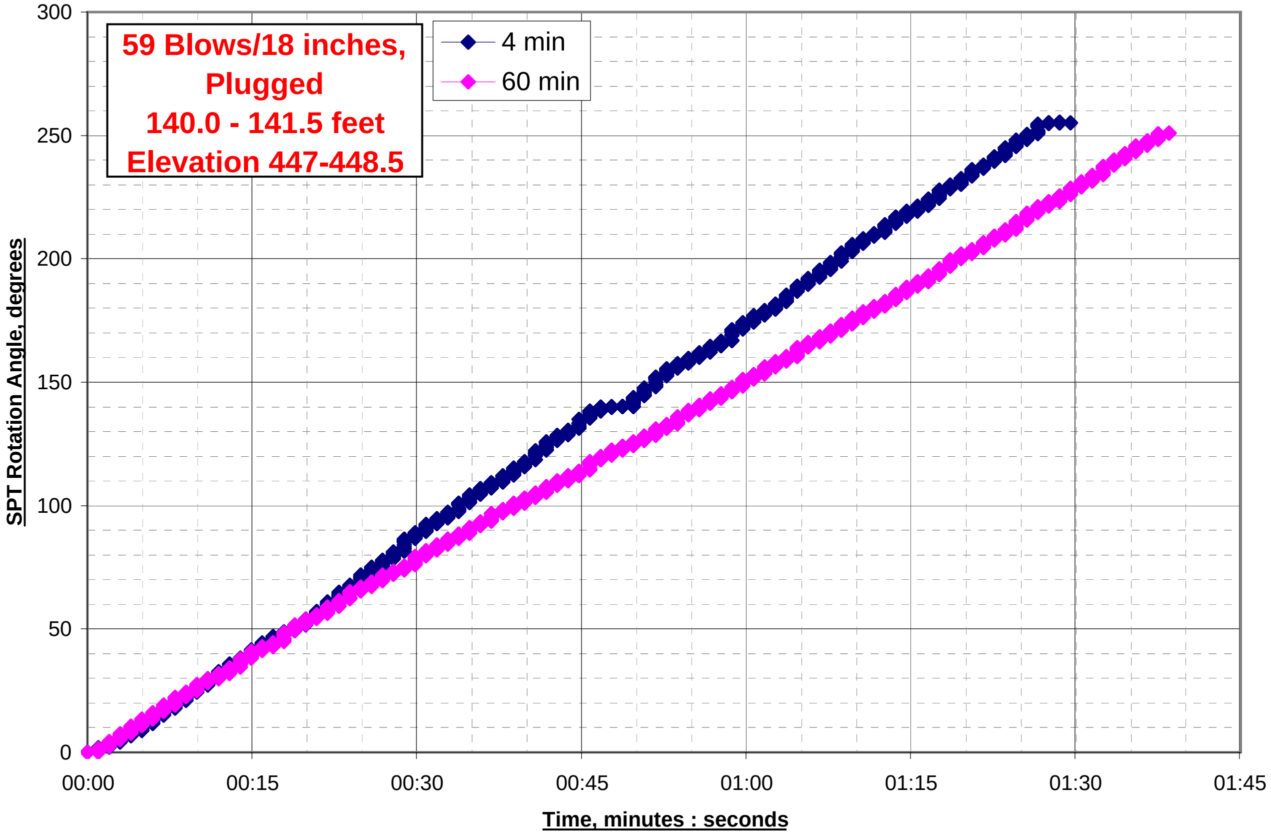

Figure D-10A(d) - SPT Unit Shaft Resistance vs. Time, Test 10A

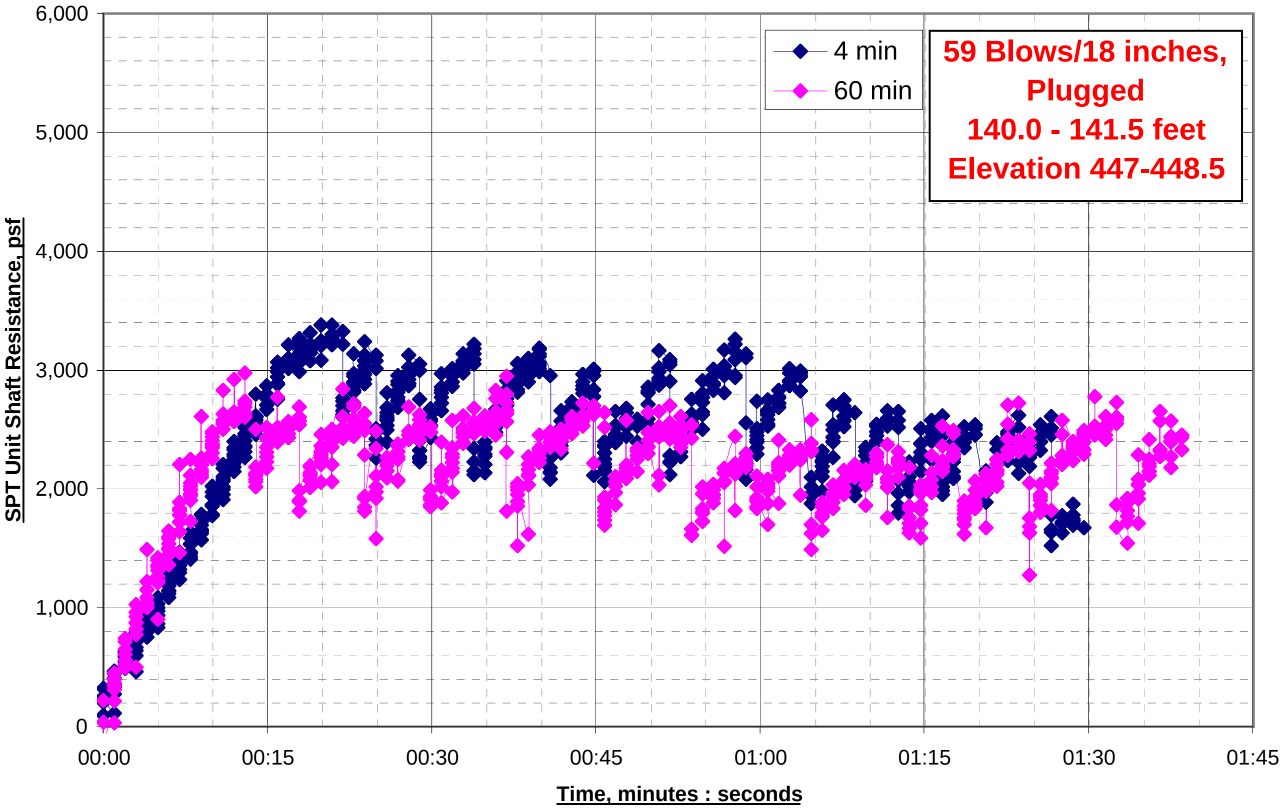

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Figure D-10B(a) - SPT Unit Shaft Resist. vs. Rotation Angle, Test 10B

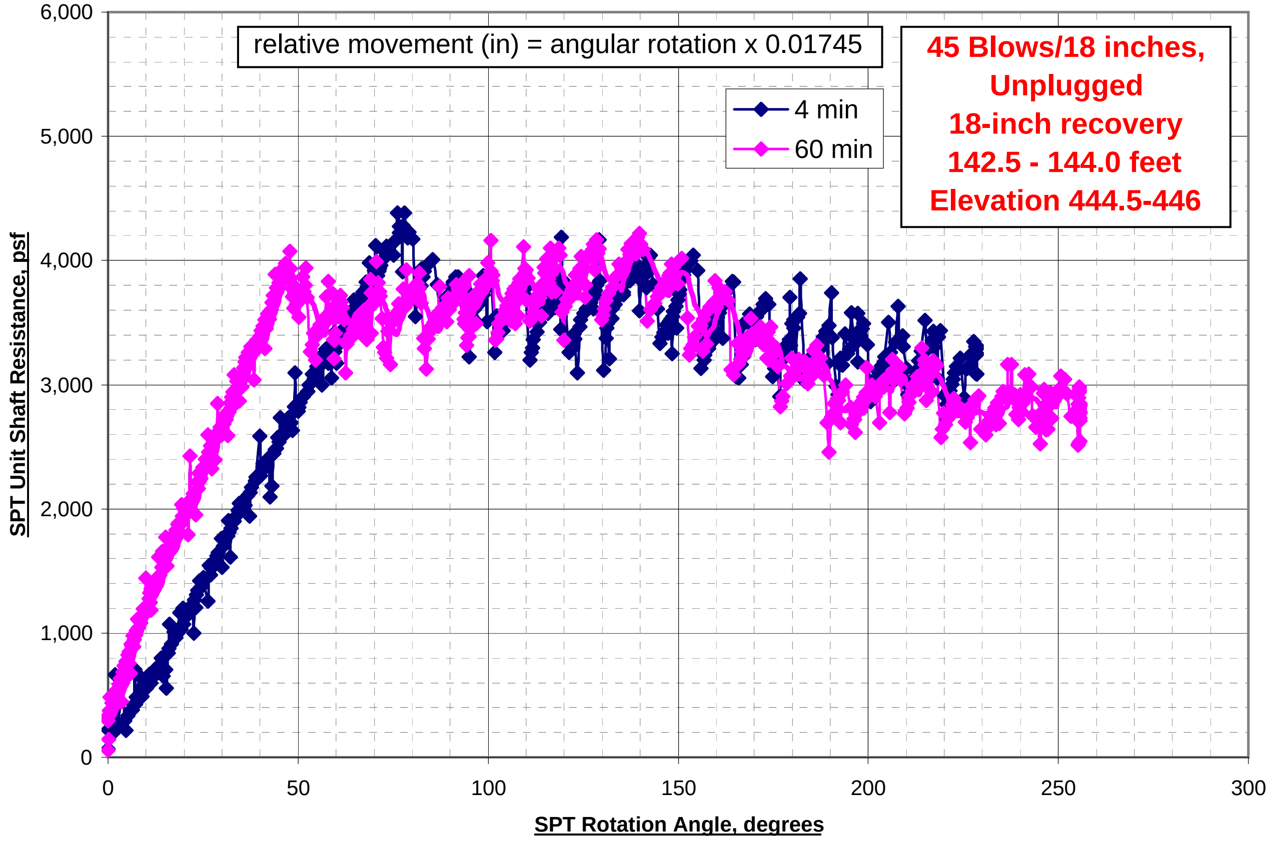

Figure D-10B(b) - SPT Unit Shaft Resistance vs. Strain, Test 10B

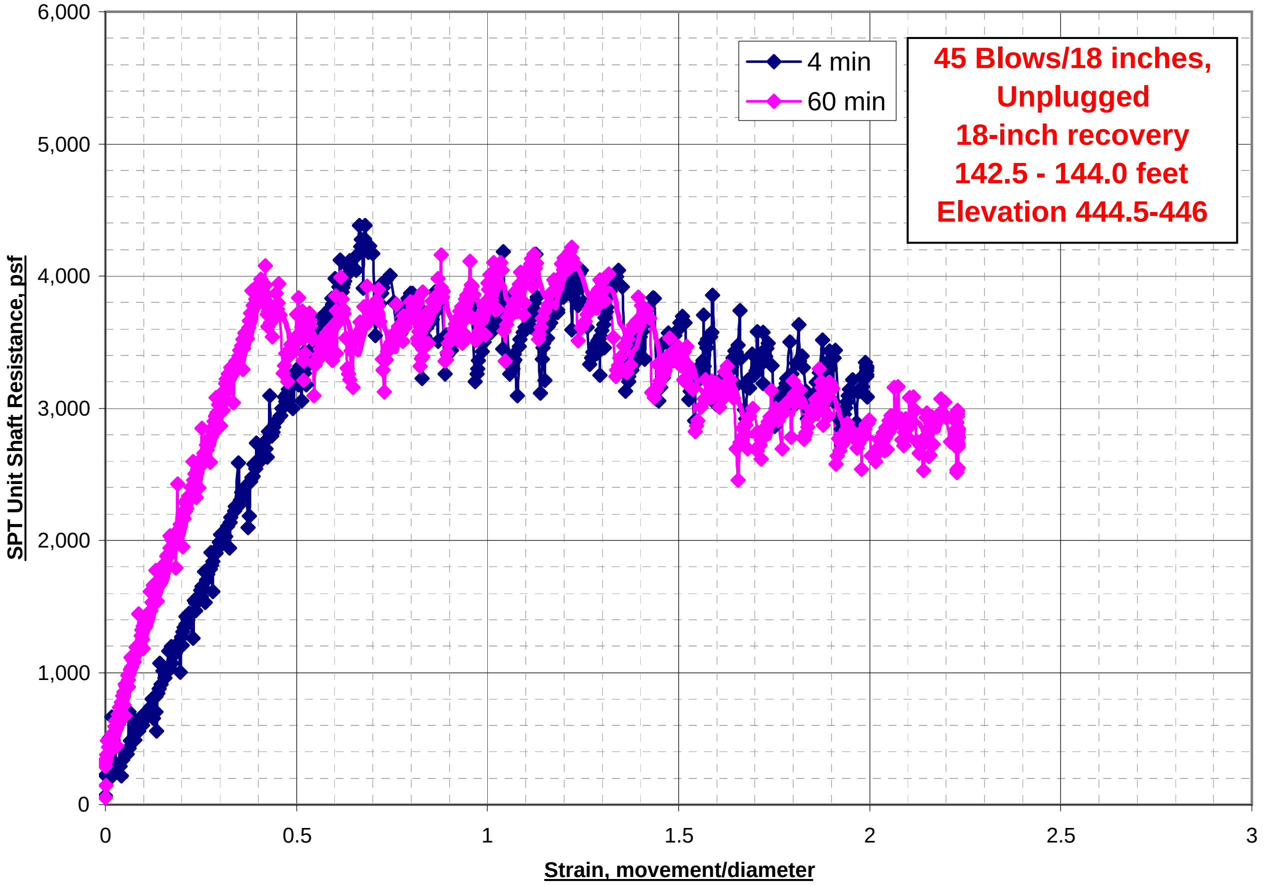

Figure D-10B(c) - SPT Rotation Angle vs. Time, Test 10B

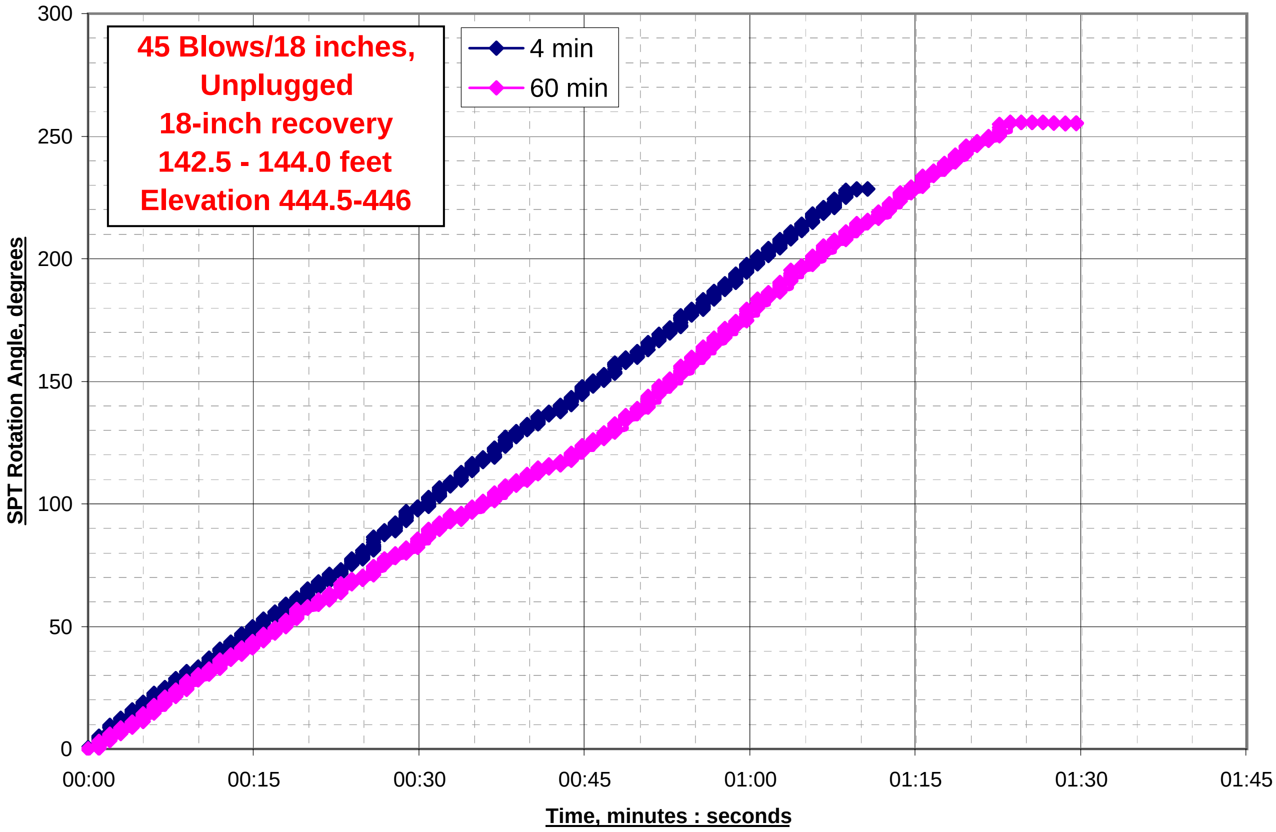

Figure D-10B(d) - Unit Shaft Resistance vs. Time, Test 10B

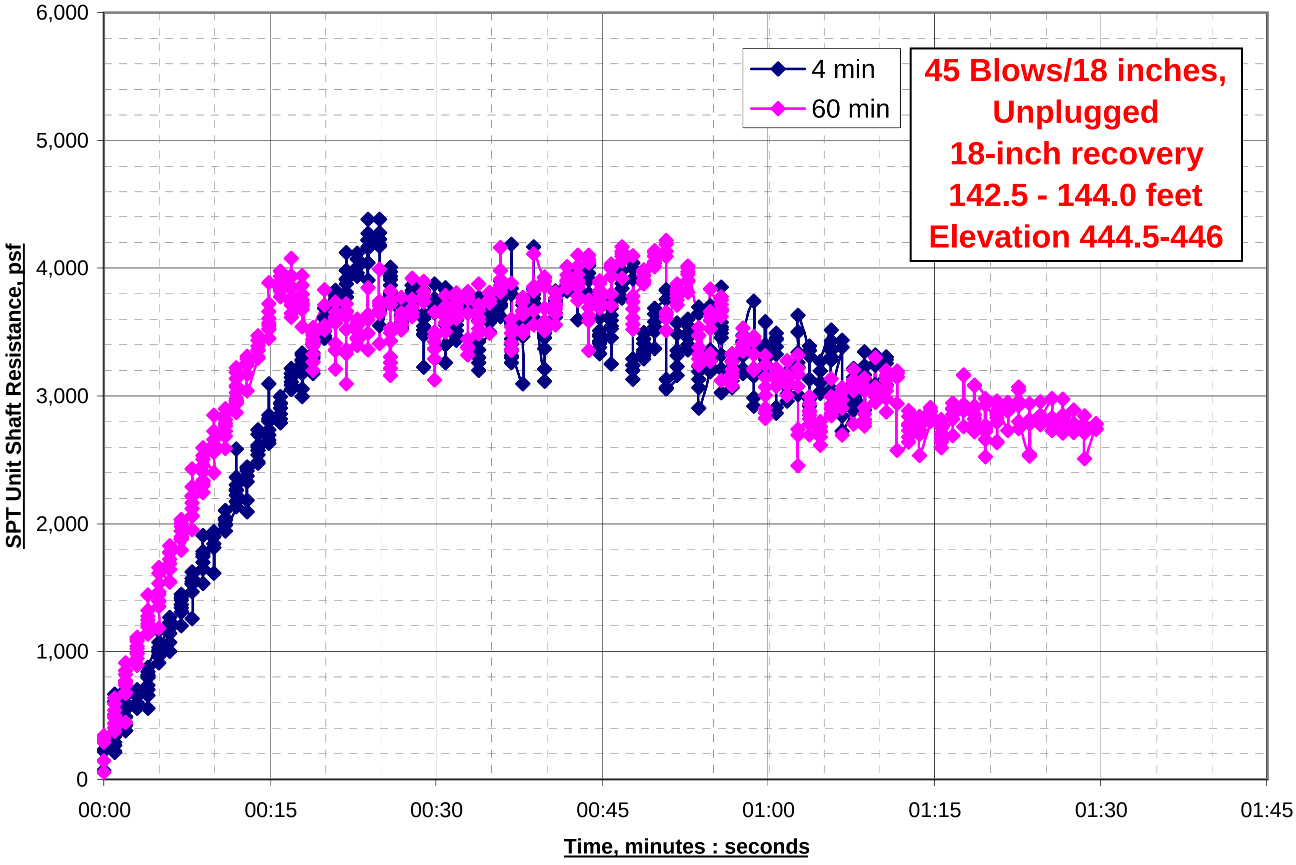

Figure D-11 - SPT-T Peak Unit Shaft Resistance vs. Time

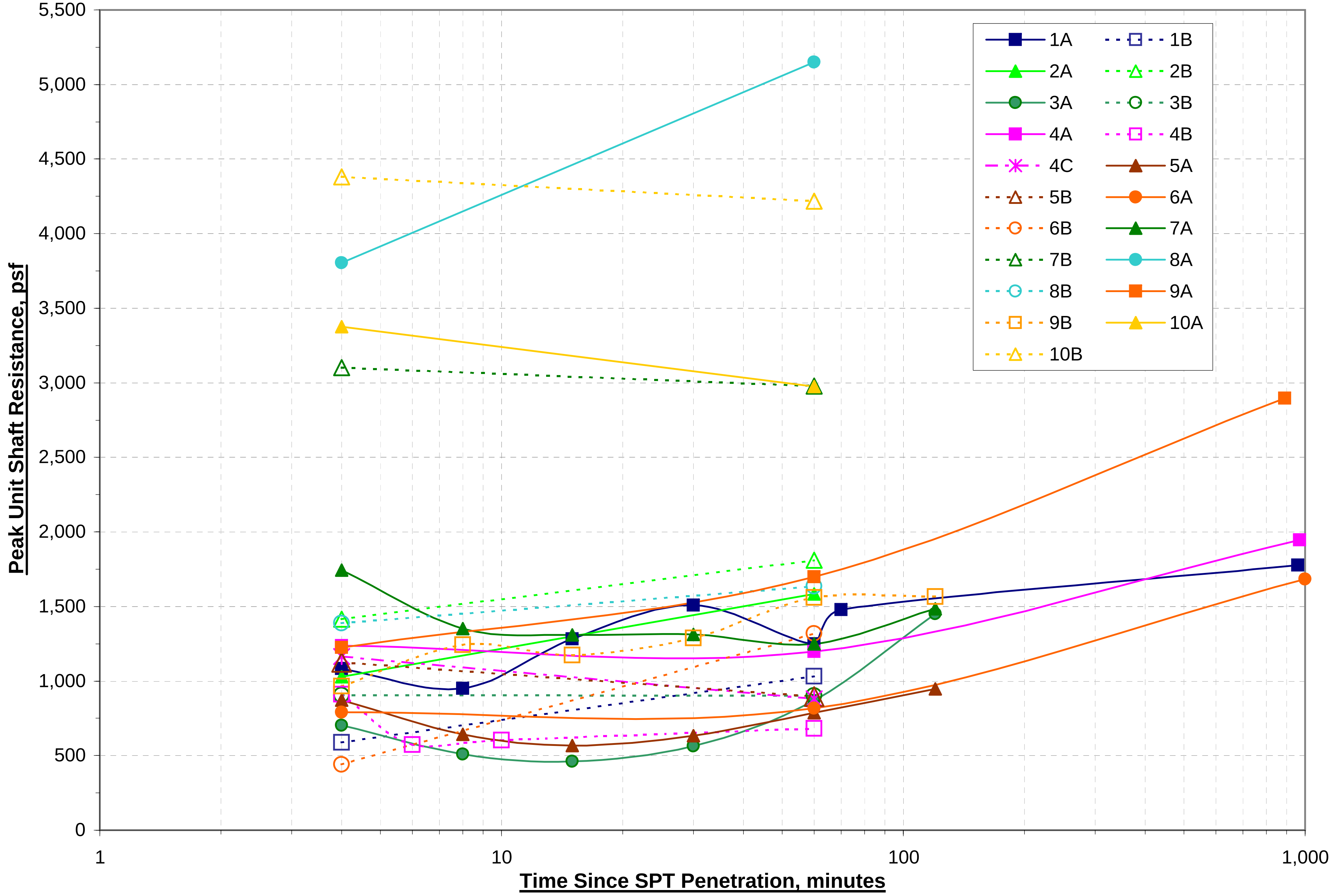

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Figure D-11a - SPT Peak Unit Shaft Resistance vs. Time - Organic Clay

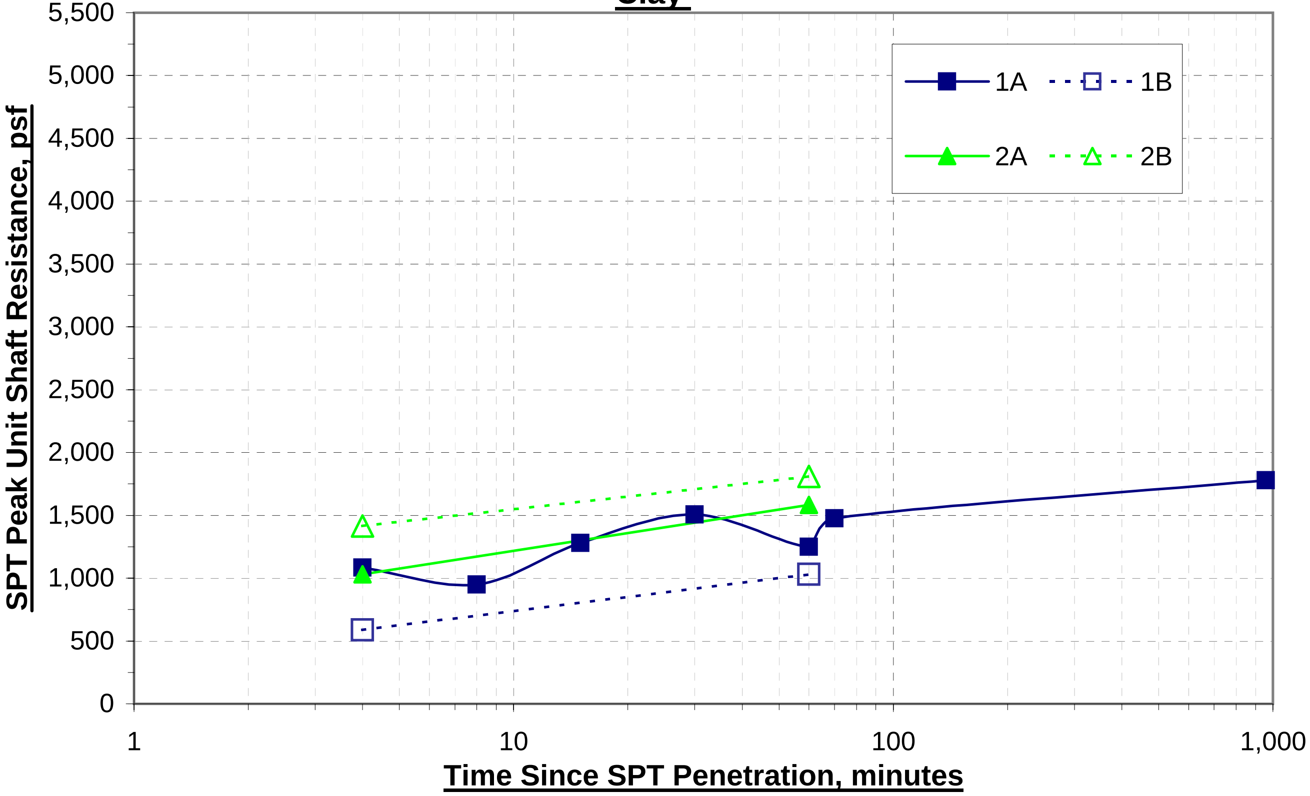

Figure D-11b - SPT Peak Unit Shaft Resistance vs. Time - Silty Clay

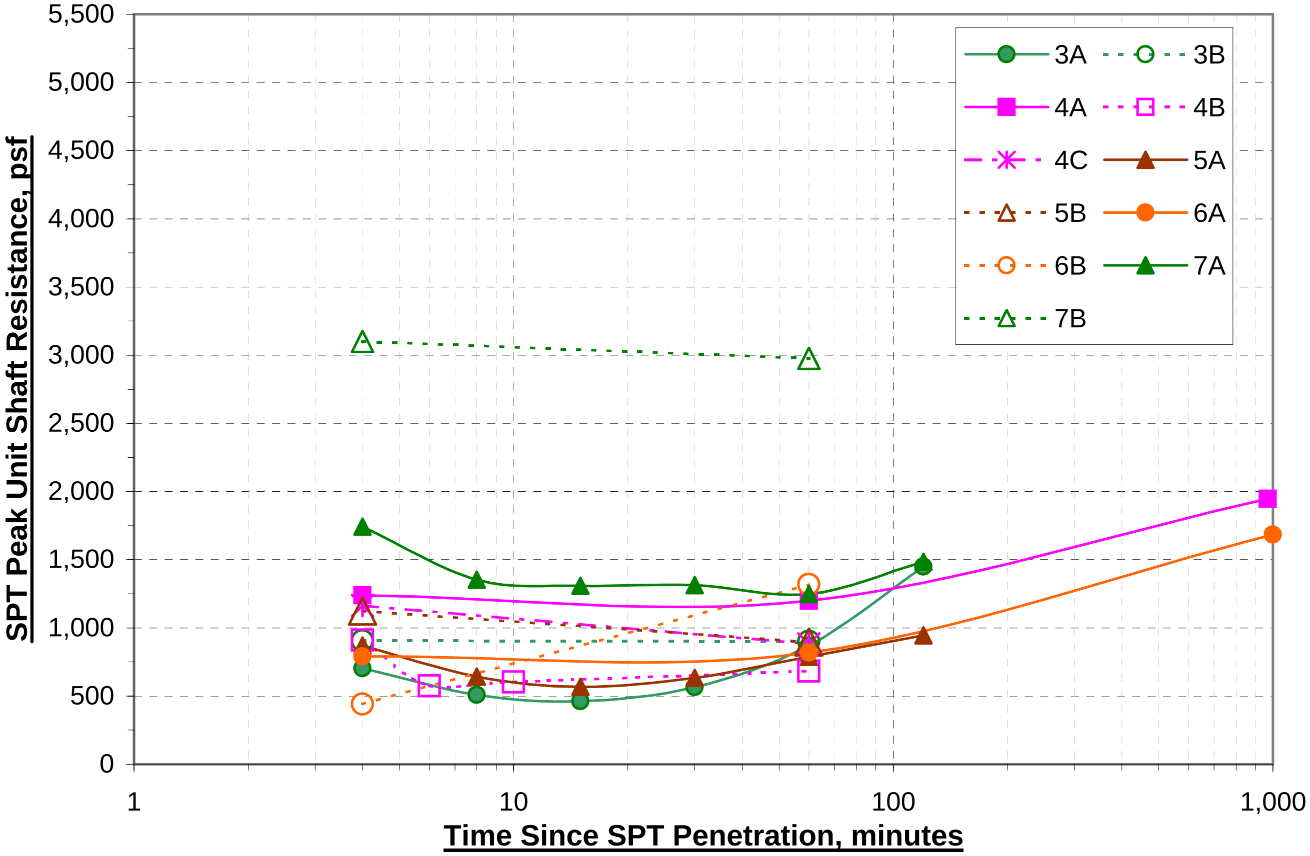

Figure D-11c - SPT Peak Unit Shaft Resistance vs. Time - Silty Sand

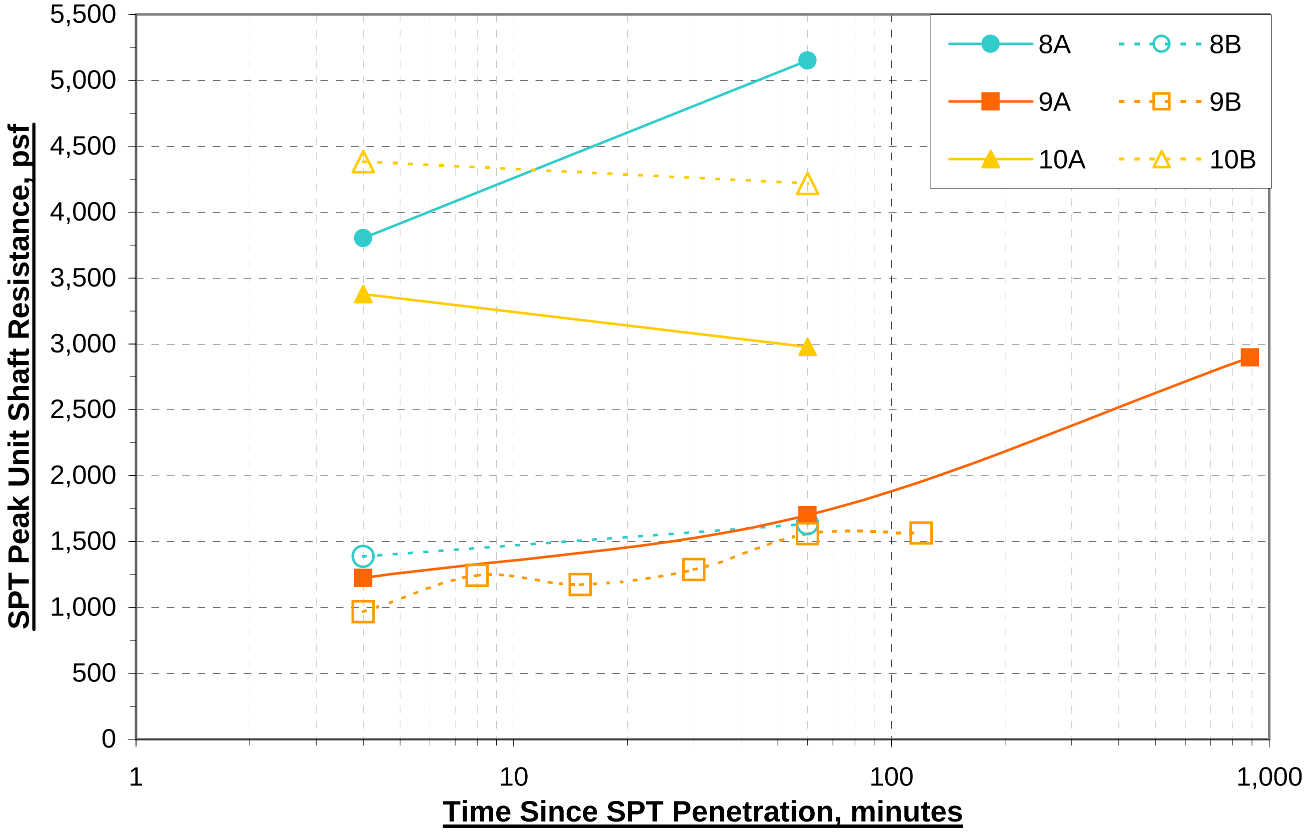

Figure D-12 - SPT Peak Unit Shaft Resistance vs. Time
4-min and 60-min trials - Plugged Sampler Tests

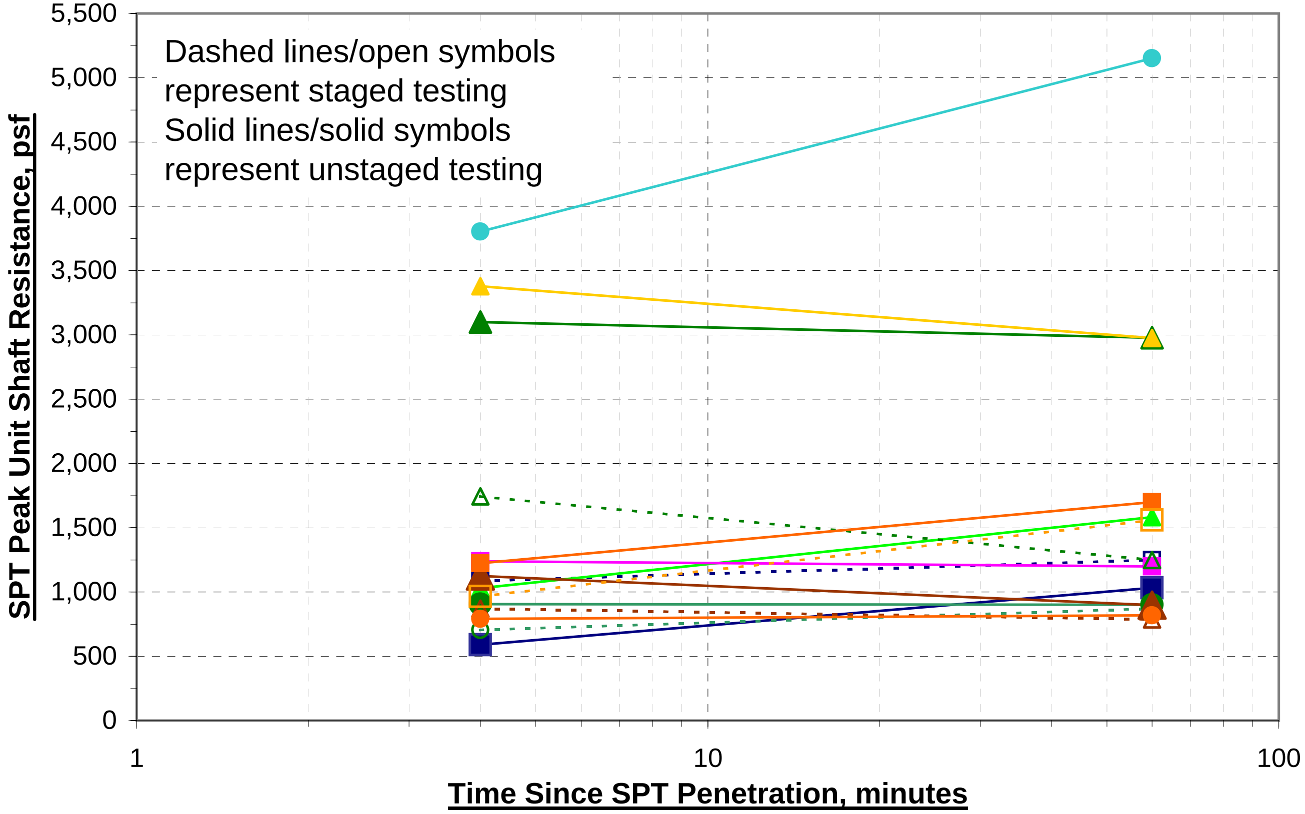

Figure D-13 - SPT-T Peak Unit Shaft Resistance vs. Time - Plugged/Unplugged Comparison Tests Only

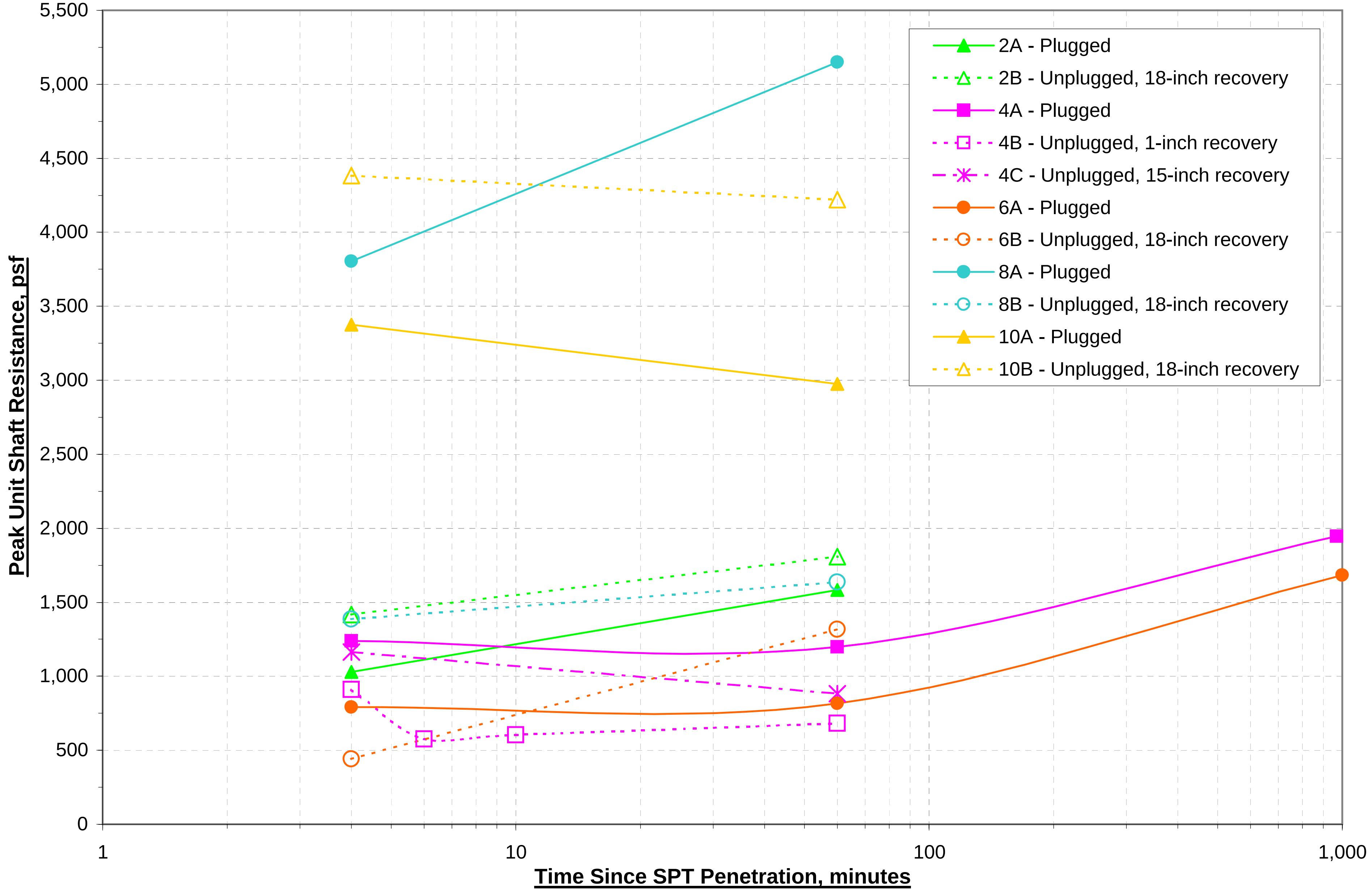

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Figure D-14 - SPT-T Peak Unit Shaft Resistance vs. Time - Staged/Unstaged Comparison Tests Only

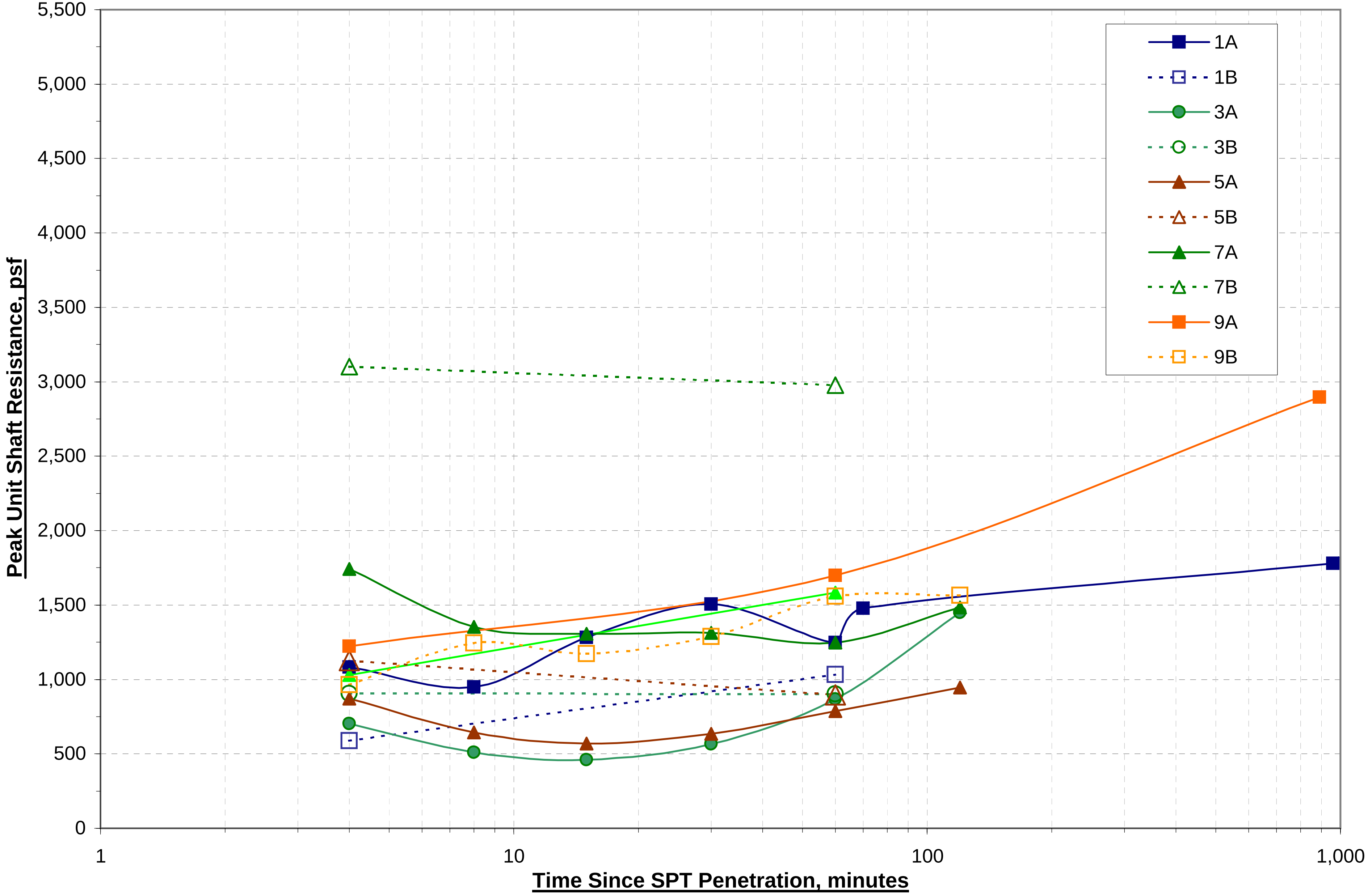

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Figure D-15 - SPT-T Test Unit Set-Up vs. Time

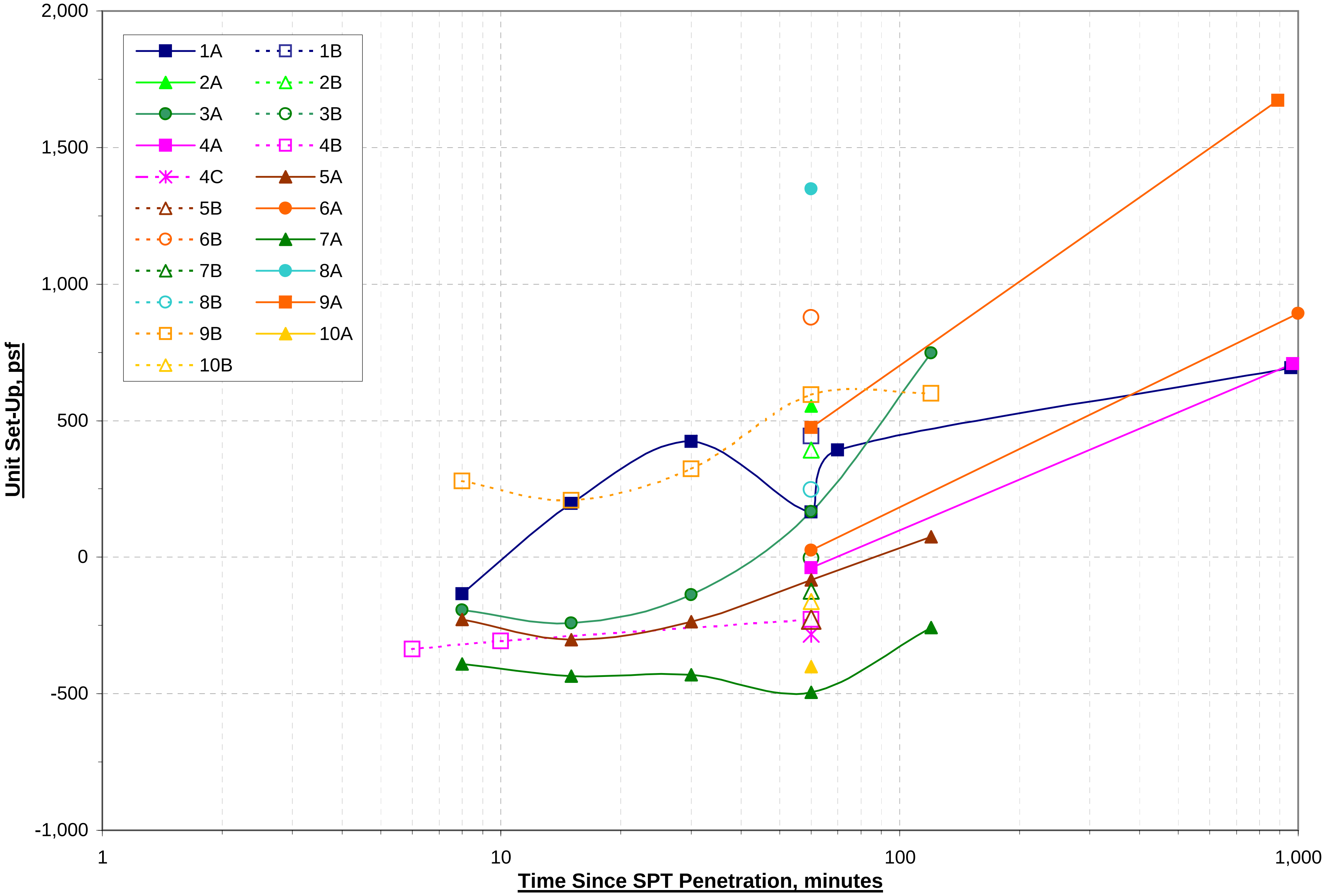

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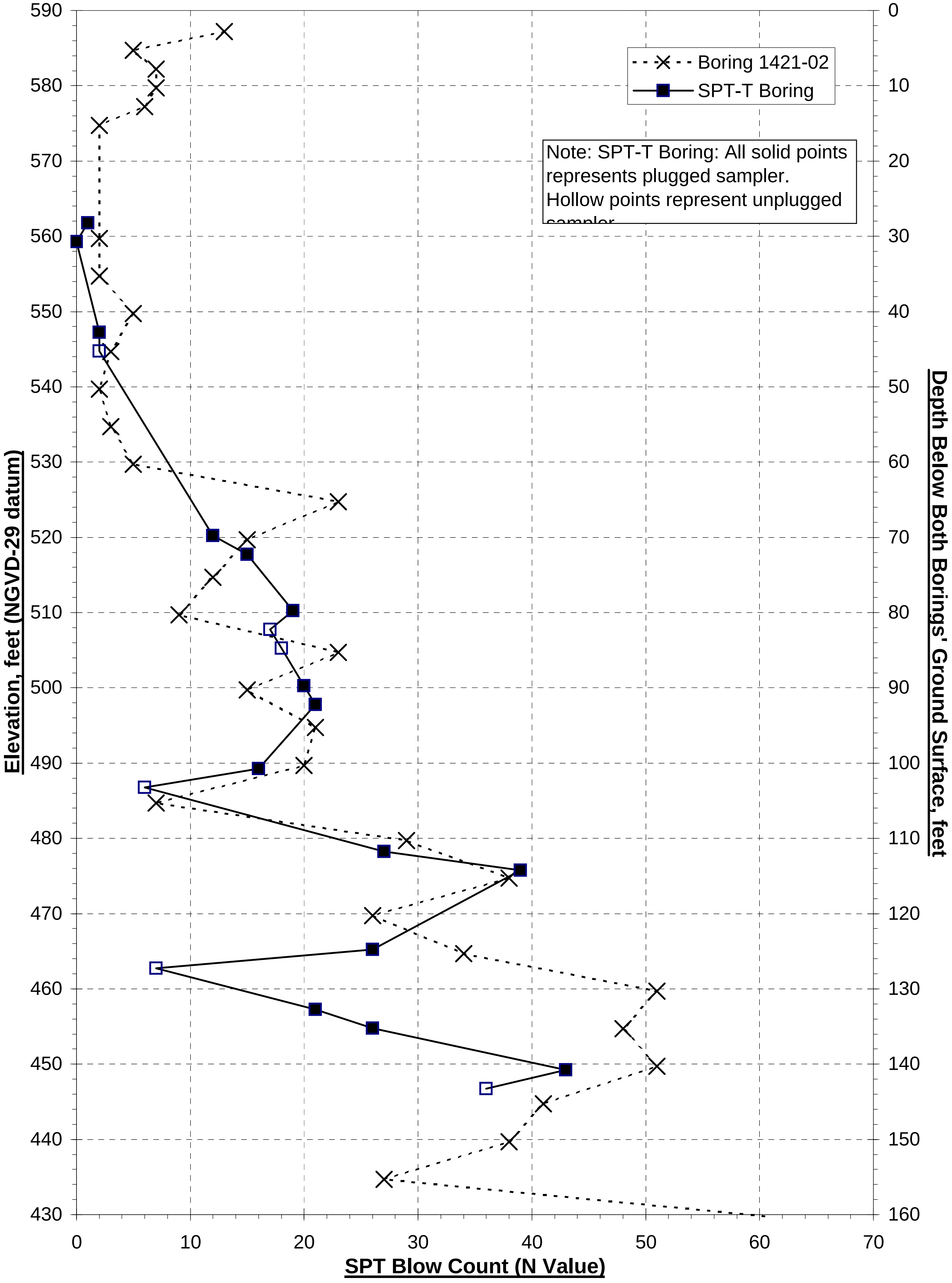
Figure E-1 - SPT Blow Count (N Value) vs. Depth Elevation - Boring P1421-02 and SPT-T Boring



Note: SPT-T Boring: All solid points represents plugged sampler.
Hollow points represent unplugged sampler

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Figure E-2 - Unit Set-Up vs. Elevation

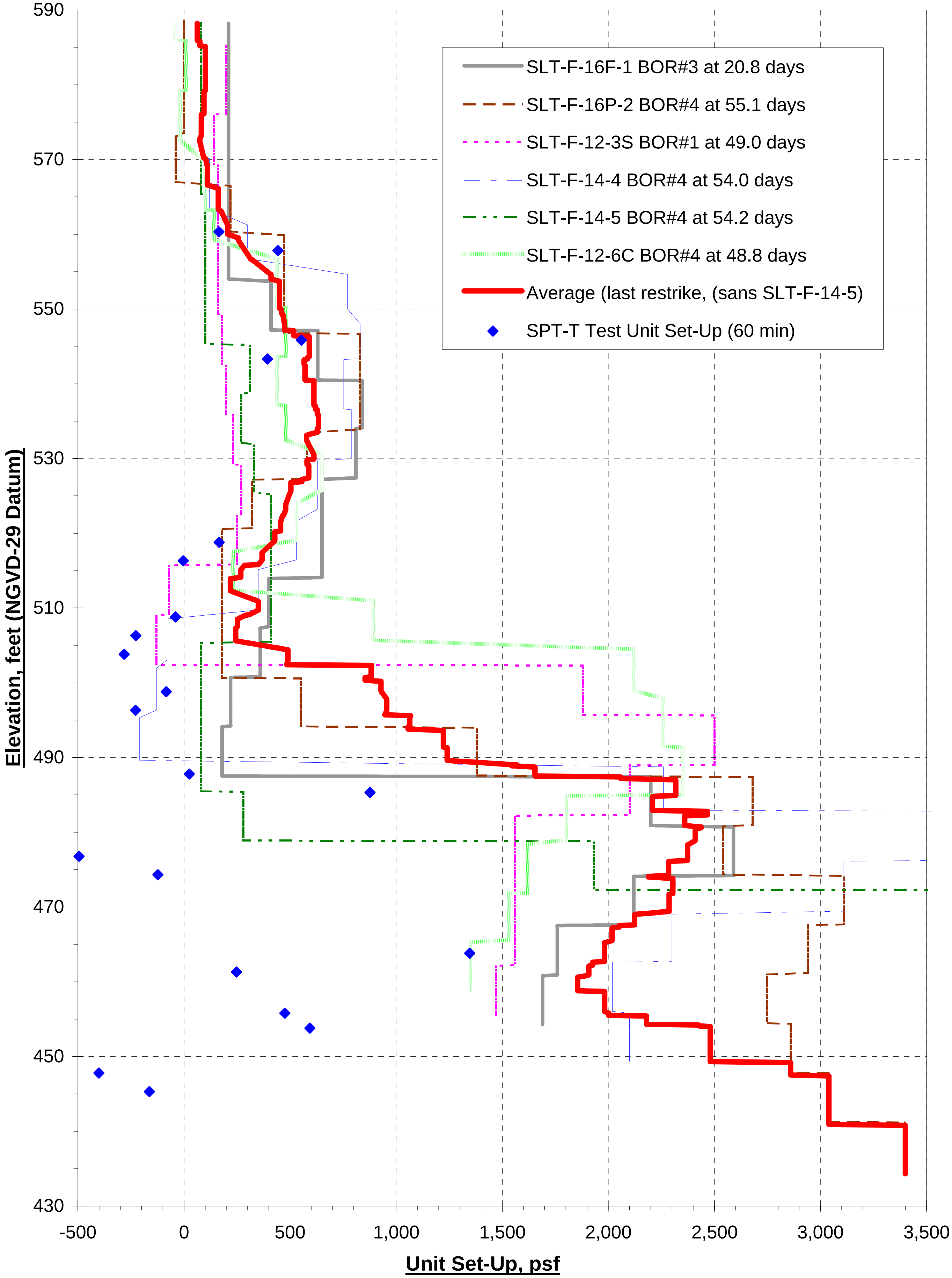

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Figure E-3 - Pile Unit Set-Up at Longest BOR vs. SPT Set-Up at 60 Minutes

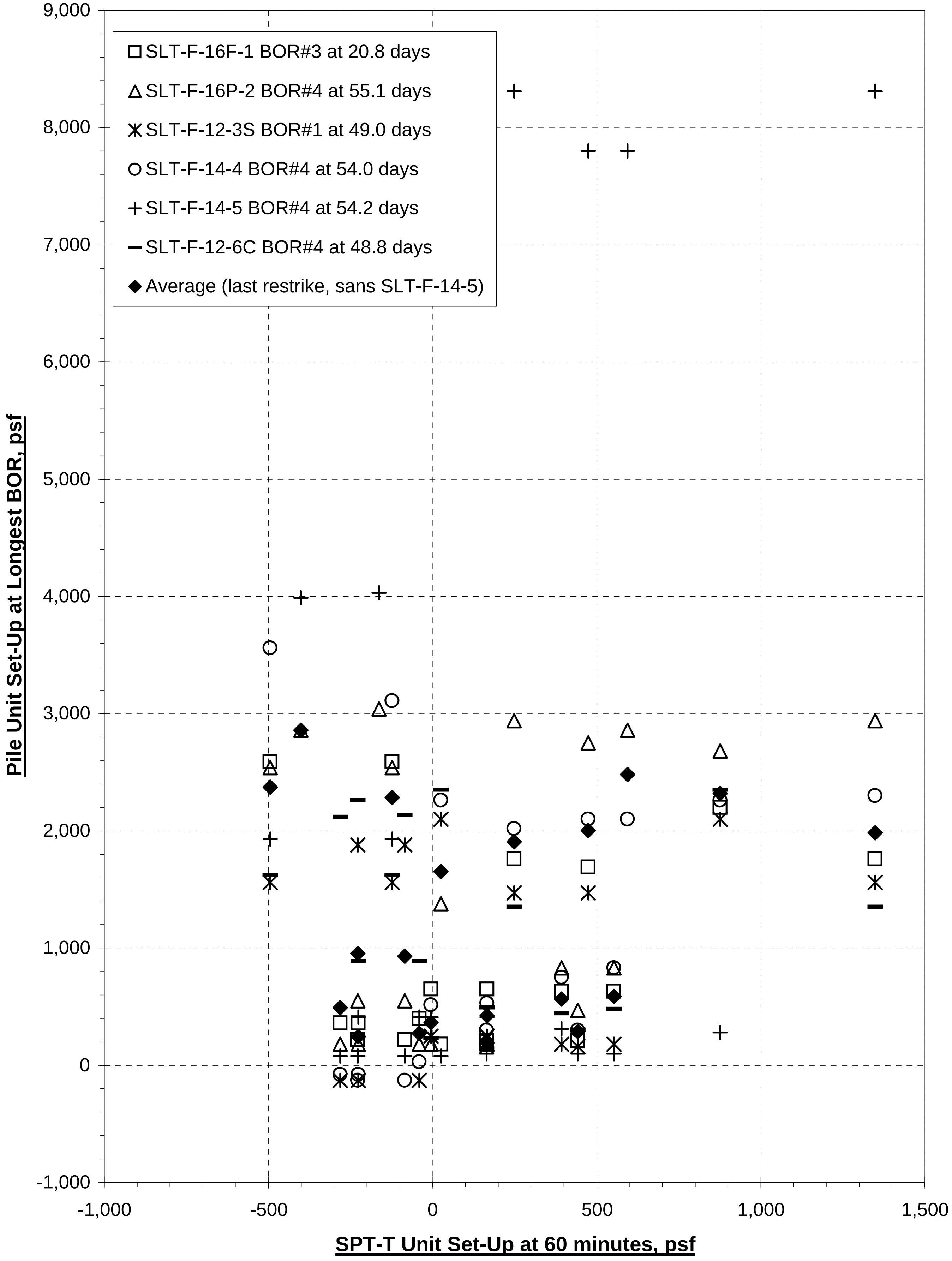

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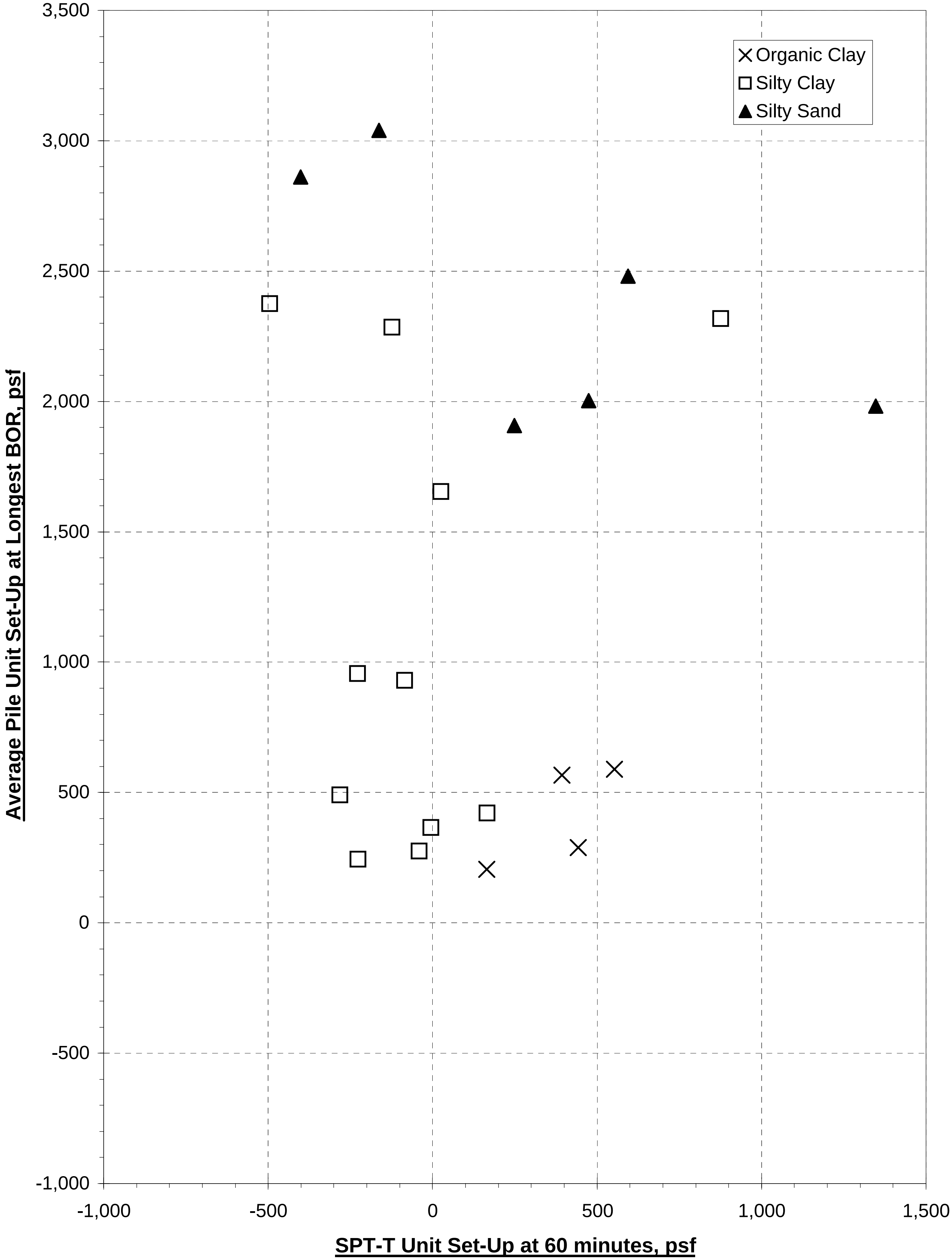
Figure E-4 - Average Pile Unit Set-Up at Longest BOR vs. SPT Set-Up at 60 Minutes



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