Strength Change Investigation of the Presumpscot Clay Formation

A. Santamaria
Sanborn Head & Associates, Westford, MA

N. Bradley
Virginia Tech, Blacksburg, VA

J. Benoît
University of New Hampshire, Durham, NH

ABSTRACT: The Presumpscot Formation is a soft to very soft sensitive marine clay deposit that is found along the New Hampshire and Maine Seacoast areas. The deposit varies in thickness but its geotechnical properties are overall very similar from location to location. Numerous studies using various in situ geotechnical tests such as the field vane, the piezocone and the flat plate dilatometer have revealed a strength shift at depth with regards to the undrained shear strength profile. The studies, dating back to the construction of the I-95 Interchange in the mid to late-60's, conducted in coastal areas of New Hampshire (Portsmouth, Dover and Newington) and Maine (South Portland) all show a sharp reduction in shear strength at depth followed by a gradual increase nearly parallel to the upper clay portion. A strength change of such significant magnitude is unusual and appears to be a regional change that may exist at a common point in geologic time rather than at a specific depth or elevation. Using specimens collected in Dover, NH across the zone depicting the strength change, laboratory tests using laser light scattering techniques were used to evaluate particle size distributions. X-Ray diffraction analyses were also used to evaluate the clay mineralogy. This paper presents the field and laboratory results at the various sites. The results from the particle size analyses showed clear evidence of significant differences in soil composition in terms of silt and clay fractions above and below the change in undrained shear strength. Possible explanations for the discrepancy include sea level changes, partial erosion of the Presumpscot clay formation or occurrence of a significant seismic event.

1 INTRODUCTION

1.1 *Background*

The New Hampshire Department of Transportation (NHDOT) began studies for a road network expansion in 2003 known as the Spaulding Turnpike Newington-Dover Project (Figure 1). The purpose of this project was to improve mobility and safety along the Spaulding Turnpike (Rt. 16) between Exit 1 and the toll plaza north of Exit 6 (NHDOT, 2009). The interchanges, geometry, and capacity of the existing roadways within this stretch of the turnpike were found to be insufficient to meet the current and future needs of the region. The project involves the addition of travel lanes in each direction, the widening and rehabilitation of the Little Bay Bridges, the elimination and reconfiguration of interchanges, and various other improvements.

At the Exit 6 interchange, the NHDOT reconfigured the on ramp from Route 4 onto the Spaulding Turnpike/Route 16 South. This interchange was underlain by an approximate 50 foot thick layer of blue clay which is part of the Presumpscot Formation. Extensive testing was performed to evaluate the compressibility of this clay. Field tests including piezocone (CPTu), dilatometer (DMT), and field vane (FVT) were conducted at various locations. Undisturbed Shelby tube samples were obtained using a piston sampler, and one-dimensional consolidation tests were performed on specimens obtained from these cores.

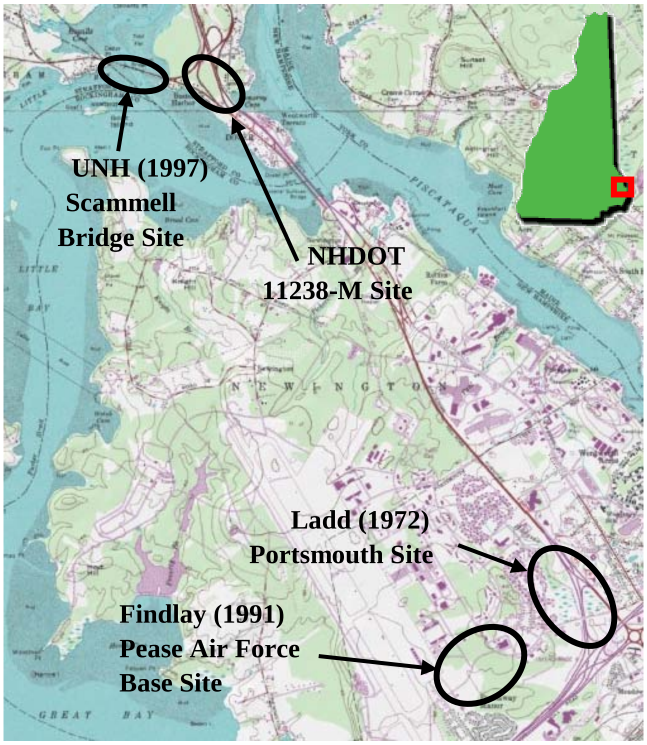

Figure 1. Locations of New Hampshire Seacoast investigations.

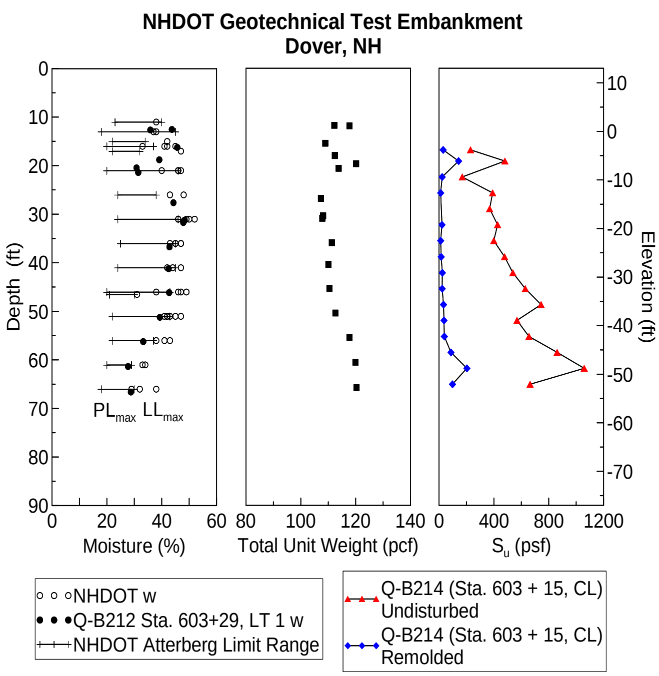

Figure 2. Profile of field vane test results with laboratory index properties at Newington-Dover Project test site.

The stratigraphy of the site at Exit 6 in Dover as shown in Figure 2 correlates well to the geologic history of the NH Seacoast. Bedrock is overlain by a layer of glacial till that was likely deposited during the retreat of the North American ice sheet. Beginning between 65 and 70 feet below ground surface is the clay of the Presumpscot formation, which exists from the top of the till layer up to approximately 10 foot depth, which is then covered by silty sand up to the ground surface. The natural water content is often near or above the liquid limit which is typical of this marine sensitive clay deposit.

2 REVIEW OF PREVIOUS WORK

2.1 *Initial findings*

This study originated from findings of an unusual strength shift observed at the Exit 6 site in Dover, NH. This shift had also been seen at several other test sites around the NH Seacoast (Ladd, 1972; Findlay, 1991; UNH, 1997) and in South Portland, ME (Roche et al., 2008). Figure 3 shows a soil profile and properties generated by Ladd (1972) for comparison with results shown on Figure 2. Field vane (FVT), flat plate dilatometer (DMT) and piezocone (CPTu) tests were conducted through the entire depth of the Presumpscot clay. The data obtained from these tests was used in part to determine the undrained shear strength (S_u) of the soil.

Field vane profiles were conducted using a Geonor H-10 Vane Borer and tests were carried out at approximately 3-foot intervals in the clay. DMT profiles were conducted at 0.5-foot intervals, and CPTu profiles were conducted “continuously” with a 2 cm/s advance rate, using a digital Hogentogler 10 ton piezocone. All data was obtained under free field conditions.

The results in terms of undrained shear strengths can be seen in Figure 4. The field vane data represents the peak strength values. The piezocone data shown was obtained from two separate boreholes spaced approximately 11 feet apart. The DMT data reflects a profile performed in close proximity to the FVT and CPTu tests.

At approximately 50 feet below the ground surface, a significant reduction in values of undrained shear strength can be observed, regardless of the test method. Across the strength change at approximately 50 feet, the peak FVT strength indicates a reduction of about 25%. Undrained shear strengths obtained from the piezocone and the flat plate dilatometer were

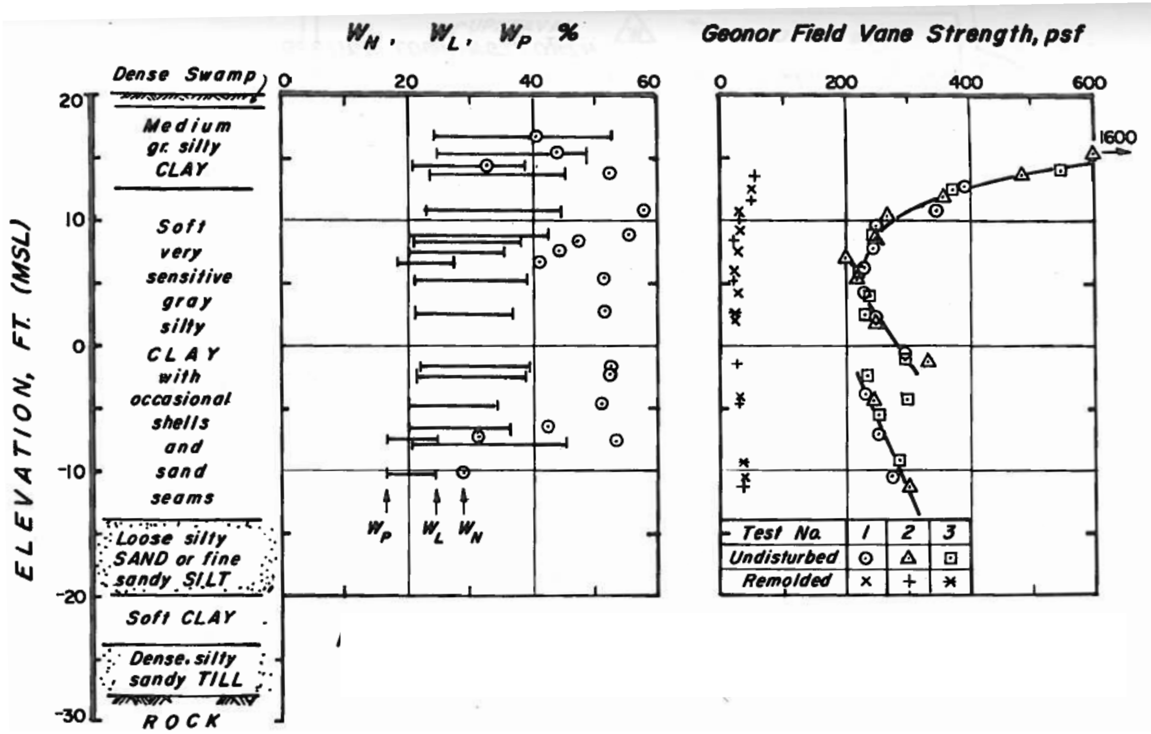

Figure 3. Soil profile, index properties and field vane strengths at experimental test section (Ladd, 1972).

empirically derived and shifted to match the peak field vane values. The CPTu strength decreased by approximately 15% while the DMT results indicate a 20% reduction in strength at the 50 foot transition zone.

2.2 *Purpose of study*

A typical profile of undrained shear strength in normally to slightly overconsolidated clays usually shows a gradual increase with depth. At the site, all in situ test results seem to indicate a sharp reduction in strength at an approximate depth of 50 feet suggesting some sort of anomaly or changes in stratigraphy. Once below this approximate depth, the strength again increases linearly with depth.

A strength change of such significance appears to be unusual for this deposit. If such a drastic decrease in strength occurs at this location in the Presumpscot Formation, then it would be reasonable to assume that the change is also geographically manifested elsewhere in the formation. Strength data was compiled from other sites around the Seacoast of New Hampshire and coastal Maine, and a strength decrease was also observed at those other locations (Ladd, 1972; Findlay, 1991; UNH, 1997; Roche et al., 2008).

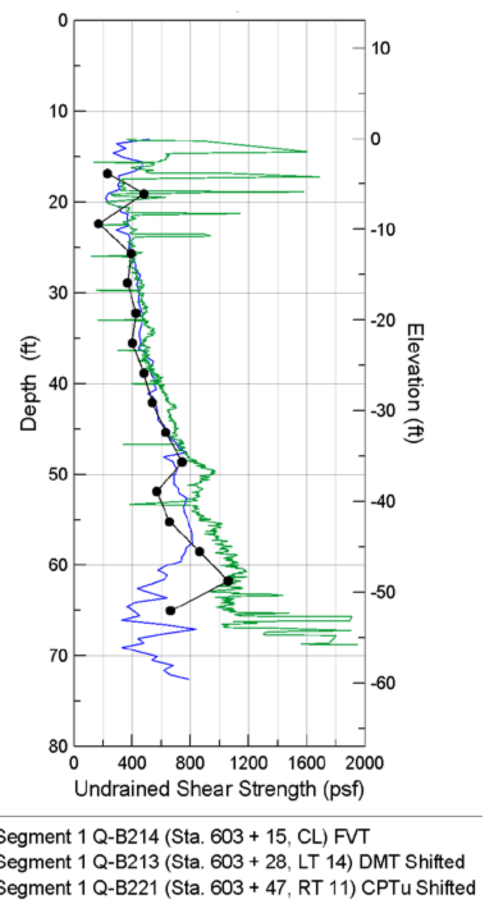

Figure 4. Undrained shear strengths from in situ testing at Newington-Dover Project test site.

The decrease in strength at the various sites vary from about 16 to 25 % and occurs at varying depth relative to sea level.

The regional pattern of reduction in S_u at depth is clear but there is no common elevation at which the strength reduction occurs. It is more reasonable to theorize that the discontinuities in these strength profiles originate from a common point in geologic time. If there is a fundamental change in the strength properties of the clay at a certain time during its deposition, then some other properties of the soil may also reflect the relative change.

3 TESTING PROGRAM

3.1 *Methods for analysis*

The change in strength at the 50 foot depth at the Newington-Dover test site is not visually observable from undisturbed samples obtained above and below that depth. Particle size analysis was undertaken to determine whether the fundamental change in the properties of the clay could be observed at the particle level. In addition, X-ray diffractometer (XRD) analysis was performed to investigate the mineralogy present in the clay both above and below the strength shift. Any significant changes in the particle size distribution or clay mineralogy of the clay could provide clues for the observed change in undrained shear strength of the Presumpscot clay.

Specimens were obtained through the full depth of sampling at approximately every 5 feet. Specimens were procured by removing 1 inch of Shelby tube at the chosen depth. Only the middle portion of the soil obtained from this inch of core was used for testing. The soil closest to the inner wall of the Shelby tube was discarded due to potential smearing effects. After sampling, specimens were sealed in plastic containers and stored at 4 degrees Celsius.

3.2 *Particle size analysis*

Particle size analyses were completed on each test specimen. Analysis was carried out using a Malvern Instruments Mastersizer 2000, which uses laser light scattering techniques to measure the particle size distribution of specimens. The Mastersizer measures particle sizes by volume. That is, the laser is scattered by the particles in suspension and the Mastersizer software returns particle sizes grouped into many pre-defined particle size categories. These are used to develop a volume-weighted particle size distribution.

To prepare a specimen for testing, approximately 1 cubic centimeter of moist soil was placed in a test tube and covered in 20 mL of the dispersant Calgon. The soil was immediately mixed with the Calgon to form a suspension and then allowed to soak for 24 hours. After 24 hours of soaking with dispersant, the soil suspension was agitated once more to disperse particles that had settled. The mixture was placed into the Mastersizer's dispersion unit immediately after dispersion and distilled water was added until the obscuration of the laser reached an acceptable range. The unit maintains a constant internal volume, so when distilled water is added, a small portion of the specimen is lost as waste. However, the particle size distribution should not be affected by specimen loss because the suspension is continually mixed by the Mastersizer, meaning that equal amounts of all particle sizes should be lost when some specimen is released from the machine.

3.3 *X-ray diffraction*

An X-ray diffractometer (XRD) makes two measurements: the angle an X-ray beam makes when reflected off the atoms within a crystalline structure, and the intensity of X-ray captured at the reflected point. At certain angles the diffraction receptor will detect reflected X-rays, measure their intensity, and processes the data which is uploaded to a computer monitoring device in the form of a graph. The graph plots the diffraction intensity over the range of 2θ predefined by the user and is then compared with preloaded known mineral standards. Generally, matching of high peaks indicates a match of the mineral; however this procedure works best for pure mineral crystals of uniform size.

XRD was conducted on two test specimens from above and below the approximate point of interest of 50 ft below the ground surface. The T-10 and T-12 specimens represent soil from approximate depths of 45.5 feet and 55.5 feet, respectively in an attempt to compare mineralogy above and below the strength shift.

X-ray diffractometer analysis requires the specimen to be dry; therefore, samples were air dried and broken down into marble size clods and pulverized in a grinding chamber. The fine powder was placed on an aluminum flat plate for analysis.

4 TEST RESULTS

4.1 *Particle size analysis results*

Two replicates of particle size analysis were conducted on each specimen using the Mastersizer. The results of the two replicates showed good agreement (Figure 5). At nearly every depth, the median particle size obtained in the first replicate is within one micrometer of that obtained in the second replicate run. Median particle sizes range from approximately 7 to 95 micrometers (medium silt to fine sand size).

The median particle sizes obtained from specimens below the depth of the strength change are greater than those above the strength change. The average median particle size of the first five specimens above the strength change (25.3-45.4 ft) is 9.03 and 8.51 µm, respectively for Runs 1 and 2. The average median particle size of the first three specimens below the strength change (50.5-60.6 ft) is 12.27 and 13.68 µm, respectively for Runs 1 and 2. One-sided heteroscedastic (two-sample unequal variance) Student's t-Tests were conducted on the data obtained in Runs 1 and 2 to determine if the median particle sizes below the strength change are significantly greater than those above the strength change. The P-values obtained from Runs 1 and 2 are, respectively, 0.0577 and 0.0396. Therefore, at a significance level of 0.05, the median particle sizes below the strength change are likely greater than those above the strength change.

It is also desirable to determine whether or not there is significant variation in one or more particle classes (clay, silt, sand) across the strength change. Thus, the clay, silt, and sand

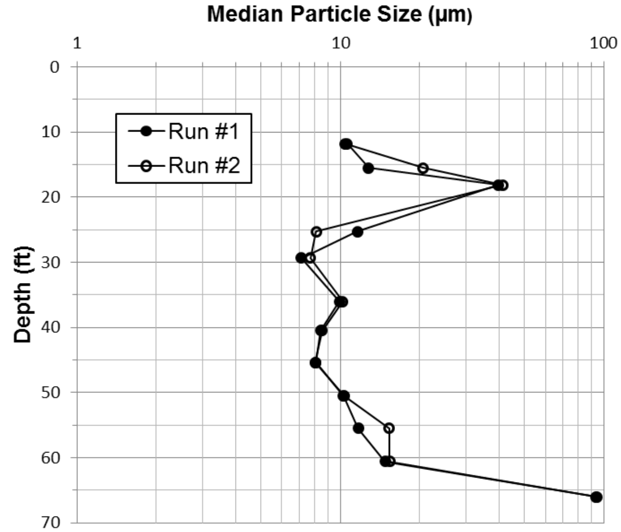

Figure 5. Plot of median particle size vs. depth using laser light scattering.

fractions of each specimen were determined based on both the Udden-Wentworth and the ISO/CEN & CFEM classification systems (Al-Hussaini, 1977). The particle class fractions for Run 1 are plotted in Figures 6 and 7 for each classification system.

The Udden-Wentworth classification system divides clay and silt at a particle size of 4 micrometers and divides silt and sand at a particle size of 63 micrometers. The variation of clay, silt, and sand fractions with depth can be seen in Figure 6. Below the strength change depth, there is a higher fraction of silt than in the specimens above the strength change. The clay fraction is noticeably lower in specimens below the strength change compared with those above.

P-values obtained from these tests are all below a 5% significance level. So, there is evidence to suggest that the clay fraction is lower and the silt fraction is higher in the soil below the strength change.

ISO/CEN and CFEM scales define the clay/silt boundary at 2 micrometers and the silt/sand boundary at 60 micrometers. The variation of clay, silt, and sand fractions with depth for these classification systems can be seen in Figure 7. In a similar manner to the Udden-Wentworth particle type fractions, the clay fraction appears to be lower and the silt fraction appears to be higher in the specimens tested below the strength change.

The results of one-sided heteroscedastic Student's t-Tests on the ISO/CEN and CFEM

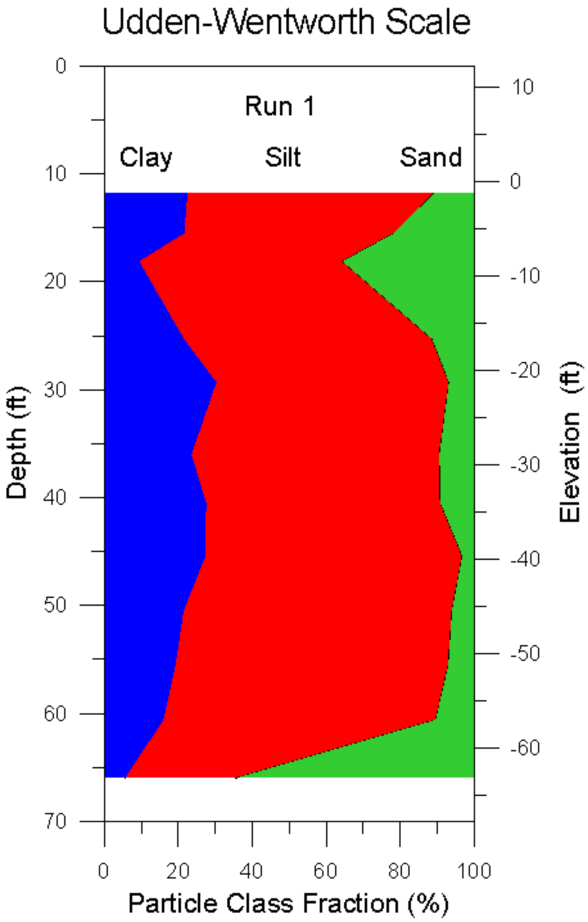

Figure 6. Plot of Udden-Wentworth Scale particle class fraction vs. depth.

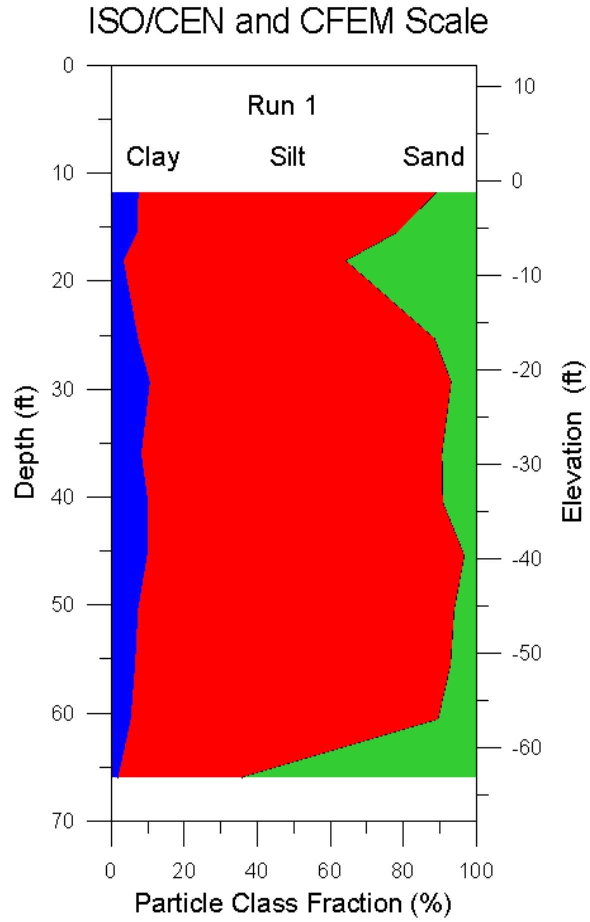

Figure 7. Plot of ISO/CEN and CFEM Scale particle class fraction vs. depth.

particle type fractions show similar results than found for the Udden-Wentworth system. The mean of the first three specimens below the strength change (T-11 to T-13) is being compared to the mean of the five specimens directly above the strength change (T-6 to T-10). Three out of four of the P-values obtained from the t-tests are below the 5% significance level. Therefore, there is evidence from the ISO/CEN and CFEM classification systems to suggest that there is a higher silt fraction and lower clay fraction in the soil below the strength change compared to the soil above the strength change.

4.2 *X-ray diffraction results*

X-ray diffraction results are plotted in Figures 8 and 9. The 2 graphs plot intensity in units of counts over a range of two theta. In this experiment a 2θ range from 5-80 was used with a rate of two samples per second. The majority of the peaks detected were observed in 2θ values between 5 and 50; therefore, this range served as the window of interest for mineral identification. The XRD results indicate the two clay samples taken from T-10, shown in green, (~45 ft below ground surface) and T-12 shown in black (~55 ft below ground surface), are nearly identical in composition with minor differences.

For comparison, the XRD results for T-10 are superimposed on top of T-12 in Figure 8. Visual observation shows the similar peak intensities at the same respective 2-theta values, indicating the two samples exhibit the same crystalline structures. Comparing the results to known mineral standards preloaded into the software, the high peaks indicate a best fit with an illite crystalline structure. Most peaks match up with the illitic fingerprint; however, additional peaks can be observed.

Numerous peaks that do not match with the illite standard indicate the sample is not purely illitic in structure. Ultimately, more minerals are present within the clay sample. Comparing the 2-

theta values with quartz and albite (feldspar) standards (Table 1) appears to accommodate the previously unexplained peaks. By this analysis, quartz and feldspar are likely to be present in the clay. Small amounts of muscovite and chlinochlore were also observed (Figure 8).

To confirm the sample is primarily composed of Illite, Figure 9 compares T-12 data to a previous study on an illitic clay sample and the illite standard. The composition matches well with the previous study with the exception of a high peak intensity at 26.6 two theta. The difference in intensity between the T-12 peak and 100% peak for the Illite standard can be assumed to be the intensity super-positioning from the quartz mineral diffraction (Table 1).

Any differences between T-10 and T-12 can be attributed to possible error in sample preparation. Variability in sample size and discrepancies in the sample surface from one specimen to the other are two common issues that can affect the diffraction of X-rays, disturbing the level of intensity detected.

Table 1: Mineral standard percent peaks and corresponding two theta values for XRD

Mineral	**Peak (%)**	**2θ**
Illite	100	26.67
Illite	90	8.84
Chlinochlore	100	12.51
Quartz	100	26.65
Albite	100	28.02

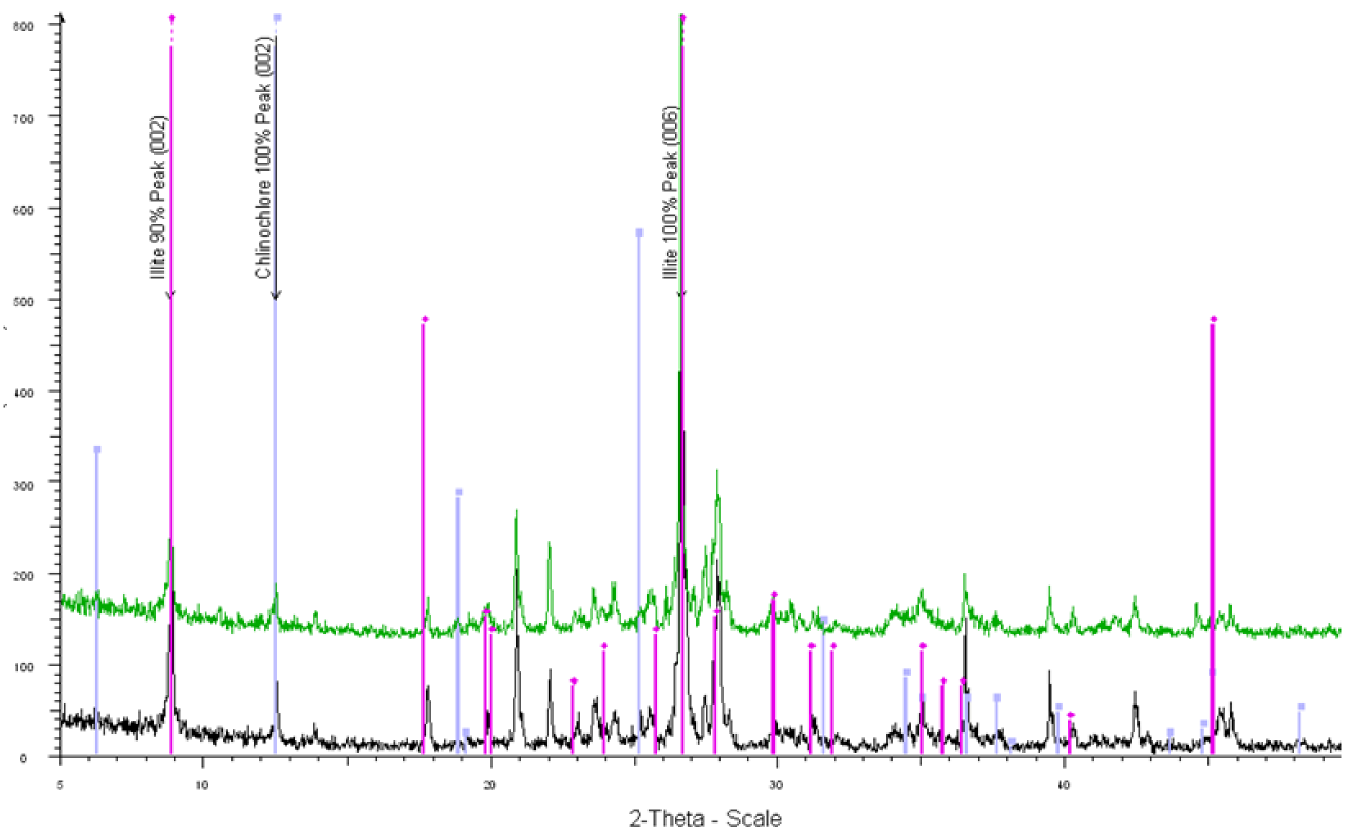

Figure 8. Contrast of T-10 and T-12 results compared with preloaded standard for Illite (magenta) and chlinochlore (blue) clay minerals Note: T-10 (green) is superimposed on top of T-12 (black) for visual observation and comparison.

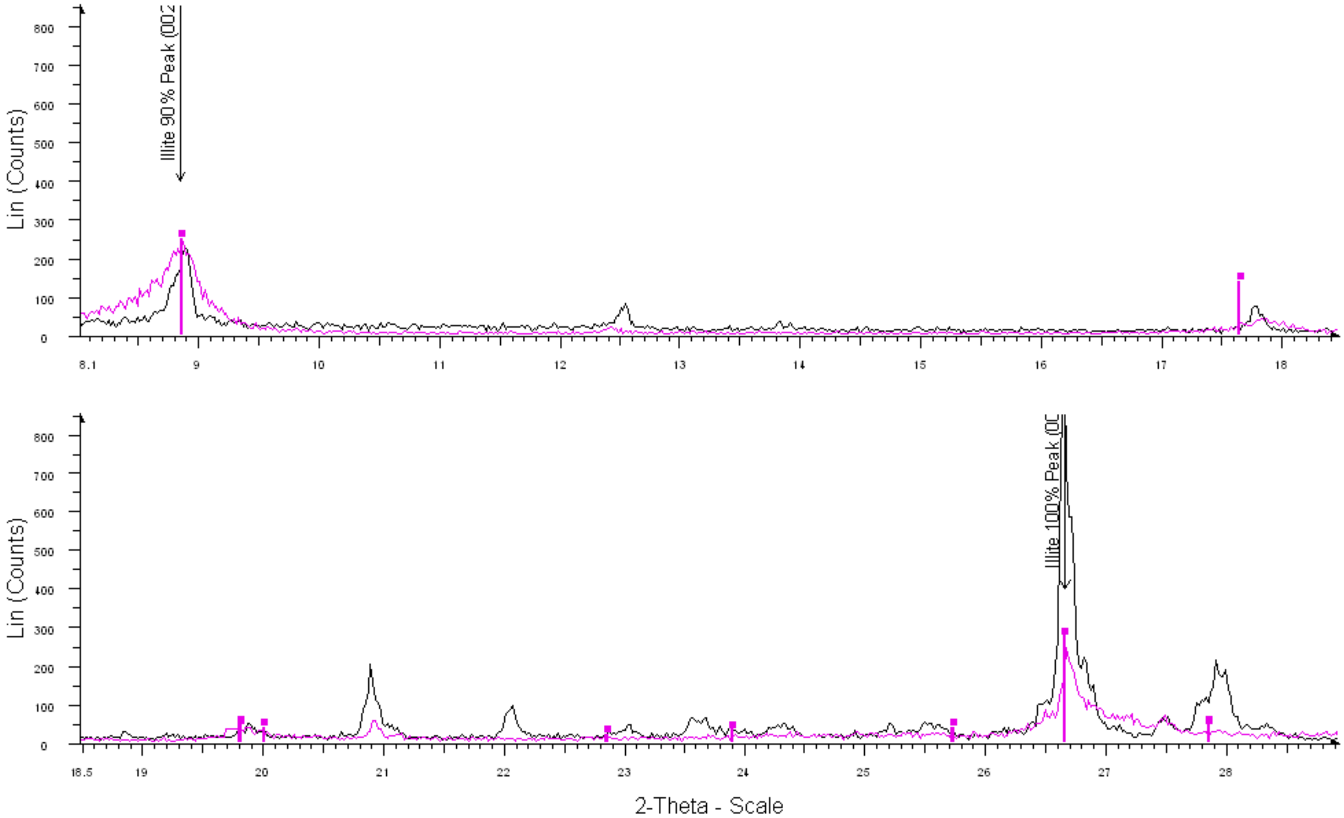

Figure 9. Contrast of T-12 test (black), with previous illitic clay test (magenta), and compared with preloaded standard for Illite (indicated by vertical magenta lines)

4.3 *Conclusions and future work*

The results of testing with the Mastersizer showed that there is evidence of a significant difference in soil composition above and below the change in undrained shear strength at 50 feet depth. Higher silt fractions and lower clay fractions could well correlate to lower undrained strength compared with overlying soil that contains higher clay fractions and lower silt fractions. Certainly, more analyses at smaller depth intervals are needed to provide more evidence for these findings, but these test results provide a possible preliminary compositional explanation for the strength change.

The two soil samples tested using X-ray diffraction are composed of the same mineral makeup and appear to be illitic clay with trace amounts of quartz, albite (feldspar), and muscovite. Therefore, clay mineralogy has no influence on the strength change exhibited in the clay at 50 ft below the ground surface at the Dover-Newington site; however, more extensive testing should be considered to establish mineralogy presence throughout the entire profile. The composition found from X-ray diffraction suggests the clays are indeed part of the Presumpscot Formation.

Another possible explanation for the existence of the strength change involves the geologic history of the deposition of the clay. The sea level lowstand during deposition of the Presumpscot Formation is of particular interest in this regard. Birch (1984) and Oakley (2000) each state that during the sea level lowstand, the surface of the Presumpscot was exposed to the air and erosion occurred, producing an unconformity at the top of the formation. Oakley also states that studies conducted at New Meadows River in mid-coast Maine showed an unconformity between the erosion surface of the Presumpscot and a layer of Holocene-era mud. Perhaps the location of the strength change could be correlated with the erosion surface of the Presumpscot. Future work could include an effort to correlate the regional strength data with mean sea level and date specimens from cores to determine if the strength change exists at elevations and time period that coincide with the end of the Presumpscot deposition.

The existence of the strength change could also be attributed to a significant seismic event. A seismic event could have liquefied or otherwise reduced the strength of the clay beneath the elevation of the strength change and then over time, the soil gradually regained strength due to the deposition of the overlying soil, thixotropic effects, cementation, or other causes. Irrespective of the potential explanations for the existence of this regional strength anomaly, it is clear that much more research must be conducted before any confidence may be placed in any one theory.

4.4 *Acknowledgments*

The support from the New Hampshire Department of Transportation under contract 11238-Q to evaluate the behavior of the Newington-Dover Test Embankment is greatly appreciated. Samples used to perform the study described in this paper were obtained as part of this contract.

4.5 *References*

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