The Engineering Aspects
Of The
Presumpscot Formation

By

David W. Andrews, P.E.
Morrison Geotechnical Engineering

Ralph Peck, a leading geotechnical engineer, has said that the three things a geotechnical engineer must have are a good understanding of Soil Mechanics and Geology and experience. It is the goal of this symposium to explore the soil mechanics and geology of one of Maine's problem soils, the Presumpscot Formation (PF) silty clay, and to share our experiences working with it. If Ralph Peck is right, we should have better success in dealing with the Presumpscot Formation after this symposium.

What are some of the problems geotechnical engineers encounter with the Presumpscot Formation?

- The deposit is prone to landslides and slope failures that are difficult to explain and predict.

- Some buildings and embankments, underlain by the Presumpscot Formation, have experienced unacceptable settlement.

- Prediction of settlement rates are often unreliable.

- Bearing failures have occurred.

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- Frost damage of roads with the Presumpscot Formation have happened.

- Hydrogeologic studies involving the Presumpscot Formation often require considerable estimation of hydraulic properties.

Engineers and geologists have been interested in the Presumpscot Formation since colonial times. As early as the 1860's professionals were trying to understand the engineering properties of the Presumpscot Formation. Professor Morse, in 1869, for example, wrote about the "slippery, very tenacious, plastic blue clay" in an article on the landslides of the Portland, Maine area. However, until recently, engineers have only had experience to guide them in solving of foundation problems involving the Presumpscot Formation.

With the development of the science of Soil Mechanics, by Terzaghi and others in the 1930's and 1940's, the understanding of the Presumpscot Formation moved from the empirical to the rational. Soil Mechanics is concerned with the behavior and performance of soil as a support (in a broad sense) for engineering construction. It is a new science and in practice, is still much dependent on empirical relationships as well as analytical theories, and experience is still an important teacher.

ENGINEERING PROPERTIES

The soft to very soft silty clay fraction of the Presumpscot Formation deposit is the soil of greatest concern to the geotechnical engineer.
Experience has taught the profession that the very soft stratum problems are related to low strength, compressibility, and sensitivity. These characteristics usually have negative (read more cost) impact on a project.

The soil properties that relate to these characteristics can be generally grouped into three categories:

- index properties,
- consolidation properties, and
- strength properties.

The following are summaries of these engineering properties commonly used in geotechnical analysis and design. The properties are taken from various published articles and unpublished geotechnical reports, including proprietary reports belonging to Morrison Geotechnical Engineering. The data presented has been taken at face value. No attempt was made to check the validity of the numbers nor the methods used in determining the values.

For some soil properties, there is a great deal of data. For others, the data is scanty. The data is all site specific and there is an obvious bias toward the Portland, Maine, area. The Presumpscot Formation has variable characteristics, and, therefore, the presented data should not be used for design purposes.
INDEX PROPERTIES

Index properties are those physical properties of a soil that can be easily, inexpensively, be determined. Index properties are usually not a direct measure of significant soil characteristics but are an indicator of (hence the name index property) these more important characteristics. The relationship between index properties and other characteristics is usually empirical. The relationship may be direct as with gradation to permeability, but usually the index properties place the soil in a classification with known characteristics.

**Natural Water Content, WC**

The soft, blue-gray stratum of the Presumpscot Formation is considered fully saturated. The average WC for the Presumpscot Formation varies with depth and stress history and generally increases with depth. Table I, Natural Water Content, presents the WC data on the silty clay.

**TABLE I**

<table>
<thead>
<tr>
<th>Location</th>
<th>WC, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portsmouth</td>
<td>45 to 55</td>
</tr>
<tr>
<td>Wells</td>
<td>36 to 44</td>
</tr>
<tr>
<td>Portland</td>
<td>42</td>
</tr>
<tr>
<td>Westbrook</td>
<td>40 to 43</td>
</tr>
<tr>
<td>Norridgewock</td>
<td>15 to 36</td>
</tr>
</tbody>
</table>

The stiff crust has a water content of around 20 to 25 percent.
Unit Weight

The dry unit weight for the soft Presumpscot Formation is in the range of 85 to 95 pounds per cubic foot. The dry unit weight appears to be constant with depth, which is interesting in that the water content does not remain constant with depth. The stiff crust has a dry unit weight of between 95 and 100 pounds per cubic foot.

Specific Gravity, G

The specific gravity, G, of the Presumpscot Formation, is reported to be 2.74 to 2.79 by several sources. This is somewhat higher than would be expected if the Presumpscot Formation's principal constituent was quartz (G = 2.62). The micas (G = 2.8 to 3.1) and chlorides (G = 2.6 to 3.0) in the Presumpscot Formation may account for the higher value.

Void Ratio, e

The void ratio of a soil is defined as:

\[ e = \frac{\text{volume of soil voids}}{\text{volume of soil solids}} \]

The void ratio can also be determined for a saturated soil by:

\[ E = (WC)G \]

Numerous reports give the e for the Presumpscot Formation in the range of 0.9 to 1.3.
Plasticity Characteristics

The plasticity characteristics of a fine-grained soil are expressed as water content "limits" above which the soil has a different consistency. The limits are determined by a set of standardized laboratory tests referred to by the name of a scientist who originated the system - A. Atterberg.

The principal limits of concern with the Presumpscot Formation are:

- **Liquid Limit**: The water content above which the soil acts as a viscous liquid, i.e., the soil has no measurable shear strength.

- **Plastic Limit**: The water content above which the soil acts as a "plastic" material.

- **Plastic Index**: The water content difference between the liquid and plastic limits.

Table II, Atterberg Limits, presents Atterberg limit data from several reports.

**TABLE II**

Atterberg Limits

<table>
<thead>
<tr>
<th>Location</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Plastic Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portsmouth</td>
<td>30 to 40</td>
<td>18 to 22</td>
<td>-</td>
</tr>
<tr>
<td>Portland</td>
<td>25 to 30</td>
<td>15 to 25</td>
<td>-</td>
</tr>
<tr>
<td>Brunswick</td>
<td>25 to 39</td>
<td>17 to 23</td>
<td>6 to 18</td>
</tr>
<tr>
<td>Waterville</td>
<td>31 to 41</td>
<td>18 to 21</td>
<td>13 to 20</td>
</tr>
</tbody>
</table>

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Gradation Analysis

The grain size distribution within the deposit varies with both horizontally and vertically. The silty clay fraction has a grain size range between 90 percent and 100 percent passing the No. 200 (0.074 mm) sieve and 40 percent to 60 percent smaller than 0.005 mm (clay size).

Classification

Classification systems are used by geotechnical engineers to determine typical properties of a soil or to determine the suitability of a soil for specific engineering applications.

Unified Soil Classification System. The unified system is widely used as a general purpose classification. The Presumpscot Formation silty clay is almost always classified as CL, "an inorganic clay of low to medium plasticity", under the system.

AASHTO. The AASHTO classification is specifically intended for road subgrade suitability. The Presumpscot Formation is reported to be an A-7-5 soil with a group index of 12.

Frost Design Classification. The Corps of Engineers Frost Design Classification places the Presumpscot Formation in the F-4 group, "banded fine-grained sediments", that are most frost reactive.
CONSOLIDATION CHARACTERISTICS

When a saturated, fine-grained soil is subjected to an increase in vertical stress, the soil skeleton undergoes deformation or strain. This compressional strain results in surface settlement. Because the Presumpscot Formation has a very low permeability, the vertical stresses are initially carried by the pressurization of the soil pore water. The stresses are then transferred to the soil skeleton as the water pressure slowly dissipates. Consolidation is, therefore, time dependent. Compression, due to increased load, is called primary compression.

The changes in soil volume with load and other related consolidation characteristics of the Presumpscot Formation are typically studied by performing consolidation tests. A small "undisturbed" Presumpscot Formation sample is vertically compressed with a series of increasing loads. The amount of soil compression at time intervals for each load is recorded. Analysis of the data plus soil index properties permit the geotechnical engineer to estimate total compression of the stratum, the consolidation rate and the stress history of the strata.

The stress history is an important factor in evaluating the settlement that a structure will experience. If a deposit appears to have been subjected to vertical stress levels in the past that were greater than currently exist due to self weight of the deposit, than the deposit is said to be preconsolidated or
over-consolidated. The higher "past pressures", \( P_c \), may be a result of soil unloading by erosion or water table change or may actually be caused by physio-chemical changes in the soil such as cementation or secondary compression. A soil that is in-equilibrium with existing stresses is normally consolidated.

If an over-consolidated soil is loaded, say with a large building or highway embankment, settlement will be less than if the soil was normally consolidated. Significant settlement will take place only after the past pressure is exceeded. This fact can be used to advantage by geotechnical engineers in the design of foundations on the Presumpscot Formation deposit.

**Compression Index, \( C_c \)**

The most commonly determined characteristic is the compression index, \( C_c \). \( C_c \) is the slope of the portion of a void ratio versus log effective vertical pressure plot at pressures greater than the past pressures. \( C_c \) values for the Presumpscot Formation are given in Table III, Compression Index.

**TABLE III**

<table>
<thead>
<tr>
<th>Location</th>
<th>( C_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wells</td>
<td>0.38</td>
</tr>
<tr>
<td>Portland</td>
<td>0.4 to 0.6</td>
</tr>
<tr>
<td>Portland</td>
<td>0.33</td>
</tr>
<tr>
<td>Augusta</td>
<td>0.4</td>
</tr>
<tr>
<td>Kennebunk</td>
<td>0.56</td>
</tr>
<tr>
<td>Bath</td>
<td>0.34</td>
</tr>
</tbody>
</table>
There is little information available on compression indices determined in-situ from instrumented sites. One study done in Portsmouth, New Hampshire, had a field derived $C_c$ of 0.8, while the laboratory value was 0.6, a significant difference.

Recompression Index

The recompression index is the slope of the void ratio versus log vertical effective pressure curve for pressures below the $P_c$. The value is usually about 8 percent to 10 percent of $C_c$.

Secondary Compression

Soil continues to compress after completion of primary compression, i.e., after compression associated with pore water pressure dissipation. The subsequent compression, called secondary compression or creep, takes place at a much slower rate and without load increase. Reported values for secondary compression are in the range of 0.5 to 1.5 percent of strain/cycle time.

The Presumpscot Formation silty clay has undergone some secondary compression, as would be expected for this soil type and geologic history.

Coefficient of Consolidation

The coefficient of consolidation is used in computing the rate of settlement. The rate of settlement is important, as it may dictate what schemes the geotechnical engineer can use to decrease the risks of settlement.
The coefficient of compression varies with orientation within the soil mass. The vertical coefficient is measured by conventional testing methods. The horizontal coefficient takes special devices. The co-efficients are also a function of testing procedures.

Vertical coefficients for the Presumpscot Formation in the Portland area are reported in the 0.05 to 0.15 square feet per day range. One report gives the ratio of horizontal to vertical coefficient of 1.2 to 1.5.

With information on the coefficient of consolidation in hand, the settlement rate can be predicted if the drainage characteristics of the deposit, such as sand layer spacings and overlying soil permeability, are known.

Over-Consolidation Ratio, OCR

The Presumpscot Formation is an over-consolidated deposit. The upper crust has been significantly over-consolidated due, probably to the combined forces of dessication, drying and wetting in the presence of certain salts (Bowles, 1979), and chemical bonding. The soft, deeper deposit is also slightly over-consolidated as the result of secondary compression.

The amount of over-consolidation can be expressed as the Over-Consolidation Ratio, OCR:

\[
OCR = \frac{\text{Apparent past vertical pressure, } P_c}{\text{Existing vertical pressure, } P}
\]
Table IV, Over-Consolidation Ratio, presents OCR data for a well-documented site in Portland, Maine.

<table>
<thead>
<tr>
<th>Depth (Feet)</th>
<th>OCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4.4</td>
</tr>
<tr>
<td>10</td>
<td>2.25</td>
</tr>
<tr>
<td>15</td>
<td>1.47</td>
</tr>
<tr>
<td>20</td>
<td>1.20</td>
</tr>
<tr>
<td>30</td>
<td>1.14</td>
</tr>
<tr>
<td>40</td>
<td>1.13</td>
</tr>
<tr>
<td>50</td>
<td>1.12</td>
</tr>
<tr>
<td>60</td>
<td>1.12</td>
</tr>
</tbody>
</table>

**Permeability**

The coefficient of permeability, $k$, of the Presumpscot Formation varies with the deposit's void ratio and is different in the horizontal and vertical directions because of natural stratification. The permeability of the silty clay is on the order of $5 \times 10^{-8}$ to $1 \times 10^{-7}$ centimeters per second. The ratio of horizontal to vertical permeability of the silty clay is estimated to be 1.2 to 1.5. It is important to note that these values are for small laboratory samples of the silty clay. The permeability of a Presumpscot Formation deposit, as a whole, would probably be higher because of sand layers.
SHEAR STRENGTH

Failure of a soil under imposed load, such as a footing, embankment, or anchor block, is due to a combination of normal compressive and shearing stresses. The ability of a soil to resist these forces lies in its frictional (angle of internal friction) and cohesive shear strength. For fine-grained soil, like the Presumpscot Formation, the resistance is primarily cohesive under normal loading conditions.

The shearing strength of the Presumpscot Formation has been determined from both field tests, such as bore hole vane shear and laboratory tests, such as unconfined compression and triaxial compression under various loading conditions.

Undrained Shear Strength, $S_u$

The undrained shear strength, $S_u$, of the Presumpscot Formation silty clay is a function of the overburden pressure. It has been found that the ratio between the undrained shear strength to the overburden pressure ($S_u/p$) is a constant for a given deposit. The overburden pressure, however, may not actually be the currently existing vertical stress but may be the past pressure, as discussed in the consolidation section of the paper. Therefore, it would be expected that the $S_u/p$ ratio will vary with the deposit's OCR.

The Presumpscot Formation crust has an undrained shear strength that is very high because of the high OCR. The Presumpscot Formation strength decreases with depth and then increases again as the overburden pressure increases.
Laboratory derived data on $S_u$ and $Su/p$ for a site in Portland, Maine, are presented in Table V, Undrained Shear Strength.

**TABLE V**

<table>
<thead>
<tr>
<th>Depth, Feet</th>
<th>$S_u$, psf</th>
<th>$Su/p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>420</td>
<td>0.41</td>
</tr>
<tr>
<td>40</td>
<td>355</td>
<td>0.24</td>
</tr>
<tr>
<td>50</td>
<td>445</td>
<td>0.23</td>
</tr>
<tr>
<td>60</td>
<td>555</td>
<td>0.23</td>
</tr>
<tr>
<td>70</td>
<td>645</td>
<td>0.23</td>
</tr>
<tr>
<td>80</td>
<td>750</td>
<td>0.23</td>
</tr>
</tbody>
</table>

$psf =$ pounds per square foot.

The stiff crust is reported to have $S_u$ in the 2,000 to 3,500 psf range.

The general opinion is that the field vanes give somewhat higher shear strengths than laboratory tests. Hand-held torvane devices are also sometimes used to obtain shear strength. My experience with the torvane indicates that the device may be under-estimating shear strength, slightly.

It should be noted that the type of test and the assumptions used in the test have a good deal to do with the resulting shear strength. (Amos, 1986), for example, obtained shear strengths of 215 psf from a field vane test and 748 psf from a triaxial test for supposedly the same soil under the same conditions.
REFERENCE LIST


Remolded Shear Strength

The remolded shear strength is the cohesion that remains after a soil has been greatly disturbed or remolded. The remolded shear strength of the Presumpscot Formation silty clay is on the order of 15 percent to 35 percent of the undisturbed shear strength.

Sensitivity

The sensitivity of a soil is the ratio of its undisturbed shear strength to its remolded shear strength. The more sensitive a soil, the greater the likelihood of rapid, progressive-type landslides. The Presumpscot Formation has a sensitivity in the 5 to 15 range which would classify it as a sensitive to very sensitive deposit.

CLOSURE

The preceding paper has presented a very brief overview of the engineering aspects of the Presumpscot Formation. Much additional information can be found in the documents in the reference list that follows.
REFERENCE LIST


Maine State Highway Commission and Haley & Aldrich, Inc., (1969), Report No. 1. "Engineering Properties of the Foundation Soils, Long Creek-Fore River and Back Cove Area". Portland, Maine. Unpublished. 36 pgs. (This report was written by Johnson and Ladd and is close to the definitive work on the Presumpscot Formation. The report forms the basis for the proceeding articles by Ladd et al.)

