Engineering properties of Bloomington-Normal subsoils

Rohn Dunseth Abbott

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Department: Civil, Architectural and Environmental Engineering

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ENGINEERING PROPERTIES OF BLOOMINGTON-NORMAL SUBSOILS

BY

ROHN D. ABBOTT

A
THESIS
submitted to the faculty of
THE UNIVERSITY OF MISSOURI-ROLLA
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Degree of
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1968

Approved by

Thomas S. Fry (advisor) James C. Armstrong
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by

Rohn D. Abbott

SYNOPSIS

The glacial subsoils of the Bloomington-Normal, Illinois area have been analyzed with regard to their engineering properties. Several boring logs are included to illustrate the horizontal and vertical variability in soil units encountered and in the engineering properties of these soil units.

The engineering properties of the two most common foundation soils, the Bloomington and Normal tills are compared and special consideration is given to evaluating the compressibility of these materials. Evidence is presented that indicates that the circumferential trimming of a highly preconsolidated soil containing stones can cause significant sample disturbance. Special sampling techniques which eliminate circumferential trimming yield results considered to be more representative of a highly preconsolidated glacial till.
INTRODUCTION

Purpose

Numerous subsurface exploration for foundation investigations have been made in the Bloomington-Normal area. Until now an attempt has not been made to correlate the data obtained from several sites within the area and present a quantitative description of the soil characteristics for use by the practicing engineer. A summary of the properties of the subsoils is presented in addition to the graphical representations of the nature of the subsoils. The description is supplemented with the geology of the area because a knowledge of the geologic origin of the subsoil leads to a better understanding of the deposits.

Location

The twin cities of Bloomington and Normal, Illinois are located in northeastern McLean County. The area is in the physiographic division of Illinois known as the Bloomington Ridged Plain, an area containing several broad morainic ridges formed during the Woodfordian substage of Wisconsin glaciation (21).

Geology

Bedrock

The Lower McLeansburo Group of Pennsylvanian age rocks comprise the bedrock of the area. This formation consists of relatively thin bedded limestone, sandstone, shale, and coal. It is not known to be cavernous, but the formation has been worked for coal southwest of
Bloomington. The bedrock is covered by 200 to 300 feet of glacial drift and is not considered to be of prime engineering importance except in localized areas previously mined for coal.

Glacial

An understanding of the glacial geology of the area is fundamental in delineating the problems associated with foundation engineering in the area. The subsoils of the Bloomington-Normal area were deposited during the Pleistocene epoch, and they consist predominately of glacial drift. Eight layers of drift, one lying on top of the other, have been identified in the area (7). Each of the drift sheets represents an advance and retreat of a continental ice sheet. The stratigraphic relationship of the drift sheets and their corresponding stage of continental glaciation are shown schematically in Table 1.

**TABLE 1**

Schematic Representation of Stratigraphic Relationship of Drift Units of Bloomington Normal Area

<table>
<thead>
<tr>
<th>GLACIAL STAGE</th>
<th>DRIFT UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Bloomington</td>
</tr>
<tr>
<td></td>
<td>Leroy</td>
</tr>
<tr>
<td></td>
<td>Shelbyville</td>
</tr>
<tr>
<td>Illinoian</td>
<td>Buffalo Hart</td>
</tr>
<tr>
<td></td>
<td>Payton</td>
</tr>
<tr>
<td></td>
<td>Jacksonville</td>
</tr>
<tr>
<td>Kansan</td>
<td>Kansan</td>
</tr>
</tbody>
</table>

The cities of Bloomington and Normal are situated upon and in front of the Normal end moraine. Thus, the drift units which have
the largest influence on foundation design are the Normal drift, the Bloomington drift, and to a lesser extent, the Leroy drift.

GENERAL DESCRIPTION OF SUBSURFACE CONDITIONS

Origin of Bloomington-Normal Area Subsoils

As previously stated, the subsoils are of glacial origin and consist largely of sheets of drift. The glacial drifts are composed primarily of till with some fluvial or outwash material and minor amounts of lacustrine deposits. The soils developed on the drift sheets appear to be those formed in depressional or swampy areas and consist of accretion gley and humic gley.

Till is an unstratified mixture of particles ranging in size from boulders to clay that was deposited directly from the glacial ice sheets. The textural composition of this heterogeneous material may vary from 99% boulders to 99% clay size or any gradation in between. The tills of the Bloomington-Normal area are composed of clayey silts or silty clays with sand, gravel, and occasional boulders (5, 8, 20).

Summary of Subsurface Conditions

The subsoils of the Bloomington-Normal are comprised of several layers of glacial drift. The glacial till associated with the drift is the most prominent and continuous feature of each strata while the outwash deposits and depressional soils are less continuous. Depending upon the action of the successive glaciers, the soils developed on a drift sheet may be removed entirely, partially, or not at all by the advancing ice sheet.
A loessial mantle five to seven feet thick once covered the area (23). The loessial soil, enriched by organics, is the basis of the fine agricultural soils of the area, and it is usually soft and wet at the contact between the loess mantle and the underlying glacial till.

The uneven surface of freshly deposited till sheet with the associated poorly developed drainage system gives rise to many temporary lakes and ponds, and pockets of soft, compressible material were formed when these silt size particles were deposited in these water-filled depressions.

Pattern of Subsurface Features

A more detailed conception of the subsurface conditions and the high degree of variability normally associated with glacial deposits may be obtained from studying boring logs (a) through (f).

The cohesive soils are described in terms of their consistency or relative stiffness which is determined by the unconfined compression test. The consistency terms corresponding to the values of unconfined compressive strength are given in Table 2. This classification, suggested by R. K. Morse (10), has been adopted because in the writer's opinion the term "firm" is more descriptive than the term "medium" which it replaces.
TABLE 2
Consistency Expressed in Terms of Unconfined Compression Strength

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Unconfined Compressive Strength (tons per sq. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft</td>
<td>Less than 0.25</td>
</tr>
<tr>
<td>Soft</td>
<td>0.25 - 0.5</td>
</tr>
<tr>
<td>Firm</td>
<td>0.5 - 1.0</td>
</tr>
<tr>
<td>Stiff</td>
<td>1.0 - 2.0</td>
</tr>
<tr>
<td>Very Stiff</td>
<td>2.0 - 4.0</td>
</tr>
<tr>
<td>Hard</td>
<td>Over 4.0</td>
</tr>
</tbody>
</table>

(Modified from Terzaghi and Peck, 1948)

Figure 1 is a stratigraphic cross-section of the subsoils near Water Street and Fell Avenue in Normal illustrating the variability that can be expected in areas where the Bloomington drift is covered by the Normal till. The log of Boring (a), Figure 2, shows the range of water content and unconfined compressive strengths associated with these materials.

Boring (b) is located less than a quarter mile north of the cross-section presented in Figure 3. At this location the tills of the Leroy, Bloomington, and Normal glaciers lie directly upon one another and are not separated by outwash deposits or soil profile developed on the tills as indicated by the profile constructed from a boring program a short distance to the south.

The logs of Boring (c) and Boring (d), Figures 4 and 5 respectively, indicate that the interglacial period between the deposition of the Bloomington and Normal tills in the area must have been extremely wet. Figure 4 shows a glacial lacustrine deposit
Figure 1. Stratigraphic Cross-Section of Subsoils near Water Street and Fell Avenue, Normal
Figure 2. Boring (a) at Water Street and Fell Avenue, Normal
Figure 3. Boring (b) at School Street near North Street, Normal
surface
798.6 black topsoil
795.6 stiff yellow-brown
(Richland Loess)
791.6 firm tan silty clay
with sand & gravel
(Superglacial Till)
785.6 stiff to very stiff
very dense gravel with sand & gravel
780.6 (Normal Till)
775.6 very stiff to hard
dense medium to fine
770.6 grey clay with silt
grained sand with gravel
765.6 dense gravel with
760.6 coarse sand
755.6 pinkish-grey silty clay
750.6 with sand & gravel
745.6 (Bloomingon Tilt)
740.6 dense gravel with sand
735.6 very stiff to hard
730.6 greenish-grey silty clay
725.6 with sand & gravel
720.6 (Shelbyville Tilt)
715.6 bottom of boring
710.6

Figure 4. Boring (c) near College Avenue and Normal Avenue, Normal
depth

0.0  surface fill
3.0  tan and yellow silty clay with pebbles, unsorted (weathered Normal Till)
8.0  grey silty clay with sand & gravel (Normal Till)
14.0 very stiff grey silty clay with pebbles (Normal Till)
19.0 very stiff black silt with organic material and thin seams of fine sand (Swamp Deposit)
27.0 stiff to very stiff pink-grey silty clay with sand & gravel (Bloomington Till)
45.5 loose grey clayey sand
47.0 grey silty clay with sand & gravel (Leroy Till)
61.0 bottom of boring

Figure 5. Boring (d) near Brokaw Hospital, Normal
nearly 20 feet thick separates the Bloomington till from the overlying Normal till. In Figure 5, about 8 feet of silt and organic material is shown to have developed in a swampy depressional area which has the same stratigraphic relationship as the glacial lacustrine deposit in Boring (c) and about a mile distant.

While the front of the Normal moraine is not associated with the broad well-developed outwash plains related to the fronts of other morainic ridges of the Woodfordian Substage; notably the Bloomington, Leroy, and Shelbyville moraines, the Bloomington-Normal area is not without outwash deposits. Melt water from the receding Normal glacier breached its frontal moraine and created a torrent in what is now known as Sugar Creek. Boring (f), Figure 7, was made in the valley of Sugar Creek on the southwest side of Bloomington, approximately five miles from the front of the Normal Moraine. The log indicates that 10 feet of gravel was deposited by the torrent before flow receded and 10 feet of sand was deposited. A slack water deposit of fine sand and silt cap the sand strata. Gravel pits in the vicinity of this boring indicate that the sand and gravel deposits in some areas are much thicker than the 20 feet shown on the log.

Boring (e), Figure 6, is located on the southern edge of Bloomington near the intersection of U.S. 150 and U.S. 66. The boring was made on a site about 2 miles in front of the Normal moraine. The important characteristics of this boring are the 6 foot layer of loessial soils overlying the Bloomington till and the absence of outwash.
842.4  surface
841.2  black topsoil
very stiff yellow to
yellow-brown silty clay
(Richland Loess)
36.4  hard tan silty clay
with sand & gravel
(weathered Bloomington Till)
829.9

very stiff pinkish grey
silty clay with sand and
gravel (Bloomington Till)
800.9

bottom of boring

Figure 6. Boring (e) Euclid Street at the Nickel Plate R.R.,
Bloomington
Figure 7. Boring (f) near U.S. 150 and U.S. 66, Bloomington
ENGINEERING PROPERTIES OF BLOOMINGTON-NORMAL SUBSOILS

Glacial Tills

Among the most significant properties of a glacial till are the unconfined compressive strength, the natural moisture content, the Atterberg limits, the grain size distribution, and its consolidation characteristics. The different tills that were laid down by successive glacial stages in a particular area cannot always be differentiated. However, the Bloomington till is easily distinguished from the other dark gray tills of the Woodfordian substage by its pinkish gray color (6). A substantial portion of the cities of Bloomington-Normal are situated on the Normal moraine, which overlies the Bloomington till and the ease of visual identification of these tills make significant differences in their engineering properties very important.

Unconfined Compressive Strength and Water Content

A study of Figures 2 to 7 and 8 to 17 shows that the results of compression tests and water content determinations from individual borings can be quite erratic. Most of the unconfined compression results presented on the logs are resulted from tests performed in the field with portable testing equipment and from samples taken in 2 inch O. D. Shelby tubes.

The water content varies much less than the unconfined compressive strength of the tills. Natural water contents usually fall in the
Figure 8. Boring between Fell Hall and McCormic Gym, ISU, Normal

<table>
<thead>
<tr>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Surface</td>
</tr>
<tr>
<td>5.0</td>
<td>Brown silty clay (Richland Loess)</td>
</tr>
<tr>
<td>12.0</td>
<td>Very stiff to hard tan silty clay with pebbles (weathered Normal Till)</td>
</tr>
<tr>
<td></td>
<td>Stiff to very stiff grey silty clay with gravel (Normal Till)</td>
</tr>
<tr>
<td>25.5</td>
<td>Bottom of boring</td>
</tr>
</tbody>
</table>

Figure 9. Boring near West Campus Residence Complex, ISU, Normal
Figure 10. Boring near School Street at Water Street, Normal
depth

0.0  surface
3.0  fill
5.0  topsoil
9.0  very stiff to firm tan to brown silty clay (loessial)
     stiff tan silty clay with sand & gravel
     (weathered Normal Till)
16.5  hard grey silty clay with sand & gravel
         (Normal Till)
29.0  medium dense sand & gravel
31.0
46.0  bottom of boring

Figure 11. Boring near Water and School Streets, Normal
Figure 12. Boring near City Route 66 at Ill. Soldiers & Sailors Home, Normal
Figure 13. Boring between Cook and Fell Halls, ISU, Normal
Figure 14. Boring near Bloomington High School, Bloomington

Figure 15. Boring near U.S. 150 and U.S. 66, Bloomington
Figure 16. Boring near Walnut and Hinshaw Streets, Bloomington

Figure 17. Boring at U.S. 150 and U.S. 66, Bloomington
range from 12 to 14 percent. The compressive strengths range from less than 1 tsf to over 10 tsf.

The logs presented in Figures 2, 5, 10, and 11 indicate that the Bloomington till is softer than the overlying Normal till. But a comparison of the strength of the Bloomington till in Figures 14 through 17 with the strength of the Normal till in Figures 8 through 10 points out that both of these materials can have consistencies ranging from very stiff to hard.

Atterberg Limits

The relationship between the liquid limit and the plasticity index of the subsoils of the Bloomington-Normal areas is shown on Figure 18, a plasticity chart (3). The values of liquid limit and plasticity index of the Bloomington till and the Normal till plot above the A-line and in a section of the chart noted for nearly cohesionless soils composed of inorganic clays and organic silts and clays of low plasticity. A good correlation exists between the liquid limit and plasticity index of these tills and a statistical relationship, \( PI = 0.7043 \, LL - 7.85 \), was developed by Peck (13). This relationship is also plotted on the plasticity chart.

The average liquid limit for both the Bloomington and Normal tills is slightly over 20. The average plasticity index of the Bloomington till samples was 6.8 while that of the normal till samples was 6.3. This difference of 0.5 is not considered to be of any
significance. Thus, the two tills may be considered to have the same liquid and plastic limits.

Grain Size and Mineralogy

Properties such as liquid limit, plasticity index, and activity which are compiled in Table 3 reflect a large percentage of silt and a small percentage of low energy clays in the Bloomington and Normal tills. Grain-size distribution curves for these tills are shown in Figures 19 and 20. Approximately 50 percent of these materials are composed of silt with less than 20 percent clay size, and the remainder consisting of sand and fine gravels.

The mineralogy of clay fraction is predominately illite with minor amounts of chlorite and frequently a trace of montmorillonite (24). Small increases in the amount of expansive clay minerals can be expected in the end moraine areas of till sheets. This increase is due to the incorporation of older till materials, loess, and accretion gley into the leading edge of the advancing glacier.

Consolidation Characteristics

Excessive settlements are normally not associated with glacial tills in the Bloomington-Normal area. Due to the great depth to bedrock in the area, heavy structures must be supported by the glacial tills. Thus, settlement forecasts are necessary.
A series of consolidation tests on representative samples is considered to be the most accurate method for determining the average values of the compression index. For this purpose two special borings were made on sites where previous subsurface investigations had been conducted. Continuous samples of the Bloomington and Normal tills were taken with 3 inch O. D. Shelby tubes. The borings were advanced by means of a continuous flight auger and the tubes were pressed into the soil by the hydraulic system of the drilling rig. The Shelby tubes were carefully sealed and transported to the laboratory for extrusion and testing.

At the laboratory, the seals on the tubes were removed and five pocket penetrometer readings were taken on the sample at the bottom of the tube; then a water content sample was removed and the tube resealed. Samples for consolidation testing were obtained by cutting the bottom six inches of each tube and extruding the soil from this section in the same direction as it entered. The trimming of the soil into the consolidation ring was carried out in a moist room to eliminate evaporation. Pebbles encountered at the surface of the sample were removed and the resulting void carefully filled with trimmings from the sample. If the void created by the removal of the stone was deemed too large, the sample was trimmed further until this area had passed through the ring and was discarded.

The consolidation tests were performed on a high capacity lever type consolidation machine using fixed ring consolidometers with a diameter of 2.5 inches and a specimen height of 1.0 inch. All samples were seated overnight with a small seating load and the samples did not
<table>
<thead>
<tr>
<th>Depth in feet</th>
<th>Density psf</th>
<th>Moisture Content (percent)</th>
<th>Liquid Limit (percent)</th>
<th>Plastic Limit (percent)</th>
<th>Colloidal Activity</th>
<th>Soil Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-17.5</td>
<td>141.0</td>
<td>13.4</td>
<td>21.6</td>
<td>16.6</td>
<td>0.33</td>
<td>NORMAL TILL</td>
</tr>
<tr>
<td>17.5-20</td>
<td>147.1</td>
<td>11.8</td>
<td>17.4</td>
<td>12.8</td>
<td>0.31</td>
<td>Hard, mottled tan and brown, silty clay with pebbles, jointing and ferromagesian inclusions.</td>
</tr>
<tr>
<td>20-22.5</td>
<td>141.4</td>
<td>15.0</td>
<td>17.9</td>
<td>13.9</td>
<td>0.33</td>
<td>Very stiff to hard, dark grey silty clay with sand and gravel (calcareous), and occasional pieces of coal and wood.</td>
</tr>
<tr>
<td>22.5-25</td>
<td>144.2</td>
<td>14.1</td>
<td>17.4</td>
<td>11.4</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>25-27.5</td>
<td>143.0</td>
<td>14.2</td>
<td>20.8</td>
<td>13.8</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>27.5-30</td>
<td>140.0</td>
<td>14.4</td>
<td>21.5</td>
<td>13.8</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>12.5-15</td>
<td>142.5</td>
<td>14.3</td>
<td>20.0</td>
<td>13.0</td>
<td>0.41</td>
<td>BLOOMINGTON TILL</td>
</tr>
<tr>
<td>15-17.5</td>
<td>142.8</td>
<td>12.9</td>
<td>19.6</td>
<td>12.6</td>
<td>0.49</td>
<td>Very stiff, pinkish-grey silty clay with sand and gravel (calcareous).</td>
</tr>
<tr>
<td>17.5-20</td>
<td>146.0</td>
<td>11.4</td>
<td>19.8</td>
<td>12.9</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>20-22.5</td>
<td>144.5</td>
<td>12.8</td>
<td>19.8</td>
<td>11.6</td>
<td>0.45</td>
<td></td>
</tr>
</tbody>
</table>
Figure 18. Plasticity Chart
Figure 20. Grain Size Distribution Curve, Normal Till
swell even though the seating load was considerably less than the present over burden pressure and the reservoir of the consolidation cell was flooded.

Accurate estimations of deformations were desired so machine deflections were determined prior to any consolidation testing, and owing to uncertainties in determining machine deflections, filter paper drains were not used.

The results of the consolidation tests in the form of void ratio versus the log of pressure are presented in Figures 20 through 29. Pressures equivalent to 30 tons per square foot were used in most instances in an attempt to further define the straight line portion of the virgin laboratory consolidation curve.

Preconsolidation loads of the samples were determined by the Casagrande construction (2) and the field consolidation curve was constructed by a method similar to that suggested by Schmertmann (17); these constructions are shown on the void ratio log pressure curves. The straight line portion of the laboratory consolidation curve was extended to a value of $0.4e_0$ (20). Then a line parallel to the section of the final rebound curve between $p_o$ and $p_c$ was drawn through the point $e_o$, $p_o$ until it intersected with the vertical $p_c$ line. The field curve is drawn from the intersection of the laboratory consolidation curve and $0.4e_o$ the intersection of the line from $e_o$, $p_o$ to $p_c$. The curved portion of the field curve is determined by the recompression portion of a loop run from a pressure considered to be in excess of the preconsolidation load. The portion of the recompression curve from its intersection with the straight line portion of the field
curve to where it is very nearly horizontal is moved upwards and fit from $e_o', p_o'$ to the field consolidation curve.

An examination of the void ratio versus log pressure curves shown in Figures 21 through 30 discloses a significant difference between the slopes of the initial portion of the laboratory consolidation curves and the slopes of the recompression portion of the hysteresis loops. Some change in slope is to be expected, but this large change may be attributable to two factors:

1. The difference in time between the effective reloading and recompression of the initial portion of the laboratory curve and that of the hysteresis loop; and,

2. The reflection of sample disturbance in the initial part of the laboratory curve.

Because the clay content and its activity is low, the change in slope caused by the time difference is considered to be small. All indications are that most of the samples were disturbed even though the greatest care was taken in both sampling and trimming operations.

Table 4 contains the values of compression index, preconsolidation load determined from the consolidation curves, initial void ratios, shear strength results, "thin-cake" unconfined compressive strength results, liquidity indexes and c/p ratios, all of which have a bearing on the consolidation characteristics of a soil. Values of $C_c$ ranging from 0.0334 to 0.0680 are considered low for a preconsolidated glacial till. Several factors suggest that the values of $C_c$ and possibly the preconsolidation loads should be higher; they are as follows:
### TABLE 4. LABORATORY TEST RESULTS

<table>
<thead>
<tr>
<th>Depth in Feet</th>
<th>Unconfined Compressive Strength (tsf)</th>
<th>Pocket Penetrometer Strength (tsf)</th>
<th>&quot;Thin-Cake&quot; Stress (tsf)</th>
<th>Preconsolidation Stress (tsf)</th>
<th>Cc</th>
<th>e_o</th>
<th>C/p</th>
<th>Liquidity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-17.5</td>
<td>-</td>
<td>4.5+</td>
<td>8.5</td>
<td>4.5</td>
<td>0.045</td>
<td>0.415</td>
<td>-</td>
<td>-0.015</td>
</tr>
<tr>
<td>17.5-20</td>
<td>8.0</td>
<td>4.5+</td>
<td>11.2</td>
<td>5.0</td>
<td>0.045</td>
<td>0.415</td>
<td>3.18</td>
<td>-0.058</td>
</tr>
<tr>
<td>20-22.5</td>
<td>1.85*</td>
<td>3.25</td>
<td>4.25</td>
<td>5.0</td>
<td>0.064</td>
<td>0.412</td>
<td>0.66</td>
<td>0.063</td>
</tr>
<tr>
<td>22.5-25</td>
<td>2.73</td>
<td>3.1</td>
<td>4.0</td>
<td>2.5</td>
<td>0.050</td>
<td>0.403</td>
<td>0.96</td>
<td>0.155</td>
</tr>
<tr>
<td>25-27.5</td>
<td>3.82</td>
<td>4.0</td>
<td>4.85</td>
<td>2.8</td>
<td>0.390</td>
<td>0.402</td>
<td>1.09</td>
<td>0.192</td>
</tr>
<tr>
<td>27.5-30</td>
<td>-</td>
<td>4.25</td>
<td>4.75</td>
<td>5.0</td>
<td>0.068</td>
<td>0.392</td>
<td>-</td>
<td>0.027</td>
</tr>
</tbody>
</table>

**NORMAL TILL**

**BLOOMINGTON TILL**

12.5-15  -  4.5+  4.0  7.0  0.082  0.394  -  0.065
15-17.5  -  2.75  3.2  2.9  0.033  0.377  -  0.031
17.5-20  3.25  4.0  4.4  4.0  0.041  0.327  -  -0.077
20-22.5  3.18  2.7  3.25  3.5  0.046  0.348  1.11  0.061

*Failed along silt seam.*
FIGURE 21 Consolidation Curve, Normal Till, depth 17 ft.
FIGURE 22. Consolidation Curve, Normal Till, depth 20 ft.
Figure 23. Consolidation Curve, Normal Till, depth 22 ft.
Figure 24. Consolidation Curve, Normal Till, depth 23 ft.
Figure 25. Consolidation Curve, Normal Till, depth 27 ft.
Figure 26. Consolidation Curve, Normal Till, depth 30 ft.
Figure 27. Consolidation Curve, Bloomington Till, depth 15 ft.
Figure 28. Consolidation Curve, Bloomington Till, depth 17 ft.
Figure 29. Consolidation Curve, Bloomington Till, depth 20 ft.
Figure 30. Consolidation Curve, Bloomington Till, depth 22 ft.
1. extremely low initial void ratios,
2. low and even negative values of liquidity index,
3. high c/p ratios,
4. "thin-cake" unconfined compression test results, and
5. the geologic history of the area.

While the other indicators of preconsolidation load and compressibility index can be found in the literature (4, 18, 19, 20) the "thin-cake" unconfined compression tests warrant some explanation. The use of the "thin-cake" unconfined compression stress to estimate the preconsolidation load was suggested by Koechlein (9) in his study of the compressibility of preconsolidated till. The "thin-cake" stress was found to be slightly less than the preconsolidation stress determined by consolidation curves, but the correlation was very good at lower preconsolidation loads.

The "thin-cake" unconfined compression test is performed in a manner similar to the standard strain controlled unconfined compression test (1). The "thin-cake" specimen consists of a 1 inch thick "cake" of soil extruded from a 3 inch O. D. Shelby tube. The ends of the specimen are carefully trimmed and is placed in the compression machine. A top platten the same diameter as the specimen is used to transmit the load to the soil. The specimen was strained at a rate of 0.049 inches per minute until approximately 30 percent unit strain had been reached. The results of the "thin-cake" unconfined compression tests are presented in the form of a stress versus strain curve as shown in Figure 30.
In Figure 31, the straight line portions of the stress strain curve are extended until they intersect. The y coordinate of the point of intersection is the "thin-cake" preconsolidation stress.

The samples which appear to be the least disturbed have the highest preconsolidation stress and exhibit the best correlation between $C_c$, the slope of the straight line portion of the field curve, and the compression index approximated from the equation developed by Terzaghi and Peck (20), $C_c = 0.009$ (LL - 10%). This evidence in
addition to data presented in Table 4 indicates sample disturbance. Rutledge (16) summarizes the general effects of sample disturbance on the laboratory consolidation test as follows:

"(1) It decreases the void ratio at which the soil will carry any given vertical stresses,

"(2) It obscures the previous stress history of the soil and its preconsolidation load; and

"(3) The straight-line portion of the remolded compression curve is displaced downward from the laboratory virgin compression curve, and its slope, or rate of decrease in void ratio with increasing stress is less.

"These results show definitely the effects of sample disturbance over the range from the best undisturbed samples which has been obtained for laboratory testing to completely remolded. Any intermediate degree of disturbance must result in a compression curve which falls between the curves that would be obtained for the same soil in these two known limiting conditions."

It is very difficult to differentiate between sample disturbance caused by sampling and that caused by trimming operations. As stated previously the samples for consolidation testing were taken in 3 inch O. D. Shelby tubes which is normally considered to be the best method of obtaining "undisturbed" samples at a reasonable cost.

Van Zelst (22) in studying a lacustrine clay found that disturbance associated with trimming the specimen's circumference was not extremely large. However, it is conceivable that a much greater degree of disturbance could be inflicted on a sample containing stones than on a sample of lacustrine clay.

Murdock (12) suggests the use of thin walled tubes having the same inside diameter as the consolidation ring as a possible means of eliminating the disturbance associated with the circumferential
tripping of a soil containing stones. This method has some merit as shown in Figure 31 by the relationship between initial void ratio for two different methods for preparing consolidation specimens. The methods of preparing consolidation test specimens are:

1. Trimming a specimen taken in a 3 inch O. D. Shelby tube into a 2.5 inch diameter consolidation ring, and
2. Using a sampling tube having the same diameter as the consolidation ring.

The data from consolidation tests performed on samples of Bloomington and Normal tills utilizing method number 2 was made available by Robert K. Morse (11).

The higher compression indices obtained by method 2 result in values of compression ratio which plot the farthest to the right on the abscissa. The relationship between initial void ratio and compression ratio for the Bloomington-Normal tills is quite different from that found by Peck and Reed for Chicago clays (15). However a nearly horizontal line is to be expected for materials exhibiting very little range in initial void ratio.

Loessial Depressional and Outwash Materials

A conception of the engineering properties of the subsoils composed of loessial, depressional, and outwash materials can be gained by studying the boring logs, Figures 3 to 18, and the plasticity chart, Figure 19.
The loessial subsoils can, in places, be an adequate foundation material for lightly loaded structures. The engineering properties of loess are dependent to a great degree on the natural moisture content (14). Local variations in water content are related to differences in shear strength and compression characteristics. Pockets of soft material at the contact of the loess mantle with the underlying material make uneven subgrade support and complex construction problems. The thickness of the loess mantle is not great enough to cause great engineering problems since a more competent foundation material in the form of glacial till can easily be reached by extending the footings or adding a basement to the structure.

The soils developed in swampy depressions would be expected to be more plastic if it had not been for the deposition translocation loess and wind blown silt in these areas. The water content of the material is high, often twice that of the till. Shear strength of the organic depressional soils is related to the degree these areas were drained and whether or not they were compressed by the weight of an ice sheet. Because of the localized extent of this type of soil, it is often missed in a foundation exploration program and often gives rise to an unexpected construction problem.

Outwash deposits in the Bloomington-Normal vary from loose to very dense as measured by the standard penetration test (20). As with the loessial and depressional soils, the thickness of this material is not great enough to prohibit the transfer of loads to the underlying glacial till.
ENGINEERING SIGNIFICANCE OF BLOOMINGTON-NORMAL SUBSOILS

Other than the fact that the Bloomington till being softer than the overlying Normal till in some locations, significant differences in their engineering properties have not been found. It should be realized that while end moraines can be prominent topographic features, they do not always mark the farthest advance of an ice sheet. Therefore, some of the material in front of the Normal end moraine, identified as Bloomington till may in actuality be pinkish Bloomington drift incorporated in the Normal till.

The primary differences in the engineering properties are not delineated by identifying the till unit but by its mode of deposition by the glacier. The effect of an overlying ice sheet compressing the soil is demonstrated by fact that the ground moraine or basal till is stronger and generally has a lower water content than the super basal till and push moraine. It is very difficult to distinguish basal till from superglacial till by superficial examination because they are composed of the same type of soil particles but they vary widely in significant engineering properties. Superglacial till mistaken for basal till is frequently the cause of building settlements in the Bloomington area.

Where desiccation has penetrated deep enough to permit oxidation the gray till assumes a tan to brown color. This weathering has little or no effect on the engineering properties of the tills. Topographic location does have an effect on the engineering properties of the tills in that the tills on high ground have a higher unconfined compressive strength than tills in lower areas indicating drainage in post-glacial times.
A problem that is inherent in foundation engineering is the variation in engineering properties and the location of the boundaries of the soil units involved. When dealing with deposits of the glacial age, this problem is magnified due to the modes of deposition and subsequent alteration of the various materials involved.

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VITA

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In September 1961 he enrolled in the Missouri School of Mines and Metallurgy and received his Bachelor of Science in Civil Engineering in May 1966. He was admitted to graduate school and began his graduate work in September 1966.

Mr. Abbott is married to the former Christine Mary Hodge of Waukegan, Illinois.
APPENDIX I - REFERENCES


