Use of Soil Preload to Mitigate Settlement in CVVC

Michael Talbot, P.E.
O’Reilly, Talbot & Okun Associates, Inc.
Springfield, Massachusetts
Connecticut Valley Varved Clay

- **Advantages:**
  - Sculpting little clay-people

- **Disadvantages:**
  - Large settlement under building loads
Case Study Sites

1. Easthampton High School
   ◦ Easthampton, Massachusetts

2. Five College Book Depository
   ◦ Hatfield, Massachusetts
Location of Sites within Lake Hitchcock

1. Easthampton High School
   - Easthampton, Massachusetts

2. Five College Book Depository
   - Hatfield, Massachusetts

Image courtesy of Ladd
Geologic Profile

Image courtesy of Ladd
Easthampton High School

- New school building constructed adjacent to previous high school
- 54,000 square foot, slab on grade structure
- Between one and three stories high
- Maximum column loads (compression) – 220 kips
- Maximum column loads (uplift) – 45 kips
- Wall loads – 3 to 5 kips/LF
- Up to six feet of fill required to establish new building slab
Map Showing Distribution and Thickness of CVVC
Published Map on Distribution and Thickness of CVVC

Easthampton High School
Subsurface Profile at Site

Summary of Boring Logs

<table>
<thead>
<tr>
<th>Boring Identification</th>
<th>Bottom of Non-Engineered Fill</th>
<th>Top of Varved Clay</th>
<th>Top of Varved Fine Sand and Silt</th>
<th>Glacial Till or Bedrock</th>
</tr>
</thead>
<tbody>
<tr>
<td>EH-1</td>
<td>5</td>
<td>22</td>
<td>&gt;112</td>
<td>NE</td>
</tr>
<tr>
<td>EH-2</td>
<td>0.5</td>
<td>30</td>
<td>&gt;92</td>
<td>NE</td>
</tr>
<tr>
<td>EH-101</td>
<td>10</td>
<td>15</td>
<td>&gt;32</td>
<td>NE</td>
</tr>
<tr>
<td>EH-102</td>
<td>10</td>
<td>16</td>
<td>&gt;32</td>
<td>NE</td>
</tr>
<tr>
<td>EH-103</td>
<td>10</td>
<td>20</td>
<td>&gt;32</td>
<td>NE</td>
</tr>
<tr>
<td>EH-104</td>
<td>10</td>
<td>15</td>
<td>60</td>
<td>113</td>
</tr>
<tr>
<td>EH-105</td>
<td>10</td>
<td>15</td>
<td>35</td>
<td>84</td>
</tr>
<tr>
<td>EH-106</td>
<td>&gt;12</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>EH-107</td>
<td>0.5</td>
<td>26</td>
<td>&gt;32</td>
<td>NE</td>
</tr>
<tr>
<td>EH-108</td>
<td>0.5</td>
<td>25</td>
<td>&gt;32</td>
<td>NE</td>
</tr>
<tr>
<td>EH-109</td>
<td>0.5</td>
<td>25</td>
<td>&gt;32</td>
<td>NE</td>
</tr>
<tr>
<td>EH-110</td>
<td>20</td>
<td>25</td>
<td>&gt;32</td>
<td>NE</td>
</tr>
<tr>
<td>EH-111</td>
<td>16</td>
<td>16</td>
<td>&gt;32</td>
<td>NE</td>
</tr>
<tr>
<td>EH-112</td>
<td>20</td>
<td>30</td>
<td>&gt;32</td>
<td>NE</td>
</tr>
<tr>
<td>EH-113</td>
<td>21</td>
<td>&gt;32</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>EH-114</td>
<td>&gt;12</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
</tr>
</tbody>
</table>
Properties of CVVC

- Moisture Content – between 25% and 70%
  - Average for 8 samples – 38%
- Void Ratio – 1.35 to 1.74
- Over Consolidation Ratio (OCR) – 1.3 to 2.0
- Compression Ratio (CR) – 0.21 to 0.26
- Recompression Ratio (RR) – 0.04 to 0.05
- Field Measurements:
  - N-Values – WOH to 9
  - Field Vane Shear – 100 to 500 psf
  - Field Pocket Penetrometer – 200 to 500 psf
Geotechnical Considerations

- Near-surface organic soils and non-engineered fill
- Up to 25 kips of uplift loads at selected columns
- Consolidation of CVVC – up to three inches of settlement observed in previous school building

<table>
<thead>
<tr>
<th>Building Segment</th>
<th>Total Settlement Without Soil Improvement (in)</th>
<th>Post-Construction Settlement With Soil Improvement (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Differential</td>
</tr>
<tr>
<td>One-Story Gym</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Two-Story Portion</td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Three-Story Portion</td>
<td>6.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Solution

• Aggregate Piers to improve near-surface soils and support slab
  • Also allow for the use of a 6,000 psf design bearing capacity

• Grouted Aggregate Piers to remove uplift loads from structure

• Soil preload to mitigate post construction settlement

• Wick drains to expedite settlement
Easthampton High School

- Five Feet of Preload Fill
- Two Feet of Preload Fill
- Three Feet of Preload Fill
Construction

Aggregate Piers
- Contractor – Helical Drilling
- 625 20-inch diameter compression piers, 15 feet deep (not grouted)
- 327 grouted uplift piers, 30 feet deep
- Approximate one-month construction period (two rigs)

Soil Preload
- Earthwork Contractor – T&M Equipment Corp.
- Composed of sand and gravel, later used beneath slabs and pavements
- Three fill heights: 5 feet, 3 feet and 2 feet
- Settlement measured via 12 settlement platforms

Wick Drains
- Contractor – American Drainage Systems
- 1,804 wick drains (81,000 LF)
- Spacing 6.5 feet OC, 45 feet deep
- Approximate two-week construction period
Installation Sequence of Soil Reinforcement and Preload

- Strip subgrade of vegetation, topsoil, and other unsuitable materials.
- Install settlement platforms and monitoring points.
- Install preload fill to 14” below concrete slab elevation or bottom of footing elevation at grouted stone aggregate column locations. Compact fill to 95% of maximum dry density, as determined by ASTM D-1557.
- Install stone aggregate columns per specification SECTION 023100. Terminate columns at ground surface as defined in sequence #3 (12” below concrete slab elevation or bottom of footing elevation at concrete filled stone aggregate column locations).
- Place preload fill to density and thickness shown on drawings.
- Extend preload to at least 15 feet beyond outside of building, except as shown.
- Monitor settlement per specification SECTION 312100.
- Remove preload fill. Do not remove until criteria in SECTION 312100 have been met, as approved by geotechnical engineer. Compact any remaining fill to 95% of maximum dry density, as determined by ASTM D-1557.
Settlement Monitoring

12 Settlement Monitoring Platforms used to evaluate preload settlement

**Easthampton High School - Preload**

Platform No. 9 Settlement

- **Placement Complete**
- **Preload Complete**

Platform No. 12 Settlement

- **Placement Complete**
- **Preload Complete**
Five College Book Depository (Hatfield, Massachusetts)

- Property formerly used as farmland
- 60,000 square foot, slab on grade structure
  - 52,000 square foot, 36’ high book shelving module
  - 8,000 single story office
- Maximum column loads – 75 kips
- Perimeter wall loads – 5 kips/LF
- Floor loads (books) – 1,000 psf
- Up to three feet of fill required to establish new building slab
Published Map on Distribution and Thickness of CVVC
Five College Book Depository (Hatfield, Massachusetts)
Subsurface Profile at Site
Laboratory Properties of CVVC

- Moisture Content – between 36% and 69%
  - Average for 22 samples – 52%
- Void Ratio – 1.76 to 1.89
- Over Consolidation Ratio (OCR) – 2.3 to 2.4
- Compression Ratio (CR) – 0.21 to 0.26
- Recompression Ratio (RR) – 0.03 to 0.033
- Atterberg Limits:
  - LL = 54
  - PL = 30
  - PI = 24
- Field Measurements:
  - N-Values – WOH to 5
  - Field Vane Shear – 40 to 400 psf
  - Field Pocket Penetrometer – 275 to 440 psf
Geotechnical Considerations

- Significant post-construction load due to 1,000 psf live load (books)
- Time rate of settlement

Comparison of Settlement Estimates With and Without Soil Improvement

<table>
<thead>
<tr>
<th>Settlement Due to Dead Loads (Fill and Building)</th>
<th>Total Settlement Without Soil Improvement (in)</th>
<th>Post-Construction Settlement With Soil Improvement (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Differential</td>
<td>Total</td>
</tr>
<tr>
<td>1.75</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Settlement Due to Live Loads (Books)</th>
<th>Total</th>
<th>Differential</th>
<th>Total</th>
<th>Differential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2.25</td>
<td>1.75</td>
<td>1.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Solution

• Preload to mitigate post construction settlement

• Wick drains to expedite settlement

• Monitor settlement following construction and during initial placement of books
Construction

Preload
- Composed of sand and gravel
- Approximately 11 feet of fill placed
  - 3 feet compacted, and left in place to form building slab
  - Additional 2.5 feet (loose) placed in office portion
  - Additional 8 feet (loose) placed in book shelving module
- Settlement measured via 6 settlement platforms

Wick Drains
- Contractor – American Drainage Systems
- 1,779 wick drains (129,500 LF)
- Spacing 6.0 feet OC, 70 feet deep
- Approximate two-week construction period
Settlement Monitoring

Six Settlement Monitoring Platforms used to evaluate preload settlement

CHANGES IN ELEVATION OF SMP-5

CHANGES IN ELEVATION OF SMP-6
Learning Questions

• Why should you preload soils?

• What information should you use:
  • To determine soil properties?
  • To estimate settlement?

• Are Wick Drains worth it?
Why Preload?

• Settlement sensitive structures
  • Easthampton High School – 3 different building heights/loading conditions
  • Book Depository – Large live load relative to dead load

• Properties of CVVC near edges of post-glacial Lake Hitchcock vary vertically and laterally
  • Settlement platform data demonstrate the variability

• Reduce post construction differential settlement
  • Preload creates a more uniform site condition

• Preload soils can be used elsewhere on site
  • Limits premium cost for material purchase and delivery
What Information Should You Use?

• Published clay thickness map (Langer) to estimate CVVC thickness prior to the start of drilling
• Site soil borings and laboratory consolidation testing
• Laboratory moisture content data and field measurements to supplement consolidation data and refine soil profiles
• Published data (Ladd, Lutenegger & DeGroot) are excellent resources
Are Wick Drains Worth It?

• Quick installation
  • Wick drain installation, preload placement, and preload settlement period can be completed within 90 days (typical)

• Wick drains work
  • Most settlement typically occurs within 60 days of preload placement when wick drains installed

• Cost
  • Cost is modest compared to the cost savings gained by expediting the construction schedule
Wick Drain Installation
Thank You!

Photo courtesy of Union College