DRAINAGE OF ARTIFICIAL TURF SYSTEMS

Lessons Learned

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9 December 2019
Learning Objectives

Through this session, the participant will gain an understanding of:

1. The complicated behavior of drainage through artificial turf field systems.
2. Common drainage performance problems of field system components.
3. Drainage features that are critical to successful field performance.
4. Best practices for performing drainage investigations.
Artificial Turf Field System Components

- Synthetic Turf Field System Components:
  - Synthetic Turf with Sand and Rubber Infill
  - 8" Drainage Layer Consisting of Finish Stone Over 7" of Base Stone
  - Geotextile Fabric
  - Compacted Subgrade
  - Flat Panel Perforated Underdrain Pipe
  - Trench Drain at Inside Edge of Track

- Track Components:
  - 3" Synthetic Track Surface
  - 1.5" Asphalt Finish Course
  - 1.5" Asphalt Binder Course
  - 32" Min Thickness Compacted Aggregate Base
  - Compacted Subgrade

- Other Components:
  - Grade Area Radially Between Synthetic Turf Curb and Trench Drain
  - Slope at 4.5% (Typ)
  - Connection for Field Underdrain System
  - 14" Width at 0.6" Thick Flat Panel Underdrain Type
  - Premanufactured Perimeter Trench Drain at Major Track Edge

- Additional Details:
  - Multi-Purpose Applied Synthetic Turf Sport Field
  - Ridge Line

ASBA 2019

Technical Meeting & Trade Show
Orlando, Florida | Rosen Shingle Creek
Common Drainage Performance Problems
Field Grading Design or Construction

• Localized low spots and ponding.
Field Grading Design or Construction

• Localized low spots and ponding.
Improper Field Grading Design or Construction

- Field sloped all to one end – reduction in field drainage area.
Impact of Field Grading Design or Construction

- Field sloped all to one end – reduction in field drainage area.
Permeability / Infiltration

• Infiltration and permeability are often confused.
• **Infiltration, I** – measure of the flow rate through the surface (in./hr).
• **Permeability, k** – measure of the flow rate based on a given gradient (in./hr).

Flow rate (Q) through a saturated porous media:

\[
Q = k_{\text{sat}} \times i \times A
\]

where:

\( k_{\text{sat}} \) = saturated permeability
\( i \) = hydraulic gradient (change in total head of water (\( \Delta H \)) over flow length (L))
\( A \) = drainage area
Permeability / Infiltration

• Infiltration = Permeability for saturated conditions ($k_{sat}$) with hydraulic gradient (i) equal to 1.

• Infiltration related to several variables, including soil type, depth of ponded water, permeability of materials, degree of saturation, etc.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>USCS Classification</th>
<th>$k_{sat}$ (in./hr)</th>
<th>Drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean gravel</td>
<td>GW, GP</td>
<td>$10^5$ – $10^3$</td>
<td>Excellent</td>
</tr>
<tr>
<td>Clean sand and sand mixtures</td>
<td>GW, GP, SW, SP, SM</td>
<td>$10^3$ – 1.0</td>
<td>Good</td>
</tr>
<tr>
<td>Very fine sands and sand-silt mixtures</td>
<td>GM, SM, ML, GC, CL</td>
<td>1.0 – $10^{-4}$</td>
<td>Poor</td>
</tr>
<tr>
<td>Clays</td>
<td>CL, CH</td>
<td>$10^{-4}$ – $10^{-6}$</td>
<td>Practically Impervious</td>
</tr>
</tbody>
</table>
Permeability / Infiltration

• STC guidelines provide the following minimum permeability requirements for turf system components:
  • Turf and backing and/or infill: 10 in./hr (ASTM F1551 or EN 12616)
  • Base and finish stone: 14 in./hr (ASTM F1551 or ASTM D2434)

• STC guidelines do not indicate these permeability requirements are for ‘saturated’ conditions ($k_{sat}$).
Permeability / Infiltration

• Important to understand the composite saturated permeability of the turf field system (turf and backing, infill, cushion, finish and base stone).

• Cedergren (1989) provides following expression for composite saturated permeability ($k_v$) for an entire section:

$$k_v = \frac{H}{\left[\frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_n}{k_n}\right]}$$

where:

$H$ = total thickness of field section (in.)

$h_n$ = thickness of individual layer (in.)

$k_n$ = saturated permeability of individual layer (in./hr)
Permeability / Infiltration

**Examples:** Impacts of changes in saturated permeability of an individual layer on the ability of the entire section to drain.

2 in. of infilled turf backing overlying 2 in. finish stone and 6 in. base stone (no cushion or other geotextiles in cross section).

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness, in.</th>
<th>$K_{sat}$, in./hr</th>
<th>$K_v$, in./hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turf &amp; Infill</td>
<td>2</td>
<td>40</td>
<td>16.1</td>
</tr>
<tr>
<td>Finish Stone</td>
<td>2</td>
<td>14</td>
<td>44.9</td>
</tr>
<tr>
<td>Base Stone</td>
<td>6</td>
<td>14</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Example 1</th>
<th>Example 2</th>
<th>Example 3</th>
<th>Example 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{sat}$, in./hr</td>
<td>40</td>
<td>14</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>$K_v$, in./hr</td>
<td>14</td>
<td>200</td>
<td>200</td>
<td>200</td>
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</tbody>
</table>

13
Gradation of Base and Finish Stone

• Gradation tests from stockpiled material (at the quarry) prior to installation are commonly used to qualify base and finish stone materials for turf fields.

• However, most project specifications do not identify whether the gradation requirements are intended to be “as-purchased from the quarry” or “as-installed”.

• If the field experiences drainage problems after construction, failure to provide a clear specification often results in a dispute between parties on the suitability of the base materials.
Gradation of Base and Finish Stone

• Research by Hoover, et al. (1970) and Pintner, et al. (1987) shows the gradation of granular materials, especially the fines content (% passing No. 200 sieve), will change due to handling and compaction.

• Breakdown of larger particles into smaller particles occurs due to point-to-point contact, abrasion, and fracturing.

• Change in gradation is dependent on the following:
  • Toughness and abrasion characteristics of the rock,
  • Amount of energy and type of compaction equipment used,
  • Moisture content at the time of compaction, and
  • Original gradation.
Gradation of Base and Finish Stone

Example: Approved submittal (from quarry) vs. installed finish stone.
Gradation of Base and Finish Stone

- Change in fines content during handling and compaction is typically about 1% to 5%.
- Impact of increased fine content on saturated permeability can be significant. Care is required to understand the expected fines increase during design and its impact on the saturated permeability.

**Example:** Impact of change in fines content between approved/specified and installed materials on $k_{sat}$.

<table>
<thead>
<tr>
<th>Material</th>
<th>Sample No.</th>
<th>Increase in Fines Content, %</th>
<th>Decrease in $k_{sat}$ in./hr</th>
</tr>
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<tbody>
<tr>
<td>Base Stone</td>
<td>1</td>
<td>1.6</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.5</td>
<td>4.9</td>
</tr>
<tr>
<td>Finish Stone</td>
<td>1</td>
<td>2.1</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.7</td>
<td>25.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.5</td>
<td>19.9</td>
</tr>
</tbody>
</table>
Effects of Compaction

• The design of artificial turf fields requires that the base materials to be both stable and permeable. STC guidelines recommend the installation of the base materials to a minimum 95% standard Proctor (ASTM D698).

• Over compaction can have a significant impact on the permeability of the base and finish stone.

• STC acknowledges the challenge of achieving a minimum 95% compaction and maintaining permeability stating:

  It may not be possible to achieve 95% Proctor for base structures that must be both stable and permeable. Consequently, the compaction of the stone base must be carefully conducted, and should be terminated once sufficient stability has been attained.
Effects of Compaction

**Example:** Impact of over compaction on the saturated permeability of the base and finish stone (standard Proctor – ASTM D698).

<table>
<thead>
<tr>
<th>Material</th>
<th>Location</th>
<th>% Compaction</th>
<th>k_{sat}, in./hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Stone</td>
<td>East Side</td>
<td>95</td>
<td>35.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>West Side</td>
<td>95</td>
<td>28.3</td>
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<tr>
<td></td>
<td></td>
<td>100</td>
<td>8.6</td>
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<tr>
<td>Finish Stone</td>
<td>East Side</td>
<td>95</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>West Side</td>
<td>95</td>
<td>34</td>
</tr>
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<td></td>
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<td>100</td>
<td>11.3</td>
</tr>
</tbody>
</table>
Performance Criteria of Base Materials

• Typical performance criteria include:

• **Stability** – to prevent segregation of base and finish stones.

• **Bridging** – to ensure separation of base and finish stone (also commonly referred to as filtration criteria).

• **Permeability** – to ensure proper drainage:
  • Relative permeability of the base and finish stones.
  • Minimum saturated permeability of base and finish stones.
  • Minimum porosity of base and finish stones.

• Criteria are generally a function of the gradations of the finish and base stone.

• Care is required to ensure performance criteria are compatible with specified gradation requirements and achievable for the contractor.
Performance Criteria of Base Materials

Example: To ensure structural stability: \[ \frac{D_{60}}{D_{10}} > 5 \quad \text{and} \quad 1 < \frac{D_{30}^2}{D_{10} \times D_{60}} < 3 \]
Fragmentation must be 100%.

To ensure separation of both stones: \[ \frac{D_{65} \text{ of finishing stone}}{D_{15} \text{ of base stone}} > 2 \]

and \[ 3 < \frac{D_{50} \text{ of base stone}}{D_{50} \text{ of finishing stone}} < 6 \]

To ensure proper drainage: Permeability of base stone > 50 in/hr (3.5 \times 10^{-2} \text{ cm/sec})
Permeability of finishing stone > 10 in/hr (7.0 \times 10^{-3} \text{ cm/sec})
Porosity of both stones > 25% (When stone is saturated and compacted to 95% Proctor.)
Gradation of Base and Finish Stone

Saturated Permeability vs. Coefficient of Uniformity

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Compatibility of Turf Backing and Infill

• The movement of infill particles can clog or partially block the perforations in the turf backing due to insufficient internal stability of the turf infill and perforation sizing.

• Soil Conservation Service, Part 633 provides criteria for grain size of sand and gravel filters needed to prevent internal erosion or soil piping through holes or slots in drain piping.

• Can also be applied to perforations in the turf backing.

Compatibility of Turf Backing and Infill

- Incompatible materials can cause clogging of perforations and geotextiles within the artificial turf system, and loss of infill into the finish stone.
Unsaturated/Partially Saturated Conditions

• Current practice for the performance of artificial turf systems materials appears to assume ‘fully saturated’ flow conditions.

• Turf system materials (turf, infill, and backing, cushion, geotextiles, and base materials) rarely experience fully saturated conditions, except during long duration rainfall events.
Unsaturated/Partially Saturated Conditions

• Unsaturated/partially saturated conditions can significantly impact field performance (in particular, the permeability or permittivity of materials).
Unsaturated/Partially Saturated Conditions

• Unsaturated/partially saturated conditions can result in trapped air under the turf and the build-up of air pressure.
Use of Geotextiles

- Geotextiles are commonly used in various locations for artificial turf fields:
  - Below the turf/cushion layer (above finish stone).
  - Between base stone and native soils.
  - Around field drains using a ‘sock’ style filter fabric.
Use of Geotextiles

- Geotextiles can act as air barriers that inhibit air flow until fabric is saturated (water ponds on the surface).

- Care is required to ensure geotextiles are used only where needed and that provisions are in place to prevent clogging and air locking.
Best Practices for Performing Drainage Investigations
Document Review

- Survey of as-built field conditions.
- Weather data.
- Design documents (drawings and specifications).
- Construction records.
- Previously performed laboratory or field testing

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<tr>
<td></td>
<td>Time</td>
<td>Rainfall (in.)</td>
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<td>23</td>
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<td>11:00 p.m.</td>
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<tr>
<td>24</td>
<td>12:00 a.m.</td>
<td>0.06</td>
<td>12:00 a.m.</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Total Rainfall: 0.45, 2.19, 0.66, 2.79
Video Inspection of Field Drainage System

- Inspection of collector pipe, field drains, and storm drainage system using closed-circuit television (CCTV).
- Looking for signs of blockage, pipe distress, etc.
Test Pits

• Inspection of turf and backing, infill, cushion, finish and base stones, collector pipe, and field drains.
• Looking for as-built conditions that explain the observed ponding.
• Collect samples for laboratory testing.
Field Infiltration Testing

• Several tests available:

  • ASTM F2898 – Permeability of Synthetic Turf Sports Field Base Stone and Surface System by Non-Confined Area Flood Test Method.
  • ASTM D3385 – Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer (EN 12616).
ASTM F1551 (top hat test)

• Falling head permeability test.
• Older test historically performed for flat, carpet-style (e.g. – Astroturf) systems (no infill).
• Test commonly listed by manufacturer as basis for permeability of turf/infill.

<table>
<thead>
<tr>
<th>ASTM F1551</th>
<th>Water Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;40.0 inches/hour</td>
</tr>
</tbody>
</table>

*Performance testing was completed with above listed infill system installed.*
ASTM F1551 (top hat test)

• Test is not representative of vertical permeability of the system since most of the water in the test apparatus leaks horizontally through the infill materials; results in artificially high infiltration rates.
ASTM F2898 (overflow test)  
• Relatively new infiltration test.  
• Test involves:  
  • Filling 5 gal bucket to measure flow rate of water from source.  
  • Pre-saturating test area with 50 gals of water and marking extents of saturation.  
  • Allowing surface to “dry”.  
  • Allowing 25 gals of water to overflow bucket and marking extents of ponding.  
  • Calculating saturated vertical infiltration rate.  
• Test considered “void” if extents of 25 gals is larger than extents of pre-saturation.
ASTM F2898 (overflow test)

• Addresses horizontal flow issues with ASTM F1551.
• Can be performed on turf/infill, base stone, and finish stone.
ASTM D3385

• Double-ring infiltrometer test.
• Can be performed on base and finish stones, but not turf and backing/infill.
• Driving rings can be challenging in gravels.
ASTM D3385
Laboratory Testing Program

• Perform laboratory testing on material collected as part of field investigation. Common tests include:
  
  • Moisture content – ASTM D2216.
  • Unit weight – ASTM D7263.
  • Gradation (and hydrometer):
    • Finish and base stone – ASTM D6913.
    • Infill – ASTM F1632.
  • Laboratory Proctor – ASTM D698 (not D1557).
  • Permeability:
    • For soils with a permeability > 1x10^{-3} cm/s (1.4 in./hr) – ASTM D2434.
    • For soils with a permeability < 1x10^{-3} cm/s – ASTM D5084.
  • Permittivity (for geotextiles) – ASTM D4491.
Hydraulics and Hydrology (H&H) Analyses

- **Hydrology** – science that deals with the properties, distribution, and circulation of water on and below the earth’s surface and in the atmosphere.
- **Hydraulics** – science that deals with practical applications of liquid in motion.
- H&H analyses determine the hydraulic grade lines and peak discharge into the local drainage system.
- During drainage investigations, H&H analyses are used to evaluate the suitability of drainage design assuming the water successfully infiltrates the turf and backing, infill, and base materials.
Conclusions

• The drainage behavior of artificial turf field systems can be complicated.

• While there are a number of common drainage performance problems of artificial turf fields, successful field performance is achievable if the behavior of the entire artificial turf system (turf and backing, infill, cushion, geotextiles, and base materials) is well understood during both the design and construction phase of the project.

• Understanding the potential interaction(s) of the various artificial turf field components is essential to designing and constructing a well-draining field.
References

1. ASTM D698 – Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³)).
4. ASTM D3385 – Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer (EN 12616).
Questions?

This concludes the presentation

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