How to Obtain a Field Infiltration Rate?

- Once Upon A Time:
  Percolation Test

- Now:
  Double Ring Infiltrometer
What if the Proposed Grade is well below Existing Grade?

- Falling Head Test Within Test Boring:
  “Encased Borehole Method”
WE’RE GEOTECHS, NOT SCM DESIGNERS

• We perform the field test then turn over the results

• We look to provide the most reliable but also cost effective field results for designers
  • We know DRI is the preferred test
  • DRI not feasible or cost effective when proposed infiltration elevation is very deep compared to existing grade

• Encased borehole method
  • PA BMP Manual says should be completed according to setup described in Maryland BMP Manual
  • Not the only approved borehole method in the PA BMP Manual (Geulph Permeameter, Amoozemeter)
  • Requires no special equipment, not much training
  • Often times is piggybacked with other subsurface investigations at a site
Encased Borehole Procedure – Maryland Method

• Drill test boring using HSA or SSA to beyond desired infiltration test depth
  • Continuously SS sampled to 4 feet below SCM bottom and classify soils
    • USDA
    • USCS
  • Observe samples for limiting zones
    • Groundwater or evidence of seasonal high groundwater table
    • Very dense weathered rock or bedrock
    • Fine-grained soil layers
    • ** Coarse-grained soils, gravels, fractured bedrock with insufficient fines **

• Offset and auger down to testing depth
  • Install 5 inch diameter casing
  • Embedded 24 inches into infiltration medium
Encased Borehole Procedure – Currently Used by EEI

- Test boring still drilled to below SCM bottom, offset (usually twice) for infiltration testing
- Smaller (3 inch) beveled, PVC casing is installed within the augered casing
- Inner casing seated 2 inches into soils at base of borehole
- Annulus between inner and outer casing is sealed with hydrated bentonite pellets
- Testing procedure similar DRI procedure
  - Presoak: 6 inches of water for two 30 minute intervals
  - If water remains then 30 minutes test intervals, otherwise 10 or 15 minutes
Encased Borehole Procedure – Currently Used

The testing setup and field data reduction procedures were submitted for review and approval to PA DEP in 2008 by Evans Mill Environmental, LLC
2008 PA DEP Protocol Review

- March 2008: Evans Mill sought approval of a modified approach to MD Stormwater Manual test setup
  - Install PVC inner casing within borehole
  - 2 inches of soil packed around annulus, seal annulus with hydrated bentonite
  - Included calculation for vertical hydraulic conductivity, $K_v$, based on a relationship developed by Hvorslev (1951)

- PA DEP concurred with Evans Mill field procedure and calculation for vertical hydraulic conductivity. Released a memo to all interested parties stating this method was in keeping with the intent of PA Stormwater BMP Manual.

- However...
2008 PADEP Protocol Review

• An order of operations misinterpretation was included in the protocol review that was released to all interested parties

• Equation as it was published in the protocol review:

\[ K_v = \left[ \frac{A}{F \times D \times t} \right] \ln \left( \frac{h_1}{h_2} \right) \]

• Equation as originally developed by Hvorslev:

\[ K_v = \left[ \frac{A}{G \times D \times t} \right] \left[ \ln \frac{h_1}{h_2} \right] \]

Where:

\( K_v \) = Vertical hydraulic conductivity

\( A \) = Inner casing cross sectional area

\( G \) = \( F \) = Shape Factor = \( d + \left( r^2 \right) \)

\( D \) = Inner casing diameter

\( d \) = Inner casing embedment depth

\( r \) = Radius of inner casing

\( t \) = Time for change in head

\( h_1 \) = Initial height of water column

\( h_2 \) = Final height of water column
Significance of Algebraic Error

$K_v$: Significance of Order of Operations Error

![Graph showing the significance of algebraic error with $K_v$ against change in time (hr)]
Significance of Algebraic Error

- All other variables being equal, the incorrect form of the $K_v$ equation overestimates its value
  - Lag time, $\Delta t = 0.5$ hour to 4 hours
  - Head change, $\Delta h = 2$ inches

- Intuitively, the same measured drop of water within the inner casing over longer time period results in a lower hydraulic conductivity

*The curve should not be increasing as time increases if all variables are the same*
But That’s Not The Only Issue

• Other sensitivities exist when using the Hvorslev relationship

\[ G = F = d + \frac{r}{2} \]

• Each variable, embedment “d” and radius “r”, is contingent upon available equipment and field conditions

• Variability in the radius of the inside casing, r
  • Many size pipes available
  • Area, Diameter and Shape Factor affected

• Variability in the embedment depth, d
  • MD method recommends 24 inches, what is this based on?
  • Difficult in dense/hard soils
  • EME protocol review uses 2 inches
Sensitivity of Hvorslev Equation to Inner Casing Radius

![Graph showing sensitivity of Kv to inner casing radius](image_url)
Sensitivity of Hvorslev Equation to Inner Casing Radius

- Sensitivity graph still sloping at approximately $r = 18$ inches... unrealistic inner casing size for a standard test boring

- If “$r$” becomes large then the diameter of the borehole that contains it must be larger

- Different size pipe for use as inner casing is available during testing, this opens the door for variability with the field results
Sensitivity of Hvorslev Equation to Inner Casing Embedment

$K_v$ Sensitivity to Inner Casing Embedment, $d$
Sensitivity of Hvorslev Equation to Inner Casing Embedment

- Maryland BMP Manual recommends 24 inch embedment, $d$, into the infiltration medium

- The shape of the curve on the previous chart shows sensitivity not fully dissipated at $d = 24$ inches

- Much more reliable results for $K_v$ when embedment is 36 inches to 42 inches or greater
Conclusions About Current Testing Procedures

• Interpretation of Hvorslev equation may contribute to overestimation of infiltration rate and underdesign of SCMs

• Variables that may have an effect on hydraulic conductivity
  • Equipment
  • Field Conditions
  • Personnel (add gravel as scour protection?)

• According to curves, we should be using very large diameter casing, and embedding it deeper than even MD recommends – is this feasible?

• Consistency amongst results may not presently be achievable in the field
Where Do We Go From Here?

• Hvorslev equation is over 60 years old, is it time to revisit?
  • Account for field conditions (fine and coarse soils, saturated and unsaturated conditions, ponded water height, etc.)
  • Adjustment factors to account for casing sizes, embedment depths
  • Test boring data coupled with infiltration data

• Is new field equipment needed?
  • Larger diameter outer/inner casing (deep DRI???)
  • Smooth out sensitivity graphs

• In the end, can the PA encased borehole infiltration testing procedures be improved in order to ensure consistency Commonwealth-wide?
Thank You,

Questions?