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RE: Arie Muilwijk
NE 10-9-27 W4

November 26, 2020

Hi Andy,

Thank you for accepting my offer on November 23, 2020 to provide you with a written analysis of the average calculated permeability on page 4 of the Compliance Report – Roller Compacted Concrete for Calf Shelter, Calf/Feeder Pens (dated November 6, 2020), from Wood Environment and Infrastructure Solutions ("Wood").

Wood information

Wood stated …."the average calculated permeability through the 150mm thick RCC mat would be 9.0×10^{-8} cm/sec."

Wood provided:

- Overall area of RCC mat of 10m by 10m
- A 20mm wide crack in both directions in the overall area
- RCC permeability is 1×10^{-9} cm/sec
- Crack permeability is 1×10^{-4} cm/sec

Wood did not provide the methodology used or the calculations that arrived at their stated average calculated permeability.

Analysis

An applicable methodology that uses area and permeability is Darcy's Law:

$$Q = kiA \qquad \text{(Equation 1)}[1]$$

where
Q is the flow rate
k is the hydraulic conductivity/permeability
i is the hydraulic gradient
A is the area

As the information provided by Wood are inputs into Equation 1, I will use Darcy's Law methodology and provide my calculations in an attempt to duplicate the Wood result for average calculated permeability of 9.0×10^{-8} cm/sec. In this report, I will refer to this value as the overall permeability (k_O).

[1] Groundwater, Freeze and Cherry, Page 16.

I assumed that the flow rate through the overall area (Q_O) will be equal to the sum of the flow rate through the area of the cracks (Q_C) and the flow rate through the uncracked area (Q_U). In equation form, this assumption reads:

$$Q_O = Q_C + Q_U \qquad \text{(Equation 2)}$$

Expanding equation 2 by substituting equation 1 for each Q provides:

$$k_O i_O A_O = k_C i_C A_C + k_U i_U A_U \qquad \text{(Equation 3)}$$

Darcy's Law is valid for analysis of liners for solid manure. However, making a reasonable numeric assumption of a hydraulic gradient (i) for solid manure is difficult because it requires information (or assumptions) about hydraulic head. Instead, I make the assumption that the hydraulic gradient (i) will be the same for the flow rate in the overall area, the cracked area, and the uncracked area:

$$i_O = i_C = i_U \qquad \text{(Equation 4)}$$

Substituting equation 4 into equation 3 (all hydraulic gradients would then be i_O), then dividing both sides of equation 3 by i_O yields:

$$k_O A_O = k_C A_C + k_U A_U \qquad \text{(Equation 5)}$$

Table 1 lists the data provided by Wood, and the assigned variables and resulting calculations (if any). All of the variables in Equation 5 have a numeric value listed in Table 1, except the variable I am trying to determine (k_O).

Table 1. Assigned variables and calculations

Wood data	Variable and Abbreviation	Calculation (if any)
Overall area of RCC mat of 10m by 10m	Area overall (A_O)	10m x 10m= 100m^2
Two cracks 20mm wide in overall area	Area of cracks (A_C)	20mm=0.02m x 2 x 10m = 0.4m^2
	Uncracked area (A_U)	$A_U = A_O - A_C$ = 100-0.4= 99.6m^2
RCC permeability is 1x10^{-9} cm/sec	Permeability of uncracked RCC (k_U)	
Crack permeability is 1x10^{-4} cm/sec	Permeability of cracks (k_C)	

Dividing both sides of equation 5 by A_O yields

$$k_O = [k_C A_C + k_U A_U] / A_O \qquad \text{(Equation 6)}$$

Substituting numeric values from Table 1 into Equation 6 and solving

$$k_O = [(1x10^{-4} \text{ cm/sec} \times 0.4m^2) + (1x10^{-9} \text{ cm/sec} \times 99.6m^2)] / 100m^2$$

$$k_O = [4x10^{-5} \text{ m}^2 \text{ cm/sec} + 9.96x10^{-8} \text{ m}^2 \text{ cm/sec}] / 100m^2$$

$$k_O = [4.00996x10^{-5} \text{ m}^2 \text{ cm/sec}] / 100m^2$$

$$k_O = 4.00996x10^{-7} \text{ cm/sec}$$

My analysis indicates that the overall permeability (k_O) for RCC using Darcy's Law is $4x10^{-7}$ cm/sec ($40x10^{-8}$ cm/sec).

Using the methodology and assumptions listed above, I was not able to duplicate the Wood result for average calculated permeability/overall permeability of $9.0x10^{-8}$ cm/sec.

In closing, please contact me if you have any questions.

Scott Cunningham

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