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More about gas transmission in geocomposite systems

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It is always encouraging to get comments which confirm that someone reads my articles. Rick Thiel has spotted a number of typos that resulted from our last draft being lost somewhere in e-mail purgatory, and he has raised some points that require clarification. Thiel's initial comments and our replies follow:

"The 'Designer's Forum' on gas transmission in geocomposite systems by Greg Richardson and Aigen Zhao (*GFR* March, 2000) contains excellent recommendations regarding the need to understand the flow regime in testing vs. field conditions when designing for in-plane transmissivity. In the main body of the article, however, there are several inaccuracies or misleading statements that should be clarified."

Comments 1 and 2, Thiel: For calculating the Reynolds number, Re, in soils, the article states that d is the diameter of the flow path. Although this could be true in theory, the vast compendium of literature defines d as the average grain size (even their referenced figure uses the average grain diameter). For a more complete discussion, see Thiel (1998). Along the same lines, we should consider the same thought for calculating Re in geotextiles—should it be the fiber diameter, or the pore size? The answer: Whichever one gives the more correlatable results.

The article states that the laminar/turbulent transition value for Re (also called the critical Re) is dependent on the flow diameter d. This is not at all definitive. The critical Re will be a result of the nature of the flow medium and how d is defined. It is too complex an issue to generalize with one statement.

Response to comments 1 and 2, Richardson: The characteristic dimension, d, in Reynold's equation is variously defined in the literature. For tubes and geonets such as triplanar, d is defined as the effective flow diameter. Flow lines in these applications do not cross, so the size of the flow "tube" is critical. For sands and probably for geotextiles, d is defined as a characteristic grain size. Fancher et al. defined this characteristic diameter for sands as:

$$d = \sqrt{\frac{\sum n_s d_s^3}{\sum n_s}}$$

where n_s is the number of grains of diameter d_s. I know of no reference that extends this equation to gravel. I am not sure about how d is empirically determined for coarse material such as gravel or geocomposite drains that have intersecting flow paths such as biaxial geonets. But Thiel is clearly correct; the determination of d goes far beyond what we discussed.

Comment 3, Thiel: The article states that flows in gravels will be turbulent. This is a totally inappropriate statement. For example, in a typical leachate collection layer having an average gravel diameter of 0.5 in. (12 mm), a permeability of 1.0 cm/s, and a 2% slope (i.e. gradient of 0.02), the Re value for water would be 2, which would generally be considered laminar. Coarser gravels with steeper flow gradients may have larger Re values that result in turbulent flow. Designers should not accept the statement from the article, but should simply go back to basic principles. There will be a critical Re where the flow turns from laminar to turbulent. The more important point is in the conclusion, where the designer should understand how the flow regime in testing compares to the design situation. The same applies to geonets and geocomposites.

Response to comment 3, Richardson: G.A. Leonards, 1962, commenting on Fancher's work: "On the basis of such experiments, the opinion is commonly expressed that a Reynolds number of 1 corresponds to the beginning of turbulence in porous media."

Scott (1963): "…under normally encountered pressure differences in soils, Darcy's law appears to be valid at least up to the size range of medium to coarse sands."

Tschebotarioff (1951): "The law of Darcy is valid for laminar flow; no turbulent flow is possible with most natural soils, except in coarse sands or gravels of uniform size."

Cedergren (1977): "In the analysis of seepage in coarse sands and gravels, Darcy's law is strictly not applicable."

Based on these references, I do not believe that Thiel's example related to flow in a gravel is correct. I do agree, however, with the conclusion that a designer should understand how the flow regime in testing compares to the design situation. Here Thiel's earlier advice should be followed; when it comes to gravel, forgo the use of relationships and criteria clearly limited to sands.

Comment 4, Thiel: The article defines the gradient in the radial flow test using Equation 6. This is the accepted definition that will be used in the newly approved ASTM standard. Later in the article, the example on page 22 uses Equation 9 to calculate the gradient, which is slightly inconsistent. The two methods give close but slightly differing results. In actual fact, both of these methods calculate an average gradient. It is useful to understand that the true gradient in the test varies from the inlet to the outlet. Therefore, the Re value also varies between the inlet and the outlet.

Response to comment 4, Richardson: Unfortunately, a section on the proposed ASTM test skillfully edited for us by Rich Lacey was deleted due to space restrictions. Rich provided a photo of the large radial device that was also edited out. Readers desiring to do such tests are encouraged to contact Rich Lacey at Geotechnics Inc. and Sam Allen at Texas Research Institute as a starting point.

Comment 5, Thiel: The example presented in the article based on Bove's data is not valid, in my opinion, without employing a handful of fudge factors. It appears that the apparatus used in that thesis had large entrance and exit losses relative to the tiny volume of material being tested. The example in the article showed how the calculated ratio of air to water flow rates (using the theory of intrinsic permeability) was only about 60% of the measured ratio. This was due to the apparatus, not the theory of intrinsic permeability. The flows in that test were laminar (mainly because of the poor transmissivity of the geotextile), and should have proven the theory. Data published in Thiel (1999a) and Thiel (1999b) show excellent agreement for air and water tests in accordance with the theory of intrinsic permeability where the flow regime was laminar using a larger testing device. The new ASTM standard for radial flow testing is based on the larger flow device because of this issue.

Response to comment 5, Richardson: All the references that I have reviewed have been consistent in detailing the great difficulties experienced in defining critical values of Reynolds numbers, even for uniform sands. The data generated by Bove was sufficient to demonstrate the conversion of permeability from one fluid to another using the intrinsic permeability concept. I think that a 60% correlation is very good in this type of conversion – even using the large radial device. Perhaps Thiel credits our ability to make the conversion with more accuracy than warranted. Historic literature does not support the implied precision of Thiel's limited testing.

Comment 6, Thiel: The article states that radial transmissivity tests are commonly performed by manufacturers. In fact, probably not a single manufacturer performs the test, and very few testing labs perform the test, either. Although the methodology has been around for a couple decades, to my knowledge, it has not been used by design practitioners or manufacturers until very recently.

Response to comment 6, Richardson: I have been provided with data from Amoco regarding their heavier nonwoven geotextile—this is dated, so obviously it may not have been performed on the new radial device. My discussion with major manufacturers indicates very little interest in this application. More specifically, unless a super cushion is also required, a drainage composite provides significantly more flow capacity than a geotextile, for less cost. Thiel's application of a very heavy nonwoven at the City of Willits, Calif., (see "Cost-effective, low-maintenance final cover for steep slope," April 2000 GFR), is atypical and does not attract the major manufacturers.

Comment 7, Thiel: The article states that the laminar/turbulent flow change in geonets occurs at a critical gradient of 0.1. This may be true for a particular geonet using water. The critical gradient will be different for different types of geonets, and more importantly, will be different for different types of fluids. If the critical gradient is known for one type of fluid, it can be calculated for another type of fluid using the theory of intrinsic permeability.

Response to comment 7, Richardson: The article does not state that the laminar/turbulent flow change in geonets occurs at a critical gradient of 0.1. The article does state that "For coarse drainage media such as geonets, it is recommended that the laboratory water transmissivity be obtained at as low a gradient as practical and [that it be] *repeatable.* For most geonets, this is a gradient of 0.1." This simply implies that the test scatter increases significantly at gradients less that 0.1. Since the use of a test gradient larger than the field gradient is conservative (see Figure 3), there is no benefit to testing below the true accuracy of current laboratory equipment.

Comment 8, Thiel: The global recommendation in the last paragraph of the article (before the acknowledgments), which suggests conducting transmissivity tests at a low gradient to get laminar flow conditions, is puzzling. This contradicts the excellent conclusions from the previous paragraph. Also, it states that the critical Re for geonets is approximately 10, which contradicts the previous, more correct statement that the critical Re for geonets is probably closer to 500. The conclusions would be more powerful and clear if this last paragraph had simply been deleted.

A final note: My critique is candid, but I have great respect for the work Richardson has done in his Designer's Forum, and I encourage and applaud his efforts.

Response to comment 8, Richardson: Typo—as previously discussed in the article, we feel the transition between laminar and turbulent occurs at $100<Re<500$ for geonets. Having said that, we must acknowledge that defining the characteristic dimension, d, in Reynolds' equation is still not fully understood.

My final note: I have previously discussed with the editor the need to see the final copy of all articles before publication. This is not always the case and did not occur with this article. I appreciate the effort that Thiel put forth to clarify these points in the article.

References (Thiel)

Thiel, R. 1998. "Design of Gas Pressure Relief Layer Below Geomembrane Cover." Geosynthetics International, vol. 5, no. 6.

Thiel, R.S. 1999a. "Design of Gas Pressure Relief Layer Below a Geomembrane Cover to Improve Slope Stability." Proceedings of Geosynthetics '99 conference held in Boston, MA in April 1999.

Thiel, R. 1999b. "Design and Testing of a NWNP Geotextile Gas Pressure Relief Layer Below a Geomembrane Cover to Improve Slope Stability." Proceedings of Sardinia '99 Seventh International Landfill Symposium, held in Oct. 1999.

References (Richardson)

Cedegren, H.R., 1977. Seepage, Drainage, and Flow Nets, John Wiley & Sons, New York, NY, pp. 89.

Fancher, G.H., J.A. Lewis, and K.B. Barnes, 1933. Mineral Industries Experiment Station, Bulletin 12, Pennsylvania State University, University Park, PA, pp. 125.

Leonards, G.A., 1962. Foundation Engineering, McGraw-Hill Book Company, New York, NY, pp.125.

Scott , R.F., 1963. Principals of Soil Mechanics, Addison-Wesley Publishing Co., Palo Alto, pp. 72.

Tschebotarioff, G.P., 1951. Soil Mechanics, Foundations, and Earth Structures, McGraw-Hill Book Company, New York, NY, pp. 75.