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Discussion of "A New Model on the Hydraulic Conductivity of Asphalt Mixtures" by J. Norambuena-Contreras, E. Asanza Izquierdo, D. Castro-Fresno, Manfred N. Partl and Alvaro Garcia

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Norambuena-Contreras et al [1] have presented an interesting data-set of hydraulic conductivity measurements on four asphalt concrete mixtures with varying gradations, with coefficient of uniformity (C_U) values ranging from 6.1 to 40.6 and coefficient of curvature (C_Z) values ranging from 1.9 to 10.3. Their use of the classification system of permeability levels published in Vardanega & Waters [2] (see also Waters [3, 4]) and their new abbreviations for the categories are welcome. However, there are some points raised by their paper which are worthy of further discussion.

Form of Mathematical Relationship

The Kozeny-Carman equation (Kozeny [5]; Carman [6, 7]) is often preferred by geotechnical engineers (e.g. Carrier [8] and Chapuis & Aubertin [9]) to the Hazen formlation [10] due to, amongst other characteristics, its ability to account for changes in void ratio. Masad et al [11] presented a semi-theoretical equation in the Kozeny-Carman form to predict the coefficient of permeability for asphalt concrete. The form of the Kozeny-Carman equation (Eq. (19)) suggests essentially a power relationship between the coefficient of permeability (k) and the measure of porosity used (in this case void ratio, e)

$$k = \frac{\gamma}{\mu}\frac{1}{C_{K-C}}\frac{1}{(S_0)^2}\frac{e^3}{(1+e)} \qquad (19)$$

where,
k is the coefficient of permeability; γ is unit weight of the permeant; μ is the viscosity of the permeant; $C_{K\text{-}C}$ is the Kozeny-Carman empirical coefficient; S_0 is the specific surface are per unit volume of particles and e is the void ratio.

Eq. (18) in the paper under discussion shows a correlation between negative natural logarithm of the coefficient of permeability (k) and the air void content (AV) of the asphalt concrete mixture:

$$-\ln(k) = 45.97\frac{1}{AV} + 1.82 \qquad R^2 = 0.82 \qquad (18)$$

The authors' model is similar to the hyperbolic model employed by Naatatmadja [12]; which is also reviewed in Vardanega [13] alongside the power and exponential fitting models.

As the power law does not allow zero values of the coefficient of permeability at air void levels greater than zero, it is, perhaps, best used when connected voids are measured (discussed in Vardanega [13].

Fig. 7 shows the data-set from the paper under discussion [1] (also presented in Norambuena-Contreras [14]) replotted with a power relationship fitted (Eq. (18) is also shown for comparison). The value of the coefficient of determination (R^2) is 0.845 and the relative deviation (RD) as defined by Waters & Vardanega [15] is 39% with

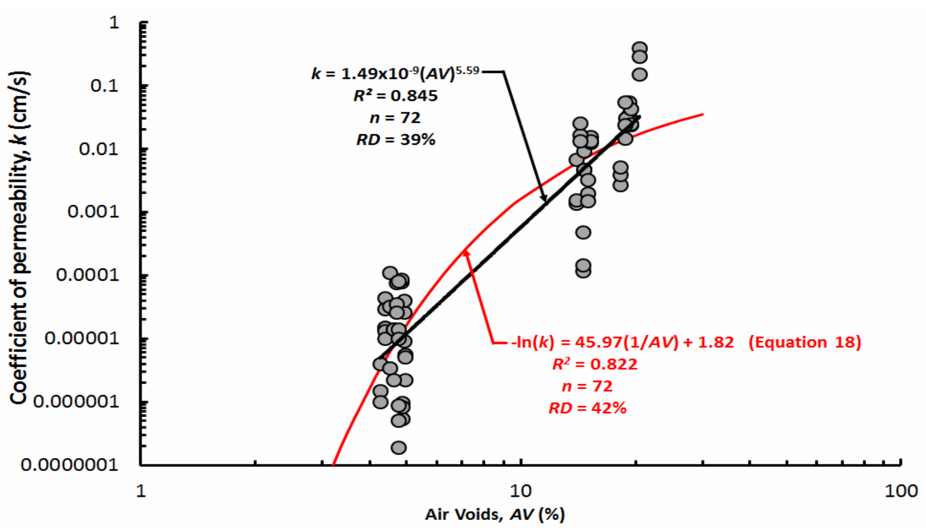

Fig. 7. Comparison of a Simple Power Law Fitting and Eq. (18).

n = 72 (i.e. 72 data-values were used to generate the regression). The exponent obtained from the fitting analysis has the value of 5.7 which is within the range reported by Masad et al [16] of 4.0 to 6.9. Masad et al [16] attributed the variation of the exponent to the test method employed. However, the Kozeny-Carman expression (Eq. (19)) has an exponent of 3.0 (for connected voids) and the value for this data-set is considerably higher.

Gradation Influence

Waters [4] and Vardanega & Waters [2] have both studied the significance of gradation to the understanding of asphalt concrete permeability presenting the *normalised voids* and *representative pore size* concepts respectively. The inclusion of the grading parameter in the data-set presented in the paper under discussion will not reduce the scatter significantly and this may be due to the method used to determine the percentage voids in the mixtures.

Air Void Connectivity

Examination of the reported data, presented on Fig. 3, shows a very wide range of coefficient of permeability values for the four asphalt concrete mixes at a given air void content (over two orders of magnitude scatter).

Obtaining values for coefficient of permeability is a difficult metrological task. Challenges of sidewall leakage and adequate sealing of specimens are necessary (to name a few). Segregation of the mix [17] can also be a problem though measuring the air voids and grading on each specimen tested could help identify if this was a problem.

Vardanega & Waters [2] and Vardanega [13] advocate the use of the hand pumping method, following the studies of Smith & Gotolski [18] and Kumar & Goetz [19], to determine accessible or connected voids as a percentage of the total voids in a mixture. When this parameter is correlated against the coefficient of permeability Vardanega & Waters [2] showed that the exponent in the fitted power formulation decreased from 5.9 (for the total voids) to 2.4 (for the connected voids) i.e. much closer to the value of 3.0 in the Kozeny-Carman formulation.

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