

Spectral induced polarization and hydraulic conductivity measurements on New Zealand unconsolidated sediments

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Spectral induced polarization (SIP) and hydraulic conductivity measurements have been made on unconsolidated samples representative of shallow coastal aquifers in New Zealand. The samples consisted of sands sieved into different fractions ranging from a mean grain size of 1.0 mm ($\phi = 0.00$) to 0.125 mm ($\phi = 3.00$).

To avoid the possibility that variations in SIP and hydraulic conductivity between samples might result from significant differences in the degree of packing of the samples into the sample holder a standardized measurement procedure was adopted consisting of the following steps. Initially each sample was thoroughly washed in distilled water over a period of two weeks and dried in an oven at 150 °C. The sample holder was filled with the dried sand and the mass of sand calculated by weighing the sample holder before and after filling. Water of a pre-determined (30-100 $\mu\text{S cm}^{-1}$) electrical conductivity was then passed through the sample until the electrical conductivity of the water coming out of the sample holder stabilized. The dc resistance of the sample was measured using a low frequency square wave and the formation factor calculated from the final recorded value of the pore fluid resistivity and the measured value of DC resistivity. Immediately after measurement of the formation factor the hydraulic conductivity of the sample was measured using the constant head method. Following the hydraulic conductivity measurement the SIP spectrum was repeatedly recorded for about 24 hours. The sample holder containing saturated sand was then reweighed to determine the mass of water saturating the sample and hence the porosity of the sample. The use of this standard procedure resulted, over all 13 samples, in an average formation factor F of 3.04 ± 0.11 , porosity of $41 \pm 2 \%$ and cementation exponent (calculated from Archie's Law) of 1.26 ± 0.07 . The resulting phase spectra measured for the all samples are shown in Fig. 1.

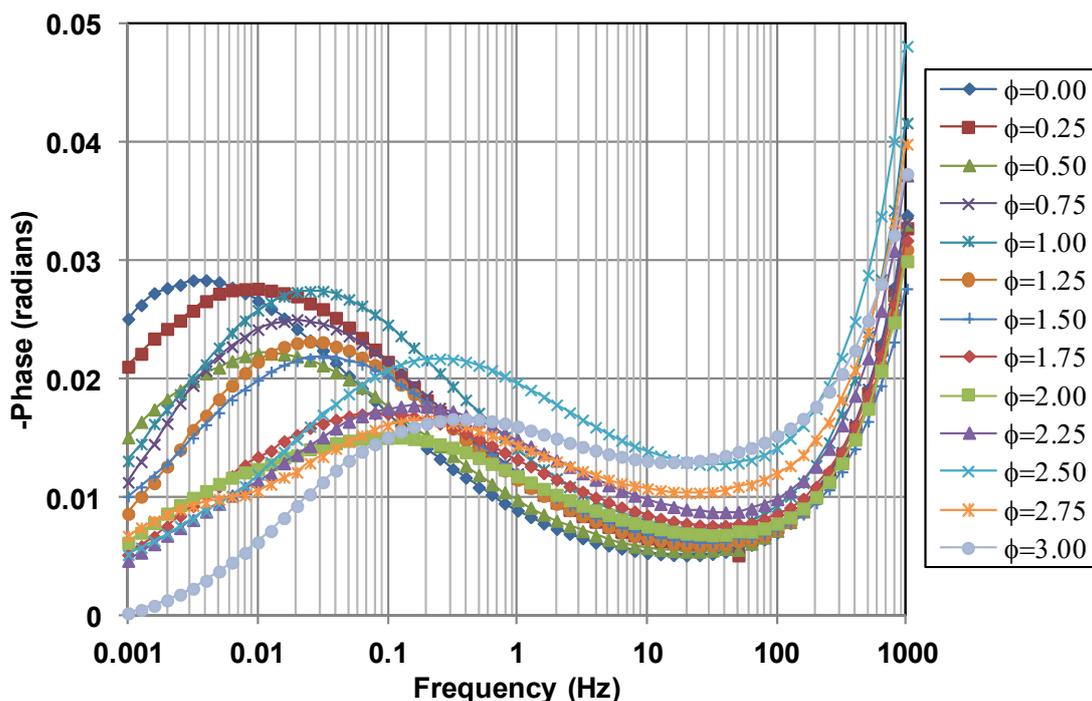


Fig. 1: SIP phase spectra measured on different sieved fractions.

To investigate any correlation between the electrical and hydraulic properties of the samples

the SIP measurements were modelled using a Cole-Cole model (Cole and Cole 1941). Thus, for each sample, the complex conductivity representation:

$$\sigma^* = \sigma_o \left\{ 1 + m \left(\frac{(i\omega\tau)^c}{1 + (1-m)(i\omega\tau)^c} \right) \right\}$$

was used to fit the conductivity magnitude and phase in the frequency range 0.001-10 Hz. Such modelling shows that although there appears to be no clear variation of the Cole-Cole exponent c with the size of the sieved fraction, there is a systematic increase in the total chargeability, m , with increasing grain size (decreasing ϕ value). This latter result is consistent with that observed by Koch et al. (2012) for measurements on sieved sand fractions. The modelled relaxation time constant (τ) increases by two orders of magnitude between the smallest and largest sieved fractions.

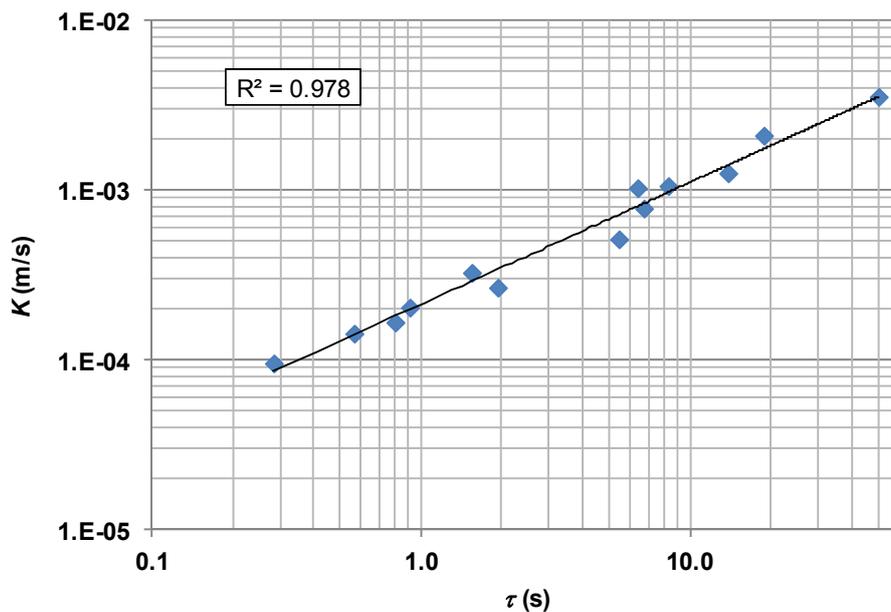


Fig. 2: Variation with of the measured hydraulic conductivity with relaxation time τ .

A plot of the measured hydraulic conductivity (K) against τ on a log-log scale is shown in Fig. 2 and demonstrates a strong correlation between the two parameters, reflecting the fact that both the SIP response and the hydraulic conductivity are controlled by the pore size and grain size structure. Assuming that polarization occurs within the Stern layer around grains, and based on the Kozeny-Carman equation, Koch et al. (2012) suggested that the permeability (k) can be related to τ by:

$$k = \frac{\tau D}{4n^2 F(F-1)^2}$$

where D is the diffusion coefficient of ionic species in the Stern layer, and n is the Archie's Law cementation exponent. Although previous results have suggested that this relationship underestimates the permeability by approximately an order of magnitude, the present measurements give a much closer agreement between predicted and measured permeability.

References

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- Koch, K., Revil, A. and Holliger, K., 2012. Relating the permeability of quartz sands to their grain size and spectral induced polarization characteristics. *Geophys. J. Int.*, 190, 230-242.