

Density, Porosity, and Permeability Measurements in Granite for Nuclear Waste Site Characterization

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Theory / Method / Workflow

As a part of NWMO's Adaptive Phased Management site selection phase the Geomechanical Reservoir Experimental Facility (GeoREF) laboratory at the University of Alberta conducted petrophysical testing of samples from 1 vertical and 2 inclined boreholes from the Wabigoon and Ignace Area in Ontario.

This paper summarizes the results of the testing of crystalline rocks (granites) on specimen cut in the axial and radial directions relative to axis of the boreholes. The specimens were prepared from 61 mm diameter (HQ3) core samples obtained from boreholes IG_BH01, IG_BH02, and IG_BH03. The testing included measuring the hydraulic conductivity (hydraulic conductivity), specific storage, water content, density, and porosity. Two rock core samples from borehole IG_BH01, eight rock core samples from borehole IG_BH02, and eight rock core samples from borehole IG_BH03 were tested.

Three types of test specimens were cut from each of the samples: 1) one 61 mm diameter by 61 mm length along the axis of the core sample (axial direction), 2) one 25 mm diameter by 25 mm length specimen along the axis (axial direction) of the core, and 3) one 25 mm diameter by 25 mm length specimen cut perpendicular to the axis of the core (radial direction). End cuttings from the 25 mm specimen preparation were used for grain density testing. Tests for petrophysical index properties included: (as-received) bulk density, water content by mass (%), water content by volume (%), dry density (g/cm^3), water saturated bulk density (g/cm^3), grain density (g/cm^3), water loss porosity (%), helium porosity (%), and total porosity from grain density (%).

Transient pulse decay testing conducted in custom made specialized triaxial cells was used to measure the hydraulic conductivity and specific storage of the test specimens under isotropic stresses. Hydraulic conductivity testing was conducted at as close as possible to fully water-saturated conditions. The analysis of all transient pulse decay hydraulic conductivity test results was completed by fitting the theoretical model provided by Hsieh et al. (1981) to the recorded laboratory data.

Results, Observations, Conclusions

The average grain density for the biotite granodiorite-tonalite lithology was $2.671 \text{ g}/\text{cm}^3$ and the grain density for the amphibolite lithology was $3.072 \text{ g}/\text{cm}^3$. The as-received bulk density varied between $2.586 \text{ g}/\text{cm}^3$ and $2.670 \text{ g}/\text{cm}^3$ with a mean of $2.635 \text{ g}/\text{cm}^3$. In general, it was difficult to differentiate between IG_BH02 and IG_BH03 specimens, but the IG_BH01 specimens showed a slightly higher as-received bulk density than the IG_BH02 and IG_BH03 specimens. Due to the low water content of the specimens, the variation in the density parameters (i.e., dry density, water saturated bulk density)

reflects the same trends as the as-received bulk density. The dry density varied between 2.584 g/cm³ and 2.669 g/cm³ with a mean of 2.633 g/cm³. The water saturated bulk density varied between 2.586 g/cm³ and 2.671 g/cm³ with a mean of 2.636 g/cm³. For water content (by mass), the range of values is from 0.030% to 0.190% with a mean value of 0.091%. Water loss porosity ranged from 0.02% to 0.53% with a mean value of 0.24%. Water loss porosity exhibits significant variability between the specimens because it is directly related to saturated, connected pore volume and the ability to move water out of the pore volume of the specimen. Water loss porosity is much less than helium porosity or grain density-calculated total porosity. Total porosity based on grain density ranged from 0.26% to 2.49% with a mean value of 1.42%, which is of the same order as the porosity measured using the helium porosimeter. Helium porosity measurements provide a valuable assessment of connected pore volume within each test specimen. Helium porosity varied from 0.58% to 3.05% with a mean value of 1.47%.

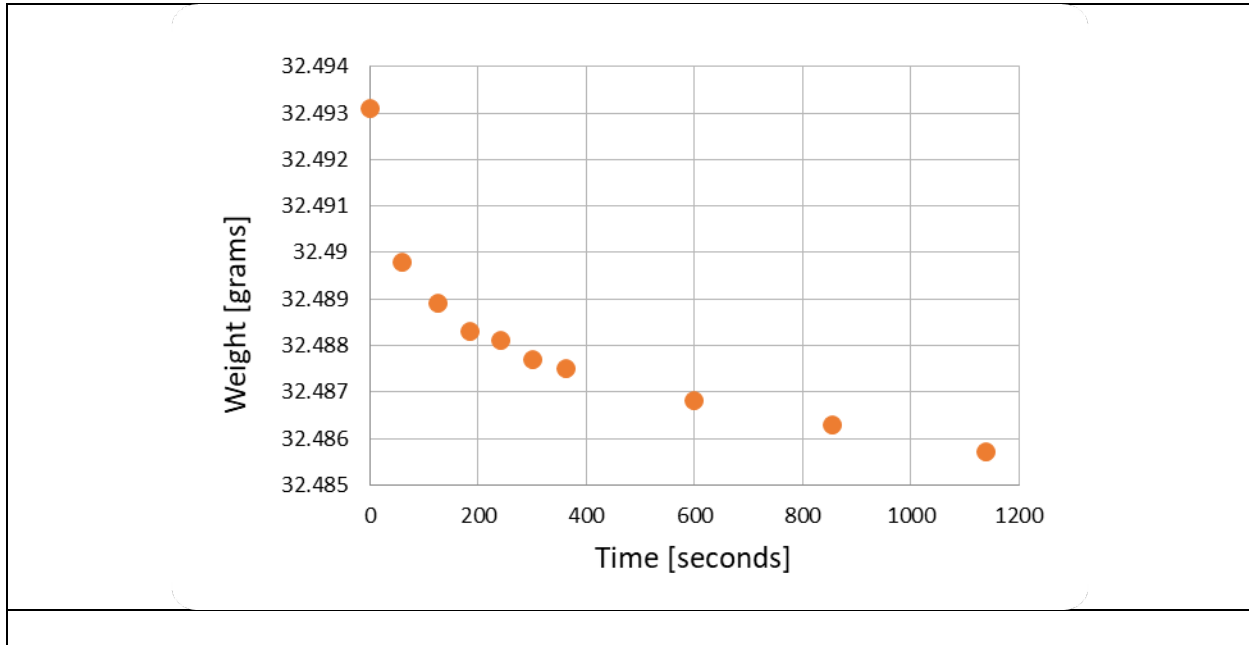
Hydraulic conductivity testing was completed for the biotite granodiorite-tonalite lithology test specimens. The effective confining stresses for tests conducted on all three borehole specimens ranged from 6.7 MPa to 28.6 MPa. Hydraulic conductivity tests conducted on the amphibolite lithology were not successful due to the extremely low hydraulic conductivity of these specimens. Within the variability of the measured hydraulic conductivities, all test specimens show a decrease in hydraulic conductivity with an increase in effective confining stress irrespective of specimen diameter or specimen orientation. The ratio of axial to radial hydraulic conductivity, defined as an anisotropy factor, was found to increase by a factor of two with an increase in effective confining stress from 10 MPa to 20 MPa.

The testing program also provided results that allows the sensitivity of hydraulic conductivity with respect to the specimen size to be examined. For borehole IG_BH01, 25 mm specimens display higher hydraulic conductivities than those of 61 mm specimens. For borehole IG_BH02, there appears to be no apparent difference between 61 mm and 25 mm specimens, and for borehole IG_BH03, 61 mm specimens show higher hydraulic conductivities, which is opposite to the trend seen in specimens from borehole IG_BH01.

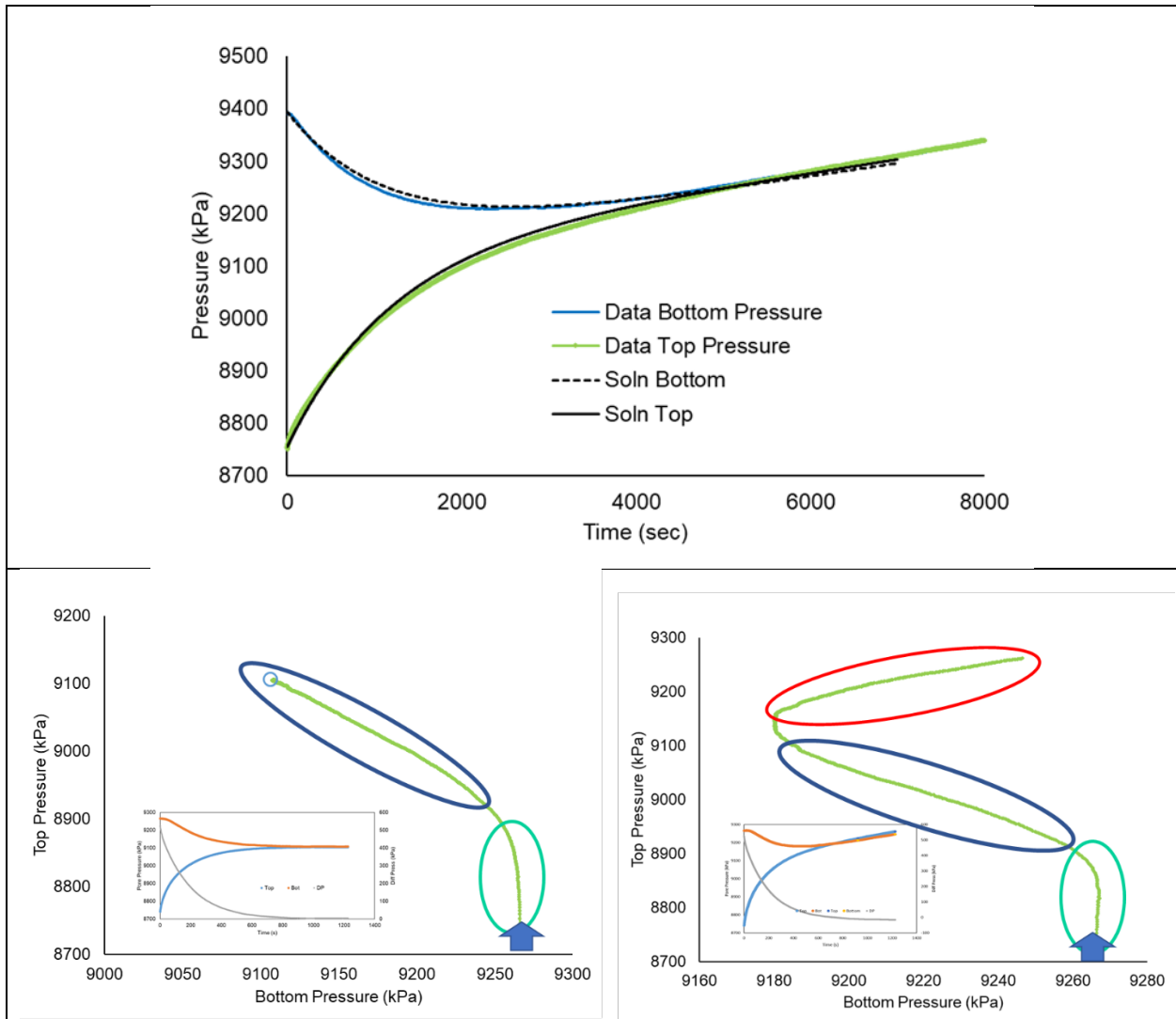
The analysis of the pulse decay hydraulic conductivity test results using Hsieh et al. (1981), provided not only a solution for hydraulic conductivity but also a determination of the specific storage of the specimen. GeoREF adopted this approach because the additional constraint of matching the pulse decay response to both hydraulic conductivity and specific storage provides a better estimate of hydraulic conductivity. However, due to the influence from test system parameters such as compressibility or upstream and downstream reservoir storage volumes, GeoREF refers to the specific storage determined in the tests carried out here as an “*apparent*” specific storage. For the complete dataset of 61mm diameter specimen results, the average $S_s = 2.4e-08 \pm 0.9e-08 \text{ m}^{-1}$. For the complete dataset of 25 mm diameter axial specimen results, the average $AS_s = 3.6e-07 \pm 0.5e-07 \text{ m}^{-1}$ and for the complete dataset of 25 mm diameter radial specimen results, the average $AS_s = 4.6e-07 \pm 1.2e-07 \text{ m}^{-1}$.

Novel/Additive Information

The low porosity characteristics also create challenging conditions to measure water saturated properties. As the rock was weight after vacuum saturation, the real saturated mass was difficult to determine due to the moisture loss to atmosphere.



For the hydraulic conductivity testing, temperature was the most difficult to control, and very small changes in ambient test temperature, on the order of ± 0.01 °C greatly impact the test. However, the greatest controllable or measurable impact on executing a successful test were leaks through fittings and/or the membrane. A solution to include the leaks into the Brace solution have been developed. This solution adds a source term into the top and bottom pressure description, allowing for the analytical inclusion of minor leaks into the solution.



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References

To be added