# Effect of the clay-water interaction in the hydration process of compacted bentonite

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## Introduction

Compacted expansive clays are being considered in the design of engineered barriers for radioactive waste disposal. In general, numerical codes used to analyse and predict the behaviour of these barriers are formulated considering the degree of saturation as the variable to indicate the water content within the porous medium. Because of that, it is common to express the retention capacity as a relation between the suction and the degree of saturation. Degrees of saturation larger than one are systematically obtained at low suction values in the case of compacted samples of expansive clay tested at constant volume (Villar, 2002; Marcial, 2003). This effect is atributed to the fact that the water confined in small pores or in the proximity of the clay layers of expansive materials presents properties that differ from those of free water (Low, 1979; Hawkins & Egelstaff, 1980; Cariati et al., 1981; Derjaguin et al., 1986). In a previous work a method which defines the density of water in samples of expansive clays as a function of the suction was developed (Jacinto et al., 2012). Using that procedure, water retention curves where the degrees of saturation are lower than one were obtained. This work analyses the influence of the clay-water interaction in the hydration processes of a compacted bentonite sample. Conclusions with respect to the hydration times as well as to the water needed to saturate the sample are obtained.

## Water density in compacted samples of expansive clays

Because of the different types of water present in a compacted bentonite sample, it is not straightforward to define a value for the water density within the sample. This will depend on the amount of water in the soil (degree of saturation) and on the clay minerals, as the hydration process depends on the exchangeable cations and the specific surface area of the smectite.

Jacinto et al. (2012) developed a general method to compute an average water density in compacted bentonite samples. The proposed methodology has been applied to analyse published experimental results obtained in MX-80 bentonite samples. This commercial material has been considered as sealing material for the barrier design of high-level waste repositories by several Agencies dealing with radioactive waste disposal [e.g. ANDRA (France), SKB (Sweden)]. Figure 1 shows the relation between the average water density and the suction in a MX-80 bentonite sample compacted at 1.60 $Mg/m^3$ when that procedure is applied. The results suggest that, as the sample becomes saturated, the average water density decreases.

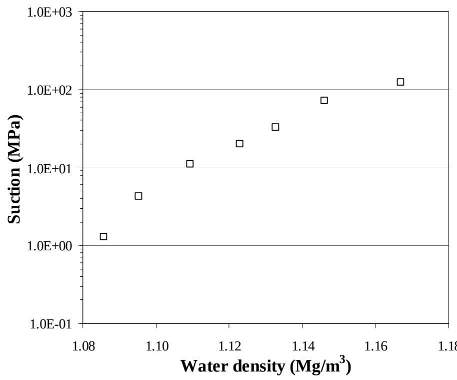


**Figure 1.** Estimated relationship between suction and average water density for a MX-80 bentonite sample compacted at a dry density of 1.60 Mg/m$^3$.

Figure 2 presents experimental results of the suction as a function of the degree of saturation for a MX-80 bentonite sample compacted at a dry density 1.60 Mg/m$^3$ and tested at 20 °C (Villar, 2005). These values were computed both using a water density of 1.0 Mg/m$^3$ (squares) and the results of water density shown in Figure 1 (circles). Results suggest that taking into account the appropriate estimation of water density results in a reduction of the degree of saturation for a particular value of suction. From a practical point of view this reduces the air entry value in the water retention curve.

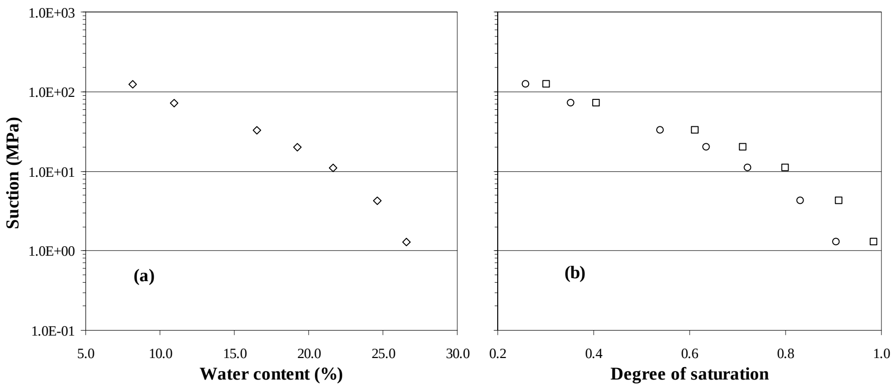


**Figure 2.** Water retention curve under constant volume conditions for a MX-80 bentonite sample compacted at a dry density of 1.60 Mg/m$^3$. (a) Suction against water content; (b) suction against degree of saturation.

## Application

The objective of this analysis was to evaluate how the clay-water interaction affects the hydration process of compacted samples made up of expansive clay. Two cases were considered and in order to simplify the evaluation of the results only the hydraulic problem was considered.

A sample is hydrated throughout one of its boundary by applying a small water flux. The imposed hydraulic boundary condition guarantees that the water injected within the sample is the same in both cases analysed.

Coefficients in the liquid density law corresponding to Case 2 were assumed equal to those used for liquid free water. In Case 1, those coefficients were derived using the results shown in Figure 1.

Parameters in the soil water retention curves were determined using experimental results shown in Figure 2. Degrees of saturation higher than one are obtained at lower suction values in Case 2. In that case, the maximum degree of saturation was fixed equal to 1.0 and automatically the fitting process forces values of degree of saturation lower than one.

Figure 3(a) presents the distribution of degree of saturation along the sample at different time steps and for each case considered. Continuous lines represent results obtained in Case 1 while doted lines correspond to those obtained in Case 2. The final time (300 days) corresponds to a total water content which is 98 % of the water content at saturation in Case 2.

Figure 3(b) shows the relation between the water content in Case 1 respect to the corresponding one in Case 2 at different zones of the sample. The zone close to the hydration boundary is designed as “wet” in the figure whereas that far away of the injection point as “dry”. In the same figure, the relation between the overall water content corresponding to each case at a given time is indicated as “average”. Values in Figure 3(a) suggest that the sample becomes saturated earlier in Case 2 than in Case 1. Results indicate that only in the zone close to the injection boundary the sample saturates approximately at the same time in both cases considered. However, at the time when sample in Case 2 becomes almost saturated (300 days), the difference in degree of saturation between both cases approximates to 15 % in the zone opposed to the injection boundary. In other words, calculations suggest that more time will be needed to saturate the sample in Case 1.

As it can be seen in Figure 3(b), until the time when sample nearly saturates for Case 2 (300 days), the global water content within the sample at a given time is the same in both cases (black bars). However, as the hydration proceeds, the relation between the water content in Case 1 with respects to that in Case 2 increases in the zone close to the injection point (grey bars) whereas this ratio decreases in the opposed zone (white zone).

Other aspect to be highlighted is the difference in the quantity of water needed to saturate the sample in each case. For the dry density considered, the gravimetric water content at saturation is about 27% in Case 2 whereas it is close to 30% in Case 1. Clearly, it will be needed to inject more water in the latter case to saturate the sample.

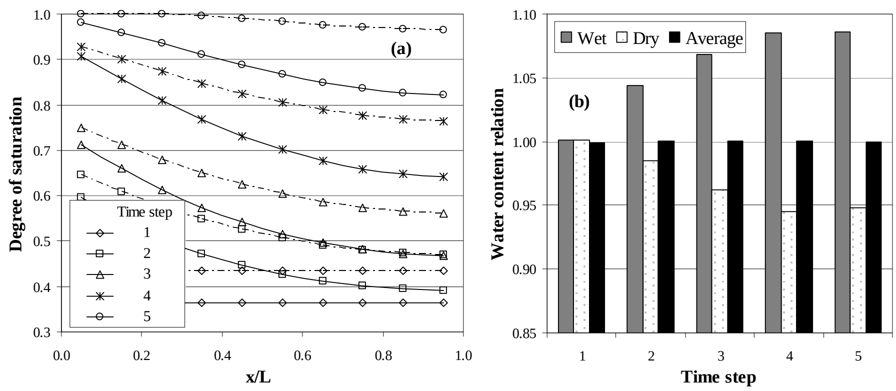


**Figure 3.** (a) Evolution of the degree of saturation at different times and for each case considered; continuous lines correspond to Case 1 and dotted lines to Case 2; (b) temporal evolution of the relation between values of water content at the wet side or at the dry side of the sample.

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