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Seismic wave velocities of compacted bentonite: an experimental study

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Introduction

Understanding mechanical-physical behavior of material employed in waste repositories is crucial. Compacted bentonite is used for this task (Koch, 2002).
We measured elastic properties of compacted bentonite (density 1.66 g/cm^3, Lloret et al. 2003) for temperatures up to 160°C and confining pressures up to 100 MPa.

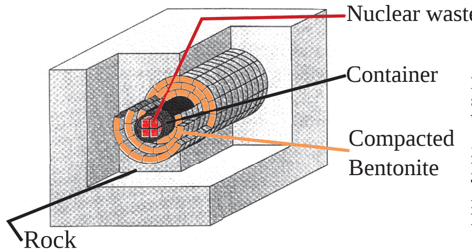


Figure 1. Typical setting of nuclear waste repository (after Villar et al, 2005 modified). Expected maximum T 80°C, expected maximum swelling P 5 MPa.

Methods

- We measured Vp and Vs with ultrasonic transmission method (Birch, 1960)
- We designed and built the ETH ultrasonic facility to measure Vp and Vs
  - Frequency range 0.1-1 MHz (0.1 MHz used in this study)
  - Samples: 20 mm length, 22 mm diameter
- ~1.66 g/cm^3 density samples prepared by cold pressing
- We characterized the material employing XRD and TG analyses

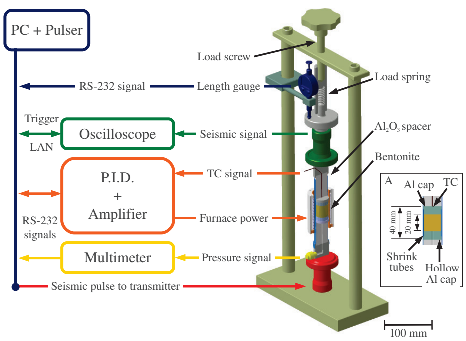
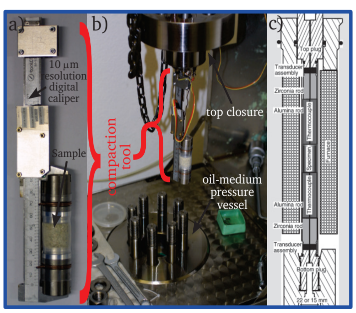


Figure 2. ETH ultrasonic facility. Maximum temperature 200°C, room pressure.



- We measured linear compaction of samples with the new compaction tool (see Figure 3a,b)
- We measured Vp and Vs for samples under confining pressure by means of Physical properties module mounted on Paterson Rig #9 (see Figure 3c)

Figure 3. a) sample mounted on the compaction tool. b) oil-medium pressure vessel and compaction tool applied on the top closure b) Physical properties module for Paterson Rig (after Ferri et al. 2007).

Results

1) XRD and TG analyses confirm the composition indicated by Lloret et al. (2003) (>90% Montmorillonite)
2) Vp and Vs for T up to 80°C (normal regime), Vp for T up to 160°C (de-hydration regime)
3) Linear compaction, Vp and Vs measurements for confining pressure up to 100 MPa

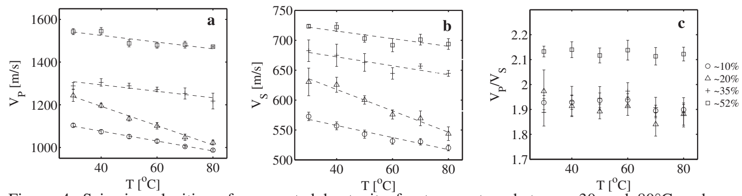


Figure 4. Seismic velocities of compacted bentonite for temperature between 30 and 80°C and room pressure.

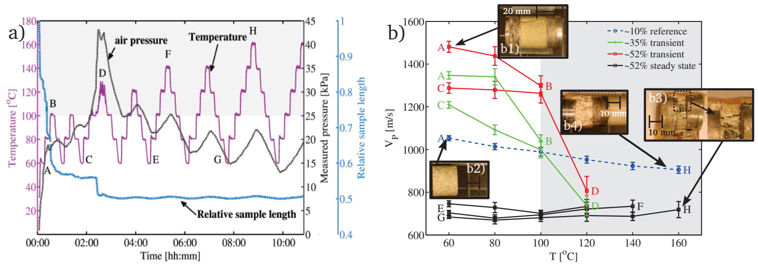
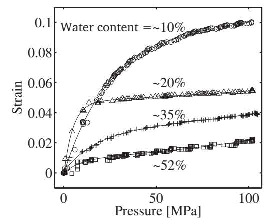


Figure 5. Seismic velocities of compacted bentonite for high temperature and room pressure on a ~52% water content sample. In panel a air pressure is the sample assembly pressure. Gray-shading defines de-hydration regime. Uppercase letters on the plots highlight key T steps of the experiment. b) Evolution of Vp for a set of samples through several of the critical times highlighted in panel a, identified by the same lettering. b1, b2, b3 and b4) show the samples at different stages. The sudden rise in pressure (panel a) between times C and D, followed by a gradual decrease, happens simultaneously with a major sample shortening. This indicates structural failure of the sample, which that may explain the decrease of velocity in panel b. from 1300 m/s to 800 m/s (b3).



Water content	Initial density [g/cm^3]	Initial porosity [%]	Final density [g/cm^3]	Final porosity [%]
~10%	1,62	35	2,05	17
~20%	1,61	23	1,90	9
~35%	1,73	10	1,81	7
~52%	1,63	10	1,71	6

Table 1. Densities and porosities for compacted samples (see Figure 6). Porosities were measured with a helium pycnometer.

Figure 6. Linear compaction for 20 mm long and 25.4 mm diameter samples. The best-fitting curves are used to correct for sample strain during seismic velocity measurements (see Figure 7).

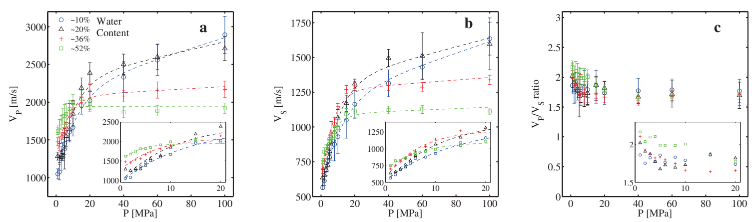


Figure 7. a. Vp, b. Vs and c. Vp/Vs ratios measured as a function of confining pressure with the physical properties module. Dashed lines represent empirical fits (Eberhart-Phillips et al. 1989). In each panel, the inset represents a magnified version of the 1 to 20 MPa data without error-bars.

Discussion

- Vp and Vs for T<80°C show a linear velocity decrease with T, no hysteresis
- Velocities increase with water content, as a consequence of decreased porosity (Table 1)
- Vp for T up to 160°C and 10% water content samples shows a linear velocity decrease (i.e. from ~1100 to ~900 m/s)
- Vp for T up to 160°C and >35% water content samples shows non linear velocity decrease, with a major drop at T~120°C and hysteresis; the drop comes with a fast loss of water, as highlighted by the increase in air pressure (see Figure 5a point D)
- After 3h at 160°C, Vp for >35% water content samples is lower that Vp for 10% water content (i.e. ~750 m/s), suggesting the permanent physical modification of the sample. The sample is cracked and dry (see Figure 5b3), XRD does not show any mineralogical change.
- Vp and Vs measurements and linear compaction tests, for confining pressures up to 100 MPa, show strong dependency with water content

- 20% water content samples show different trends for all the experiments
  - this behavior is attributed to double porosity model (Figure 8, Lloret et al. 2003)
  - intra-aggregate pores are filled for ~25% water content (suction tests, Lloret et al. 2003)

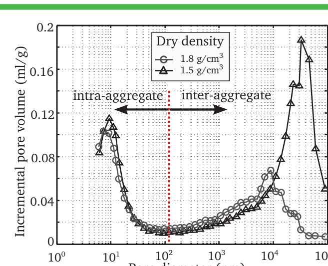


Figure 8. Distribution of incremental pore volume for two compacted bentonite samples at different dry densities. Mercury intrusion porosimeter test. (after Lloret et al, 2003, modified)

Conclusions

We measured elastic properties (K, G) in compacted bentonite for:
- T ranging between 30 and 160°C
- P ranging between 0 and 100 MPa

Permanent physical modification in the de-hydration regime (>120°C) have been found

Elastic properties are dependent on T, P and water content

Results are useful for seismic imaging techniques (e.g. full waveform tomography) of a compacted bentonite barrier during its evolution (e.g., Marelli et al. 2010)

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