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# Complex dielectric permittivity database of porous limestone (tuffeau)

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## 1. GENERAL INFORMATION

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This database comes from the electromagnetic (EM) characterization of porous limestone (coming from Loire Valley, France), in the frequency band of ground penetrating radar (GPR), for several saturation degrees.

### 1.1. ELECTROMAGNETIC CELL

In collaboration with Ifsttar, the laboratory of Electronics and Telecommunication systems (LEST), from Western Brittany university (FR), designed a special electromagnetic cell for heterogeneous civil engineering materials. This EM cell is using a 75-millimetre coaxial-cylindrical shape associated to a vector network analyzer (VNA). It enables to cover a bandwidth typically from below 100 MHz to above 1.4 GHz for civil engineering materials, the upper limit depending on the dielectric constant of the tested material. Its precise characteristics and performances are described in Adous *et al.* [2006] and Dérobot *et al.* [2017].

This method of measurement provides a penetration depth large enough to give a reliable measure of the complex dielectric permittivity of bulk material. Then, taking into account this penetration depth and the dimensions of the studied sample, the Representative Volume Element (RVE) criterion is satisfied for concrete mixes containing aggregates whose diameter is below 20 mm [Villain *et al.*, 2018].

The VNA (model VNA E8362A) from Agilent Technologies was used for the acquisition with the following parameters:

- Frequency range: 50MHz - 1.6 GHz
- Number of points: 801
- IFbandwidth: 1.5 kHz
- Power: 0dB

## **1.2. LIMESTONE CONDITIONING**

The material study in this work is tuffeau, a kind of very porous limestone from the Loire Valley in France, which porosity is about 46-48 %. Ten cores (70 mm length × 75 mm diameter) were drilled from several blocks of tuffeau from different areas of a quarry located in Saint-Cyr-en-Bourg (FR). The axis of the cores were such as to be oriented perpendicularly to the sedimentary stratigraphy of the limestone.

All ten cores were conditioned in the same way. At the beginning of the procedure, cores were dried at 60 °C, following the AFPC-AFREM French recommendation [1997], to avoid any mineral destruction of the limestone [Beck, 2006].

The principle of humidification protocol was to perform a homogeneous imbibition procedure in order to get different hydric state of limestone [Guilbert *et al.*, 2020]. To reach this homogeneous state, the Parrots protocol [1988], used for concrete sample homogenising and for evaluating the concrete calibration curve for permittivity vs. water content [Villain *et al.* 2018], is adapted to the case of limestone.

All the cores were saturated in water under vacuum pressure for 24 h, according to the standard AFPC-AFREM recommendation. Samples were soaked to reach approximately twelve different hydric states, from 0 to 98 % (about 0%, 10 %, 20 %, 30%, 35%, 40 %, 50%, 60%, 70%, 80%, 90% and 99%). After allowing the cores to lose weight, the cores are returned to an oven at 60°C for at least a week. Before each weight loss procedure, data acquisition with the EM Cell is done. Finally, when the data acquisition with the EM Cell ended, the cores were dried at 105 °C, tested and weighted to confirm the dry mass measured at 60 °C, leading to a total of 13 hydric states.

## **1.3. EXPERIMENTATIONS**

The experimental protocol is as follows. Cores are extracted from their conditioning and weighted. Then, for each expected hydric state, the ten cores were characterized with the EM cell. Then, they were turned and characterized again in the other side, thus leading to 26 relative complex dielectric permittivity curves versus frequency. At last, cores are weighted again, to verify no loss of water, and reconditioned for the following expected hydric state.

All EM measurements were performed at a temperature between 19 and 20 °C.

## 2. DATA PRESENTATION

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### 2.1. DATA FILES AND STRUCTURE OF DATA

This data paper is associated to two files in ascii format which describe the following points:

- File Properties\_samples.csv presents the nomenclature of the tuffeau samples, their saturated and dry masses in gramme, the bulk and saturated densities in gramme per cubic centimeter and their porosity in percentage,
- File Database\_Nomenclature.csv presents the name of the samples, date (yyyy-mm-dd) and time of measurement (hh:mm:ss), orientation of the core during the EM cell measurement (T: top, B: bottom), mass measurement before and after permittivity measurement in gramme, saturation degree and water content in percentage, then name of the file.

259 data are gathered in a same folder (Data). The name of the file is the date of the measurement then the sample name, at the end the orientation and the extension is “.txt”. Each data file (format ascii) is organized as followed:

- The header file is defined in six first lines, as presented in figure1,
- Line 2 recalls the work of M. Adous in the frame of his PhD [Adous et al., 2006],
- then the file is composed in three columns corresponding to the frequency (in GHz), the relative permittivity (real part - EPS1) and the relative permittivity (imaginary part - EPS2) respectively, separated by blanks.

```
%=====
%<<-ADOUS MOURAD->> C(C) CORPORATION 2004
%LOGICIEL MA711T00S
%
%Freq[GHz]   EPS1 EPS2
%=====
0.0500  23.98383  7.15920
0.0519  25.23060  7.31636
0.0539  26.17613  7.33291
0.0558  26.59762  7.37477
0.0578  26.40665  7.08228|
0.0597  26.28242  7.81139
0.0616  26.45584  7.15432
0.0636  26.00126  7.63049
0.0655  26.07234  6.98694
0.0674  26.00937  7.06361
0.0694  25.92870  6.68813
0.0713  24.70709  6.34717
```

Figure 1: Example of 18 first lines of a data file (format .txt)

## CONCLUSION

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The data base is available to the GPR community and may serve as a reference benchmark for both developing and testing the performance of various processing techniques for the estimation of the degree of saturation of porous material, such as the tuffeau limestone, and their complex dielectric permittivity. Likewise, it can also serve for the study of EM characterization models.

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