Crude earth: assessing the variability of densities, dynamic modulus and resistivity

Mircea BARNAURE[1], Philippe POULLAIN[2], Stephanie BONNET[2]

[1] *Faculty of Civil Engineering, Technical University of Civil Engineering of Bucharest, Romania, Blv. Lacul Tei 122 - 124, 020396, Bucharest, Romania, mircea.barnaure@utcb.ro*

[2] *UBL, Université de Nantes, GeM, Institut de Recherche en Génie civil et Mécanique – CNRS UMR 6183, 52 rue Michel Ange, BP 420, 44606 Saint-Nazaire cedex, France, philippe.poullain@univ-nantes.fr, stephanie.bonnet@univ-nantes.fr*

ABSTRACT: *In recent years, in light of the current trend for sustainable buildings, earth was reassessed as a viable building solution. Most of the studies on earth have focused on analysing the possibility of standardising material properties by stabilising earth with cement or lime or on improving the construction methods by using modern equipment. In light of assessing the viability of using local materials and simple traditional techniques, the study focuses on analysing material variability by laboratory testing. Density, dynamic modulus, electrical resistance are measured on soil specimens constructed with traditional non-engineered methods. Non-destructive testing methods are used. An analysis in terms of variability is made based on these measurements. Comparisons are made between different specimens with or without fibres. For earth without fibres the coefficient of variation is 2%, 8.6% and 9.5 for the density, the modulus, the resistivity respectively. For the formulation with fibres, the variability is greater due to the heterogeneity of the material.*

RÉSUMÉ: *On redécouvre de nos jours les techniques de constructions en terre afin de limiter l'impact carbone des bâtiments. De plus les moyens de mise en œuvre sont souvent simples et demandent peu de transformations. La plupart des études existantes se sont focalisées sur des terres comprimées avec stabilisation par un liant à base de chaux ou de ciment. Cette étude s'intéresse plutôt à la construction en terre mais sans ajout de liant et avec des techniques de mise en œuvre manuelle utilisées en Bretagne Pays de Loire: adobe ou bauge. Ces techniques artisanales entrainent une variabilité du matériau qu'il est important d'évaluer. Pour cela nous quantifions la variabilité de certaines propriétés de la terre de Guérande : la densité, le module d'Young dynamique et la résistivité. Des comparaisons sont faites pour des échantillons avec et sans fibre naturelles. Pour ceux sans fibre les coefficients de variations sont respectivement de 2%, 8.6% and 9.5% pour la densité, le module et la résistivité. Pour les formulations avec fibres la variabilité des propriétés est plus importantes car la présence des fibres entraine une hétérogénéité plus importante du matériau.*

MOTS-CLÉS : *terre crue, fibres naturelles, évaluation non destructive, module dynamique, coefficient de variation.*

KEY WORDS: *crude earth, Natural fibres, non-destructive testing, dynamic modulus, coefficient of variation*

1. Introduction

Earth has been used for a very long time as a building material. In the last century, in developed countries, it was generally replaced by modern, standardised materials. Yet, in the last 20 years, a revival of the interest in using earth in buildings can be observed. This is mainly due to earth being perceived as a material that can lead to solutions with very low environmental impact. This interest has also lead to more scientific publications on earthen materials. Most of these publications focus on rammed earth and compressed blocks (with raw material being often stabilised with lime or cement), as these solutions are more controllable in terms of consistency of results.

The problem of using standardised material formulations is that the local material might not always be suitable. Earth composition can vary in significant extents between sites, and transport of materials to the building site, the use of big mechanised tools for construction or even the use of stabilisers lowers the eco-friendliness of the solution. For this reason, the present study focuses on assessing the possibility of using locally supplied materials and traditional manual building techniques. The properties of earth used in buildings can be highly variable. Silveira et al. analysed existing houses and land dividing walls and observed a high variability on measurements for the compressive or tensile strength and the modulus of elasticity, not only in terms of average values, but also in terms of standard deviations (in particular for the houses) [SIL 12].

Despite of this situation, many studies, even very recent ones, tend to ignore the variability of measurements values and only present results in terms of average values. Ashour el al presents the variability of measurements for the density of the specimens, but only the mean for the measured thermal conductivity values [ASH 10]. Liuzzi et al. shows the standard deviation only in the figures and only for some of the tests performed, but no values are given and no comparison is done between the tests [LIU 18]. The work of Nakamatsu et al. is a rare positive example of analysing conducted tests in terms of coefficients of variation, which is consistently computed for each type of mechanical tests [NAK 17]. The results of Nakamatsu et al. highlight that for the same specimens, different type of tests have different coefficient of variation, ranging from 9.6% for three point bending up to 24.2% for splitting.

The present study highlights the values of the coefficients of variation not only for different formulations of earthen materials, but also for different measured properties. An emphasis is placed on using non-destructive testing methods.

2. Materials

The soil used is from the Guérande area in Loire-Atlantique region in north-western France. In this region, traditional earth houses also included cob, some of the buildings still being in use today. The soil is a silt loam composed of 8% clay, 63% silt and 29% sand. The plastic limit is w_P=20%, while the liquid limit is w_L=30%. The value of the plasticity index is IP=10. The activity of clay is 1.25, which represents the lower value for active clays. The methylene blue test indicated a VBS=1.9 value. Because traditional houses involved the use of fibres mixed with the soil, we decided to use available natural fibres in order to assess their influence on the properties of the material as well as on the variability of the results. The chosen fibres were hemp shivs (commercial product Chanvribat) and reed from the marsh of Camargue cut at approximately 25 cm length. Both types of fibres considered are mentioned in the literature as being traditionally used in earth buildings [LAB 16].

The quantity of materials in the mix was established based on traditional method which only refers to the mix workability. The earth is placed in a large steel bowl and is mechanically mixed with a kneading hook at low speed while gradually adding water to the mix until the desired workability is obtained. In the case of earth mixed with fibres, the fibres were introduced once the earth and water are mixed. During the mechanical mix, reed was broken into smaller (up to 5 cm) length. The final water content is close to the liquid limit (30%) and was checked after drying at 50°C the specimens until mass stabilization. In terms of mass, this corresponds to a mix with 8% fibres (7% hemp and 1%) and 24% of water.

The samples were cast in wooden moulds with interior dimensions of 31 × 19 × 5.3 cm^3 placed on a base wooden tray. The earth is thrown a handful at a time with force into the mould. Our goal was not only to use locally available materials, but also to replicate simple building methods with manual application of the material. They involve throwing with strong impact (or sometimes manually pressing) successive clods of loam mixed so that each new layer adheres to the previous ones and a certain degree of compaction is obtained for the material [TUG 18]. Adobes are not mechanically pressed. After the removal of the moulds, the freshly cast earth was cut into 6 pieces, with an average dimension of the specimens of 5.2 × 19 × 5.3 cm (Fig. 1). For each mix, 3 slabs were made: two were cut (noted slab 1 and 2) while the third was kept intact as reference. The measurements were made on each of the 6 specimens from slabs 1 and 2.

After casting, the specimens were naturally dried until constant mass in a climate chamber with constant 20 °C and 50% relative humidity. Despite the initial high water content, no cracks were observed to form during the slow drying.

a) b)

Figure 1. *Construction of specimens: a) casting earth into mould, b) specimens after wire-cutting.*

3. Results and discussion

The mass and dimension, the dynamic modulus and the resistivity of each specimens were measured at 1,5,12,15,19 and 28 days after casting to observe the evolution during the drying. As the mass loss was almost stabilized at 28 days due to the equilibrium with the climatic chamber (20 °C and RH 50%), the figures 2,3 and 4 present the results obtained at 28 days of the experimental measurements concerning respectively the density, the dynamic Young modulus and the electrical resistivity. The dynamic modulus was determined using the Impulse

Excitation Technique (Grindo Sonic equipment). The Wenner resistivity meter is a measurement device using Wenner protocol to determine the apparent resistivity of the materials. The values shown in figure 4 are apparent resistivity values, as they were not corrected to account for sample dimension. As samples have almost identical geometry and as the measures were done similarly, the analysis of the results in terms of variability is relevant.

The coefficient of variation (CV) is computed as the standard deviation divided by the mean value of the measurements (table 1). Interquartile range (IQ) represents the difference between the values corresponding to the 3rd and 1st quartile of the data. The value of normalized interquartile range (NIQ) was computed as NIQ = 0.7413 × IQ. It was transformed into a relative value (NIQR) by dividing NIQ by the mean value (table 1).

Table 1. Variability of density, dynamic modulus and electrical resistivity at 28 days.

	Water content (%)	Density			Dynamic modulus			Electrical resistivity		
	(mean 2 specimens)	Mean kg/m^3	CV %	NIQR %	Mean MPa	CV %	NIQR %	Mean Ω × m	CV %	NIQR %
WF	2.28	1913	2.01	2.21	6304	8.59	5.58	1170	9.49	6.96
F	2.47	1453	2.93	0.97	1917	25.41	16.42	2500	16.23	12.95

The mean value of the density is 1913 kg/m3 for the non-fibre formulation (WF) and 1453 kg/m3 for the fibre formulation (F). The incorporation of light natural fibres is responsible for the decrease in the density. We can see that the CV on the value of the density is as low as 2-3%.

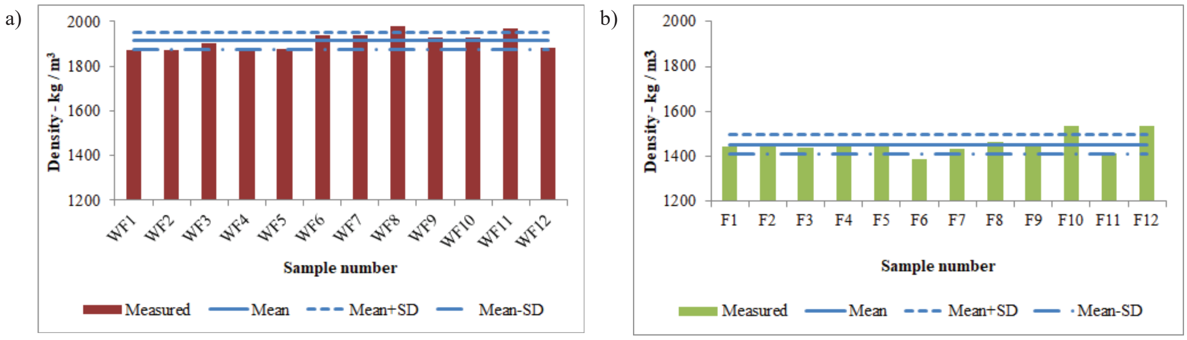

Figure 2. Density at 28 days: a) without natural fibres, b) with natural fibres.

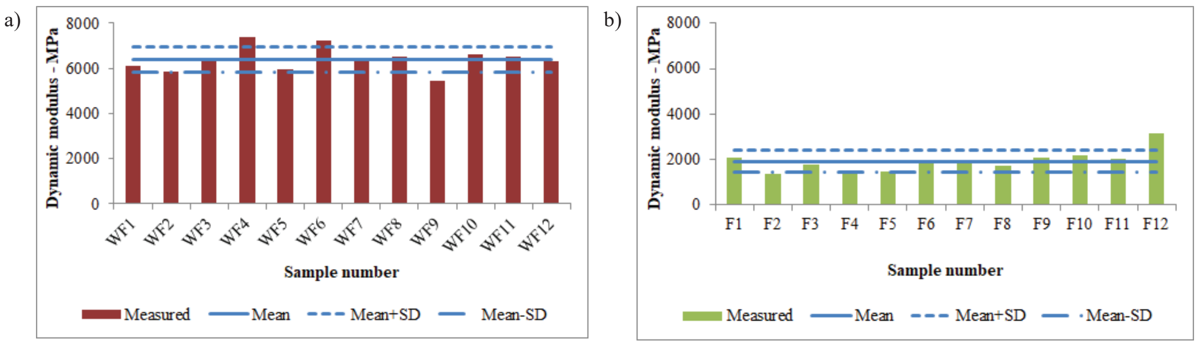

Figure 3. Dynamic modulus at 28 days: a) without natural fibres, b) with natural fibres.

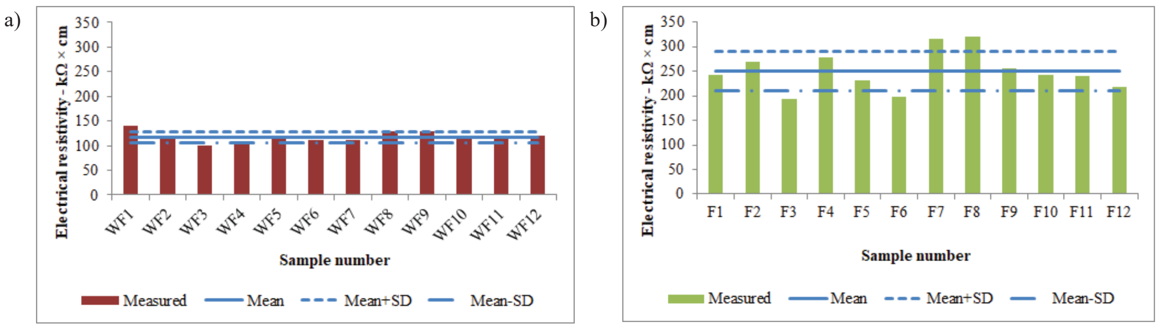

Figure 4. Electrical resistivity at 28 days: a) without natural fibres, b) with natural fibres.

The variability on the two other parameters is greater and can be very high as the values of CV and NIQR prove it. However, the variability is lower for the formulation without fibres as the material is more homogeneous. Contrary to the density, the electrical resistivity and the dynamic Young modulus are not parameters predictable with a simple linear model. Their values depend not only on the values of the constituents and on the volumetric amount of each but also on the microstructure of the material. As the microstructure of the formulation with fibres is less homogeneous than the formulation without fibres, the values are more dispersed around the mean value of the parameters. This is why the value of CV for the dynamic modulus is equal to 8.5% for WF and can reach 25% for F. The values of CV for resistivity is 9,5% for WF and can be as high as 25% for F. The CV obtained for earth without fibres are about the same as those obtained on concrete specimens [BON 18] which proves that hand-made earth specimens are homogeneous.

4. Conclusion

In this paper, we presented the experimental results obtained on raw earth composites made of raw earth excavated in the region of Guérande. Two formulations were tested: one without natural fibres (hemp shivs and reed) and one without fibres. The parameters investigated were the density, the electrical resistivity, the dynamic Young modulus. The values of these different parameters were obtained from 12 different specimens for each formulation in order to study the variability due to the intrinsic heterogeneity of the material and to the way the specimens are made by hand. The values of the parameters were presented using statistical indicators: mean value, coefficient of variation and normalized interquartile range.

For earth without fibres the coefficient of variation is 2.01%, 8.59%, and 9.49% for the density, the modulus, the resistivity respectively. The values of NIQR are 2.21%, 5.58%, and 6.86% for the same measurements. The values are rather low, which indicates that the handmade material is homogenous. The CV and NIQR values are similar, which proves that no single measurement is very distant from the mean. A slight difference was observed for the dynamic modulus, as two specimens exhibited higher values than the others.

For the formulation with fibres, CV values are 2.93%, 25.41%, and 16.23% for the density, the modulus, the resistivity respectively. The NIQR values are 0.97%, 16.42% and 12.95%. The values of CV and NIQR are generally higher than the values obtained for earth without fibres which can be explained by a non-homogenous spreading and orientation of fibres in the moulds. This is also shown by the difference between CV and NIQR. Density measurements, which are based on directly measurable physical parameters, have much lower CV and NIQR values both for earth and earth-fibre formulations.

Values of CVs are required in order to compare different formulations of earth or different tests, in particular for the mixes with fibres. A difference of CV and NIQR values was observed if 6 or 12 specimens are considered. We intend to expand the database with more specimens and different measured properties.

5. Bibliographie

[ASH 10] Ashour, T., Wieland, H., Georg, H., Bockisch, F. J. & Wu, W. (2010). The influence of natural reinforcement fibres on insulation values of earth plaster for straw bale buildings. Materials & Design, 31(10), 4676-4685.

[BON 18] Bonnet S. & Balayssac J.P., 2018, Combination of the Wenner resistivimeter and Torrent permeameter methods for assessing carbonation depth and saturation level of concrete, Construction and Building Materials, 188, pp. 1149–1165

[LAB 16] Laborel-Preneron, A., Aubert, J. E., Magniont, C., Tribout, C. & Bertron, A. (2016). Plant aggregates and fibers in earth construction materials: A review. Construction and building materials, 111, pp. 719-734.

[LIU 18] Liuzzi, S., Rubino, C., Stefanizzi, P., Petrella, A., Boghetich, A., Casavola, C., Pappalettera, G. (2018). Hygrothermal properties of clayey plasters with olive fibers. Construction and Building Materials, 158, pp. 24-32.

[NAK 17] Nakamatsu, J., Kim, S., Ayarza, J., Ramírez, E., Elgegren, M., & Aguilar, R. (2017). Eco-friendly modification of earthen construction with carrageenan: Water durability and mechanical assessment. Construction and Building Materials, 139, pp. 193-202.

[QUA 10] Quagliarini, E. & Lenci, S. (2010). The influence of natural stabilizers and natural fibres on the mechanical properties of ancient Roman adobe bricks. Journal of Cultural Heritage, 11(3), pp. 309-314.

[SIL 12] Silveira, D., Varum, H., Costa, A., Martins, T., Pereira, H. & Almeida, J. (2012). Mechanical properties of adobe bricks in ancient constructions. Construction and Building Materials, 28(1), pp. 36-44.

[TUG 18] Tugui, E., Barnaure, M. & Coman, M. (2018, August). Earth buildings in Romania. Tradition and perspectives. In IOP Conference Series: Materials Science and Engineering (Vol. 399, No. 1, p. 012049). IOP Publishing.