Time necessary for microwave drying of mineral soils

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Abstract: Construction of large earthworks (cuts and embankments) brings the necessity of fast and reliable testing quality control procedures to be applied directly on the building sites. The paper presents a conventional, standardized method for determining soil moisture - consisting in drying a sample in a machine that circulates dry, hot air. This procedure is widely used and is considered to be very reliable and effective for any type of soil. Its main disadvantage is the time it takes to complete, as it takes a minimum of 24 hours to obtain the results of moisture content and consequently, to compute the compaction (density) indicator. An experiment was conducted, based on former Jastrzębska’s experiments and recommendations, consisting in drying soil samples in a microwave oven. The results were confronted and discussed with a special regard to necessary for microwave drying of mineral soils of different nature. Some recommendations were given in conclusions. As all the authors are still students, some remarks were juxtaposed concerning the importance of practical “experience-based” education within a frame of international exchange programs.

1. Introduction – the scope of the study
Construction of hydrotechnical embankments - in particular earth dams, levees is a complicated undertaking, implemented to achieve specific goals - economic profits, production of ecological electricity, protection of material goods against the negative effects of floods, ensuring access to drinking water, for agriculture, protection against drought [1]. They are objects of considerable size, and their catastrophe can cause huge destruction, death of people and financial losses [2]. That is why the lead time is usually longer and the costs much higher than in the case of, for example, housing or building construction. These types of projects require many hours of work of experienced specialists in the industry, special care is required for the correctness of the works performed. High demands are placed on the materials used [3] and meticulous quality controls are carried out, and a number of phenomena are monitored, such as water filtration and building deformations throughout the lifetime. This work presents selected methods for testing soil embankments used for the construction of hydrotechnical embankments - dry dams of earthen reservoirs built in southern Poland.

The first attempts to use this method were made in the 1960s [4]. Many researches were conducted and some recommendations were given in the 70s [5], 80s [6,7], and 90s of the 20th century [8-12]. Recently, for the last 5 years, the application of the microwave drying technology for the purpose of
geotechnical testing was developed in Silesian University of Technology (Poland) [13,14] and Tomsk Polytechnic University (Russia) [15,16] with a special regard to time required to obtain a reliable result of moisture content in various kinds of mineral soils. Current study was focused on both: cohesive and granular soils. One of the granular soils was crushed amphibolite (gr5a).

2. Materials and methods of testing
For this work, the moisture content of four different soil materials was tested - a total of 40 samples altogether. The test procedure consisted in weighing the empty evaporators with an accuracy of 0.01g and after placing the soil in them, heating in a 900W microwave oven (figure 1) and re-weighing every minute. The traditional method of humidity tests was carried out independently to compare the results and determine the optimal drying time (figure 2).

It was assumed that if using this method results that differ by 1 percentage point from the standard test in several minutes can be obtained, then it is worth considering using it in the field due to simplicity, availability, short time and the possibility of frequent humidity control and confrontation of results with lab results. Drying in a microwave oven, however, may depend on many factors, such as the type of soil, weight of the sample, the number of samples to be dried and their arrangement, drying time, oven power, and the material from which the evaporators are made. There are also cases of explosion of samples in the oven. This may be caused by too much sample mass and uneven drying, inability to quickly release water vapor from the soil pores and the formation of excessive pressure. In cohesive soil samples, the phenomenon of sparking or ignition of the sample can also be observed - a sharp increase in temperature under the influence of microwaves causes an exo-energetic oxidation reaction. Therefore, developing a specific test procedure and standardizing it can be a complicated issue. In order to eliminate as many factors disturbing the results as possible, samples weighing about 18-22 g were tested and ceramic evaporators of similar sizes were used.

3. Results of microwave testing
Sample graphs of the moisture dependence on drying time in a microwave oven are presented in this section. The blue dotted line shows how the determined humidity changes during drying in the microwave, while the orange (constant) line indicates the humidity determined by the conventional method for each sample. In fact, blue dots indicate the water loss of the samples in course of drying.

Subsequent subsections present exemplary results of four materials used for the analysis. Codes of samples are related to actual material tested and its original moisture content. A-B and C-D symbols mean 2 samples from each material under study. All mineral materials were used for construction of hydraulic structures in Poland. Gravelly sand (gr5a) anthropogenic material achieved from crushed amphibolite was tested as an example of reuse of by-product (spoil material) from mining industry to the civil engineering constructions [3]. Medium sand (MSa) with roughly uniform grain sizes was taken as a second example. This material was used to form some road embankments and used for
mineral soil mixing for dike construction. Cohesive grounds: sandy silty clays (sasi Cl) taken for the analysis were brought from actual building sites in Kotlina Klodzka (Poland) where the Authors had an opportunity to follow the conduct of construction works. Both grounds were classified as glacier originated tills with different number of fractions. Some additional comments concerning the educational value of joined international practical geotechnical training will be given in conclusions.

3.1 Tested soil - “grSa” anthropogenic crumble – crushed amphibolite for dam construction

3.2 Tested soil - "MSa" medium sand for mixed soil (river dike construction)
3.3 Tested soil - "sasiCl" moraine clay (till) from Roztoki Bystrzyckie region (Poland)

Figure 9. Moisture loss in course of drying (sample 9A – initial moisture content 23.43%).

Figure 10. Moisture loss in course of drying (sample 9B – initial moisture content 22.58%).

Figure 11. Moisture loss in course of drying (sample 1C – initial moisture content 21.75%).

Figure 12. Moisture loss in course of drying (sample 1D – initial moisture content 25.22%).

Figure 13. Moisture loss in course of drying (sample 2C – initial moisture content 31.08%).

Figure 14. Moisture loss in course of drying (sample 2D – initial moisture content 31.12%).

3.4 Tested soil - "sasiCl" moraine clay (till) from Szalejów Górny region (Poland)

Figure 15. Moisture loss in course of drying (sample 6C – initial moisture content 16.46%).

Figure 16. Moisture loss in course of drying (sample 6D – initial moisture content 16.55%).
Figure 17. Moisture loss in course of drying (sample 7C – initial moisture content 18.17%).

Figure 18. Moisture loss in course of drying (sample 7D – initial moisture content 19.28%).

Table 1. Results of testing with derived error of the method.

| Ground description | No | Time of drying | Moisture content | | |
|-------------------|----|----------------|------------------|----|------------------|
| | - | min | | | |
| | | | from microwave | 24 hours hot-air | Total error |
| | | | drying | drying | |
| | | | [%] | [%] | [%] |
| Anthropogenic „grSa” (crushed amphibolite by-product) | 0A | 16 | 5.66 | 5.76 | 0.11 |
| | 0B | 16 | 5.34 | 5.69 | 0.36 |
| | 1A | 10 | 5.60 | 6.47 | 0.87 |
| | 1B | 10 | 6.70 | 6.69 | 0.01 |
| | 2A | 9 | 10.54 | 10.68 | 0.14 |
| | 2B | 9 | 10.52 | 12.06 | 1.54 |
| | 3A | 10 | 14.15 | 14.14 | 0.01 |
| | 3B | 10 | 14.01 | 14.01 | 0.00 |
| | 4A | 8 | 15.7 | 15.67 | 0.03 |
| | 4B | 8 | 15.73 | 15.72 | 0.02 |
| | 5A | 7 | 16.96 | 17.01 | 0.06 |
| | 5B | 7 | 17.06 | 17.10 | 0.03 |
| Medium sand “MSa” | 6A | 15 | 4.44 | 4.5 | 0.06 |
| | 6B | 15 | 3.62 | 4.12 | 0.50 |
| | 7A | 19 | 7.97 | 8.49 | 0.53 |
| | 7B | 19 | 7.75 | 8.06 | 0.31 |
| | 8A | 24 | 11.92 | 12.27 | 0.35 |
| | 8B | 24 | 12.98 | 13.1 | 0.12 |
| | 9A | 19 | 22.97 | 23.43 | 0.46 |
| | 9B | 19 | 22.51 | 22.58 | 0.07 |
| Moraine clay "sasiCl" (till) from Roztoki Bystrzyckie | 1C | 9 | 21.62 | 21.75 | 0.13 |
| | 1D | 9 | 25.14 | 25.22 | 0.08 |
| | 2C | 9 | 30.91 | 31.08 | 0.17 |
| | 2D | 8 | 31.04 | 31.12 | 0.09 |
| | 3C | 8 | 17.69 | 17.8 | 0.11 |
| | 3D | 8 | 17.97 | 17.97 | 0.00 |
| | 4C | 8 | 54.89 | 55.01 | 0.12 |
| | 4D | 8 | 58.03 | 58.03 | 0.00 |
| | 5C | 9 | 68.03 | 68.17 | 0.14 |
| | 5D | 9 | 67.50 | 67.64 | 0.14 |
| Moraine clay "sasiCl" (till) from Szalejów Górnny | 6C | 9 | 16.19 | 16.46 | 0.27 |
| | 6D | 9 | 16.28 | 16.55 | 0.27 |
| | 7C | 8 | 17.88 | 18.17 | 0.28 |
| | 7D | 8 | 19.00 | 19.28 | 0.28 |
| | 8C | 9 | 22.44 | 22.74 | 0.30 |
| | 8D | 9 | 21.95 | 22.10 | 0.15 |
| | 9C | 8 | 40.28 | 40.57 | 0.29 |
| | 9D | 8 | 40.29 | 40.59 | 0.30 |
| | 1E | 8 | 42.49 | 42.76 | 0.28 |
| | 1F | 8 | 46.12 | 46.33 | 0.21 |
For all figures 3-18: “w[\%]” means moisture content and czas [min] means time of test in minutes. All results of testing were juxtaposed in table 1. One may notice that so called “total error” is of the same range (or even smaller) than the difference of moisture content between 2 samples from the same portion of ground. So, it seems to be negligible for practical reasons.

4. Discussion of obtained results
The conducted study shows that for cohesive soils, the ground should be heated in a microwave oven for about 8-10 minutes, regardless of its initial humidity (in the tested range - 16-70\%). In cohesive soils, there is no regular trend and the drying time depends on the sample moisture and soil granulation. Therefore, it is recommended to heat cohesive soils for at least 10 minutes, non-cohesive soils for up to 20 minutes (or longer) and observe the results in comparison with the results after drying with hot air for 24 hours, and adjust the heating time in the microwave oven individually depending on the granulation and estimated humidity of the sample. A total of 40 samples of different soils and of various humidity were tested. In the case of only one sample, the test result differs by more than 1\%, which suggests that drying in a microwave oven does not significantly affect the obtained value.

Due to the simplicity of implementation, saving energy and time, it should be stated that this method can be very useful for earthworks contractors to control the quality of performed works, due to the fact that very often technical specifications specify the value of humidity at which the soil compaction process can be optimized. However, the implementation of such a procedure should be preceded by multiple tests with the use of an air dryer in order to determine the time of heating the samples in the oven. It is also necessary to verify the tests with the results of parallel laboratory tests. However, you can continue construction works without waiting for results, which can translate into shortening the time to erect the embankment.

The study carried out for the purposes of this work, due to the small sample population, is not a statistically significant sample and cannot be the basis for formulating specific equations for e.g. determining the time of sample heating. However, it may constitute an executive guideline that allows to optimize the investment implementation time, improve the quality control of the works performed, through the possibility of much more frequent confrontation of the humidity parameter of the built-in material with the designer’s requirements in this regard.

5. Final conclusions
The authors would like to emphasize, on the basis of own experience, the role and importance of international education within Erasmus [16] and other exchange programs [17] in gathering experiences and knowledge [18], especially for those areas of science, where individual contact with industrial process is crucial and vital [19,20].

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