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Original Article

Analysis Study of Soil Materials Based on Different Moisture Measurements

Ahmed Amin Jubair[1], Yousif Al Mashhadany[2]

[1]*Waters Resources and Dams Engineering Department, College of Engineering, University of Anbar, Anbar, Iraq.*
[2]*Department of Electrical Engineering, College of Engineering, University of Anbar, Iraq.*

[2]*Corresponding Author : yousif.mohammed@uoanbar.edu.iq*

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Abstract *- Rapid determination of the moisture content is usually required for the control testing of the soil materials used in the construction of earthworks such as embankment dams and roads. This Investigation examines the reliability and accuracy of the microwave drying method in determining the moisture content for different soil types and conditions; the soils considered included clean, silty and clayey sand soils and clay soils with low to very high degrees of plasticity. Many calibration tests were carried out on samples carefully prepared to investigate the main factors that affect the determination of moisture content in the microwave oven; these factors include the drying time, the total mass of soil specimens, the arrangement of specimens inside the oven and the type of the microwave oven used for testing. The standard and microwave oven methods were applied to perform moisture content tests on many samples initially prepared at different moisture conditions from seven other sand and clay soil types. The analysis of study results yielded relationships with an extremely high correlation between the data measured by the two test procedures for all soil types tested. Using the developed correlation relationships, the microwave method was applied for performing more than 500 control tests while constructing a 1.2 km earth embankment length for Al Garah 2 dam heightening. The microwave oven method proved to be a convenient and accurate means of determining soil moisture content quickly (15 min).*

Keywords *- Moisture measurements, Soil materials, Investigation examines, Microwave testing, Soil Specimens.*

1. Introduction

The moisture content is probably the simplest but one of the most important properties that profoundly affect soil engineering behaviour. The soil characteristic is perhaps most frequently measured on soil samples and used in calculating many other engineering parameters [1-3].

It is generally used as a guide to the classification of naturally occurring soils and as a control criterion in soil fill compaction during the construction of earthwork projects such as embankment dams and road pavements. Airport-strips and other similar earthworks, the standard or definitive method for measuring the moisture content of the soil is the conventional oven drying method, which is recommended in the widely recognized testing standards such as the BS and the ASTM [4].

In this test procedure, the soil specimens are normally dried at 105-110 °C in the oven, varying from a few hours to 16-24 hours, depending on the soil type tested [5, 6]. In practice, the programmed construction in most earthworks will be seriously affected if the site engineers have to wait more than 1-2 hours to obtain the control test results needed for approving, correcting or rejecting the works constructed by the contractor. Therefore, the construction of earthworks (e.g. embankments and roads) dictates the use of a rapid method of moisture content determination for compaction control. The method adopted should give a sound and accurate correlation with the definitive method of moisture content measurement [7, 8]. At present, there are several methods in use for the rapid determination of the moisture content of soils, such as:

- Drying soil in a pan over an open flame.
- Combining the moist soil in a pressure-tight chamber with chemical compounds, e.g., calcium carbide, that reacts with gas degrees and relating the gas pressure to the moisture content (1).
- Using unclear devices which detect the presence of hydrogen atoms in the soil-water mixture (2) and.
- Using microwave radiation, energy is transferred to the soil-water mixture, causing either a phase change or a temperature rise (3, 4).

Discussion on the advantages and drawbacks of each method is available in published literature (4, 5). The microwave oven method of moisture content determination is not considered a standard test in many countries, and, to the author's knowledge, the technique has not been used routinely for drying samples in local soil laboratories.

Therefore, the microwave moisture content test procedure must be calibrated against the standard method by performing appropriate test series to evaluate and/or eliminate the main factors affecting the test results [9].

The study described in this research investigated the possibility of using the microwave oven method to measure the moisture content during the control testing programmed for Al Garah 2 dam heightening. This significant development irrigation project involves filling 1.5 million cubic meters of earth dams.

For such a project, a considerable number of control tests should be performed, and, at the same time, a sufficiently high rate of material filling must be maintained to complete the construction within a reasonable period. The supervising engineers should issue their approval for the works completed by the contractor within a short time so that the building structure can proceed according to the planned program [10].

As indicated earlier, such a situation necessitates using a quick, simple and accurate method of moisture content determination of the various rapid test techniques available. The microwave method was chosen for this study [11-14].

2. Test Programmed

2.1.General

A comprehensive experimental program was planned and undertaken to define the relationship between the moisture contents measured by the microwave and the standard test methods and to confirm the former's reliability and accuracy for various soil types and conditions. The details of this programme are described in the following section.

2.2. Sample Preparation

To obtain a helpful comparison between the moisture content determined by the standard and the microwave oven test methods, care was taken to ensure that the soil specimens tested from each soil sample were as identical as possible [15, 16]. All samples were air-dried, broken down into small lumps, and thoroughly mixed with water to give the initial moisture content.

The samples were then stored in tight containers for 24 hours for curing. Each piece was then divided into two portions: the standard test method and the microwave oven test method [17]. The sample portion to be tested in the microwave oven was divided into live specimens, and the portion to be tested by the standard method was divided into three specimens [18].

2.3. Test Methods

The procedure for determining the soil moisture content by the oven drying method conforms with that specified in the British standard BS1377: Part 2:1990; Method 3.2 . Two different types of microwave oven models, manufactured by the Goldstar Co. (Model ER-935E) and the National Co. (Model NN 6550) in Japan was used in this Investigation to determine soil moisture content [19] rapidly.

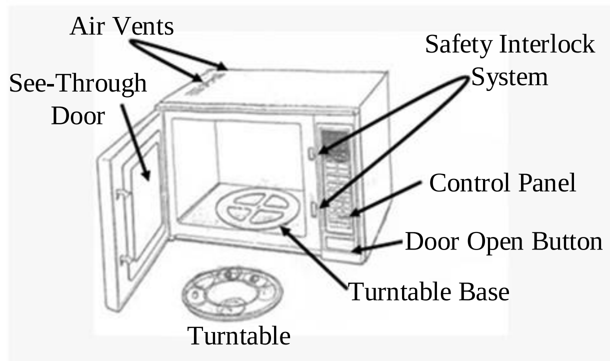

Fig. 1 Main features and parts of the turntable-type microwave used in the study

The Goldstar-type oven was the primary device used throughout to examine the main factors affecting the moisture content measurement and to establish a correlation with the standard method for the various soils.

The National microwave oven was used later to confirm the validity of the study findings for the moisture content data measured by a similar oven manufactured by a different firm. A schematic illustration of the main features of the two microwave ovens is shown in Figure 1 [20, 21].

3. Factors Affecting Moisture Content Measurement by the Microwave Method

3.1. Arrangement of Soil Specimens Inside the Oven

It is difficult to evaluate quantitatively the effect due to the positioning of soil specimens inside the microwave oven on the measured moisture content. Still, this effect may somehow be controlled during testing. To minimize the possible impact on the moisture content due to this factor, the drying dishes containing the soil may be arranged in a pattern that must be followed throughout the testing program.

Such an arrangement was adopted in this Investigation for placing the soil material to be dried inside the oven. In each test, the porcelain dishes containing the soil specimens were put on and along the perimeter of the circular turntable (Figure 1) to ensure an even distribution of the radiated microwave energy during the turntable rotation. The possible variations in the moisture content due to the random positioning of soil specimens inside the microwave oven are believed to be minimized if not eliminated. The practical testing and evaluation of all results to analyse the many cases illustrated in this work are shown in the reasonable six steps in Figure 2. These same steps and registration achieve all instances of the results with time.

Fig. 2 Practical installation with six steps

3.2. Drying Time

Many test series were carried out to investigate the effect of drying time on the moisture content determined by the microwave oven method and to decide on the most suitable times required to give test results similar to those obtained by the standard way. Seven soil types were tested after being prepared at different initial moisture conditions covering relatively wide ranges. They encompass the moisture content values of interest in constructing various zones of the dam embankments. The soils included three sandy soils, namely clean, silty and clayey sand types and four clayey soils, with low, medium, high and very high degrees of plasticity. For each sample of a specific soil, five identical specimens weighed about 50g. were dried in the microwave oven at different times, ranging from 1 to 9 minutes for sandy soils and 3 to 10 minutes for clayey soils.

After each time, the moisture content was determined for the dried specimens arid, and the average value was taken as the sample microwave moisture content. Three other specimens were prepared from the same sample and tested by the standard oven method, and the average moisture content value was also obtained. This test was repeated on samples from the same soil having different initial moisture contents. The other six soil types were tested similarly, and the average microwave moisture content (Wm) values obtained from these tests were plotted against the microwave drying time in Figures 3 and 4 for the sandy soils and the clayey soils, respectively. It may be noted from the relationships between moisture content and drying time shown in both figures that the soil samples start to lose moisture at a relatively high initial rate, decreasing gradually with an increase in the microwave oven drying time. In some tests, a stage was reached beyond which there was practically no change in the sample's moisture content with increasing drying time. It was also observed that the microwave oven drying time depends on the soil's initial moisture condition.

Soil samples with relatively high initial moisture content typically require longer drying to reach constant microwave moisture content values. Using the curves shown in Figures 3 and 4, the drying time necessary to get fairly constant microwave moisture content or deals equivalent to those obtained from the standard were estimated for each soil sample as summarized in Table 1.

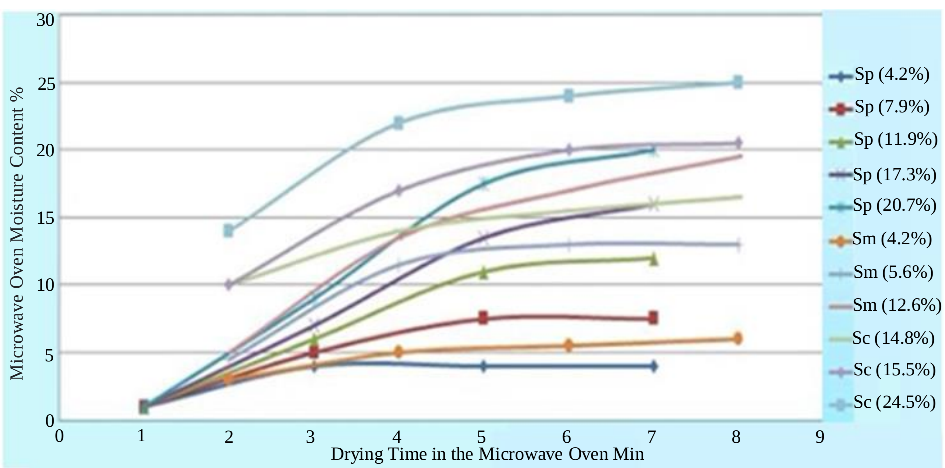

Fig. 3 Effect of drying time on the measured microwave oven moisture content for different samples of SP, SM, and SC sand soil types

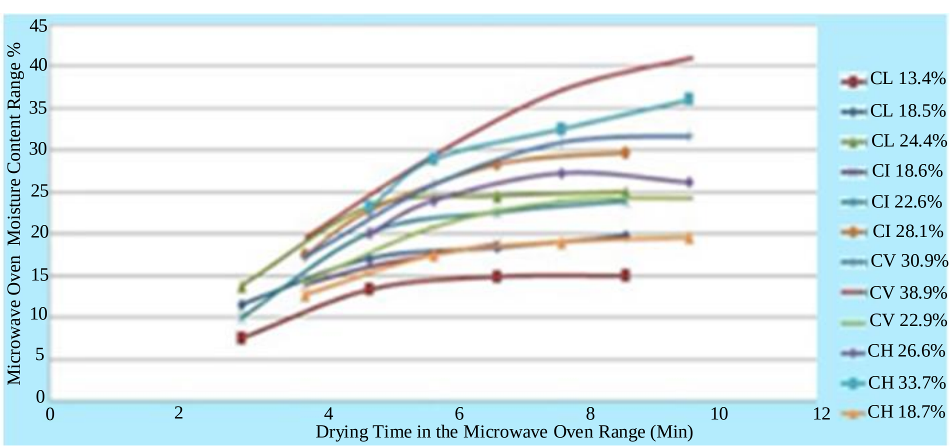

Fig. 4 Effect of drying time on the measured microwave oven moisture content for different samples of CL, CI, CH and CV clay soil types

Table 1. Drying time ranges required to give a constant microwave content or equivalent values of the standard moisture content

Soil Type	Sand Soils			Clay Soils			
Soil USCS Designation	**SP**	**SM**	**SC**	**CL**	**CI**	**CH**	**CV**
Moisture Content Range (%)	4.2-20.7	5.6-18.1	14.8-24.5	13.4-24.4	18.6-29.1	18.7-33.7	22.9-38.9
Drying Time Range (Min)	6.5-7.0	6.0-7.0	6.0-8.0	6.0-8.5	6.8-9.0	7.5-9.0	7.8-9.2

According to the information in Table 1, the time for which specimens from the clean, silty and clayey sand soils should be dried in a microwave oven varies between 6 and 8 minutes; in 80% of the sand samples tested in this series, the drying time was found to be 7 minutes which also represents the overall average for the drying time range for all sand samples, The time of 7 minutes may therefore be adopted for all sandy soil types. For the clay soils, the appropriate drying time for specimens in the microwave oven varies from 6.0 to 9.2 minutes, depending on the degree of plasticity of the clay soil tested. To simplify the test procedure, it would be desirable to fix the drying time for all clay types because:

a) Such soils often naturally occur in variable degrees of plasticity even within the same site and
b) Prior classification of the soils will be required if the drying time in the microwave oven has to be specified for each clay type. For these two reasons, it was decided to set the microwave drying time at a fixed time, i.e. 7, S or 9 minutes in tests made on all clay types.

To choose the most suitable time duration, a further investigation was carried out on 100 samples prepared from clay soils with variable degrees of plasticity at different initial moisture conditions. Each sample was divided into four identical portions. three of which were tested by the microwave oven method using drying times of 7, 8 and 9 minutes and the fourth portion was tried by the standard oven method.

A statistical linear regression analysis was conducted to establish the mathematical relationship between the moisture content data measured by the standard method and the three microwave test methods. The analysis results, which include the correlation equations of the best-fit trend Tines, the correlation coefficient, R2 and the standard error, are given in Table 2 and Figures 5, 6 and 7.

Table 2. Comparison of moisture content values for clay samples subjected to different drying times in the microwave oven

Microwave Drying Time (Min)	**7**	8	9
Correlation Equation (Ws)	1.024*Wm–1.2677	1.1146*Wm- 3.8616	1.0139*Wm-0.8269
Correlation Coefficient (R^2)	0.9691	0.9781	0.9921

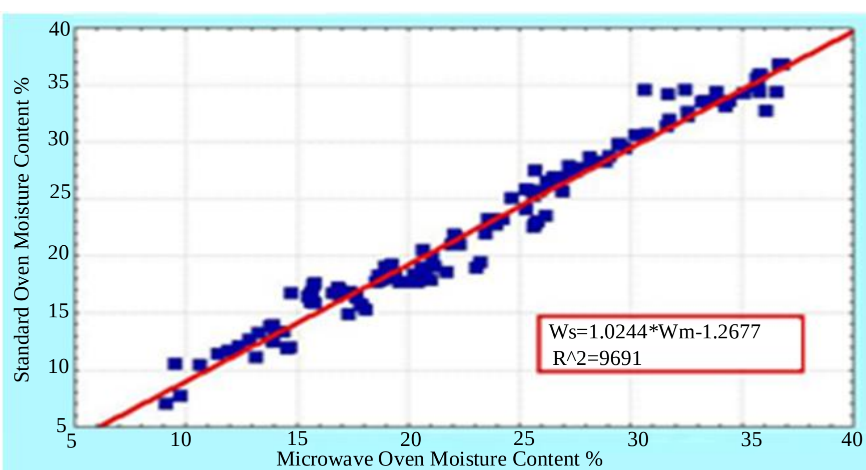

Fig. 5 Moisture content values for clay samples subjected to 7 minutes of drying in the microwave oven

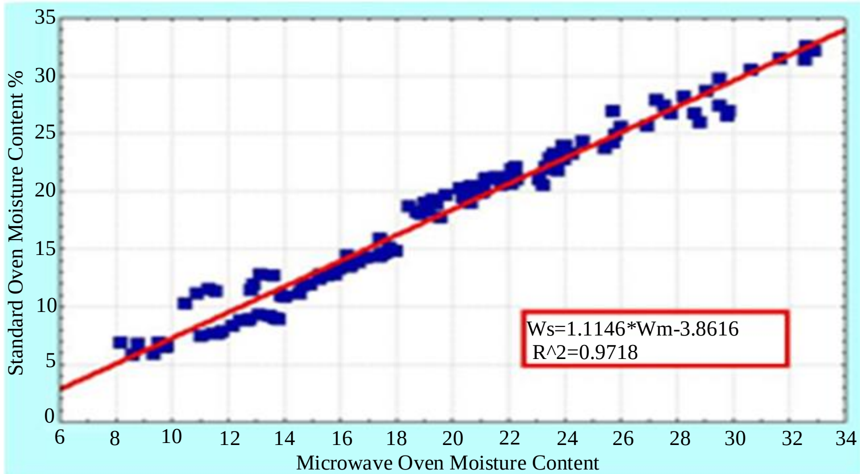

Fig. 6 Moisture content values for clay samples subjected to 8 minutes of drying in the microwave oven

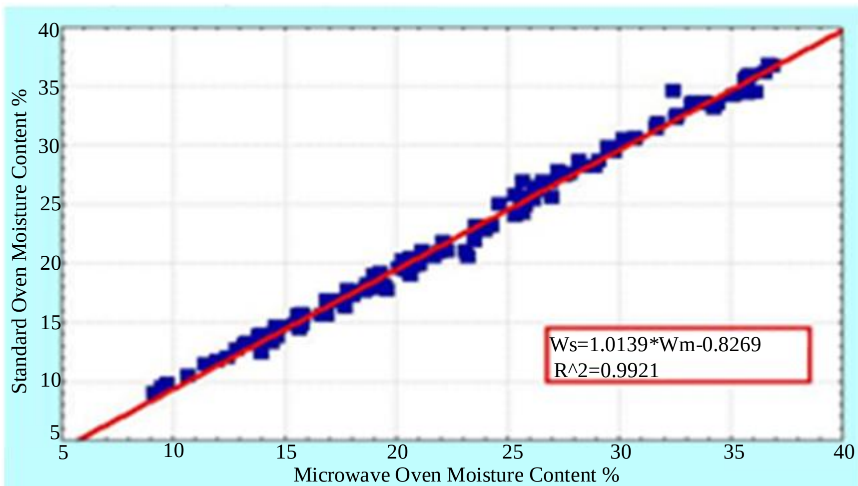

Fig. 7 Moisture content values for clay samples subjected to 9 minutes of drying in the microwave oven

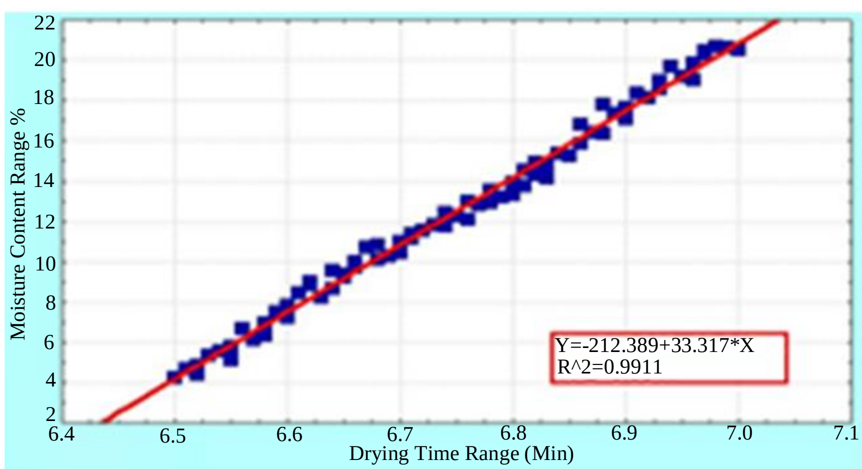

Fig. 8 Effect of drying time on the measured oven moisture content for (SP) sand soil

The coefficient, R^2, measures the strength of correlation between the moisture content data determined by two different test methods such that the closer its value to unity, the higher the degree of correlation. From the comparison of slopes, three correlation equations, and the importance of correlation coefficient and standard error in Table 2, it is clear that the best moisture content correlation results correspond to the 9-minute microwave drying time. Based on the calibration tests described above, the drying times of 7 and 9 minutes were considered appropriate. They were subsequently used for determining the moisture content by the microwave method in the sand and clay soils, respectively. The seven soil types were tested in the same manner, and the average microwave moisture content (Wm) values obtained from these tests were plotted against the microwave drying time in Figures 8 to 14.

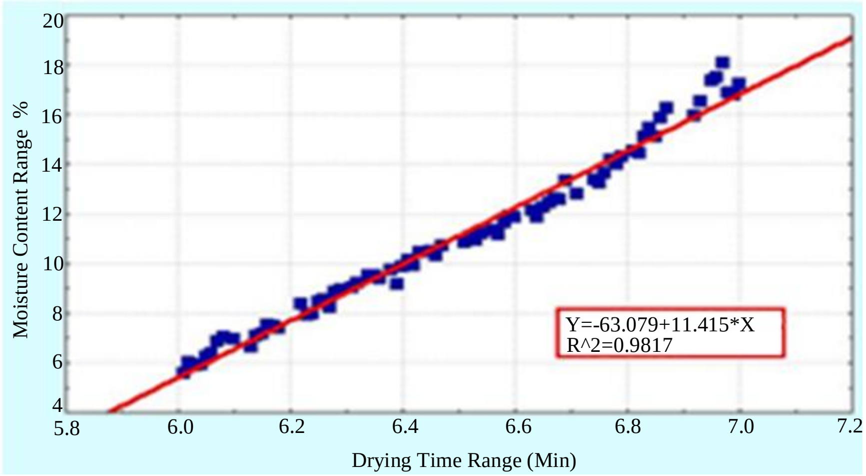

Fig. 9 Effect of drying time on the measured oven moisture content for (SM) sand soil

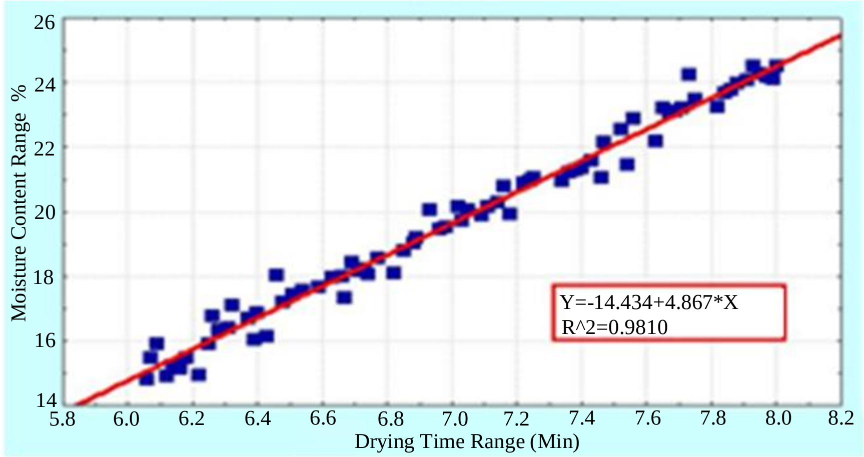

Fig. 10 Effect of drying time on the measured oven moisture content for (SC) sand soil

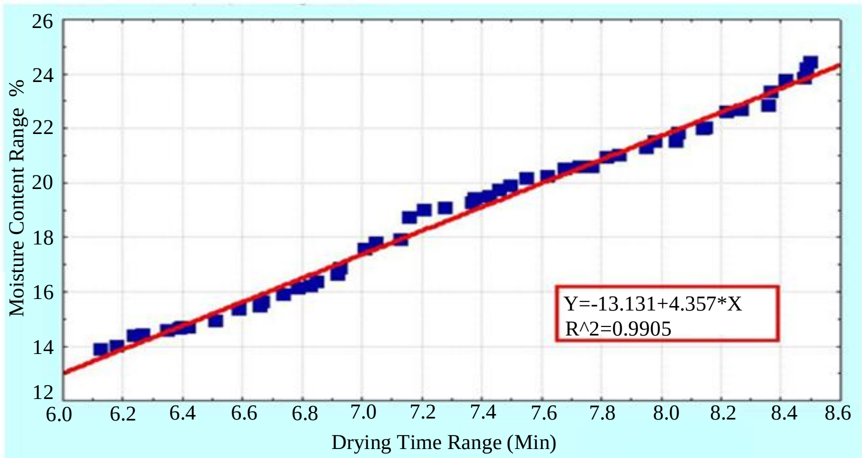

Fig. 11 Effect of drying time on the measured oven moisture content for (CL) clay soil

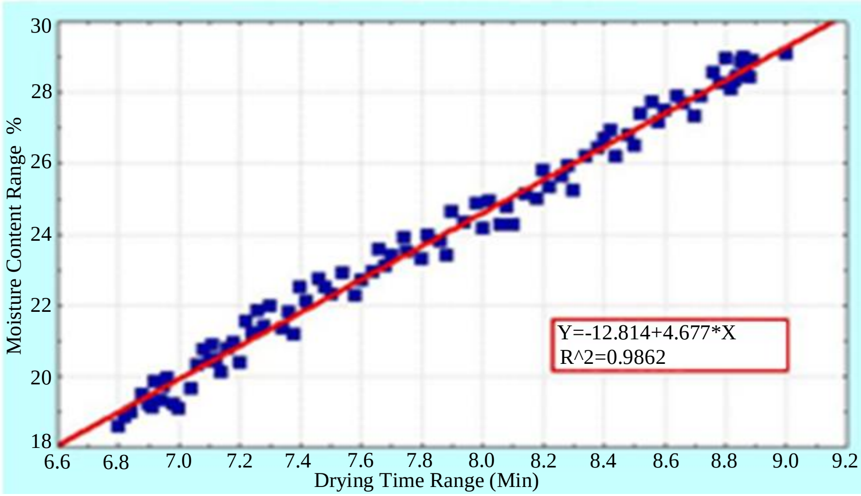

Fig. 12 Effect of drying time on the measured oven moisture content for (CI) clay soil

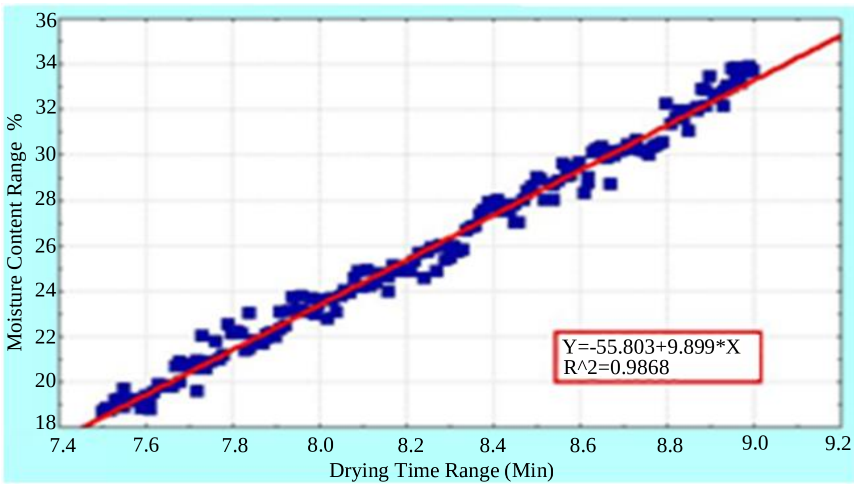

Fig. 13 Effect of drying time on the measured oven moisture content for (CH) clay soil

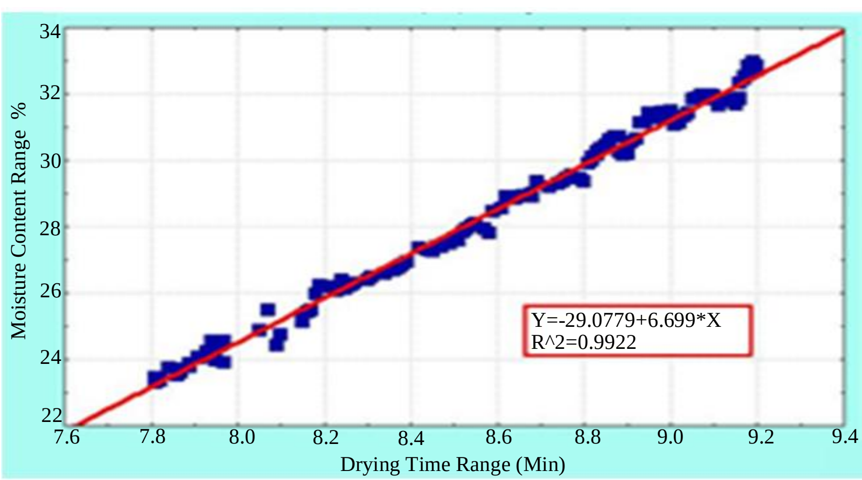

Fig. 14 Effect of drying time on the measured oven moisture content for (CV) clay soil

3.3. Effect of Sample Mass on Moisture Content

To investigate the effect of the sample's size (i.e., mass) on the moisture content determined by the microwave method, a third calibration test series was carried out on some samples from the seven soil types considered in section 2.3.1. The samples were initially prepared at moisture contents ranging from 4% for the clean sand to 38% for the clay of very high plasticity.

Intermediate moisture content values, which roughly represent the soil conditions likely to be used for construction, were selected for the remaining five soil types; in each test, the total mass of the material placed in the microwave oven was varied to cover a relatively wide range by changing the number and size of the specimens tested from each soil sample. The number of models tested at a time varied between 1 and 5, whereas the mass of individual specimens changed from 30 to 70g to give an overall sample mass range of 30 to 350g. During testing, the microwave oven drying times were set at 7 and 9 minutes for the sandy and clayey soil types, respectively.

The average moisture content values determined were plotted against the total mass of soil specimens, as shown in Figure 4 for the seven soil samples. From the relationships shown in Figure 15, the sample size has a practically insignificant effect on the moisture contents determined by the microwave oven method for sands and clays of low to intermediate degree of plasticity. For the clay samples of high and very high plasticity. The sample mass has a little inverse effect on the measured moisture content within the mass range between 30 and 250g.

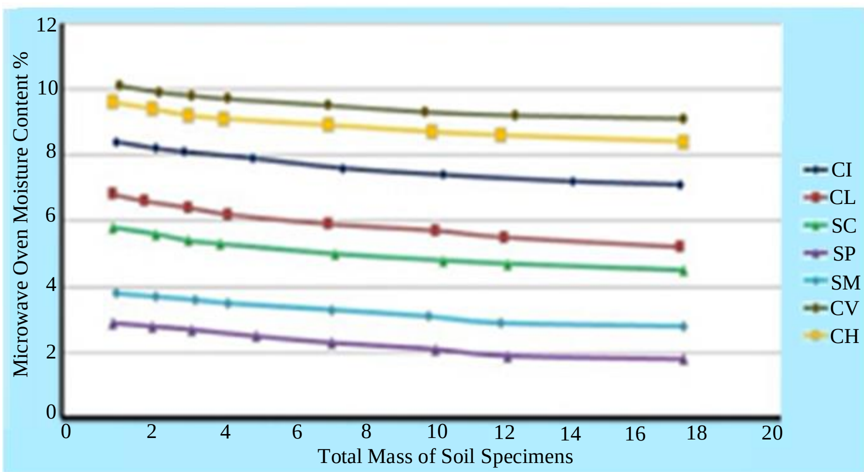

Fig. 15 Effect of soil specimens' mass on microwave moisture content

This effect may be attributed to the. The material's nature and the relatively high initial moisture contents in the samples tested from the highly plastic soils.

However, if the total mass is maintained during testing within a narrow range, e.g., 250-300g, its effect on the measured moisture content becomes insignificant practically. It might be neglected. Therefore, for low-plasticity sands and clays, the soil samples' total mass does not affect the lowest results, and any value within the range of 30 to 350g may be loaded in the microwave oven.

For highly plastic soil samples of relatively high initial moisture contents, the total mass of the soil specimens tested in the microwave oven at any time should preferably be within 250-300g.

As a maximum of six 100mm diameter specimen dishes could be contained inside the microwave oven used in this study, the mass of each specimen was adjusted at 50g throughout each test for all types of soil. The microwave method test procedure of moisture content measurement was amended according to the findings drawn from the results of the various calibration tests about the three main factors discussed in this section. The effect of the microwave oven type cm on the measured moisture content was discussed in section 3.3.

4. Correlation between Moisture Content Data by the Standard and Microwave Oven Test Methods

Before applying the microwave test method on a routine basis, it is necessary to establish the correlation between the moisture content data determined by this method and the standard oven method for each soil type.

Several test series were planned and performed on samples prepared from the soil types considered in this study to achieve this objective at widely different moisture contents. Details of these tests and the findings drawn from the analysis of the moisture content data corresponding to the sandy and clayey soils are described below.

4.1. Moisture Content Correlation for Sandy Soil

Comparison moisture content tests were performed on 106 sample pairs of clean sand (SP) and 139 sample pairs of silty and clayey sand (SM, SC) soil types by the standard and the microwave oven methods, Eight identical specimens, each weighing 50g, were prepared from each soil sample for moisture content testing: of which five were dried in the Goldstar microwave oven for 7 minutes and three in the conventional oven for 24 hours.

The average moisture content values determined by the two methods were plotted in Figure 5 for the clean sand and Figure 6 for the silty and clayey sand. For comparison, the statistical regression method analysed the test data to define the mathematical relationship between the moisture content measured by the two test methods and as a result. The following two correlation equations were obtained in Figures 16, and 17.

Ws = 1.095 wm – 2.2141, For the clean sand (1)

and

Ws = 1.5705 wm – 4.1697, For the silty and clayey sands (2)

Where,Wm:moisture content measured by the microwave method dried for 7 minutes (%).
Ws:moisture content measured by the standard test method (%)

The correlation coefficient R2 values very close to unity (0.9857 to 0.9883) were obtained for both soil types. This indicates an excellent correlation between the moisture content data determined by the standard and the microwave test methods. It is worth noting that the moisture contents computed according to equations 1 and 2 will give a minimal constant difference of 0.26%.

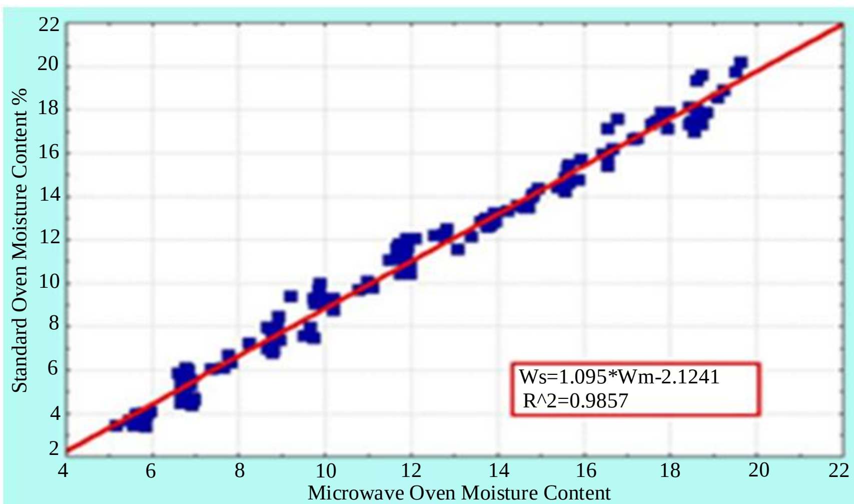

Fig. 16 Moisture content correlation for clean sand soils

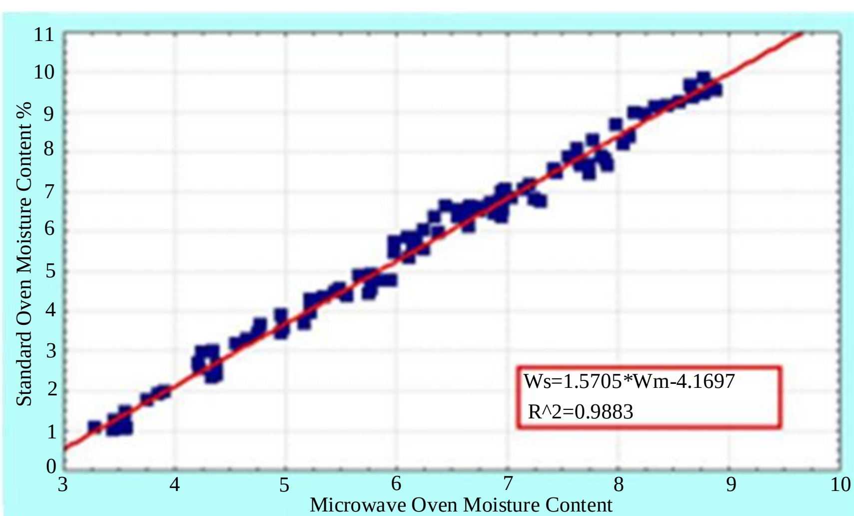

Fig. 17 Moisture content correlation for silty and clayey sand soils

From a practical viewpoint, this discrepancy in moisture content is insignificant. It implies that the type of sandy soil does not affect the relationship between the moisture content measured by the two methods; thus, a single equation may be proposed for all sandy soils. Such a moisture content correlation was developed using test data for 245 sample pairs of SP. SM and SC materials as follows between ws and wm:

Ws = 0.9994*wm +0.059, With a value of R2 = 0.994 (3)

This combined moisture content correlation equation may be used for all sandy soils with fines content (i.e. the percentage of soil fraction finer than 0.075mm grain size) less than 50% and for moisture content values ranging from 2.5 to 25.0%.

4.2. Clay Soils with Variable Degrees of Plasticity

A large number of moisture content comparison tests were carried out on clay soils of different initial moisture contents, including clay samples of low plasticity (CL), intermediate plasticity (CI), high plasticity (CH) and very high plasticity (CV). For each sample, five specimens were tested in the Gold Star microwave oven for 9 minutes and three in the conventional oven for 24 hours. The average moisture content values determined by the two test methods were plotted against each other, as shown in Figure 7 for all clay types.

The small degree of data scatter, which may be observed for the samples with relatively high moisture content, i.e., between 28 and 38% in Figure 17, is believed to be within the range of random experimental errors caused by specimen sampling, preparation and testing. Statistical analysis of the data plotted in Figure 18 was carried out using the linear regression method for each clay type separately. The moisture content correlation equation was established between the two-test data for the clays with variable degree of plasticity and are given in Table 3.

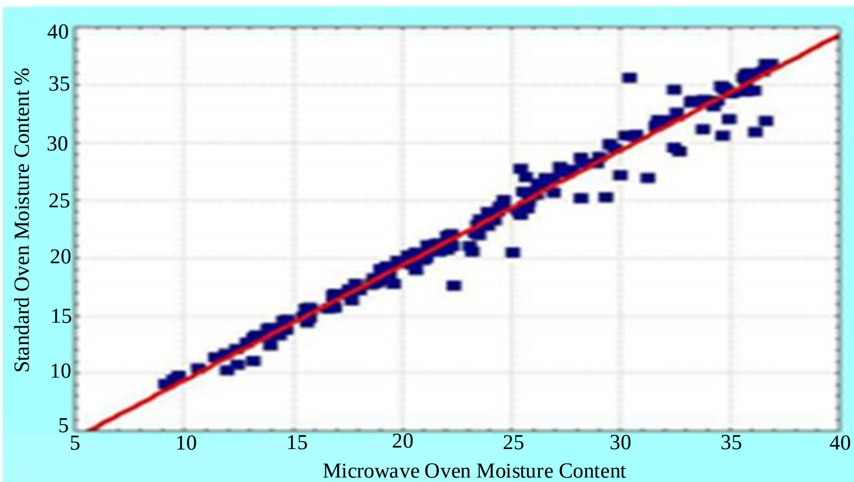

Fig. 18 Combined moisture content correlation for all clay soil

Table 3. Moisture content correlation for clay variable degree of plasticity

Clay Type	No. of Samples	Correlation Equation	Correlation Coefficient
CL	50	$W_S = 0.0353 + W_m$	0.994
CI	90	$W_S= 0.03 + 1.0004\ W_m$	0.984
CH	179	$W_S= 0.059 +0.9994W_m$	0.982
CV	132	$W_S=02039+0.9938W_m$	0.986

WS = moisture content measured by the standard by the standard or definitive test method (%)
Wm = moisture content measured by the rapid microwave oven test method dried for 9 minutes (%)

From a practical viewpoint, it would be desirable and preferable to have a single moisture content correlation for all clay types; the use of an individual correlation equation would require pre-classification of each material tested, which may not be more convenient for the laboratory technicians to use a single rather than several correlation equations notably when the moisture content values estimated according to individual and combined correlation methods will not differ significantly. Based on this, the moisture content data measured in all clay soil types (451 sample pairs) were used to develop the following combined correlation equation:

Ws = 0.9938 *Wm +0.2039, (R^=0.986) (4)

To check the validity of this equation for all clay soils, a comparison was made between the moisture content data calculated for each clay type according to the appropriate individual equation (listed in Table 3) and the combined correlation given by Equation 4. Assumed moisture content values, Wm covering wide ranges were used to compute the corresponding Ws values. The results in Figure 19 clearly shows that the data points of individual soils are virtually lying on the trend line for the combined grounds.

This indicates that the moisture content differences are insignificant for virtually all clay type and, thus, the combined correlation equation 4 may be used for all clay soils regardless of their degree of plasticity.

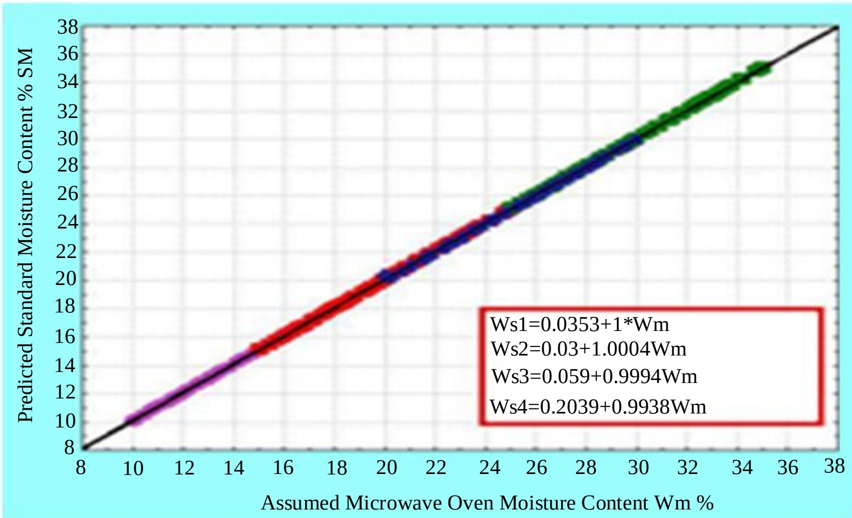

Fig. 19 Comparison of moisture content from individual and combined correlation for clays of low to very high plasticity

4.3. Application of Developed Moisture Content Correlation Methods

The moisture content correlation relationships developed for sandy and clay between the standard and microwave oven test methods were used to control compaction during the construction of embankment sections in the resources dam. Heightening project. More than fifteen thousand in situ moisture content and dry density tests have been performed on different fill materials since 1994 by the microwave method, which proved very successful and reliable. The type of microwave oven regularly used since the start of the construction was the same Goldstar Co.

Device described in this paper. However, due to the intensive laboratory work required for this project. a National Co (Japan) microwave oven (Model 6550) with features similar to those of the Goldstar microwave (figure 1) was also used during construction; however, before using the National oven, an investigation was made to study the effect on microwave oven type on the moisture content correlation A test series was carried out to compare the moisture content values measured by the National device with the standard and the Goldstar microwave oven methods.

The three test procedures were followed in testing samples of clean sand, silty and clayey sand and clay soils with different moisture content; the test results were analysed by the linear regression method to establish the correlation between the moisture content data measured by the standard procedure on the one hand and by the two microwave methods on the other. The results of this analysis are summarized in Table 4.

Values of the moisture content Ws estimated according to the equations in Table 4 yielded a close comparison between the Goldstar (Wg) and the National (Mmw)-microwave methods with maximum differences of 0.5% for the sandy and clay soils, respectively.

The moisture content ranges used in the calculation were chosen for the different soils to encompass their corresponding optimum moisture contents that are of interest in the compaction control for most earthworks.

They varied from 4 to 12 % for clean sands-10 to 20 % for silty and clayey sands, and 15 to 35 % for clays. The excellent correlation between the test data measured by the Goldstar and the National microwave ovens indicates that the turntable microwave ovens similar to these two models are suitable for rapidly determining soil moisture content. However, the microwave ovens used differ from those considered in this study.

Table 4. Comparison of moisture content data for soil samples tested indifferent

Soil Type	Analysis Data	Goldstar Microwave Oven	National Microwave Oven
Clean Sands	Data Size Correlation Equation Coefficient R^2	68 W_S=1.06W_{mg}-0.14 0.929	63 W_g=1.11W_{mn} -0.34 0.929
Silty and Clay	Data Size Correlation Equation Coefficient R^2	35 W_S=0.935W_{mg}+0.08 0.949	35 W_g=0.984W_{mn} + 0.25 0.974
Clay soil	Data Size Correlation Equation Coefficient R^2	55 W_S=1.026W_{mg}-0.45 0.931	69 W_g=1.989W_{mn} – 0.58 0.943

Wmg = Moisture content measured by the goldstar microwave oven method (%)
Wmn = Moisture content measured by the national microwave oven method (%)

5. Conclusions

The following conclusions may be drawn from the results of the present study:

Although it is not a universal technique, the microwave oven drying method proved to be a convenient and reliable testing procedure for rapidly determining the soil moisture content of sand and clay soils with widely different moisture contents. To establish moisture content correlation with the standard test method, calibration tests must be conducted to refine and ratify the test procedures based on the microwave drying technique-the time required for drying, the number.

The mass and arrangement of soil specimens tested in the microwave oven should be specified based on the results obtained from the calibration tests. For the two types of microwave oven used in this study, the drying time was set at 7 minutes for all sandy soils and 9 minutes for all clay soils for a maximum of six soil specimens, each weighing 50g per test. Empirical moisture content equations of the extremely high degree of correlation were developed in this study by analysing data from many sandy and clayey soil samples tested by the standard ‘and the microwave oven methods. Using the microwave method, the two correlation equations 3 and 4 have been proposed for estimating the moisture content of the various types of sandy and clay soils. The moisture content correlation methods established for sandy and clayey soils were successfully applied in the compaction control of soil materials used for the Al Kagarah embankment dam construction works. The microwave oven method described in this search was used for testing over five thousand samples and proved to be a reliable and accurate means of measuring soil moisture content in about 15 minutes.

The validity of the microwave moisture content method was checked using an oven similar to the main Goldstar oven employed in this research by a different company. For many sandy and clayey soil samples tested by two microwave ovens, the measured moisture content data fully agreed with those determined for the same samples by the standard test method.

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