STUDY ON THE DETERMINATION OF MOISTURE CONTENT OF SOILS BY MICROWAVE OVEN METHOD

GEO REPORT No. 221

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Table of Contents

Table of Contents

Table of Contents

Table of Contents

PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

The Geotechnical Engineering Office also produces documents specifically for publication. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

R.K.S. Chan
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January 2008

FOREWORD

Microwave oven method is an alternative to the oven-drying method specified in the General Specification of Civil Engineering Works (1992 Edition). This method is much quicker for drying of soils than the oven-drying method and therefore would be ideal for rapid moisture content determination. However, there is a concern that the determination of moisture content of soils using microwave oven may give erroneous results due to the possibility of overheating. Thus, microwave oven method is not routinely used. There is merit to further develop microwave oven method for routine soil testing.

In the past few years, the Public Works Central Laboratory of the Geotechnical Engineering Office conducted a study on the reliability of using microwave oven for determination of moisture content of soils. This report documents the details and results of the study.

The study was initially carried out by Mr. Philip W K Chung under the supervision of Mr. Joe B N Leung and was later taken over by Mr. Michael M Y Ho and Mr. Tony Y K Ho under the supervision of Mr. Willie W L Wong. The draft report was prepared by Philip W K Chung and was finalised by Mr. Tony Y K Ho under the supervision of Mr. Rick C K Tam. Mr. P P Fan and other colleagues of the Public Works Regional Laboratories provided useful comments on a draft of this report.

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

ABSTRACT

The standard test method for determination of moisture content of soils in Hong Kong is given in Geospec 3 - Model Specification for Soil Testing (previously GEO Report No. 36). The method is based essentially on use of traditional convection oven operating at a temperature of either 45ºC ± 5ºC or 105ºC ± 5ºC depending on the types of soil samples tested. It needs a drying time of at least 20 hours, which is considered to be too time consuming for some construction jobs (e.g. fill compaction works) where a quick but fairly accurate determination of moisture content of soils is required.

This study contains a review of literature and existing test standards in relation to the use of microwave oven for moisture content determination. In addition to the test method stated in the General Specification (GS) for Civil Engineering Works (1992 Edition), ASTM D4643 is found to be another readily available standard test method, which includes requirements to control the power ratings of microwave ovens and the period of drying procedure. Thus, the possibility of overheating of a soil sample can be greatly reduced.

Based on the laboratory tests conducted under this study, both the ASTM and GS methods give comparable test results and agree reasonably well with those obtained by convection oven method (maximum actual difference within 1%). In addition, the methods are found to be suitable for most common fill materials adopted in Hong Kong (usually from CDG and CDV origins). Provided that proper power setting of microwave oven is used, the tests can normally be completed within an hour. As regards the test procedures, the GS method is relatively less labour-intensive than the ASTM method and is thus more preferable from site operation point of view.

To enhance the reliability of the GS method, some amendments to the existing test requirements and procedures are suggested, such as control on maximum drying period and output power ratings of microwave ovens. Moreover, several safety precaution measures for using microwave ovens are proposed.

CONTENTS

1. INTRODUCTION

The standard test method for determination of moisture content of soils in Hong Kong is given in Geospec 3 - Model Specification for Soil Testing (GEO, 2001). The method is based essentially on use of traditional convection oven operating at a working temperature of either 45ºC ± 5ºC or 105ºC ± 5ºC depending on the types of soil samples tested. It needs a drying time of at least 20 hours, which is considered to be too time consuming for some construction activities (e.g. fill compaction works), where a quick but fairly accurate determination of moisture content of soils is required.

Microwave oven method is much quicker in drying of soils than the convection oven method. A standard method for the determination of moisture content of soils using microwave oven is given in Appendix 6.2 of General Specification for Civil Engineering Works, Volume 1, 1992 Edition (Hong Kong Government, 1992). However, this method does not specify any control on the period of drying or input/output power ratings of microwave ovens. Therefore, there is a possibility of overheating of a soil sample, hence yielding erroneous results, as water of crystallisation in the minerals may be driven out together with the interstitial water under a certain high temperature. In addition, there is no documented information concerning the reproducibility of the test results, and the applicability of the microwave oven method on some soil types is questionable.

The above issue was discussed in the Laboratory Accreditation Board (renamed as Accreditation Advisory Board) Working Party on Soil and Rock Testing. The Working Party suggested that the Geotechnical Engineering Office (GEO) undertake a study on the use of microwave oven for the determination of moisture content of soils. The Public Works Central Laboratory (PWCL) of the then Materials Division of the GEO (now under the Standards and Testing Division) took up the study.

In the past few years, the PWCL conducted a literature review and various laboratory tests to examine the feasibility of using microwave ovens for the determination of moisture contents of soils in Hong Kong and to identify a suitable test method for such determination. In addition, the reliability of different test methods on major types of soil commonly encountered in Hong Kong has been examined. Details of the study are presented in the following sections.

2. LITERATURE REVIEW

According to He (1994), microwaves were used as early as 1939 during the Second World War to detect Nazi aircrafts. Military officers discovered that cold coffee near a microwave radar became hot and hence recognised the heating effect of microwaves. The production of microwaves for domestic use by means of a magnetron was invented by a Japanese, Keishi Ogura in the early 1960s. Since then, the use of microwave ovens for heating purposes has become increasingly popular. A review of the theory of microwave heating is given in Appendix A.

The use of microwave heating to measure the moisture content of soil has been investigated by engineers since 1960s. A summary of the details and results of the previous studies is shown in Table 1.

Creelman & Vaughan (1966) claimed that they could obtain fairly accurate results for some Canadian soils by heating samples in microwave oven for 10 minutes. Ryley (1969) concluded that for most soils, the microwave oven drying method gives a result accurate to within 0.4% moisture content. However, the method is unsuitable for soil containing gypsum or for materials with a high carbon content.

Gilbert (1974) reported that the difference in moisture content between microwave heating and conventional heating ranges from 0.01% (for sand) to 1.4% (for clay with Plasticity Index = 53%). Miller et al (1974) tried two different procedures to dry soil samples. He found that the two procedures yielded different moisture content values and required drying time increased with specimen size and initial moisture content. Lade & Nejadi-Babadai (1975) also studied soil drying by microwave oven method and noticed that soil with higher moisture content required longer microwave drying time.

Hagerty et al (1990a, 1990b) were concerned about the overheating problem of soil specimens by microwave oven drying method and therefore developed some procedures to tackle it. They concluded from the test results that the microwave oven drying method using the modified procedures should be acceptable in earthwork quality control, especially when the microwave oven results were calibrated against values obtained by use of conventional oven method.

3. REVIEW OF CURRENT STANDARDS AND PRACTICE

In 1987, American Society for Testing and Materials (ASTM) published for the first time a standard test method, D4643-87, for determining moisture content of soil using a microwave oven. ASTM stated that the microwave oven method is intended not as a replacement for the conventional oven method, but rather as a supplement when rapid results are needed to expedite other phases of testing. The use of this method may not be appropriate when highly accurate results are required, or the test using the data is extremely sensitive to moisture variations. When questions of accuracy between this test method and convection oven method arise, the latter shall be the reference method. In general, the test method is applicable for most soil types. However, for some soils, such as those containing significant amounts of halloysite, mica, montmorillonite, gypsum or other hydrated materials, highly organic soils, or soils in which the pore water contains dissolved solids, this test method may not yield reliable moisture content values. For routine laboratory applications, microwave ovens with rated input powers between 1 and 2 kW have proven to be adequate.

ASTM issued the first revised edition of the standard test method, D4643-93, in 1993 (ASTM, 1993). No significant change in the test procedures was made, but the use of microwave ovens with rated input powers of about 700 W was recommended. Based on their studies, ASTM stated that the single laboratory average precision of using microwave drying, expressed as a percentage of moisture content, is 0.96% or less, depending on the soil type, initial moisture content and specimen size. The mean difference between the value of moisture content tested by the microwave oven method and the convection oven method (ASTM D2216) is 0.24% for micaceous soils (having 5 to 25% mica particles by mass) and 0.61% for other soils. The standard deviation of the value of the difference between the water content, expressed as a percentage of mass, by the microwave oven method and convection oven method (ASTM D2216) is 0.2% for the micaceous soils and 0.3% for other

soils. The results suggested that the use of microwave oven is very comparable to the convention oven method.

In 2000, ASTM issued the second revised edition of the standard test method, D 4643-00 (ASTM, 2000). In this revised edition, only very minor changes were made and all of them are not related to the test procedures and the requirement on the input power ratings of microwave ovens.

As for the local practice, a standard test method for determination of moisture contents of soils using microwave oven is given in Appendix 6.2 of the General Specification for Civil Engineering Works (GS), Volume 1, 1992 Edition (Hong Kong Government, 1992). This method is simpler than the ASTM method, without particular precautions to prevent overheating of soils. In addition, there is no control of the initial drying period and the rated input or output powers of microwave oven. According to the GS, this method is applicable to fine and medium grained soil.

The Public Works Regional Laboratories (PWRL) frequently carry out moisture content tests by using microwave ovens which in general follow the procedures laid down in the GS. To reduce the potential for overheating of soil samples, the PWRL have adopted several measures including the following:

(a) Microwave ovens used shall have rated output powers not greater than 1700 W.

(b) Time for each drying cycle is controlled to 5 minutes.

(c) In between each drying cycle, test specimens shall be mixed thoroughly to achieve a more uniform heating.

The PWRL regularly carry out comparative tests to check the microwave oven method against the convection oven method to assess the reliability. The majority of soil used for the tests is fill material ranging from sandy SILT to gravelly SAND (fine-grained and medium-grained soils). In general, the moisture content of soil samples seldom exceeds 30%. According to the comparative test results obtained thus far, the difference in moisture contents determined by the two methods does not exceed 1% (see Appendix B). Further discussion of the test results is given in Section 5.3.

4. TESTING PROGRAM

4.1 Background

Based on the literature review, the feasibility of using microwave oven to determine moisture content of soils is well demonstrated. In addition to the GS, there is an available international standard test method (ASTM D4643) for such determination. This method includes requirements to control the power ratings of microwave ovens and the period of drying procedure. Therefore, the possibility of overheating of a soil sample can be greatly reduced. In addition, the soil sample is required to be carefully mixed after each time of microwave heating for a certain period in order to prevent non-uniform heating of the sample.

In the past few years, the PWCL carried out a number of laboratory tests to examine the reliability of the ASTM test method in comparison with the convection oven method laid down in GEO Report No. 36 (GEO, 1996) and Geospec 3 (GEO, 2001). Through the tests, the PWCL aimed to assess the suitability of introducing the ASTM test method for application in Hong Kong.

The tests conducted are divided into two stages. The first stage of the tests were carried out in 1998. The test method was mainly based on ASTM D4643-93 with some modifications. The main objective of the tests is to assess the reliability of the proposed test method by comparing the results with those obtained by the convection oven method. In addition, the effect of using different power setting of microwave oven on the test results was also assessed. In 2004, the PWCL performed the second stage of the tests to provide more results for comparison of the ASTM test method with the convection oven method. The test method adopted at that time strictly followed ASTM D4643-00.

A comparison amongst the ASTM D4643 (ASTM, 1993 & 2000), General Specification for Civil Engineering Works and the test methods tried by the PWCL is given in Table 2. Details of each stage of the tests are given in the following sections.

4.2 The First Stage of Tests

4.2.1 Test Methods

The test procedures for the microwave oven method mainly followed ASTM D4643-93 with the following modifications:

(a) No heat sink was used in the tests. (Heat sink is a material or liquid placed in the microwave oven to absorb energy after the moisture has been driven from the test specimen. It is a measure to reduce the possibility of overheating the specimen and damage to the oven. In this trial, this measure was not provided with a view to simplifying the test procedures.)

(b) Initial drying period of 2 minutes was adopted. (The initial drying period specified in ASTM D4643 is 3 minutes. In this trial, a shorter initial drying period was used.)

(c) Weighing procedure following recommendations given by Hagerty et al (1990a) was adopted. Seven readings were taken at 10 seconds intervals. The average value of these seven readings from the 1-minute weighing period was used in developing the drying curve. (According to Hagerty et al (1990a), the apparent weight of specimen may continue to change after the specimen was removed from an oven. Because of the variation of weight with time, such weighing procedure was introduced in the trial to assess the significance of this effect.)

Regarding the convection oven method, the tests were carried out in accordance with Test Methods 2.3.2A and 2.3.2B of GEO Report No. 36 (i.e. by oven drying at both 45°C±5°C and 105°C±5°C).

The output power of microwave ovens under different settings (viz high, medium and low) were measured by using the method given in the Australian/New Zealand Standard AS/NZS 2895.1:1995 (AS/NZS, 1995). This standard is essentially identical to the IEC 705, which was adopted by the Consumer Council in their studies in 1995 and 2002, as mentioned in Section 2.2. In this test, about 1 kg of water at 10°C±1°C in a glass container is raised to ambient temperature (20°C±2°C) by heating in a microwave oven. The time for the water to be heated is then measured. The output power of microwave oven (in Watt) is calculated by the following formula:

$$P = \frac{4.187M_w(T_2 - T_1) + 0.844M_c(T_2 - T_0)}{t}$$

where M_w = mass of water (in g);
M_c = mass of container (in g);
T_0 = initial ambient temperature (in °C);
T_1 = initial water temperature (in °C);
T_2 = final water temperature (in °C) ; and
t = time for the water to be heated (in second).

4.2.2 Test Samples

Based on the soil grouping method given in BS1377: Part 1: 1990 (BSI 1990), three types of soils were prepared, viz coarse-grained soils, medium-grained soils and fine-grained soils. Definitions of these soil types are as follows:

(a) Coarse-grained soils - soils containing more than 10% retained on a 20 mm test sieve but not more than 10% retained on a 37.5 mm test sieve;

(b) Medium-grained soils - soils containing more than 10% retained on a 2 mm test sieve but not more than 10% retained on a 20 mm test sieve;

(c) Fine-grained soils - soils containing not more than 10% retained on a 2 mm test sieve.

The coarse-grained and medium-grained soil samples were obtained from a mixture of grade IV to grade V saprolitic and colluvial soils while the fine-grained soil sample was prepared from a SILT/CLAY soil (50% silt + 40% clay). In addition, tests were performed on saprolitic soils from two different geological origins, namely decomposed granite and decomposed volcanic. The number of specimens for each type of soil samples is listed in Table 3.

Microwave ovens with different power settings (viz high, medium and low) and

convection ovens operated at 45°C±5°C and 105°C±5°C were used to determine the moisture contents of the soils. The testing program is summarized in Table 3.

4.2.3 Sample Preparation

Prior to commencement of the tests, soil specimens with different target moisture contents were prepared. The samples were first dried out by using a convection oven operated at 105°C±5°C. Afterwards, each sample was mixed thoroughly with a pre-determined amount of water and was then placed in a plastic bag for curing overnight. The wet mass of the specimens used in the microwave oven tests is tabulated below:

Fine-grained soil	Medium-grained soil	Coarse-grained soil
100 to 200 g	300 to 500 g	500 to 1000 g

4.3 The Second Stage of Tests

4.3.1 Test Methods

From the first stage of the tests, it was found that the change of specimen mass weighed in 1 minute after each time of drying in microwave oven was not so significant (in general within 0.5% of the average value of the readings). A typical one-minute weighing curve is shown in Figure 1. In the second stage of the tests, the use of one-minute weighing procedure was omitted and the test procedures for the microwave oven method solely followed ASTM D4643-00 without any modification.

Regarding the convection oven method, the tests were carried out in accordance with Test Method 5.2 of Geospec 3 (i.e. by oven-drying at 105°C±5°C).

At the time of the tests, only two microwave ovens with rated output power of 1700W (the same model) were available for the use. Prior to the commencement of the tests, the output power of the microwave ovens at different settings (viz high, medium and low) were measured in accordance with the method given in Australian/New Zealand Standard AS/NZS 2895.1:1995 (AS/NZS, 1995). Based on the results, it was found that ‘medium’ power setting could provide an equivalent output power of about 700W, which is adequate for determination of moisture contents of soils, as recommended by the ASTM D4643. Thus, this setting was adopted for the microwave oven tests.

4.3.2 Test Samples

Nine soil samples obtained from fill compaction projects (either CDG or CDV fill) were tested. For each sample, a total of eight specimens were prepared. Four of them were tested by using the convection oven method with temperature controlled at 105°C±5°C (Method 5.2 of Geospec 3) while the other four were tested by the microwave oven method following ASTM D4643-00. The preparation method is the same as that adopted in the first stage of the tests (see Section 4.2.3). From the results on the particle size distribution, all samples are medium-grained soils in accordance with the definitions given in Geospec 3. The test program is summarised in Table 4.

5. RESULTS AND DISCUSSIONS

5.1 The First Stage of Tests

The results for CDG are shown in Figure 2 and Table 5. It can be seen that the moisture contents determined by microwave oven method agree very well with those obtained from convection oven method. The normalized difference of the results between microwave oven method and convection oven method (using the 105°C±5°C result as a reference) is 0.8% (maximum actual difference in moisture content is less than 0.1%). It is noted that the microwave oven results lie between the 45°C±5°C and 105°C±5°C results.

The results for CDV are shown in Figure 3 and Table 5. Again, the results obtained from microwave oven and convection oven are very close to each other with maximum normalized difference (using the 105°C±5°C result as a reference) of about 2.3% (maximum actual difference in moisture content is less than 0.3%). Same as the case in CDG, the microwave oven results lie between the 45°C±5°C and 105°C±5°C results.

The results for coarse-grained soil are shown in Figure 4 and Table 5. The specimens with target moisture content of 9% show larger normalized difference. However, the actual difference in moisture content between the microwave oven and convection oven (105°C±5°C) results is still less than 1%. Regarding the specimens with target moisture content of 14%, the maximum actual difference in moisture content is about 0.7%.

The results for medium-grained and fine-grained soils are shown in Figures 5 and 6 respectively and also in Table 5. The results obtained from different drying methods agree with each other quite well with maximum normalized difference (using the 105°C±5°C result as a reference) of about 2% (maximum actual difference in moisture content is less than 1%). Again, the microwave oven results lie between the 45°C±5°C and 105°C±5°C results.

The drying time required for moisture content determination under different microwave power setting is shown in Table 6. When ‘high’ power setting (measured output power of about 700W) was used, all the tests could be finished within half an hour. For coarse-grained soils, CDG and CDV, the drying time could even be reduced to around 15 minutes. The time required for ‘medium’ power heating (measured output power of about 450W) was approximately twice that required under ‘high’ power setting. When ‘low’ power setting (measured output power of about 110W) was used, the time required for complete drying of CDG and CDV was considerably longer. It took 35 minutes and 53 minutes to evaporate away only 60% of the water content for CDV and CDG respectively.

Most microwave ovens have variable power settings. To determine the actual output power of microwave ovens under different settings, the measurement method suggested in Australian/New Zealand Standard AS/NZS 2895.1:1995 (AS/NZS, 1995) can be used. The effect of different settings (viz ‘high’, ‘medium’ and ‘low’) on the output power of three different microwave oven models (Sharp R-8R51, National NN-5207 and National NN-6752) was assessed by this method. These microwave ovens have different rated output powers. The measurement results are presented in Table 7. In all three cases, the measured output powers under ‘high’ setting do not differ much from the rated output power quoted by the manufacturers. For ‘medium’ and ‘low’ settings, the output power varies from 57% to 89% and from 12% to 40% of that under ‘high’ power setting respectively. The measured output

powers quoted in Table 7 for 'medium' and 'low' settings are only 'equivalent' values. Under these two power settings, most of the microwave ovens only produce intermittent microwaves by switching off the magnetron at some regular intervals. The heating energy produced will hence be reduced. Normally, the energy output of microwave ovens will decrease with age and usage, therefore, power settings should be checked for each oven at suitable intervals.

The minimum mass required for moisture content determination for fine-grained soils as recommended in the GEO Report No. 36 is 30 g only. However, for the microwave oven test, a minimum mass of 100 g is recommended. It is because the drying time may be too rapid if a small sample mass is adopted, thus yielding inaccurate results.

5.2 The Second Stage of Tests

A summary of the test results is given in Table 8. It can be seen that moisture contents determined by the microwave oven method agree very well with those obtained by the convection oven method. The maximum actual difference in moisture content is generally less than 0.5% (except for Sample No. 1 with 1.30%). Moreover, the normalised difference was smaller than 5% (except for Sample 1 with 8.85%).

To assess the reliability of the microwave oven method (ASTM D4643-00), the test results were compared with those of the convection oven method (Method 5.2 of Geospec 3) by use of a statistical method called T-test. A computer program called SPSS (Version 7.5) was adopted for the analysis. The principle of the T-test can be found in many statistics textbooks and therefore is not discussed in this report. Detailed results of the analysis are given in Appendix C.

Table 9 presents a summary of the results of the T-test. It can be seen that, except for Sample No. 1, the means of the moisture content results from the both methods do not differ from each other significantly. Regarding Sample No. 1, the operator explained that the tests were carried out at the beginning stage. At that time, the operator was still not familiar with the test procedures of the ASTM method. Therefore, this may affect the accuracy of the test results for this sample. To conclude, the statistical analysis by the T-test reveals that the test results determined by both methods in general agree reasonably well with each other.

5.3 Comparison of the ASTM and GS Methods

As mentioned in Section 3, the PWRL regularly conduct comparative tests to check the microwave oven drying method stated in Appendix 6.2 of the GS against Test Method 5.2 of Geospec 3 (i.e. by convection oven method with operating temperature at 105°C±5°C). Therefore, there is a considerable amount of test data available for assessing the reliability of the GS method. The test results are presented in Appendix B.

The microwave ovens used by the PWRL are all of rated output power not greater than 1700W. The majority of the comparative tests were performed for fine-grained and medium-grained soils. As shown in Tables B1 to B4, most microwave oven tests could be completed within 10 drying cycles (less than 1 hour). Only a few tests needed longer drying

time, but it was still not greater than 15 drying cycles (around 1.5 hours).

Figure B1 shows the frequency distribution plot of the comparative test results (i.e. the difference in moisture content results obtained by the microwave oven and convection oven methods). The data set is observed to fit a normal distribution. The validity of the assumed probabilistic model is checked by Kolmogorov-Smirnov goodness-of-fit test (Ang & Tang, 1975) and is not rejected at the 5% significant level. By fitting the probability distribution of the data set with a normal distribution model, the mean and standard deviation of the model are found to be 0.13% and 0.21% respectively. Based on the statistical analysis, the interval, which covers at least 95% of population of test results with 95% confidence level, is between -0.4% to 0.6%. Moreover, no individual comparative test result is found to be greater than 0.8%. Therefore, this shows that moisture contents determined by the GS method are comparable to those obtained by the ASTM method.

As regards the test procedures, the GS method is considered to be relatively less labour-intensive than the ASTM method. For the ASTM method, the test specimen is required to be weighed very frequently throughout the test (initial drying period of 3 minutes followed by 1-minute heating cycle), thus requiring almost full attendance of an operator during the entire process. This may not be favourable in the working environment of construction sites, where only limited staff can be provided to handle a large amount of test requests with the need for rapid results. Given that the reliability of the two methods is similar, the GS method is thus preferable from site operation point of view.

5.4 Suggested Amendments to the GS Method

Based on the above reasons, the GS method is recommended. However, some amendments to the existing test requirements and procedures are suggested to reduce the potential for overheating of soil samples, which have already been adopted by the PWRL as their internal practice, including the following:

(a) Microwave ovens used shall have rated output power not greater than 1700 W. (The rated output power of common microwave ovens for industrial use is as high as 1700 W. Based on the test results in Appendix B, the use of this kind of microwave ovens still yield fairly accurate results provided proper control on drying procedures is exercised. Thus, the maximum limit of 1700 W is suggested.)

(b) Time for each drying cycle is controlled to 5 minutes.

(c) In between each drying cycle, test specimens shall be mixed thoroughly to achieve a more uniform heating.

In addition, several safety precaution measures as mentioned in ASTM D4643 are also recommended. Details of the proposed amendments are tabulated in Appendix D.

6. CONCLUSIONS AND RECOMMENDATIONS

From the results of the tests conducted, coupled with the findings from the literature review and regular comparative tests carried out by the Public Works Regional Laboratories, the feasibility of using microwave oven to determine moisture content of soils is well demonstrated. In addition, both the test methods stated in the GS and ASTM D4643 are proven to be quick and fairly accurate means for moisture content determination. The ASTM method also includes requirements to control the power ratings of microwave ovens and the period of drying procedure. Thus, the possibility of overheating of a soil sample can be greatly reduced.

Based on the study, the test results obtained by the ASTM and GS methods are comparable to each other and agree reasonably well with those obtained by convection oven method in accordance with GEO Report No. 36 or Geospec 3 (maximum actual difference within 1%). In addition, the methods are found to be suitable for most common fill materials adopted in Hong Kong (usually from CDG and CDV origins). Provided that proper power setting of microwave oven is used, the tests can normally be completed within an hour. Regarding the test procedures, the GS method is considered to be relatively less labour-intensive than the ASTM method. In the ASTM method, the test specimen is required to be weighed very frequently throughout the test (initial drying period of 3 minutes followed by 1-minute heating cycle), thus requiring almost full attendance of an operator during the entire process. This may not be favourable in the working environment of construction sites, where only limited staff can be provided to handle a large amount of test requests with the need for rapid results. As a result, the GS method is more preferable from site operation point of view.

To enhance the reliability of the GS method, some amendments are proposed, such as control on maximum output power rating of microwave ovens used and time for each drying cycle. In addition, as the use of microwave oven is more hazardous compared to the operation of using convection oven, some safety precaution measures are recommended. Details of the proposed amendments are tabulated in Appendix D.

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF TABLES

Table 1 - Summary Table Showing Details and Results of Previous Studies on the Use of Microwave Oven to Determine Moisture Content of Soils (Sheet 1 of 3)

Reference	Mass of Specimen (g)	Output Power of Microwave (Watt)	Drying Time	No. of Specimen	Type of Soil	Difference in Moisture Content (m.c.) (See Note 1)	Remarks
Ryley (1969)	100	500 – 2000	10 to 15 min.	13	Sand, organic earth, chalk, limestone gravel, coal, clays	< 0.4 % (for output ~ 830W)	1. Coal specimens ignited. 2. Large errors found in specimens of clay mixed with gypsum.
Gilbert (1974)	280 – 990	700	10 min. (for sand at 5.1% m.c.) to 24 min. (for Aquagel at 373% m.c.)	9	Sand to highly plastic clays	0.01% (for sand) to 1.4% (for clay with P.I. = 53%)	1. Microwave oven m.c. was predicted on the basis of an equation relating microwave drying time and conventional oven m.c.
Miller (1974)	----	----	1. 30 hours in convection oven, then 15 min. in microwave oven. 2. 35 min. in microwave oven, then 24 hours in convection oven.	12 12	Clays	----	1. Required drying time increased with specimen size and initial m.c. 2. The specimens dried initially in the microwave oven showed higher moisture content than those dried initially in the convection oven.
Lade & Nejadi-Babadai (1975)	100 (wet)	970	20 min.	12	Sands: 2 Silty sand: 1 Clayey silts: 2 Low plasticity clays: 3 Highly plastic clays: 4	0-0.5% for sandy soils 0.3-1.4% for silts 1.1- 2.4% for low plasticity clays 11-56% for highly plastic clays	1. Specimens drying in the microwave oven were removed periodically and weighed, and then replaced in the oven until constant mass was obtained. 2. Limited tests on some of the soils showed that required microwave drying time increased with m.c. and specimen size 3. Only clay minerals appeared to be sensitive to the difference in drying procedures. 4. Differences between m.c. decreased regularly with specimen size for all clay soils tested.

Table 1 - Summary Table Showing Details and Results of Previous Studies on the Use of Microwave Oven to Determine Moisture Content of Soils (Sheet 2 of 3)

Reference	Mass of Specimen (g)	Output Power of Microwave (Watt)	Drying Time	No. of Specimen	Type of Soil	Difference in Moisture Content (m.c.) (See Note 1)	Remarks
Hagerty et al (1990a)	50, 100 and 200	700	8 to 28 min. to obtain two consecutive identical mass	9	Loess: 1 Aggregate: 1 Sand: 1 Silt: 1 Clay: 5	*1 min. method:* Loess: -0.19% Aggregate: -0.37% sand: 0.22% silt: -0.18% clay: -0.14 to 1.54% *2 min method:* Loess: 0.12% Aggregate: -0.92% sand: 0.06% silt: 2.02% clay: -0.38 to 0.97%	1. For 1 min method, the specimens were dried for 1 min, removed for weighing for 1 min and replaced in the oven. 2. For 2 min method, the specimens were dried for 2 min, removed for weighing for 1 min and replaced in the oven. 3. 7 readings were taken during the weighing period and the average value was taken to plot the drying curves. 4. Results of this study indicated that very careful drying in short heating intervals minimizes the loss of absorbed water, thus eliminating m.c. loss dependent on plasticity. 5. In this study, the small specimen size, dictated by limited availability of some materials, could have contributed to the observed differences in m.c. The variability of m.c. noted for specimens dried in the convection oven also could have accounted for some of the differences.

Table 1 - Summary Table Showing Details and Results of Previous Studies on the Use of Microwave Oven to Determine Moisture Content of Soils (Sheet 3 of 3)

Reference	Mass of Specimen (g)	Output Power of Microwave (Watt)	Drying Time	No. of Specimen	Type of Soil	Difference in Moisture Content (m.c.) (See Note 1)	Remarks
Hagerty et al (1990b)	100	700	Soil (1): 60 to 105 min. Soil (2): 15 to 60 min. Soil (3): 7 to 45 min. Soil (4): 9 to 45 min. Soil (5): No data Soil (6): No data Soil (7): No data	Soil (1): 11 Soil (2): 10 Soil (3): 11 Soil (4): 11 Soil (5): 1 Soil (6): 1 Soil (7): 1	Soil (1): Tile clay (34% silt & 66% clay) Soil (2): Bentonite (4% silt & 96% clay) Soil (3): 4:1 tile clay/ bentonite Soil (4): 8:1 tile clay/ bentonite Soil (5): Clay + 2% peat Soil (6): Clay + 5% peat Soil (7): Clay + 10% peat	Soil (1): -2.83 to 0.67% (-4.8 to 1.36%) Soil (2): -7.95 to 35.92% (-3.82 to 6.4%) Soil (3): -1.95 to 1.36% (-2.53 to 1.1%) Soil (4): -5.57 to 0.67% (-8.28 to 0.85%) Soil (5): 3.3% (4.5%) Soil (6): -1.1% (-1.5%) Soil (7): 0.5% (0.5%)	

Note: (1) Difference in moisture content = microwave oven result - convection oven result (i.e. the value shown is the actual difference in moisture content values between microwave oven and convection oven methods). The figure shown in parentheses is the normalized difference determined by the following equation:

$$\frac{\text{m.c. from microwave oven} - \text{m.c. from convection oven}}{\text{m.c. from convection oven}} \times 100\ \%$$

Table of Contents Table of Contents Table of Contents Table of Contents

Table 2 - Table Showing Detailed Comparison among ASTM D4643 (ASTM, 1993 & 2000), General Specification for Civil Engineering Works (Hong Kong Government, 1992) and Test Methods Tried by the PWCL (Sheet 1 of 6)

	ASTM D4643-93 (ASTM, 1993)	GS (Hong Kong Government, 1992)	Proposed Test Method (Tried by PWCL in 1998)	ASTM D4643-00 (ASTM, 2000)	Proposed Test Method (Tried by PWCL in 2000)
Scope	Applicable for most soil types, but may not yield reliable results for the following types of soil: (a) soil containing significant amounts of halloysite, mica, montmorillonite, gypsum or other hydrated materials; (b) highly organic soils (c) soils in which the pore water contains dissolved solids	Applicable for fine grained and medium grained material	The scope is suitable for a variety of soils with main emphasis on fill materials. The soil types (a) to (c) listed in ASTM D4643-93 may not yield reliable results and therefore are not suggested for the tests.	Same as ASTM D4643-93.	Follow ASTM D4643-00.
Apparatus	*Microwave Oven* - preferably with a vented chamber, variable power controls and input power ratings of about 700 W.	*Microwave Oven* - with a timer and an adjustable power setting.	Follow ASTM D4643-93.	Same as ASTM D4643-93.	Follow ASTM D4643-00.
	Balance - readable to 0.1 g and have a capacity of 2000 g or greater.	*Balance* - readable and accurate to 0.01 g.	*Balance* - readable to 0.1 g and accurate to 0.3 g	Same as ASTM D4643-93.	*Balance* - readable to 0.1 g and accurate to 0.3 g
	Specimen containers - non-metallic non-absorbent material, resistant to thermal shock and not subject to changes in mass or shape when subjected to repeated heating, cooling or cleaning.	*Specimen containers* - an airtight container of microwave safe and non-reflective material.	Follow ASTM D4643-93. Porcelain evaporating dishes and standard borosilicate glass perform satisfactorily.	Same as ASTM D4643-93.	Follow ASTM D4643-93. Porcelain evaporating dishes and standard borosilicate glass perform satisfactorily.
	Suitable glove or holder - for removing hot containers from the oven.	No requirement.	Follow ASTM D4643-93.	Same as ASTM D4643-93.	Follow ASTM D4643-00.
	Desiccator - desiccator cabinet or jar of suitable size containing silica gel, anhydrous calcium phosphate or equivalent.	*Desiccator* - containing anhydrous silica gel	Follow ASTM D4643-93.	Same as ASTM D4643-93.	Follow ASTM D4643-00.
	Heat sink - a material or liquid placed in the microwave oven to absorb energy after the moisture has been driven from the test specimen. The heat sink reduces the possibility of oveheating the specimen and damage to the oven. A beaker filled with water and material having a boiling point above water, such as nonflammable oil, can be used.	No requirement.	Not used.	Same as ASTM D4643-93.	Follow ASTM D4643-00.

Table 2 - Table Showing Detailed Comparison among ASTM D4643 (ASTM, 1993 & 2000), General Specification for Civil Engineering Works (Hong Kong Government, 1992) and Test Methods Tried by the PWCL (Sheet 2 of 6)

	ASTM D4643-93 (ASTM, 1993)	GS (Hong Kong Government, 1992)	Proposed Test Method (Tried by PWCL in 1998)	ASTM D4643-00 (ASTM, 2000)	Proposed Test Method (Tried by PWCL in 2000)
Apparatus (Con't)	*Stirring Tools* - short length of glass rods have been found useful for stirring and may be left in the specimen container during testing, reducing the possibility of specimen loss due to adhesion to the stirring tool.	No requirement.	Follow ASTM D4643-93.	Same as ASTM D4643-93.	Follow ASTM D4643-00.
	----	----	*Heat insulating material* - prevent the hot container from damaging the balance.	----	----
	----	----	*Stopclock or stopwatch* - readable to 1 s.	----	----
Sample size	90% passing 2 mm sieve: 100 - 200 g 90% passing 4.75 mm sieve: 300 - 500 g 90% passing 19 mm sieve: 500 - 1000 g	Fine grained: 30 g Medium grained: 300 g	Fine grained: 100 - 200 g Medium grained: 300 - 500 g Coarse grained: 500 - 1000 g	Same as ASTM D4643-93.	Fine grained: 100 - 200g Medium grained: 300 - 500 g Coarse grained: 500 - 1000 g
Sample preparation	(a) For stored samples, prior to testing, keep samples in non-corrodible airtight containers at a temperature between approximately 3 to 30°C in an area that prevents direct exposure to sunlight. (b) Prepare and process the specimens as quickly as possible to minimize unrecorded moisture loss. (c) Cut or break up the soil into small size aggregations to aid in obtaining more uniform drying of the specimen.	(a) Specimen shall be crumbled and placed loosely in the container.	Follow GEO Report No. 36	Same as ASTM D4643-93.	Follow ASTM D4643-00.

Table 2 - Table Showing Detailed Comparison among ASTM D4643 (ASTM, 1993 & 2000), General Specification for Civil Engineering Works (Hong Kong Government, 1992) and Test Methods Tried by the PWCL (Sheet 3 of 6)

	ASTM D4643-93 (ASTM, 1993)	GS (Hong Kong Government, 1992)	Proposed Test Method (Tried by PWCL in 1998)	ASTM D4643-00 (ASTM, 2000)	Proposed Test Method (Tried by PWCL in 2000)
Procedures	(a) Determine and record the mass of a clean dry container. (b) Place the soil specimen in the container and immediately determine and record the mass. (c) Place the soil and container in a microwave oven with the heat sink and turn the oven on for 3 min. *(See notes 1 to 3)* (d) Remove the container and soil from the oven, either weigh the specimen immediately or place in desiccator to cool to allow handling and to prevent damage to the balance. Determine and record the mass. (e) With suitable stirring tools, carefully mix the soil, taking special precaution not to lose any soil. (f) Return the container and soil to the oven and reheat in the oven for 1 min. (g) Repeat (d)-(f) until the change between two consecutive mass determinations differ by 0.1% or less of the initial wet mass of the soil. (h) Use the final mass determination in calculating the water content. Obtain this value immediately after the heating cycle, or if the mass determination is to be delayed, after cooling in desiccator.	(a) The container shall be cleaned, dried and weighed to the nearest 0.01 g. (b) The container and contents shall be weighed to 0.01 g. (c) The lid of the specimen container shall be removed and the container with its lid and contents shall be placed in the microwave oven and dried. (d) The specimen shall be considered to be dry when after an initial drying period, successive weighings at intervals of 1 min produce results which are the same to the nearest 0.01 g. (e) Alternatively, the oven may be set to an appropriate time and power setting to dry the specimen as determined by calibration of the oven on soil of a similar type (f) After drying, the container and contents shall be removed from the microwave oven and placed in the desiccator to cool (g) The lid shall be replaced and the container and contents shall be weighed to the nearest 0.01 g.	Mainly follow ASTM D4643-93 with the following modifications to procedures (b), (c) and (g): <u>Procedure (b)</u> No heat sink is used and the initial drying period of 2 min. is adopted. <u>Procedures (c) and (g)</u> In order not to damage the balance, some heat insulating material such as foam should be used. Take seven balance reading at 10 second intervals. The average value of these 7 readings are used to determine the moisture content. Such weighing procedure is suggested by Hagerty et al (1990a). As recommended by ASTM D4643-93, a stirring tool is placed together with the soil and container during testing to reduce the possibility of specimen loss due to adhesion to the stirring tool.	Same as ASTM D4643-93.	Follow ASTM D4643-00. As recommended by ASTM D4643-00, a stirring tool is placed together with the soil and container during testing to reduce the possibility of specimen loss due to adhesion to the stirring tool.

Table 2 - Table Showing Detailed Comparison among ASTM D4643 (ASTM, 1993 & 2000), General Specification for Civil Engineering Works (Hong Kong Government, 1992) and Test Methods Tried by the PWCL (Sheet 4 of 6)

	ASTM D4643-93 (ASTM, 1993)	GS (Hong Kong Government, 1992)	Proposed Test Method (Tried by PWCL in 1998)	ASTM D4643-00 (ASTM, 2000)	Proposed Test Method (Tried by PWCL in 2000)
Procedures (Con't)	(i) When routine testing of similar soils is contemplated, the drying times and number of cycles may be standardized for each oven. Periodic verification should be performed.	See sheet 4 of 5	See sheet 4 of 5	See sheet 4 of 5	See sheet 4 of 5
Calculations	From m.c. definition. *(See Notes 4)*	Same as ASTM D4643-93.	Follow ASTM D4643-93.	Same as ASTM D4643-93.	Follow ASTM D4643-00.
Report	(a) Identification of the sample being tested. (b) Moisture content of the specimen to the nearest 0.1 or 1%, depending on the purpose of the test. (c) Indicate the minimum mass is met or not. (d) Indication of any material excluded from the test specimen. (e) Time and setting of initial drying period and subsequent incremental drying periods. (f) Initial mass of test specimen prior to drying and the mass after the final incremental drying periods. (g) Identification of the microwave oven and the drying settings and cycles used, when standardized drying is utilized.	(a) Source and identification of the soil. (b) Moisture content of the soil to the nearest 0.1%. (c) That the test method used was in accordance with the Specification.	Proposed contents of the report are as follows: (a) Method of test used. (b) Moisture content of the specimen to the nearest 0.1%. (c) Model of microwave oven and its input power rating. (d) Power setting used. (e) Calibrated power output of microwave oven. (f) Duration of drying. (g) Sample identification reference number. (h) Type of sample. (i) Visual description of soil in accordance with Geoguide 3 (GCO, 1988). (j) Additional information provided by the Specifier.	Same as ASTM D4643-93.	Proposed contents of the report are as follows: (a) Method of test used. (b) Moisture content of the specimen to the nearest 0.1%. (c) Model of microwave oven and its input power rating. (d) Power setting used. (e) Calibrated power output of microwave oven. (f) Duration of drying. (g) Sample identification reference number. (h) Type of sample. (i) Visual description of soil in accordance with Geoguide 3 (GCO, 1988). (j) Additional information provided by the Specifier.

Table 2 - Table Showing Detailed Comparison among ASTM D4643 (ASTM, 1993 & 2000), General Specification for Civil Engineering Works (Hong Kong Government, 1992) and Test Methods Tried by the PWCL (Sheet 5 of 6)

	ASTM D4643-93 (ASTM, 1993)	GS (Hong Kong Government, 1992)	Proposed Test Method (Tried by PWCL in 1998)	ASTM D4643-00 (ASTM, 2000)	Proposed Test Method (Tried by PWCL in 2000)
Hazards	(a) Soils with particle size larger than 4.75 mm may increase chance of particle shattering. (b) Suitable eye protection is recommended. (c) Handle hot containers with a suitable container holder. (d) Safety precautions supplied by the manufacturer of the microwave should be observed. Particular attention should be paid to keeping the door sealing gasket and door interlocks clean and in good working condition. (e) Highly organic soils and soils containing oil or other contaminates may ignite into flames during microwave drying. Fumes given off may be toxic. (f) A covering over the sample container may be appropriate to prevent operator injury or oven damage. (g) Do not use metallic containers in a microwave oven. (h) The placement of the test specimen directly on the glass liner tray is strongly discouraged	No requirement.	Follow ASTM D4643-93.	Same as ASTM D4643-93.	Follow ASTM D4643-00.

Table of Contents Table of Contents Table of Contents Table of Contents

Table 2 - Table Showing Detailed Comparison among ASTM D4643 (ASTM, 1993 & 2000), General Specification for Civil Engineering Works (Hong Kong Government, 1992) and Test Methods Tried by the PWCL (Sheet 6 of 6)

Notes:

(1) If experience with a particular soil type and specimen size indicates shorter or longer initial drying times can be used without overheating, the initial and subsequent drying times may be adjusted.

(2) The 3-min initial setting is for a minimum sample mass of 100 g. Smaller samples are not recommended when using the microwave oven because drying may be too rapid for proper control. When very large samples may need to represent soil containing large gravel gravel particles, the sample may need to be split into segments and dried separately to obtain the dry mass of the total sample.

(3) Most ovens have a variable power setting. For the majority of soils tested, a setting of 'high' should be satisfactory. However, for some soils such a setting may be too severe. The proper setting can be determined only through the use of and experience with a particular oven for various soil types and sample sizes. The energy output of microwave ovens may decrease with age and usage. Therefore, power settings and drying time should be established for each oven.

(4) Moisture content is calculated by the following equation:

$$m.c. = \frac{\text{mass of water}}{\text{mass of ovendried soil}} \times 100\,\% = \frac{(M_1 - M_2)}{(M_2 - M_c)} \times 100\,\% = \frac{M_w}{M_s} \times 100\,\%$$

where: m.c. = moisture content, %;
M_1 = mass of container and moist specimen (with stirring rod), g;
M_2 = mass of container and ovendried speciment (with stirring rod), g;
M_c = mass of container (with stirring rod), g;
M_w = mass of water, g; and
M_s = mass of solid particles, g.

Table of Contents Table of Contents Table of Contents Table of Contents

Table 3 - Testing Program for the First Stage of the Tests

Soil Type	Target Moisture Content for Sample Preparation	Type of Oven	No. of Specimen
CDG	10%	Microwave (High)	2
		Microwave (Medium)	2
		Convection (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
	14%	Microwave (High)	2
		Microwave (Medium)	2
		Convection (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
	9%	Microwave (Low)	1
		Microwave (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
CDV	11%	Microwave (High)	2
		Microwave (Medium)	2
		Convection (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
	16%	Microwave (High)	2
		Microwave (Medium)	2
		Convection (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
	9%	Microwave (Low)	1
		Convection (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
Coarse-grained	9%	Microwave (High)	2
		Microwave (Medium)	2
		Convection (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
	14%	Microwave (High)	2
		Microwave (Medium)	2
		Convection (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
Medium-grained	20%	Microwave (High)	2
		Convection (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
Fine-grained	40%	Microwave (High)	2
		Convection (45˚C±5˚C)	1
		Convection (105˚C±5˚C)	1
			Total no. of specimen = 50

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4 - Testing Program for the Second Stage of the Tests

Soil Sample Number	Target Moisture Content for Sample Preparation	Type of Oven	No. of Specimen
1	15%	Microwave (Medium)	8
		Convection (105˚C±5˚C)	8
2	14%	Microwave (Medium)	8
		Convection (105˚C±5˚C)	8
12	9%	Microwave (Medium)	8
		Convection (105˚C±5˚C)	8
13	17%	Microwave (Medium)	8
		Convection (105˚C±5˚C)	8
15	17%	Microwave (Medium)	8
		Convection (105˚C±5˚C)	8
17	10%	Microwave (Medium)	8
		Convection (105˚C±5˚C)	8
19	14%	Microwave (Medium)	8
		Convection (105˚C±5˚C)	8
23	11%	Microwave (Medium)	8
		Convection (105˚C±5˚C)	8
24	19%	Microwave (Medium)	8
		Convection (105˚C±5˚C)	8
			Total no. of specimen = 144

Table 5 - Test Results of Moisture Content Determination (for the First Stage of the Tests)

Soil Type	Target m.c. (%)	Microwave Oven Method			Convection Oven Method			
		Test 1 (*)	Test 2 (*)	Average	45°C±5°C	Normalised Difference	105°C±5°C	Normalised Difference
		m.c (%)	m.c (%)	m.c (%)	m.c (%)	(%)	m.c (%)	(%)
CDG	10	9.74	9.78	***9.76***	***9.53***	2.4	***9.84***	-0.8
	14	13.67	13.42	***13.55***	***13.34***	1.5	***13.62***	-0.6
CDV	11	11.11	11.31	***11.21***	***10.72***	4.6	***11.47***	-2.3
	16	16.33	16.3	***16.32***	***15.64***	4.3	***16.48***	-1.0
Coarse grained	9	8.01	8.28	***8.15***	***8.6***	-5.3	***9.01***	-9.6
	14	13.71	14.9	***14.31***	***13.29***	7.6	***13.65***	4.8
Medium grained	20	18.32	19.38	***18.85***	***18.32***	2.9	***19.22***	-1.9
Fine grained	40	43.06	43.25	***43.16***	***40.69***	6.1	***44.11***	-2.2

Notes:
(1) The test procedures for the microwave oven method followed ASTM D4643-93 (ASTM, 1993) with modifications as described in Section 4.2.1 of this report. Microwave oven of Model No. SHARP R-8R51 was adopted for the tests.
(2) The test procedures for the convection oven method followed GEO Report No. 36 (GEO, 1996).
(3) (*) represents that tests were carried out under ‘high’ power setting.
(4) Normalised dfference = (microwave oven result - convection oven result)/convection oven result × 100%

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 6 - Time Required for Moisture Content Determination under Different Microwave Power Setting (for the First Stage of the Tests)

Soil Type	Target m.c.	Power Setting of Microwave Oven		
		High	Medium	Low
		Total Drying Time (min)	Total Drying Time (min)	Total Drying Time (min)
CDG	9%	--	--	50 (*)
	10%	8.5	15.5	--
	14%	9	16.5	--
CDV	7%	--	--	35 (*)
	11%	11	19	--
	16%	14	24	--
Coarse grained	9%	12	23	--
	14%	16	27	--
Medium grained	20%	28	--	--
Fine grained	40%	20	--	--

Notes: (1) Microwave oven of Model No. SHARP R-8R51 was adopted for the tests and the 'equivalent' output powers under different settings are given in Table 7.
(2) (*) Test not yet finished up to the reported time.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 7 - Measurement of Equivalent Output Power of Microwave Ovens
(for the First Stage of the Tests) (Sheet 1 of 2)

Microwave Oven Model:
SHARP R-8R51 (rated output power = 700 W)

Power level	M_w (g)	T_0 (°C)	T_1 (°C)	T_2 (°C)	Time (s)	Measured Output Power (Watt)
High	1000.1	21.0	11.9	20.5	50	716
	1000.0	22.0	12.1	21.3	50	765
	999.8	23.5	13.9	22.7	50	731
Medium	1000.0	23.5	13.9	22.6	80	451
	999.9	22.5	12.9	21.8	80	462
	1000.0	22.5	12.9	21.5	80	445
Low	1000.9	20.0	9.4	18.9	360	110
	1002.4	20.0	9.2	19.1	360	115
	1000.2	22.0	10.3	19.9	360	110

Microwave Oven Model:
National NN-5207 (rated output power = 600 W)

Power level	M_w (g)	T_0 (°C)	T_1 (°C)	T_2 (°C)	Time (s)	Measured Output Power (Watt)
High	1000.0	20.0	9.4	17.4	50	650
	999.9	20.0	10.4	18.4	50	658
	1000.0	20.0	10.5	18.4	50	650
Medium	1000.7	21.0	9.5	20.7	80	585
	1000.4	21.0	9.4	20.5	80	579
	1001.7	20.5	9.2	20.3	80	581
Low	1000.1	21.0	9.2	29.2	360	241
	999.9	21.0	10.8	32.0	360	258
	1000.2	21.0	9.4	32.0	360	274

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 7 - Measurement of Equivalent Output Power of Microwave Ovens
(for the First Stage of the Tests) (Sheet 2 of 2)

Microwave Oven Model:
National NN-6752 (rated output power = 850 W)

Power level	M_w (g)	T_0 (°C)	T_1 (°C)	T_2 (°C)	Time (s)	Measured Output Power (Watt)
High	1000.2	19.0	9.0	18.9	50	828
	999.0	19.0	10.5	19.9	50	793
	1003.2	19.0	9.0	18.6	50	803
Medium	1004.3	19.0	9.0	18.2	80	480
	1004.0	20.0	10.3	19.1	80	458
	998.7	20.0	9.4	18.3	80	457
Low	1001.6	20.0	10.4	18.6	360	94
	999.7	20.0	9.9	18.1	360	93
	--	--	--	--	360	--

Notes: (1) All the microwave ovens used were operating at a frequency of 2450 MHz.

(2) The measurement method for the output power of microwave oven followed Clause 12 of Australian/New Zealand Standard AS/NZS 2895.1:1995 (AS/NZS, 1995). In the test, about 1 kg of water at 10°C±1°C in a glass container is raised to ambient temperature (20°C±2°C) by heating in the microwave oven. The time for the water to be heated is then measured. The equivalent output power of microwave oven (in Watt) is calculated from the following formula:

$$P=\frac{4.187M_w(T_2-T_1)+0.844M_c(T_2-T_0)}{t}$$

where M_w = mass of water (in g)
M_c = mass of container = 427 g
T_0 = initial ambient temperature (in °C)
T_1 = initial water temperature (in °C)
T_2 = final water temperature (in °C)
t = time for the water to be heated (in s)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 8 - Test Results of Moisture Content Determination (for the Second Stage of the Tests)

Soil Sample Number	Target m.c.	Results of Moisture Content Determination (%)						Normalised Difference (%)
		Convection Oven Method			Microwave Oven Method			
1	15%	15.01	14.41	*Mean = 14.6800* *Std. Dev. = 0.6704*	15.52	14.97	*Mean = 15.9788* *Std. Dev. = 0.6978*	8.8%
		13.80	15.35		16.16	16.08		
		14.42	13.81		15.56	16.13		
		15.10	15.54		16.04	17.37		
2	14%	15.15	13.48	*Mean = 14.0663* *Std. Dev = 0.7070*	13.48	14.36	*Mean = 14.4875* *Std. Dev. = 0.5937*	3.0%
		14.34	14.81		14.00	14.66		
		13.13	13.41		15.29	15.17		
		14.25	13.96		14.30	14.64		
12	9%	9.64	9.31	*Mean = 9.3575* *Std. Dev. = 0.1793*	9.57	9.48	*Mean = 9.4350* *Std. Dev. = 0.1945*	0.8%
		9.07	9.49		9.14	9.54		
		9.26	9.51		9.70	9.43		
		9.27	9.31		9.46	9.16		
13	17%	16.73	17.29	*Mean = 16.9675* *Std. Dev. = 0.0566*	17.06	16.76	*Mean = 16.8638* *Std. Dev. = 0.1284*	-0.6%
		17.02	17.00		17.39	16.66		
		16.96	16.96		16.21	16.99		
		16.85	16.93		17.15	16.69		
15	17%	17.92	17.59	*Mean = 17.7250* *Std. Dev. = 0.2580*	17.39	17.52	*Mean = 17.5700* *Std. Dev. = 0.4699*	-0.9%
		17.43	17.61		17.88	18.52		
		18.12	17.40		17.09	17.36		
		17.93	17.80		17.70	17.10		
17	10%	11.01	10.20	*Mean = 10.6563* *Std. Dev. = 0.3683*	10.36	10.36	*Mean = 10.6763* *Std. Dev. = 0.5238*	0.2%
		10.44	10.27		9.92	10.35		
		10.87	11.17		11.13	11.47		
		10.88	10.41		11.13	10.69		
19	14%	14.57	15.43	*Mean = 14.7113* *Std. Dev. = 0.4565*	14.02	14.93	*Mean = 14.4525* *Std. Dev. = 0.3926*	-1.8%
		14.75	15.37		14.28	13.99		
		14.46	14.23		14.44	14.43		
		14.59	14.29		15.10	14.43		
23	11%	10.43	10.12	*Mean = 10.7675* *Std. Dev. = 0.7406*	10.77	9.11	*Mean = 11.2725* *Std. Dev. = 1.0294*	4.7%
		12.10	11.24		11.14	11.94		
		10.62	10.22		12.49	11.84		
		11.47	10.14		11.73	11.16		
24	19%	19.52	18.74	*Mean = 19.3988* *Std. Dev. = 0.3018*	18.76	18.80	*Mean = 19.1963* *Std. Dev. = 0.6897*	-1.0%
		19.62	19.30		18.48	18.40		
		19.61	19.55		19.39	20.04		
		19.60	19.25		20.19	19.51		

Notes:
(1) The test procedures for the microwave oven method followed ASTM D4643-00 (ASTM, 2000). Two microwave ovens of the same model (National NE-1756) under 'medium' power setting were adopted (the 'equivalent' output power is about 700 W).
(2) The test procedures for the convection oven method followed Test Method 5.2 (105°C±5°C) of Geospec 3 (GEO, 2001).
(3) 'Std. Dev.' stands for 'standard deviation'.
(4) Normalised dfference = (microwave oven result - convection oven result)/convection oven result × 100%
(5) A summary of statistical analysis by T-test method for comparison of the means of the results between the convection oven and microwave oven methods is given in Appendix C.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 9 - A Summary of the Results of the T-Test (for the Second Stage of the Tests)

Soil Sample Number	Target m.c.	Results of Moisture Content Determination (%)		Results of T-Test (2-tailed)	
		Convection Oven Method	Microwave Oven Method	Significance (p-value)	Meaning Implication from Statistical Point of View
1	15%	Mean = 14.6800 Std. Dev. = 0.6704	Mean = 15.9788 Std. Dev. = 0.6978	0.002 (< $\alpha/2 = 0.025$)	Two means differ significantly.
2	14%	Mean = 14.0663 Std. Dev. = 0.7070	Mean = 14.4875 Std. Dev. = 0.5937	0.218 (> $\alpha/2 = 0.025$)	Two means do not differ significantly.
12	9%	Mean = 9.3575 Std. Dev. = 0.1793	Mean = 9.4350 Std. Dev. = 0.1945	0.421 (> $\alpha/2 = 0.025$)	Two means do not differ significantly.
13	17%	Mean = 16.9675 Std. Dev. = 0.0566	Mean = 16.8638 Std. Dev. = 0.1284	0.477 (> $\alpha/2 = 0.025$)	Two means do not differ significantly.
15	17%	Mean = 17.7250 Std. Dev. = 0.2580	Mean = 17.5700 Std. Dev. = 0.4699	0.427 (> $\alpha/2 = 0.025$)	Two means do not differ significantly.
17	10%	Mean = 10.6563 Std. Dev. = 0.3683	Mean = 10.6763 Std. Dev. = 0.5238	0.931 (> $\alpha/2 = 0.025$)	Two means do not differ significantly.
19	14%	Mean = 14.7113 Std. Dev. = 0.4565	Mean = 14.4525 Std. Dev. = 0.3926	0.244 (> $\alpha/2 = 0.025$)	Two means do not differ significantly.
23	11%	Mean = 10.7675 Std. Dev. = 0.7406	Mean = 11.2725 Std. Dev. = 1.0294	0.279 (> $\alpha/2 = 0.025$)	Two means do not differ significantly.
24	19%	Mean = 19.3988 Std. Dev. = 0.3018	Mean = 19.1963 Std. Dev. = 0.6897	0.465 (> $\alpha/2 = 0.025$)	Two means do not differ significantly.

Notes:
(1) The test procedures for the microwave oven and convection oven methods followed ASTM D4643-00 and Test Method 5.2 of Geospec 3 respectively.
(2) 'Std. Dev.' stands for 'standard deviation'.
(3) T-test was adopted to compare means for the above two methods for determination of moisture content of soil.
(4) In the analysis, the level of significance (α) is set at 0.05 (i.e. $\alpha/2 = 0.025$ for 2-tailed cases).
(5) A computer program called SPSS (Version 7.5) was adopted for the analysis. Detailed results are attached to Appendix C.

LIST OF FIGURES

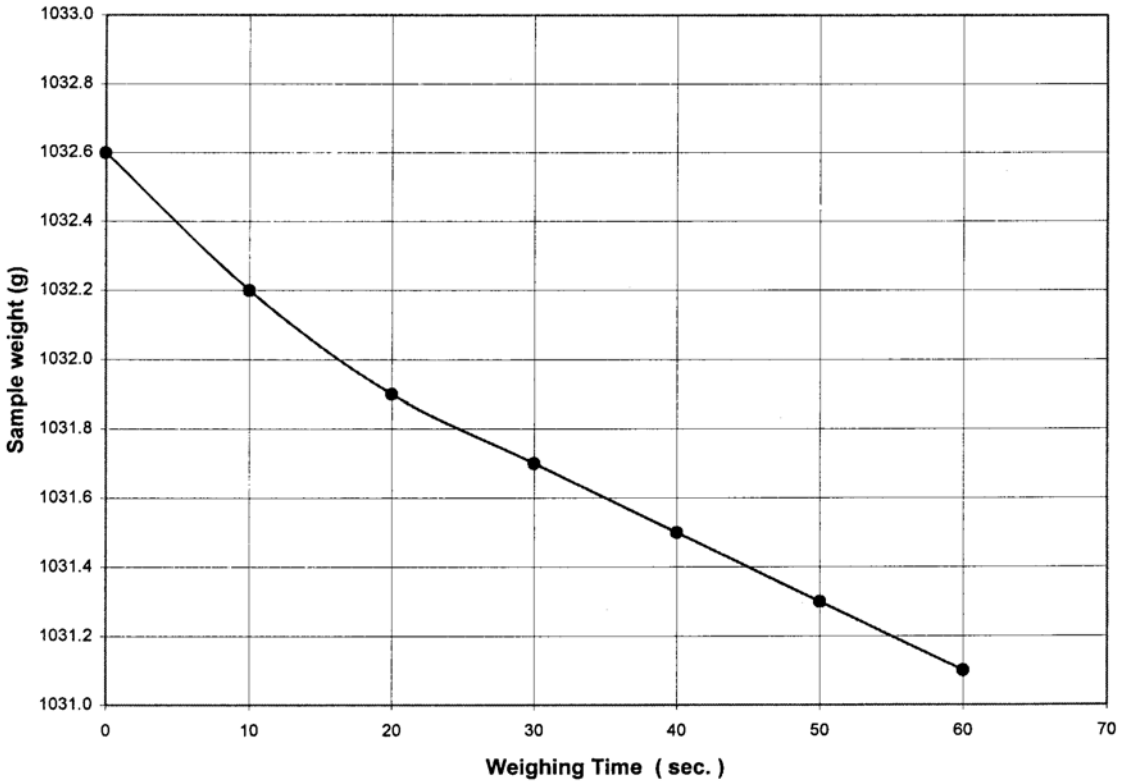


Figure 1 - Typical One-minute Weighing Curve

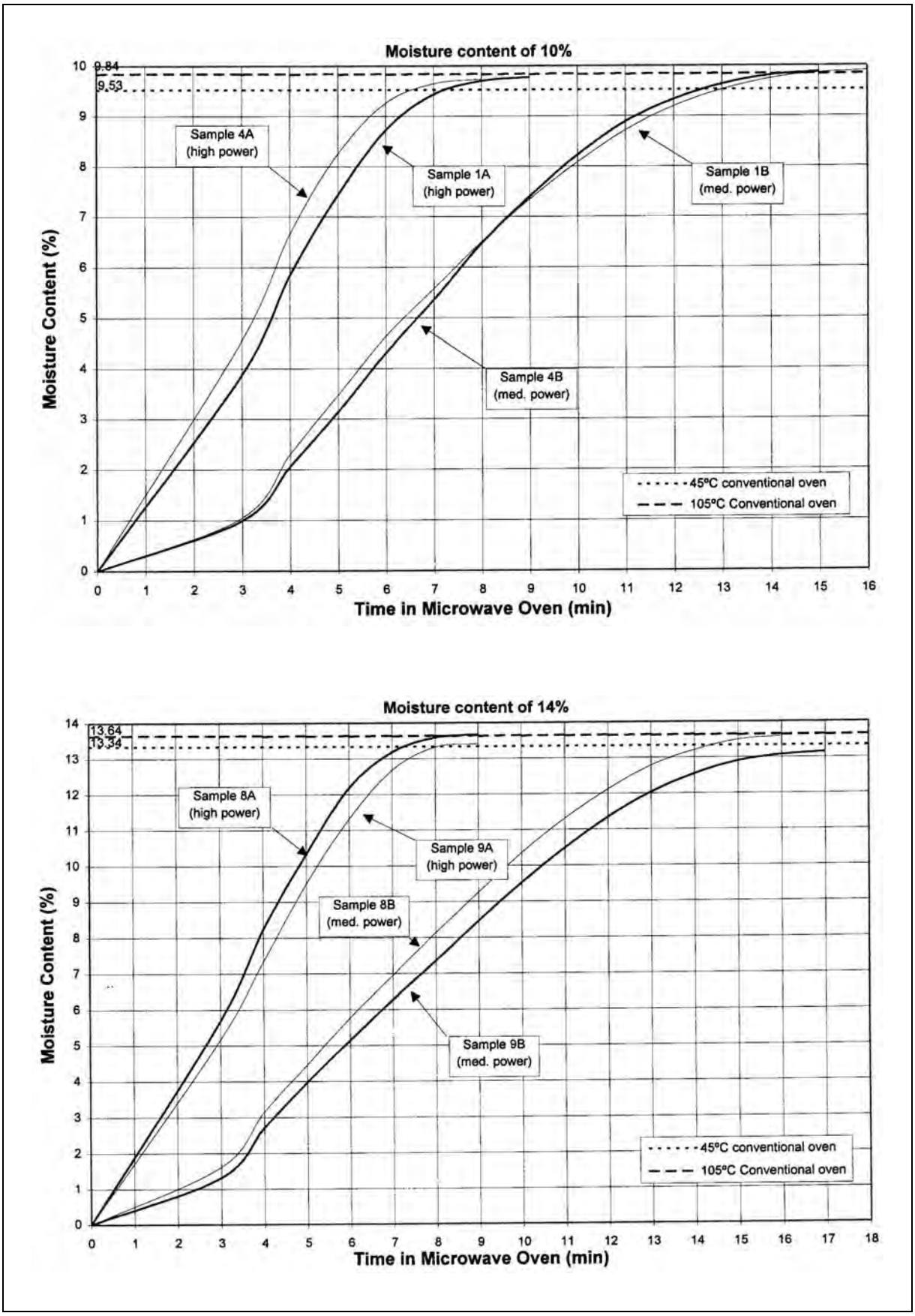


Figure 2 - Drying Curve for CDG with Target Moisture Content of 10% and 14%

Table of Contents
Table of Contents
Table of Contents
Table of Contents

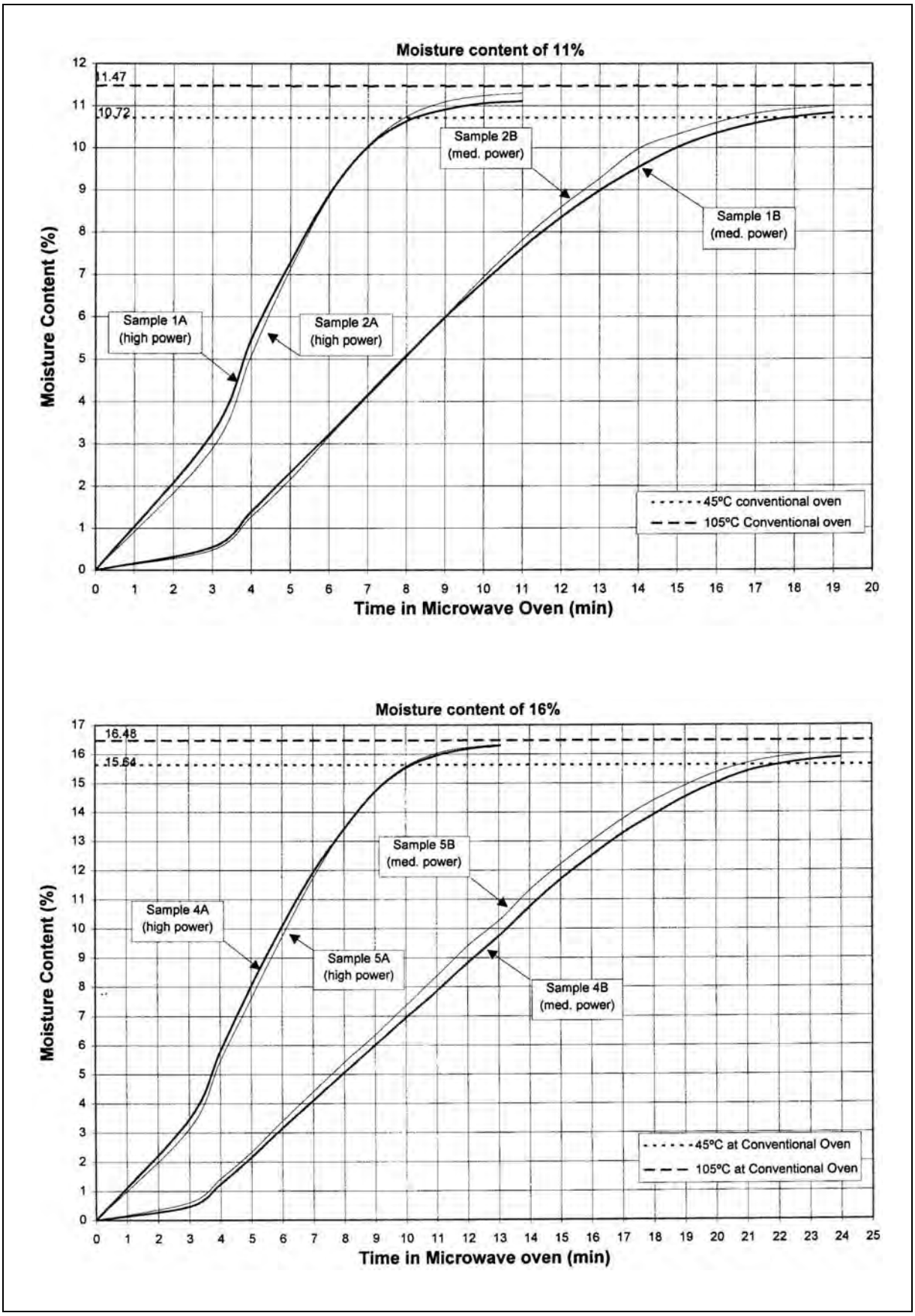


Figure 3 - Drying Curve for CDV with Target Moisture Content of 11% and 16%

Table of Contents
Table of Contents
Table of Contents
Table of Contents

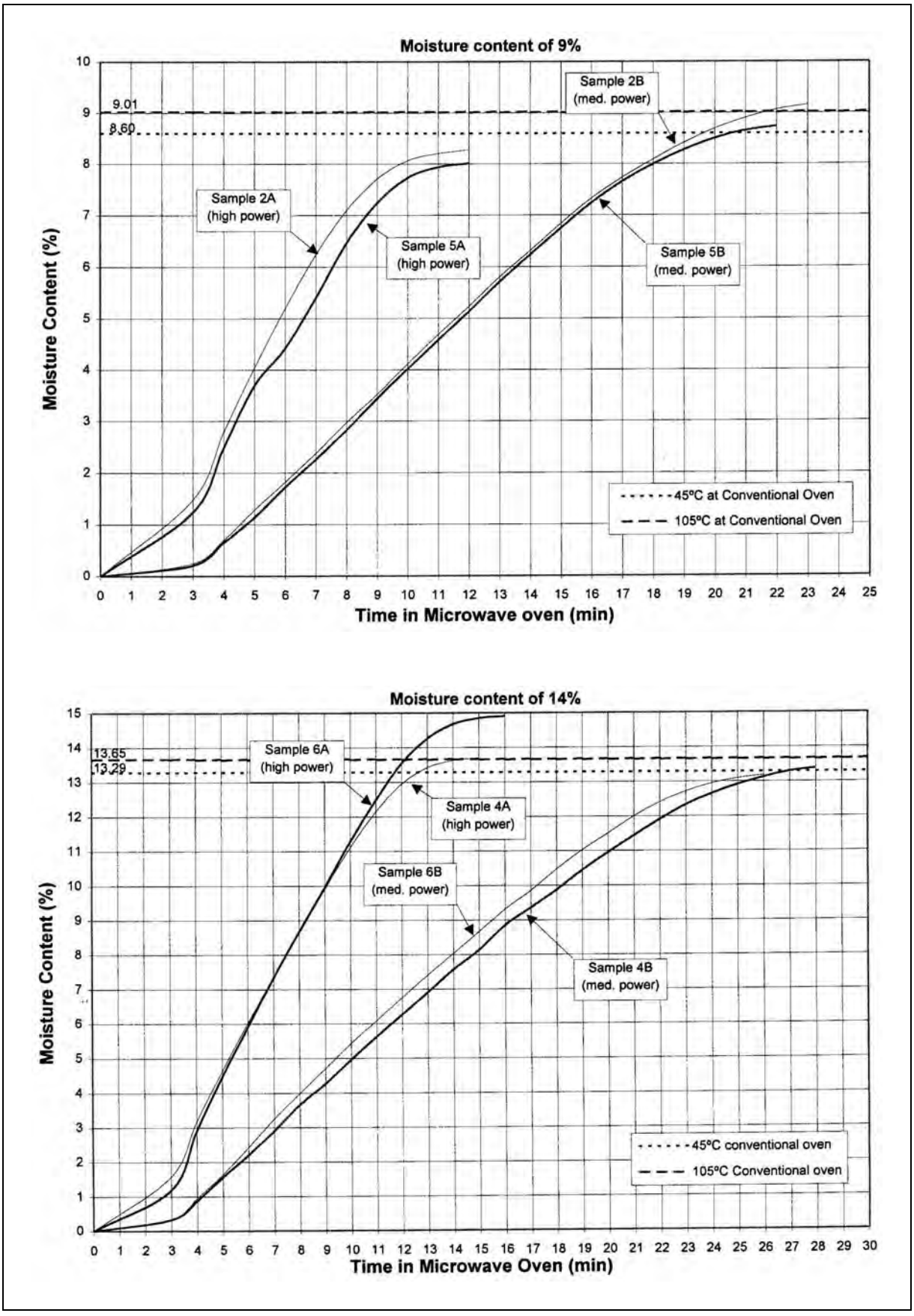


Figure 4 - Drying Curve for Coarse-grained Soils with Target Moisture Content of 9% and 14%

Table of Contents
Table of Contents
Table of Contents
Table of Contents

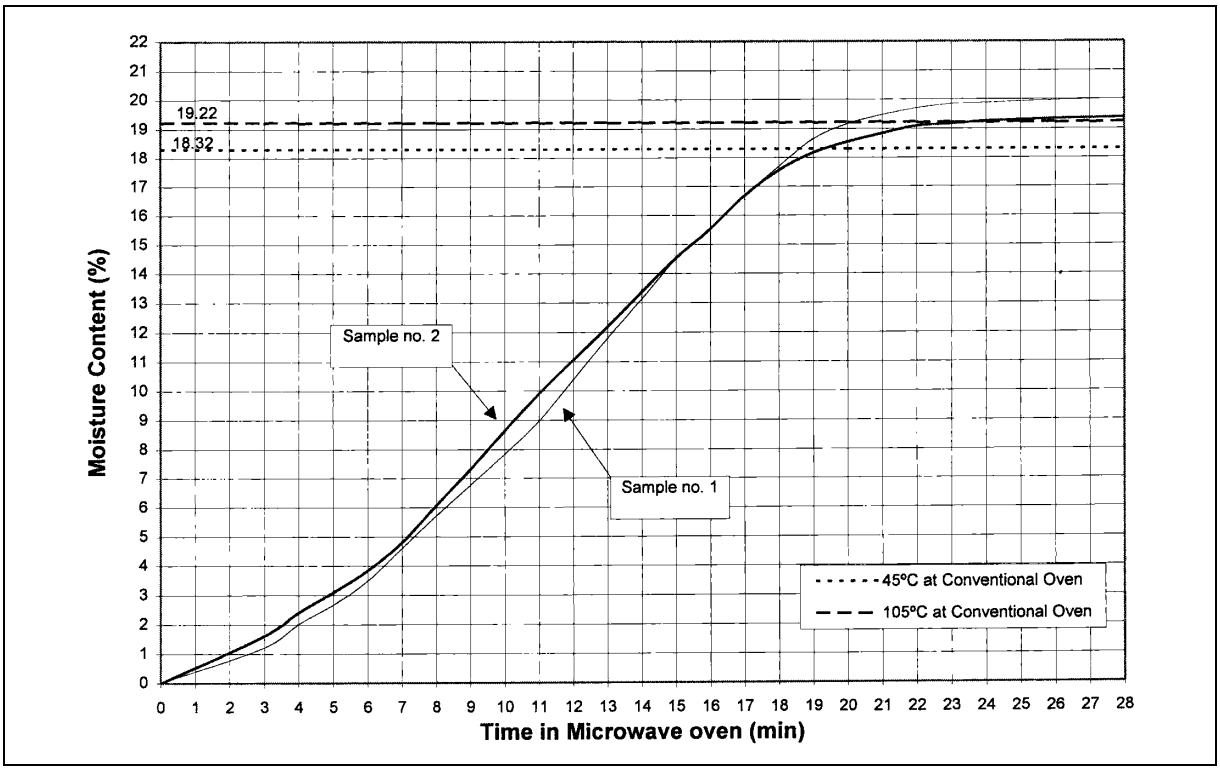


Figure 5 - Drying Curve for Medium-grained Soils with Target Moisture Content of 20%

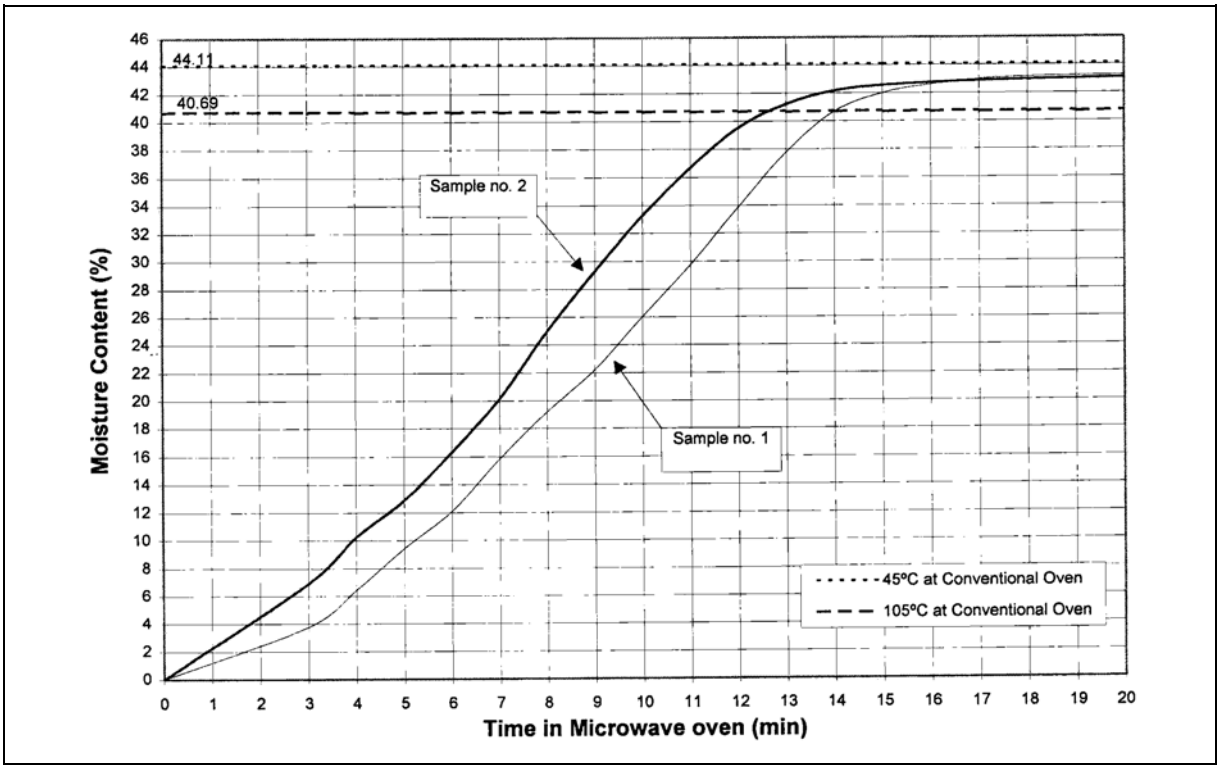


Figure 6 - Drying Curve for Fine-grained Soils

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

APPENDIX A

THEORY OF MICROWAVE HEATING

Theory of Microwave Heating

As shown in Figure A1, the microwaves in a microwave oven are produced by a continuous wave magnetron valve and are fed into a drying cabinet (or cavity) by means of a wave-guide system. The inner and outer cores of the magnetron in fact serve as cathode and anode of the system respectively. Electrons are emitted from the cathode towards the anode. The magnetic field then causes the electrons to spin about the cathode (i.e. accelerates towards the cathode). From electromagnetic theory, acceleration of charged particles will emit electromagnetic waves. This is the physical basis for the production of microwaves.

Microwaves are part of the electromagnetic spectrum and have wavelengths from approximately 1 mm to 1 m (300 GHz to 0.3 GHz). Most domestic microwave ovens in the market have a rated microwave frequency of 2.45 GHz. This frequency is close to the natural frequency of water molecule. In fact, most of the domestic microwave ovens are intended for heating food and beverages. At this frequency, the vigorous vibration of water molecules (up side down movement because of the dipolar structure) contained within food causes intermolecular friction which in turn generates heat to cook up the food. When first introduced, microwave ovens were reported to affect heart pacemakers, primarily because of the operating frequencies of the two devices. Since that time, pacemakers have been redesigned and the microwave oven is no longer regarded as a health hazard it once was.

Microwaves can either be absorbed by, reflected by or pass through a material. They have good penetration properties and materials which absorb them are rapidly heated. The increase in temperature of a material resulting from microwave heating depends on the specific heat and density of the material. In soil, water absorbs microwaves far more readily than soil particles. Hence water is preferentially heated and quickly converted to vapour.

Somlo (1995) described how the microwave frequency affected the depth of penetration of the microwave applied. The electrical properties of materials can be characterized by the complex dielectric constant, ϵ, as follows:

$$\epsilon = \epsilon' - i\epsilon''$$

where ϵ' is a measure of the concentration of the electrical field inside the material;

ϵ'' is a measure of the 'lossyness' of the material, i.e. how much of the energy of an alternating field is converted into heat in the material and so becoming 'lost'. (The conversion of electrical energy into heat may be looked upon as a form of friction); and

$i=\sqrt{-1}$

In 'lossy' materials, the microwave entering the material will be attenuated as it penetrates deeper. How a 'lossy' material is getting heated depends on the depth of penetration into that material, which is defined as the depth at which the signal (microwave) has decayed by one neper, i.e. the signal amplitude has dropped by a factor of e (=2.7181828…). The depth of penetration in dielectric materials in general is:

$$D_P = \frac{\lambda}{2\pi\sqrt{2\varepsilon'}}\left(\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1\right)^{-\frac{1}{2}}$$

where λ is the free space wavelength (λ = c/f, in which c is the velocity of light = 2.99795 x 10^8 m/s and f is the frequency of the microwave).

Assuming that a dry soil having dielectric properties of ϵ' = 12 and ϵ'' = 0.2 is mixed with water to achieve moisture content of 30%, Somlo (1995) showed that the depth of penetration is in the centimetre range when frequency is near 2.45 GHz (see Figure A2). This thickness is ideal for heating samples a few cm thick. This is also one of the reasons why industrial/domestic microwave heating of bulk materials is carried out mostly at 2.45 GHz. This calculation gives some clues to specify the amount of soil to be used in a microwave oven for determination of moisture content.

Somlo (1995) also demonstrated by calculations that the thickness of the material will affect the uniformity of heating owing to the refraction-caused focusing effect. When the sample is thin, fairly uniform heating will take place since microwaves refracted from all directions will pass through the centre without the intensity having decayed significantly. For a thick sample, the microwaves will get attenuated when passing through the increased depth of the sample. Hence, most heating will just take place below the surface of the sample (i.e. non-uniform heating). The results of Somlo's calculations match the observed effect of microwave heating. In general, it is difficult to achieve uniform heating of a sample by use of microwave energy unless the sample is small or thin.

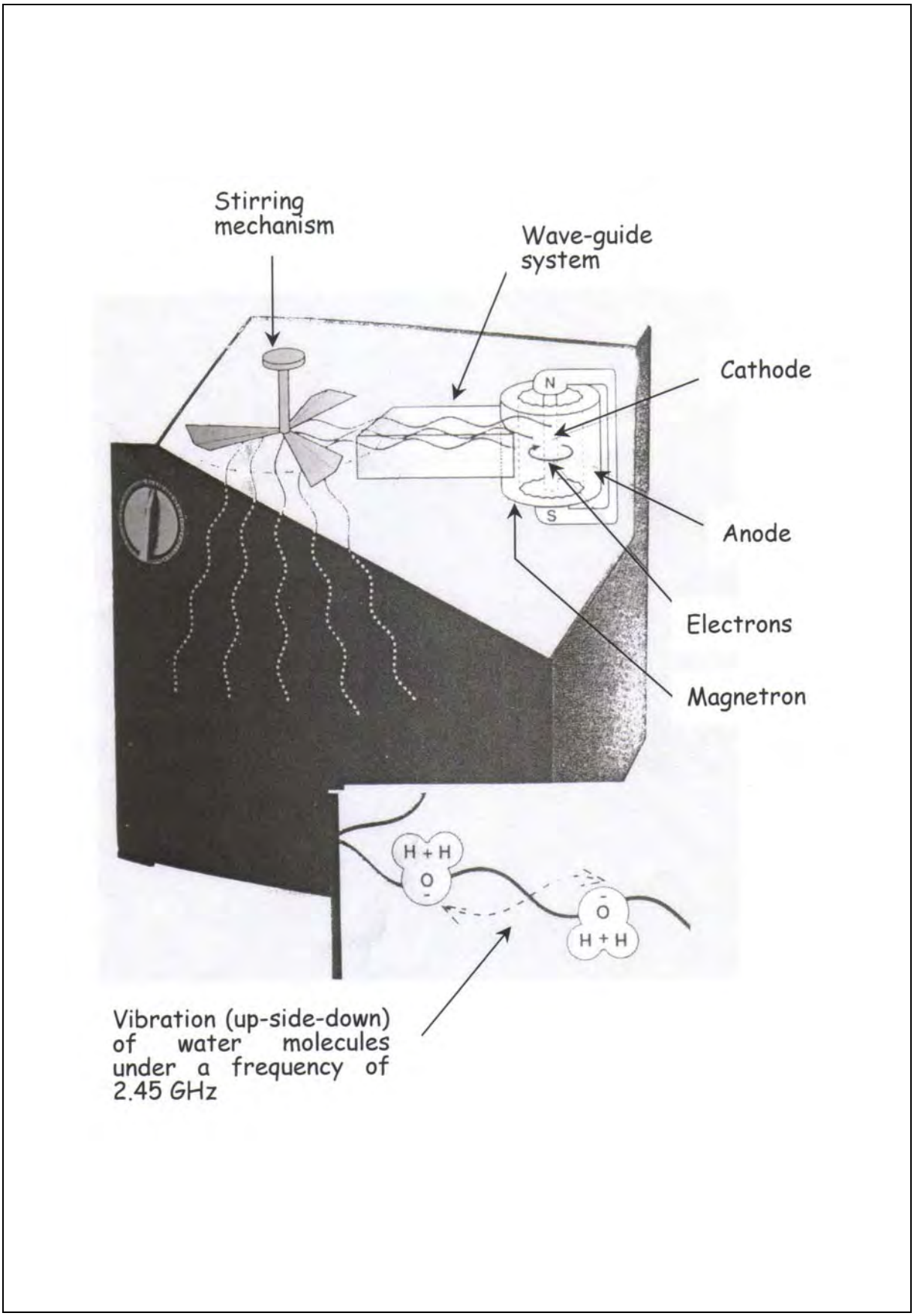


Figure A1 - Principle of Microwave Heating (He, 1994)

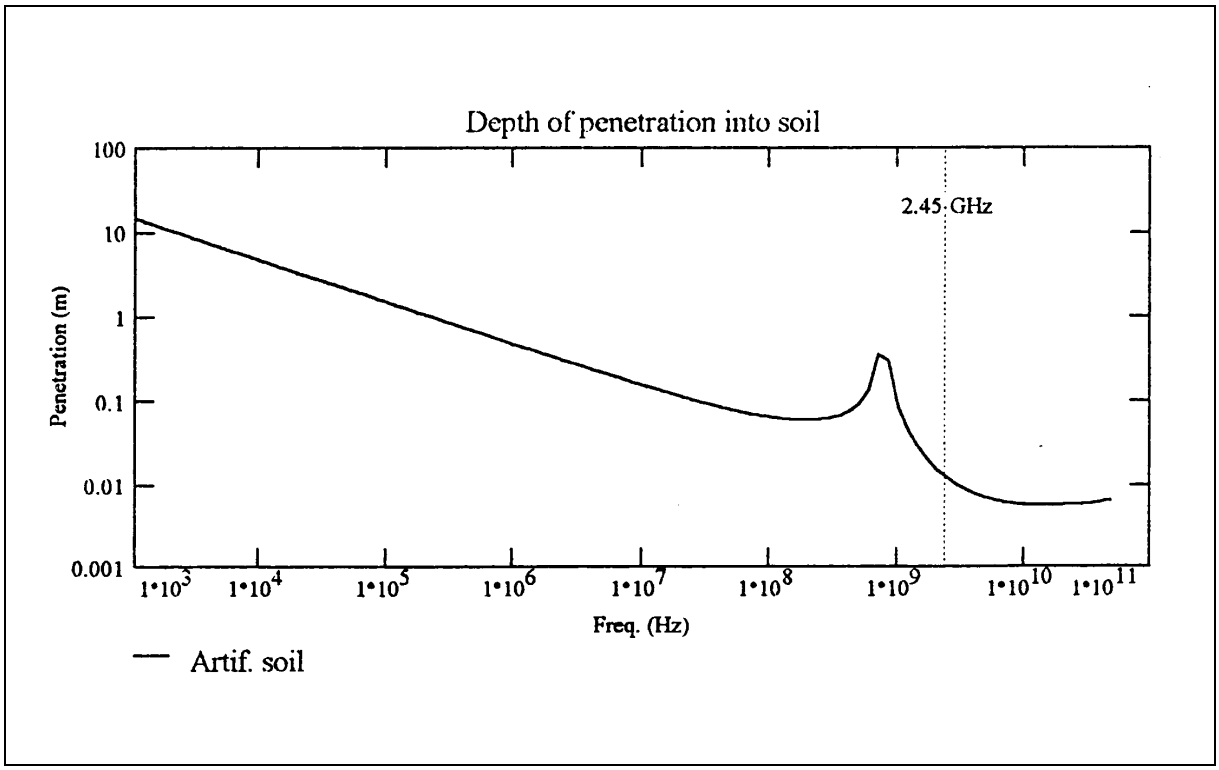


Figure A2 - Relationship between Microwave Frequency and Depth of Penetration for An Artificial Soil

Table of Contents
Table of Contents
Table of Contents

APPENDIX B

RESULTS OF COMPARATIVE TESTS CARRIED OUT BY PUBLIC WORKS REGIONAL LABORATORIES

Table B1 - Results of Comparative Tests Carried by Public Works Regional Laboratory (Tin Shui Wai)

Laboratory: Public Works Regional Laboratory (Tin Shui Wai)

Date of Checking	Microwave Oven ID No.	Equivalent Power Output (W)	Sample Type	Moisture Content (%) by Convection Oven Method				Moisture Content (%) by Microwave Oven Method							Difference in m.c. Results (%)	Total Drying Cycles for Microwave Oven Method
				Sample No	Test 1	Test 2	Average	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average		
21-Jan-04	TS0614 (High)	1513	Slightly sandy SILT	1	6.27	6.10	6.19	6.88	6.84					6.86	0.68	5
				2	15.39	15.58	15.49	15.90	15.90	15.77	15.73			15.83	0.34	5
				3	20.82	21.12	20.97	21.25	20.98	21.19	20.49	20.90	20.89	20.95	-0.02	5
20-Jul-04	TS0614 (High)	1513	Slightly sandy SILT	1	9.83	9.50	9.67	10.03	9.96					10.00	0.33	5
				2	16.85	16.98	16.92	17.50	17.31	17.25	17.00			17.27	0.35	5
				3	22.59	22.77	22.68	22.08	22.10	21.66	22.03	22.57	22.68	22.19	-0.49	5
20-Jan-05	TS0614 (High)	1513	Slightly sandy SILT	1	10.32	10.37	10.35	10.48	10.53					10.51	0.16	6
				2	17.35	17.44	17.40	17.29	17.36	17.60	17.41			17.42	0.02	6
				3	21.98	22.15	22.07	22.49	22.61	22.22	22.45	22.30	22.16	22.37	0.31	6
21-Jan-04	TS0633 (High)	1057	Slightly sandy SILT	1	6.25	6.33	6.29	6.66	6.56					6.61	0.32	5
				2	15.99	15.65	15.82	15.99	15.99	16.10	16.28			16.09	0.27	5
				3	21.29	21.87	21.58	21.89	21.74	22.00	22.19	22.22	22.62	22.11	0.53	5
20-Jul-04	TS0633 (High)	1057	Slightly sandy SILT	1	9.79	9.65	9.72	9.90	9.54					9.72	0.00	6
				2	18.55	18.47	18.51	18.37	18.08	18.55	18.46			18.37	-0.14	6
				3	22.06	21.81	21.94	22.89	22.55	21.94	22.06	22.12	22.32	22.31	0.38	6
20-Jan-05	TS0633 (High)	1057	Slightly sandy SILT	1	10.28	10.41	10.35	10.32	10.59					10.46	0.11	7
				2	17.66	17.59	17.63	17.62	17.75	17.58	17.30			17.56	-0.06	7
				3	22.03	21.86	21.95	22.41	22.58	22.10	22.71	22.21	22.37	22.40	0.45	7
21-Jan-04	TS0988 (High)	No information	Slightly sandy SILT	1	6.32	6.50	6.41	6.61	6.84					6.73	0.32	5
				2	15.21	15.64	15.43	15.89	16.07	15.78	16.05			15.95	0.52	5
				3	21.91	21.83	21.87	22.18	22.33	22.07	22.41	22.22	22.03	22.21	0.34	5
20-Jul-04	TS0988 (High)	No information	Slightly sandy SILT	1	9.88	10.02	9.95	9.96	10.08					10.02	0.07	5
				2	17.97	17.43	17.70	18.03	17.61	18.31	18.20			18.04	0.34	5
				3	23.35	22.80	23.08	22.98	23.50	23.08	23.49	23.16	23.64	23.31	0.23	5

Notes:
(1) The test procedures for the microwave oven method in general followed GS (Hong Kong Government, 1992). Details are given in Section 3 of this report.
(2) The test procedures for the convection oven method follwed Method 5.2 (105°C ± 5°C) of Geospec 3 (GEO, 2001).
(3) 'Equivalent' output power of microwave oven is determined based on the method given in Clause 12 of AS/NZS 2985.1:1995 (AS/NZS, 1995). Results are listed in Table B5.
(4) Difference in m.c. results = microwave oven result - convection oven result.

Table B2 - Results of Comparative Tests Carried by Public Works Regional Laboratory (Tsuen Wan)

Laboratory: Public Works Regional Laboratory (Tsuen Wan)

Date of Checking	Microwave Oven ID No.	Equivalent Power Output (W)	Sample Type	Sample No.	Moisture Content (%) by Convection Oven Method			Moisture Content (%) by Microwave Oven Method							Difference in m.c. Results (%)	Total Drying Cycles for Microwave Oven Method
					Test 1	Test 2	Average	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average		
28-May-04	TW0748 (High)	796	Silty/clayey very gravelly SAND	1	11.40	11.50	11.45	11.40	11.50					11.45	0.00	6
				2	15.90	15.70	15.80	15.80	16.00	15.70	15.70			15.80	0.00	6
				3	21.40	21.40	21.40	21.40	21.50	21.50	21.50			21.48	0.08	6
05-Jul-04	TW0525 (High)	1392	Silty/clayey very gravelly SAND	1	8.90	9.00	8.95	9.00	9.00					9.00	0.05	4
				2	16.70	16.80	16.75	16.90	16.70	16.90	17.00			16.88	0.13	4
				3	22.20	22.30	22.25	22.40	22.20	22.20	22.50			22.33	0.07	4
24-Sep-04	TW0466 (High)	1496	Very silty/clayey gravelly SAND	1	9.70	9.70	9.70	9.80	9.70					9.75	0.05	4
				2	17.30	17.50	17.40	17.30	17.30	17.40	17.40			17.35	-0.05	4
				3	24.30	24.30	24.30	24.20	24.40	24.40	24.40			24.35	0.05	4
17-Nov-04	TW0748 (High)	796	Silty/clayey gravelly SAND	1	10.70	10.80	10.75	10.80	10.80					10.80	0.05	6
				2	16.20	16.20	16.20	16.10	16.40	16.30	16.30			16.28	0.07	6
				3	21.10	21.20	21.15	21.00	21.20	21.30	21.20			21.18	0.03	6
03-Jan-05	TW0525 (High)	1392	Silty/clayey gravelly SAND	1	6.40	6.50	6.45	6.50	6.50					6.50	0.05	4
				2	17.50	17.50	17.50	17.80	17.50	17.60	17.60			17.63	0.13	4
				3	21.50	21.60	21.55	21.50	21.70	21.90	21.50			21.65	0.10	4
23-Mar-05	TW0466 (High)	1496	Silty/clayey gravelly SAND	1	8.30	7.90	8.10	7.80	7.80					7.80	-0.30	6
				2	15.50	15.50	15.50	15.40	15.40	15.40	15.40			15.40	-0.10	6
				3	22.40	22.50	22.45	23.10	23.00	23.00	22.80			22.98	0.52	6
13-May-05	TW0748 (High)	796	Silty/clayey gravelly SAND	1	11.20	11.20	11.20	11.20	11.20					11.20	0.00	6
				2	17.40	17.80	17.60	17.30	17.20	17.20	17.40			17.28	-0.33	6
				3	21.30	21.30	21.30	21.30	21.30	20.90	21.30			21.20	-0.10	6

Notes:
(1) The test procedures for the microwave oven method in general followed GS (Hong Kong Government, 1992). Details are given in Section 3 of this report.
(2) The test procedures for the convection oven method follwed Method 5.2 (105°C ± 5°C) of Geospec 3 (GEO, 2001).
(3) 'Equivalent' output power of microwave oven is determined based on the method given in Clause 12 of AS/NZS 2985.1:1995 (AS/NZS, 1995). Results are listed in Table B5.
(4) Difference in m.c. results = microwave oven result - convection oven result.

Table of Contents Table of Contents Table of Contents Table of Contents

Table B3 - Results of Comparative Tests Carried by Public Works Regional Laboratory (Tseung Kwan O)

Laboratory: Public Works Regional Laboratory (Tseung Kwan O)

Date of Checking	Microwave Oven ID No.	Equivalent Power Output (W)	Sample Type	Sample No.	Moisture Content (%) by Convection Oven Method			Moisture Content (%) by Microwave Oven Method							Difference in m.c. Results (%)	Total Drying Cycles for Microwave Oven Method
					Test 1	Test 2	Average	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average		
03-Mar-03	TK0640 (High)	748	Sandy SILT/CLAY	1	9.4	9.4	9.40	10.0	9.9					9.95	0.55	8
				2	16.6	16.6	16.60	16.8	16.7	16.6	16.7			16.70	0.10	8
				3	22.1	22.2	22.15	22.1	22.1	22.3	22.2	22.2	22.2	22.18	0.03	8
03-Mar-03	TK0640 (High)	748	SAND	1	9.5	9.5	9.50	9.6	9.5					9.55	0.05	10
				2	16.2	16.5	16.35	16.3	16.4	16.3	16.3			16.33	-0.03	10
				3	21.5	21.5	21.50	21.2	21.2	21.2	21.6	21.8	21.8	21.47	-0.03	10
03-Sep-03	TK0640 (High)	748	Slightly silty gravelly SAND	1	8.5	8.5	8.50	8.8	8.8					8.80	0.30	8
				2	18.0	18.0	18.00	18.2	18.1	18.1	18.2			18.15	0.15	8
				3	22.3	22.2	22.25	22.1	22.0	22.1	22.0	21.9	22.1	22.03	-0.22	8
03-Jan-05	TK0640 (High)	748	Slightkly gravelly sandy SILT	1	6.9	6.9	6.90	7.1	7.4					7.25	0.35	9
				2	17.5	17.9	17.70	16.6	17.1	17.2	16.9			16.95	-0.75	9
				3	21.4	21.7	21.55	21.5	21.9	21.7	21.5	21.7	21.9	21.70	0.15	9
03-Mar-03	TK0641 (High)	724	SAND	1	9.4	9.4	9.40	9.6	9.6					9.60	0.20	10
				2	16.5	16.5	16.50	16.4	16.4	16.4	16.5			16.43	-0.08	10
				3	21.5	21.2	21.35	21.3	21.2	21.6	21.4	21.4	21.1	21.33	-0.02	10
03-Mar-03	TK0641 (High)	724	Sandy SILT/CLAY	1	9.5	9.5	9.50	9.9	9.9					9.90	0.40	8
				2	16.6	16.6	16.60	16.7	16.7	16.6	16.8			16.70	0.10	8
				3	22.2	22.2	22.20	22.0	22.2	22.1	22.1	22.2	22.3	22.15	-0.05	8
03-Sep-03	TK0641 (High)	724	Slightly silty gravelly SAND	1	8.6	8.5	8.55	8.8	8.9					8.85	0.30	8
				2	17.1	17.1	17.10	17.0	17.0	17.1	17..1			17.03	-0.07	8
				3	20.9	21.0	20.95	21.0	21.2	21.2	21.3	21.2	21.0	21.15	0.20	8
03-Jan-05	TK0641 (High)	724	Slightkly gravelly sandy SILT	1	6.9	6.9	6.90	7.4	7.1					7.25	0.35	2
				2	17.5	17.9	17.70	16.9	17.2	17.3	17.1			17.13	-0.57	4
				3	21.4	21.7	21.55	22.0	21.5	21.7	21.9	21.7	21.6	21.73	0.18	9

Notes:
(1) The test procedures for the microwave oven method in general followed GS (Hong Kong Government, 1992). Details are given in Section 3 of this report.
(2) The test procedures for the convection oven method follwed Method 5.2 (105°C ± 5°C) of Geospec 3 (GEO, 2001).
(3) 'Equivalent' output power of microwave oven is determined based on the method given in Clause 12 of AS/NZS 2985.1:1995 (AS/NZS, 1995). Results are listed in Table B5.
(4) Difference in m.c. results = microwave oven result - convection oven result.

Table of Contents
Table of Contents
Table of Contents

Table B4 - Results of Comparative Tests Carried by Public Works Regional Laboratory (North Lantau) (Sheet 1 of 2)

Laboratory: Public Works Regional Laboratory (North Lantau)

Date of Checking	Microwave Oven ID No.	Equivalent Power Output (W)	Sample Type	Sample No.	Moisture Content (%) by Convection Oven Method			Moisture Content (%) by Microwave Oven Method							Difference in m.c. Results (%)	Total Drying Cycles for Microwave Oven Method
					Test 1	Test 2	Average	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average		
07-Nov-03	NL0553 (High)	891	Gravelly silty SAND	1	10.3	10.3	10.30	10.6	10.5					10.55	0.25	9
				2	18.1	17.9	18.00	17.9	18.1	17.8	17.9			17.93	-0.08	9
				3	22.9	23.2	23.05	23.0	23.2	23.3	23.0	23.2	23.0	23.12	0.07	9
03-May-04	NL0553 (High)	891	Gravelly silty SAND	1	10.7	10.6	10.65	10.7	10.5					10.60	-0.05	11
				2	17.0	16.8	16.90	17.0	17.2	17.3	17.3			17.20	0.30	11
				3	22.4	22.4	22.40	22.5	22.7	22.5	22.6	22.6	22.6	22.58	0.18	11
26-Oct-04	NL0553 (High)	891	Gravelly silty SAND	1	9.6	9.5	9.55	9.8	9.7					9.75	0.20	11
				2	16.2	16.2	16.20	15.9	16.2	15.9	16.0			16.00	-0.20	11
				3	20.9	20.7	20.80	20.9	20.6	20.8	21.0	20.8	20.9	20.83	0.03	11
25-Apr-05	NL0553 (High)	891	Gravelly silty SAND	1	11.7	12.0	11.85	12.3	12.3					12.30	0.45	11
				2	17.5	17.4	17.45	17.8	17.9	18.0	17.8			17.88	0.43	11
				3	22.7	22.9	22.80	23.1	23.2	22.9	22.9	23.0	23.2	23.05	0.25	11
26-Feb-04	NL1070 (High)	No Information	Gravelly silty SAND	1	10.0	9.9	9.95	10.3	10.4					10.35	0.40	15
				2	17.2	17.6	17.40	17.7	16.9	17.3	17.2			17.28	-0.13	15
				3	21.5	21.8	21.65	22.0	21.6	21.7	22.0	21.8	22.3	21.90	0.25	15
12-Aug-04	NL1070 (High)	No Information	Gravelly silty SAND	1	8.6	8.5	8.55	8.8	8.8					8.80	0.25	13
				2	17.1	17.2	17.15	17.2	17.3	17.2	17.4			17.28	0.13	13
				3	23.6	23.7	23.65	23.9	24.1	24.2	23.9	24.0	23.9	24.00	0.35	13
28-Jan-05	NL1070 (High)	No Information	Gravelly silty SAND	1	5.3	5.3	5.30	5.6	5.7					5.65	0.35	14
				2	18.1	18.0	18.05	18.3	18.3	18.4	18.1			18.28	0.22	14
				3	23.7	23.9	23.80	23.7	23.8	23.6	23.9	23.9	23.7	23.77	-0.03	14
28-Feb-04	NL1071 (High)	No Information	Gravelly silty SAND	1	10.9	10.7	10.80	10.8	10.7					10.75	-0.05	9
				2	17.2	17.5	17.35	17.3	17.2	17.2	17.6			17.33	-0.02	9
				3	22.7	23.0	22.85	23.1	23.0	22.9	22.9	23.1	23.6	23.10	0.25	9
13-Aug-04	NL1071 (High)	No Information	Gravelly silty SAND	1	8.6	8.7	8.65	8.8	8.9					8.85	0.20	9
				2	17.2	16.9	17.05	17.1	17.4	17.0	17.3			17.20	0.15	9
				3	24.2	24.2	24.20	24.7	24.5	24.7	24.7	24.9	24.7	24.70	0.50	9
13-Mar-04	NL1072 (High)	No Information	Gravelly very silty SAND	1	10.6	10.6	10.60	10.5	10.6					10.55	-0.05	10
				2	17.4	17.6	17.50	17.5	17.7	17.6	17.7			17.63	0.13	10
				3	23.1	23.4	23.25	23.4	23.2	23.5	23.3	23.3	23.5	23.37	0.12	10
26-Aug-04	NL1072 (High)	No Information	Slightly gravelly silty SAND	1	10.0	10.0	10.00	10.1	10.2					10.15	0.15	10
				2	18.0	18.2	18.10	18.1	18.3	18.2	18.2			18.20	0.10	10
				3	22.6	22.9	22.75	22.7	22.8	23.0	22.7	22.9	22.8	22.82	0.07	10
03-Feb-05	NL1072 (High)	No Information	Gravelly silty SAND	1	9.5	9.6	9.55	9.8	9.7					9.75	0.20	10
				2	18.0	18.0	18.00	18.1	18.2	18.0	18.4			18.18	0.17	10
				3	23.5	23.7	23.60	23.9	23.7	23.8	23.7	23.9	23.7	23.78	0.18	10

Table of Contents
Table of Contents
Table of Contents

Table B4 - Results of Comparative Tests Carried by Public Works Regional Laboratory (North Lantau) (Sheet 2 of 2)

Laboratory: Public Works Regional Laboratory (North Lantau)

Date of Checking	Microwave Oven ID No.	Equivalent Power Output (W)	Sample Type	Sample No.	Moisture Content (%) by Convection Oven Method			Moisture Content (%) by Microwave Oven Method							Difference in m.c. Results (%)	Total Drying Cycles for Microwave Oven Method
					Test 1	Test 2	Average	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average		
09-Mar-04	NL1073 (High)	1318	Gravelly silty SAND	1	10.7	10.4	10.55	10.7	10.6					10.65	0.10	10
				2	17.6	17.3	17.45	17.6	17.6	17.3	17.3			17.45	0.00	10
				3	23.3	23.3	23.30	23.5	23.3	23.6	23.1	23.3	23.3	23.35	0.05	10
07-Sep-04	NL1073 (High)	1318	Gravelly very silty SAND	1	9.4	9.6	9.50	9.6	9.4					9.50	0.00	10
				2	16.7	16.6	16.65	16.7	16.8	16.5	16.6			16.65	0.00	10
				3	22.5	22.5	22.50	22.5	22.9	22.7	22.6	22.6	22.4	22.62	0.12	10
24-Feb-05	NL1073 (High)	1318	Gravelly very silty SAND	1	9.7	9.6	9.65	10.0	10.0					10.00	0.35	10
				2	18.3	18.0	18.15	18.1	18.2	18.5	18.3			18.28	0.13	10
				3	23.4	23.3	23.35	23.6	23.5	23.8	23.3	23.7	23.4	23.55	0.20	10
11-Mar-04	NL1074 (High)	No Information	Gravelly silty SAND	1	10.5	10.3	10.40	10.6	10.7					10.65	0.25	9
				2	17.3	17.4	17.35	17.9	18.0	18.0	17.9			17.95	0.60	9
				3	22.8	23.0	22.90	23.2	23.1	22.9	22.8	23.2	23.5	23.12	0.22	9
24-Aug-04	NL1074 (High)	No Information	Gravelly very silty SAND	1	10.2	10.3	10.25	10.3	10.4					10.35	0.10	9
				2	18.6	18.7	18.65	18.8	18.9	18.6	18.7			18.75	0.10	9
				3	23.1	23.1	23.10	23.5	23.1	23.5	23.3	23.2	23.2	23.30	0.20	9
01-Feb-05	NL1074 (High)	No Information	Slightly gravelly silty SAND	1	9.2	9.3	9.25	9.6	9.7					9.65	0.40	9
				2	18.3	18.1	18.20	18.1	18.0	18.1	18.1			18.08	-0.13	9
				3	23.1	23.5	23.30	23.6	23.5	23.6	23.4	23.9	23.3	23.55	0.25	9
28-Oct-03	NL1075 (High)	1358	Gravelly silty SAND	1	10.1	10.2	10.15	10.3	10.2					10.25	0.10	9
				2	17.9	18.1	18.00	17.9	18.1	18.0	18.1			18.03	0.02	9
				3	23.6	23.6	23.60	23.9	23.7	23.6	23.8	23.6	23.8	23.73	0.13	9
16-Nov-04	NL1075 (High)	1358	Gravelly very silty SAND	1	10.1	10.3	10.20	10.5	10.2					10.35	0.15	9
				2	15.5	15.6	15.55	15.4	15.5	15.5	15.8			15.55	0.00	9
				3	20.9	21.0	20.95	21.1	21.0	21.1	21.4	21.1	21.2	21.15	0.20	9
14-Apr-04	NL1075 (High)	1358	Gravelly very silty SAND	1	10.8	10.6	10.70	11.2	10.9					11.05	0.35	9
				2	18.0	17.7	17.85	17.9	17.7	18.0	17.7			17.83	-0.03	9
				3	21.7	22.1	21.90	22.5	22.0	22.3	22.1	22.0	22.1	22.17	0.27	9
12-May-05	NL1075 (High)	1358	Gravelly very silty SAND	1	10.6	10.8	10.70	10.7	11.0					10.85	0.15	10
				2	16.8	16.9	16.85	17.2	17.1	16.9	16.9			17.03	0.17	10
				3	21.5	21.6	21.55	21.6	22.0	21.8	21.9	21.7	21.8	21.80	0.25	10

Notes:
(1) The test procedures for the microwave oven method in general followed GS (Hong Kong Government, 1992). Details are given in Section 3 of this report.
(2) The test procedures for the convection oven method follwed Method 5.2 (105°C ± 5°C) of Geospec 3 (GEO, 2001).
(3) 'Equivalent' output power of microwave oven is determined based on the method given in Clause 12 of AS/NZS 2985.1:1995 (AS/NZS, 1995). Results are listed in Table B5.
(4) Difference in m.c. results = microwave oven result - convection oven result.

Table of Contents
Table of Contents
Table of Contents

Table B5 - Measurement of Equivalent Output Power for Microwave Ovens

Public Works Regional Laboratory	ID No.	Brand Name	Model No.	Power Setting	Equivalent Power Output (W)
Tin Shui Wai	TSO614	National	NE-1756	High	1513
	TSO633	National	NE-1070	High	1057
Tsuen Wan	TW0466	National	NE-1756	High	1496
	TW0525	National	NE-1756	High	1392
	TW0748	National	NE-1037	High	796
Tseung Kwan O	TKO640	National	NE-1037	High	748
	TKO641	National	NE-1037	High	724
North Lantau	NL0553	National	NE-1070	High	891
	NL1073	National	NE-1756	High	1318
	NL1075	National	NE-1756	High	1358
	NL1077	National	NE-1756	High	1340

Notes:

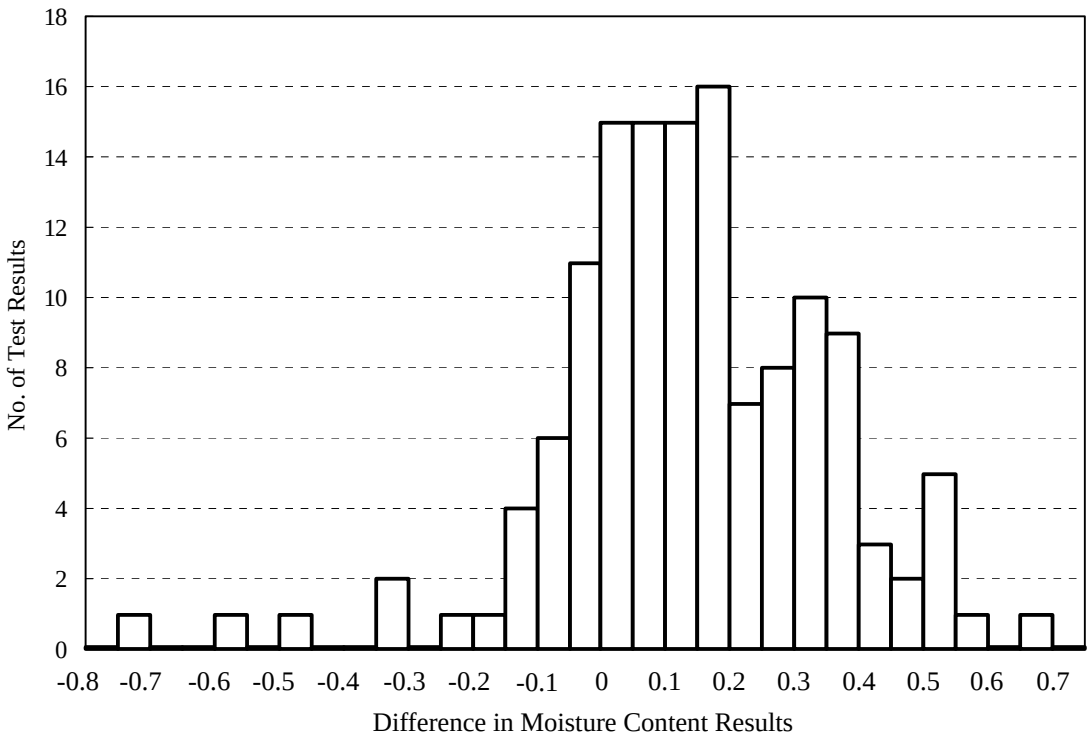
(1) The measurement method for the output power of microwave ovens followed Clause 12 of AS/NZS 2895.1:1996 (AS/NZS, 1995).

(2) The following microwave ovens were out-of-service at the time of the measurement:

Public Works Regional Laboratory (Tin Shui Wai):	ID No. TSO688	NATIONAL NE-1756
Public Works Regional Laboratory (North Lantau):	ID No. NL1070	NATIONAL NE-1457
	ID No. NL1071	NATIONAL NE-1756
	ID No. NL1072	NATIONAL NE-1756
	ID No. NL1074	NATIONAL NE-1756

(3) According to the manufacturer's technical specifications, the output power of the above microwave ovens are listed below:

NATIONAL NE-1756: 1700 W
NATIONAL NE-1457: 1400 W
NATIONAL NE-1070: 1000 W
NATIONAL NE-1037: 950 W



Notes:

(1) Difference in moisture content results = microwave oven result (w_m)– convection oven result (w_c)

(2) The test results obtained by the four regional laboratories (altogether 135 nos.) are taken into account in the analysis.

(3) Based on Grubb's test (BSI, 1994) for the test results for each regional laboratory, no statistical outliners are found (with Grubb's test statistic greater than 1% critical value).

(4) The data set is observed to fit a normal distribution. The validity of the assumed probabilistic model is checked by Kolmogorov-Smirnov goodness-of-fit test (Ang & Tang, 1975) and is not rejected at the 5% significance level.

(5) By fitting the probability distribution of the data set with a normal distribution model, the mean and standard deviation of the model are found to be 0.13% and 0.21% respectively. On this basis, the interval that covers at least 95% of population (p=0.95) of the results on difference in moisture content with 95% confidence level (1-α=0.95) is between -0.34% to 0.60% (i.e. 0.13% ± 2.234 × 0.21%), where 2.234 is the statistical tolerance limit factor determined from Table E.4 of BS ISO 16269-6:2005 (BSI, 2005). For p=0.99 and 1-α=0.99, the statistical tolerance limit factor is 3.098 from Table E.5 of BS ISO 16269-6:2005 (BSI, 2005) and the corresponding interval is between -0.52% to 0.78% (i.e. 0.13% ± 3.098 × 0.21%).

(6) With the aid of the statistical analysis, it can be seen that the chance of having the difference in the test results (w_m-w_c) greater than 1% is very low.

Figure B1 - Distribution Graph of Difference in Moisture Content Results

Table of Contents
Table of Contents
Table of Contents

APPENDIX C

DETAILED RESULTS OF T-TEST METHOD (FOR THE RESULTS OBTAINED FROM THE SECOND STAGE OF THE TESTS)

SAMPLE NO. 1

Group Statistics[a]

2		N	Mean	Std. Deviation	Std. Error Mean
RESULT	Heating Oven	8	14.6800	.6704	.2370
	Microwave	8	15.9788	.6978	.2467

a. SAMPLE = 1

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RESULT	Equal variances assumed	.249	.625	-3.796	14	.002	-1.2988	.3421	-2.0325	-.5650
	Equal variances not assumed			-3.796	13.977	.002	-1.2988	.3421	-2.0326	-.5649

a. SAMPLE = 1

SAMPLE NO. 2

Group Statistics[a]

2		N	Mean	Std. Deviation	Std. Error Mean
RESULT	Heating Oven	8	14.0663	.7070	.2499
	Microwave	8	14.4875	.5937	.2099

a. SAMPLE = 2

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RESULT	Equal variances assumed	.460	.509	-1.291	14	.218	-.4212	.3264	-1.1213	.2788
	Equal variances not assumed			-1.291	13.593	.218	-.4212	.3264	-1.1232	.2807

a. SAMPLE = 2

SAMPLE NO. 12

Group Statistics[a]

2		N	Mean	Std. Deviation	Std. Error Mean
RESULT	Heating Oven	8	9.3575	.1793	6.338E-02
	Microwave	8	9.4350	.1945	6.876E-02

a. SAMPLE = 12

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RESULT	Equal variances assumed	.001	.973	-.829	14	.421	-7.7500E-02	9.352E-02	-.2781	.1231
	Equal variances not assumed			-.829	13.908	.421	-7.7500E-02	9.352E-02	-.2782	.1232

a. SAMPLE = 12

SAMPLE NO. 13

Group Statistics[a]

2		N	Mean	Std. Deviation	Std. Error Mean
RESULT	Heating Oven	8	16.9675	.1602	5.662E-02
	Microwave	8	16.8638	.3632	.1284

a. SAMPLE = 13

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RESULT	Equal variances assumed	4.932	.043	.739	14	.472	.1038	.1403	-.1972	.4047
	Equal variances not assumed			.739	9.624	.477	.1038	.1403	-.2106	.4181

a. SAMPLE = 13

SAMPLE NO. 15

Group Statistics[a]

2		N	Mean	Std. Deviation	Std. Error Mean
RESULT	Heating Oven	8	17.7250	.2580	9.120E-02
	Microwave	8	17.5700	.4699	.1661

a. SAMPLE = 15

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RESULT	Equal variances assumed	1.419	.253	.818	14	.427	.1550	.1895	-.2515	.5615
	Equal variances not assumed			.818	10.867	.431	.1550	.1895	-.2628	.5728

a. SAMPLE = 15

SAMPLE NO. 17

Group Statistics[a]

2		N	Mean	Std. Deviation	Std. Error Mean
RESULT	Heating Oven	8	10.6563	.3683	.1302
	Microwave	8	10.6763	.5238	.1852

a. SAMPLE = 17

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RESULT	Equal variances assumed	1.074	.318	-.088	14	.931	-2.0000E-02	.2264	-.5055	.4655
	Equal variances not assumed			-.088	12.563	.931	-2.0000E-02	.2264	-.5108	.4708

a. SAMPLE = 17

SAMPLE NO. 19

Group Statistics[a]

2		N	Mean	Std. Deviation	Std. Error Mean
RESULT	Heating Oven	8	14.7113	.4565	.1614
	Microwave	8	14.4525	.3926	.1388

a. SAMPLE = 19

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RESULT	Equal variances assumed	.329	.575	1.215	14	.244	.2588	.2129	-.1979	.7154
	Equal variances not assumed			1.215	13.693	.245	.2588	.2129	-.1988	.7163

a. SAMPLE = 19

SAMPLE NO. 23

Group Statistics[a]

2		N	Mean	Std. Deviation	Std. Error Mean
RESULT	Heating Oven	8	10.7675	.7406	.2619
	Microwave	8	11.2725	1.0294	.3640

a. SAMPLE = 23

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RESULT	Equal variances assumed	.146	.708	-1.126	14	.279	-.5050	.4484	-1.4667	.4567
	Equal variances not assumed			-1.126	12.715	.281	-.5050	.4484	-1.4759	.4659

a. SAMPLE = 23

SAMPLE NO. 24

Group Statistics[a]

2		N	Mean	Std. Deviation	Std. Error Mean
RESULT	Heating Oven	8	19.3988	.3018	.1067
	Microwave	8	19.1963	.6897	.2438

a. SAMPLE = 24

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RESULT	Equal variances assumed	8.976	.010	.761	14	.459	.2025	.2662	-.3684	.7734
	Equal variances not assumed			.761	9.586	.465	.2025	.2662	-.3940	.7990

a. SAMPLE = 24

Notes:
(1) T-test method was adopted to compare means obtained by the microwave wave method (named as 'microwave' in the tables) and the convection oven method (named as 'heating oven' in the tables).
(2) A computer program called SPSS (Version 7.5) was adopted for the analysis. Detailed results are presented in the above tables (being the output of the computer program).
(3) In each table, results for Levene's Test for Equality of Variances is given. This test is used to determine if the spread of the groups differs significantly. The null hypothesis for this test is that the two variances (not the means) are equal. If the calculated significance (p-value) is less than the required α value, this means that the two variances differ significantly and separate-variance t-test for means should be used in this case (results given under 'equal variances not assumed' in the table). Otherwise, pooled-variance t-test for means should be adopted (results given under 'equal variances assumed' in the table).
(4) In the analysis, the required α value (level of significance) is set at 0.05.
(5) The principles of T-test and Levene's Test can be found in many statistics textbooks and therefore are not discussed in this report.

Table of Contents
Table of Contents
Table of Contents

APPENDIX D

SUGGESTED AMENDMENTS TO THE EXISTING MICROWAVE OVEN DRYING METHOD GIVEN IN THE GENERAL SPECIFICATON FOR CIVIL ENGINEERING WORKS

APPENDIX 6.2 - DETERMINATION OF THE MOISTURE CONTENT OF FINE-GRAINED AND MEDIUM-GRAINED MATERIAL BY THE MICROWAVE OVEN DRYING METHOD

Item	Existing Version of GS (Hong Kong Government, 1992)	Proposed Amended Version	Details of Amendments Included
Scope	6.2.1 This method covers the determination of the moisture content of fine grained and medium grained material as a percentage of the mass of the dry material.	6.2.1 (a) This method is used for the determination of the moisture content of fine grained and medium grained soils by the microwave oven drying method. (b) For the following soils, this method may yield unreliable moisture content results and therefore shall not be used, unless otherwise instructed by the Engineer: (i) soils containing significant amount of halloysite, mica, montmorillonite, gypsum and other hydrated materials; (ii) highly organic soils; and (iii) soils in which the pore water contains dissolved solids (such as salt in case of marine deposits). (c) Owing to the localised high temperatures that the specimen is exposed to in microwave heating, physical characteristics of the soil may be altered. Therefore, samples dried by this method shall not be reused for other tests.	(a) The drying method is clearly stated in the scope of the test method. (b)(c) The limitations of the test method are specified.

Item	Existing Version of GS (Hong Kong Government, 1992)	Proposed Amended Version	Details of Amendments Included
Apparatus	6.2.2 The following apparatus is required: (a) A microwave oven with a timer and an adjustable power setting. (b) An airtight container of microwave safe and non-reflective material. (c) A balance readable and accurate to 0.01 g. (d) A desiccator containing anhydrous silica gel.	6.2.2 The following apparatuses are required: (a) a microwave oven with a timer and an adjustable power setting (the rated output power as specified by the manufacturer shall not be greater than 1700 W). (b) a container made of a non-metallic, non-absorbent material and not subject to changes in mass or shape under repeated heating, cooling and cleaning. (c) For fine-grained soils: a balance readable to 0.01 g and accurate to 0.05 g. (d) For medium-grained soils: a balance readable to 0.1 g and accurate to 0.3 g. (e) A desiccator containing anhydrous silica gel. (f) Stirring tool.	(a) To reduce the potential for overheating of soil samples, control on rated output powers of microwave ovens used is given. (b) Minor editing amendment. (c)(d) The requirements for the resolution and accuracy of balances used for fine-grained and medium-grained soils, as specified in Geospec 3, are used. (e) No change. (f) New added.
Sample Preparation	A new item that is not included in the existing GS clauses.	6.2.3 (a) The minimum mass of soil required for the preparation of a test specimen for the microwave oven drying method shall be as follows: (i) Fine-grained soil: 100 g (ii) Medium-grained soil: 300 g (b) The specimens shall be prepared and processed as quickly as possible to minimise unrecorded moisture loss that will result in erroneous water content determination. If the specimens are not to be tested immediately, store them in sealed containers to prevent loss of moisture.	(a) Part of the existing Clause 6.2.3(b) related to minimum mass for fine-grained and medium-grained soils is written as a separate clause for clarity purposes. For fine-grained soil, the minimum mass of 100 g is recommended, as the drying time may be too rapid if a small sample mass is adopted, thus yielding inaccurate results, (b) The need for performance of the test in a quick manner and its reason is specified.

Item	Existing Version of GS (Hong Kong Government, 1992)	Proposed Amended Version	Details of Amendments Included
Test Procedure	6.2.3 The procedure shall be as follows: (a) The container shall be cleaned, dried and weighed to the nearest 0.01 g (m_1). (b) A specimen shall be crumbled and placed loosely in the container and the lid shall be replaced. Each specimen of fine grained material shall be at least 30 g and each specimen of medium grained material shall be at least 300 g. Specimens of medium grained material may be tested in several parts each less than 300 g and the results aggregated. (c) The container and contents shall be weighed to the nearest 0.01 g (m_2). (d) The lid of the specimen container shall be removed and the container with its lid and contents shall be placed in the microwave oven and dried. The specimen shall be considered to be dry when, after an initial drying period, successive weighings at intervals of 1 minute produce results which are the same to the nearest 0.01 g. Alternatively, the oven may be set to an appropriate time and power setting to dry the specimen as determined by calibration of the oven on soil of a similar type. (e) After drying, the container and contents shall be removed from the microwave oven and placed in the desiccator to cool. (f) The lid shall be replaced and the container and contents shall be weighed to the nearest 0.01 g (m_3).	6.2.4 The test shall be carried out as follows: (a) Clean and dry the container and weigh it (m_1).	(a) Minor editing amendment.
		(b) Take the test specimen, crumble and place it loosely in the container.	(b) Minor editing amendment.
		(c) Weigh the container with contents (m_2). The reading shall be recorded to the nearest 0.01 g for fine-grained soils and 0.1 g for medium-grained soils.	(c) Minor editing amendment.
		(d) Place the container with contents in the microwave oven. Select a suitable power setting and dry the soil for a period of 5 minutes. After the set time has elapsed, remove the container and contents from the microwave oven. Either weigh the specimen immediately or place it in desiccator to cool to allow handling and to prevent damage to the balance. Record the mass of the container and contents to the nearest 0.01 g for fine-grained soils and 0.1 g for medium-grained soils.	(d) To avoid overheating of a soil sample, the maximum time for each drying cycle is specified.
		(e) Mix the soil carefully by using stirring tool. Take special precaution to prevent loss of any soil.	(e) This step helps achieve a more uniform heating of a soil sample over the entire drying process.
		(f) Return the container and contents to the microwave oven. Repeat steps 6.2.4(d) to 6.2.4(e) until the sample gets dry. The sample shall be deemed to be dry when the difference in successive weighings of the sample does not exceed 0.1% of the original mass of the sample.	(f) This acceptance criterion is the same to that for Test Methods 5.1 and 5.2 of Geospec 3 and ASTM D4643 related to moisture content determination by microwave oven drying method.
		(g) Record the number of drying cycles.	(g) A new added step.

Item	Existing Version of GS (Hong Kong Government, 1992)	Proposed Amended Version	Details of Amendments Included
Calculation	6.2.4 The moisture content of the material (w) shall be calculated as a percentage of the dry mass of the material from the equation: $w = (m_2 – m_3)/(m_3-m_1)\times100\%$ where: - m_1 is the mass of the container (g) - m_2 is the mass of the container and contents before drying (g) - m_3 is the mass of the container and contents after drying (g)	6.2.5 Calculate the moisture content of the soil sample, w, as a percentage of the dry soil mass to the nearest 0.1% from the equation: $w = (m_2 – m_3)/(m_3-m_1)\times100\%$ where: - m_1 is the mass of the container (in g); - m_2 is the mass of the container and contents before drying (in g); and - m_3 is the mass of the container and contents after drying (g).	Minor editing amendment.
Reporting of results	6.2.5 The following shall be reported: (a) Source and identification of the soil. (b) The moisture content of the material to the nearest 0.1%. (c) That the test method used was in accordance with this Specification.	6.2.6 The following information shall be reported: (a) source and identification of the sample; (b) date of sampling; (c) date of test; (d) model and rated output power of microwave oven. (e) power setting of microwave oven used. (f) visual description of soil in accordance with Geoguide 3; (g) fine-grained or medium-grained soil; (h) moisture content; (i) number of drying cycles; (j) whether the test method used was in accordance with this Specification; and (k) additional information provided by the Specifier.	Several new items are added.

Item	Existing Version of GS (Hong Kong Government, 1992)	Proposed Amended Version	Details of Amendments Included
Safety Precaution	A new item that is not included in the existing GS clauses.	6.2.7 The following safety precautions are suggested: (a) Handle hot containers with a container holder. (b) Suitable eye protection is recommended. (c) Soils containing oil or other contaminates may ignite into flames during microwave drying. Also, fumes given off may be toxic. Therefore, for safety reason, this method is not suitable for such soil. (d) A covering over the sample container may be appropriate to prevent operator injury or oven damage. A heavy paper toweling has been found satisfactory for this purpose. This also prevents scattering of the test sample in the oven during the drying cycles. (e) Other safety precautions as recommended by the manufacturer should be followed.	The safety precautions in reference to ASTM D4643 are recommended.

Table of Contents Table of Contents Table of Contents Table of Contents

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Table of Contents
Table of Contents
Table of Contents

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Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2000).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

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Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.

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The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

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