International Test and Evaluation
Program
for Humanitarian Demining

Lessons Learned

Test and Evaluation of Mechanical Demining Equipment according to the CEN Workshop Agreement (CWA 15044)

Part 3: Measuring soil compaction and soil moisture content of areas for testing of mechanical demining equipment

ITEP Working Group on Test and Evaluation of Mechanical Assistance Clearance Equipment
(ITEP WGMAE)

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1. Background

The CEN Workshop Agreement on Test and Evaluation of Demining Machines (CWA 15044) recommends the measurement of soil compaction (or soil bulk density) in test zones prior to the execution of a performance or acceptance trial evaluating mine neutralisation and/or ground penetration performance. Soil compaction has been shown to be a significant factor influencing the performance of ground engaging mechanical equipment and also a critical characteristic determining the reliability of the performance trial results [1]. Furthermore, knowledge about soil compaction can also be fundamental to optimise flail parameters, such as flail hammer type and flail rotational speed, for specific operational conditions [24].

This document provides a summary of the definitions used in the CWA 15044 and lists commonly used methods to measure soil compaction and soil moisture.

2. Definitions

Compaction is a reduction of the volume of a given mass of soil consisting of solid soil particles, air, and water by the application of mechanical energy. It involves an expulsion of air without a significant change in the amount of water in the soil mass (Figure 1). Thus, the ***moisture content*** of the soil, which is defined as the ratio of the weight of water to the weight of dry soil particles, is normally the same for loose, uncompacted soil as for the same soil after compaction [2]. When soil is compacted the porosity is decreased. The degree of compaction is measured in terms of ***dry bulk density*** (D_b). Dry bulk density is the ratio of the mass of oven-dried (105° - 110° C) solids/particles to the volume of soil, which includes the volume of the particles and the pore space between the soil particles (g/cm^3)[1] [5].

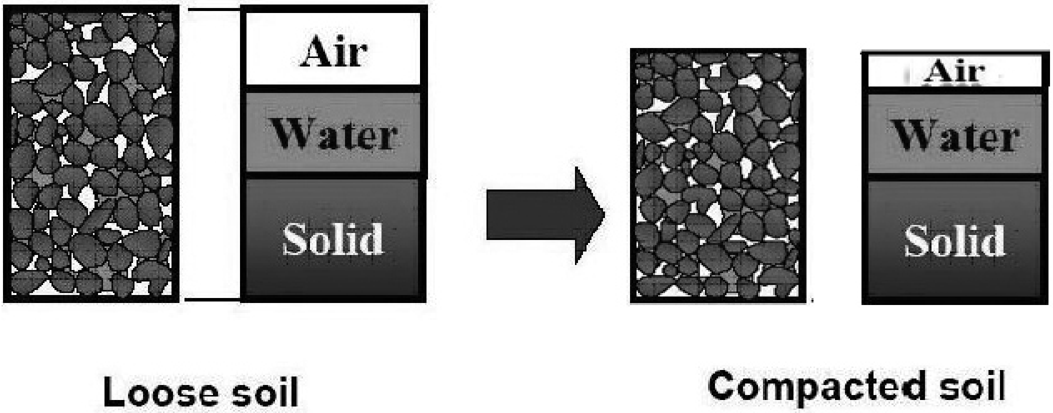

Figure 1: Soil compaction involves an expulsion of air without a significant change in the amount of water in the soil (adapted from [3])

For any soil and *for a given amount of compacting effort*, the bulk density obtained depends on the moisture content. At low moisture contents, there is greater friction between soil particles, reducing the capacity for particle movement and hence compaction is more difficult. Increasing moisture content will reduce particle friction and allow for greater compaction and hence higher bulk densities. The bulk density increases as the moisture content increases to a certain point. Beyond that point, any increase in moisture content tends to reduce the bulk density because water occupies the pore space [3, 4]. This peak bulk density is the ***maximum bulk density*** that can be obtained, while the moisture content corresponding to the maximum bulk density is frequently referred to as the optimal moisture content (Figure 2).

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[1] The soil particle density (Dp) refers to the mass of a unit volume of solid soil particles. Soil particle density differs from soil bulk density in that it does not account for the pore space between the particles.

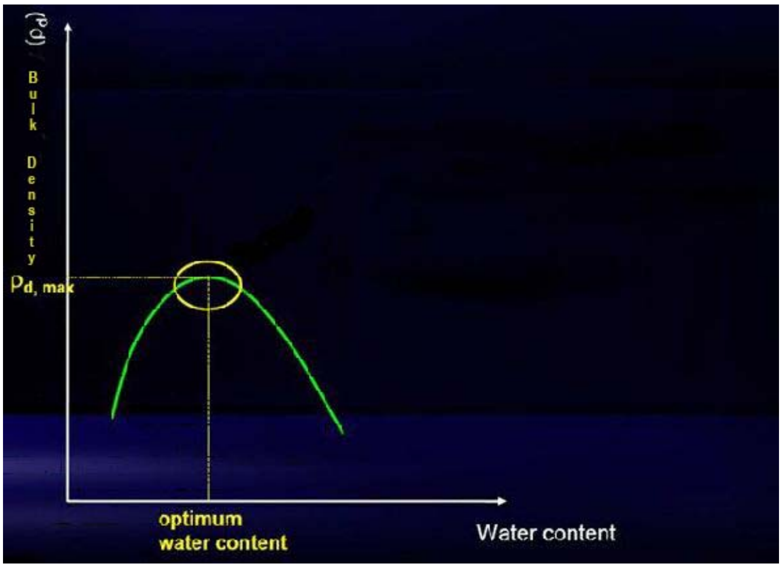

Figure 2: Example of a compaction curve indicating soil optimum water content and maximum bulk density ($\rho_{d, max}$) for a specified compacting effort (adapted from [6])

The maximum bulk density and optimum moisture content depends on the soil texture and the compacting effort. Bulk densities are therefore, when specified, commonly indicated within a certain percentage of the maximum bulk density determined from a specified compaction test, such as the ***Standard Proctor Compaction Test***. The latter compaction test is the most frequently used to experimentally determine the moisture content and bulk density relationship, and hence the optimal moisture content and maximum bulk density of a soil. It is a laboratory test which compacts the soil material at various moisture contents and is defined by the American Association of Highway Officials and American Standard Testing Material (ASTM D-698, AASHTO T-99) [9]. Further details on the test can be found in [7], [8] and [25]. The Proctor test was designed to assist in the field compaction of earth works and is often used in road construction to indicate the soil compaction that should be obtained prior to road surfacing [25]. These specifications are generally given as a percentage of the maximum bulk density which is referred to as the **Relative Soil Density or Relative Compaction**[2]. Generally, the optimum moisture content derived from the Proctor test on a given soil is a useful guide to the moisture content range that is suitable for that soil's compaction[3] [23]

The CWA 15044 recommends the determination of the ***Standard Proctor*** moisture content – dry density relationship for all standard test lanes used for mechanical demining performance testing. Many soil and engineering laboratories can perform the Standard Proctor test. The compaction of the standard test lanes is specified in the

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[2] Common specifications in road construction are relative compactions of 90 or 95% of the standard Proctor maximum dry density [23].

[3] Generally, for UK climatic conditions, well-graded or uniformly graded soils are normally suitable for compaction if their in-situ moisture contents are not more than 0.5 to 1.5 % above the optimum moisture content for the maximum dry density as determined from the standard Proctor test [23].

CWA 15044 as a relative soil density, i.e. gravel, sand and local soil test lanes are to be compacted prior to testing to 92 -96 %, 88 – 92% and 83 – 87% of their respective maximum bulk densities. Annex 1 provides an example of the ***Standard Proctor*** moisture content and bulk density relationship curve for the SWEDEC test lanes in local soil at the Norra Kulla test facility for mechanical demining equipment. It further illustrates how the information derived from the latter curve is used in preparing the test lane prior to the execution of the CWA 15044 performance test.

3. Measurement of soil bulk density and soil moisture content

3.1. Introduction

The determination of soil dry bulk density and soil moisture content typically involves the removal of a known volume of soil (soil sample) which is dried in an oven (105 degrees C or 220 degrees F) and weighed. The dry weight of the soil divided by the volume yields dry bulk density in g/cm^3. Various methods exist which differ in the way the soil sample is obtained and its volume determined (core sampling method and volume excavation) [11]. Except for recently tilled soil, dry bulk density is considered to exhibit relatively low spatial variability. Thus, about four samples of a particular soil type and depth should be sufficient to estimate the mean dry bulk density to within 10% of the true values, 95% of the time [28]

Completely different principles are employed when soil bulk density is determined with the radiation method (nuclear densometer) or estimated by the soil resistance method (penetrometer). These methods involve the measurement of transmitted or scattered gamma radiation [10] and the determination of soil resistance to vertical penetration of a probe or cone [19] respectively. While nuclear densometers will allow for conversion of the readings into soil dry bulk density (and soil moisture content) values, penetrometers provide a relative measurement of soil density (soil cone index) which cannot directly be converted into absolute soil density values.

3.2. Determination of soil bulk density and soil moisture content of soil samples removed from the field

3.2.1. Removal of samples

Core sampling is the most common technique for taking soil samples to measure dry soil bulk density in agricultural soils. A field core sampling tool (Figure 3) is used wherein a cylinder is driven into the soil and a sample of known volume (cylinder) is extracted. This technique provides a relatively simple and rapid method. However, the core sampler has very limited use in very dry or very wet soils and loses accuracy in gravelly or rocky soils [11].

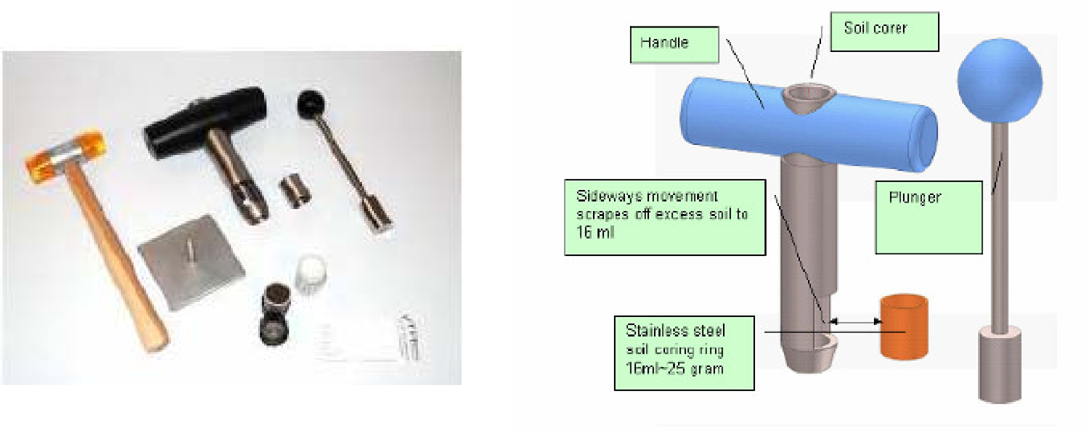

Figure 3: Example of a soil coring kit

The **volume excavation technique** is more often used by soil engineers to sample soil for dry soil bulk density measurements. A small hole is dug and all soil excavated. The volume of the hole is measured by lining it with plastic and pouring a substance of known density (sand, water or oil) and determining the volume of material required to fill the hole. For accurate volume estimation care must be taken to level the soil surface prior to sampling and collect all soil removed from the hole [11]. The low cost and the wide availability of the tools required for the volume excavation technique make it a suitable technique for soil sampling to determine soil bulk density in demining equipment trials. This technique was applied in the Demonstration Trial of the Bozena-4 and MV-4 Flails [1]. However, when soils have to be sampled at discrete depths in the soil profile the excavation method is impractical due to the need for a relatively large level surface surrounding the excavation pit.

The dry weight and the volume of the soil sample are then used to calculate the soil dry bulk density and soil moisture content. Note that when soil bulk density is determined it refers to the bulk density of the fine earth fraction (particle size < 2 mm). When coarse fragments / rocks are present in the soil, the density of the coarse fragments / rocks is subtracted from the density of the total soil sample to obtain the soil bulk density [13].

3.2.2. Calculation of soil bulk density and soil moisture content

Annex 2 provides detailed protocols to 1) sample the soil according to the soil excavation method, 2) determine the oven dry weight of a soil sample, and 3) determine the mass and volume of coarse fragments/rocks in a soil sample. It further includes all formulas required to calculate moist soil bulk density, dry soil bulk density and soil moisture content.

3.3. Determination of soil bulk density and soil moisture content in the field (in situ)

3.3.1. Nuclear densometer (soil density and moisture content)

Nuclear Densometers are a set of devices that measure the decay of a radioactive source and correlate this decay to the density and water content of soils. When using nuclear densometers, two independent parameters are determined: the soil moist density and the soil moisture content.

To determine the soil moist density a radioactive isotope source (Cesium 137) is placed at the soil surface (backscatter) or a probe placed into the soil (direct transmission). The isotope source gives off photons (usually Gamma rays) which are scattered by collisions with electrons of atoms in their path. The higher the density of the surrounding medium, the greater the scattering. In the range of densities normally occurring in soils, greater scattering results in fewer Gamma rays returning to the detector on the bottom of the unit and hence lower soil density readings [7, 17].

The measurement of the soil moisture content is based on the principle that when fast neutrons emitted from a radioactive source (Americium 241/Beryllium) collide with hydrogen atoms they are slowed down to a much greater extent than by collisions with other atoms. The number of slow neutrons thus produced is a measure of the number of hydrogen atoms present in the vicinity of the source. Because water is the principal contributor of hydrogen atoms in a soil medium [20] the soil moisture content is measured immediately below the gauge as the amount of reflected slow neutrons [7]. The higher the soil moisture, the higher the neutron count. Note that the soil moisture measurement technique using fast neutrons gives soil moisture on a volumetric basis[4] [22].

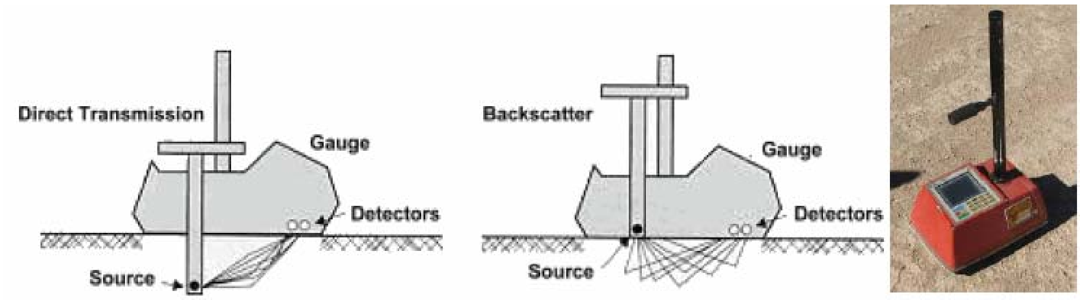

Figure 4: Presentation of the nuclear densometer working principle [7] and the CPN MC-3 PortaProbe nuclear densometer used by the Swedish EOD and Demining Centre - SWEDEC.

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[4] See Annex 2 for an explanation of the terms gravimetric and volumetric moisture content.

Most of the commercially available nuclear densometers provide direct read-outs of soil moist bulk density, volumetric moisture content and dry bulk density as well as of relative soil density[5]. Prior to each measurement session they need calibration against a standard block of known density material, usually delivered with the densometer.

Nuclear densometers allow rapid, accurate and repeatable measurements. The instruments can be manually operated and are mobile. Disadvantages are that radioactive material is used which requires a license as well as properly trained operators. The equipment is also expensive and needs proper calibration for each site [21]. Nuclear densometers are therefore probably only practical for use in permanent test facilities or by organizations performing lots of measurements[6].

Detailed instructions on how to use a nuclear densometer can be found in [18].

3.3.2. Soil Penetrometer (soil resistance[7])

Soil compaction is related to soil resistance which can be measured using a soil cone penetrometer. This instrument measures the soil resistance to vertical penetration of a probe or cone. There exist hand-held penetrometers as well as vehicle-mounted penetrometers. The latter are driven into the ground at constant speeds to great depths and are mainly used in environmental and geotechnical site investigations [27]. Manual soil cone penetrometers, on the other hand, are primarily used in agriculture and horticulture because they attempt to measure the resistance a root meets when growing in soil. They are reasonably easy to operate, give an instant result, and are relatively economical [17]. However, they only give a relative indication of soil compaction and hence cannot be used as a substitute for direct measurements of soil bulk density [26]. Proper calibration of the instruments is also required and periodic testing of the stability of the calibration before, during, and immediately following field use is recommended [27]

Hand-held cone penetrometers consist of a rod or a shaft, which is pushed into the soil, usually vertically, using some device to measure the force required to insert the device to a desired depth. The end of the rod, or tip, engaging the soil is most commonly conical in shape. Similarly, a number of force-sensing methods are used along with a variety of recording devices. Penetrometer data are typically reported as the resistance to soil penetration in terms of penetration force per unit area using units of pressure. For penetrometers using conical tips, the resistance pressure is often referred to as **cone index** (CI) and expressed in units of kilopascals (kPa) or pounds per square inch (PSI) [26, 27]. Most penetrometers used meet American Society of Agricultural Engineers (ASAE) standards adopted in 1999 and have a cone angle of 30 degrees [27].

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[5] For relative soil density the standard Proctor values (maximum dry density and optimum moisture content) of the soil have to be entered.

[6] The Swedish EOD and Demining Centre (SWEDEC) uses the CPN MC-3 PortaProbe to determine the soil compaction of the test lanes for mechanical demining equipment testing.

[7] Soil penetrometers have also been developed which measure the soil water content [27]. They are not included in this document.

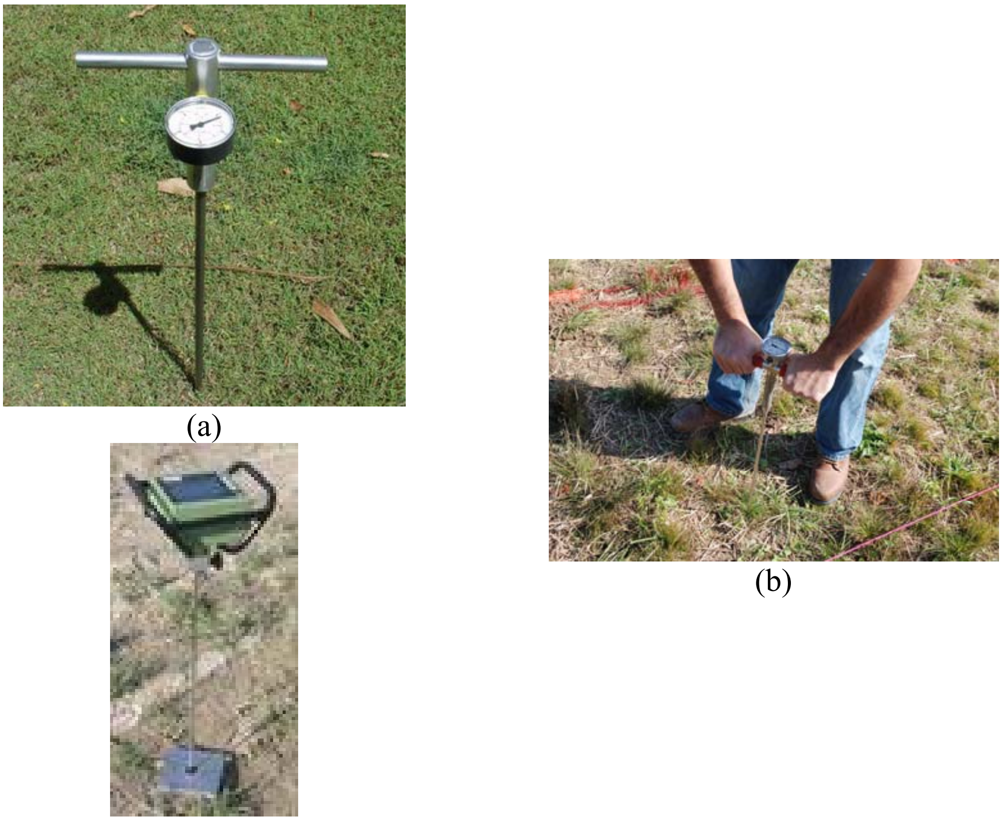
(a)
(b)
(b)

Figure 4: Examples of (a) a static hand-held cone penetrometer with dial indicator, (b) the latter penetrometer being used during mechanical demining testing (© GICHD) and (c) a static hand-held cone penetrometer with electronic read-out.

There are several factors that will affect a penetrometer reading, particularly soil water content and soil texture. Soil moisture values should be taken into account when making comparisons between penetrometer readings, as these will impart significant variability in the readings.

Soil penetrometers are classified as static or dynamic penetrometers depending on how the force is applied to the cone. Static cone penetrometers measure the force required to push a metal cone through the soil at a constant velocity (Figure 4). The force is usually measured by a load cell or strain gauge providing an analog or electronic read-out. Although the methods for static cone penetrometer operation have been standardized (ASAE 1999), it can still be problematic to compare readings [25]. Static penetrometers must be moved through the soil at a constant velocity (i.e., pressure), which means that different rates of insertion by different observers can yield variable results and affect repeatability[8] [26, 27]. Even the pressure exerted by a single operator can be difficult to apply at a constant and repeatable rate. Operator strength may also limit the use of static penetrometers in dry soils. Repeatability and

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[8] Some commercial hand-held penetrometers have aids to indicate when the desired push rate is exceeded [27].

difficulties sampling hard or dry soils are the primary drawbacks of this type of penetrometer.

Dynamic penetrometers (Figure 5] do not rely on constant penetration velocity, as they use a slide hammer of fixed mass and drop height to apply consistent energy with each blow. Either the number of blows required to penetrate a specified depth or the depth of penetration per blow are measured. The weight of the hammer, slide distance, and cone angle influence the energy delivered and can be adjusted to local conditions (e.g., soft vs. hard soils]. Soil resistance is calculated using standard equations that account for differences in hammer weight, drop distance, and cone size. Dynamic penetrometers tend to yield more consistent results and have a greater range of repeatability because they are not subject to operator variability. They also have fewer limitations in dry soils and tend to be less expensive than static penetrometers [19, 26).

Another type of penetrometer is the drop-cone penetrometer. This instrument is inexpensive, easy to use, rapid and precise, allowing many samples to be obtained in a short period of time but can only be used to measure compaction effects at the soil surface. The device consists of a 30 degree metal cone and lifting rod with a combined weight of 2.0 kg, and a 1 m long PVC or acrylic guide tube. To take a measurement, the base of the guide tube is placed on the ground surface and the cone is lifted until its top is flush with the top of the tube. The cone is released and penetrates the ground surface. Penetration depth is recorded at the top of the guide tube by reading the ruler inlaid in the holding rod [19].

Due to the fact that hand-portable penetrometers are widely available and relatively easy to use, they can provide a useful indication of soil compaction when carrying out in-field mechanical demining equipment trials. Care should be taken, however, that they are properly applied and that the obtained cone index values are used for indicative purposes only.

(a) (b)

Figure 5: Example of (a) a dynamic cone penetrometer showing slide hammer,

extension rods and cone attachment and (b) a drop-cone penetrometer held in release position [19]

3.3.3. Dielectric constant probe and meter (Soil moisture content)

There are various methods to determine soil moisture content. The gravimetric method and the neutron scatter techniques have been described in previous paragraphs. Dielectric constant methods (Figure 6) are other frequently used techniques. They measure the volumetric moisture content of the soil[9].

Dielectric constant methods seek to measure the capacity of soil to conduct transmitted high frequency electromagnetic waves or pulses. The resultant values are related through calibration to soil moisture content. Two approaches have been developed for measuring the dielectric constant of the soil and the subsequent determination of the volumetric soil water content: Time Domain Reflectometry (TDR) and Frequency Domain Reflectometry (FDR). The difference is that the TDR measures the time it takes for an electromagnetic wave to travel through the soil between probes while the FDR uses radio frequency waves to measure soil capacitance [22].

FDR and TDR probes are relatively cheap with the FDR probes at the cheaper end of the price range. Either type of instrument provides a direct read-out of volumetric water content percentage and is relatively accurate provided they have been carefully calibrated [22]. More information on dielectric constant probes and a list of examples can be found in [12].

(a) (b) (c)

Figure 6: Examples of FDR (a) and TDR systems (b, c) consisting of measuring probe and meter.

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[9] See Annex 2 for an explanation of gravimetric and volumetric soil moisture content.

4. References

[1] Demonstration Trial of Bozena-4 and MV-4 Flails, G. C. Coley, D. J. Roseveare, P.G. Danielsson, T.T. Karlsson, S. M. Bowen, L. M. Wye, F. C. A. Borry http://www.itep.ws/pdf/NairobiFinal.pdf

[2] Soil Compaction and Stability, C. S. Gresser http://www.gilesengr.com/Literature/soil_compaction_and_stability_long.pdf

[3] CE 240 Soil Mechanics and Foundations, Lecture 3.3. Soil Compaction, Das http://www.engr.uconn.edu/~lanbo/CE240LectW033Compaction.pdf

[4] Wikipedia, Proctor Compaction Test http://en.wikipedia.org/wiki/Proctor_compaction_test

[5] Bulk Density Determination, IUPUI, Indiana University, Purdue University, Indianapolis, Department of Earth Sciences http://www.geology.iupui.edu/research/SoilsLab/Procedures/bulk/Index.htm

[6] What is Compaction, Presentation, N. Sivakugan, Center for Integrating Information on Geoengineering http://www.geoengineer.org/files/Compaction-Sivakugan.ppt#257

[7] Soil Compaction Handbook, Multiquip Inc. http://www.concrete-catalog.com/soil_compaction.html

[8] Standard Proctor Compaction Test, University of Texas, Arlington http://geotech.uta.edu/lab/Main/cmpct/index.htm

[9] http://www.pdhonline.org/courses/c167/c167content.pdf

[10] Field Compaction Methods for Soils, V. D. Reynolds, PDH Center http://www.geology.iupui.edu/research/SoilsLab/Procedures/bulk/Index.htm

[11] An Evaluation of Volume Excavation and Core Sampling Techniques for Measuring Soil Bulk Density, J.M. Lichter and L.R. Costello, Journal of Arboriculture 20(3), May 1994 http://joa.isa-arbor.com/request.asp?JournalID=1&ArticleID=2622&Type=2

[12] Soil sensor types and technology, SoilSensor.com http://www.soilsensor.com/soilsensors.aspx

[13] Bulk Density Protocol, Global Learning and Observations to Benefit the Environment (GLOBE) Student Data Archive http://archive.globe.gov/sda/tg/bulkden.pdf

[14] Volumetric Water Content, Argonne National Laboratory, U.S. Department of Energy http://web.ead.anl.gov/resrad/datacoll/volcont.htm

[15] Gravimetric Soil Moisture Protocol, University of Arizona, GLOBE, http://www.hwr.arizona.edu/globe/globe3/SMGrav.html

[16] Measurement of Soil Moisture, Colorado State University http://www.ext.colostate.edu/drought/soilmoist.html

[17] Measuring Soil Compaction on Construction Sites: A Review of Surface Nuclear Gauges and Penetrometers, T.B. Randrup and J. M. Lichter, Journal of Arboriculture 27 (3), May 2001 http://www.treelink.org/joa/2001/may/01_MEASURING_SOIL_COMPACTION_randrup.pdf

[18] Field Density and Moisture Tests of Soils by Nuclear Gauge (Kansas Test method KT-51), Kansas Department of Transportation
http://www.ksdot.org/burConsMain/Connections/ConstManual/pdfact5/16_51.pdf

[19] Guide to Sampling Soil Compaction using Hand-Held Soil Penerometers, The Center for Environmental Management of Military Grounds, Colorado State University
http://www.cemml.colostate.edu/files/TPS_04-1_Sampling_Compaction.pdf

[20] Measurement of Moisture Content and Density of Soil Masses using Radioactivity Methods, I. Goldberg, L. J. Trescony, J. S. Campbell Jr. and G. J. Whyte, Clays and Clay Minerals; 1954 v. 3; no. 1
http://www.clays.org/journal/archive/volume%203/3-1-516.htm

[21] Measuring of Stockpile Density by Nuclear Densitometer, S. Treasure, AAMHATCH
http://fr.aamhatch.com/resources/pdf/publications/documents/AIMS2006Density_1.pdf

[22] Soil Moisture Measurement Technology, T.L. Prichard, University of California Davis,
http://ceeldorado.ucdavis.edu/files/45069.pdf

[23] Highways: the Location, Design, Construction and Maintenance of Road Pavements, C.A. O' Flaherty, Book, 2002.
http://books.google.com/books?id=Ren4sWQ3jKkC&source=gbs_navlinks_s

[24] Performance of Flail Hammers, F. Guerne, Journal of ERW and Mine Action, Issue 13.1, Summer 2009
http://maic.jmu.edu/journal/13.1/rd/guerne/guerne.htm

[25] Achieving and Measuring Proper Road Compaction, D. MacGuire, University of New Hampshire, technology Transfer Center Technical Note
http://www.t2.unh.edu/spring06/7-10.pdf

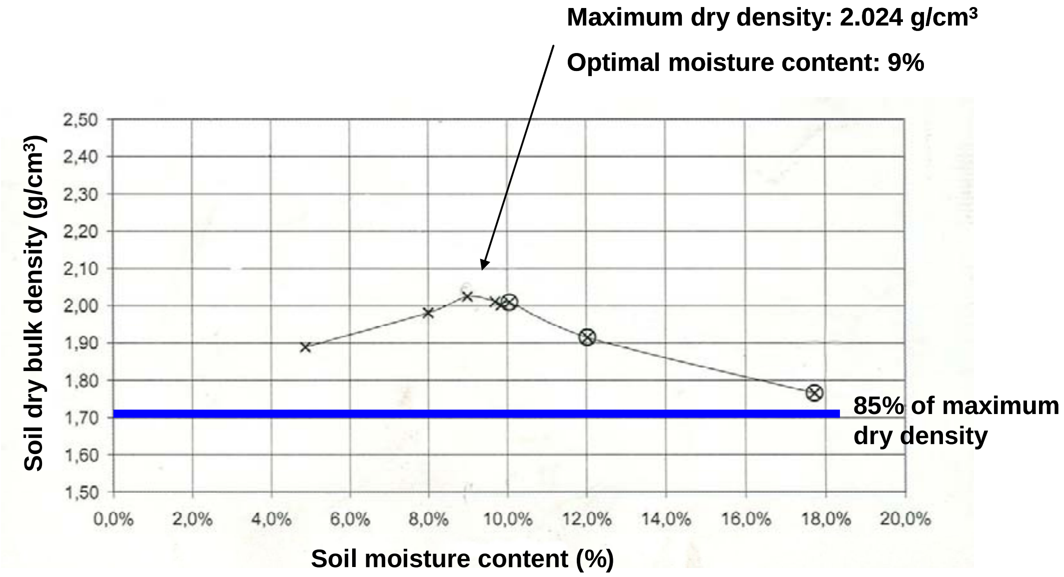
[26] Hand-Held Electronic Cone Penetrometers for Measuring Soil Strength, U.S. Department of Agriculture, Forest Service.
http://www.fs.fed.us/t-d/pubs/pdfpubs/pdf05242837/pdf05242837dpi300.pdf

[27] Soil Penetrometers, R. Fee, Spectrum Technologies, Inc
http://www.specmeters.com/articles/soil_penetrometers.pdf

[28] Soil Sampling and Methods of Analysis, M.R. Carter, E.G. Gregoric, Book, Canadian Society of Soil Science, 2007
http://books.google.com/books?id=ZTJsbXsikagC&source=gbs_navlinks_s

5. Annex 1: *Standard Proctor optimum* moisture content and dry bulk density relationship

Figure 1 lists the Standard proctor curve data for the local soil used by SWEDEC to produce one of the three standard test lanes used for CWA 15044 performance testing at the Norra Kulla mechanical test facility.


Maximum dry density: 2.024 g/cm^3

Optimal moisture content: 9%

85% of maximum dry density

Figure 1: Standard Proctor curve for the local soil at the Norra Kulla test facility.
© SWEDEC

The CWA 15044 specifies that the local soil test lane for performance testing should be compacted to within 85% (+-2%) of the maximum theoretical dry bulk density, which is 1.72 g/cm^3. The above Standard Proctor curve shows that the specified compaction can be obtained for soil moisture contents varying between 4% and 20%.

Procedure for test lane preparation:

1. Determine test lane soil moisture content and check that soil moisture content is within the range for which a relative soil compaction of 85% can be obtained.
2. Loosen the soil. This can be done with ordinary agricultural or construction equipment (Figure 2)
3. Compact the soil to the specified level using compactors such as the one shown in Figure 3 (vibratory compactor). Monitor relative density until the defined level for that soil type is obtained. Monitoring of soil compaction can be done using one of the measurement techniques described in the main body

of this document. At SWEDEC, it is executed using the nuclear densometer (CPN International Model MC-3 Portaprobe, Figure 5)

Figure 2: Preparation of standard test lanes – loosening the soil
Picture © SWEDEC

Figure 3: Preparation of standard test lanes – compacting the soil
Picture © SWEDEC

Figure 4: Prepared test lane with the soil compacted.
Picture © GICHD

Figure 5: CPN International Model MC-3 Portaprobe nuclear densometer used by SWEDEC to monitor soil compaction levels of the standard test lanes.
Picture © SWEDEC

6. Annex 2: Protocols and formulas to determine moist soil bulk density, dry soil bulk density and soil moisture content on extracted soil samples

6.1. Protocol to extract a soil sample

Apparatus:

- Waterproof containers with lids or re-sealable plastic bags for storing samples
- Digging tools – Shovel or trowel, screwdriver or heavy knife.
- Sheet of non-porous material, e.g. polythene bag
- Graduated container or container of known volume
- Container of water
- Balance (weighing scale)
- Marking implement – permanent markerpen etc.

Method:

1. Weigh the sample container and mark the weight on the sample container (example: 15 g)
2. Mark the sample container with the soil sample number and location
3. Level the soil surface where the hole will be excavated
4. Place non-porous material on the ground next to the location of the hole to be excavated and place the sample container on the non-porous material
5. Using the shovel or the trowel, excavate the hole ensuring that **ALL** material from the excavation is placed in the sample container. Take the samples as quickly as possible.
6. Seal and weigh the container immediately and mark the gross weight on the container (example: 1600.90 g). The wet weight of the soil can then be calculated by subtracting the sample container weight from the gross weight (example: 1600.90 g - 15 g = 1585.90 g)
7. Smooth the sides and bottom of the excavation with the trowel or the knife, without removing any additional material
8. Place the non-porous material in the excavation ensuring that it is in contact with the sides and bottom
9. Fill the graduated container from the water container and note the amount of water in the graduated container (example: 1000 ml)
10. Pour water from the graduated container into the lined excavation. Fill the excavation with water as close as possible to ground level without overflowing and note the amount of water left in the graduated container (example: 500 ml)
11. Subtract the amount remaining from the starting amount (example: 1000 ml – 500 ml = 500 ml). The difference is the amount of water used to fill the excavation and represents the volume of the excavation (example: 500 ml). Mark this volume on the sample container

6.2. Protocol to determine the oven dry weight of a soil sample

Apparatus:

- Shallow containers. Note that if a microwave is used to dry the soil sample plastic ware should not be used as it may melt.
- Balance (weighing scale) readable and accurate to 0.01 g (fine-grained soils) – 1g (coarse-grained soils)
- Heat source (hot plate, heat lamp laboratory oven or microwave oven)
- Spatula

Method:

1. Weigh a shallow container and record the weight (example: 11 g)
2. Thoroughly mix the soil sample in its container/bag to ensure uniform distribution of the sample and then place the soil from the sample container in the shallow container
3. Place the shallow container with soil on the heating element of the hot plate or in the oven.
4. DO NOT OVERHEAT. Small pieces of paper mixed with the soil will act as an indicator and turn brown if overheated.
5. If heated on a hot plate, frequently turn the soil with a spatula during heating. The drying time will vary depending on the method used[10] but regular weight checks should be carried out to determine the minimum drying time necessary.
6. Weight checks:
    a. Remove the shallow container with the soil from the heat, cover and allow to cool. The container can be weighed as soon as it is cool enough to handle.
    b. Record this weight
    c. Reheat, cool and weigh the sample until the weight no longer changes and record the final dry weight (example: 1446.20 g)
7. Determine the dry weight of the soil sample by subtracting the weight of the container from the measured dry weight (example: 1446.20 g – 11 g = 1435.20 g)

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[10] The appropriate steps for drying with a microwave oven are as follows:

- Place the sample into the microwave and run the microwave oven for 10 minutes
- Weigh the sample and return to the microwave oven for 5 minutes and reweigh. If the weight of the sample has changed, return to the microwave oven for 5 more minutes. Repeat the process until the weight does not change. Typical drying times for a wet sample are close to 20 minutes. Water is the first component of the soil to heat and evaporate. If the sample is dry and microwave drying continues, the soil temperature will increase and oxidize the organic matter. This will bias the results [16].

If you use a conventional oven, place samples in the oven at 105 degree centigrade (220 Fahrenheit) for 24 hours [16].

6.3. Protocol to determine the mass and volume of coarse fragments / rocks in a soil sample

Apparatus:

- Sieve (2 mm mesh)
- Large piece of paper
- Balance (weighing scale)
- Graduated cylinder with water (minimum 100 ml)

Method:

1. Place the sieve on a large piece of paper and pour one sample into the sieve
2. Carefully push the dried soil material through the mesh onto the paper. Rocks will stay on top of the sieve (if no sieve is available, carefully remove the rocks by hand)
3. Weigh the rocks that are left on top of the sieve and record the mass (example: 20 g)
4. Place 30 ml of water in a 100 ml graduated cylinder, and gently place the rocks in the water.
5. Read the level of the water after all the rocks have been added (example: 95 ml) and subtract the original amount of water in the cylinder to obtain the volume of the rocks (example: 95 ml – 30 ml = 65 ml)

6.4. Formulas to calculate moist bulk density, dry bulk density and moisture content

To calculate moist density, dry bulk density and moisture content[11] at time of sampling you need the moist weight of the sample (g), the dry weight of the sample (g) and the volume of the sample (cm^3).

Moist density (ρ_w) =
moist weight (grams) ÷ volume (cm3)

Example: ρ_w = 11585.90 ÷ 500 = 3.17 g / cm3 = 3170 Kg / m3

Dry bulk density (ρ) =
dry weight (grams) ÷ volume (cm3)

Example: ρ = 1435.20 ÷ 500 = 2.87 g / cm3 = 2870 Kg / m3

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[11] The method to determine soil moisture using the weighing and drying of a soil sample is called the gravimetric method [15]

Corrected dry bulk soil density (ρ) =
[dry weight of soil (g) ÷ volume of soil (cm3)] - [dry weight of rocks (grams) ÷ volume of rocks (cm3)]

Example: ρ corrected = [1435.20 ÷ 500] - [70 ÷ 65] = 2.87 – 1.08 = 1.79 g / cm3 = 1790 Kg / m3

The moisture content of the soil sample at the time of sampling can be expressed as a mass to mass ratio (gravimetric moisture content) or as a volume to volume ratio (volumetric moisture content) according to following formulas:

Gravimetric moisture content (gravimetric Θ%) =
[(moist weight – dry weight) ÷ dry weight] × 100

Example: gravimetric Θ % = [(1585.90 – 1435.20) ÷ 1435.20] × 100 = 10.5 %

Volumetric moisture content (volumetric Θ %) =
Gravimetric Θ % × ρ

Example: volumetric Θ % = 10.5 × 2.87 = 30.1 %

To avoid confusion between the two dimensionless water content ratios, their basis (i.e., mass or volume) should always be stated. However, in cases in which no indication is given, the figure is assumed to be based on mass because in the determination of the soil water content, the mass-basis figure is usually obtained first and then converted to a volume-basis figure [14]

6.5. Extraction of soil samples according to the excavation technique – pictures


(a)


(b)

Soil sampling using the excavation technique. The hard soil is loosened using a screwdriver (a) and then excavated using a spoon (b). The excavated soil is put on a plastic sheet next to the soil to ensure that all excavated soil is collected. The depth of the excavated hole is the same as the target burial depth.

All excavated soil from one soil sample is put in a plastic bag which is immediately sealed.

Note that a wind screen was placed next to the excavation in order to prevent the excavated soil from drying out between the moment of excavation and sealing into the bag.

Pouring water from a graduated container in the excavated hole lined with non-porous material to determine the volume of the excavation (a).

When the water is poured into the excavation care is taken that the plastic lining is in contact with the sides and the bottom

Date, soil sample number, test lane details, wet weight of the sample and volume of the excavated hole are marked on the plastic bag which contains the sample.