National Defence | Défense nationale

DEFENCE RESEARCH AND DEVELOPMENT CANADA (DRDC)
RECHERCHE ET DÉVELOPPEMENT POUR LA DÉFENSE CANADA (RDDC)

A Method for Controlling the Water Content and Provide More Consistent Soil Conditions When Preparing Buried Explosive Charge Test Sites

Robert Durocher
DRDC – Valcartier Research Centre

Defence Research and Development Canada

Reference Document
DRDC-RDDC-2022-D136
April 2024

Abstract

This Reference Document presents a method for controlling and monitoring the soil conditions during the preparation of buried explosive test sites. This method includes a step-by-step approach to ensure required information is gathered for the planning and the execution of the test site fill process. The Document also presents theory related to soil condition and phase composition, and examples of calculations. Although requiring some calculations and additional actions during the site preparation process, the method proposed is simple to implement and will result in more efficient test site preparation operations. This will also provide more accurate and consistent test conditions for conducting buried explosive charge tests.

Significance to Defence and Security

Buried explosive charge testing in soil is often considered to be more difficult to execute and control, as they required the test bed soil conditions to meet a define specification. Also, the variable nature of soil may lead to believe the test conditions produced will be less repeatable, when compared to the use of a steel pot, as allowed in the North Atlantic Treaty Organization (NATO) 4569 Allied Engineering Publication (AEP)-55 Volume 2 [4]. This Document addresses some of the gaps and recommendations identified in previous work [1]. The longer-term objective is to develop and recommend a formal buried charge test site preparation document, to complement and improve the current AEP-55 Volume 2 [4] and tests conducted at the national level. This work along with other activities in Pact Army 043, will yield a better understanding of the buried charge loading and its effects on equipment and personnel. It will contribute ensuring the test conditions used for developing and accessing and acquiring our equipment are rigorous, repeatable and representative of operational conditions.

Résumé

Ce document de référence présente une méthode pour contrôler et surveiller les conditions du sol pendant la préparation des sites d’essai d’explosifs enfouis. Cette méthode comprend une approche étape par étape pour s’assurer que les renseignements nécessaires sont recueillis pour la planification et l’exécution du processus de remplissage du site d’essai. Le document présente également la théorie liée à l’état du sol, à la composition des phases et des exemples de calculs. Bien qu’elle nécessite certains calculs et des mesures supplémentaires au cours du processus de préparation du site, la méthode proposée est simple à mettre en œuvre et permettra d’avoir des opérations plus efficaces de préparation du site d’essai. Elle permettra également d’obtenir des conditions d’essai plus précises et uniformes pour la réalisation des essais de charges explosives enfouies.

Importance pour la défense et la sécurité

Les essais de charges explosives enfouies dans le sol sont souvent considérés comme plus difficiles à exécuter et à contrôler, car ils exigent que les conditions du sol du banc d’essai répondent à une spécification définie. De plus, la nature variable du sol peut porter à croire que les conditions d’essai produites seront moins reproductibles comparativement à l’utilisation d’un pot en acier, comme le permet l’Organisation du Traité de l’Atlantique Nord (OTAN) 4569 Publication interalliée sur l’ingénierie (AEP)-55 Volume 2 [4]. Ce document aborde certaines des lacunes et recommandations qui ont été cernées dans les travaux précédents [1]. L’objectif à plus long terme consiste à élaborer et à recommander un document officiel de préparation des sites d’essai de charges enfouies, afin de compléter et d’améliorer la publication actuelle AEP-55 Volume 2 [4] et les essais réalisés au niveau national. Ces travaux, ainsi que d’autres activités du Pact Army 043, permettront de mieux comprendre le chargement des charges enfouies et ses effets sur l’équipement et le personnel. Ils permettront d’assurer que les conditions d’essai utilisées pour l’élaboration, l’accès et l’acquisition de notre équipement sont rigoureuses, répétables et représentatives des conditions opérationnelles.

Table of Contents

Abstract . . . i
Significance to Defence and Security . . . i
Résumé . . . ii
Importance pour la défense et la sécurité . . . ii
Table of Contents . . . iii
List of Figures . . . iv
List of Tables . . . v
Acknowledgements . . . vi
1 Introduction . . . 1
2 Method . . . 3
2.1 Characterization of the Soil using the Proctor Compaction Curve . . . 3
2.2 Identification of the Desired Soil Conditions . . . 4
2.3 Calculation of the Soil Volume Portions per Phase . . . 6
2.4 Measurement of the Fill Material Conditions . . . 8
2.5 Calculation of the Soil Initial and Desired Phase Partitions . . . 9
2.6 Calculation of the Volume of Soil and Water During the Fill Operation . . . 12
2.7 Measuring the Soil and Water Volume During the Fill Operation . . . 16
2.8 Compaction and Measurement of the Resulting Soil Conditions . . . 19
3 Conclusion and Recommendations . . . 22
References . . . 23
Annex A Data Record Template for Documenting Fill Operations . . . 24
List of Symbols/Abbreviations/Acronyms/Initialisms . . . 26

List of Figures

Figure 1: Adding water to the soil during a test site preparation. 1
Figure 2: Measurement of the soil condition during a test site preparation using the nuclear method. 2
Figure 3: Typical Proctor curve with OWC, ODD and optimum wet density (OWD) conditions. . 4
Figure 4: Desired range of soil condition transposed on the proctor compaction curve. 5
Figure 5: Soil Phases and volume portion. 6
Figure 6: Schematized process to bring initial soil condition to the desired soil condition. 8
Figure 7: Proctor compaction curve of the example provided with ODD and OWC. 9
Figure 8: Initial condition and desired condition of the example provided, transposed on the proctor compaction curve. 10
Figure 9: Excavated crater shape and dimension parameters. 12
Figure 10: Fill material layers with associated soil volume. 13
Figure 11: Soil total volume (V_{Ti}) added as a function of the fill layer (for L1 = 3.0 m, L2 = 0.5 m, L3 = 1.25 m, Th_i = 100 mm). 13
Figure 12: Water volume (V_{Wi}) to be added as a function of the fill layer (for L1 = 3.0 m, L2 = 0.5 m, L3 = 1.25 m, Th_i = 100 mm). 14
Figure 13: Sketch of soil layer thickness gauges for achieving constant layer thicknesses. . . . 16
Figure 14: Watering of a fill layer using a garden hose with spray nozzles. 17
Figure 15: Water flow meter Make: Great Plains Industries, Model No. RK-05611-10. 17
Figure 16: Assessment of the moisture content using the touch and feel method. 18
Figure 17: Measurement of the soil conditions using the nuclear method [5]. 18
Figure 18: Compaction of the soil using as small vibrating plate compactor. 19
Figure 19: Small vibrating plate compactor Make: Mikasa, Model MVC88VTHW, producing 15 kN of centrifugal force. 20
Figure 20: Medium vibrating plate compactor, Make: Wacker Neuson, Model: BPU5545A, producing 55 kN of centrifugal force. 20
Figure A.1: Soil parameters data. 24
Figure A.2: Excavation crater data.. 24
Figure A.3: Fill operation data. 25

List of Tables

Table 1: Summary of initial and desired soil parameters.. 11

Table 2: Summary of soil volume and associated additional water volume required per fill layer to achieve the desired soil conditions.. 15

Acknowledgements

The author would like to thank Patrick Lacoursière and Guy-Philippe D’Amours, from the Defence Research and Development Canada (DRDC) – Valcartier Research Centre, for their technical support in the work leading to this Reference Document.

1 Introduction

A method for preparing or repairing test beds for conducting buried explosive charge tests was presented in [1]. In this work, the following recommendations were made:

> **"A method for achieving higher compaction levels and reduce operation time should be investigated. This should include:**
>
> - **The use of a more powerful compactor; and**
> - **Adding more water before compacting and investigating methods to monitor the amount of water added."**

This Reference Document addresses specifically the control and monitoring of the amount of water required to reach the desired soil conditions. It presents the theory and principles guiding the characterization and calculation of soil conditions, and proposes a method to achieve desired soil conditions, when preparing a buried explosive charge test site. Also, a method to measure the water added throughout the preparation of the test bed. Finally, new compaction equipment, are proposed for reducing the operation time, as well as achieving higher compaction levels.

This work in intended to provide a wider understanding of the principle surrounding the preparation of buried explosive charge test bed and a reference for guiding the preparation of test sites. The use and application of the proposed method will contribute to achieving desired soil conditions and will contribute to providing more consistent and repeatable conditions when conducting buried explosive charge tests, see Figure 1 and Figure 2.

Figure 1: *Adding water to the soil during a test site preparation.*

Figure 2: *Measurement of the soil condition during a test site preparation using the nuclear method.*

This Document is produced under the Research and Development Program Activity (Pact) Army 043, Land Vehicle Integrated Survivability (LVIS), Work Breakdown Element (WBE) 03: Vehicle Protection against blast threats.

2 Method

This section will present a step-by-step method for planning and executing the construction of a buried explosive test site, more specifically how to determine the quantity of water that is required to compact the soil as to meet required specifications. It also provides guidelines to conduct the fill operation and record information to document the test site conditions. The method include the following steps:

1. Characterization of the soil using the Proctor compaction curve,
2. Identification of the desires soil conditions,
3. Calculation of the soil volume portion per phase,
4. Measurement of the initial fill material conditions,
5. Calculation of the soil initial and desired phase portions,
6. Calculation of the volume of soil and water required during the fill operation,
7. Measuring the water volume during the fill operation, and
8. Compaction and measurement of the resulting soil conditions.

The description of each step, supported by an example, is provided in the following subsections.

2.1 Characterization of the Soil using the Proctor Compaction Curve

Each soil has a specific density and humidity relationship. This relationship will be influenced by the material composing the soil, the size of the soil particle and their size.

A method to establish the density-humidity of a given soil is the Modified Proctor test, American Society for Testing and Materials (ASTM) D1557 [2]. In this test, a curve representing the upper limit of the compacted soil dry density for varying water content is produced, Figure 3.

The maximum of this the curve represents the soil conditions with maximum compaction. The conditions at this point are defined as:

- Optimum dry-density (ODD), and
- Optimum water content (OWC).

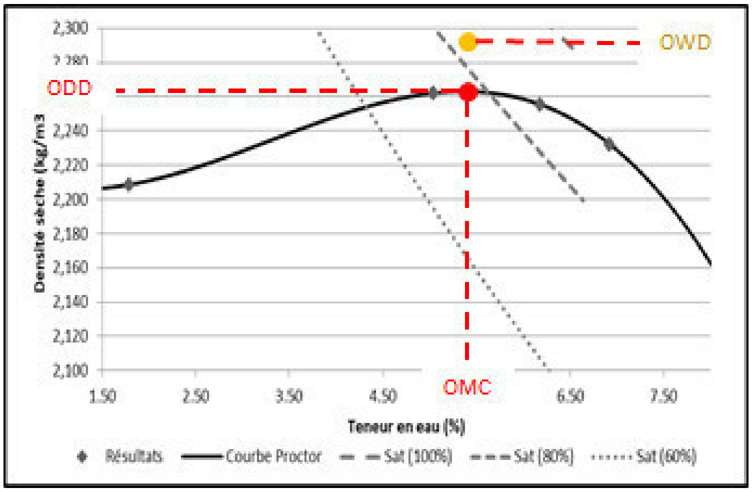

Figure 3: *Typical Proctor curve with OWC, ODD and optimum wet density (OWD) conditions.*

The specific gravity (G_s) of the soil is a parameter that allows measuring the void ratio (e) and the degree of saturation (S) of the soil. The G_s can be measured using ASTM D854 [3]. The specific gravity of a specific soil is a constant. For most soils.

- $2.5 < Gs < 2.8$; and
- ODD is achieved at $0.75 < S < 0.85$.

Note, the soil wet density, sometime identified in soil specifications. The wet density (WD) represents the mass of the solid phase plus the mass of the water phase per unit soil volume. The WD can be calculated using the dry density (DD) and water content (WC) using:

$$DD = DD + DD \cdot WC = DD(1 + WC) \tag{1}$$

DRDC – Valcartier Research Centre soil material lab is equipped to characterize aggregates using ASTM D1557 [2] as well as to measure the specific gravity as per ASTM D854 [3]. However, this can often be executed more efficiently using external laboratory that specializes in these types of testing. If external resources are used, it is important to request the production of the compaction curve as a specific deliverable, as some contractor will only provide the ODD and OWC values.

2.2 Identification of the Desired Soil Conditions

The soil conditions are physical parameters of a given soil aggregate, which can vary in time or by the application or removal of water or energy. In our case, the two (2) conditions will consist in the density of the material and the humidity (or the water content).

As presented in the previous section, the Proctor compaction curve provides an envelope of soil's conditions for given water contents and compaction levels. Therefore, soil conditions relative to the proctor curve and optimum values are often used to specify required conditions or specifications.

As an example, for road construction where the stability of the road subbase is of prime importance, fill aggregate standards (particulate size corridor) are identified, as well as a compaction level. Typically a minimum value of 95% of optimum proctor density (ODD) is required.

The AEP-55 Volume 2 [4] follows a slightly different, but nevertheless similar approach, by defining an aggregate particle size, total density and a specific water content at time of the test. AEP-55 Soil specification are:

- Sandy-Gravel with specified garnolometry;
- Total density (wet density): 2100–2300 kg/m^3; and
- Water content: Optimum proctor (OWC) +/- 1.5%.

It can be a good practice to specify the range of the desired conditions in terms of density and water content and to present it on the soil compaction curve, such as in Figure 4.

- DWC: Desires water content +/- X; and
- DDD: Desired dry density +/- Y.

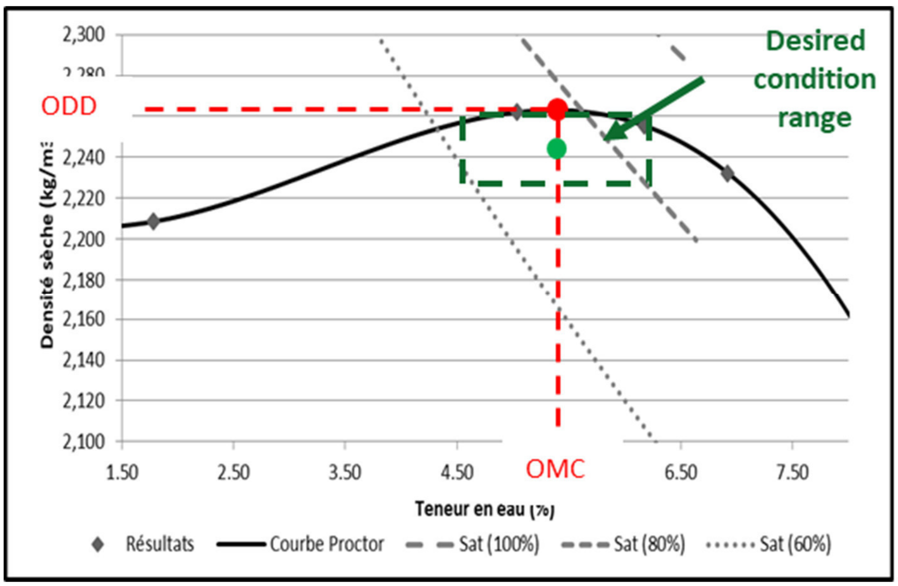

Figure 4: *Desired range of soil condition transposed on the proctor compaction curve.*

2.3 Calculation of the Soil Volume Portions per Phase

To calculate the soil condition and the volume occupied by the different soil constituents (solid, water, air), a basic understanding of the soil partition theory can be useful.

A soil is composed of the three (3) following phases:

- Solid,
- Water, and
- Air.

For a given volume of soil, each phase will occupy a portion of the total volume, Figure 5.

$$V_T = V_S + V_W + V_A \tag{2}$$

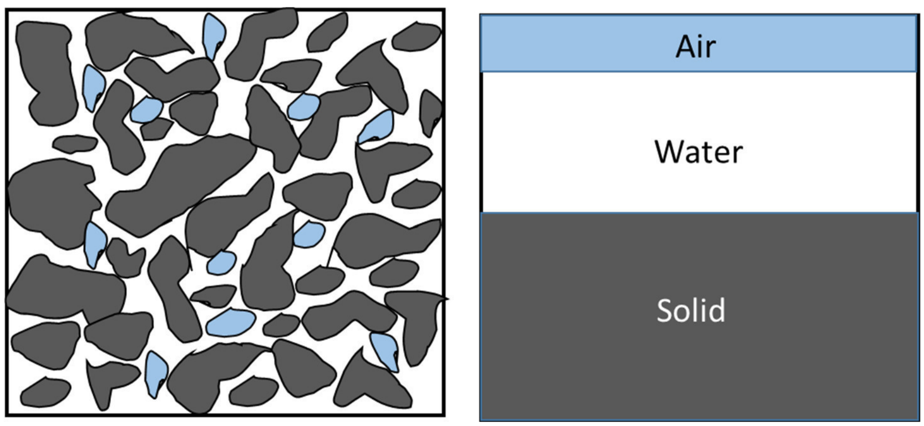

Figure 5: *Soil Phases and volume portion.*

The dry density (DD) is the mass of the solid phase over the total volume of soil and is expressed as:

$$DD_s = \frac{M_S}{V_T} \tag{3}$$

The dry density is influenced by the void ration (e) and porosity (n) of the soil. These parameters are related and defined as:

$$e = \frac{V_W + V_A}{V_S} \tag{4}$$

$$n = \frac{V_W + V_A}{V_T} = \frac{e}{1 + e} \tag{5}$$

The compaction of a soil will reduce the void ratio (e) and the porosity (n) accordingly, therefore increasing M_s in a same volume, thus the DD_s. It is worth mentioning that once a soil has been compacted to a given level, unless it is re-compacted or loosen, its dry density will remain fairly constant. However, the water and air partition will vary with environmental condition, depending on whether the soil is in dry or wet environment.

The water (or moisture) content *MC* of the soil is defined as the ration of the mass of the water phase to the mass of the solid phase and expressed as:

$$MC = \frac{M_W}{M_S} \tag{6}$$

Another important parameter affecting the soil behaviour is the degree of saturation (S). S can be calculated using:

$$S = \frac{G_S \cdot \mathrm{MC}}{e} \tag{7}$$

The void ratio can also be calculated using:

$$e = 1 - \frac{DD}{G_s \cdot \rho_W} \tag{8}$$

Using the above equations, for a soil of known G_s, the volume of solid, water and air can be calculated for each combination of soil dry density (DD) and moisture content (MC). This will be used to determine the amount of water that is required to be added to a given soil volume in order to achieve a defined moisture content condition. For a given volume of soil, the volume of each phase can be calculated using:

$$V_S = (1 - \mathrm{n})V_T \tag{9}$$

$$V_w = eSV_S \tag{10}$$

$$V_A = eV_S(1 - S) \tag{11}$$

2.4 Measurement of the Fill Material Conditions

In order to measure the volume occupied by each phase, measurement of the specific gravity (G_s), the dry density (DD) and the water content (WC) are required. These values will provide the information required on the soil condition and allow planning the process to bring the soil at the desired specifications. The measurement of the soil conditions can be done using:

- In-place measurement using nuclear gauge ASTM D6938 [4], and
- Laboratory measurements.

A practical method is to take measurements using the nuclear method [4] in the backscatter mode on top of the loose-fill layer. These measurements will provide the initial soil conditions specified by:

- IDD: Initial Dry Density; and
- IWC: Initial Water Content.

Unless important changes in the fill material occurs during the refill operation, the same values of IDD and IWC can be used to establish water input to the soil. If variation in IDD and IWC are suspected, measurements at each layer are recommended.

The process to bring the soil conditions to the desired range will consist of (Figure 6):

1. Adding water to the soil to achieve the desired water content (DWC), and
2. Compacting the soil to achieve the desired dry density (DDD).

This process will be done at each layer of fill added during the test bed build process.

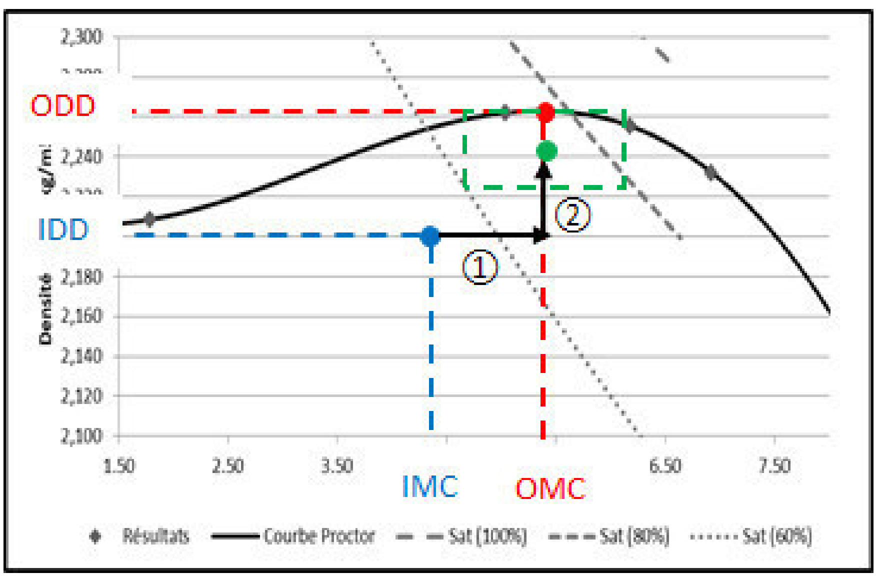

Figure 6: *Schematized process to bring initial soil condition to the desired soil condition.*

2.5 Calculation of the Soil Initial and Desired Phase Partitions

In this section, the amount of water required to bring the fill material to the desired moisture content will be calculated using information and theory presented in the previous sections. To achieve this end, the phase partition of the fill material in its initial conditions and its desired conditions will be calculated and demonstrated using an example.

One wants to fill a test site at a minimum of 98% of ODD and OWC +/- 1% using a granitic fill material having the following properties:

- Specific gravity (G_s) = 2.75;
- Modified Proctor test results:
  - ODD = 2264 kg/m^3;
  - OWC = 5.4%; and
  - Compaction curve, Figure 7.

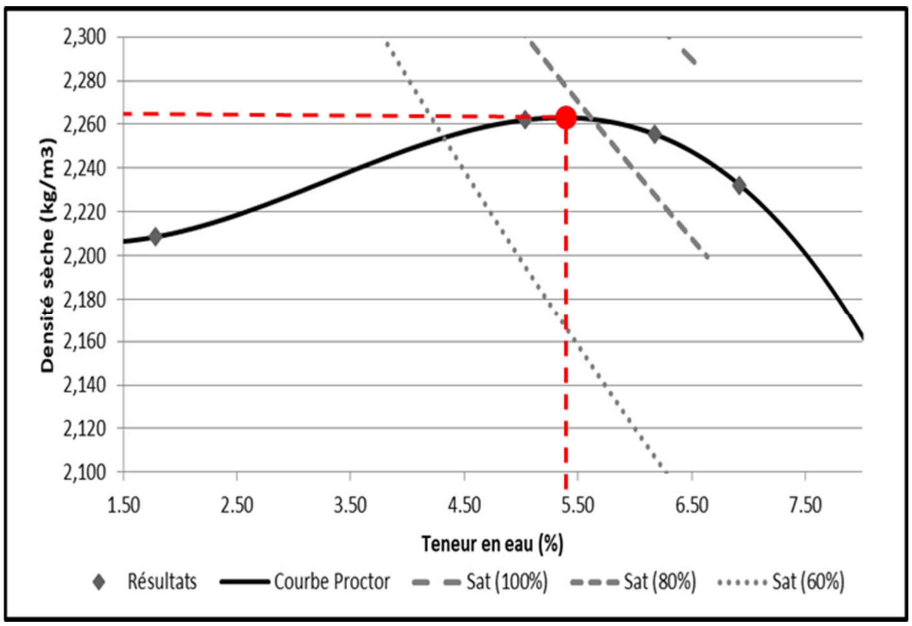

Figure 7: *Proctor compaction curve of the example provided with ODD and OWC.*

The measurement of the initial conditions of the stock pile fill material provided the following results:

- IDD: 2120 kg/m^3; and
- IWC: 2.5%.

We want to calculate the volume of water that needs to be added to achieve the desires soil conditions.

First, the range of desired conditions of the soil can be defined as:

- 2220 kg/m^3 < DDD < 2264 kg/m^3; and
- 4.4% < DWC < 6.4%.

For this calculation, and to ensure meeting the specification, the DDD and DWC are set to be:

- DDD = ODD = 2264 kg/m^3; and
- DWC = OWC = 5.4%.

The difference in the dry density and water content can be calculated as:

- ΔDD = DDD – IDD = 2264 kg/m^3 – 2120 kg/m^3 = + 144 kg/m^3; and
- ΔWC = OWC – IWC = 5.4%- 2.5% = + 2.9%.

The desired condition, initial condition and differences are shown on the compaction curve at Figure 8.

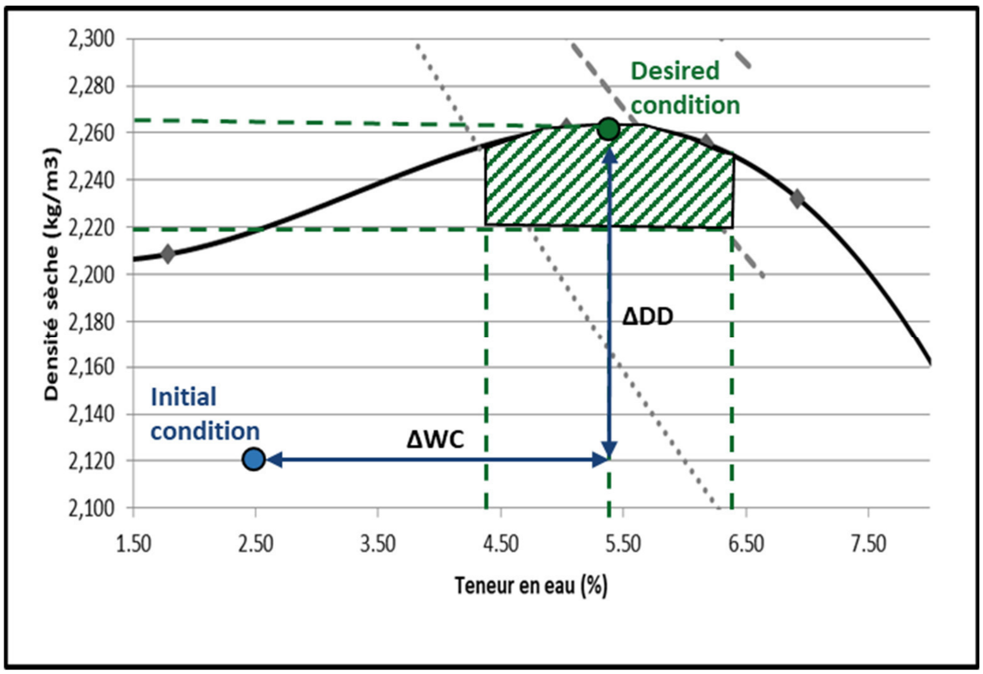

Figure 8: *Initial condition and desired condition of the example provided, transposed on the proctor compaction curve.*

In order to determine the volume of water required to bring the fill material to the DWC, the volume partition of the initial and desired condition of the soil is required.

These are calculated using Equations (3) to (11) for both soil conditions. Table 1 presents the results of these calculations with values of the void ratio (e), porosity (n), saturation level and volume of each phase per unit volume of soil.

Table 1: *Summary of initial and desired soil parameters.*

Parameter	Symbol	Initial value	Desired value
Dry density (kg/m^3)	DD	2120	2264
Water content (%)	WC	2.5	5.4
Void ratio (-)	e	0.229	0.177
Porosity (-)	n	0.186	0.150
Saturation (%)	S	0.300	0.840
Volume of solids (m^3)	V_S	0.814	0.850
Volume of water (m^3)	V_W	0.056	0.126
Volume of air (m^3)	V_A	0.130	0.024
Total volume (m^3)	V_T	1.000	1.000

From these results, one can easily observe the desired conditions will be achieved by increasing the volume of water (from 0.056 m^3 to 0.126 m^3). Also, compaction is required to reduce the void ratio from 0.23 to 0.18.

The difference of desired and initial volume of water represents the amount of water required to be added per unit volume of soil, and can be simply calculated using:

$$\Delta VW = \text{Desired Vw} - \text{Initial VW}$$

And in our case: (12)

$$\Delta V_W = 0.126\ m^3 - 0.056\ m^3 = 0.056\ m^3 = 56\ \text{L per } m^3 \text{ of soil.}$$

Using this value, and knowing the total volume of soil being added at each layer during the fill operation, one can calculate the volume of additional water required in litres for each fill layer.

2.6 Calculation of the Volume of Soil and Water During the Fill Operation

In order to evaluate the volume of water needing to be added, the volume of soil of each layer must be determined.

As specified in [1], and Figure 9 the excavated crater will typically have the shape of a truncated cone of dimensions:

- L1: Top diameter;
- L2: Bottom diameter; and
- L3: Depth.

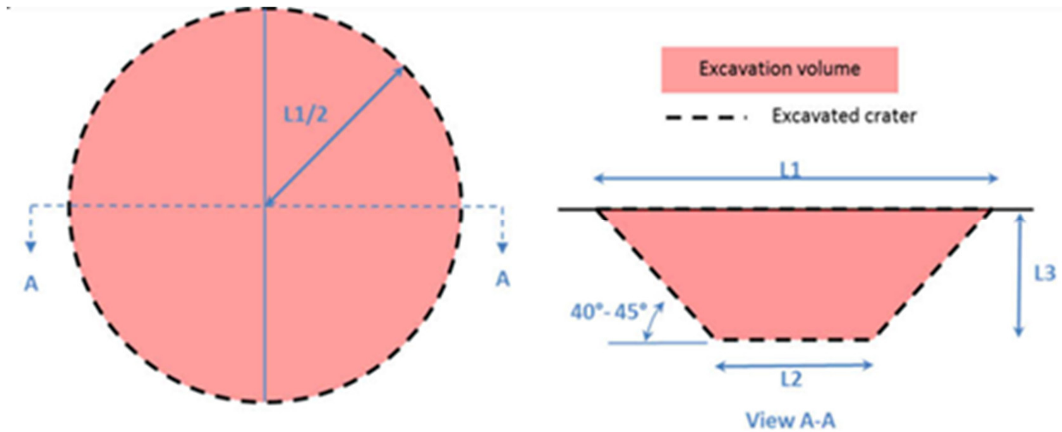

Figure 9: *Excavated crater shape and dimension parameters.*

Using this geometry and the thickness (Th_i) of fill material added at each layer i, the volume of soil (V_{Ti}) of each lift layer (Figure 10) can be calculated using a crater of following dimensions with a constant fill layer thickness of 100 mm.

- L1 = 3.0 m;
- L2 = 0.5 m;
- L3 = 1.25 m; and
- Th = 0.100 m (In this case Th_i = constant).

The calculation results of the volume of soil per layer is presented graphically at Figure 11.

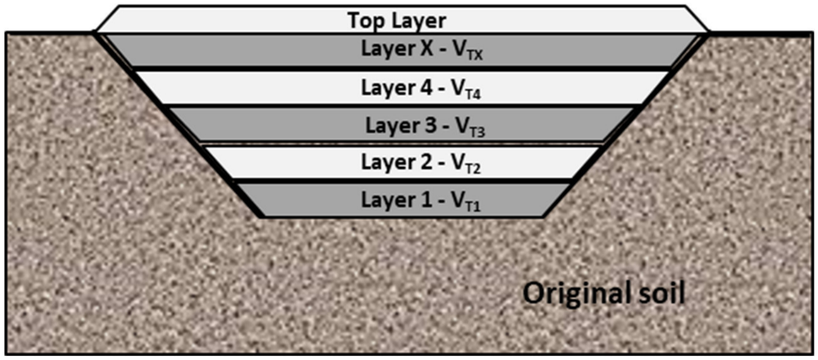

Figure 10: *Fill material layers with associated soil volume.*

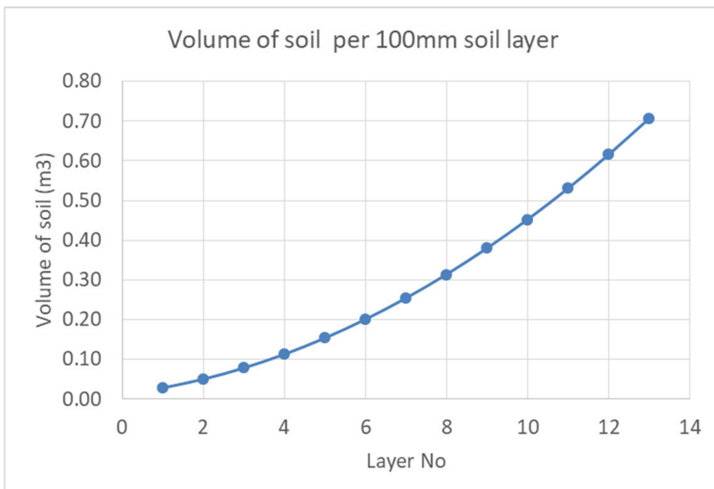

Figure 11: *Soil total volume (V_{Ti}) added as a function of the fill layer (for L1 = 3.0 m, L2 = 0.5 m, L3 = 1.25 m, Th_i = 100 mm).*

Using the additional water volume per unit of soil calculated previously using Equation (12), the volume of water required at each fill layer *i* can be calculated using:

$$V_{Wi} = \Delta V_W \cdot V_{Ti} \qquad (13)$$

The results are presented graphically at Figure 12 and the tabulated at Table 2. The later table includes the estimated soil volume and water volume for each fill layer.

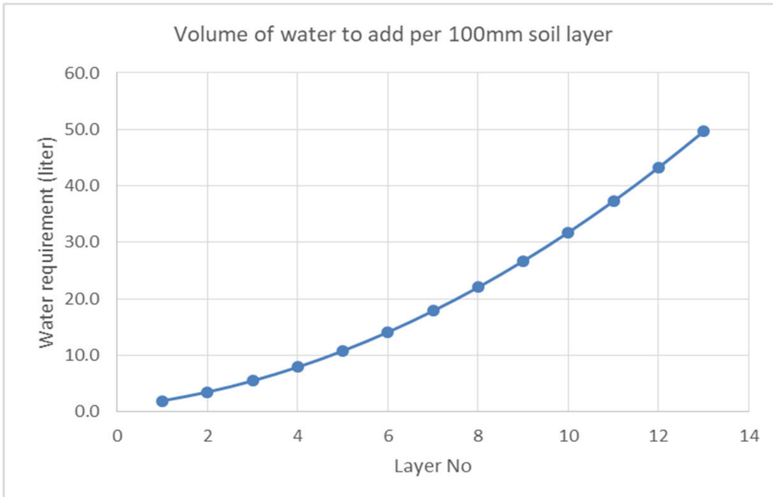

Figure 12: *Water volume (V_{Wi}) to be added as a function of the fill layer (for L1 = 3.0 m, L2 = 0.5 m, L3 = 1.25 m, Th_i = 100 mm).*

Table 2: *Summary of soil volume and associated additional water volume required per fill layer to achieve the desired soil conditions.*

Layer No	**Soil Volume m^3**	**Water Volume Litre**
1	0.03	2.0
2	0.05	3.5
3	0.08	5.5
4	0.11	7.9
5	0.15	10.8
6	0.20	14.1
7	0.25	17.9
8	0.31	22.1
9	0.38	26.7
10	0.45	31.8
11	0.53	37.3
12	0.62	43.3
13	0.71	49.7

The results indicate water addition, ranging from 2 to 50 litres per layer of fill will be required to bring the soil from its initial conditions to the desired water content. As expected the quantity of water required increases proportionally to the fill material volume.

The same type of results can be calculated for any initial and desired soli conditions as well as excavated crater dimensions.

2.7 Measuring the Soil and Water Volume During the Fill Operation

The actual calculation of the soil volume added is done by measuring the previous layer top diameter, controlling each fill material layer thickness and measuring the layer top surface diameter. To help maintain a constant layer thickness, the installation of reference thickness gauges, is recommended (Figure 13). For larger surfaces (upper layers), the use of multiple gauges distributed on the surface to be filled is recommended.

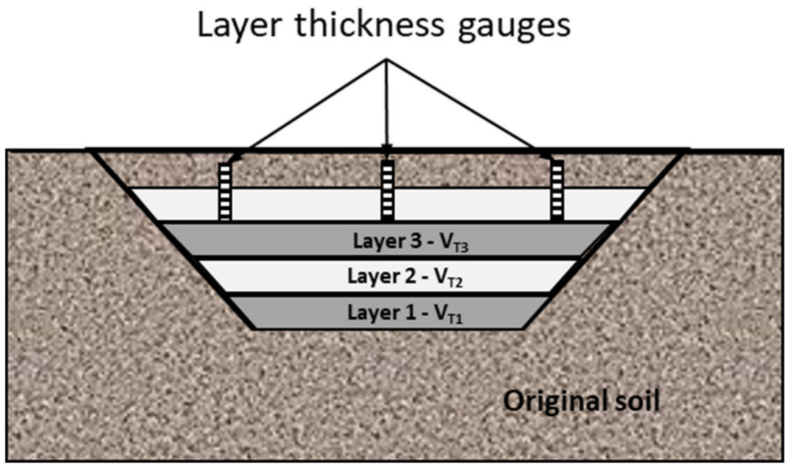

Figure 13: *Sketch of soil layer thickness gauges for achieving constant layer thicknesses.*

The loose fill material is poured in the crater, spread and levelled to the desired thickness using shovels and garden rake.

Measurement of the fill layer bottom and upper diameters, and layer thickness, must be taken to calculate the actual volume of soil added and the required volume of water.

The layer thickness should be adapted to the compaction level and the compaction equipment used. It is found fill layers of approximately 100 mm can be compacted efficiently. It also provides a good resolution for monitoring of the soil conditions throughout the fill process.

The volume of water added must be measured and be accordance with the calculated volume of water required to reach the desired moisture content. Watering of the soil is best done and controlled using a garden hose equipped with a spray nozzle (Figure 14) and a water flow meter. The flow meter should be able to be reset to measure the volume of water in litres at each layer (Figure 15).

Figure 14: *Watering of a fill layer using a garden hose with spray nozzles.*

Figure 15: *Water flow meter Make: Great Plains Industries, Model No. RK-05611-10.*

The watering operation should be done in a slow oscillatory pattern, and continued until the desired quantity of water volume, for the associated soil volume added is reached.

After water is added, an assessment of the soil water content using the touch and feel method (Figure 16), should be done. As a rule of thumb, a soil near OWC can be formed and remain in a ball shape, and will break in defined fragments when crushed between the thumb and index. If too dry, the soil will not stay in shape. If too wet, the soil will deform plastically and will not break.

Also, an actual measurement of the uncompacted layer should be done using the nuclear method [4] in backscatter mode, Figure 17, to provide experimental values required to adjust the amount of water content as required.

Figure 16: *Assessment of the moisture content using the touch and feel method.*

Figure 17: *Measurement of the soil conditions using the nuclear method [5].*

2.8 Compaction and Measurement of the Resulting Soil Conditions

As discussed previously, compaction will densify the soil by reducing its void content. Although, in theory it is possible to calculate the work required to bring the soil from its initial to the desired conditions, an experimental approach is preferred and is more practical and precise. The establishment of the compaction operation procedures should be done as described in [1], by controlling the compaction energy using the speed and the number of compactor passes. In essence, this process is a "calibration" of the compaction process to achieve the desired soil compaction, for given compaction equipment, type of soil and lift layer thicknesses, see Figure 18.

Figure 18: *Compaction of the soil using as small vibrating plate compactor.*

As discussed in [1], compacting the soil to high compaction levels using a small compactor took considerable time. For future tests, the use of the following two (2) compactor models is recommended to optimize the process and reduce the compaction time:

1. For the bottom layers (diameter up to approx. 1.5 m), a small vibrating plate compactor fits best and should be used. DRDC – Valcartier Research Centre weapons effects and protection section (WEP) acquired a new, and more performant, compactor with the following characteristics (Figure 19):
    - Make and Model: Mikasa, Model MVC88VTHW;
    - Centrifugal Force: 15 kN;
    - Exciter Speed: 100 Hz;
    - Plate Size: 500 mm × 525 mm; and
    - Max. Forward Speed: 25 m/min.

2. For the upper layers (diameter > 1.5 m), a larger plate compactor will achieve the desired compaction faster (less compaction pass). DRDC – Valcartier Research Centre transport section has a medium size compactor with the following characteristics (Figure 20):
   - Make and Model: Wacker Neuson, Model BPU5545A;
   - Centrifugal Force: 55 kN;
   - Frequency: 69 Hz;
   - Plate Size: 440 mm × 900 mm; and
   - Max. Forward Speed: 27 m/min.

Figure 19: *Small vibrating plate compactor Make: Mikasa, Model MVC88VTHW, producing 15 kN of centrifugal force.*

Figure 20: *Medium vibrating plate compactor, Make: Wacker Neuson, Model: BPU5545A, producing 55 kN of centrifugal force.*

The model of compactor and the number of compaction passes must be recorded for each layer. Following compaction, the measurement of the compacted soil layer density and water content should be done in the backscatter and direct transmission modes using the nuclear method [5] to confirm the soil conditions are within the acceptable range values.

Adjustment to the watering or compaction process should be done as required and as specified by the technical authority in place.

A record templates to summarize the data required before and during the fill operation is proposed in Annex A.

3 Conclusion and Recommendations

A method for controlling and monitoring the soil condition during the preparation of buried explosive test sites was presented. This method includes a step-by-step approach to ensure proper information is available for the planning and the execution of the test site fill process. Theory of the soil phase volume portion and a method for calculating the volume of water required to achieve desired soil conditions was also presented and demonstrated. A method to measure the actual volume of soil and water during the site preparation process is presented and improved compaction equipment was also presented and recommended.

These steps and method presented, although requiring some calculation and additional activities, are simple to implement and will result in more efficient test site preparation operations as well as more accurate and consistent test conditions for conducting buried explosive charge tests.

It is recommended future research and development (R&D) tests with buried explosive charges be performed using this proposed method as well as procedures presented in [1] to validate the process and to produce additional observations on the proposed methods. Subsequently, a formal buried charge test site preparation document should be produced to complement or improve the current AEP-55 Volume 2 [4] test procedures. As a minimum, such procedures should be used at the national level, and be provided as guidelines or requirements in future Canadian Armed Forces (CAF) acquisition projects, when buried charge tests results are requested.

References

[1] Durocher, R., Development of a Soil Preparation Method and Crater Refill Procedure for Buried Explosive Charge Test Site—Initial Study. Defence Research and Development Canada, Reference Document, DRDC-RDDC-2022-D039, October 2021.

[2] ASTD D1557, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 [2,700 kN-m/m^3]), July 2021.

[3] ASTD D854, Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer, December 2021.

[4] NATO Standard, AEP-55 Volume 2, Procedure for Evaluating the Protection Level of Armoured Vehicles—Mine Threat, Edition C, Version 1, May 2014.

[5] ASTM D6938, Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth), November 2017.

Annex A Data Record Template for Documenting Fill Operations

Soil Parameters Data	
Modified Proctor Values	
Optimal dry density - ODD (kg/m3)	
Optimal water content- OWC (%)	
Solid phase specific gravity	
Gs	
Desired Soil Conditions	
Desired dry density - DDD (kg/m3)	
Desired water content - DWC (%)	
Initial Soil Conditions of fill	
Initial dry density - IDD (kg/m3)	
Initial water content - IWC (%)	

Figure A.1: *Soil parameters data.*

Excavation Crater Data	
ID	
L1 (m)	
L2 (m)	
L3 (m)	
Center coordinate	
Long	
Lat	
Excavation	
Excavator model	
Excavation time (hr:min)	

Figure A.2: *Excavation crater data.*

Fill Operation Data																	
		Fill layer measurements			Layer Volume	Backscatter mode		Wetting		Backscatter mode		Compaction		Backscatter Mode		Direct Mode - 150mm	
Layer ID (i)	Depth	L_{Bi}	L_{Ti}	Th_i	Calc V_{Ti}	IDD	IWD	Calc V_{wi}	Actual V_{wi}	DD	WD	Compactor model	No Pass	DD	WD	DD	WD
	m	m	m	m	m3	kg/m3	%	Liter	Liter	kg/m3	%			kg/m3	%	kg/m3	%
0	=L3	=L2		0	0			0	0								
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	

Figure A.3: *Fill operation data.*

List of Symbols/Abbreviations/Acronyms/Initialisms

AEP	Allied Engineering Publication
ASTM	American Society for Testing and Materials
CAF	Canadian Armed Forces
DD	dry density
DDD	desired dry density
DRDC	Defence Research and Development Canada
DWC	desired water content
e	void ratio
G_s	specific gravity
IDD	initial dry density
IWC	initial water content
L	layer
LVIS	Land Vehicle Integrated Survivability
MC	moisture content
n	porosity
NATO	North Atlantic Treaty Organization
ODD	optimum dry density
OWC	optimum water content
OWD	optimum wet density
Pact	Program Activity
R&D	research and development
S	degree of saturation
Th_i	thickness
V_A	volume of air
V_S	volume of solids
V_T	total volume
V_{Ti}	volume of soil
V_W	volume of water
WBE	work breakdown element
WC	water content
WD	wet density
WEP	weapons effects and protection

DOCUMENT CONTROL DATA

*Security markings for the title, authors, abstract and keywords must be entered when the document is sensitive

1. ORIGINATOR (Name and address of the organization preparing the document. A DRDC Centre sponsoring a contractor's report, or tasking agency, is entered in Section 8.) DRDC – Valcartier Research Centre Defence Research and Development Canada 2459 route de la Bravoure Québec (Québec) G3J 1X5 Canada	2a. SECURITY MARKING (Overall security marking of the document including special supplemental markings if applicable.) CAN UNCLASSIFIED 2b. CONTROLLED GOODS NON-CONTROLLED GOODS DMC A

3. TITLE (The document title and sub-title as indicated on the title page.)

A Method for Controlling the Water Content and Provide More Consistent Soil Conditions When Preparing Buried Explosive Charge Test Sites

4. AUTHORS (Last name, followed by initials – ranks, titles, etc., not to be used)

Durocher, R.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total pages, including Annexes, excluding DCD, covering and verso pages.)	6b. NO. OF REFS (Total references cited.)
April 2024	32	5

7. DOCUMENT CATEGORY (e.g., Scientific Report, Contract Report, Scientific Letter.)

Reference Document

8. SPONSORING CENTRE (The name and address of the department project office or laboratory sponsoring the research and development.)

DRDC – Valcartier Research Centre
Defence Research and Development Canada
2459 route de la Bravoure
Québec (Québec) G3J 1X5
Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
Army_043	

10a. DRDC PUBLICATION NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
DRDC-RDDC-2022-D136	

11a. FUTURE DISTRIBUTION WITHIN CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

Public release

11b. FUTURE DISTRIBUTION OUTSIDE CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

12. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Use semi-colon as a delimiter.)

Buried Mine; Mines; Soil Characterization; Soil Moisture; Soil Preparation; Experiment; Soil Test

13. ABSTRACT (When available in the document, the French version of the abstract must be included here.)

This Reference Document presents a method for controlling and monitoring the soil conditions during the preparation of buried explosive test sites. This method includes a step-by-step approach to ensure required information is gathered for the planning and the execution of the test site fill process. The document also presents theory related to soil condition and phase composition, and examples of calculations. Although requiring some calculations and additional actions during the site preparation process, the method proposed is simple to implement and will result in more efficient test site preparation operations. This will also provide more accurate and consistent test conditions for conducting buried explosive charge tests.

Ce document de référence présente une méthode pour contrôler et surveiller les conditions du sol pendant la préparation des sites d'essai d'explosifs enfouis. Cette méthode comprend une approche étape par étape pour s'assurer que les renseignements nécessaires sont recueillis pour la planification et l'exécution du processus de remplissage du site d'essai. Le document présente également la théorie liée à l'état du sol, à la composition des phases et des exemples de calculs. Bien qu'elle nécessite certains calculs et des mesures supplémentaires au cours du processus de préparation du site, la méthode proposée est simple à mettre en œuvre et permettra d'avoir des opérations plus efficaces de préparation du site d'essai. Elle permettra également d'obtenir des conditions d'essai plus précises et uniformes pour la réalisation des essais de charges explosives enfouies.