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Geotechnical causes for variations in output measured from shallow buried charges

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ABSTRACT

The role of the geotechnical conditions on the impulse delivered by a shallow buried charge has received much attention in recent times. As the importance of the soil in these events has become better understood, the control over the geotechnical conditions has improved. While previous work has investigated directly the role of geotechnical conditions on the magnitude of the impulse from a buried charge, the current work aims to identify how these same conditions also affect the repeatability of testing using soils. In this paper the authors draw together their work to date for a wide range of different soil types and moisture contents to investigate the variation in output from nominally identical tests. The methodology for the preparation of soil beds and the measurement of impulse is described along with the measured variations in peak and residual deflections of a target plate fixed to the impulse measurement apparatus.

1. Introduction

With the increasing use of buried improvised explosive devices in current conflict zones, a need for a deeper understanding of the role of soil in the resulting explosive events has emerged. Being able to design protective structures to withstand such events, and save lives, depends on the accurate assessment of the blast loading produced by the detonation of such shallow-buried explosives. This is a highly complex detonation event, involving the interaction of extremely high-energy shock waves with multiple materials in different phases.

Experimental research into characterising the loading from buried explosives has typically focused on the structural response of a target [1,2] with the geotechnical conditions prior to detonation being of secondary concern. In more recent studies attention has been given to the geotechnical conditions albeit without a full understanding of their role in the underlying repeatability of the event [3–8]. As an alternative, the shock-related aspects can be removed altogether by using well controlled small scale laboratory samples loaded by compressed gas [9]. This approach has the drawback of over-simplifying the problem by ignoring the air shock, geometrical and thermal aspects of the loading, and perhaps even more critically concentrating only on the sand throw as the mechanism for impulse transfer.

It is generally accepted that geotechnical properties of the soil surrounding a buried charge are of key importance in determining the variation in output. Significant parameters include bulk density, moisture content, particle size distribution and burial depth. With so many possible principal variables being present, control of the geotechnical conditions is key to understand the relationships between them and the generated impulse.

The authors have shown previously that by carefully controlling the burial conditions very repeatable impulse data can be obtained (±3% for nominally identical tests [10]). This has enabled parametric studies to be conducted to assess the influence of individual geotechnical parameters on the resulting blast. With careful control during the preparation of the soil beds, variations in density of ±0.2%, and in moisture content of ±0.05–0.1% have been achieved. Previous testing has shown that for a fixed bulk density, an increase in moisture content leads to an increase in generated impulse with all other variables remaining constant [10] (series 'a' reported below). Since the previously published work by the authors, a more comprehensive test series, comprising 77 tests (in total) has been conducted. These tests have incorporated the test modifications

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Table 1
Soil types used in the current research.

Soil	PSD	w (%)	ρ (Mg/m^3)
Leighton Buzzard 14/25 (LB)	Uniform (0.6–1.18 mm)	0–25	1.5–2.0
Leighton Buzzard 6/14 (2LB)	Uniform (1.18–2.8 mm)	0–25	1.6–2.0
Leighton Buzzard 25B grit (LBF)	Well graded (0.5–5.0 mm)	0–25	1.6–2.0
Sandy gravel (Stanag) [12]	Well graded (0–20 mm)	0–14	1.9–2.2
Red building sand (RBS)	Uniform (0.1–0.5 mm)	25	1.9
Brown laminated silty clay	66% < 0.002 mm	~27	1.93

reported in Ref. 11 which improved the accuracy of the image tracking through the use of LEDs set into the target markers. The aim of the research reported herein was to investigate whether certain soil types and conditions produce more repeatable output when comparing the total impulse generated, and the deformation of the target plate. These outputs were also compared to the outputs from tests conducted using a surrogate mine in a steel pot (Minepot) described in the Allied Engineering Publication on procedures for evaluating the protection level of armoured vehicles (AEP-55) [12]. The use of the Minepot hence removes any of the geotechnical conditions as possible causes for the variations in measured impulse and plate deflections.

2. Geotechnical conditions

Soil is a naturally variable material. As such the achievable degree of control of the geotechnical conditions should be a product of this natural variation. Six soils have been tested in the current research at a range of moisture contents (w = mass of water/*dry* mass of solids) and bulk and dry densities (ρ, ρ_d).

The soil types tested are given in Table 1 with information on the particle size distribution for each soil type being shown in Fig. 1. Uniform soils have a small range of particle sizes and hence plot as steep lines in Fig. 1 e.g. Leighton Buzzard 14/25 (LB) and 6/14 (2LB) sands. Well graded soils have a large range of particle sizes and plot as shallow lines e.g. 'Stanag'. Stanag is the sandy gravel recommended for use in buried charge tests given in the AEP-55 [12], which is itself a testing addenda to NATO standardisation agreement, STANAG 4569 [13]. The Leighton Buzzard sands are renowned in the UK for their well-rounded and uniform nature and have a long history of use in geotechnical testing due to their inherently repeatable nature. Their name comes from the town in which they are quarried. For two of the Leighton Buzzard sand gradings (14/25 (LB) and 25B grit sand (LBF)) the test beds were first compacted to a constant bulk density (series 'a' in Table 2, which indicates how each test series varied). Hence, as the water content increased so the dry density decreased. As the dry density decreases the soil becomes more prone to self weight and vibration induced compaction, so great care must be taken when moving soil containers once prepared. In test series 'b', the dry density was kept constant with increased water content leading to an increased bulk density in each test. There is a natural limit on the moisture content achievable whilst still creating a homogeneous sample. Once this limit is passed the water in the soil matrix settles to the bottom of the soil container creating a fully saturated zone at the base with a partially saturated zone above. This is related to the particle size distribution, with the well graded soils being able to sustain higher moisture contents whilst remaining homogeneous. In the case of the Leighton Buzzard sands this limit was found to be around ≈8% moisture content. In test series 'c' the air void ratio (volume of air/total volume) in the sample was kept constant, leading to a reduction in both bulk and dry densities as the water content increased. As in test series 'a' the soils are prone to self compact once the natural minimum dry density is neared, hence low moisture contents were used. The test series types are summarised in Table 2. Further soil types were also tested using the series 'b' methodology, these included Leighton Buzzard 6/14 sand (2LB), AEP-55 sandy gravel (Stanag), brown laminated silty clay (Clay), and red building sand (RBS). The Leighton Buzzard sands provide an opportunity to investigate the effects of particle scaling and particle size distribution for nominally identical materials. Leighton Buzzard sand can be described as a rounded to well-rounded quartz silica sand shown in Fig. 2a. The red building sand has a smaller average particle size and can be described as sub-angular, as shown in Fig. 2b. For all the soils tested with the exception of the clay, silica is the predominant mineral, giving the soils an identical specific gravity, G_s of 2.65 (Clay $G_s \approx 2.75$).

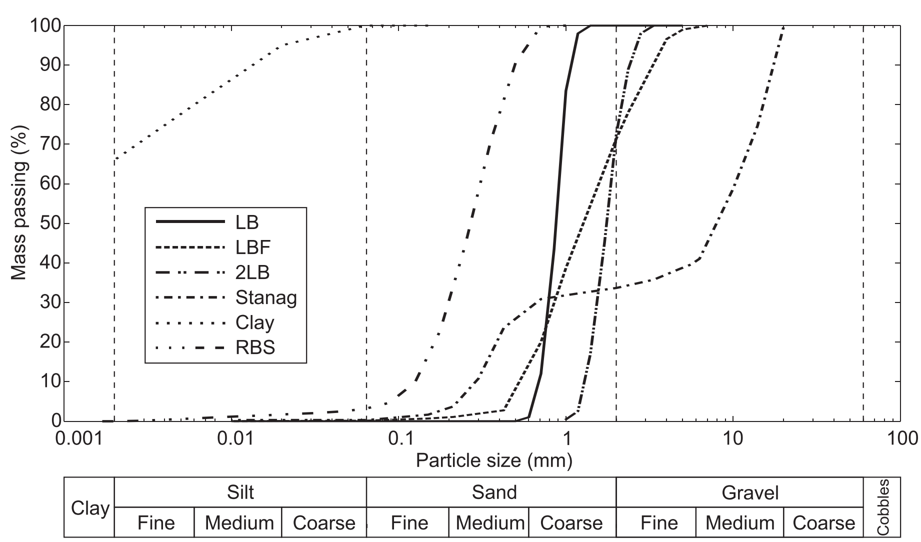

Fig. 1. Particle size distribution curves for each soil type.