International Journal of Impact Engineering 102 (2017) 117–128

Contents lists available at ScienceDirect

International Journal of Impact Engineering

journal homepage: www.elsevier.com/locate/ijimpeng

Predicting the role of geotechnical parameters on the output from shallow buried explosives

S.D. Clarke[1,a], S.D. Fay[a,b], J.A. Warren[a,b], A. Tyas[a,b], S.E. Rigby[a,*], J.J. Reay[b], R. Livesey[c], I. Elgy[c]

[a] Department of Civil & Structural Engineering, University of Sheffield, Mappin Street, Sheffield, S1 3JD, UK
[b] Blastech Ltd, The Sheffield Bioincubator, 40 Leavy Greave Road, Sheffield, UK, S3 7RD
[c] Physical Sciences Group, DSTL Porton Down, Salisbury, SP4 0JQ, UK

ARTICLE INFO

Article History:
Received 12 August 2016
Revised 8 December 2016
Accepted 12 December 2016
Available online 21 December 2016

Keywords:
Buried charges
Impulse
Geotechnics
Soil
Plate deformation
IEDs

ABSTRACT

Experiments have been conducted to quantify the effect the geotechnical conditions surrounding a buried charge have on the resulting output. From the results obtained the critical importance of moisture content in governing the magnitude of impulse delivered is highlighted. This has led to the development of a first-order predictive model for the impulse delivered from a buried charge, based on bulk density and moisture content, allowing rapid assessment of the effect of varying the geotechnical conditions. The work utilised a half-scale impulse measurement apparatus which incorporated a deformable target plate. Impulse, peak and residual target deflections were recorded for each test. No variations the charge geometry, mass of explosive, burial depth or stand-off were considered, with the focus solely being on the effect of the geotechnical conditions on the magnitude of loading and structural response. Five different types or grades of soils were used in the work, with both cohesive and cohesionless soils represented. The effect of air voids on the impulse generated was also investigated which showed that while strongly correlated, air voids alone is a poorer predictor of impulse than moisture content.

1. Introduction

The accurate quantification of the loading and structural deformation occurring when a shallow buried charge is detonated has received considerable attention in recent times. The conducted research has equal applicability in both civilian (demining) and military (protection from improvised explosive devices (IEDs)) arenas. The role geotechnical conditions play in our understanding of the mechanisms of load transfer from buried mines and IEDs is critical to our ability to protect against such events. In the first instance knowledge of which measurable geotechnical parameters can indicate an increased output from a mine or IED can play an important role in route planning for military and civilian endeavours. These same data also allow validation of numerical models to allow a more accurate assessment of the blast loading produced by the detonation of shallow-buried explosives, to aid in future predictive work.

A large effort has been made to investigate the effects of soil on the output of buried charges. Many previous studies have concentrated on assessing the deformation of a target [1–3]. These deformation data are useful for protective system design and platform validation purposes, but fail to directly assess the effect the soil has on the distribution of the loading applied. Most direct load measurement studies have concentrated on quantifying the impulse imparted to a target, which is typically spatially integrated over the entire target face [4–10], and hence these studies only provide a single data point for the validation of numerical modelling approaches.

This research effort has identified that the geotechnical properties of the soil surrounding a buried charge are of key importance in determining the magnitude of the impulse generated, and the form of the structural response. Significant parameters have been shown to include in rank order; moisture content / saturation / air voids, bulk density, and particle size distribution. Burial depth is also known to have a significant role on the impulse generated with an initial increase in delivered impulse and plate deflection at shallow depths [2] giving rise to a reduction in the deflection and energy imparted [5] as the depth increases further.

Much attention has also been given to the generation of numerical modelling techniques for the prediction of loading from buried

---

[*] Corresponding author.
E-mail address: sam.clarke@sheffield.ac.uk (S.D. Clarke), sam.rigby@sheffield.ac.uk (S.E. Rigby).
[1] Tel.: +44 (0) 114 222 5703.

http://dx.doi.org/10.1016/j.ijimpeng.2016.12.006
0734-743X/© 2016 Elsevier Ltd. All rights reserved.

charges. This varies from simplified load curve type models [11] to fully 3D high-fidelity numerical modelling of the explosive, soil and air domains [12,13].

With knowledge of the principal variables, control of the geotechnical conditions is still key to understanding the relationship between the impulse generated and the structural response. It has been shown previously that by carefully controlling the burial conditions in uniform soils very repeatable impulse data can be obtained (relative standard deviation = 1.22% for nominally identical tests [14]). The work reported herein expands on the previous data set providing both the absolute magnitude of the impulse generated from each test and the resulting peak and residual plate deformations to allow for the validation of numerical models. As in previous work the measured outputs were also benchmarked against 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) [15]. The use of the Minepot removes any influence of the soil overburden giving near perfect confinement to the explosives, channelling the blast directly at the centre of the target plate.

The test series comprises 74 tests in total, with the results used to generate a first-order impulse predictive method as a function of moisture content and bulk density.

2. Geotechnical conditions

In the current research programme five different types or grades of soils have been tested at a range of moisture contents (w = mass of water / *dry* mass of solids) and bulk and dry densities (ρ, total mass of soil and water per unit volume, and ρ_d, dry mass of soil per unit volume). This leads to a natural variation in the air voids (A_v, ratio of volume of air to total volume) present in each of the soils as moisture content and initial dry density are varied.

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. Here, the results of a sieve analysis are plotted, with 'mass passing' referring to the percentage mass passing through each sieve size.

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) [15]	Well graded (0–20 mm)	0–14	1.9–2.2
Brown laminated silty clay	66% < 0.002 mm	~ 27	1.93

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'. The 'Stanag' soil is similar to the sandy gravel recommended for use in buried charge tests given in AEP-55 [15], which falls within the basic parameters prescribed for NATO standardisation agreement, STANAG 4569 [16]. Three test series were conducted, series a, b and c, where the bulk density, dry density, and air void ratio were kept constant respectively. Further details on the soils tested and geotechnical preparation of the soils can be found in Ref. [14]. The target geotechnical conditions are given in Table 2. The achieved conditions are shown graphically in Fig. 2 as bulk density plotted against moisture content. This figure clearly shows that the Stanag soil has a much higher dry density (1.93 Mg/m^3) due to a lower natural porosity as the soil is well graded. This naturally leads to a high saturated bulk density (2.2 Mg/m^3) at a comparatively low moisture content. Both the LB and Clay soils achieve higher moisture contents at lower bulk densities due to the soils' higher porosity.

3. Experimental setup

3.1. Test frame

The experimental work was conducted by Blastech Ltd at the University of Sheffield Blast & Impact laboratory, Buxton, UK as part of a research project funded by the UK Defence Science and

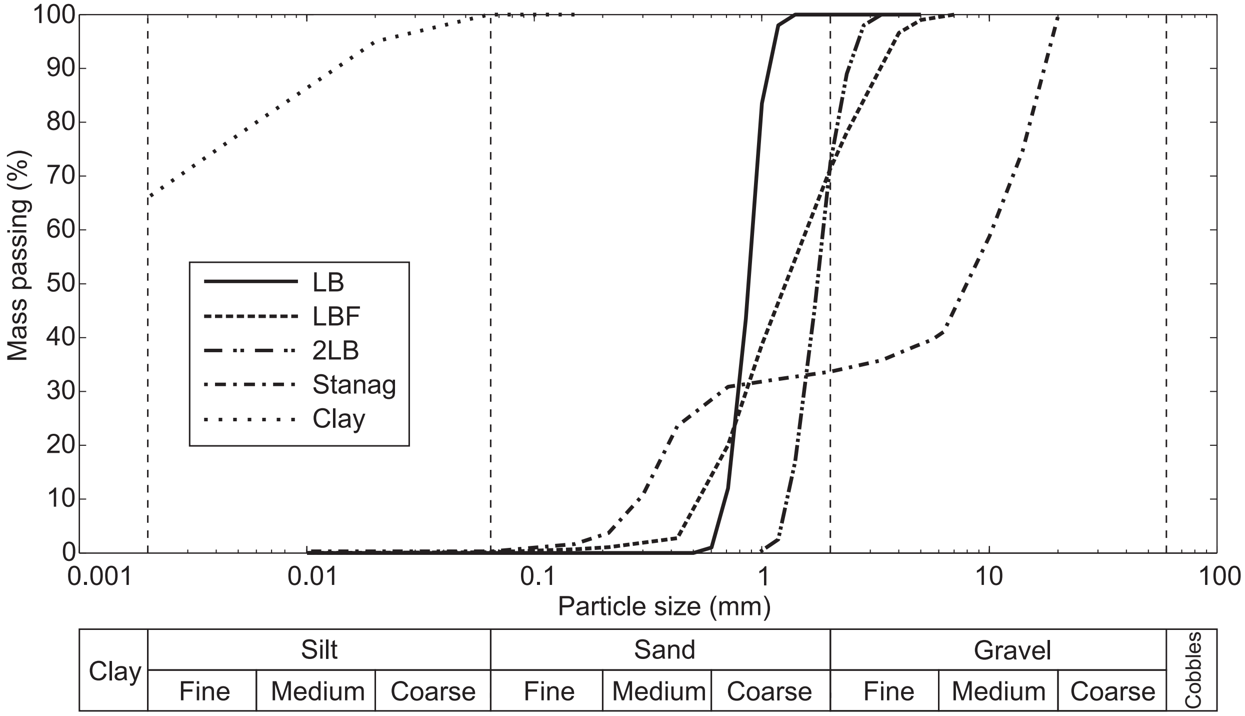

Fig. 1. Particle size distributions for the soils utilised.