Proceedings Paper:
Waddoups, R., Clarke, S., Curry, R. et al. (2026) DIC determination of localised loading on blast loaded plates from coarse soils. In: Light-Weight Armour for Defence & Security LWAG 2026. Light-Weight Armour for Defence & Security 2026, 02-04 Jun 2026, Oslofjord, Norway.

Light-Weight Armour for Defence & Security
LWAG 2026

DIC determination of localised loading on blast loaded plates from coarse soils

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Abstract

Buried charges pose a serious threat to nearby people and structures. An increased understanding of the loading from buried charges allows for the design of improved protective measures. To this end, results from buried blast testing in uniform sand, well-graded sandy gravel and uniform gravel were compared to establish the effect that large discrete particles have on the delivery of loading across a plate. All tests were conducted with fully saturated soils. The data indicates that the inclusion of large individual particles within the soil matrix leads to localised increases in loading, however the overall peak displacement was similar across soil types. Inspecting the development of velocity uptake across the plate demonstrated markedly different loading behaviours between the uniform sand and the soils containing coarser gravel particles. For lightweight armour systems this distribution of loading could have a profound impact on the protective capacities of the system.

Introduction

The threat from buried charges (landmines, or explosive remnants of war (ERW)) is pervasive in regions of present and past conflict across the world. "At least 6,279 casualties of landmines and ERW were recorded" in 2024, across "52 countries and areas", 90% of which were civilians [1]. Loading from these buried charges can be devastating for structures in the vicinity. It is well established that buried charge loading varies considerably according to the geotechnical properties of the soil in which it is situated [2,3], with testing previously conducted across scales. It was previously suggested that localisations of specific impulse were introduced from testing with well-graded soils (such as the STANAG sandy gravel according to AEP-55 [4]) due to discrete particles striking a measurement surface with high individual momentum [5,6].

Methodology

The current work has utilised high-speed digital image correlation (DIC) at 210,000 frames per second to determine the deformation of 4 mm thick S275 mild steel plates under buried charge loading. The setup uses 78 g PE4 charges for a quarter-scale version of the methodology described in AEP-55 [4]. This geometric setup was utilised to recreate the same loading conditions as used previously when recording pressure-time histories at discrete locations with Hopkinson pressure bars housed in a rigid plate [7]. The deformation of the plate, and the uptake of velocity across the recorded plate surface, was used to establish a high-fidelity spatial distribution of the loading.

Two Photron SA-Z high-speed video (HSV) cameras, with matching 50mm lenses, were positioned on a support structure suspended above the loaded plate, which was clamped between two 20mm thick mild steel clamp frames with an exposed circular area of 315mm diameter. The clamp frame bore on an effectively rigid reaction frame via a 50mm thick mild steel 'adapter plate', which allows for a reduction in the scale of testing from previous work with 995mm square plates [8] to the 450mm square plates used in this work. This setup is shown in Figure 1.

The plates were sand-blasted and a white spray paint applied, overlaid by a black speckle pattern for the DIC process. Before testing, the system was calibrated using approximately 30 pairs of images of a known calibration target board in various orientations. Images were recorded at a resolution of 384 x 160 pixels during the period of

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loading, covering a field of view (FOV) of approximately 230 x 100mm. The plate was illuminated using two GS Vitec MX LED lights.

Figure 1: Experimental apparatus during a test

3:1 cylindrical charges (57mm diameter, 19mm height) in 3D-printed open-topped cases were positioned at a depth of burial of 28mm and a stand-off distance of 140mm from the soil surface to the plate, as shown in Figure 2(a). Soil type was varied between uniform Leighton Buzzard (LB) sand, ‘Stanag’ sandy gravel (an approximation of that specified by AEP-55 [4]), and uniform ‘pea’ gravel, each fully saturated via a bottom-up saturation technique [9]. Charge excavation and burial in each soil type is shown in Figure 3, after which the overburden was replaced, soil saturated, and the soil container placed in position on the test apparatus.

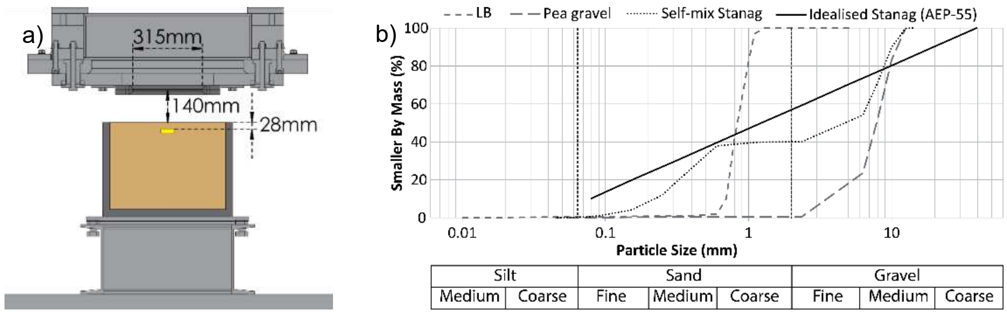

Figure 2: (a) Charge, soil and plate geometry diagram; (b) particle size distributions of soils used in this work

Figure 3: Charge burial in: (a) Uniform LB sand, (b) 'Stanag' sandy gravel, (c) uniform pea gravel

Results and Discussion

A surface of plate displacement data can be derived from the DIC process, as shown in Figure 4. From this, time-histories can be extracted at individual points, or full-field data can be examined.

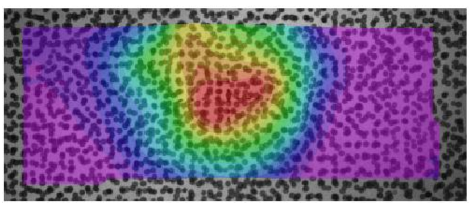

Figure 4: Camera FOV with displacement data surface overlaid

Plate displacement

Taken along the central axis of the measured points, Figure 5 shows the plate displacement from one test in each soil type, with data extracted at 0.1ms intervals. From this, it can be seen that each of the soils resulted in similar deflection behaviour, but with some localised bulging in the plate for the Stanag and gravel tests.

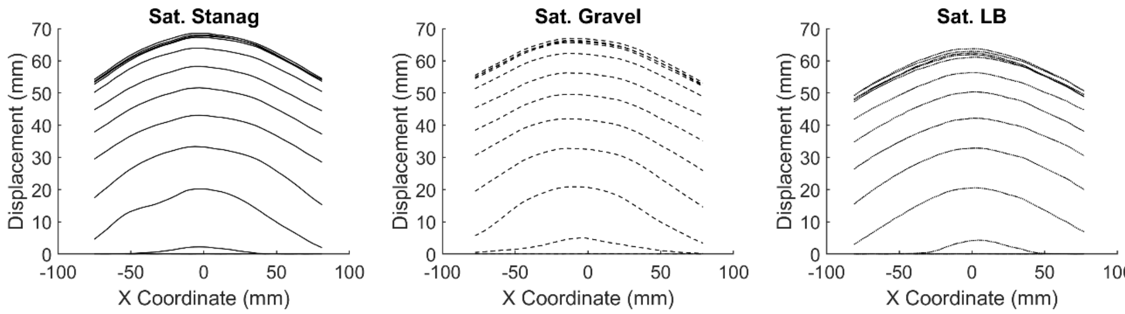

Figure 5: Plate deflection line-slices along X axis

Plate velocity

From the DIC-determined plate displacement, velocity was determined as the derivative with respect to time. As plate thickness and material were maintained between all tests, and given that specific impulse can be determined as the momentum per unit area under impulsive conditions [10-12], plate velocity can be used to characterise the loading impinging on the plate. Figure 6(a) shows the development of velocity for each of the tests, wherein it can be seen that the uniform LB resulted in a reasonably uniform distribution of velocity, which propagated radially from a centrally loaded point. In contrast, the plates exposed to soils containing larger gravel particles underwent non-uniform loading with discrete areas of increased velocity occurring at different times during the loading period.

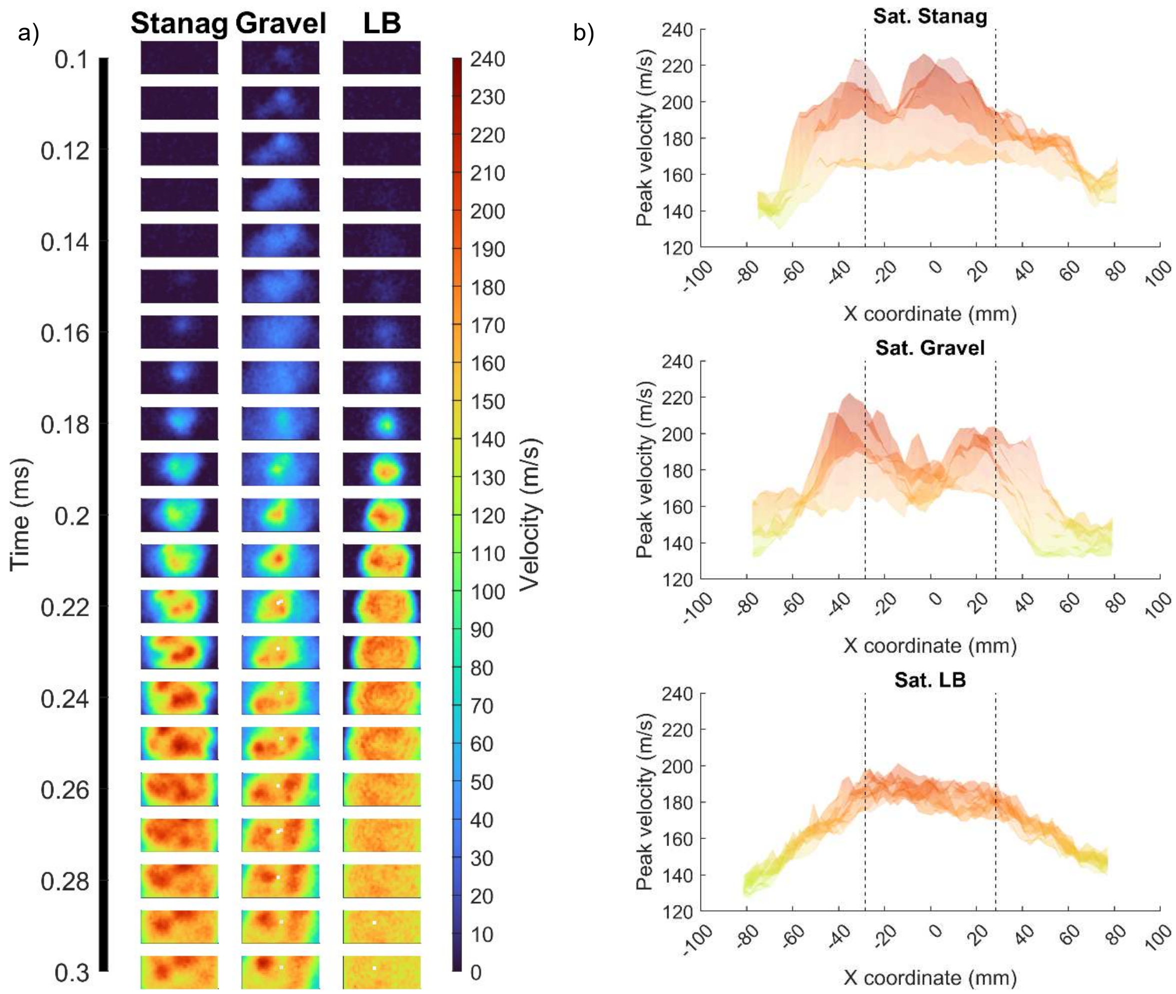

Figure 6: (a) Development of velocity across the plate surface for each test; (b) Peak plate velocity across the surface

Figure 6(b) shows the peak velocity across the measured area of the plate surface for the three soils (surface plots viewed side-on), demonstrating the non-uniformity of the loading sustained by structures exposed to blasts from charges buried in coarse soils containing large particles. It can be seen that the uniform LB sand resulted in a relatively uniform loading across the region directly above the charge (with the charge diameter indicated by the dashed lines), with reductions in loading at positions away from this zone. Small, localised variations in the LB data are anticipated to result primarily from noise in the image-based processing method. On the other hand, large peaks and troughs in velocity can be seen in the Stanag and gravel data of around 20% of the velocity magnitude. Discrete strikes from gravel particles (with a D_{50} of 8mm in this work) can be seen to contribute to significant localised increases in loading due to high-momentum individual impacts.

Conclusion

Buried charge blast testing has been undertaken at a quarter-scale of that prescribed by AEP-55 [4], using saturated soils of varying particle size distribution, to determine the effect of large discrete particles in a soil matrix on loading distribution. High-speed DIC was used to determine the displacement of mild steel plates under this loading, with the velocity distribution used to understand variations in loading between soil types. It was shown that buried charges in soils containing larger gravel particles resulted in more variable loading across the plate surface, with localised increases in velocity on the order of 20%. On the other hand, uniform sand resulted in a smooth distribution of loading across the plate. This has significant implications for the design of lightweight armour systems.

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