CHARACTERIZATION OF BURIED LANDMINE BLAST

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ABSTRACT

The procurement and employment of vehicles for use in military operations requires a detailed understanding of the protection offered by these vehicles against threats on the modern battlefield. NATO Standardization Agreement 4569 Protection Levels for Occupants of Armoured Vehicles (STANAG 4569) specifies standardized protection levels from various threats. The detailed procedures for evaluating the protection levels and additional details on other types of threats are specified in Allied Engineering Publication 55 Procedures for Evaluating the Protection Level of Armoured Vehicles (AEP-55). Volume 2 of AEP-55 specifies the test conditions for occupant survivability testing against landmines, however validation tests in the past have shown an unexpectedly high variation in total impulse. Some questions about the consistency of the test protocol exist, both for the explosive used and soil preparation procedures. Work was undertaken at the Defence Research and Development Canada, Suffield Research Centre to characterize this variation and to adjust the test protocol so as to reduce this variability.

INTRODUCTION

A detailed understanding of the protection offered by military vehicles against threats on the modern battlefield is required in order to allow their specification and use. Canadian Armed Forces (CAF) deployed operations in Bosnia, Eritrea, and Afghanistan have subjected vehicles and their occupants to a variety of potentially lethal buried threats including landmines and Improvised Explosive Devices (IEDs).

NATO Standardization Agreement 4569 Protection Levels for Occupants of Armoured Vehicles (STANAG 4569) [1] specifies standardized protection levels from various threats. While blast mine protection levels are specified within STANAG 4569, the procedures for evaluating the protection levels are specified in Allied Engineering Publication 55 Procedures for Evaluating the Protection Level of Armoured Vehicles (AEP-55) [2]. Canada is an active participant in the continuing development of both of these international standards.

Although AEP-55 Volume 2 specifies the test conditions for occupant survivability testing against landmines, some questions about the consistency of the test protocol exist. Additionally, the soil used for buried landmine tests varies between potential test sites. This work was undertaken to adjust the test protocol so as to reduce the observed variability between test sites and has been reported to the Canadian Armed Forces to assist in future vehicle assessments [3].

METHOD

AEP-55 Mine Blast Test Methods

Two conditions for landmine testing are defined – one using a TNT charge buried in soil, and the second method uses a surrogate charge placed in a steel pot with no soil and a PETN-B or C4 charge. The in-soil test method uses 6 kg, 8 kg, or 10 kg charges.

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The soil condition is specified as a saturated sandy-gravel, with a burial depth of 100mm from the ground surface to the top of the surrogate charge. The particle size analysis for the soil is described as 100% passing a 40mm sieve, between 40% and 60% passing a 5mm sieve, and a maximum of 10% passing an 80um sieve. This is slightly different from Figure C1 of AEP-55 Volume 2 indicating a straight line on a linear-log plot for the acceptable particle size distribution, while the text indicates that 100% of the material should pass a 40mm sieve, between 60% and 40% should pass through a 5mm sieve, and a maximum of 10% should pass through a 80µm sieve. There are differences between these two specifications, particularly at the 5mm particle size.

Figure 1 shows the particle size distribution for a number of samples from both the 2012 and 2013 tests at Suffield as well as the two AEP-55 specifications (graphical and descriptive). The soil used for these tests lies approximately between the graphical and descriptive specifications for soil particle size distribution in AEP-55 Volume 2, both of which are indicated in Figure 1.

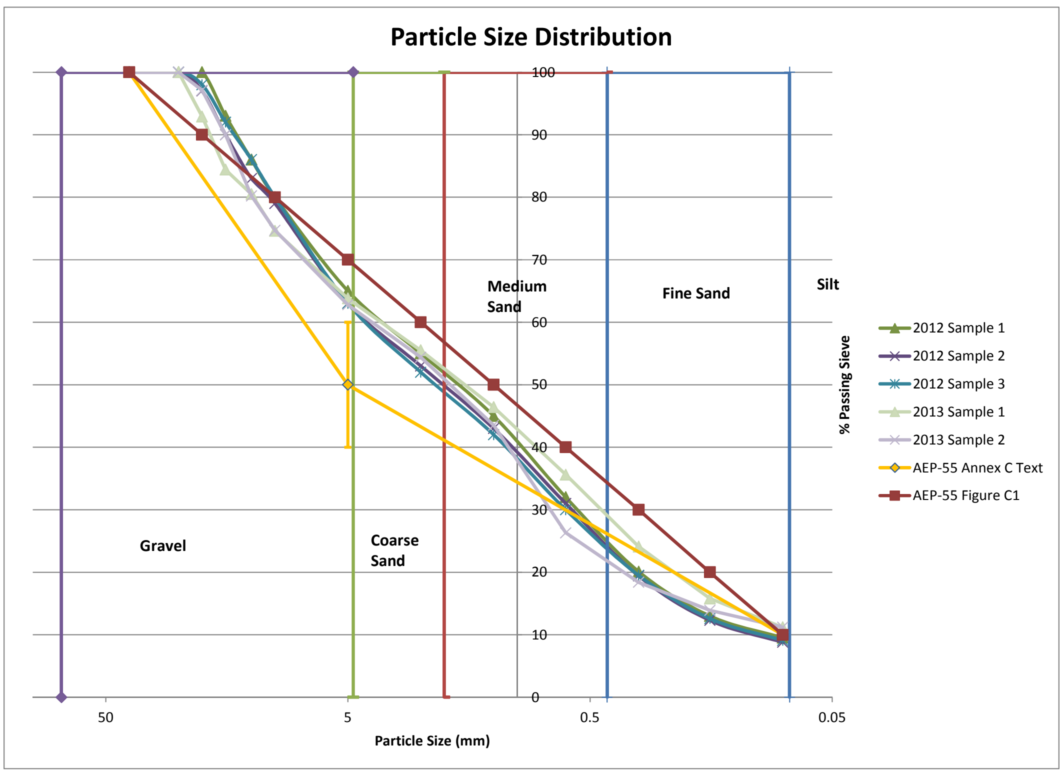

Figure 1: Particle size distribution

A slight, intentional deviation from the AEP-55 Volume 2 soil preparation procedure was used for these tests. The test area was not saturated with water prior to the test. Instead, a consistent soil moisture and compaction target was maintained while emplacing the entire test pit. This ensured that a moisture gradient was not created by saturating only the top layer.

Test Pit Construction

The target moisture content and compaction were selected based on the optimum moisture content and density determined using the ASTM D698 test method [4].

To improve the consistency between tests, it was decided to build a single 15 m long x 3 m wide x 2 m deep pit, shown in Figure 2, in which to conduct four tests within a two week testing window. It is expected that the moisture content profile of the test area would vary over time, thus limiting the length of time between preparing and conducting tests in the pit would likely be advantageous – although this has not been studied in detail. A construction technique similar to road construction was used, except an excavated area was used rather than an aboveground embankment in order to limit any edge effects. Plastic sheeting was used to line the pit in order to reduce moisture loss to the surrounding soil.

Soil properties including density and water content were characterized per ASTM D6938-10 [5] using a Humboldt Scientific 5001B nuclear densometer with a probe length of 100 mm, and a normal (1 minute) count. These results were validated using a smaller number of measurements with the ASTM D2167 [6] and ASTM D4959 [7] methods.

Figure 2: Test pit construction

Test Target and Instrumentation

A test target with a mass of approximately 11000 kg was placed at a standoff distance of 400 mm above the ground. The test rig was composed of a large steel frame with several relatively thick 100 mm (4”) steel plates. These plates were bolted together, with a large framework on top of the steel plates to provide a visual reference point outside the debris cloud in the high speed videos. The bottom of the target presented an area of 2.13 m x 2.13 m (84” x 84”) to the detonation. A photograph of the overall test rig is shown below in Figure 3.

Figure 3: Test target.

Data recorded with Pacific Instruments 9355 signal conditioner/recorders included PCB 350B02 and PCB 3200B5 accelerometers mounted on the test frame and PCB 113B28 pressure transducers on "lollipop" stands at various distances. Additionally, a TSR Pro self-contained accelerometer recorder was fitted to the test target. Acceleration measurements from the TSR Pro were found to be the most reliable as they were less susceptible to electrical noise induced in the wired data acquisition system immediately following the detonation.

A displacement-time history of the test target after detonation was obtained using photogrammetry based on high speed video from Vision Research Phantom high speed cameras, generally with a frame rate of 2000 frames per second. This proved to be the most important diagnostic for evaluating impulse imparted on the test rig as both the initial velocity from the first few centimeters of movement as well as peak displacement were captured using this technique. The open-source "Tracker" software [7] was used to automatically capture points both on the test rig as well as static reference points in order to remove the effects of camera movement due to passage of the shock wave.

Charge Types

A total of four types of charges were used for these tests. TNT charges with masses of 6 kg and 8 kg were prepared at the Suffield Research Centre using two manufacturing techniques, with 5.04 kg C4 charges also prepared at Suffield. The two manufacturing techniques used for the 6 kg charges were machining from larger existing TNT blocks and carefully controlled casting into a mold. As there were some concerns that the explosive casting technique may play a role in the impulse experienced by a target, 6 kg TNT charges prepared at the Valcartier Research Centre were also tested at the Suffield Research Centre.

EXPERIMENTAL RESULTS

Total impulse imparted on the test rig was calculated using both initial velocity and displacement at the apex. The impulse calculated using both methods generally agreed to between 0 and 2 percent, which was within the measurement error of these techniques. As could reasonably be expected, this is an impulsive event wherein the target did not begin to move until after the loading from the detonation had occurred.

The normalized impulse calculated using maximum displacement of the test rig is shown below in Figures 4 and 5. Figure 4 provides a comparison between the two charge manufacturing techniques, while Figure 5 compares the 6 and 8 kg cast TNT charges to C4. Each bar represents the average normalized impulse from an individual test pit, with the error bars indicating the range of data. Impulse was normalized using the average impulse for all cast 6 kg TNT charges.

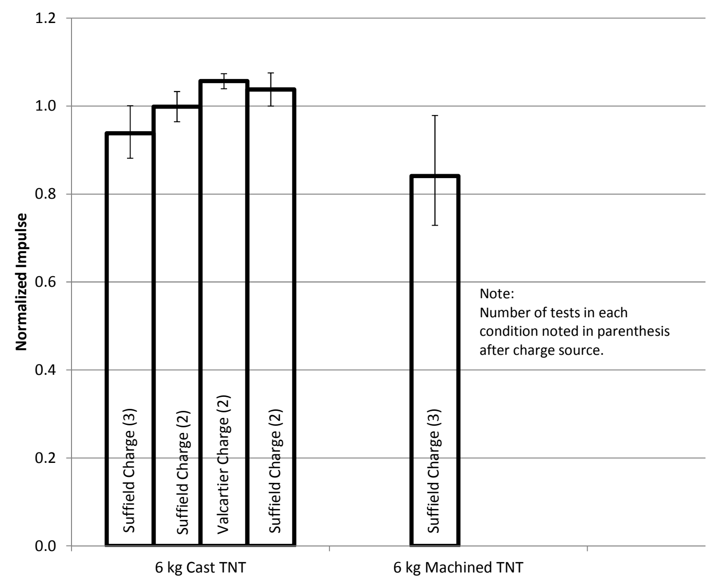

Figure 4: Comparison of normalized impulse for cast and machined 6 kg TNT charges.

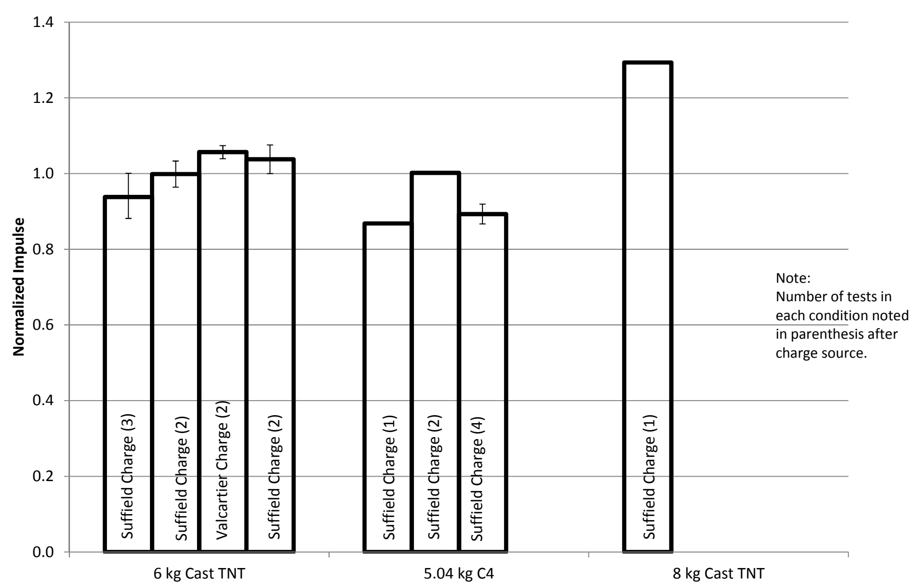

Figure 5: Comparison of normalized impulse for C4 and cast TNT charges.

Although the soil moisture content was kept relatively constant, a correlation between the measured soil moisture content and impulse was observed as shown in Figure 6 below. The normalized specific impulse used in Figure 6 is simply the impulse divided by the explosive mass, to allow tests with different explosive masses to be compared. Specific impulse was normalized using the average specific impulse for the 6 kg TNT charges as the baseline.

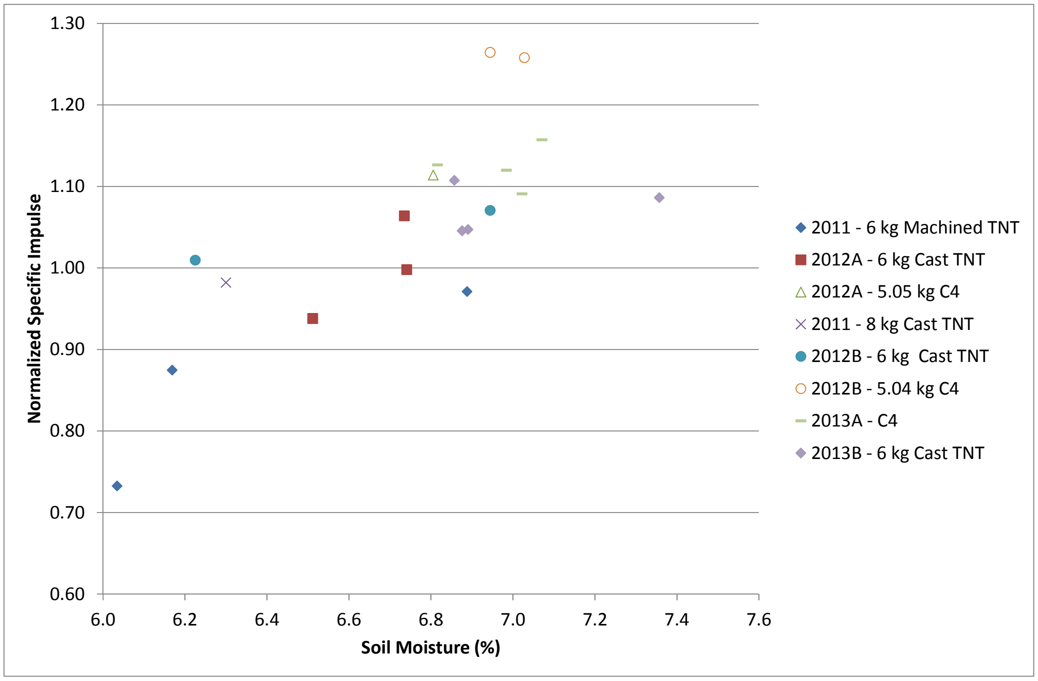

Figure 6: Effect of soil pit moisture content on normalized specific impulse.

DISCUSSION

As illustrated in Figure 5, the normalized impulse for the machined TNT charges varied within a range of -12% to +16% of the average impulse. This is significantly more than the range of -12% to +8% observed for the cast TNT charges and thus the cast TNT was used as a baseline.

Histograms of the normalized impulse, shown below in Figure 7, show that the normalized impulse was reasonably consistent between pits for the 6 kg cast TNT charges. Figure 8 provides a similar histogram for the 5.04 kg C4 charges.

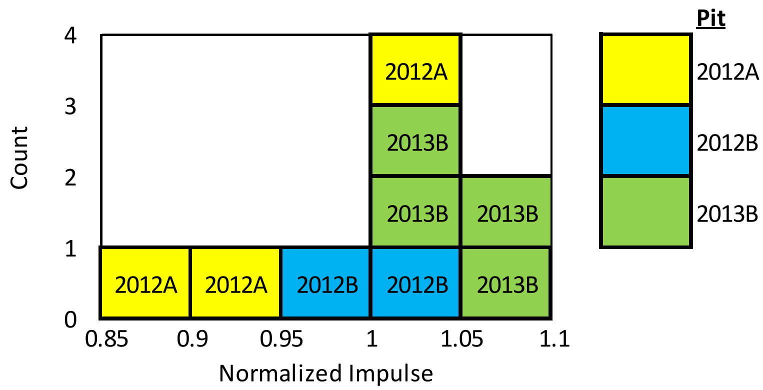

Figure 7: Normalized impulse histogram by pit for 6 kg TNT charges.

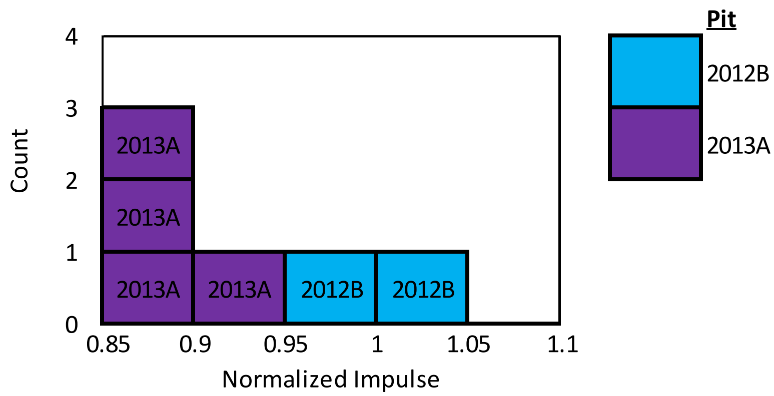

Figure 8: Normalized impulse histogram by pit for 5.04 kg C4 charges.

As illustrated in Figures 7 and 8, there was a strong correlation between the impulse imparted on the target and the individual pit. A variation of -12% to +8% from the mean was observed for 6 kg TNT charges in different pits. With C4, this range was reduced to -6% to +9% between pits. When a single pit is considered, the range was reduced to -5% to +3% for the TNT and +/- 3% for the C4 charge types.

To ensure consistency between AEP-55 tests, a test protocol could be utilized where a single pit is constructed and validated prior to conducting a survivability test. A standard target could be used to ensure that a specified impulse is obtained from the particular conditions within a prepared test pit. Based on the impulse measured with this standardized target and charge, the decision about whether acceptable conditions have been obtained can be made and the survivability test either conducted or a new test pit prepared.

Two potential sources of variability not specifically examined during these test that should be considered are the length of time between construction and testing within a pit and the soil moisture content. The infiltration rate of water into the specific local fill material will affect the formation of a moisture gradient within the soil if a saturated test condition is used. Thus a more consistent optimum moisture content based on ASTM D698 is recommended. Test pit age should also be limited as moisture may be gained or lost from the air and surrounding soil, and density will likely change due to natural freeze/thaw or wetting/drying cycles. As determined during these tests, the soil moisture content plays a significant role in the impulse imparted on a target.

CONCLUSION

Ensuring repeatable test conditions from buried charges requires careful control of soil moisture and density. Even with the same soil material prepared in the same manner, the variation in impulse between tests was much smaller within a pit than between pits. The following are thus recommended for AEP-55 Volume 2 survivability tests:

- A test protocol should be considered where a test pit is prepared and the impulse imparted on a standardized impulse target confirmed prior to conducting AEP-55 Volume 2 survivability tests within the same pit.
- Owing to better repeatability, it may also be desirable to use C4 rather than TNT.
- Test pit age should be limited, to reduce the effects of natural freeze/thaw and wetting/drying cycles on moisture content and soil density.
- An optimum moisture content and density target should be established for the specific soil used on a test site.

The combination of these four recommendations should reduce the uncertainty in repeatability for buried charge testing, while allowing a test condition with realistic soil to be used to validate vehicle survivability.

REFERENCES

[1] NATO Standarisation Agency, 2011, Protection Levels for Occupants of Armoured Vehicles, STANAG 4569

[2] NATO Standarisation Agency, 2011, Procedures for Evaluating the Protection Level of Armoured Vehicles: Volume 2 for Mine Threat, AEP-55 Volume 2

[3] Ceh, M., W. Roberts and T. Josey, 2016, Characterization of Buried Charge Loading: Examination of Level Two Charges, DRDC - Suffield Research Centre, DRDC-RDDC-2016-R043 (C)

[4] ASTM D698-12, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort

[5] ASTM D6938-10, Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

[6] ASTM D2167, Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method

[7] ASTM D4959, Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating

[8] Brown, D. Tracker, Open Source Physics.