Test, Measurement and Evaluation with the Mine Boot Test and Evaluation System

PM Ramaloko[*] JT van Dyk[**] E Smit[***]

[*]Landward Sciences, Defence Peace Safety and Security, CSIR, MeiringNaude Road, Pretoria, RSA.[**]CSIR retired.
[***]Veolia Water Technologies, Modderfontein.

Abstract

Protective footwear that mitigates the shock transferred to the victim's leg during an antipersonnel landmine blast need to be evaluated to verify their protection levels. The Mine Boot Test and Evaluation System which include a surrogate lower leg, the Test Measurement and Evaluation Support system and the Explosive surrogate, is such an evaluation system. In addition to the physical evaluation of the damage to the surrogate lower leg, the Test Measurement and Evaluation Support system measurements are used to evaluate and relatively compare the protective footwear.

Introduction

Antipersonnel landmines are designed to damage the victim's lower limb when detonated. These devices affect both military and civilian personnel indiscriminately. As such, there is a need for development of personal protective equipment (PPE) for military or humanitarian demining. A mine boot is one of such personal protective equipment. It mitigates the degree of shock transferred to the user's leg during an antipersonnel mine activation incident. The functionality of this mine boots needs to be tested to verify and compare its protection level.

The Mine Boot Test and Evaluation System (MBTES)

The CSIR designed a test jig called the Mine Boot Test and Evaluation System for test and evaluation of protective footwear for the lower extremity of the leg against the detonation of an antipersonnel mine directly underneath the victim's foot [1].The Mine Boot Test and Evaluation System was designed, developed, constructed and tested according to defined requirements specified in a System Specification. The system breakdown for the Mine Boot Test and Evaluation System is shown in Figure 1 [1].

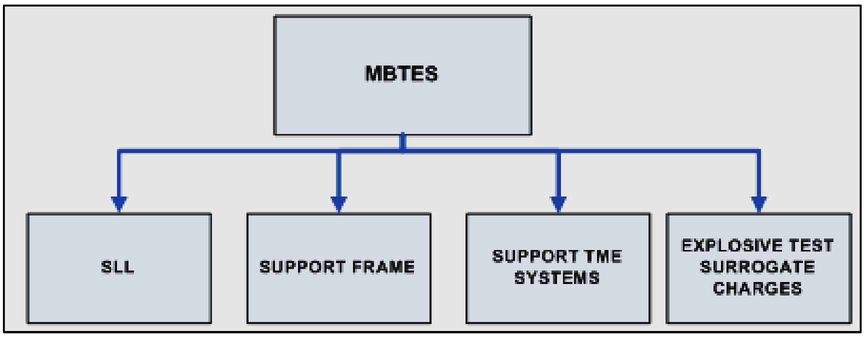

Figure 1: System breakdown for the Mine Boot Test and Evaluation System.

During a test using the Mine Boot Test and Evaluation System, an explosive surrogate test charge is detonated underneath the heel of the CSIR designed and manufactured instrumented surrogate lower leg (SLL) fitted to the Mine Boot Test and Evaluation System. To determine the degree of protection rendered by a specific protection concept, zero protection levels are established by using the surrogate lower leg with no footwear protection fitted. Experimental protective footwear is then fitted to the surrogate lower leg, and measured levels compared to the zero level to compare protection values.

MBTES with the Test, Measurement and Evaluation (TME) Support System [2]

The test, measurement and evaluation (TME) system interface with the Mine Boot Test and Evaluation System was evaluated during the baseline test of the surrogate lower leg. The time of arrival of the shockwave through the surrogate lower leg was measured using coaxial polyvinylidene fluoride (PVDF) sensors instrumented at fourteen different positions within the surrogate lower leg. Vertical displacement of the surrogate lower leg is measured by the linear displacement measurement (LDM) system, drag rings at the top of the frame and a medium speed camera. The vertical velocity of the surrogate lower leg is measured with a velocity barrel at the top of the frame and the surrogate lower leg is weighed down with a mass of 65 kg to represent the mass of an average human. The typical layout of the test setup of the Mine Boot Test and Evaluation System with the test, measurement and evaluation support system is illustrated in Figure 2.

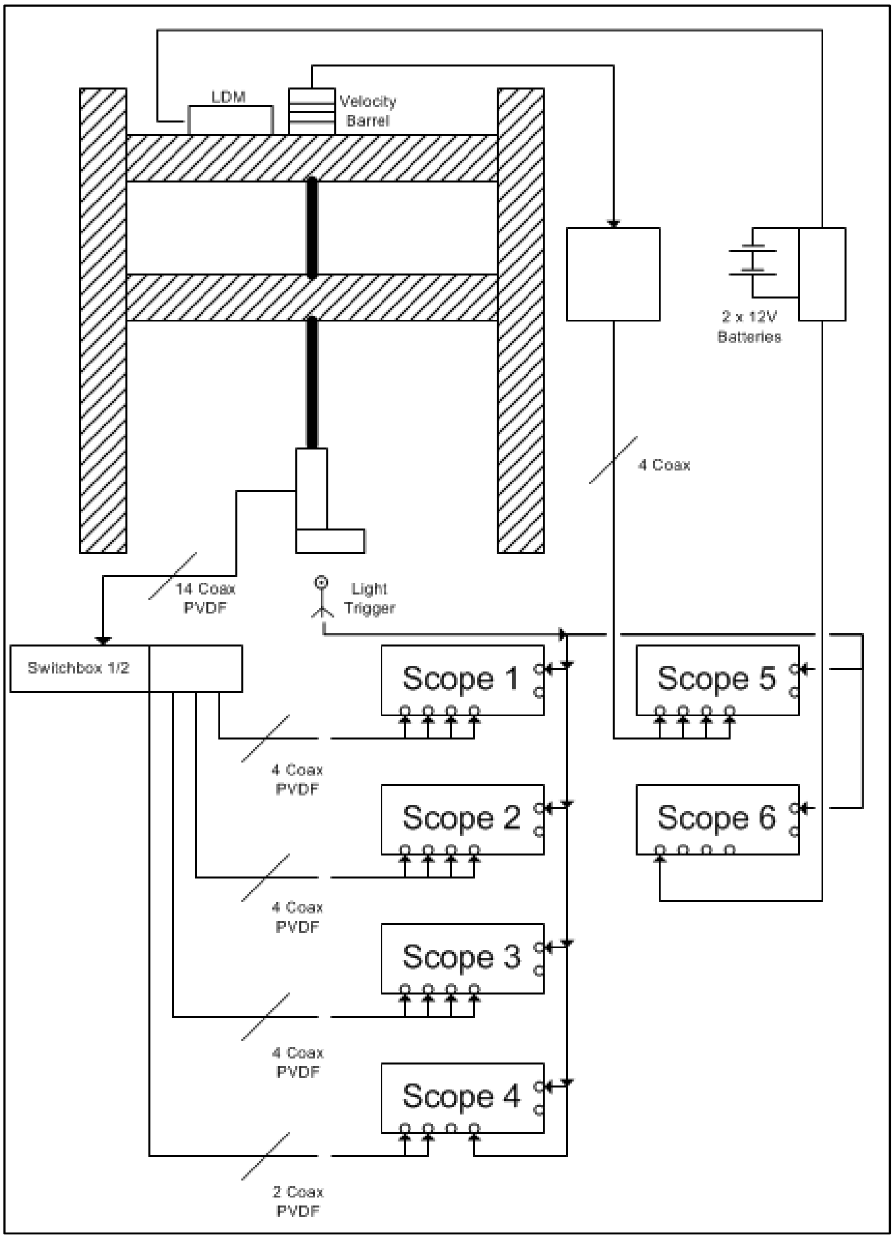

Figure 2: Test setup layout of the Mine Boot Test and Evaluation System with the Test, Measurement and Evaluation support system

Figure 3 shows the surrogate lower leg fitted under the Mine Boot Test and Evaluation System.

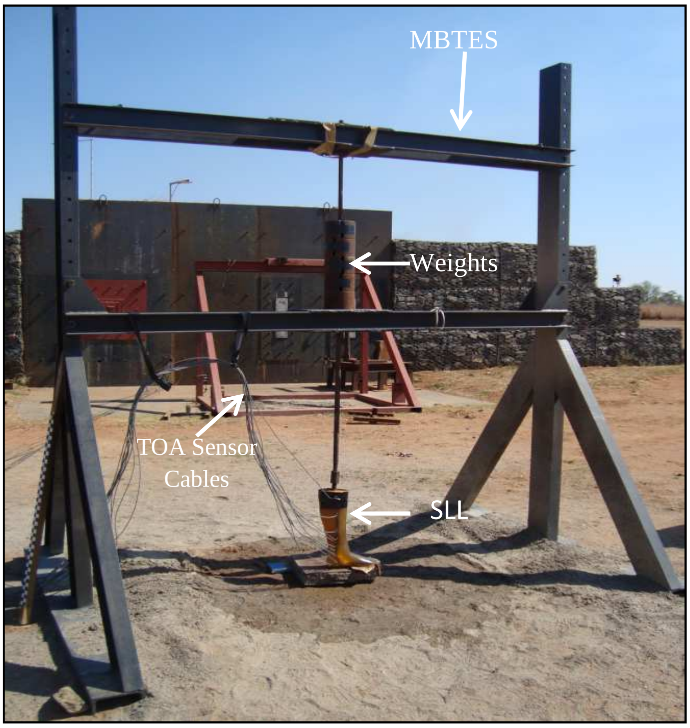

Figure 3: Mine Boot Test and Evaluation System with the surrogate lower leg fitted

Figure 4 shows the positions of the time of arrival sensors in the surrogate lower leg schematically (left) and instrumented (right).

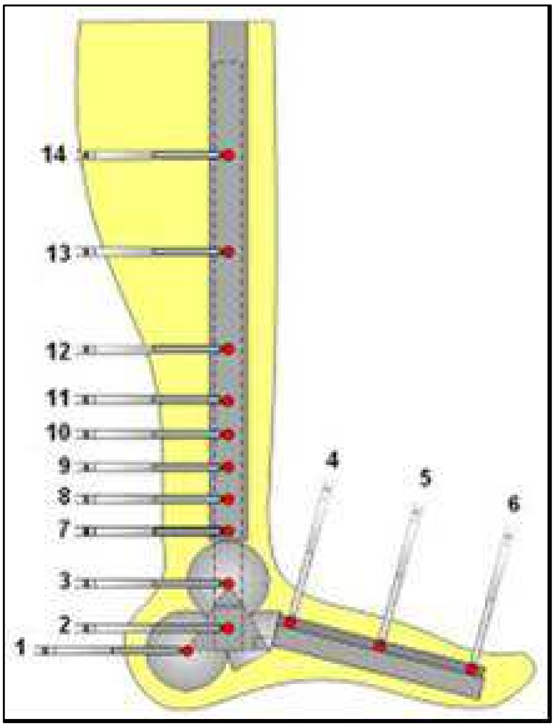

Figure 4: Positions of the PVDF Sensors in the surrogate lower leg schematically (left) and with the Sensors Fitted (right).

The recorded time of arrival signals are used to calculate the shock velocity profile in the tibia of the surrogate lower leg. The breakpoint of the sensor occurs in the region where amputation is required in the lower leg. Tissue damage is expressed as the percentage volume reduction of the ballistic gel of the surrogate lower leg after the shot. A post mortem is conducted on the surrogate lower leg after the test by a combat surgeon, who determines the point of amputation and classifies the injuries in terms of the Mine Trauma Score.

The linear displacement measurement system and the velocity barrel are installed on the top of the Mine Boot Test and Evaluation System as shown in Figure 5.

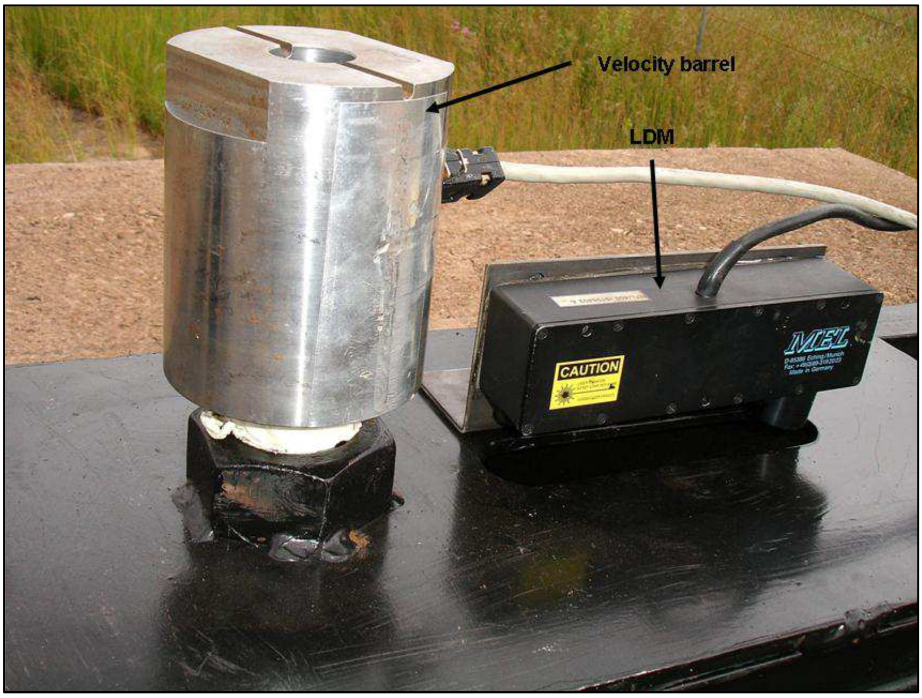

Figure 5: Velocity barrel and linear displacement (LDM) mounted on top of the frame.

All sensors used during the test were connected to the digital storage oscilloscopes and Graphtec, which can record faster and for longer duration. A light sensitive trigger was used as system trigger for the oscilloscopes and Graphtec to record data from all sensors. The signal from the trigger is time-0 of the event. Figure 6 shows the oscilloscopes used for data capture and the light sensitive trigger system.

Figure 6: Oscilloscopes and Graphtec used for Data Capture (left) and Light Sensitive Trigger System (right).

Small, medium and large surrogate anti-personnel land mine charges were used during the tests. These charges were manufactured using Pentolite to have an equivalent of 35g, 100g and 200g trinitrotoluene (TNT) respectively as listed in Table 1 for each test event and are shown in Figure 7. They were manufactured to represent the array of AP land mines encountered during operations.

Table 1: Surrogate Test Charges used during the Three Test Events

Charge Type	Pentolite [g]	TNT equivalent [g]	Test Event
Small	30	35	1
Medium	88	100	2
Large	180	200	3

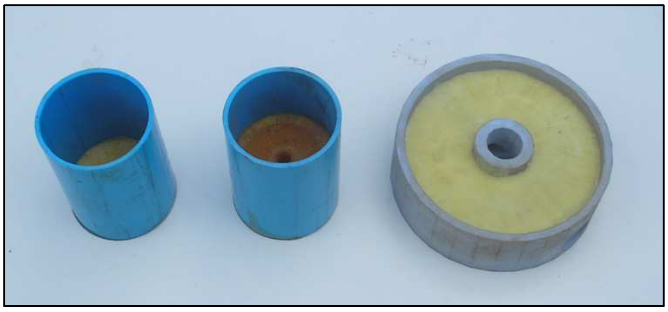

Figure 7: Explosive surrogate charges: 30 g (left), 88 g (centre), 180 g (right).

A Photron Fastcam APX-RS medium speed camera was used to record the test events and to also measure the vertical displacement by focussing on the drag rings fitted around the vertical shaft of the Mine Boot Test and Evaluation System.

Test Results

Figures 8**Error! Reference source not found.**, 9 and 10 show the recorded data for shots 1 (30 g), 2 (88 g) and 3 (180 g).The test, measurement and evaluation system could not record reliable Time of arrival data for Shots 1 and 2 (see Figures 8 and 9**Error! Reference source not found.** respectively) due to non-optimal triggering system. Time of arrival data was successfully recorded for Shot 3 and a shock profile could be established in the surrogate lower leg.

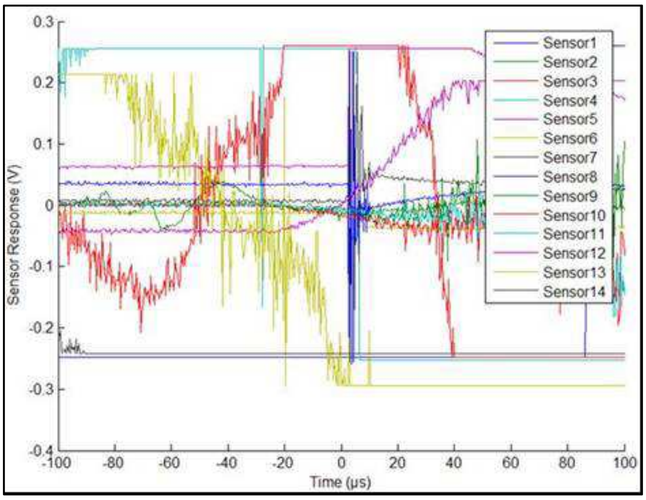

Figure 8: Recorded data for Shot No. 1 (30 g).

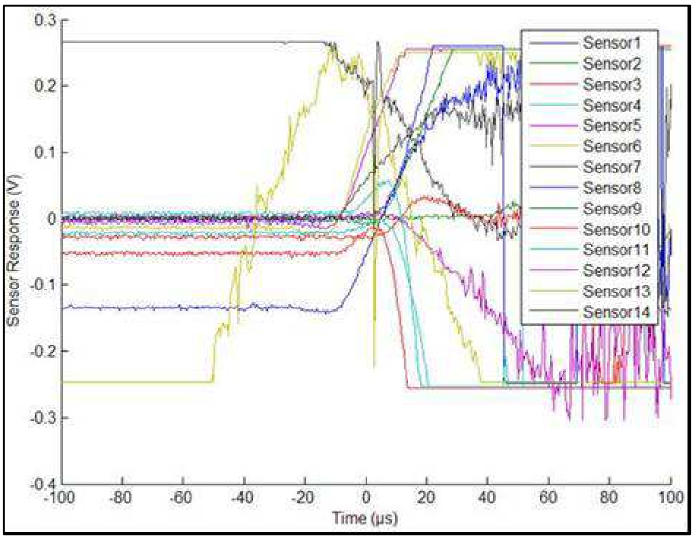

Figure 9: Recorded data for Shot No. 2 (88 g).

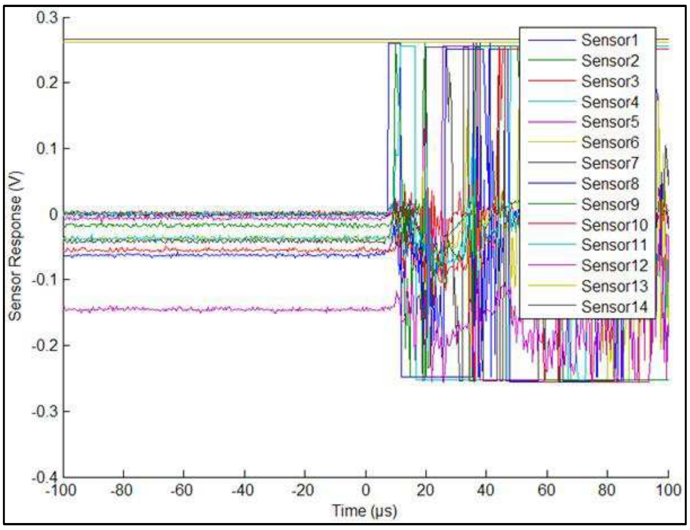

Figure 10: Recorded data for Shot No. 3 (180 g).

The arrival times of shots 1, 2 and 3 (see Figures 8, 9 and 10**Error! Reference source not found.** respectively) are given in Table 2. The recorded values for shots 1 and 2 are not useable.

Table 2: Arrival times for Shots 1, 2 and 3

	Arrival Times (µs)											
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
Shot 1	<-100	<-100	<-100	<-100	2.4	2.4	2.4	2.4	-28	-27.2	-20	-22.4
Shot 2	1.6	18.4	18.4	7.2	-10.4	-11.6	19.2	24.8	4.8	-8	-7.2	-3.6
Shot 3	7.2	8.4	12	8.8	24.8	49.6	18.8	25.6	35.6	43.2	55.6	82.8

The shock velocity profile along the surrogate lower leg for shot 3 was determined from Table 2. During the calculation, the recorded time of arrival of sensor 2 is used as reference point. The arrival times of every other vertical sensor (sensors 3, 7, 8, 9, 10, 11 and 12 – see Figure 4) are used with reference to sensor 2 to evaluate the shock velocity over the distance between those two sensors. Thus the complete length of the surrogate lower leg (see Figure 4) is used during this calculation resulting in values being less susceptible to inaccuracies in the measured distances between the various sensor positions. Results are given in Table 3.

Table 3: Estimated Shock Velocities within the Surrogate Lower Leg

	S2-S3	**S2-S7**	**S2-S8**	**S2-S9**	**S2-S10**	**S2-S11**	**S2-S12**
Distance between sensors (mm)	23.1	48.1	73.1	98.1	123.1	148.1	198.1
TOA between sensors (µs)	3.6	10.4	17.2	27.2	34.8	47.2	74.4
Shock Velocities (m/s)	6417	4625	4250	3607	3537	3138	2663

The shock profile through the surrogate lower leg for Shot 3 is shown in Figure 12.

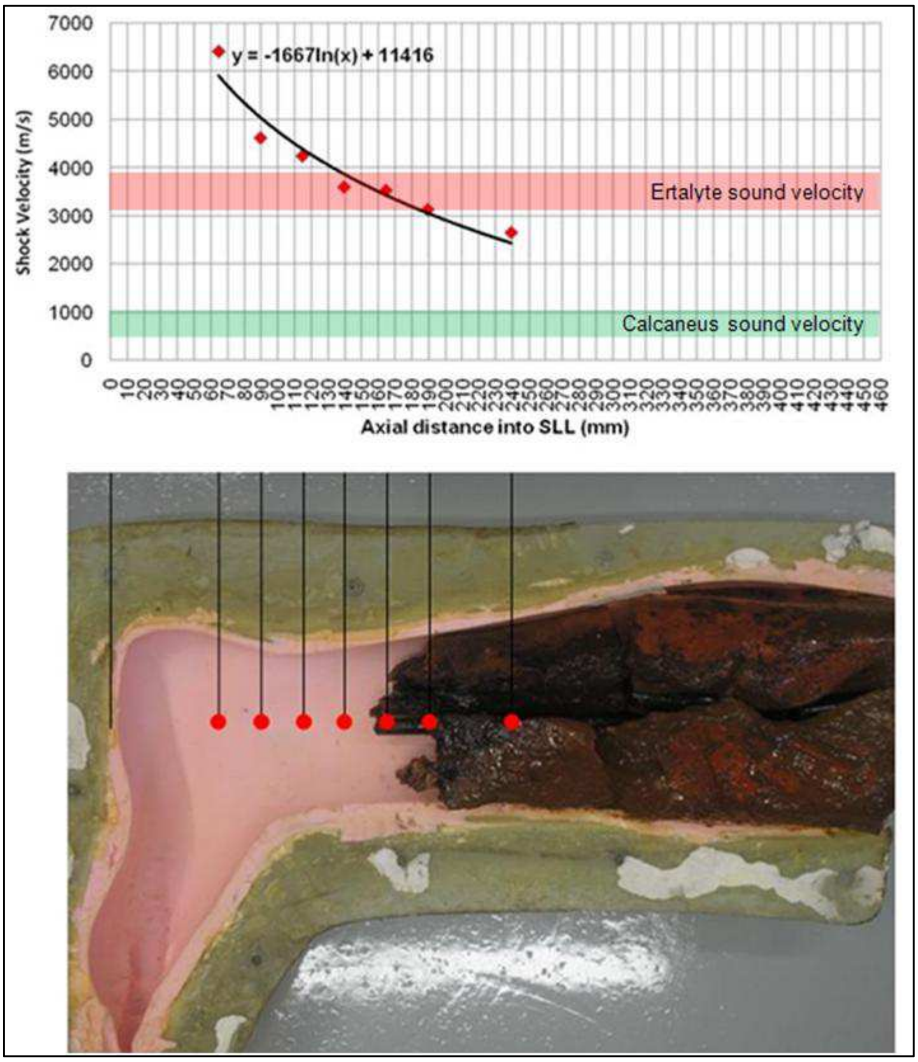

Figure 11: Shot 3 – Shock velocity profile through the Surrogate Lower Leg for Shot No.3

The test, measurement and evaluation system could not record the vertical displacement of the surrogate lower leg, since the linear displacement measurement system was saturated by the detonation light itself. Also the vertical movement was too small to be recorded by the velocity barrel. However, the high-speed camera was successful in measuring the displacement of the surrogate lower leg, and the small drag rings fitted to the vertical rod of the Mine Boot Test and Evaluation System recorded the maximum displacement. The vertical displacement could only be measured for Shots 2 and 3 and was recorded as 3 and 5 mm respectively. No displacement was measured for Shot 1 because there was very small movement resulting from the small 30 g explosive charge. These displacements correspond with imparted impulse values of 16 and 20 Ns for the 88g and the 180g Pentolite surrogate charges.

Discussion

The responses from the small charge (30g) were too small, making it difficult to discern the true time of arrival at sensor locations. This is despite the fact that the test, measurement and evaluation system could not record time of arrival data for shots 1 and 2 and the vertical displacement of the surrogate lower leg. The presence of the drag rings on the vertical rod assisted in obtaining the displacements for shots 2 and 3 and their resultant imparted impulse.

Conclusions

The interfacing of test, measurement and evaluation system to the Mine Boot Test and Evaluation System was successful even though some of the measurements could not be made. Measurements obtained were used successfully to evaluate the baseline surrogate lower leg for protective footwear (mine boot) evaluation. These measurements will be used on a comparative basis for the determination of the protection rendered to the surrogate lower leg for a particular protective system or boot. The use of the high-speed camera and drag rings to determine the vertical displacement of the surrogate lower leg proved to be successful. Successful test, measurement and evaluation measurements will enable experimentation with different boot parameters to evaluate protective footwear.

Looking forward, the linear displacement measurement system needs to be shielded from the detonation emitted light and the measuring sensitivity of the velocity barrel should be increased in order to measure small movements.

If the International demining fraternity (UNMAS, GICHD etc.) accepts this test method, it is foreseen that the Mine Boot Test and Evaluation System can be used for the testing of protective footwear on an international basis.

References

1. Van Dyk J T, PIRATE Technology Study: Test plan for the establishment of the 0-protection levels for the T&E of mine boots. GLCO-0CPIR-10-031 Rev 01.
2. Van Dyk J T, Smit E. PIRATE Technology Study: Report on the establishment of the 0-Protection Levels as acceptance criteria for the testing of mine boots. GLCO-0CPIR-10-032 Rev. 01