Measurement of impulse generated by the detonation of anti-tank mines by using the VLIP technique.

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Abstract

The impulse generated by the detonation of anti-tank mines is an important characteristic of the mine used to design and develop protective countermeasures and to define the threat in terms of scientific and engineering terms. CSIR in collaboration with CTRO conducted explosive testing to determine the impulse generated by anti-tank mines. Testing was conducted in two phases. Phase 1 occurred during September 2008 in Croatia. The Vertical Launched Impulse Plate (VLIP) technique was used to measure the impulses generated by the TMA-3 and TMRP-6 anti- tank mines. The test data resulting form these tests were used to establish empirical formulas to determine the impulse generated by anti-tank mines.

These formulas were used to predict impulse values for a number of anti-tank mines. Phase 2 was completed in the RSA during March 2009 where the impulse values of these mines were established by using the VLIP technique. The measured values correlated closely with the predicted values.

Introduction

The impulse of an anti-tank mine detonating underneath a target at a given distance is an important characteristic used to asses the threat that anti-tank mines pose to vehicles. Impulse values can not be calculated accurately with current computational and simulation methods-especially when the effects of soil on top of the mine and other mine debris have to be considered as well. Empirical test data have to be accumulated and used in the design of protection systems to counter the threat.

CSIR Landwards Sciences (LS) [1] identified and defined the following threat levels that mines and UXO pose to Landward Forces and Humanitarian Demining entities.

Table 1: Mine and UXO Threat Level definition.

MTL	Description	Typical examples
MTL-01	A/P mine blast type	PMN, PMD-6, Type 72
MTL-02	A/P mine shrapnel type	POM-Z, OZM-4, OZM-72, PROM-1
MTL-03	UXO small size	Hand grenades, rifle grenades a/c bomblets
MTL-04	**A/T blast type**	
MTL-04A	A/T blast under wheel	TM46, TM57, TMA-3
MTL-04B	A/T blast under hull	TM46, TM57, TMA-3
MTL-05	UXO medium size (mortars and artillery rounds)	60-120 mm Mortar. Artillery rounds up to 155mm
MTL-06	A/T HC	AT-4
MTL-07	**A/T SFF**	**TMRP-6, TMRP-7, TMK-2, UKA-63**
MTL-08	UXO heavy size	250-500 kg a/c bombs, sea mines

[1] Landwards Sciences is a competency research area within the Defense Peace Safety and Security Research Unit within the CSIR.

LS has developed the VLIP method to conduct such tests in order to characterize the various mine types and gain some understanding of the impulses that is imparted on to targets above detonating mines. [1]. Of particular interest is the impulse generated by SFF type anti-tank mines (Threat Level 07). It is expected that the detonation of these mine types would result in higher impulse values than those of the normal blast type anti-tank mines (TMA-3, Threat Level 04). Typical examples of the SFF type mines are the TMRP-6 (Yugoslav) and UKA-63 (Hungarian). LS has further established international cooperation with HCR-CTRO in Croatia in order to conduct collaborative testing due to the availability of TMRP-6 anti-tank mines in Croatia as well as the availability of suitable test facilities and technical support rendered by CTRO and Croatian Industry.

The VLIP method

The VLIP method for measuring impulse uses a thick steel plate with a steel mast that is accelerated as a unit vertically by the detonation of an anti-tank mine underneath the plate. (Figure1). The velocity of the plate during its vertical displacement and the mass of the plate are required to determine the impulse that is imparted to the plate.

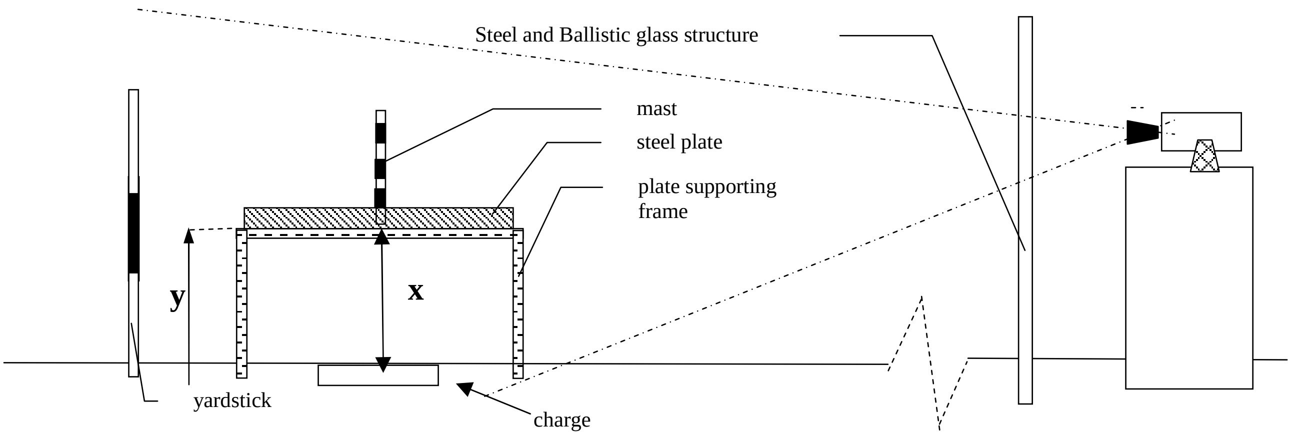


Figure 1: Schematic layout of VLIP method.

Impulse equals a change in momentum and the initial momentum is zero, therefore the following formula is valid:

$$I = mv \qquad \text{(i)}$$

Where m is the mass of the plate [kg] and v, the velocity [m/s] of the plate at any given position. The mass of the plate is known as it is weighed for each of the experiments prior to the tests in the workshop. The velocity of the plate is determined using video footage from a medium speed camera. The tip of the mast is used to track the upward distance traveled in order to create a distance (x) vs time (s) curve. Velocity is obtained by differentiation of this curve.

PHASE 1 Testing (Croatia)

Testing was conducted at the HCR-CTRO test facility at Cerovac on the outskirts of Karlovac in Croatia on 3 and 4 September 2008. Technical support and manufacture of the VLIP test plates were conducted by Dok Ing D.o.o. All tests were conducted in accordance with the Test Instruction issued by HCR-CTRO. A medical team consisting of a medical doctor, nurse and ambulance driver as well as an ambulance was present on the range during testing. An Olympus D medium speed camera was used to record the movement of the vertical pole during and directly after the detonation. Recording was done at a speed of 5 000 frames per second. Normal digital cameras were used to capture still images of the test procedure. TMRP-6 and TMA-3 anti-tank mines were used during testing.

Figure 2 shows typical high-speed film extracts from one of the explosive events.

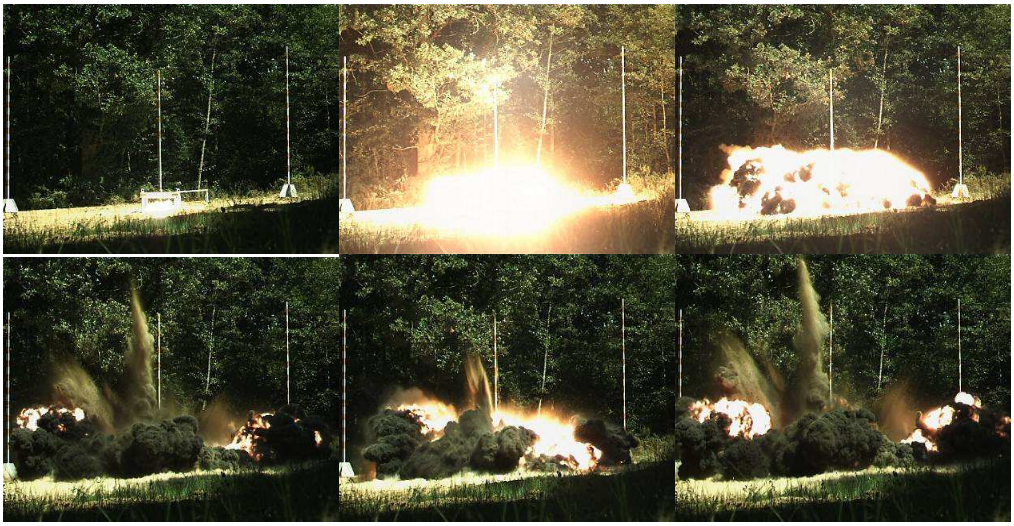
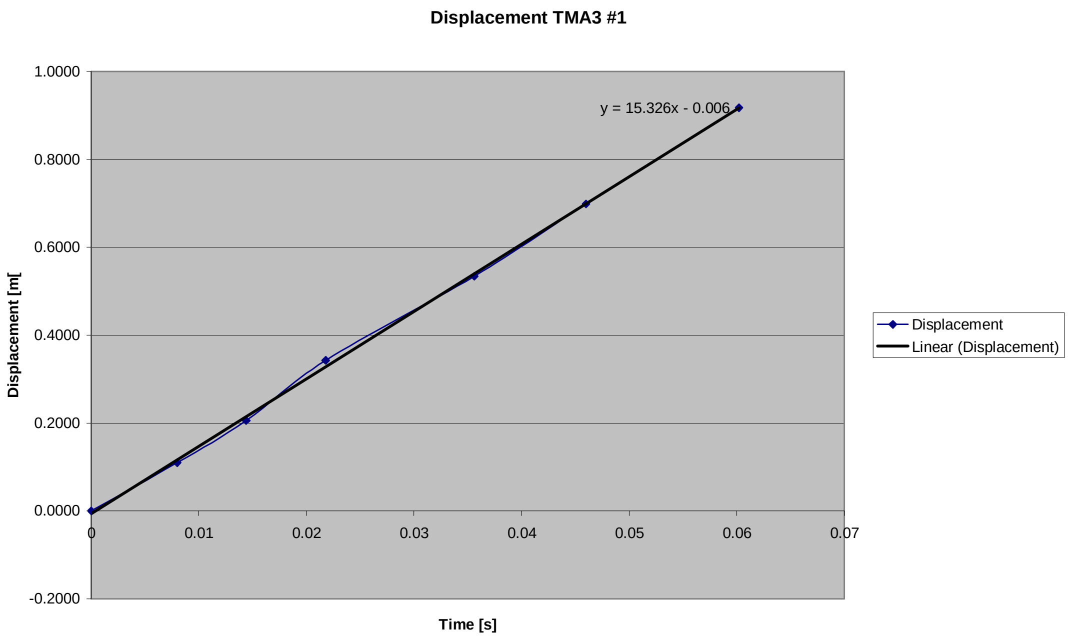
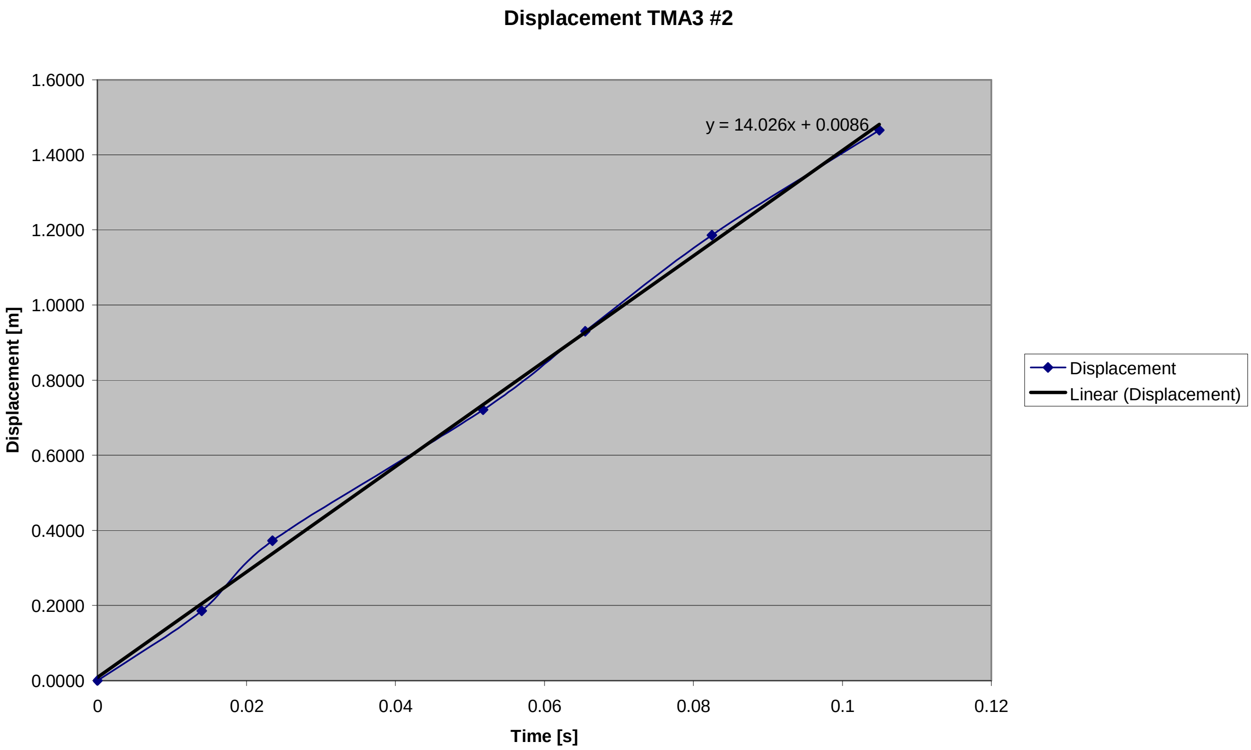


Figure 2: High speed extracts from explosive event.

The distance-time curves that resulted from these tests are shown in Figure 3.


Displacement TMA3 #1
y = 15.326x - 0.006
1.0000
0.8000
0.6000
0.4000
0.2000
0.0000
-0.2000
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
Displacement [m[
Time [s]
Displacement
Linear (Displacement)


Displacement TMA3 #2
y = 14.026x + 0.0086
1.6000
1.4000
1.2000
1.0000
0.8000
0.6000
0.4000
0.2000
0.0000
0
0.02
0.04
0.06
0.08
0.1
0.12
Displacement [m]
Time [s]
Displacement
Linear (Displacement)

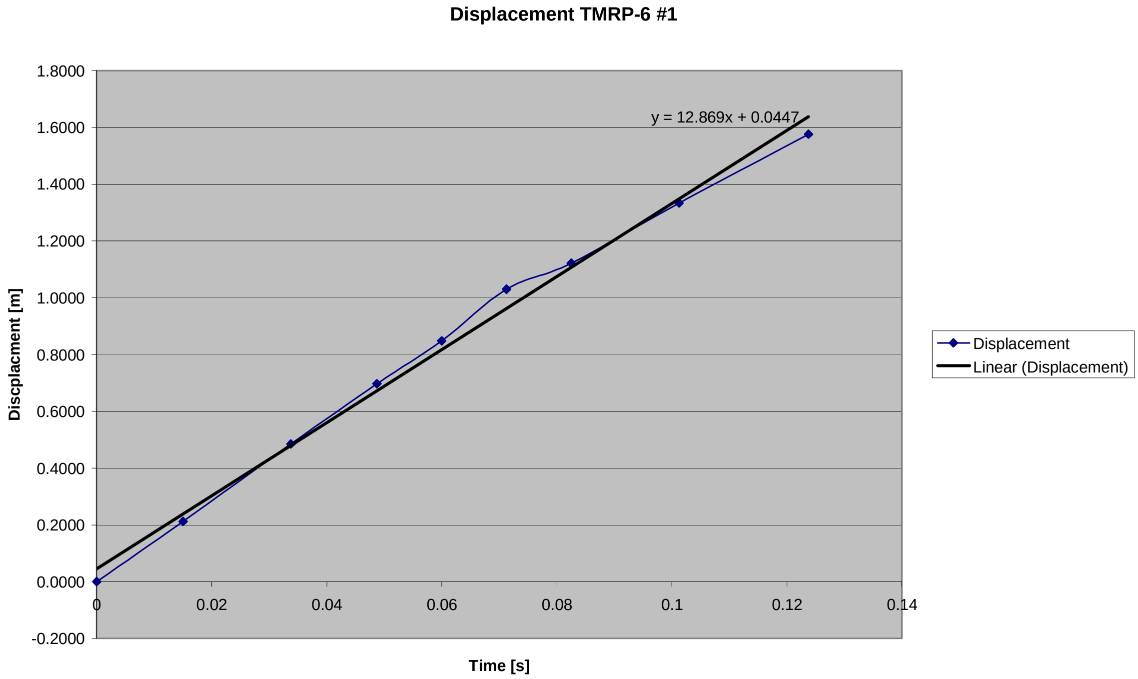


Figure 3: Displacement (x)-time (t) curves for TMA-3 and TMRP-6 mines.

The test results are summarised in Table 2.

Table 2: Summary of test results.

Test event	Explosive charge		VLIP Mass (kg)	Measurements	
	Type	NEC (kg)		Velocity (m/s)	Impulse (kNs)
1	TMA-3	6.5	1310	15.32	20.33
2	TMA-3	6.5	1310	14.026	19.96
3	TMRP-6	5.1	1310	No recording	No recording
4	TMRP-6	5.1	1310	12.869	16.86

The values in Table 2 shows that the average impulse value (20.15 kNs) for the TMA-3 mine is considerable higher that the impulse measured for the TMRP-6 mine (16.86 kNs). However, while the TMA-3 generates a higher impulse than the TMRP-6 during detonation, it only causes damage to a target (vehicle) in the 500 mm region above the target through the combination of shock and blast effect. The TMRP-6 causes more damage to unprotected targets (vehicles) in the same region due to the ballistic effect associated with the SFF generated during the detonation of the mine as well as the associated shock and blast effect. The TMRP-6 is therefore rated as a higher threat (Level 07) than the TMA-3 a/t mine (Level 04).

Thus, in order to compare the different impulse values more accurately, the effect of explosive contents should be considered as well. Thus if weighted impulse is defined as the netto impulse value divided by the NEC (netto explosive contents), the weighted impulse values are summarised in Table 3.

Table 3: Summary of weighted Impulse values.

Mine Type	NEC (kg)	Impulse (kNs)	Weighted Impulse (kNs/kg)
TMA-3	6.5 (TNT)	20.15	3.1
TMRP-6	5.1 (TNT)	16.86	3.3

The values in Table 3 can be used to establish the following relationship between NEC (TNT based) of a particular mine type to give a rough estimate of the impulse expected against a target (vehicle) within the 500 mm region above the mine (mine not covered with soil):

For blast type mines: $I = 3.1\ M$ (ii)

Where I is the impulse (kNs)

M is the NEC (TNT) in kg

For SFF type mines: $I = 3.3\ M$ (iii)

Where I is the impulse (kNs)

M is the NEC (TNT) in kg

Where the mine is filled with explosives other than TNT, the TNT equivalent values as determined by Petes [2] can be used. Thus equations (ii) and (iii) are adapted to include the TNT equivalent value as follows:

For blast type mines: $I = 3.1\ M\ A$ (iv)

Where I is the impulse (kNs)

M is the NEC (TNT) in kg

A is the TNT equivalent value

For SFF type mines: $I = 3.3\ M\ A$ (v))

Where I is the impulse (kNs)

M is the NEC (TNT) in kg

A is the TNT equivalent value

Equivalent values (A) for some explosive types are summarised in Table 4.

Table 4: TNT equivalent values.

Explosive type	TNT equivalent for impulse (A)
TNT	1.00
RDX/5% wax	1.16
Comp B	1.06

Explosive type	TNT equivalent for impulse (A)
Torpex	1.28
Pentolite (TNT/PETN: 50/50)	1.15
Minol ii	1.22

Thus the following impulse values are predicted for the mine types listed in Table 5.

Table 5: Prediction of Impulse values for various mine types.

Mine Type	NEC (kg)	Predicted Impulse (kNs)
TM-46 (blast)	5.3 (TNT)	16.43
TM-57 (blast)	6.5 (TNT) 7 (Torpex)	20.15 27.78
TM-62B (blast)	7.01 (TNT) 7.57 (Torpex)	21.73 30.04
TM-62M (blast)	7.46 (TNT) 8.06 (Torpex)	23.10 31.98
UKA-63 (SFF type)	6 (TNT)	18.60

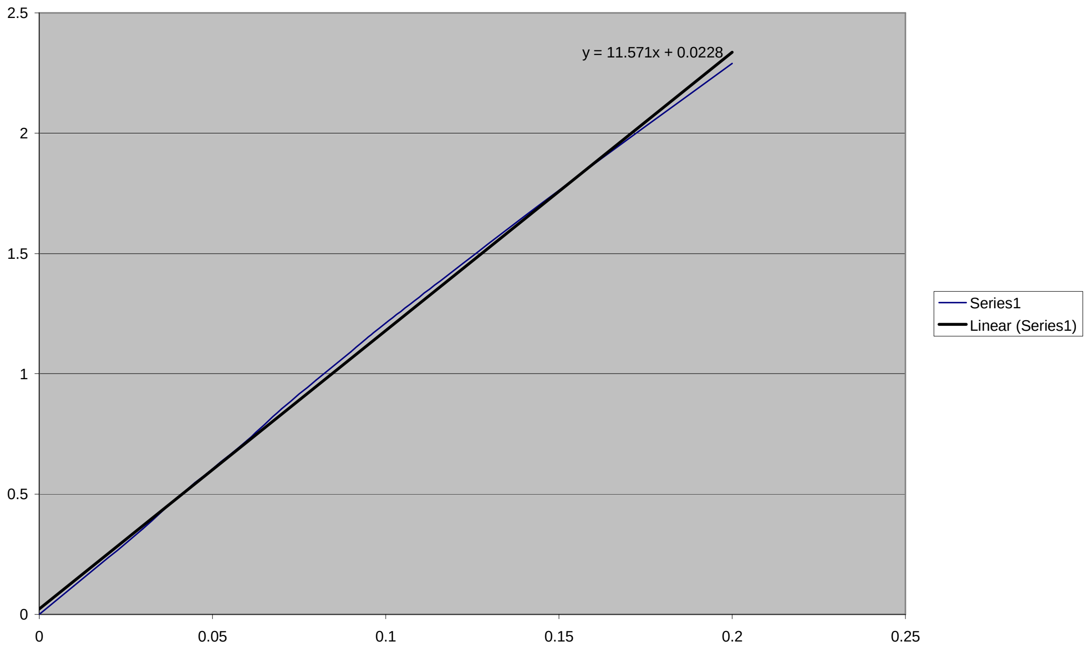
Phase 2 Testing (Rep. of South Africa)

Testing was conducted at LS explosive test range at Paardefontein outside Pretoria on 9 and 10 March 2009. Testing was conducted with the TM-46, TM-62M and TM-62B blast anti-tank mines. The VLIP method was used in a similar fashion as the tests conducted in Croatia. The test results are summarized in Table 6.

Table 6: Summary of test results.

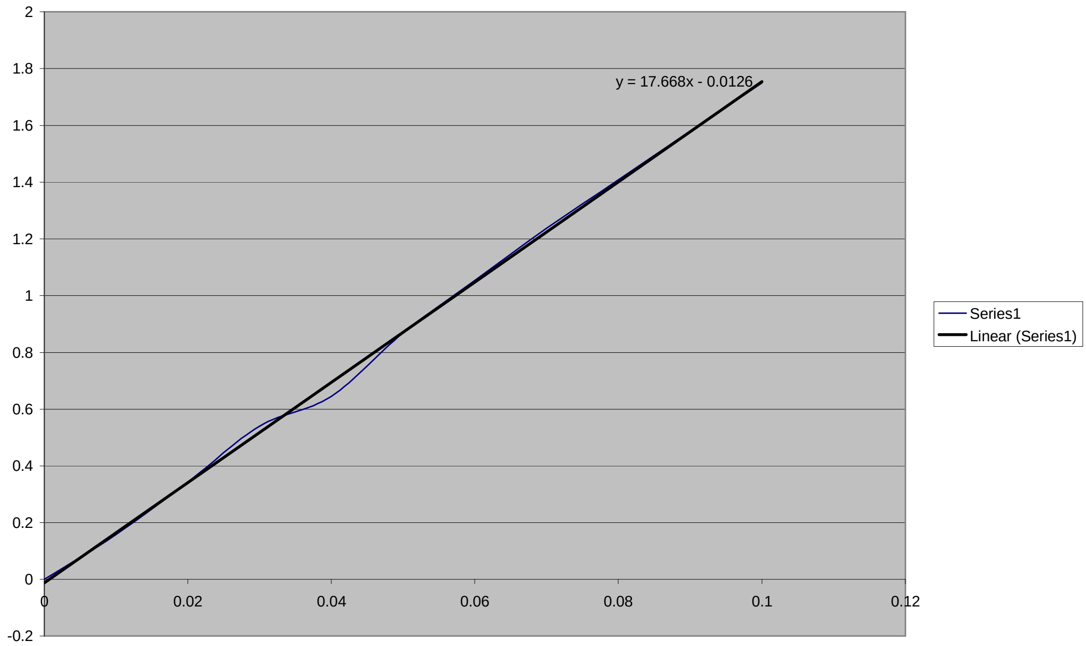
Test event	Explosive charge		VLIP Mass (kg)	Measurements	
	Type	NEC (kg)		Velocity (m/s)	Impulse (kNs)
1	TM-46	5.3 (TNT)	1262	11.57	14.6
2	TM-62M	7.46 (TNT)	1250	17.67	22.1
3	TM-62B	7.01 (TNT)	1247	16.99	21.2

The displacement (x)-time (t) curves for the various tests are shown in Figure 4.



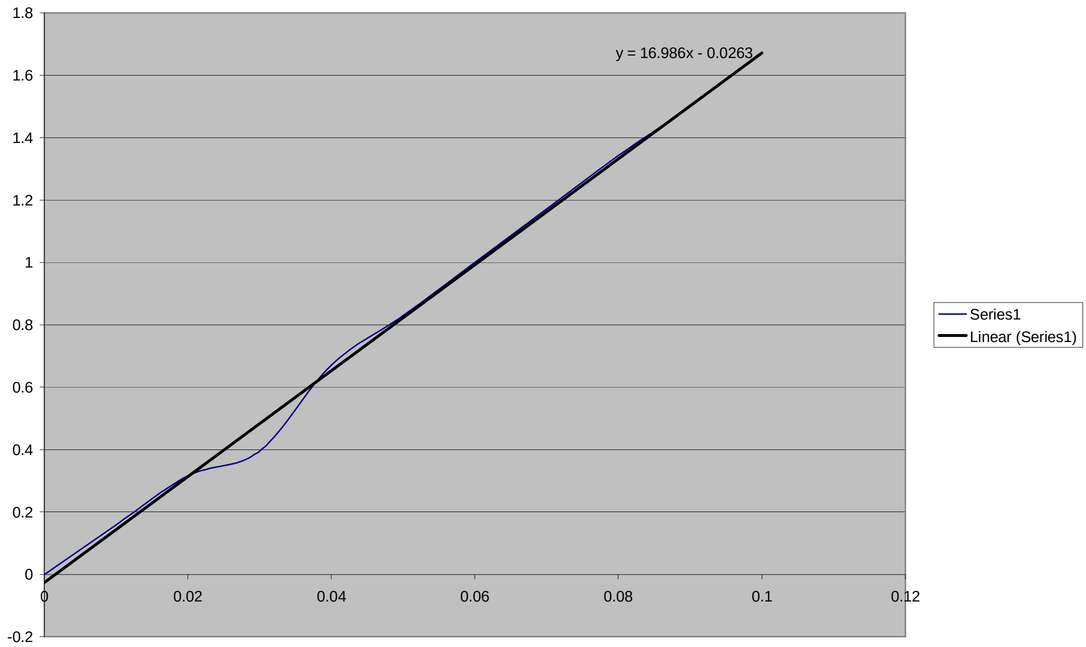
y = 11.571x + 0.0228
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
Series1
Linear (Series1)

TM-46



y = 17.668x - 0.0126
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.02
0.04
0.06
0.08
0.1
0.12
Series1
Linear (Series1)

TM-62M



TM-62B

Figure 4: Distance-time curves for the TM-46, TM-62M and TM-62B mines.

Table 7 shows the comparison between the calculated and measured impulse values for the TM-47, TM-62M and TM-62B anti-tank mines.

Table 7: Comparison between calculated and measured impulse values.

Mine Type	**Impulse (kNs)**	
	Calculated	**Measured**
TM-46	16.43	14.6
TM-62M	23.10	22.1
TM-62B	21.73	21.2

Conclusions

The calculated impulse values for the mines as shown in Table 7 correlates sufficiently with the measured values to validate the use of the empirical equation for the calculation of impulse generated by blast type anti-tank mines.

This test programme must be extended to include testing of SSF type anti-tank mines in order to validate the second empirical equation.

Testing should also be conducted with mines buried at various depths in the soil to determine soil factors that should be added to the existing equations.

References

[1] Smith P, Mostert F, Snyman I M. Comparison of methods to measure the blast of an explosive charge. 24th International Symposium on Ballistics, New Orleans. 2008.

[2] Petes J. Blast and fragmentation characteristics. US Naval Ordnance Laboratory White Oak. Silver Springs MA. Annals New York Academy of Sciences