Applying Buried Mine Blast Loads to a Structure Utilizing the User Module Capability

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Abstract

Developing armored vehicles to withstand a buried mine blast is a challenging task. The development of solution with optimum trade-off between mobility and survivability cannot be done by trial and error alone. The development of reliable CAE model of the vehicle and threat, using a simulative tool, is essential.
In the early design phase, extensive use of simulation is done to optimize the structure. This process requires a short turnover time for the simulations. Use of ALE or Particle Blast can give good results but involves long runtimes. On the other hand, using Load Blast (ConWep) or Initial Impulse Mine is fast and simple.
Initial Impulse Mine works by applying initial velocity on selected elements. The unselected elements have initially zero velocity. This velocity discontinuity can lead to unreasonable results.
The aim of the Load Blast is to simulate an air blast, but it is not designed to simulate buried mines. It is possible to calibrate Load Blast to get the correct peak pressure or the local impulse, but not both. Further, it is impossible to change Load Blast spatial pressure distribution.
In this work a new user-defined module was implemented. This ConWep-like user loading enables the simulation of a buried mine explosion by modification of pressure distribution via a shape function. Using this technique a better pressure and momentum distribution over the target can be achieved with running times similar to **`*LOAD_BLAST_ENHANCED`** *(ConWep). The new module is implemented in FORTRAN and is activated using the* **`*USER_LOAD_SEGMENT`** *keyword. The compiled module is activated in the LS-DYNA® deck by using the new* **`*MODULE_LOAD`** *keyword. The use of the new solvers with dynamic loading of modules enables our simulation team members to use this code easily and to issue new versions of the module as needed.*

1 Introduction

The spatial properties of a mine blast may be affected by many variables such as charge mass, charge geometry, initiation point, location of charge above or under the ground, soil properties and others [8]. Another important factor that affects the blast results is whether the target is in near-field or far-field. In buried mine at far-field, the blast front is spherical and uniform, with temporally decaying pressure. For this situation the semi-empirical predictors of Kingrey and Bulmash give good correlation, and can be used with no modification in computer codes. On the other hand, in near-field, the target is close to the blast, and can experience loads from blast products, soil ejecta and crater focus, as presented in Figure 1. This leads to highly temporal and spatial loads, therefore less suitable to use with Kingrey and Bulmash predictors [10].
In order to measure mine impulse magnitude and its spatial distribution, different technics are available. Some of them are: impulse pendulum [4], Impulse plugs [5], blast deflectors [12], momentum gauges [7] and Hopkinson pressure bars [3]. Of these, the impulse pendulum can measure only total impulse imparted by the mine, while the rest of the methods can be used to measure the spatial distribution of the impulse.
The momentum gauges method [7] is easy to reproduce and simulate, even with a full scale blast.
The ConWep subroutine implemented in LS-DYNA® (as **`*LOAD_BLAST`**) calculates the pressure distribution of blast load on a set of segments. The spatial distribution of the blast load is spherical, as ConWep varies the times and pressures only [9], but the buried mines behave, as explained above, differently than air or surface blasts, as the spatial distribution is not spherical and the energy is more “focused”, similar to an egg shape. MM-ALE and discrete particle simulations achieve the desired result, but the running time is much longer than using **`*LOAD_BLAST`**.

Fig.1: Shape of sand bulging created by explosion of 50gr C4, buried 100mm underground. Plasan internal test, high speed video.

In order to take advantage of the **`*LOAD_BLAST`** running time, without compromising on the spatial pressure and impulse distribution, we have written a FORTRAN code based on the load blast, that allows the user to change the spatial distribution of these parameters. The code was implemented in LS-DYNA by using the LS-DYNA subroutine **`loadsetud`** and the new MODULE functionality. By using the new MODULE functionality of LS_DYNA® V9, it becomes trivial to compile and use the user subroutine, since one does not need to compile the solver again, but only the required subroutine.

Momentum plate simulations were done to calibrate the new user defined load model according to the experiment described by Held [7]. Three other common LS-DYNA methods to simulate blast, MM-ALE, Initial impulse mine and load blast were used to simulate this experiment.
The results of the common blast simulations and the user defined load were compared to the test results as described by Held.

2 User defined load

A user defined **`loadsetud`** subroutine was written in FORTRAN code [1], thus enabling us to change the peak pressure, time duration and the impulse, as well as the spatial distribution of these variables.
Calculation of Time of Arrival, Reflected and Incident Peak overpressure, Positive time duration and Reflected and Incident Impulse are done with Equation (1):

$$Function = Exp\left[A + B \cdot Ln(Z) + C \cdot Ln(Z)^2 + D \cdot Ln(Z)^3 + E \cdot Ln(Z)^4 + F \cdot Ln(Z)^5 + G \cdot Ln(Z)^6\right], \quad (1)$$

where A, B, C, D, E, F and G are the coefficients related to the function type (i.e. TOA, Reflected peak overpressure etc.), and Z is the scaled distance according to Equation (2):

$$Z = \frac{R}{\sqrt[3]{W}}, \quad (2)$$

where R is the range from blast location (o) to point of interest (p) in [m], and W is the charge mass in [Kg] of TNT [11].
The Time of Arrival (TOA), Reflected Peak Overpressure (P_{Ref}), Positive Time Duration (TD) and Reflected Impulse (I_{Ref}), were scaled by multiplying each in an independent hyperbolic tangent that depends on the planar distance of point of interest (p) from blast origin (o), and is further multiplied by a factor. This allows the user control over the spatial scaling of the function as a relation to the planar distance. For example, the pressure can be scaled by

$$P_{new} = P \cdot \tanh(p(x, y) - o(x, y)) \cdot factor\,. \quad (3)$$

Figure 2 (left) shows the results of (1) for pressure at a certain point in time, and (right) the results after adding the spatial factors as in (3).

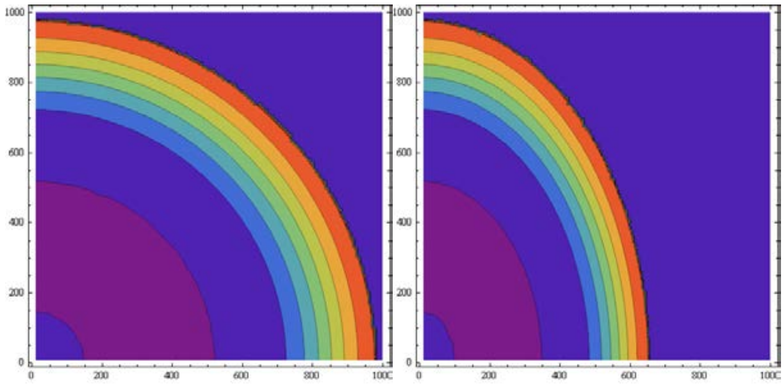

Fig.2: Left: Pressure field by using Equation (1). Right: Pressure field by using Equation (3).

The pressure time dependency was calculated by the use of Friedlander equation

$$P(t) = P_{\max} e^{-\alpha t} (1 - \frac{t}{TD}) , \tag{4}$$

where $P_{\max}$ is peak pressure, α is decay coefficient, t is time and TD is positive time duration. As in Load Blast, the pressure acting on an element is a ratio between reflected and incident pressure, that depends on the orientation angle θ of the element to blast location

$$P = P_{reflected} \cdot \cos^2\theta + P_{Incident} \cdot (1 + \cos^2\theta - 2\cos\theta) . \tag{5}$$

To get an element pressure time history, the code goes through the following steps:

1. *Find the distance of the element center from the blast origin*
2. *Calculate scaled distance Z relative to blast origin and charge mass*
3. *Find TOA, P_{Ref}, P_{Inc}, TD, I_{Ref} and I_{Inc} related to that element, and multiply by spatial factors*
4. *Calculate decay coefficient*
5. *For each time step Fridlander's Eq. (4) is solved for current time T*
6. *Calculating current pressure with respect to element orientation with Eq. (5)*

3 The Calibration Model

In order to calibrate the new user defined load, in a way that will show the spatially distributed momentum, the momentum plates experiment described by Held [7] was chosen, since it is a well-documented test procedure which is easy to replicate and to model. The experiment consists of blast charge of a 5kg explosive cylinder with a ratio of one to three between height and diameter. Burial depth of the explosive is 100mm. As the soil was said to be sand with no further reference, dry sand was assumed. To measure the vertical impulse, momentum plates with dimensions 25mm x 100m and different heights and weights were placed next to each other on long steel bands, 500mm above ground. The velocities of the plates in the vertical direction were measured, and by multiplying them with the plates masses the individual momenta could be calculated.
The test facility was modeled by Lagrangian formulation and presented in Figure 3. The Steel bands and momentum plates were modeled with solid elements. The Element size was 6.25mm and ratio close to 1 for momentum plates was set. 0.5mm gap between each plate was set. The total length of the steel band is 1500mm. The steel bands were fixed in space with SPC at both ends. A body load of 1g for gravity was applied. Single surface contact between all parts was assigned.

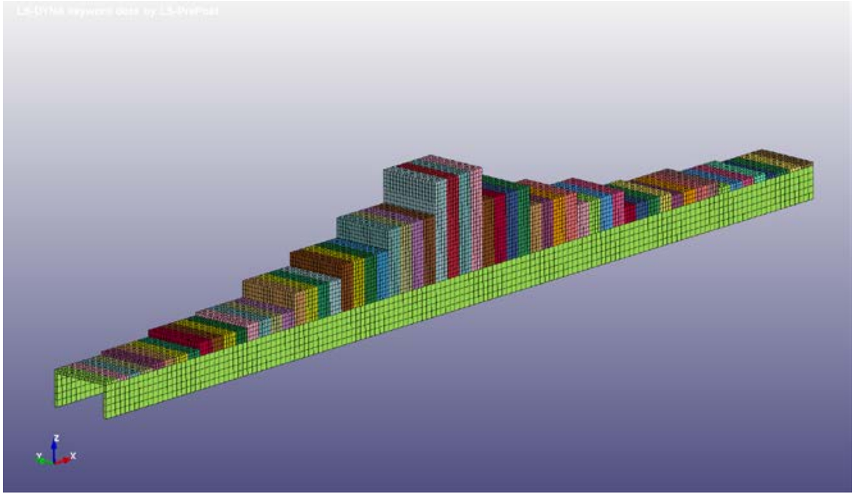

Fig.3: Lagrangian Model. Momentum plates on steel bands

In addition to the calibration of the new user defined subroutine, three different simulations were done with the other built-in methods of LSDYNA for buried blast simulation - MM-ALE, Load Blast scaled and initial impulse mine.

The parameters for the calibration of simulations impulse were taken from Plasan internal report, comparing buried mine impulse exerted on Mine Impulse Pendulum for different soils and saturation levels to different simulation technics. The parameters were chosen to fit the experiments of dry sand (0-35% saturation) [2].

3.1 MM-ALE model

The MM-ALE numerical model is depicted in Figure 5. The MM-ALE model includes the Lagrangian model, and an MM-ALE computational volume. The volume was defined with S-ALE keywords and includes the following materials: Air, Sand and TNT charge. The size of the volume is 3000x3000x3500mm. Air is modeled with ***MAT_NULL** and ***EOS_LINEAR_POLYNOMIAL.** Soil is modeled with ***MAT_SOIL_AND_FOAM**, charge is modeled with ***HIGH_EXPLOSIVE_BURN** and ***EOS_JWL** suitable for TNT.
All the Lagrangian parts are coupled to the Eulerian domain using the keyword ***CONSTRAINED_LAGRANGE_IN_SOLID**.

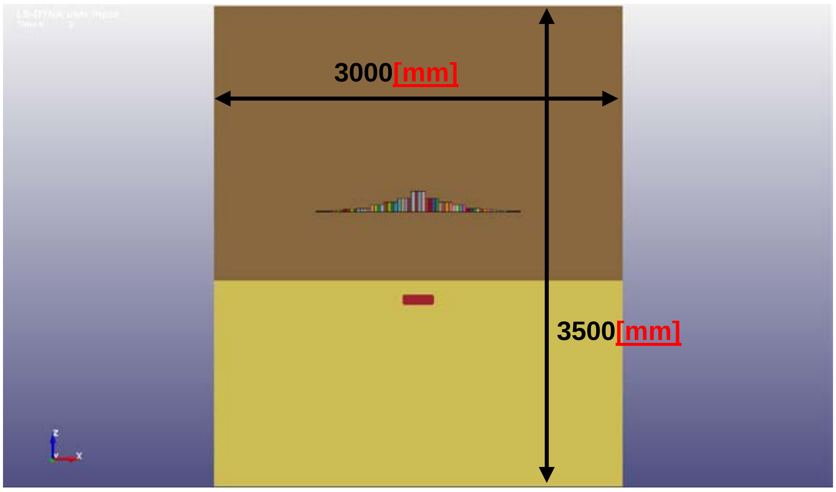

Fig.4: MM-ALE domain, divided to Soil, Air and Charge. The momentum plates are also visible.

3.2 Initial Impulse

The ***INITIAL_IMPULSE_MINE** was operated on a segment set, which included all the bottom elements of the momentum plates.
Scale 0.7 was applied to account for dry sand.

3.3 Load Blast Enhanced

The ***LOAD_BLAST_ENHANCED** was operated on a segment set, which included all the bottom elements of the momentum plates.
By using a user defined units in the unit conversion flag (option 5) different factors can be entered. CFT factor is used to convert model units to load blast units. A factor of 400 [ms/s] was used.

3.4 User Defined Load and Module use

The user subroutine was implemented by calling ***MODULE_LOAD**, and applying ***USER_LOADING_SET** on segment set [13]. The set included all the bottom elements of the momentum plates.
User parameters were applied via ***USER_LOADING**, and were calibrated to fit to the described test results. By using ***MODULE_LOAD** it is not necessary to compile the whole solver, only the specific subroutine itself. Further simplifying development, it is possible to use gfortran (a free compiler available on any LINUX installation) for the compilation [6].

4 Results and discussion

To be consistent with the experiment results described by Held, only the z-momentum was retrieved from each plate, and normalized by the plate area. This procedure gives the specific impulse (or impulse density) for each plate. The specific impulse was plotted vs. distance of the plate from the center (Figure 5). The continuous line shows the buried mine test from Held [7].

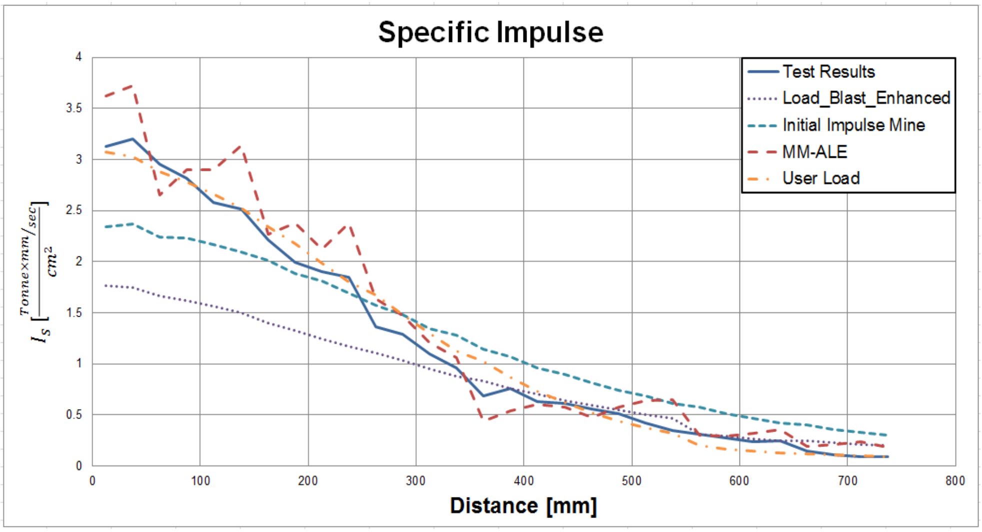

Fig.5: Specific Impulse

The momentum plates can be viewed as a sector of a full disc. In this case, each plate represents a ring of 25mm width with a radius R represented by the distance from the center to the plate. Calculating the ring area and then multiplying it by the specific impulse can show the contribution of each ring to the overall impulse. The resulting graph shows the Impulse per 25mm ringzone vs. distance from the center (Figure 6).

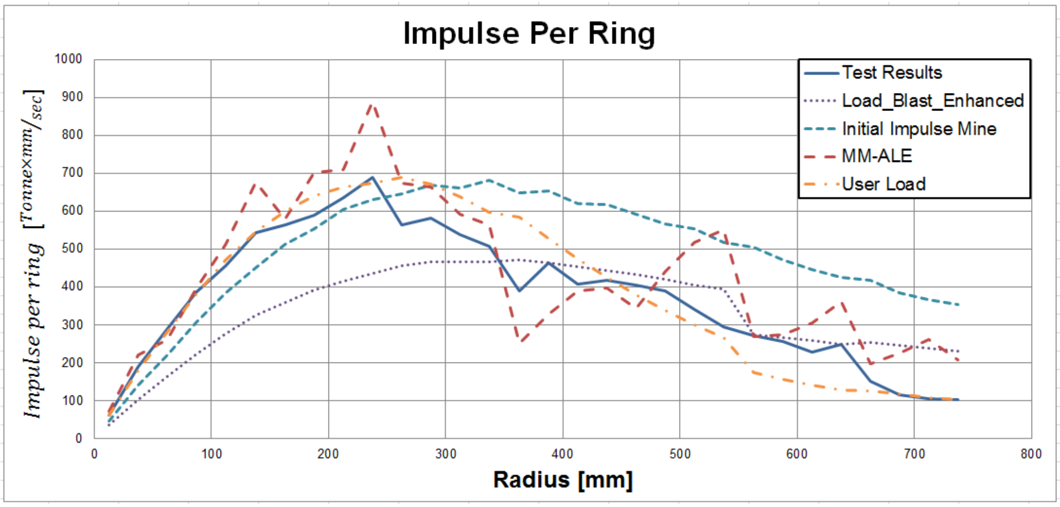

Fig.6: Impulse per ring

Finally the total momentum of a circular plate with a radius of 750mm can be calculated by adding up all the rings impulses. The resulting graph shows the total impulse for a circular plate vs. plate radius (Figure 7).

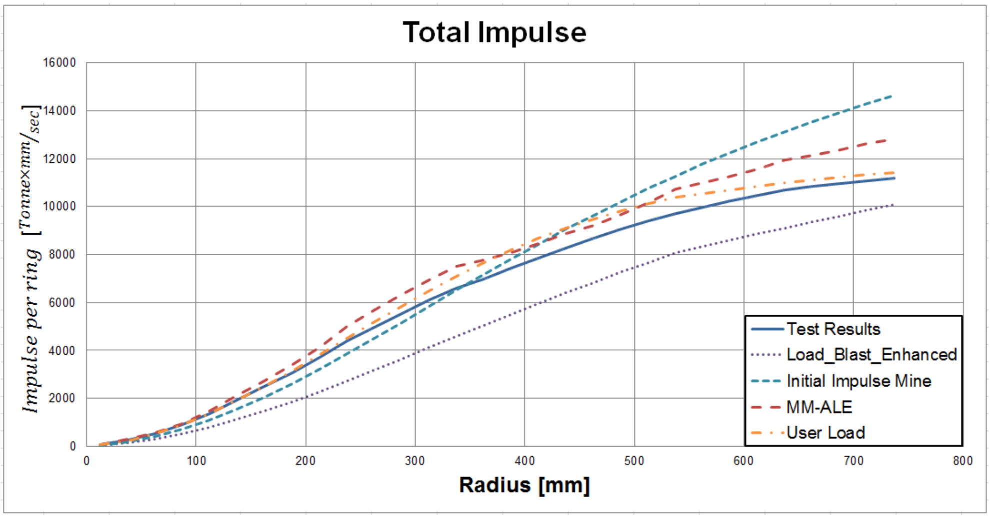

Fig.7: Total impulse

From the above results, it can be seen that the load blast has the lowest impulse especially close to the center (Figure 5). From center to about 300mm the MM-ALE, Initial impulse and user defined have good correlation to the test, while the load blast impulse is too low (Figure 6). From 350mm to the end, the load blast impulse is close to the test (Figure 6), but it is too late to get the total impulse correct, and it falls short (Figure 7). The Initial impulse has high impulse from about 300mm to the end (Figure 6), this causes the total impulse to be too high (Figure 7). The MM-ALE and the user defined stay close to the measured test impulse, and show good correlation.

A comparison of the momentum plates location, after 8ms for the different methods can be seen in Figure 8. The location is compared to the MM-ALE simulation.The low center impulse of load-blast, and the high "far part" impulse of the initial-impulse, in comparison to the MM-ALE, can be clearly seen. It is also visible that the MM-ALE applies some of the load sideways which cannot happen on a pressure based load.

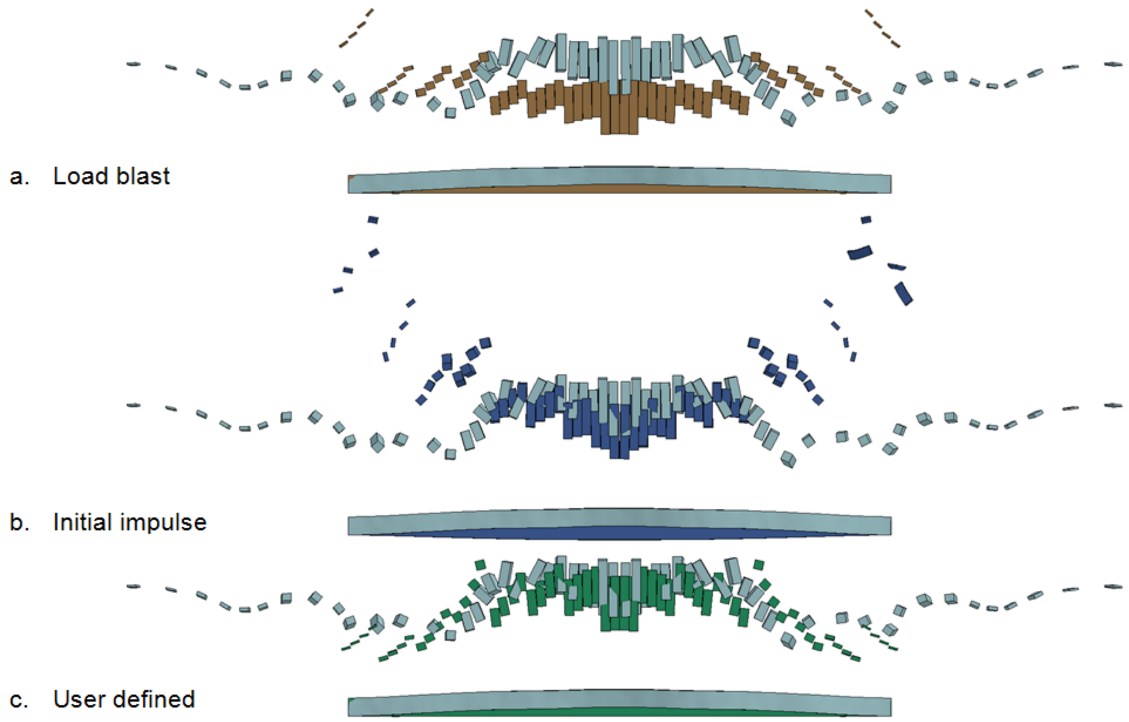

Fig.8: Plates displacement comparison of MM-ALE blast (light blue), after 8ms to load blast (brown), initial impulse (blue) and to user-defined (green)

5 Summary

A user defined load subroutine was written, in order to give the user control over the spatial blast parameters. This method has been compared to experimental results and to three other methods available in LS-DYNA: MM-ALE, Initial-impulse, and Load-blast. It was demonstrated that all methods have different spatial distributions, and that MM-ALE is correlated well to the test results. By having means to control this distribution via a user-load function, a better correlation to different blast scenarios and to test results was achieved. Another aspect demonstrated in this work, is the ease of use and implementation of a user defined load subroutine with the new LS-DYNA module capability.

6 Literature

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