A Comparison between Three Different Blast Methods in LS-DYNA®: LBE, MM-ALE, Coupling of LBE and MM-ALE

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Abstract

A previous experimental test was modeled in LS-DYNA®. Three different methods of simulation were performed. These methods are empirical blast method, arbitrary Lagrangian Eulerian (ALE) method, and coupling of Lagrangian and ALE method. Free field pressure history recorded from experimental test was compared with the first method. Peak pressure for all these three methods were compared together and discussion of results is provided.

Keyword: Blast, Lagrangian (LAG), Load Blast Enhanced (LBE), Multi-Material Arbitrary Lagrangian Eulerian (MM-ALE), LS-DYNA

Section Title

Modeling Techniques

Civil Engineering

Introduction

During recent years, several promising finite element solutions have been presented for determining the response of structures subjected to blast loading. For simulating structures subjected to blast loads, three different methods of analysis are available in LS-DYNA. First, a purely Lagrangian approach, where the air blast pressure is computed empirically with ConWep [1] data, referred to as

LOAD_BLAST_ENHANCED (LBE). This pressure is directly applied to Lagrangian elements of the structure. Second, the Multi-Material Arbitrary Lagrangian Eulerian (MM-ALE) method, where the explosive as well as the air are explicitly modeled. An initial charge is detonated within an air domain and impulse transferred through contact algorithms. Third, LBE and MM-ALE coupling. Available experimental test is modeled with all three methods to determine the most accurate approach. For each model, problem description, input deck is provided in detail, for LBE case comparison with experimental results is provided.

Keyword: Blast, Lagrangian (LAG), Load Blast Enhanced (LBE), Multi-Material Arbitrary Lagrangian Eulerian (MM-ALE), LS-DYNA

Test Description

A test model based on the previous work of Tabatabaei and Volz [2] was used as the basis for the comparison of various air blast simulation techniques. The charge weight for this testing had a net equivalent weight (NEW) of 36 kg of TNT. The charge was centered 168 centimeters over the 184 cm by 184 cm concrete panel. The panel contained steel reinforcement based on U.S. Army TM5-1300 "Structures to Resist the Effects of Accidental Explosions" [3], now UFC 3-340-02 [4]. Two types of blast pressures, the free-field incident pressure and the reflected pressure, were measured. The free-field incident pressure and the reflected pressure on the concrete specimens were measured at standoff distances of 742 cm and 168 cm, respectively, from the center of the explosive charge. The reflected pressure transducers on the specimen were placed at the specimen's center, referred as Sensor A. The free field pressure sensor was referred as Sensor B. The primary response quantity used for comparing the simulation results is the peak pressure at these two different sensors.

Figure 1 shows the geometric axis and blast epicenters for all the models. In order to reduce computational time and allow for high mesh refinement, constraints were imposed normal to the x-y, x-z and y-z planes such that 1/4 of the blast was considered. A finite element model of concrete panel is developed using Lagrangian solid elements. The model used for Concrete is the CSCM in LS-DYNA. *MAT_PIESWISE_LINEAR_PLASTICITY in beam element was used to model rebar in concrete. This model represents steel reinforcement behavior, with plastic deformation, strain rate effects and failure. The *CONSTRAINED_LAGRANGE_IN_SOLID formulation implemented in LS-DYNA was used to model interface between concrete and rebar (CTYPE=2).

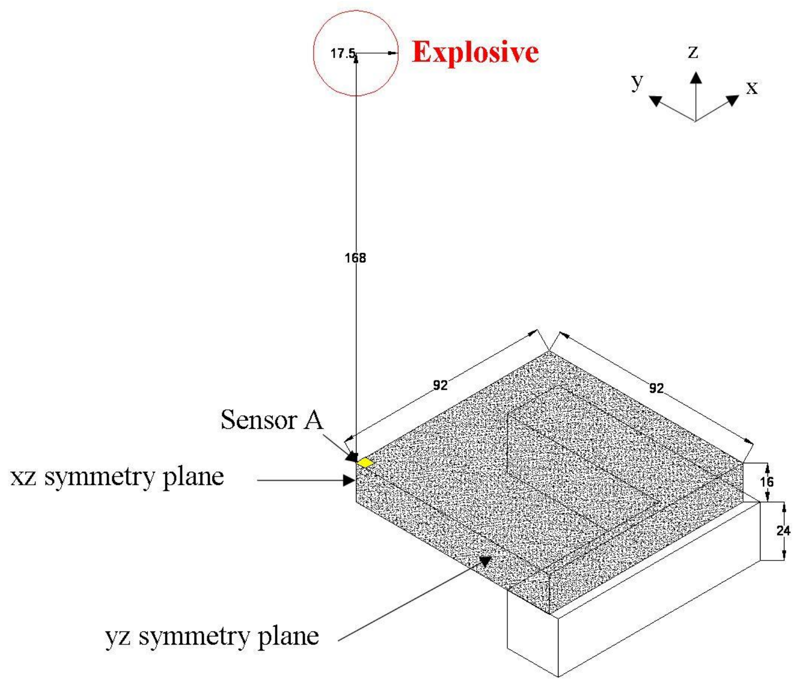

Figure 1. Test setup

Method 1: Purely Lagrangian Approach

A segment surface in the top face of the plate is defined to apply blast load using CONWEP blast function, LOAD_BLAST_ENHANCED. This method is based on a vast amount of experimental data and is the only method which free field pressure at Sensor B was recorded. Due to long distance of Sensor B from the panel, for the other two methods (ALE and Coupling) it was too CPU time intensive to calculate pressure at Sensor B.

Method 2: ALE Approach

In this method, Lagrangian and ALE solution were combined in the same model and the fluid-structure interaction (FSI) handled by a coupling algorithm. The background air mesh configuration was chosen as cubic. The cube consists of two materials, air and TNT. The *ALE_MULTI_MATERIAL_GROUP defines the two materials. The explosive (TNT) is defined using *Mat-High-Explosive-Burn, which controls the explosive's detonation characteristics. For TNT, a JONES_WILKINS_LEE (JWL) EOS is used. The JWL EOS defines the pressure as a function of the relative volume, V, and initial energy per initial volume, E, such that

$$P = A\left(1 - \frac{\omega}{R_1 V}\right)\exp(-R_1 V) + B\left(1 - \frac{\omega}{R_2 \omega}\right)\exp(-R_2 V) + \frac{\omega}{V}E$$

The parameters A, B, R_1, and R_2 are constants pertaining to the explosive are shown in Table 1. The *INITIAL_VOLUME_FRACTION_GEOMETRY card defines the initial distribution of air and TNT. It also defines where the TNT is placed, and its initial shape. Initial detonation defines where and when the detonation starts.

*MAT_NULL is used to model the air. The linear polynomial EOS is linear in internal energy per unit initial volume, E. The pressure used is given by:

$$P = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + (C_4 + C_5\mu + C_6\mu^2)E$$

Where C_0, C_1, C_2, C_3, C_4, C_5, and C_6 are constants and $\mu = \frac{\rho}{\rho_0} - 1$ with $\frac{\rho}{\rho_0}$ the ratio of current density to initial density. For gases which the gamma law equation of state applies such as air, the above equation reduces to $P = (\gamma - 1)\frac{\rho}{\rho_0}E$ with γ the ratio of specific heats. All the used parameters for this method are given in Table 1. A monotonic, second order accurate Van-Leer and Half-Shift Index advection scheme is used for material transport. The *CONSTRAINED_LAGRANGE_IN_SOLID keycard is used to couple the air domain (Master) to the plate (Slave). Since Lagrangian slave side of this model comprised of solids which may be eroded (concrete) due to material failure criteria, CTYPE was set to 5. An appropriate degree of refinement for the ALE mesh is partially dictated by the geometric characteristics of the Lagrangian parts. A reasonable goal is to have the ALE elements be nearly the same size as the Lagrangian elements where coupling is to take place.

Table 1. ALE material property and EOS input data

Material	Unit (cm, g, μs)								
TNT	*MAT_HIGH_EXPLOSIVE_BURN								
	RO	D	PCJ						
	1.63	0.693	0.21						
	*EOS_JWL								
	A	B	R_1	R_2	OMEG	E_0	V_0		
	3.71	3.23E-02	4.15	0.95	0.3	4.30E-02	1		
Air	*MAT_NULL								
	RO	PC	MU						
	1.23E-03	-1.00E+05	0						
	*EOS_LINEAR_POLYNOMIAL								
	C_0	C_1	C_2	C_3	C_4	C_5	C_6	E_0	V_0
	-1.00E-06	0	0	0	0.4	0.4	0	2.58E-06	1.00E+00

Figure 2 shows time sequence of pressure fringes of wave propagating from the explosive source into the concrete panel.

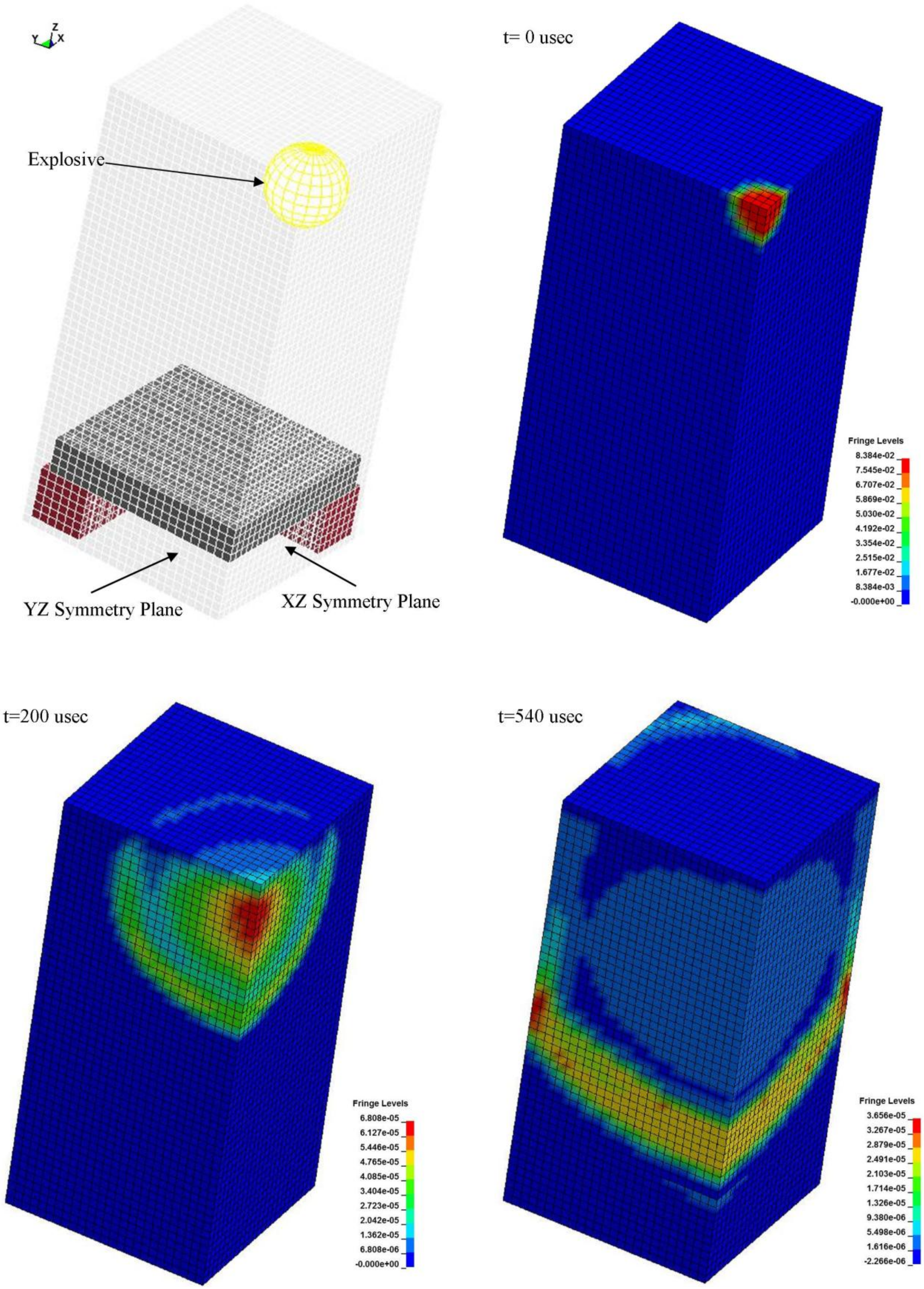

Figure 2. Time sequence of pressure fringes showing wave propagating from the explosive source

Method 3: Coupling the Empirical Blast Load to ALE

In this method, the size of background mesh is reduced and covers only 8 cm on top of the panel and 4 cm around the panel. Explosive is not modeled in this method. A single element of background mesh towards explosive, referred to as the ambient layer, is receiving information from the blast equations (Figure 3). All the parameters and definitions of air and EOS is identical to Method 2, the only difference is that the ambient layer will be activated by setting AET=5 in *SECTION_SOLID and this segment is identified with *LOAD_BLAST_SEGMENT. Figure 3 shows time sequence of pressure fringes of wave propagating from the ambient layer into the concrete panel.

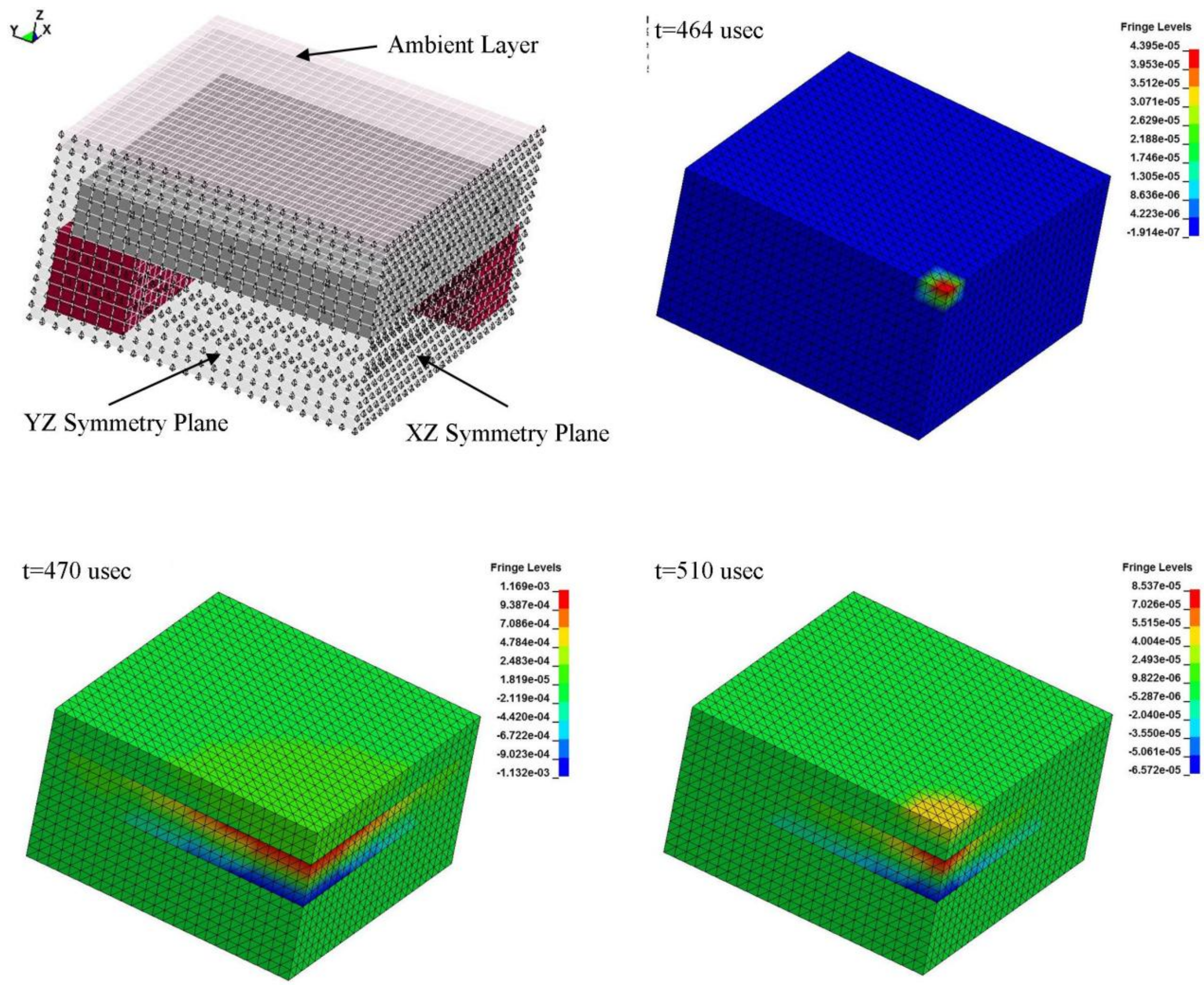

Figure 3. Time sequence of pressure fringes showing wave propagating from the ambient layer

Results

All the simulations for this study were run using single precision SMP-DYNA 5.0. Table 2 contains comparison of model size and the statistics on the CPU time for these models. The MM-ALE model took approximately twice as long for completion than the Coupling method and 21 times more than Lagrangian simulation. The Coupling method model took 10 times more than LBE method for completion.

Table 2. Statistics on three blast models

	LBE	MM-ALE	Coupling
No. of elements	4179	37856	12930
Initial time step	6.06E-04	6.06E-04	6.06E-04
Total CPU time	02:13:35	84:40:03	41:42:00
Element processing time (% of total CPU time)	77.22	87.87	76.9
Contact algorithm (% of total CPU time)	19.14	12.06	22.9

Pressure at Sensor B is recorded from LBE method and results are compared with experimental data. Figure 4 shows that LBE method underestimates peak pressure at this sensor but overestimates impulse.

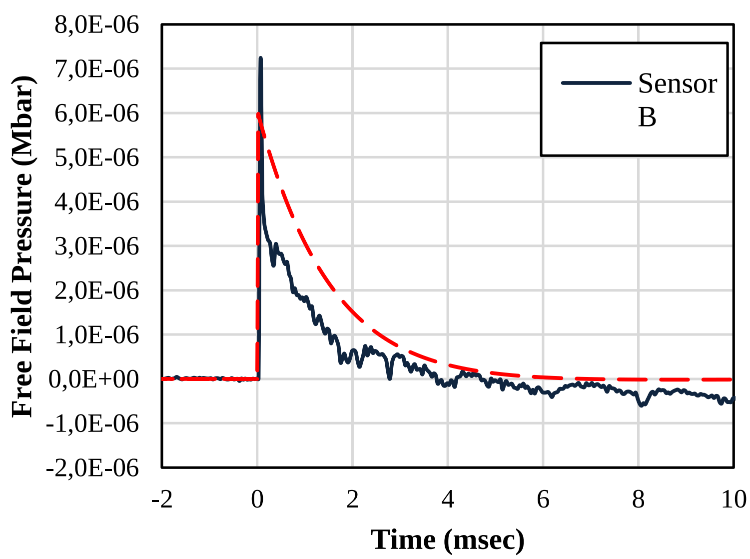

Figure 4. Comparison of reflected pressure histories in Sensor B with LBE method and experimental results

Peak pressure at Sensor A for all the models are summarized in Table 3. The experimentally measured pressure at Sensor A was 1.5 E-3 Mbar.

Table 3. Comparison of results for all three blast modeling

	Peak Pressure (Mbar)
LBE	0.29E-3
ALE	0.71E-3
Coupled	0.55E-3

Conclusions

This paper presented three different methods for blast modeling in LS-DYNA and compared the results with experimentally measured test data. The LBE method underestimates peak pressure of blast and overestimates impulse at Sensor B. LBE method shows smaller peak pressure in comparison to ALE and Coupled method. Coupled method shows very close results to ALE method while using considerably less CPU time. All three methods underestimate blast pressure at Sensor A.

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