.Increasing Initial Internal Energy of Air Elements near Explosive for Fluid-Structure Models of a Steel Plate Subjected to Non-contact Explosion

Wen-Chih Li, Wen-Feng Yu, Ding-Shing Cheng
Department of Environmental Information and Engineering, Chung Cheng Institute of Technology, National Defense University, Taoyuan, Taiwan

Wen-Feng Yu (correspondence)
Department of Environmental Information and Engineering, Chung Cheng Institute of Technology, National Defense University, Taoyuan, Taiwan
Phone 886-3-3809579
Fax 886-3-3805576
Email y1970316@hotmail.com

Abstract

This study was to simulate a steel plate subjected to non-contact explosion by using Arbitrary Lagrangian-Eulerian (ALE) algorithm of the LS-DYNA software. A 3-D Fluid-Structure interaction model was considered. The numerical result would be compared with S.D. Boyd's experiment, which 250g Pentolite explosive detonated above a 5 mm thick steel plate. The Eulerian mesh for explosive and air and the Lagrangian mesh for steel plate and its supporting system were coupled together with overlap. The JWL equation of state and the linear polynomial equation of state were used for explosive and air respectively. A bilinear stress-strain relationship was assumed for the steel plate which was modeled with shell elements. By increasing initial internal energy of air elements near explosive with a temperature of 3000K, the maximum displacement of the midpoint of the steel plate from the ALE model for explosive with a standoff distance of 50 cm was improved from an error of -46.7% to -15.3% after compared with S. D. Boyd's experiment in 2000. Besides, the maximum displacement for the case of explosive with a standoff distance of 25 cm can have an significant improvement with only 0.5% error.

Keywords:

LS-DYNA, explosion, ALE

Introduction

The blast protection of structure is applied mainly for military structures. In general, uniform blast loading is applied on structures directly and nonlinear dynamic analysis is considered. But, if explosive is near structures, the assumption of uniform blast loading is incorrect. Hence, this study was to simulate a steel plate subjected to non-contact explosion by using Arbitrary Lagrangian-Eulerian (ALE) algorithm of LS-DYNA software [1]. The numerical result would be compared with S.D Boyd's experiment, which 250g Pentolite explosive detonated above a 5 mm thick steel plate [2]. A 3-D Fluid-Structure interaction model was considered. The Eulerian mesh for explosive and air and the Lagrangian mesh for steel plate and its supporting system were coupled together with overlap. The JWL equation of state and the linear polynomial equation of state were used for explosive and air, respectively. A bilinear stress-strain relationship was assumed for the steel plate which was modelled with shell elements. The effect of increasing initial internal energy of air elements near explosive with a temperature of 3000 K on the maximum displacement of the steel plate will be the major concern of this study.

Arbitrary Lagrangian-Eulerian (ALE) Algorithm

In general, there are two classical algorithms for finite element meshes of continuums: the Lagrangian algorithm and the Eulerian algorithm. For the Lagrangian algorithm, nodes on meshes can be moved with linked material points and have deformation for element meshes. For the Eulerian algorithm, element meshes are fixed in space and material points move in pre-planned meshes. Element meshes can't be deformed during object's moving, therefore large fluid meshes are needed to pre-plan. The arbitrary Lagrangian–Eulerian (ALE) algorithm was developed to combine the advantages of the Lagrangian algorithm and the Eulerian algorithm. For ALE algorithm, nodes of meshes for solids use Lagrangian algorithm, then nodes move with deformation of solids. But, meshes for fluids use Eulerian algorithm, then nodes of meshes are fixed in space. The ALE algorithm can describe the motion of fluid and show the dynamic response of solids together [3-6]. In the ALE algorithm, the Eulerian and Lagrangian meshes must be overlapped to get better accuracy, but the two meshes are not necessary to be consistent. [7-8]

Numerical Model for Boyd's Experiment

Based on S.D Boyd's experiment in 2000[2], an ALE numerical model shown in Figure 1 was built up. To simplify Lagrangian meshes shown in Figure 2, concrete blocks for supporting the steel plate are assumed to be in the elastic range. Besides, a rigid ground is assumed. Since the 120*120cm steel plate has a thickness of 5 mm only, shell elements are used for the steel plate. Contact-tied surface was applied for the steel plate and concrete blocks, then there are no relative displacement between the steel plate and concrete blocks. The Eulerian meshes shown in Figure 3 used common nodes for air and explosive. But, the Lagrangian and Eulerian meshes do not have common nodes and have overlapped meshes.

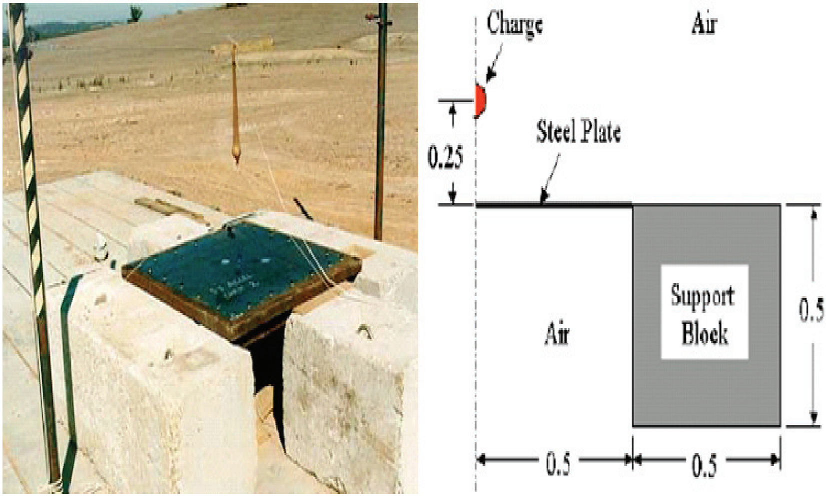

Figure 1: Explosion experiment for a steel plate (Boyd, 2000)

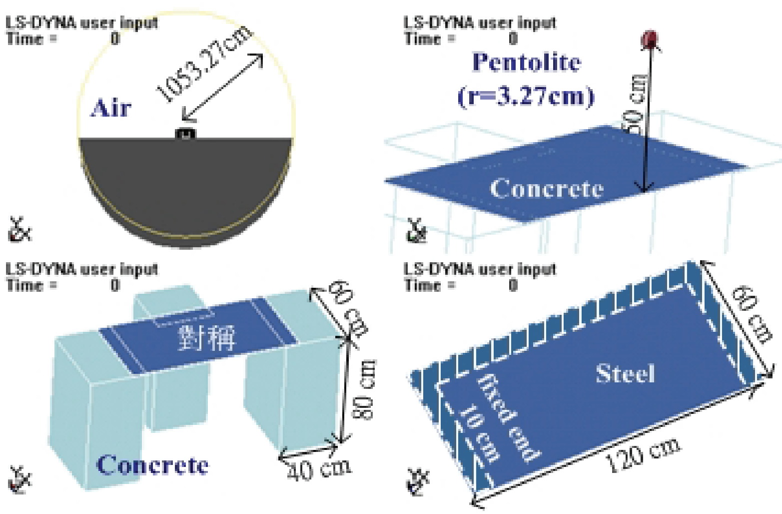

Figure 2: Lagrangian Meshes for a steel plate and concrete blocks

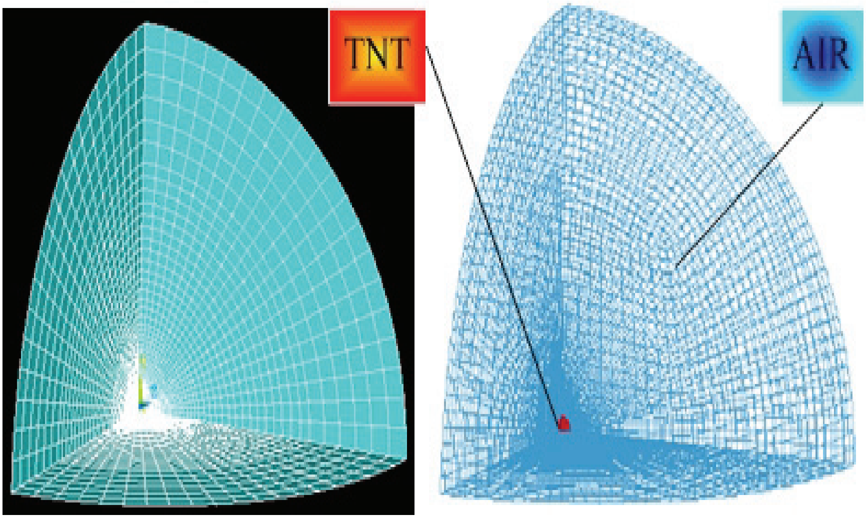

Figure3: Eulerian Meshes for air and explosive

Selection of material models plays an important role on the behaviour of materials. In the numerical model, there are five kinds of materials : air, explosive, steel, concrete, and rigid body. For air material, MAT-NULL (number 9) is applied and combined with linear polynomial equation of state shown in equations (1) and (2). E_0 indicates initial internal energy, and μ as dynamic viscosity coefficient. Air is assumed as ideal gas, therefore $C_0 \square C_1 \square C_2 \square C_3 \square C_6$ are set to zero. $C_4 = C_5$ is $\gamma - 1$, where γ is air specific heat. P is air pressure, $\rho_{initial}$ is initial air density, C_v is air specific heat for fixed volume, and *T* is initial temperature for air.

$$P = C_o + C_1\mu + C_2\mu^2 + C_3\mu^3 + (C_4 + C_5\mu + C_6\mu^2)E_o \qquad (1)$$

$$E_0 = \rho_{initial} C_v T \qquad (2)$$

So, the equation of state is simplified as

$$P = (\gamma - 1)\frac{\rho_{current}}{\rho_{initial}} E_0 \qquad (3)$$

where $\rho_{current}$ is current air density. For Explosive material, Mat-high-Explosive-Burn is used. A JWL equation of state is necessary to simulate the behaviour of explosive.

$$P = A\left(1 - \frac{\omega}{R_1 V_r}\right)e^{-R_1 V_r} + B\left(1 - \frac{\omega}{R_2 V_r}\right)e^{-R_2 V_r} + \frac{\omega E_o}{V_r} \quad (4)$$

where A, B, R_1, R_2, ω are coefficients for specific explosive, P is pressure, V_r is relative volume, and E_o is the initial energy density. If A and B are set to zero and ω is γ-1, equation (4) can be used for ideal gas [9]. For rigid materials (MAT_020), deformation of the material is neglected. Ground is assumed to be a rigid material.

For steel material, Plastic Kinematic (Mat_003) model is applied for isotropic and dynamic harding. β' is chosen for plastic strain hardening. β' =0 is for kinematic hardening, but β' =1 is for Isotropic Hardening [10]. β' =1 has been applied in this study. Since concrete is assumed to be in elastic range, Isotropic Elastic Plastic (MAT_012) model is used for low computation cost [10].

Result

The wave propagation of shock wave approaching the steel plate was shown in Fig 4. When shock wave hit the steel plate, concrete blocks were also hit by shock wave. After shock wave passed through opening between concrete blocks, whole steel plate and concrete blocks are enclosed by shock wave completely, and shock wave hit at the back face of the steel plate.

In order to verify the correctness of overpressure and impulse of shock wave, a numerical model for air and explosive only was built up. Based on shock wave parameters for a spherical explosion in free-air burst from TM 5-1300 manual [11], parametric studies of air and explosive material models were conducted. The result showed that initial internal energy of air elements around explosive plays an important role on controlling the correctness of overpressure and impulse of shock wave. Comparison of numerical result and parameters from TM 5-1300 are shown in Figure 5 and 6. When the initial internal energy of air elements around explosive has a specified temperature of 288.15 K, the error of overpressure is about 5 to 10 % for scaled distance of 0.3-1.6 m/kg$^{1/3}$, and the error of impulse is about 2.5 to 5 %. After increasing the initial internal energy of air elements around explosive with specified temperature of 1000 to 3000 K, the error of overpressure can be reduced to be within 5 % for scaled distance of 0.3-1.6 m/kg$^{1/3}$, and the error of impulse can be reduced to be within 2.5%. Hence, increasing temperature of air elements around explosive can improve the correctness of overpressure and impulse of shock wave. Therefore, a temperature of 3000 K was selected as the basis of ALE numerical model of the steel plate subjected to explosion.

For the midpoint displacement of the steel plate subjected to explosion, when the distance from explosive source to steel plate is 50 cm, the maximum middle displacement of the steel plate is 17.58 mm for a temperature of 288.15 K. But, with a temperature of 3000K, and the maximum middle displacement of the steel plate is 27.96 mm which is about -15.3% error compared to experimental result shown in Table 1. When the distance is 25 cm, the maximum midpoint displacement is 34.82 mm for a temperature of 3000 K, and the error compared to experiment is only 0.5%. The result of the distance of 25 cm is closer to experimental value than the result of distance 50 cm. After investigating impulse values at Z=0.4 and Z=0.79 m/kg$^{1/3}$, the impulse value for 25 cm distance had a higher value of 4.1% than value from the TM5-1300 manual, but the impulse value for 50 cm distance had a lower value of -6.3% than value from the TM5-1300 manual. Therefore, adjusting temperature of air elements around explosive to fit the impulse value near steel plate can provide a good ALE simulation of a steel plate subjected to explosion.

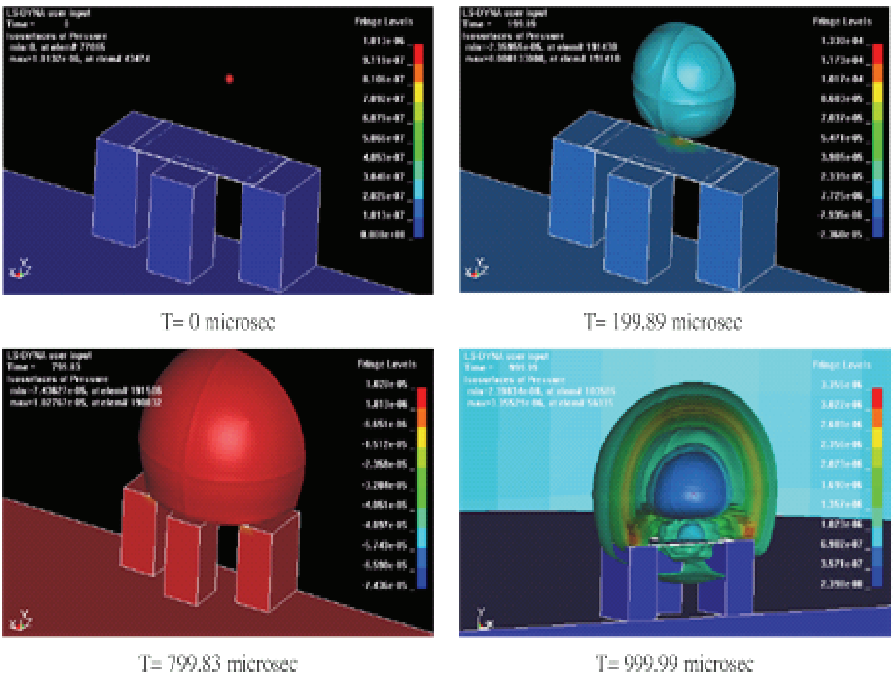

Figure 4: Fluid-Structure interaction for explosion process

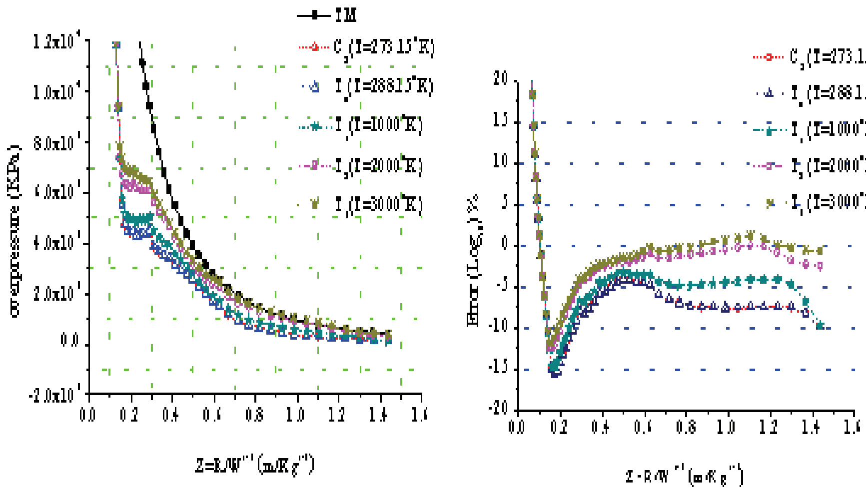

Figure 5: A comparison of overpressure between numerical result and the TM5-1300 manual.

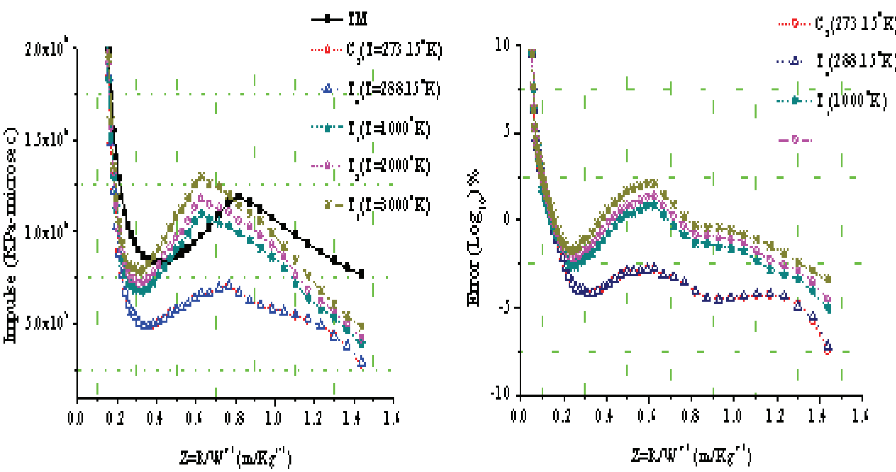

Figure 6: A comparison of impulse between numerical result and the TM5-1300 manual.

The distance from the steel plate to explosive source □cm□	Midpoint displacement for steel plate (air temperature is 3000 K)		
	Boyd's Experiment □mm□	Numerical Result □mm□	Error (%)
50	33	27.96	15.3
25	35	34.82	0.5

Table 1: The maximum midpoint displacement of the steel plate.

Conclusions

By increasing temperature of initial internal energy of air elements around explosive, an ALE fluid-structure interaction numerical model for a steel plate subjected to non-contact explosion is conducted by LS-DYNA software. A comparison of overpressure and impulse values between a numerical model of explosive and air, and the TM 5-1300 manual shows that increasing air elements around explosion with a temperature of 3000 K can reduce error of overpressure within 5% for scaled distance of 0.3-1.6 m/kg$^{1/3}$ and error of impulse within 2.5%. When the distance from explosive source to steel plate is 50 cm, error of impulse compared to value of the TM5-1300 manual is about –6.3%, and error of maximum midpoint displacement of steel plate, compared to Boyd's experiment, is 15.3%. When the distance is 25 cm, the error of impulse is about 4.1%, and error of maximum midpoint displacement is 0.5%. Therefore, adjusting temperature of initial internal energy of air elements around explosive to control impulse value near steel plate in an ALE fluid-structure interaction numerical model for a steel plate subjected to non-contact explosion is important.

Acknowledgements

The numerical work in this paper was performed with computers and software in the National Center for High-Performance Computing, Taiwan. The authors gratefully acknowledge Dr. J-K.Liou for valuable discussions on this work.

References

[1] LS-DYNA version 970 User's Manual, Livermore Software Technology Corporation, Livermore 2003.

[2] Boyd, S.D. ,"Acceleration of a Plate subject to Explosive Blast Loading-Trial Result, " DSTO-TN-0270, Australia , pp.1-13, 2000.

[3] Wang, J. and Gadala, M. S., "Formulation and Survey of ALE Method in Nonlinear Solid Mechanics," Finite Elements in Analysis and Design, Vol. 24, pp. 253-269, 1997.

[4] Stoker, H. C., "Developments of the Arbitrary Lagrangian-Eulerian Method in Non-linear Solid Mechanics," ISBN 90-36512646, 1999.

[5] Donea, J. and Huerta, A., "Arbitrary Lagrangian-Eulerian Methods," Encyclopedia of Computational Mechanics, Vol. 1, 2004.

[6] Haufe, A., Weimar, K. and Göhner, U., "Advanced Airbag Simulation Using Fluid-Structure-Interaction and the Eulerian Method in LS-DYNA," DYNAmore, Stuttgart 2004.

[7] Gebbeken, N. and Ruppert, M., "On the Safety and Reliability of High Dynamic Hydrocode Simulations," International Journal for Numerical Methods in Engineering, 1999.

[8] Michael, J. M. and Brendan, J. O., "Simulation of Energy Absorbing Materials in Blast Loaded Structures," 8th International LS-DYNA Users Conference Penetration/Explosive, Detroit 2004.

[9] Pricop, M. V., Wang, B. and Rehn, W., "Fluid-Structure-Interaction for the Detonation of a Gaseous Mixture in a Nuclear Reactor Containment," Institute National de Cercetari Aerospatiale "Elie Carafoli" Bucharest 1998~2002.

[10] LS-DYNA Version 970 User's Manual, Livermore Software Technology Corporation, 2003.Experience from Using a New Material Model for Stainless Steels with TRIP-effect.

[11] U.S. Departments of the Army, the Navy and the Air Force, "Structures to Resist the Effects of Accidental Explosions," Revision 1, (Department of the Army Technical Manual TM 5-1300, Department of the Navy Publication NAVFAC P-397, Department of the Air Force Manual AFM 88-22), Washington 1990.