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NUMERICAL MODELLING OF INTERACTION BETWEEN PRESSURE WAVE AND RIGID BARRIER

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Abstract: *This paper is focused on computer modelling of blast wave propagation in interaction with rigid blast barriers. The 3D numerical FEM model was created using LS-DYNA software. The pressure wave reflections are also studied. Suitable material model of explosive charge and equations of state for TNT and air are presented. The paper also includes validation of FEM analysis results in comparison to experimental data and FEM model calibration to ensure accuracy of obtained results in various arrangements. If FEM modelling produces sufficiently accurate results, the need for many expensive experiments will be eliminated and experiments only limited to validation tests.*

Keywords: Blast Wave, FEM modelling, Barrier, LS-DYNA.

1. Introduction

Explosions can occur because of number of reasons, most likely by an accident or a terrorist attack. Public buildings such as railway stations, airports or embassies should be constructed to provide safety to the people inside. That could be arranged for example by an installation of blast barriers.

An experimental program was conducted in order to determine ways of influencing the propagation of the blast wave by a system of concrete blast barriers. Due to high cost, it is appropriate to replace experiments with computer modelling. However the accuracy of computer model can vary significantly so it is imperative to validate results of such model by comparison with actual experiment. When properly calibrated, the FEM model can be useful, fast and cheap tool for an optimization process.

2. Computer Modelling

The proposed experiments were performed by Institute of Energetic Materials, Faculty of Chemical Technology, University of Pardubice, Czech Republic. Prior to the experiment itself a preliminary numerical study was conducted to predict behaviour of pressure wave in interaction with solid barrier and multiple arrangements of blast barriers were designed. Four blast barrier arrangements were then chosen for experimental measuring of the peak overpressure at the front of passing blast wave after explosion of TNT charge in standoff distances from 1 to 8 m behind the barriers.

2.1. Model calibration

Pure TNT charge was used as an explosive. This means that obtained results can be easily compared with experimental data from other authors. Pachman et al. (2013) conducted series of experiments with varying yield and standoff distance from the explosive charge, the same as and Foglar and Kovář (2013). The results were used for calibration of the material models of air and explosive on elementary computer model without any barriers. Equations of state used to define both materials had to be also properly calibrated. The Barriers were then added and the model with barriers was evaluated again based on data obtained from experimental program (Hájek & Foglar, 2014).

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2.1.1. Meshing and element type

A finite element mesh was created using ANSYS and LS-DYNA software. There were two separate meshes defined; first for air and explosive, second for barriers. The contact between the two meshes is automatically generated by the LS-DYNA solver. The air and explosive are modelled using ALE (Arbitrary Lagrangian-Eulerian) elements, barriers are modelled using standard solid elements. Mesh size and timestep of the explicit dynamics solver engine have dramatic impact on model accuracy. The size of the air and explosive ALE elements was determined based on scale of the experiment and comparison with experimental data from Pachman et al. (2013). Maximal length of element edge is 25 mm. Hexahedral mesh is used for air and explosive, tetrahedral mesh for concrete barriers.

2.1.2. Modelling of air and explosive material

Material model 009-NULL was defined for air elements and model 008-HIGH_EXPLOSIVE_BURN was defined for the TNT charge.

The equation of state for ideal gas (1) was used to model the air. Parameters of the equation were defined according to Huang & Willford (2012).

$$P = (C_4 + C_5\mu)e_{ipv0} = (\gamma - 1)\frac{\rho}{\rho_0}e_{ipv0} \tag{1}$$

where:

$$C_4 + C_5 = \gamma - 1 = 0.4$$

$$P_0 = 101.3$$

$$v_0 = 1.0$$

$$e_{ipv0} = P_0 v_0 / (\gamma - 1)$$

For TNT the JWL (Jones-Wilkins-Lee) equation of state was used (2). Calibration of this equation of state is quite difficult. The parameters were derived from Zukas & Walters (1997) and Toussaint & Durocher (2008).

$$p = A\left(1 - \frac{\omega}{R_1}\frac{\rho}{\rho_0}\right)e^{-R_1\frac{\rho_0}{\rho}} + B\left(1 - \frac{\omega}{R_2}\frac{\rho}{\rho_0}\right)e^{-R_2\frac{\rho_0}{\rho}} + \omega E\frac{\rho}{\rho_0} \tag{2}$$

2.1.3. Modelling of concrete barriers

The deformations of the barriers have an unintended impact on results. It was decided to model the concrete barriers as rigid structures. The simplified material model of barrier is linear elastic, but the value of modulus of elasticity *E* is significantly increased to provide rigid-like behaviour. The interaction between air and barrier was in question, but results clearly prove that blast wave is reflected of the barrier surface properly (Fig. 1).

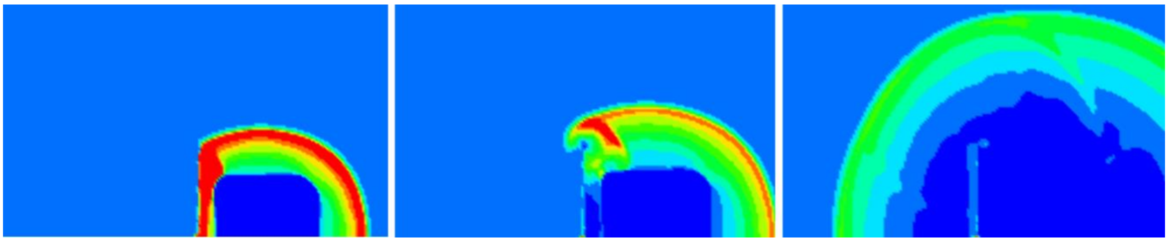

Fig. 1: Contours of overpressure: Blast wave interacting with rigid barrier.

2.2. Experimental program

Given typical dimensions of public building and predicted maximal weight of explosive charge to be carried by single person, it was decided to conduct experiments in reduced scale 1:n. Four arrangements were chosen for the reduced scale experiments (Fig. 2). Reinforced concrete precast panels were used to model solid barriers (Fig. 3). Thorough information and complete results of the experiments can be found in Hájek & Foglar (2014).

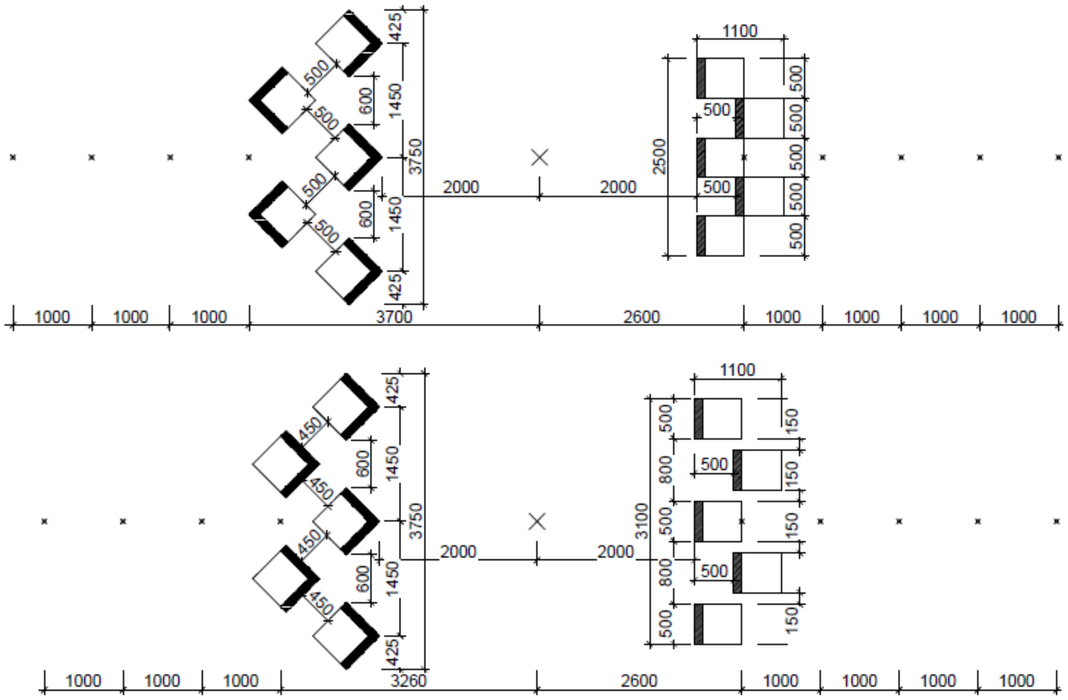

Fig. 2: Tested Arrangements of Concrete Barriers: 1A (top left), 1B (top right), 1D (bottom left), 1E (bottom right). Dimensions in mm.

Fig. 3: Barrier Layout 1A set up on site.

2.3. Validation of computer models with experimental results

During the experiment, pressure sensors were used to measure the peak overpressure at the front of passing pressure wave. For each arrangement, sensors were placed in multiple distances with step of 1000 mm as shown in Fig. 1. Each experimental arrangement was repeated at least twice. Values of element pressure at corresponding coordinates were obtained from the FEM model and compared to experimental data. The comparison is summarized in Fig. 4.

The results indicate that computer model is capable of predicting the peak overpressure with relatively high accuracy in most cases. The time difference between peaks in standoff distance of 0 m and 1 m was also predicted correctly.

Based on the acquired data, it can be assumed that the model is calibrated correctly enough to be used for optimization of barrier shape and arrangement. This way a large number of possibilities can be studied without the need for many expensive experiments.

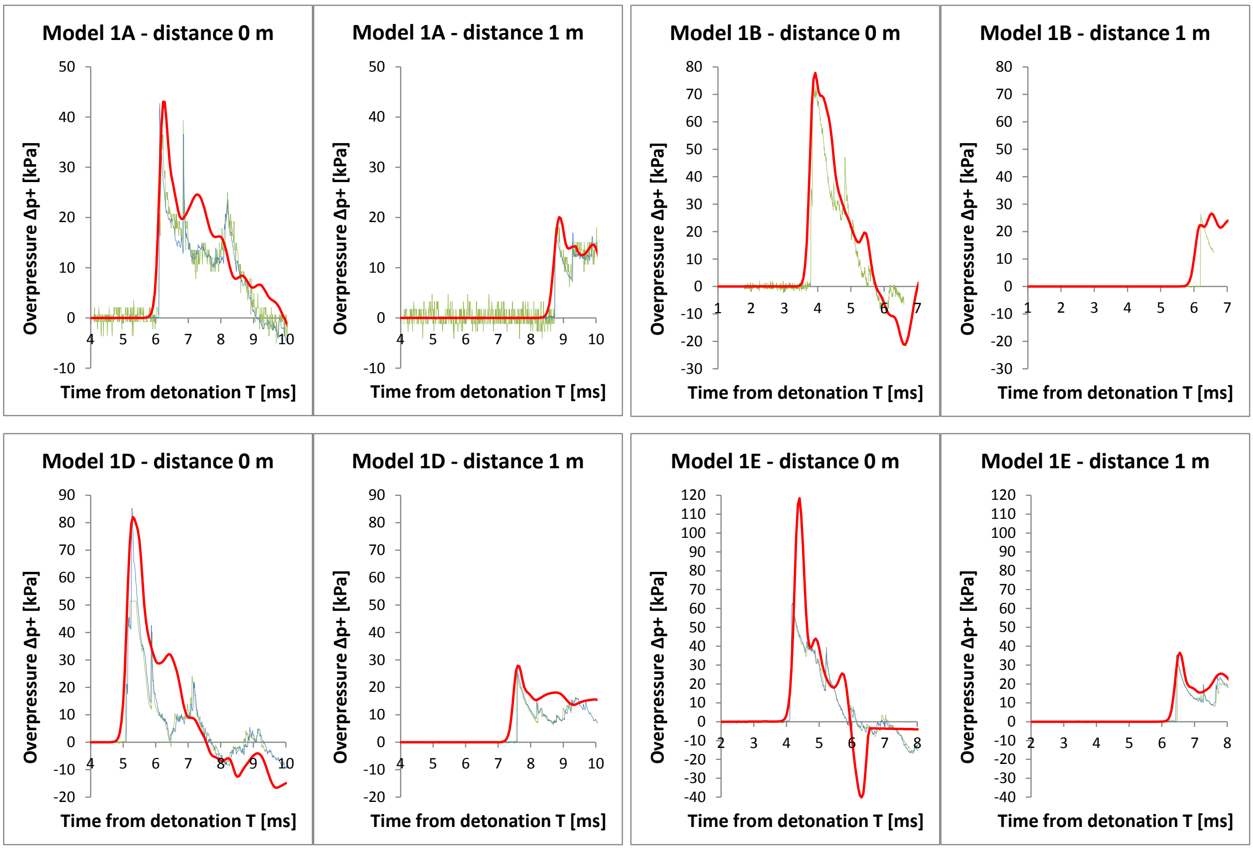

Fig. 4: Comparison of the measured and computed overpressure behind barrier for multiple arrangements (FEM results red, experiments blue and green).

3. Conclusions

Comparison of computer modelling results and experimental data shows that FEM modelling of a blast event can in particular cases and boundary conditions substitute the experimental measuring. The credibility of the results is defined by the configuration of the model. The calibrated model can be useful when optimizing the barrier arrangement because it can dramatically reduce cost of the experiment. On the other hand, at least one validation test should still be performed for each change in materials or major change in arrangement of the experiment.

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