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MODELING OF THE BLAST LOAD EFFECTS IN EXPLICIT DYNAMICS

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Abstract: *The present paper deals with a detonation modeling. Comparison of the blast simulation and following propagation of pressure waves within an electric switchboard container is considered using Abaqus and LS-DYNA via the multi material arbitrary Lanrangian–Eulerian method. A simplified model is created in order to study the influence of domain and structure sizes and finite element mesh dependency using selected output variables.*

Keywords: Detonation, Pressure wave, arbitrary Lagrangian–Eulerian method, Explicit dynamics

1. Introduction

Short circuits result in a sudden overloading of structural parts of electric machines, cabling and switchboards, which resemble explosive detonation under some circumstances. Induced pressure waves act on the protection container of such devices. Wrong design of such parts may lead to the damage of the container and its surroundings. That is why the containers have to be properly protected against such failures as described the standards. Those sudden load states have to be considered in the development of new devices and the structure has to be designed to withstand in testing. However, such testing is expensive so it is suitable to use the numerical modelling in the design stage of new device. It is possible to computationally simulate the blast in detail and analyze the pressure waves propagation in time with evaluating its effect to critical sections of the structure. There are many issues in computational modeling of this, like calibration of the material model, finite element mesh setting, defining the boundary conditions and material models or substituting the short circuit by equivalent explosive. Besides calibration of the whole model, it is necessary to assess the behavior of particular computational models, which cannot be conducted on a complex structure but using simplified models. The aim of the present paper is to test the capabilities of particular computational models as the material models, boundary conditions and finite element mesh setting in commercial finite element codes LS-DYNA and Abaqus/Explicit. There are also studied options in creating the model and post processing.

2. Methods

Modeling of blast may be advantageously solved within Multi Material Arbitrary Lagrangian–Eulerian (MMALE) method, when there is a strong coupling between the structure and fluid. The advantage is in possibility of including more different materials in one finite element, such as air or gases generated by the explosion, using a certain volume fraction. In the model is also included a Lagrangian structure presenting the electric apparatus. Both structures, MMALE and Lagrangian, are then coupled using penalty-based algorithm which tracks the relative motion between the structures and applies the penalty forces that resist the penetration of MMALE material through the Lagrangian mesh (Sherkar et al., 2010).

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3. Computational model

The basic geometrical model consists of three parts. The first represents the structure itself which consists of sheet container of dimensions 500×500×500 mm with sheet thickness of 2 mm and square hole in the upper part for possible simulation of exhaust with propagation of pressure waves into surroundings. The explosive is modeled as a prismatic body with dimensions of 25×25×150 mm and the surrounding air as a cube with dimensions of 1500×1500×1500 mm. The assembly is depicted in Fig. 1. Everything is placed so that two planes of symmetry can be used. Points 1 and 2 correspond to centers of the structure surfaces and point 3 to center of the edge of exhaust. Point 4 is located 75 mm above exhaust in its axis in the Eulers's domain. Point 5 is placed 25 mm from all surfaces belonging to of the structure corners in the Euler's domain. Finally, point 6 is in the center of one of structure surfaces 25 mm in front of the structure and above the bottom surface in the Euler's domain.

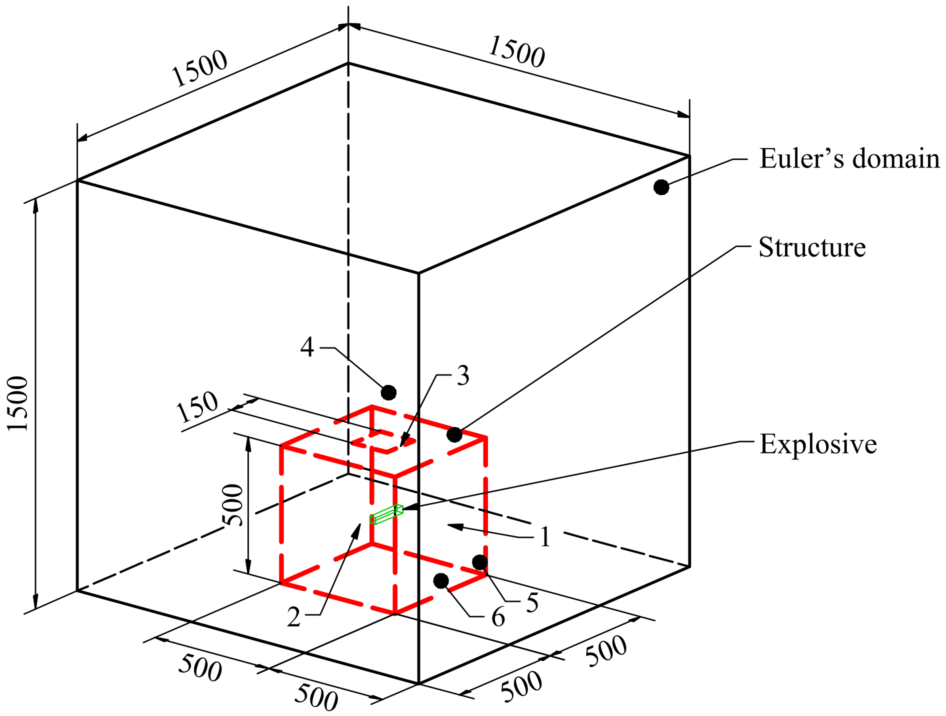

Fig. 1: The basic geometrical model (all dimensions are in mm).

Euler's domain represents both the explosive and air. The geometry was discretized by 8-node solid hexahedron elements in case of Euler's domain which is both inside and outside of the structure and by 4-node shell elements in case of structure. Mapped mesh with 25 mm characteristic element size for structure, surroundings and explosive. The presented model will be considered as the basic one and will differ for particular variants in testing of influence of various variables on the results.

The bottom is represented by surface which reflects the pressure waves. The pressure waves outflow was prescribed to other surfaces. The bottom surface of structure was fixed. The blast load was prescribed by detonation of the explosive in time zero (Puryear, 2012; Vasko, 2012). The blast hits dynamically the structure walls and there is mutual interaction between structure and surroundings. The time scaling factor of 0.6, recommended for extremely fast actions, was used within the time step of 10 ms.

Material properties were set according to real conditions. Isotropic homogeneous elastic-plastic model with linear hardening was used for structure. Elastic behavior was characterized by Young's modulus $E = 210\,000$ MPa, Poisson's ratio $\mu = 0.3$ and density $\rho = 7850$ kg·m^{-3}. Plastic behavior was described by yield stress σ_y = 300 MPa and plastic modulus H = 850 MPa. There is still room for sophisticated description of material behavior including the damage propagation (Kubík et al. 2014; Šebek et al. 2014) but it was not the aim of this paper. The explosive simulating the trinitrotoluene bomb was modeled as high explosive burn material model described by Equation Of State (EOS) for Jones Wilkens Lee as:

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

Detailed description of particular variables is given in manuals (Abaqus, 2014; LS-DYNA, 2014). Following constants were used, ρ_0 = 931 kg·m^{-3}, A = 49460 MPa, B = 1891 MPa, ω = 0.33333, R_1 = 3.907, R_2 = 1.118 and E_m = 266809881847.476 MPa. Detonation wave speed was 200 m·s^{-1}. The air was modeled as an ideal gas using null material model with linear polynomial EOS in Abaqus and LS-DYNA, respectively, as:

$$p = \rho_a R(\theta - \theta_Z) \text{ and } p = E\frac{\rho_a}{\rho_0}(\gamma - 1) \tag{2}$$

In Eq. (2), following constants were used, ρ_a = 1.225 kg·m^{-3}, R = 287 J·kg^{-1}·°C^{-1}, θ_Z = 0.245°C and γ = 1.4. Additionally, specific heat at constant volume was 717.5 J·kg^{-1}·°C^{-1} and detonation energy per unit volume was 0.245 MPa.

4. Results

There are evolutions of total displacement magnitude and pressure in time in Fig. 2. Those are obtained from nodes, denoted by N in Fig. 2, in case of displacements and from elements, denoted by E in Fig. 2, in case of pressure. Their positions correspond to the points 1–6 in Fig. 1. Finally, ABQ and DYN represent abbreviations for Abaqus and LS-DYNA, respectively.

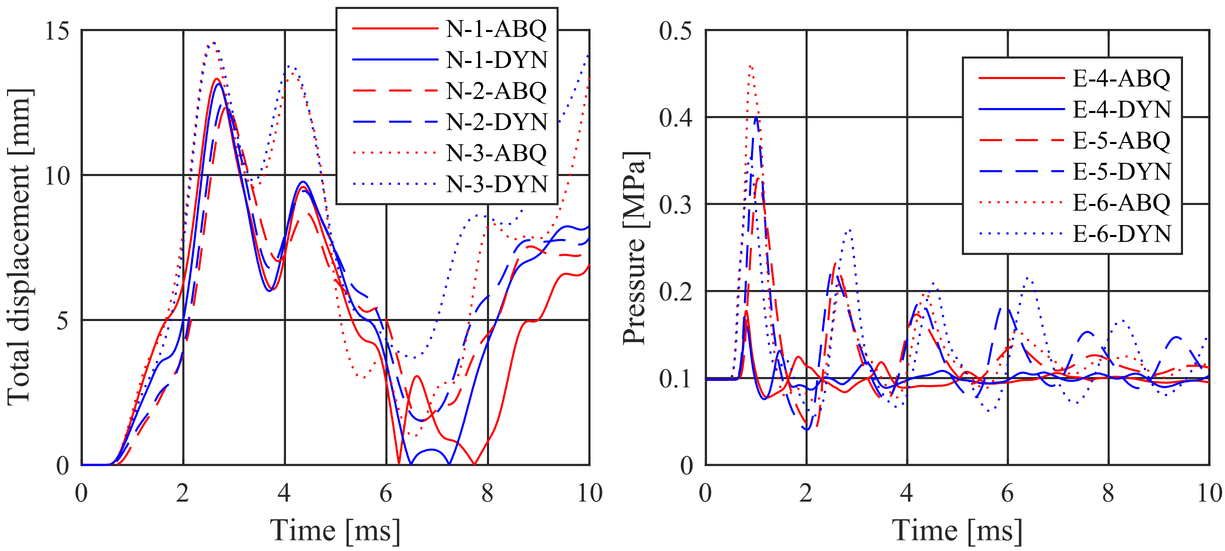

Fig. 2: Evolutions of the total displacement (left) and pressure (right) in time.

There is comparison of contours of pressure waves in time 3.09 ms in Fig. 3.

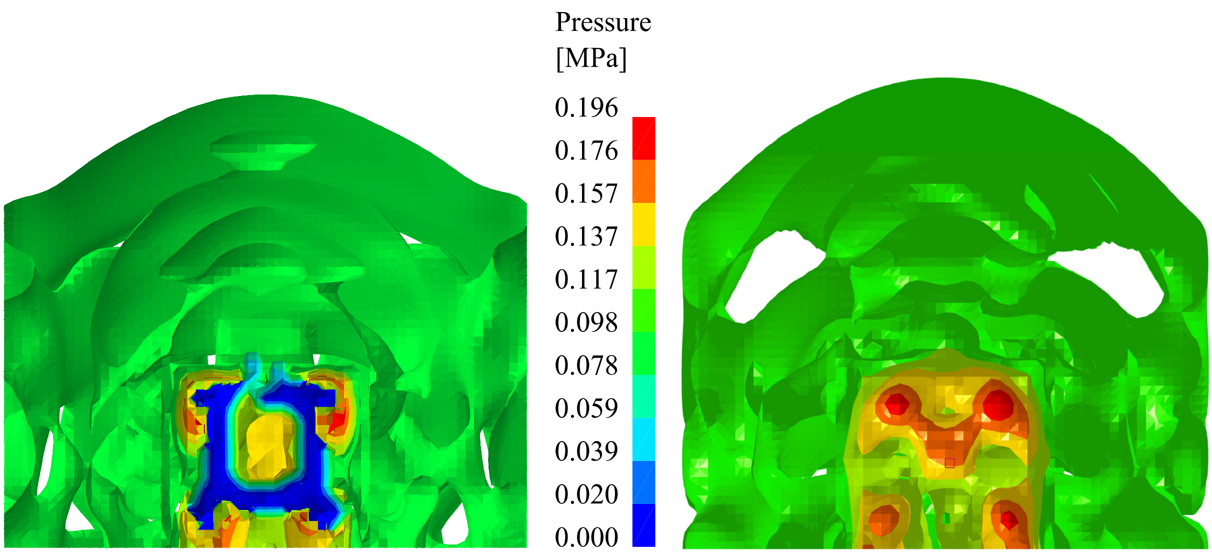

Fig. 3: Contours of pressure waves for Abaqus (left) and LS-DYNA (right).

The computation of basic configuration above took 1586 s within Abaqus. It was for 25 mm sized elements both for structure and domain. It was carried out using two cores of Intel® Core™ i7-980 processor with 3.33 GHz frequency and 24 GB of Random Access Memory (RAM). There were also conducted further analyses in Abaqus on the same computer in order to study the influence of element size both of structure and domain on the computational time. Results are summarized in Tab. 1. It was found that there is quadratic dependency of computational time on the element size of the structure. The dependency on the element size of the domain was not evaluated because the need of memory exceeded the capacity of used RAM in the case of 9717 s and using a hard drive slowed down the process. The influence of the domain dimensions on the computational time was studied as well. It was found that 7429 s was needed for Euler's domain with characteristic size of 3000 mm. The variant with 6000 mm did not even started because the lack of memory.

Tab. 1: Computational times for different variants of simulations.

Element size [mm]	Structure	5	10	20	25		
	Domain	25			15	20	50
Computational time [s]		8844	4363	1992	9717	3538	210

5. Conclusions

The comparison analysis of modeling options of the pressure waves propagation was conducted. The simulations of the blast caused by detonation of the explosion were carried out in two commercial codes, Abaqus and LS-DYNA, respectively. The contours of pressure waves were depicted for qualitative comparison from which it is clear that those are similar. This is confirmed by the quantitative comparison of pressure evolution in time. Nevertheless, it shows there is phase shift in the end of the simulations. Besides the pressure, there was also conducted a quantitative comparison of displacements and computational times. The values of total displacements differ in the second half of the simulations, therefore further investigation is needed. Man-power needed for creation of the models was similar in both finite element codes. Nevertheless, there are more possibilities within LS-DYNA for model and boundary conditions settings. Moreover, the possibilities of post processing in LS-DYNA are far more comprehensive and less time consuming.

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