# Failure of the masonry structure under blast loading

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In the presentation the behavior of brittle masonry wall subjected to different explosive loadings is discussed. The equation of state in numerical examples and further empirical formulae are presented to obtain the pressure that acts on the obstacles. To overcome the computational difficulties in particular with sub-modeling technique the new method of explosive loading distribution is proposed. The Cumulative Fracture Criterion (CFC) was accepted for modeling mortar phase. Some instructive numerical examples of masonry walls for a different compression range are in focus of the presentation.

## 1 Introduction

The structures like brick walls can be subjected of unusual loadings. For example the pressure wave, rigid hitting or high-speed impact belong to this type of loadings. The paper deals with the blast threats. To describe correctly the pressure wave propagation in the air, produced by detonation, it is necessary to simulate the behavior of the charge. For the numerical solution of the detonation process, we accepted pressure $p$ according to the Jones-Wilkins-Lee (JWL) equation of state for explosive material [1]:

$$p(\rho, E_{m0}) = A\left(1-\frac{\omega\rho}{R_1\rho_0}\right)\cdot\exp\left(-R_1\frac{\rho_0}{\rho}\right)+B\left(1-\frac{\omega\rho}{R_2\rho_0}\right)\cdot\exp\left(-R_2\frac{\rho_0}{\rho}\right)+\frac{\omega\rho^2}{\rho_0}E_{m0}, \tag{1}$$

where $A, B, R_1, R_2, ,\omega$ are material constants, $E_{m0}$ is internal energy per unit mass, $\rho_0$ is initial density of explosive material and $\rho$ is current density of detonation product. The air is also modeled by equation of state and typical equation of ideal gas for the air.

$$p + p_A = \rho R\left(T - T^Z\right), \tag{2}$$

where $p_A$ is the ambient pressure, $\rho$ is initial density of air, $R$ is gas constant, $T^Z$ and $T$ are the temperatures. $T^Z$ corresponds to -273.15°C. The values of material constants are presented in Tab.1.

Tab.1 Used constants

| Air | | Explosive | |
|---|---|---|---|
| $R$ | 287 [J/(kg K)] | $A$ | 3.73e11 [Pa] |
| $\rho$ | 1.293 [kg/m$^3$] | $B$ | 3.74e9 [Pa] |
| $p_A$ | 101325 [Pa] | $R1$ | 4.15 [-] |
| $E_{m0}$ | 0.193e6 [J/kg] | $R2$ | 0.9 [-] |
| $T^Z$ | 0 [K] | $E_{m0}$ | 5e6 [J/kg] |
| $T_0$ | 288.4 [K] | $\omega$ | 0.35 [-] |
| $c_v$ | 1003.5 [J/(kg K)] | $v_d$ | 6930 [m/s] |
| | | $\rho_0$ | 1630 [kg/m$^3$] |

In this complex analysis we assume the splitting into two steps. In the first one the acoustic pressure is considered. In the successive step we analyze the stress waves reaching the structure and finally its failure under this dynamic loadings. In practical application the pressure distribution can be also presented in the form suggested by Friedlander [2, 3]:

$$p_{FR}(t) = p_C\cdot\left(1-\frac{t}{t_0}\right)\exp\left(-\frac{b(p_C)\cdot t}{t_0}\right) \tag{3}$$

In this equation $p_c$ is the peak of overpressure and $t_0$ positive phase duration, $b$ is so called wavefront parameter and its depending on $p_c$, $t$ means time.

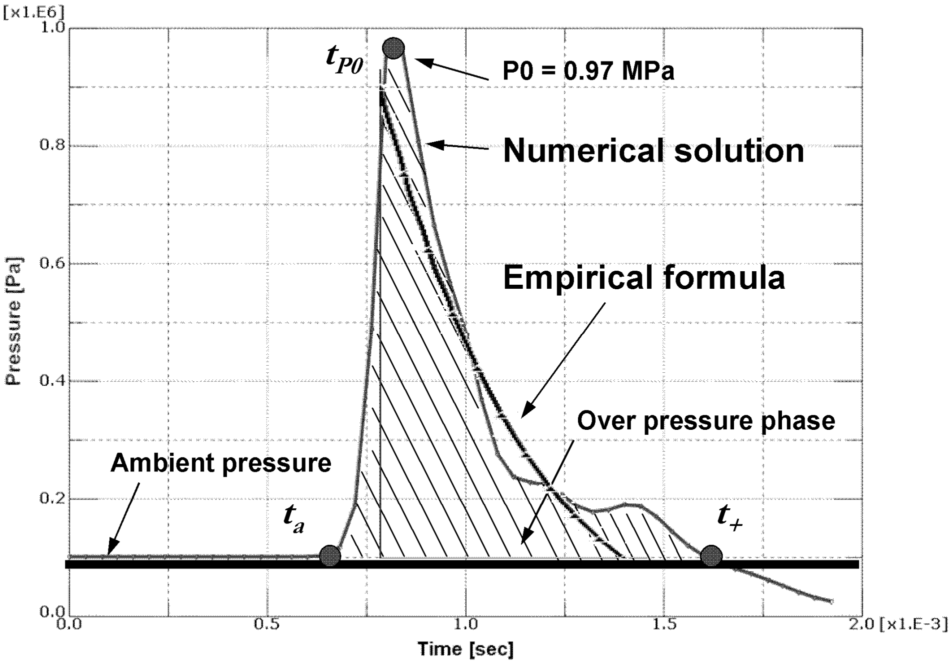


Fig.1 The comparison of two models pressure distribution

The above graph describes the change of the positive pressure in the time, right before the obstacle which is placed 1m from the 10kg TNT explosive. Two independent solutions are presented. The first one obtained in numerical analysis and the second one is Friedlander results in agreement Eq.3. The numeric part is performed in Abaqus code. The both result curves are convergent. In the initial moment the pressure has the constant value equals to ambient pressure which next is growing rapidly. A moment about T=0.0015s in numerical result presenting no discontinuity of the curve. There is an effect of reflected pressure from the front surface of the obstacle. The empirical solution appears to be satisfactory. Next, the 3D surface (Fig.2) of the pressure evolution in time and distance function is presented as a result. The maximum over-pressure is falling down with increasing the distance. The subsequent time moments and suiting them pressure values are emphasized in distance function.

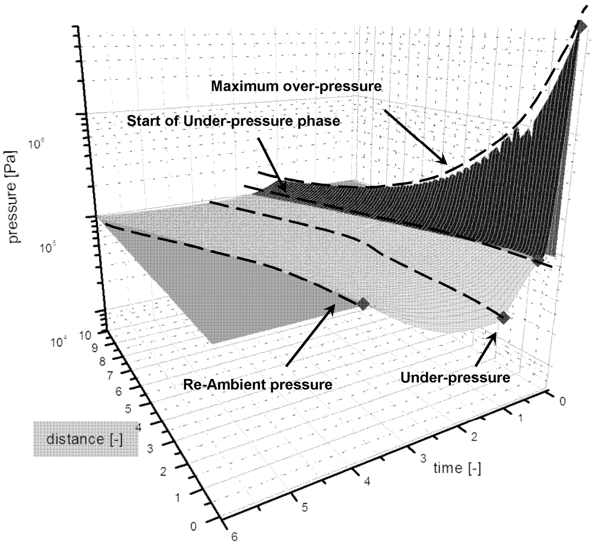


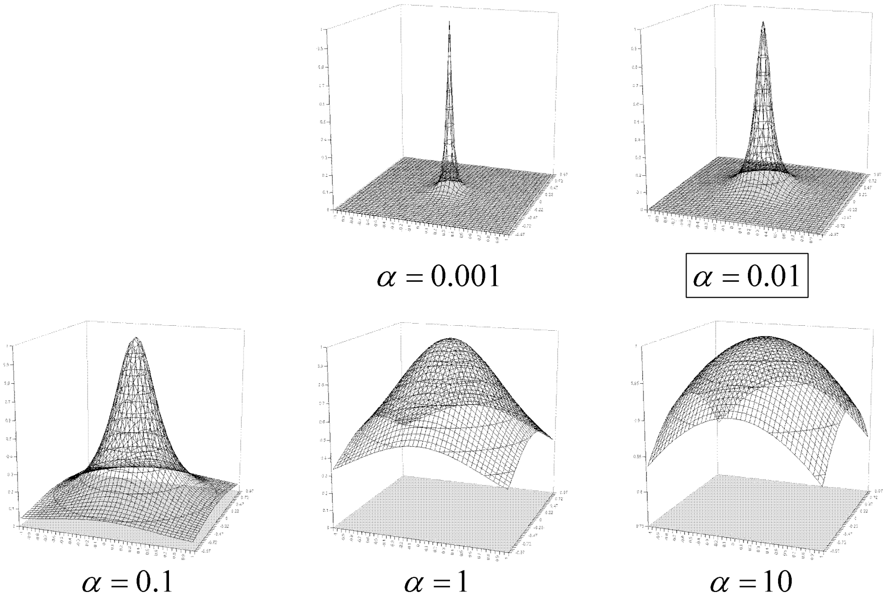
Fig.2 Pressure changes in the air in time and distance function

The darker part of the surface presents the positive phase. The maximum values of peak pressure in different distance are showed.

Some of the results restrict the attention only to 2-D examples [4] which should be treated only as the preliminary studies. For the whole process of blast simulation and its influence on any kind of obstacle like walls, one can propose to split it into two phases. Based on the previously study there is possible to use only a loading function which acting on the front obstacle surface. The simple formula (Eq.4) describes a pressure topology in function of the position $x$ and $y$ parameters and $\alpha$ variable:

$$p(x,y,\alpha)=\frac{\alpha}{(x^2+y^2+\alpha)} \tag{4}$$

This approach considerably accelerates the time of computation without influence on the results. The alpha corresponds with distance between obstacle and charge. The evolution of topology surfaces are presented depending on $\alpha$, see Fig.3.



$\alpha=0.001$ $\boxed{\alpha=0.01}$

$\alpha=0.1$ $\alpha=1$ $\alpha=10$

Fig.3 Analytical loading topology function

The $\alpha$ parameter is changing in range 0.001:10, and lover value corresponds the explosion directly on the obstacle; $\alpha$ grows with increasing the distance from the charge. The advanced study of $\alpha$ in distance, power of explosive function is not a goal of this paper. The obtained values in Eq.4 are multiply by pressure course in the Fig.1, commonly load the structure.

## 2 Numerical experiment

The wall is build periodically of regular bricks (0.25m by 0.12m by 0.06m) and mortar with bad and head joints of 0.01m thick. The structure under consideration is of dimensions 2m by 2m. The wall thickness as for single brick is 0.12m, see Fig.4. The masonry wall combines two separate phases as bricks and mortar and is divided into two material sections. The constitutive model for bricks is elastic without any damage criteria while for mortar we employed CFC, specified and discussed in other works [5, 6]. In the numerical examples the mortar elements are deleted only if the CFC is accomplished.

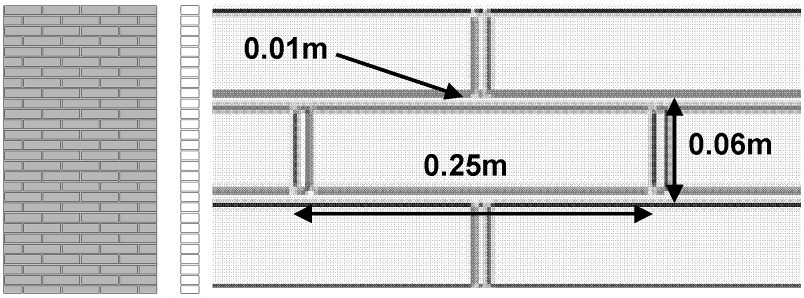


Fig.4 The symmetry part of the analyzed wall

The three edges of the wall are fixed while the top one remains free. This one is loaded by compressive pressure and simulates in the analysis the loading which comes from ceiling. Finally, we assumed the ideal spherical blast of 1kg TNT charge in front of the obstacle. The ground reflection is not taken into consideration. The job uses the loading surface, see Fig.3, where $\alpha$ parameter equal to 0.01, what corresponds with distance equals to 1m from the explosive. The numeric model is symmetric and it consists of 0.24e6 linear 8-node elements with 1800 finite elements per one brick and 1 on the mortar thickness. This approach allows for neglecting a contact problem on the mortar-brick bond.

There is analyzed the failure scheme under different compression range its equals to 0 to 0.2MPa. The selected schemes of the structure destruction are presented in Fig.4.

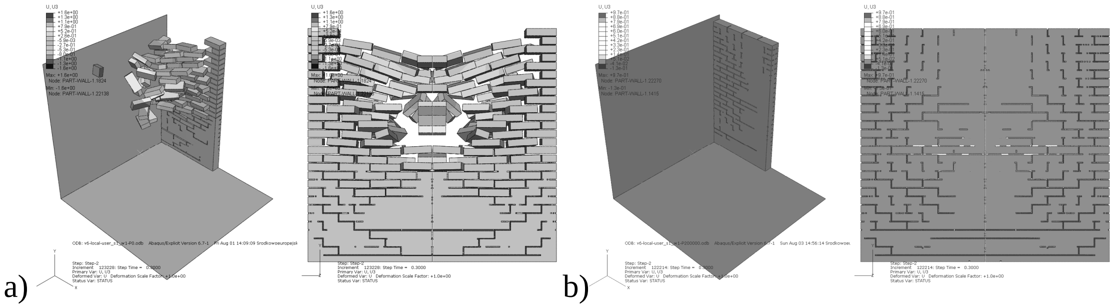


Fig.5 Wall failure: a) without initial compression, b) compression stress equal to 50 kPa

The above pictures show destroyed elements of mortar 0.3 second after explosion. The Fig.5a represents only a compressive under gravity force while Fig.5b 50kPa in addition. In the second result the masonry remains constant. The varied compression stages cause a different mortar element deletion.

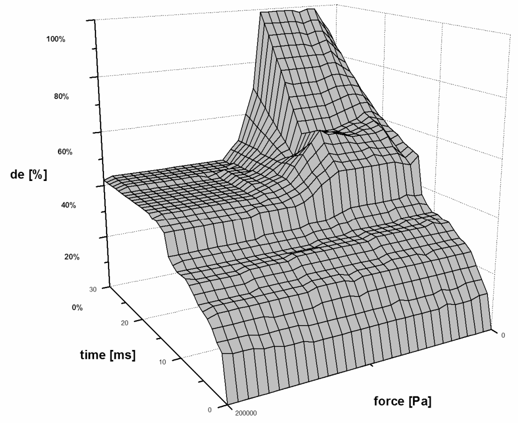


Fig.6 Percentage of damaged elements of mortar in time and distance function

The above picture (Fig.6) shows the percentage of the destroyed elements as function of time and initial compression function.

## 3 Conclusions

There is explained and proved that sub-modeling technique can be good considered the analyses of explosion processes and structure response. The reduction of the computational time can be successfully reached by introducing the Friedlander idea instead of acoustic wave analysis and sub-modeling technique. The results of the initial compression stress if the wall (pre-stressing) influence significantly the mortar damage.

## 4 References

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