Failure and fracture of concrete and brick walls imposed by explosion

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Abstract

The structures like concrete or bricks wall are often subjected of unique loadings. For example the blast wave as well as impact belongs to this type of loadings. The paper presents only the first class of structural external forces, that comes from an explosion of the material as TNT. To describe properly the pressure wave propagation in the air, produced by detonation, which acts on the structure, it is necessary to simulate the explosion and the waves' motion. In the numerical simulation of the explosion process, we accept the Jones-Wilkens-Lee (or JWL) equation of state for TNT and typical equation of state for air [1]. The data of TNT and the air are in Tab. 1. Using these values of material parameters and ALE description of deformations guarantee the proper solution of explosion simulation and finally the distribution of pressure loading on structure. There are many analytical functions in literature [1], which describe the influence of time and distance from the ignition on the pressure distribution. The numerical simulation results [2] are compared with analytical functions of the blast to validate the accepted models. The results of the pressure distribution change depends on time after explosion and the distance from the ignition point are presented in Fig. 1.

The interaction of the fluid (air) with both walls is performed using sub-modeling. There are two kinds of models for both cases, the global and local. The global model consists the cubic explosive material, surrounded air and the structure wall. The local models include only structural parts (the concrete and masonry walls). Sub-modeling technique is accepted if the coupling exist in one way between the global to local models, but not in opposite. It is sufficient assumption for blast simulation. The idea of global and local models is presented in Fig. 2. When modeling 1/8 part of the space three planes of symmetry are assumed. The global model is extended up to 5 meters from the model center. It is possible to obtain the positive and negative overpressure phase on the surface of the structure like in experiments [1, 2]. The first kind of structure under consideration is concrete wall and the second is periodic composite masonry wall created of mortar and bricks. Both form the local models. Cumulative Fracture Criterion (CFC) introduced in [3, 4] and discussed before [5, 6] is used and has been added to Abaqus/Explicit environment by VUMAT procedure. This criterion in integral form is as following:

$$t_{c0} = \int_0^{t_c} \left(\frac{\sigma_F^{eq}(t)}{\sigma_{F0}^{eq}} \right)^{\alpha(T)} dt \qquad if \qquad \sigma_F^{eq}(t) > \sigma_{F0}^{eq}, \tag{1}$$

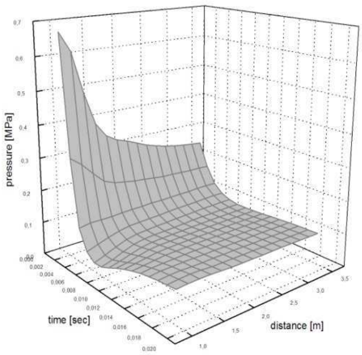

Fig. 1 The positive and negative overpressure (above or below atmospheric pressure)

Tab.1 EOS parameters

AIR
R=287(J/(kgK)), ρ=1.293(kg/m^3), p_A=101325(Pa), E_{m0}=0.193e6(J/kg), T^Z=0(K), T_0=288.4(K), c_v=1003.5(J/(kg K))
TNT
A=3.73e11(Pa), B=3.74e9(Pa), $R1$=4.15(-), $R2$=0.9(-), E_{m0}=(J/kg), ω=0.35(-), v_d=6930(m/s), ρ_0=1630(kg/m^3)

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where t_{c0} is the longest critical time, $\alpha(T)$ is the parameter connected with energy activated during the separation process and σ_{F0}^{eq} is quasi-static equivalent tensile strength of concrete. This measure is introduced to describe better the deformation in advanced triaxial state of stress [6]:

$$\sigma_F^{eq} = \frac{k-1}{2k(1-2\nu)} I_1 + \frac{1}{2k}\sqrt{\left(\frac{k-1}{1-2\nu} I_1\right)^2 + \frac{6k}{(1-\nu)^2} J_2}\,, \qquad (2)$$

where

$$I_1 = \sigma_1 + \sigma_2 + \sigma_3 \quad and \quad J_2 = \frac{1}{3}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2\right] \qquad (3)$$

σ_F^{eq} is the generalization of the Huber-Mises equivalent stresses [6]. I_1 and J_2 are the first and the second invariants of the stress tensor and deviatoric part of the stress tensor, respectively. The k influences the shape of the critical failure surface in the space of principal stresses. The criterion describes generally the time up to failure under the stress impulse. In both, concrete and masonry structures this criterion is used. In the second one only for the mortar CFC is accepted. It means that we assumed elastic-visco-brittle material, see Tab. 2. This criterion results in strain rate sensitivity of the material behavior. In the presentation the sensitivity of structure failure patterns to the constitutive parameters, the boundary conditions and the geometry of the global and local models is considered. Particularly, important is the distance between the explosive material and the wall obstacle. Instructive numerical examples will be presented and discussed during the conference.

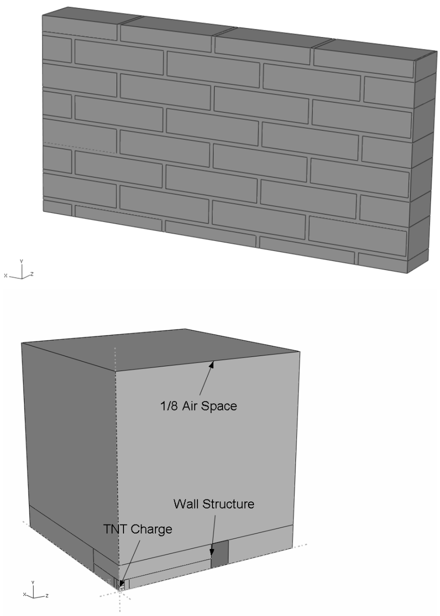

Fig. 2 Analyzed models: a) Local b) Global

Tab. 2 The parameters of concrete

E	35e9 [Pa]
v	0.2
ρ	2395 [kg/m3]
k	10
t_{c0}	0.000049 [s]
α(T)	0.95
σ_{F0}^{eq}	4.2e6 [Pa]

References

[1] P.D. Smith and J.G. Hetherington, *Blast and Ballistic Loading of Structures*, Butterworth-Heinemann, Oxford 1994.

[2] Jankowiak T., Łodygowski T., Sielicki P.W., *Modeling of pressure distribution after explosion*, Computer Methods in Mechanics, 2007

[3] J.R. Klepaczko, *Behavior of rock like materials at high strain rates in compression*, Int. J. Plasticity 6, (pp. 415-432) 1990.

[4] J.R. Klepaczko and A. Brara, *An experimental method for dynamic tensile testing of concrete spalling*, Int. J. Imp. Eng. 25, (387-409) 2001.

[5] T. Jankowiak and T. Łodygowski, *Numerical modeling of fracture in brittle material under impact loading*, Vibrations in Physical Systems 22, (pp. 143-148) 2006.

[6] T. Jankowiak, J.R. Klepaczko, and T. Łodygowski, *Numerical modeling of wave propagation and interaction in bars*, Found. Civ. Env. Eng. 7, (pp. 187-199) 2006.

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