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NUMERICAL ANALYSIS OF STEEL FRAME SUBJECTED TO AIR BLAST

The paper focuses on the numerical analysis of steel frame subjected to air blast load. ABAQUS/Explicit was employed to establish 3D finite element model. Two-storey steel frame was discretized with solid elements. Air blast load was generated using CONWEP generator. 3 different weight of TNT was considered.

Key words: steel, frame, air blast, damage mechanics, explicit dynamics.

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ЧИСЛЬНИЙ АНАЛІЗ СТАЛЕВИХ РАМ ПІД ВПЛИВОМ ПОРИВУ ВІТРУ

Робота присвячена чисельному аналізу сталевої рами, на яку впливає поривисте повітряне навантаженню. ПК ABAQUS/Explicit був використаний для створення моделі 3D-кінцевих елементів. Двоповерховий сталевий каркас був дискретизований обємними елементами. Навантаження від пориву вітру було згенеровано за допомогою генератора CONWEP. Було розглянуто 3 різні маси ТНТ.

Key words: сталь, рама, порив вітру, механізм руйнування, явна динаміка.

Introduction. In last, the likelihood of terrorist attack is increasing. Blast attacks can cause excessive damage to structural elements, that can lead to progressive collapse of structures. Blast effect on structures has been already presented in many papers [1], [2], [3]. In this paper, a two-storey steel frame subjected to air blast is investigated using numerical simulation.

Air blast load. An explosion is a rapid increase in volume and release of energy in an extreme manner, usually with the generation of high temperatures and the release of gases. Supersonic explosions created by high explosives are known as detonations and travel via supersonic shock waves. The equation for a Friedlander's equation [4] describes the pressure of the blast wave as a function of time:

$$p_r(t) = p_{r,\max}\left(1-\frac{t}{t_d}\right)e^{-bt/t_d} \tag{1}$$

where $p_{r,\max}$ is the peak overpressure, t_d is the positive phase duration and b is a decay coefficient of the waveform. Kinney [4] presents a formulation for determination of the peak overpressure. It is described by equation:

$$p_{r,\max} = p_0 \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\left\{\left[1+\left(\frac{Z}{0.048}\right)^2\right]\left[1+\left(\frac{Z}{0.32}\right)^2\right]\left[1+\left(\frac{Z}{1.35}\right)^2\right]\right\}^{0.5}} \tag{2}$$

where p_0 is the ambient pressure and $Z=\frac{R}{\sqrt[3]{W}}$ is the scaled distance, R is distance from explosion and W is charge mass of equivalent TNT. Figure 1 shows the idealized profile of the pressure in relation to time.

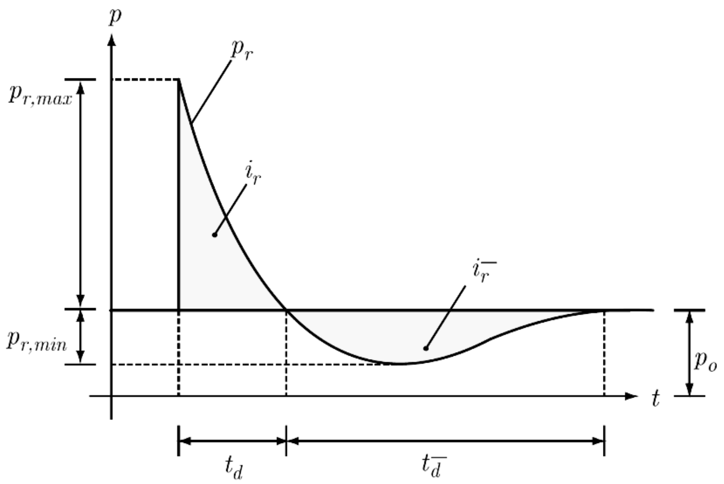

Fig. 1. Ideal blast wave's pressure time history

In many studies [5–7] has been used air blast load generator CONWEP (Convetional Weapons) [8] developed by U. S. Army.

Numerical model – geometry and boundary conditions. The spatial model of two-storey steel frame was created using software ABAQUS/Explicit [9].

Geometry and boundary conditions are shown in Fig. 2, 3. HEA 340 cross section was used for columns and beams of steel frame. The thickness of the flange is 16.5 mm and web thickness is 9.5 mm.

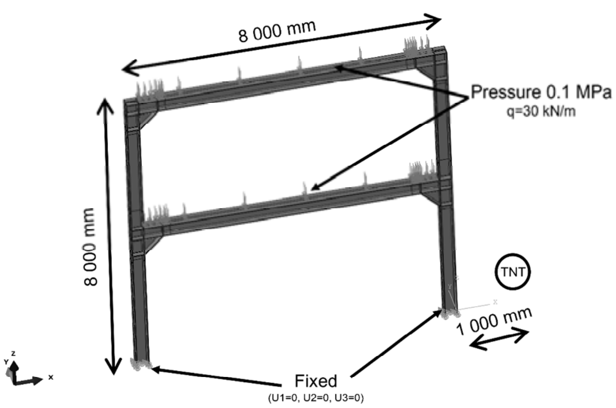

Fig. 1. Two-storey steel frame

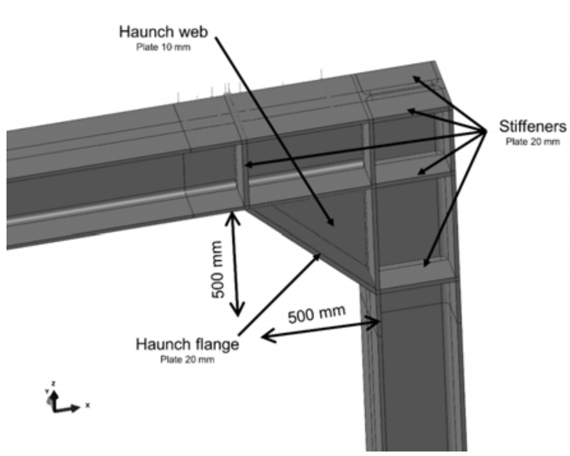

Fig. 2. Detail of frame corner

Numerical model – material model. In the numerical model, the behavior of the steel columns was described by an elastic-plastic material model with progressive damage. In Fig. 4 is a stress-strain diagram of steel, which was point by point entered into the software for numerical analysis.

Material properties of steel are in Table 1. Material degradation and progressive damage of elastic-plastic material was described by damage mechanics and schematic representation is in Fig. 4.

Table 1

Material properties of steel

ρ (kg/m^3)	E (GPa)	ν (-)	f_y (MPa)	ε_p (-)	ε_f (-)
7 850	210	0.3	360	0.125	0.22

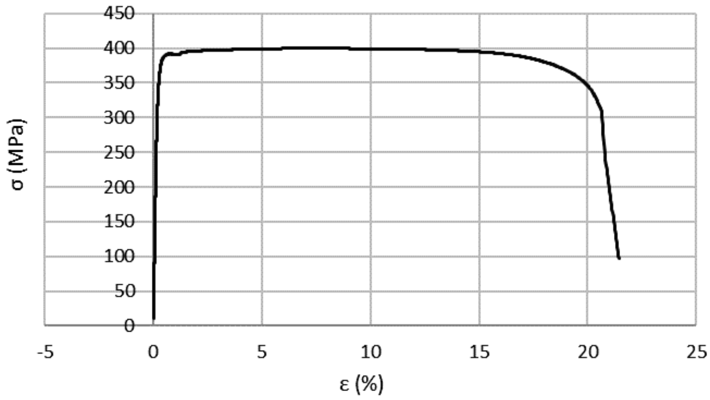

Fig. 3. Stress-strain diagram of steel

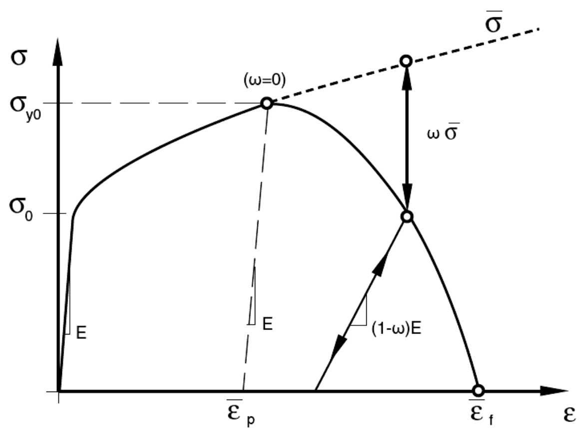

Fig. 4. Schematic representation of elastic-plastic material with progressive damage [9]

Numerical model – mesh. In numerical analysis were used first order 8-node brick elements with reduced integration (C3D8R). In order to avoid negative impacts (hourglassing, shear locking), the individual parts of the cross-section – wall and flange – were created using 4 finite elements through thickness. The model consists of 579 968 finite elements and 735 397 nodes. Finite element mesh is shown in Fig. 6, 7.

Numerical model – analysis. Numerical simulation was divided into 2 phases.

In the first phase, beams of steel frame was subjected to load of 30 kN/m. Load was applied as pressure on top face on top flange. To avoid negative dynamic effects, load was gradually increasing using function *SMOOTH STEP*. Duration of the first phase was 0.05 s.

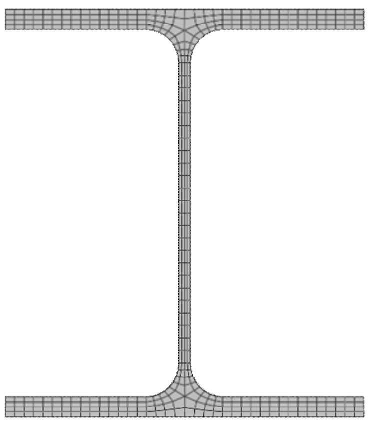

Fig. 5. Mesh – cross section

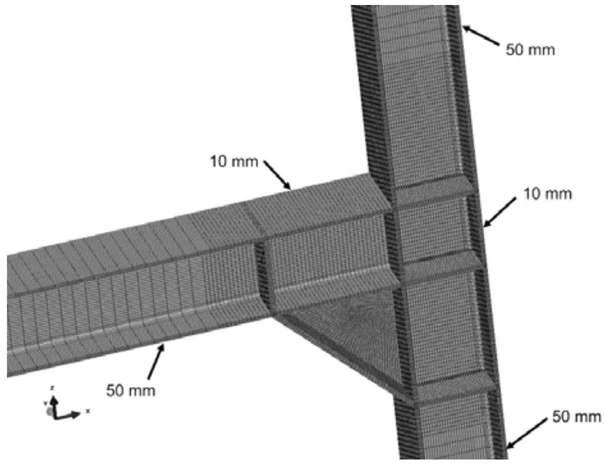

Fig. 6. Mesh – frame

In the second phase air blast load was applied. Air blast load was generated using CONWEP generator. 3 different weight of TNT was considered – 5 kg, 10 kg, 15 kg. Standoff distance was 1 000 mm. Time of explosion was 0.055 s. Time history of generated air blast loads are shown in Figure 8.

Total time of simulation was 0.075 s.

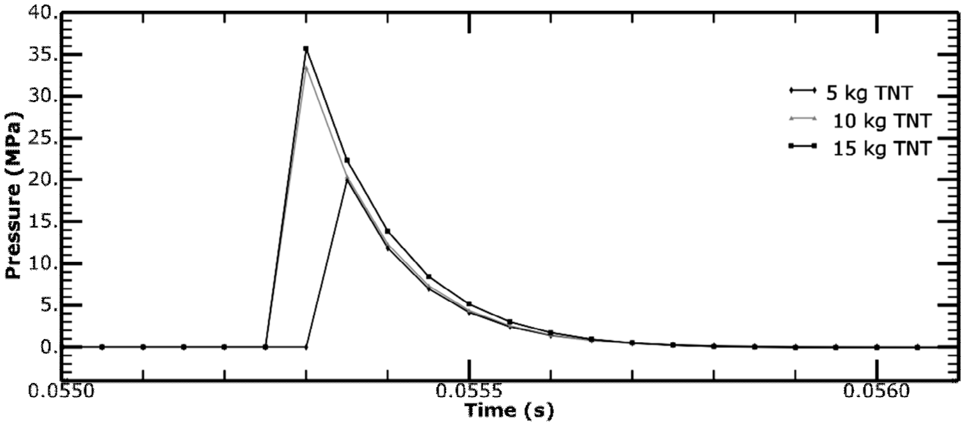

Fig. 7. Time history of generated air blast loads

Results. Von Mises stresses before air blast load are shown in Fig. 9. As expected the highest values were in corners. After air blast, plastic zones were created in the nearest places from explosion. Equivalent plastic strain in case of 5 kg TNT are shown in Fig. 10. Comparison of time history of maximum equivalent plastic strain and time history of maximum damage criterion for all scenarios are shown in Fig. 11, 12.

Conclusion. Numerical simulation of steel frame subjected to air blast load was presented. Analysis was carried on using the method explicit dynamics in software ABAQUS/Explicit. The results shows impact of weight of TNT. Method of explicit dynamics associated with damage mechanics and CONWEP generator is capable of simulate behavior of steel frame subjected to air blast.

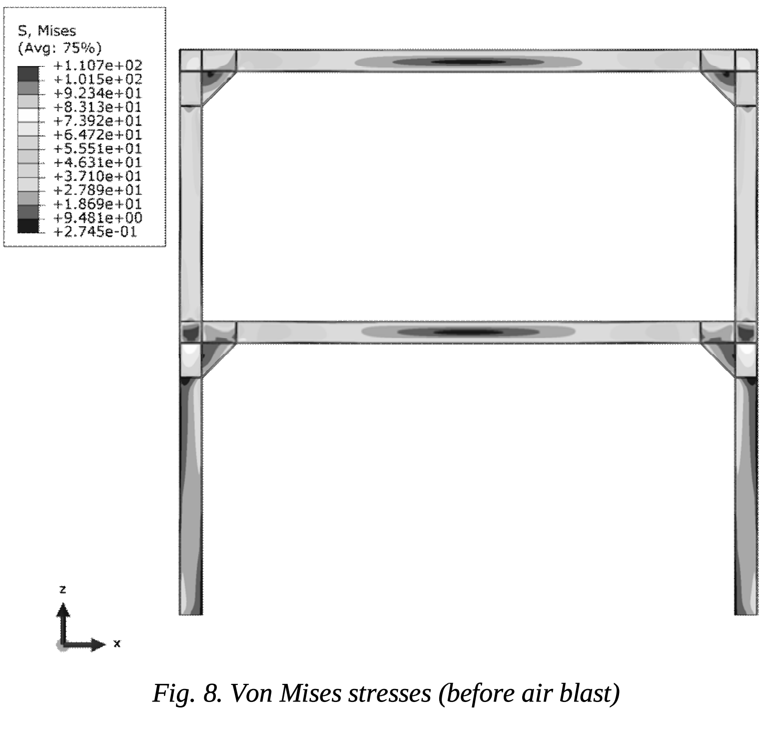

Fig. 8. Von Mises stresses (before air blast)

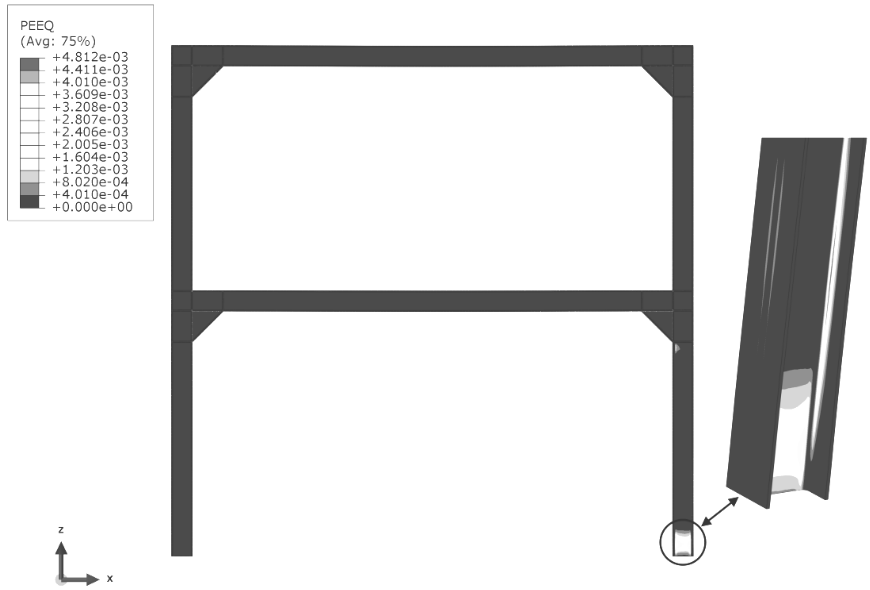

Fig. 9. Equivalent plastic strain – 5kg TNT (after air blast)

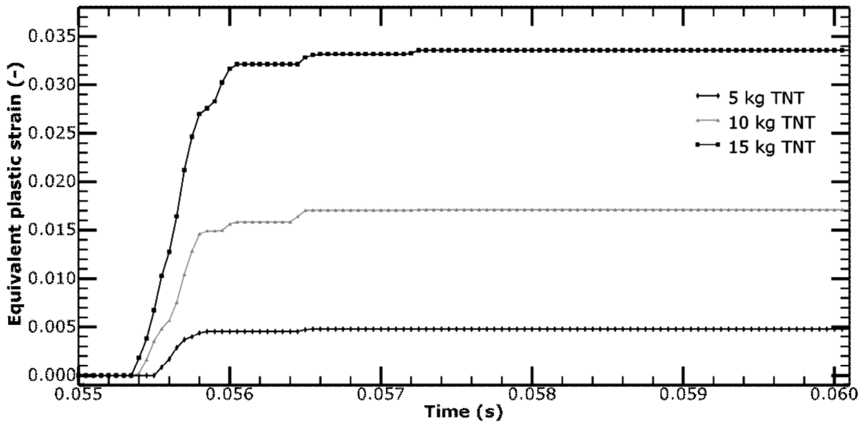

Fig. 10. Time history of maximum equivalent plastic strain

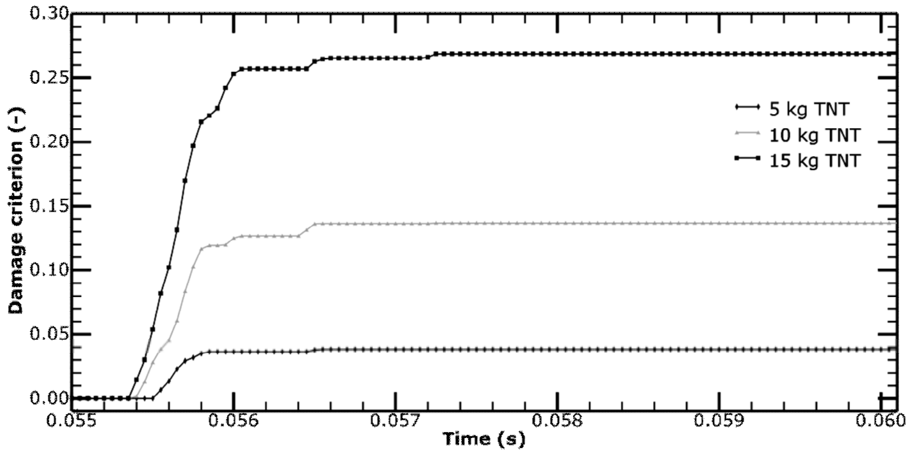

Fig. 11. Time history of maximum damage criterion

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