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Influence of blast-induced ground motion on dynamic response of masonry minaret of Yörgüç Paşa Mosque

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ABSTRACT

This paper focuses on the dynamic response analysis of masonry minaret of Yörgüç Paşa Mosque subjected to artificially generated surface blast-induced ground motion by using a three-dimensional finite element model. The mosque is located in the town of Kavak of Samsun, in Turkey. This study intended to determine the ground motion acceleration values due to blast-induced ground motions (air-induced and direct-induced) calculated by a random method. In order to model blast-induced ground motion, firstly, peak acceleration and the time envelope curve function of ground motion acceleration were obtained from the distance of the explosion center and the explosion charge weight and then blast-induced acceleration time history were established by using these factors. Non-stationary random process is presented as an appropriate method to be produced by the blast-induced ground motion model. As a representative of blast-induced ground motion, the software named BlastGM (Artificial Generation of Blast-induced Ground Motion) was developed by authors to predict ground motion acceleration values. Artificial acceleration values generated from the software depend on the charge weight and distance from the center of the explosion. According to the examination of synthetically generated acceleration values, it can be concluded that the explosions cause significant effective ground movements. In the paper, three-dimensional finite element model of the minaret was designed by ANSYS. Moreover, the maximum stresses and displacements of the minaret were investigated. The results of this study indicate that the masonry minaret has been affected substantially by effects of blast-induced ground motion.

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1. Introduction

Blasting is used in jobs such as construction, mining, oil and agriculture and forestry in our country and in the world. Blast technology is commonly applied to most civil engineering applications such as housing, railways, roads, dams, airports. However, while blasting is advantageous, it is also disadvantageous. Negative effects are occurred such as ground motion and air shock during blasting operations. This paper examines the effects of blast-induced ground motion on dynamic response of historical masonry minarets.

Once an explosion originates at approximate the ground surface, ground shock results from the energy given to the ground due to the explosion. Some of this energy is transmitted through the air in the form of air-induced ground shock and some is transmitted through the ground as direct-induced ground shock. Air-induced ground shock results when the air-blast shock wave compresses the ground surface and sends a stress pulse into the underlying media. The magnitude and duration of the stress pulse in the ground depend on the character of the air-blast pulse and the ground media. Generally, the air-induced ground motions are downward. They are

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maximum at the ground surface and attenuate with depth. However, the presence of a shallow water table, a shallow soil-rock interface, or other discontinuities can alter the normal attenuation process (UFC, 2008).

Direct-induced ground shock results from the explosive energy being transmitted directly through the ground. This motion includes both the true direct-induced motions and cratering-induced motions. The latter generally have longer durations and are generated by the crater formation process in cratering explosions. The induced ground motion resulting from both types have a longer duration than air-blast-induced ground shock and the wave forms tend to be sinusoidal (UFC, 2008).

2. Modelling of Blast-Induced Ground Motion

Blast-induced ground motions are high frequency and very short-term. This ground motions are effected by many parameters such as TNT charge weight, the distance between the explosion center and structure, depth of charge center, geotechnical properties of soil and rock. Seismic analysis is often done for all structures. Similarly, dynamic analysis even must be done for structures subjected to blast-induced ground motion. Therefore, this study is very important. Moreover, both in our country and in the world, researchers are interested in blast-induced ground motion (Wu and Hao, 2004, 2007; Ma et al., 2004; Hao and Wu, 2005; Lu and Wang, 2006; Wu et al., 2005; Singh and Roy, 2010; Hacıefendioğlu et al., 2012, 2014). Fig. 1 shows a structure at distance of R from charge center.

Peak particle acceleration and time envelope function of explosion pressure are used in blast-induced ground motion modelling. Peak particle acceleration (PPA) depends on TNT charge weight and the distance between the explosion center and structure. Non-stationary random process method is used for the modeling of blast-induced ground motions (Ruiz and Penzien, 1969). In this study, time histories of ground shocks are simulated by BlastGM (Artificial Generation of Blast-induced Ground Motion) software (Köksal, 2013). Thanks to this software, it is generated that artificial acceleration values depend on TNT charge weight and the distance between the explosion center and structure. Moreover, velocity, displacement and explosion pressure is generated with this software.

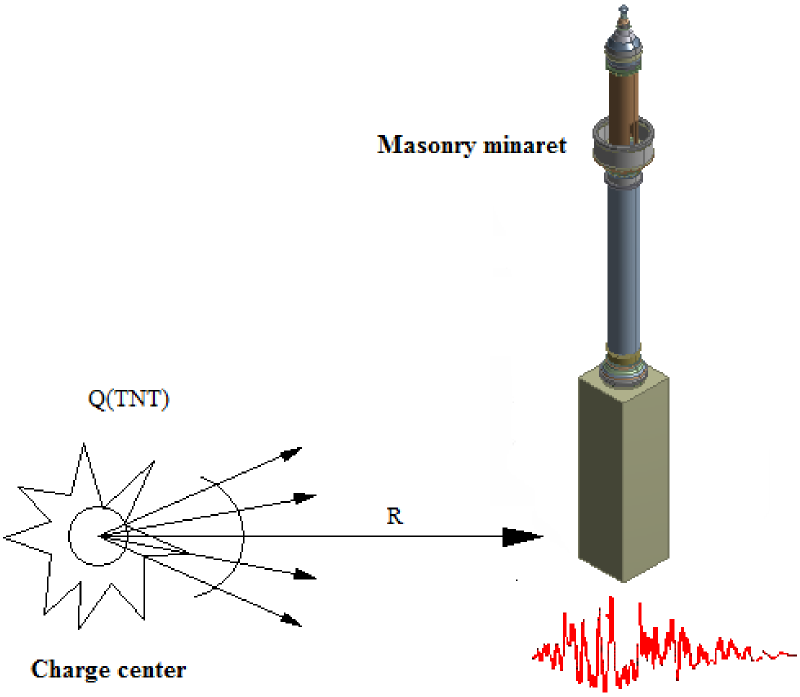

Fig. 1. Masonry minaret at distance of R from charge center.

3. Direct-induced ground motion

For the granite site, the PPA of acceleration time history was predicted as a function of charge weight and distance by

$$PPA = 3.979R^{-1.45}Q^{1.07}\,, \tag{1}$$

in which, PPA (g) is peak particle acceleration, R (m) is the distance between the explosion center and structure, and Q (kg) is TNT charge weight (Wu ve Hao, 2005).

Non-stationary random process method is used for the modeling of blast-induced ground motions in this study. In this method, the shape function ($p(t)$) and stationary process ($w(t)$) are used to characterize seismic ground vibration nonstationarity in the time domain (Bolotin, 1960; Jennings et al., 1969; Ruiz and Penzien, 1969). Acceleration time history can be expressed with two equations (Amin and Ang, 1968).

$$a_b(t) = p(t)\,w(t)\,. \tag{2}$$

The shape function is obtained by the Hilbert transform (Kanasewich, 1981). This function is used to blast induced ground motion as follows (Wu and Hao, 2005).

$$p(t) = \begin{cases} 0, & t \leq 0, \\ mte^{-nt^2} & t > 0, \end{cases} . \tag{3}$$

In this equation, m and n are parameters depend on non-stationary characteristics of ground motion. e is the base of natural logarithm. m and n parameters depend on t_p that is the duration for ground shock to reach its peak value from t_a (Wu and Hao, 2005).

$$t_P = \sqrt{1/_{2n}} , \tag{4}$$

$$m = \sqrt{2ne} . \tag{5}$$

From the experimental data, the arrival time at a point on ground surface with a distance R from charge center can be determined by Eq. (6).

$$t_a = 0.91R^{1.03}Q^{-0.02}/c_s , \tag{6}$$

where c_s is the P wave velocity of the granite site type. The empirical equation of the time instant t_p is estimated by Eq. (7).

$$t_p = 5.1 \times 10^{-4} Q^{0.27} \left(R/Q^{1/3}\right)^{0.81} = 5.1 \times 10^{-4} R^{0.81} , \tag{7}$$

where t_p (s) only depends on R distance. In this study, ground shock wave duration t_d is expressed as in Eq. (8).

$$t_d = t - t_a . \tag{8}$$

Fig. 2 shows the envelope function for simulated acceleration time histories on granite site at 20 m from the charge center with a charge weight of 100 kg. BlastGM is used to plot envelope function of blast-induced ground motion.

The wave forms of the bedrock acceleration are derived from second order differential equation as shown in Eqs. (9a, 9b).

$$z + 2\xi\omega_0 z + \omega_0 z = -a_b(t) , \tag{9a}$$

$$a_g(t) = -2\xi\omega_0 z + \omega_0^2 z . \tag{9b}$$

The solution of Eq. (9) can be obtained by using step-by-step procedure (Ruiz and Penzien, 1969). Fig. 3 shows acceleration time histories on granite site at 20m from the charge center with charge weights of 100 kg, 500 kg and 1000 kg.

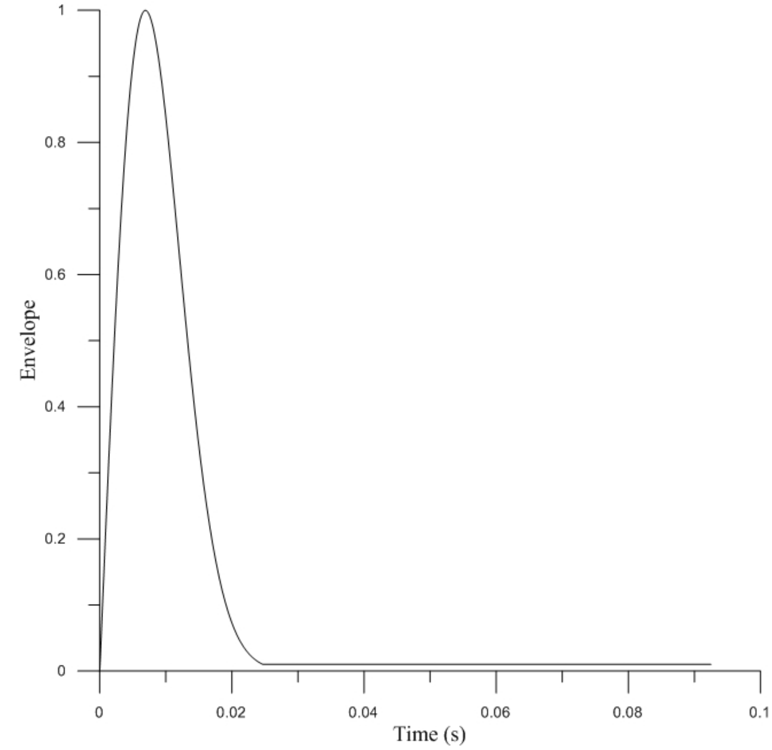

Fig. 2. Time intensity envelope function of blast-induced ground motion.

4. Finite Element Modelling of Yörgüç Paşa Mosque's Masonry Minaret

The mosque is located in the town Kavak of Samsun, in Turkey. It was built by Pasha Yörgüç in the Ottoman period. The first mosque made of wood. This mosque was collapsed. It was made of stone by Haji Yusuf in 1911. Its minaret complies with the Ottoman and the Seljuk architecture. In this study, masonry minaret of Yörgüç Paşa Mosque was selected for numerical modelling and dynamic analyses. Masonry structures can be subjected to ground motions due to the surface explosions.

Therefore, influence of blast-induced ground motion on dynamic response of masonry minaret of Yörgüç Paşa Mosque is examined by this study. Fig. 4 shows photograph, geometrical properties and finite element model of Yörgüç Paşa Mosque's minaret.

Masonry minaret of Yörgüç Paşa Mosque is modelled by using ANSYS (2014) that computes the dynamic response of the masonry minaret. The maximum height of the minaret is 25.55 meters. Three-dimensional (3D) SOLID45 elements are exhibited a quadratic displacement behavior, model the minaret body, the internal helical stair and the foundation. Table 1 shows material properties of the minaret taken from literature (Hacıefendioğlu, 2010).

Table 1. Material properties of the minaret.

Material	Elasticity Modulus (N/m^2)	Poisson's Ratio	Mass Density (kg/m^3)
Masonry minaret	$2x10^9$	0.2	1600

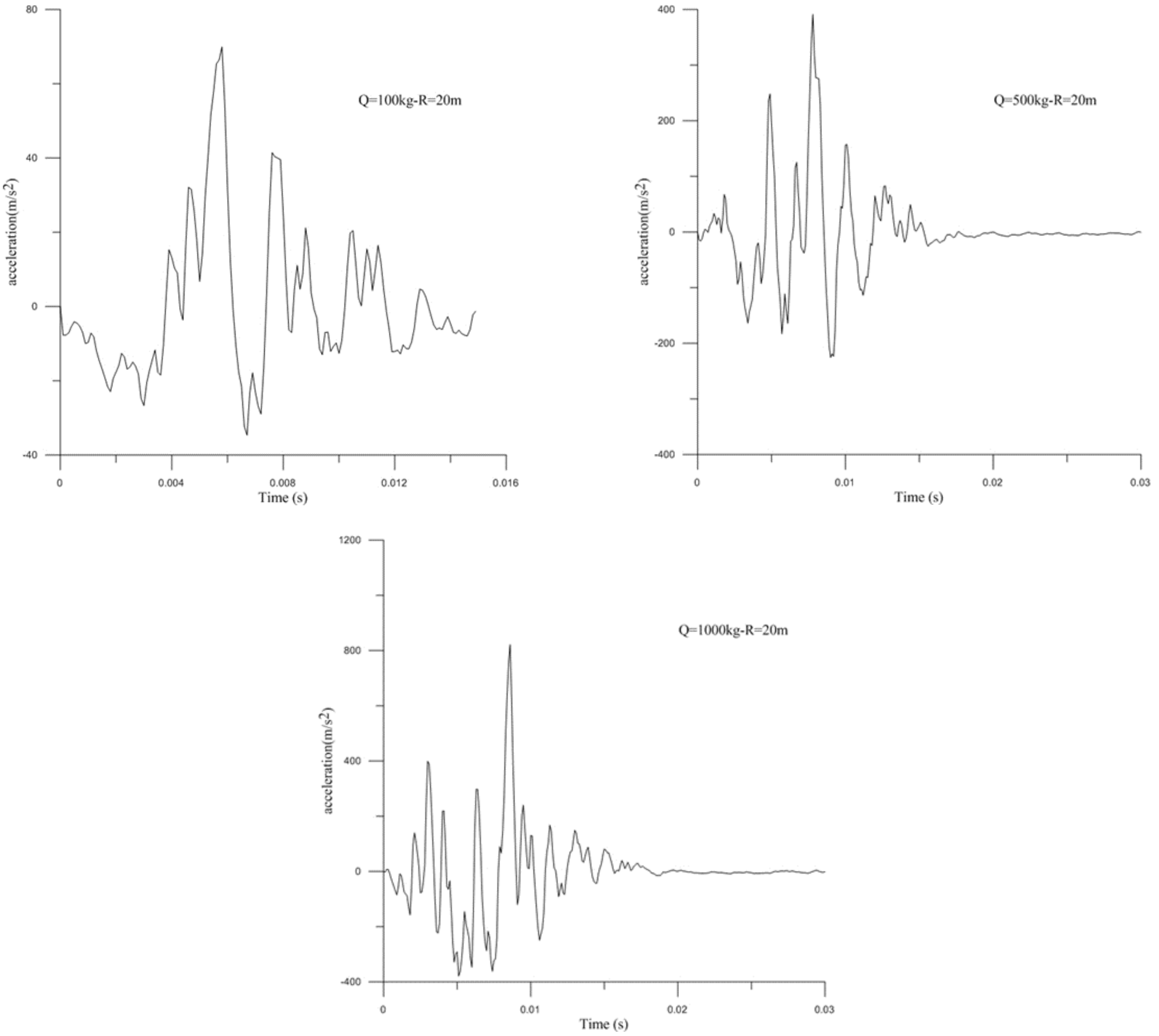

Fig. 3. Acceleration time histories of blast-induced ground motion.

5. Formulation of Equation of Motion

The matrix equation of motion with nonlinear stiffness under blast-induced excitation for multi-degree of freedom system can be written as

$$[\mathrm{M}]\{\ddot{U}\} + [\mathrm{C}]\{\dot{U}\} + [\mathrm{K}]\{U\} = \{F\}, \tag{10}$$

in which M, C and K are the mass, damping and stiffness matrices, respectively $\ddot{U}, \dot{U}$ and U are the vectors of the acceleration, velocity and displacement, respectively. Newmark-β method is used for blast-induced ground motion. In this method

$$\begin{bmatrix} U_{k+1} \\ \dot{U}_{k+1} \\ \ddot{U}_{k+1} \end{bmatrix} = F_N \begin{bmatrix} U_k \\ \dot{U}_k \\ \ddot{U}_k \end{bmatrix} + H_N F_{k+1}, \tag{11}$$

$$F_N = \frac{1}{\beta}\begin{bmatrix} \beta - \omega_n^2\alpha(\Delta t)^2 & \beta\Delta t - 2\zeta\omega_n\alpha(\Delta t)^2 - \omega_n^2\alpha(\Delta t)^3 & \frac{1}{2}\beta(\Delta t)^2 - \alpha(\beta+\gamma)(\Delta t)^2 \\ -\omega_n^2\delta\Delta t & \beta - 2\zeta\omega_n\delta\Delta t - \omega_n^2\delta(\Delta t)^2 & \beta\Delta t - \delta(\beta+\gamma)\Delta t \\ -\omega_n^2 & -2\zeta\omega_n - \omega_n^2\Delta t & -\gamma \end{bmatrix}, \tag{12}$$

$$H_N = \left(\frac{1}{m\beta}\right)\begin{bmatrix} \alpha(\Delta t)^2 \\ \delta\Delta t \\ 1 \end{bmatrix}, \tag{13}$$

$$q_k = \begin{bmatrix} U_k \\ \dot{U}_k \\ \ddot{U}_k \end{bmatrix}, \tag{14}$$

$$q_{k+1} = F_N q_k + H_N F_{k+1}\,. \tag{15}$$

Numerical analysis is done using Eqs. (11), (12), (13), (14) and (15) (Hart and Wong, 1999).

6. Numerical Application

Three different charge weights with single charge center were simulated to analyze the dynamic response of blast-induced ground motion. According to these ground motions, the maximum displacements and von Mises stresses (VMS) through the height of the minaret were evaluated. Fig. 5 shows displacement values at *t*=0.0059, 0.0079, 0.0087 sec in x-direction of ground motions occurred at 20m from the charge center with charge weights of 100 kg, 500 kg and 1000 kg. Fig. 6 shows von Mises stresses (VMS) at *t*=0.0059, 0.0079 and 0.0087 sec of ground motions occurred at 20 m from the charge center with charge weights of 100kg, 500kg and 1000kg.

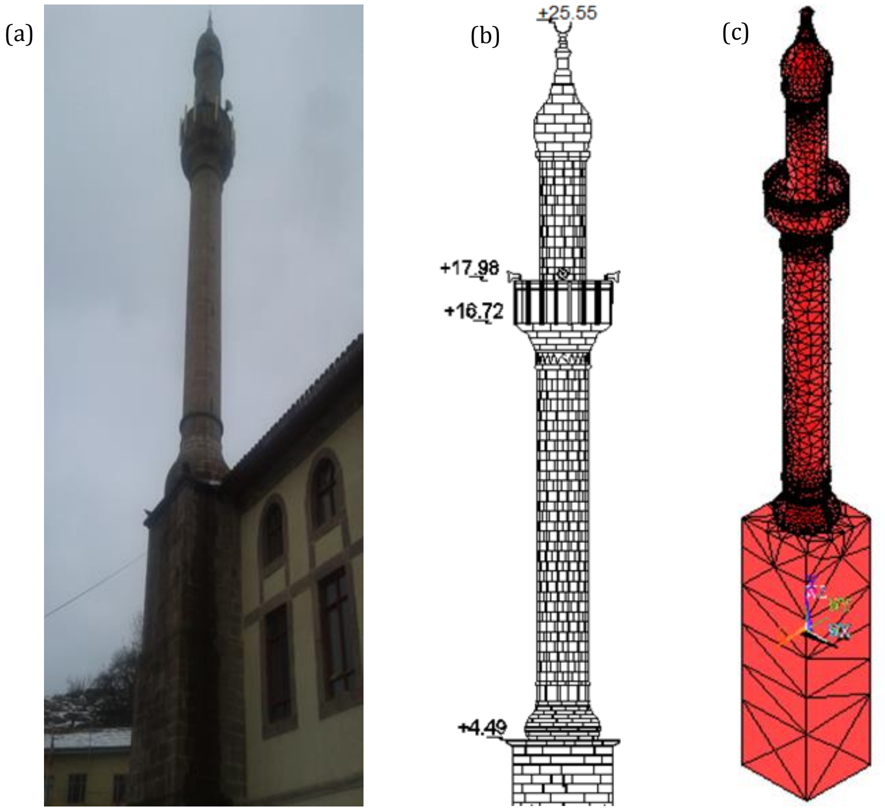

Fig. 4. (a) Photograph, (b) drawing and (c) finite element model of Yörgüç Paşa Mosque's minaret.

7. Conclusions

The main aim of this paper is to investigate the effect of blast-induced ground motions on dynamic response of masonry minaret structures. For this purpose, a minaret was chosen and modeled by the finite element method in ANSYS software program. Blast-induced ground accelerations is obtained in the BlastGM software that developed by authors. The dynamic response analysis is carried out for the masonry minaret of Yörgüç Paşa Mosque in Samsun, Turkey.

As a conclusion, while charge weight increases (constant charge center), displacements and von Mises stresses also increase. Therefore, it can be observed that blast-induced ground motions have a significant effect on dynamic behaviour of masonry minarets.

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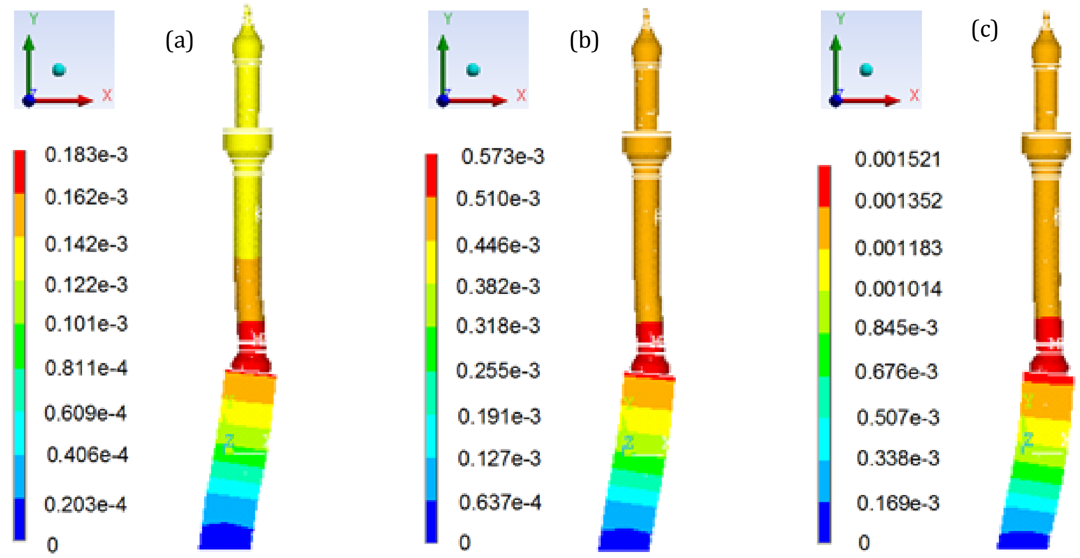

Fig. 5. Displacements obtained by blast-induced ground motion for: (a) 100 kg TNT-20m; (b)500 kg TNT-20m; (c)1000 kg TNT-20m.

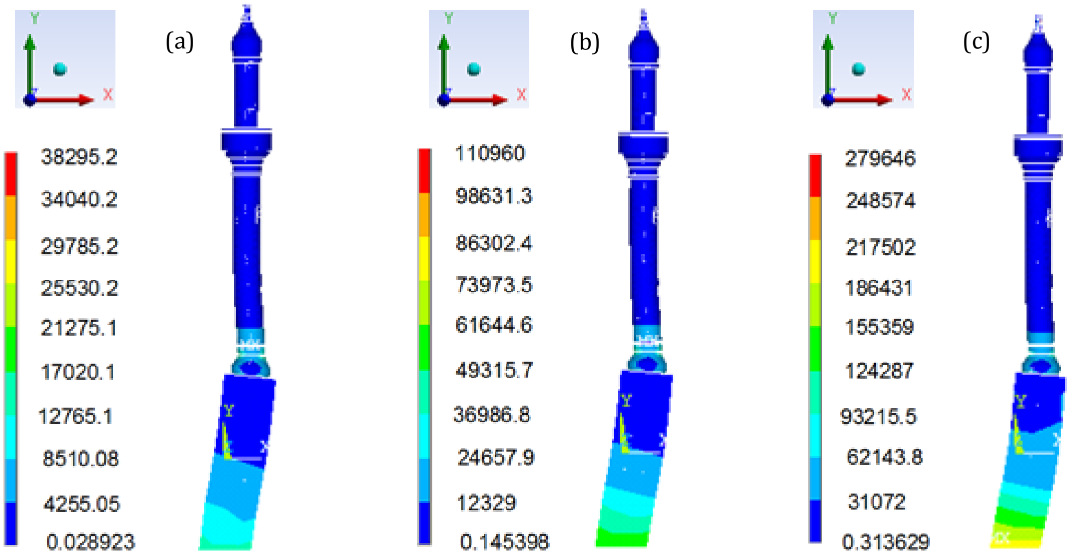

Fig. 6. von Mises stress contours obtained by blast-induced ground motion for: (a) 100kg TNT-20m; (b)500kg TNT-20m; (c)1000kg TNT-20m.

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