Journal of Structural Engineering & Applied Mechanics
2020 Volume 3 Issue 2 Pages 85-92
https://doi.org/10.31462/jseam.2020.02085092
www.goldenlightpublish.com

RESEARCH ARTICLE

Influence of blast-induced ground motion on dynamic response of reinforcement retaining walls

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Abstract

Blasting is used in jobs such as construction, mining, oil and agriculture and forestry in our country and the world. Blast technology is commonly applied to most civil engineering applications such as housing, railways, roads, dams, airports. Although this technology benefits many construction applications, it also causes some negative effects such as ground motion and air shock. This paper only studies blast-induced ground motion. The ground motion acceleration time histories are simulated using the software. The software generates acceleration time histories of blast-induced ground motions using peak acceleration and the time envelope curve function of ground motion acceleration. Moreover, it obtains shock response spectra determined from ground shock time histories. In this study, the influence of blast-induced ground motion on reinforcement retaining walls was investigated. These walls are very often built in Turkey. Therefore, the influence of blast-induced ground motion is important for them. The three-dimensional finite element model of the reinforcement retaining wall was designed. The maximum stresses and displacements of the reinforcement retaining wall were investigated. As a conclusion, when charge weight increases (constant charge center), displacements and Von Misses stresses also increase. Therefore, the blast-induced ground motion must also be taken into account for important structures such as retaining walls, bridges, dams and historic buildings.

Keywords

Reinforcement retaining walls; Blast induced ground motion; Finite element method; Modal analysis; Shock response spectrum analysis.

Received: 25 September 2019; Accepted: 20 April 2020
ISSN: 2630-5763 (online)

1. Introduction

Blasting is used in jobs such as construction, mining, oil and agriculture and forestry in our country and 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 the dynamic response of retaining walls.

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 are transmitted through the ground as the direct-

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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 depending on the character of the air-blast pulse and the ground media. Generally, the air-induced ground motions are downward. They are 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 [1].

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 has a longer duration than air-blast-induced ground shock and the waveforms tend to be sinusoidal [1].

2. Modeling of blast-induced ground motion

Blast-induced ground motions are high frequency and very short-term. These ground motions are affected 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. Moreover, both in our country and in the world, researchers are interested in blast-induced ground motion [2-18]. Fig. 1 shows the reinforcement retaining wall at a distance of R from the charge center.

Peak particle acceleration and time envelope function of explosion pressure are used in blast-induced ground motion modeling. Peak particle acceleration (PPA) depends on TNT charge weight and the distance between the explosion center and structure. The non-stationary random process method is used for the modeling of blast-induced ground motions [18]. In this study, time histories of ground shocks are simulated by BlastGM (Artificial Generation of Blast-induced Ground Motion) software [19]. 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 are generated with this software.

2.1. 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

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

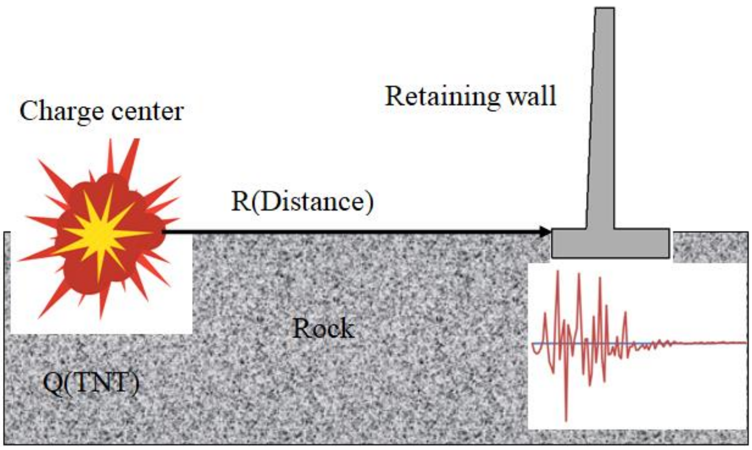


Fig. 1. Reinforcement retaining wall at a distance of R from the charge center

in which, PPA is peak particle acceleration, $g = 9.81$ m/s^2 is the acceleration of gravity, R (m) is the distance between the explosion center and structure, and Q (kg) is TNT charge weight [4].

The 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 [18,20]. Acceleration time history can be expressed by [21].

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

The shape function is obtained by the Hilbert transform [23]. This function is used to blast-induced ground motion as follows [4].

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

In this equation, m and n are parameters depend on non-stationary characteristics of ground motion. e is the base of the natural logarithm. m and n parameters depend on t_p that is the duration for the ground shock to reach its peak value from t_a [4].

$$t_p = \sqrt{1/2n} \tag{4}$$

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

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

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

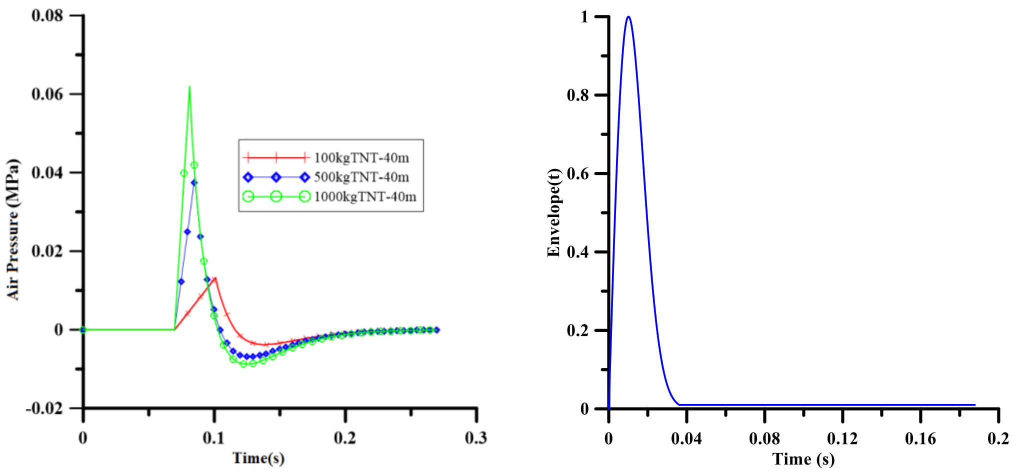
c_s is the P wave velocity of the granite site type. The empirical equation of the time instant t_p is estimated by the equation.

$$t_p = 5.1\times10^{-4}Q^{0.27}(R/Q^{1/3})^{0.81} = 5.1\times10^{-4}R^{0.81} \text{ (s)} \tag{7}$$

t_p is only depends on R distance. In the study, ground shock wave duration td is expressed as

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

Fig. 2a shows the simulated air pressure time histories in the horizontal direction on the granite surface at a distance of 40 m from the charge center with a charge weight of 100 kg, 500 kg,1000 kg, respectively. Fig. 2b shows the envelope function for simulated acceleration time histories on the granite site at 40 m from the charge center with a charge weight of 100 kg. The location of the pressure measurement point on the wall is the point at 40 m from the charge center in the horizontal direction. BlastGM is used to plot the envelope function of blast-induced ground motion.



(a) (b)

Fig. 2. (a) Air pressure and (b) time-intensity envelope function of blast-induced ground motion

The waveforms of the bedrock acceleration are derived from the second-order differential equation as

$$\ddot{z} + 2\xi\omega_0\dot{z} + \omega_0 z = -a_b(t)$$
$$a_g(t) = -2\xi\omega_0\dot{z} + \omega_0^2 z \quad (9)$$

The solution of Eq. (9) can be obtained by using the step-by-step procedure [18]. Fig. 3 shows shock response spectra and acceleration time histories in the horizontal direction on the granite site at 40m from the charge center with charge weights of 100 kg, 500 kg, and 1000 kg.

3. Finite element modeling of reinforcement retaining wall

Reinforcement retaining walls are special engineering structures that are used in many applications of civil engineering with many different goals. Highways embankments, in which a significant amount of earthwork is required, canals and water tanks, bridge abutments, material depository fields, and erosion and flood control are some of the most common engineering applications where reinforcement retaining walls are used. In this study, the reinforcement retaining wall was selected for numerical modeling and dynamic analyses. Reinforcement retaining walls can be subjected to ground motions due to the surface explosions. Therefore, the influence of blast-induced ground motion on the dynamic response of the reinforcement retaining wall is examined by this study. Fig. 4 shows a photograph, geometrical properties and finite element model of reinforcement retaining wall.

The reinforcement retaining wall is modeled by using ANSYS (2014) [23] that computes the dynamic response of structures. The maximum height of the reinforcement retaining wall is 3.50 m and the length of it is 6 m. The depth of the foundation is 0.40 m (see Fig. 4a). For the model, the quadratic element is used to model the reinforcement retaining wall. Three-dimensional (3D) SOLID elements are exhibited a quadratic displacement behavior. These elements have three degrees of freedom at each node. The finite element model includes 8695 nodes and 1500 solid finite elements in total. In the model, the chosen mesh of the solid model is 200 mm (see Fig. 4c). C30 material was assumed for the modeling. In the model, linear elastic material behavior was assumed and the stiffness degradation was neglected. The steel reinforcing bar was not modeled in this study. The reinforcement retaining wall has been rigidly fixed to the ground and the soil-structure interaction has not been taken into account. Table 1 shows the material properties of the reinforcement retaining wall taken from the literature.

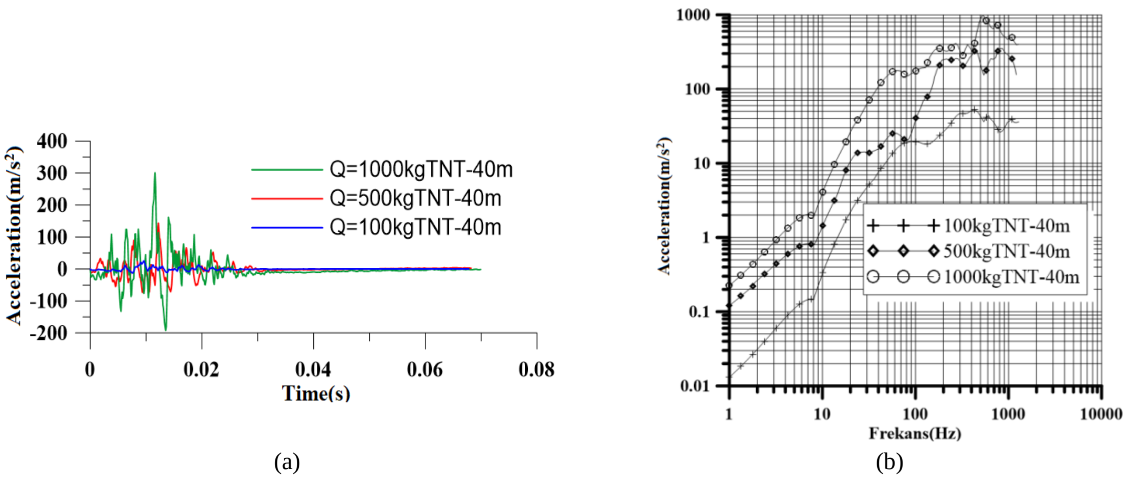
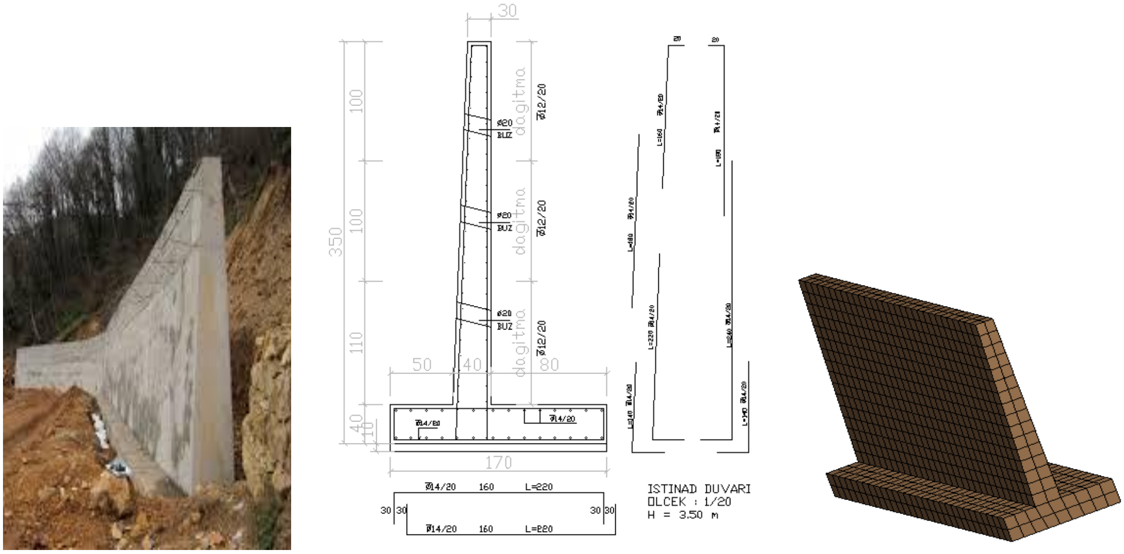


Fig. 3. (a) Acceleration time histories and (b) shock response spectrum of blast-induced ground motion.



(a) (b) (c)

Fig. 4. (a) Photograph, (b) drawing and (c) finite element model of reinforcement retaining wall.

Table 1. Material properties of reinforcement retaining wall

Material	Modulus of elasticity (GPa)	Poisson's ratio	Mass density (kg/m^3)
Concrete (C30)	32	0.2	2400

4. Blast induced numerical analysis

Three different charge weights with a single charge center were simulated to analyze the dynamic response of blast-induced ground motion. It is assumed that blasting occurs on hard ground with 100 kg, 500 kg and 1000 kg TNT explosive at a distance of 40m for blasting induced ground motion. These three ground motions were obtained by BlastGM software. The response spectra for ground motions were obtained with the same software. Response spectra were taken into consideration only in the *x*-direction. In ANSYS (2014) software, the reinforcement retaining wall is modeled with finite elements and the frequency ranges of the structure are determined by modal analysis. In the response spectrum analysis, the square root of the sum of the squares (SRSS) was used for combining the modes. Shock Response Spectrum Analysis was performed for three different blast-induced ground motion. According to these analyses, the maximum displacements and von misses stresses (VMS) through the height of the reinforcement retaining wall were evaluated. Fig. 5 shows the results of the modal analysis. Table 2 shows the frequencies obtained by the modal analysis.

Fig. 6 shows displacement values in the *x*-direction of ground motions that occurred at 40m from the charge center with charge weights of 100 kg, 500 kg, and 1000 kg. It can be seen from Fig. 6 that the maximum displacements can be read at the top side of the reinforcement retaining wall.

Table 2. First six frequencies of reinforcement retaining wall

Mode	Frequency (Hz)
1	23.558
2	34.083
3	61.352
4	109.040
5	119.890
6	133.710

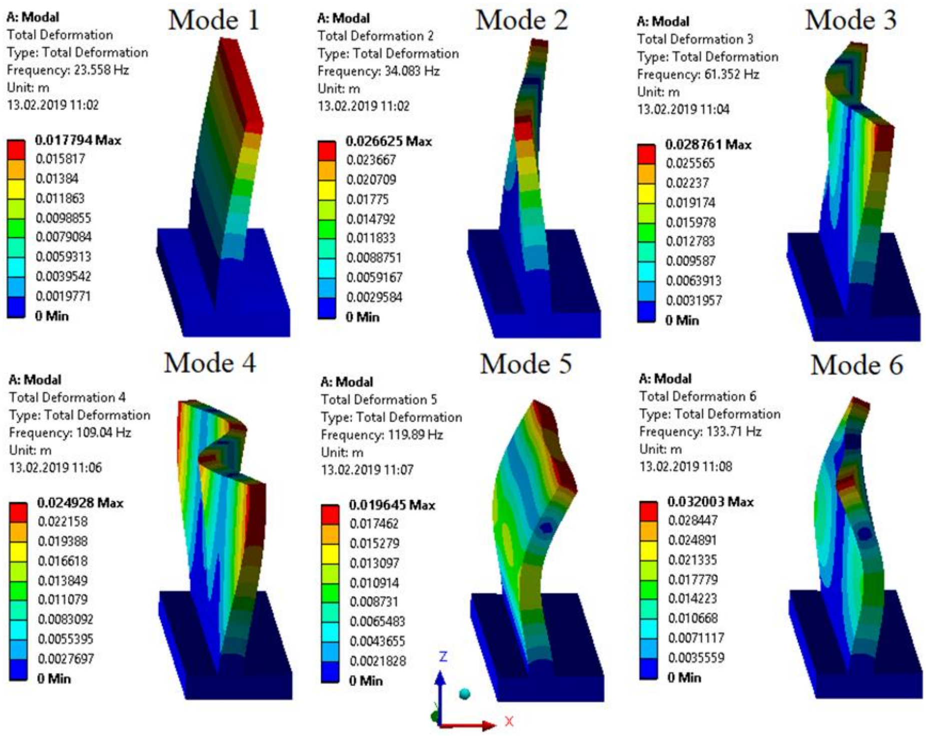


Fig. 5. Results of the modal analysis

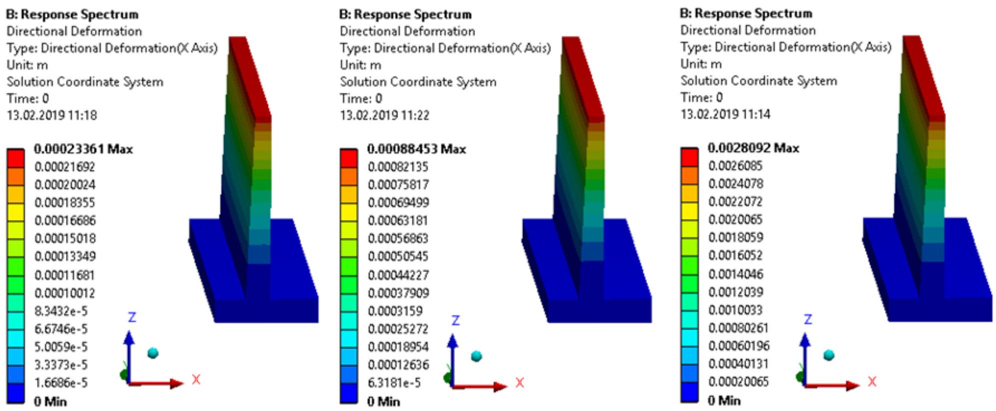


Fig. 6. Displacement contour diagrams in the *x*-direction obtained by blast-induced ground motion for (a) 100 kg TNT-40 m (b) 500 kg TNT-40 m (c) 1000 kg TNT-40 m

At these points, the maximum displacement value in the *x*-direction for the 100 kg, 500kg, 1000kg charge weight with 40 m is 0.234 mm, 0.855 mm, 2.81 mm, respectively. Fig. 7 shows von Mises stresses caused by blast-induced ground motion that occurred at 40 m from the charge center with charge weights of 100 kg, 500 kg, and 1000 kg. It can be seen from Fig. 7 that the maximum von Mises stresses can be read at the top of the foundation. At these points, the maximum von Mises stresses for the 100 kg, 500 kg, 1000 kg charge weight with 40 m is 0.363 MPa, 1.299 MPa and 4.251 MPa, respectively.

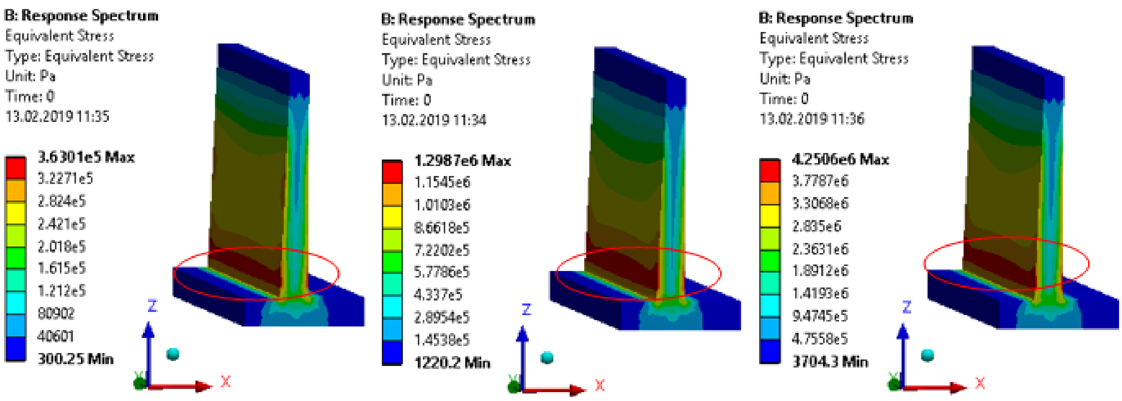


Fig. 7. Von Misses stress contours obtained by blast-induced ground motion for (a) 100 kg TNT-40 m (b) 500 kg TNT-40 m (c)1000 kg TNT-40 m

5. Conclusion

The main aim of this paper is to investigate the effect of blast-induced ground motions on the dynamic response of reinforcement retaining walls. For this purpose, a reinforcement retaining wall was chosen and modeled by the finite element method in ANSYS (2014) software program. Blast-induced ground accelerations were obtained in the BlastGM software. Shock Response Spectrum Analysis was performed for three different blast-induced ground motion. According to analysis results, at the top side of the reinforcement retaining wall, the displacement value in the *x*-direction obtained from 40 m distance from the blast center, 1000 kg of TNT produces 1016.6% and 194.9% larger displacement values than those of 100 kg and 500 kg, respectively. Moreover, at the point where occurring the maximum Von Mises stress values, 1000 kg of TNT produces 1070.93% and 227.29% larger Von Mises stress values than those of 100 kg and 500 kg, respectively. The effects of surface blast-induced ground shocks on nearby structures depend on the distance between the explosion centre and the structure and charge weight. As a conclusion, it can be observed that blast-induced ground motions have a significant effect on the dynamic behavior of reinforcement retaining walls. Therefore, the blast-induced ground motion must also be taken into account for important structures such as reinforcement retaining walls, bridges, dams and historic buildings.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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