Simulation of Underground Structures Explosion using Finite Difference Method for Different Applications

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ABSTRACT:

Analysis of underground structures under blast has challenges due to the complexity of blast dynamic loading and soil behavior. Due to the role of underground structures as a shelter and the vulnerability of these structures to explosive loads, it is vital to investigate and analyze the effect of explosions on these structures. The aim of this study is to investigate the effect of explosive projectile distance from the underground structure and the diameter of the explosive sphere on the underground structure. For this purpose, using the finite difference method and dynamic analysis, the underground structure was simulated for different distances of the explosive projectile and different diameters of the explosive sphere. In this study, the propagation of explosion waves in a spherical manner was considered by applying an explosion pressure on the wall of the explosive sphere. The results show that with increasing the distance of the underground structure from the center of the explosion, the maximum soil pressure on the maintenance system as well as the bending moment and axial force in the canopy and wall of the tunnel maintenance structure decrease exponentially. In addition, after the explosion wave reaches the tunnel maintenance system, the displacement and vertical velocity of the storage system particles in the tunnel crown is the highest. As the diameter of the explosive sphere increases, the bending moment at the crown and wall of the tunnel increases almost linearly, which is three times the slope for the tunnel crown.

Keywords:

Dynamic analysis, Projectile, Explosion, Underground structure, Numerical method.

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1. Introduction

In recent decades, due to terrorist threats around the world and the impact of this phenomenon on the underground space, the impact of the waves caused by the explosion of penetrating projectiles on the underground space maintenance system has been analyzed [1]. The analysis of the effect of blast loading on structures began in the 1960s. In 1959, the US Army published a publication entitled Structures Resistant to the Impact of Accidental Explosions [2]. After the 2004 London Underground bombings and the 2010 Moscow Underground bombings that killed 40 people, the analysis of the stability of tunnels under the load of the blast was considered by more researchers [1]. Many researchers such as Remnikov [3], Rashiddel et al. [4] and Wang et al. [5] have studied this issue.

Studies show that research on buried explosive loading for underground structures and how to apply explosive load on these structures has received less attention from researchers. Most research in the field of explosive loading focuses on surface explosions. The propagation of the blast wave causes stresses and induced forces on the underground space maintenance system, but this issue has received less attention in the analysis and design of underground spaces. In this study, using the finite difference numerical method and FLAC3D software code, the effect of explosive projectile distance from the underground structure and the diameter of the explosive sphere on the forces and induced stresses caused by the explosion in the underground structure and the stresses and displacement around the structure are investigated.

2. Methodology

Due to the many assumptions that must be considered in analytical methods and the limitations of experimental methods and due to hardware and software advances in numerical methods, most researchers in recent decades have used numerical methods to solve problems. The finite difference method is one of the oldest numerical methods for solving differential equation systems that models the problem space continuously with the algorithms that are connected in nodes. In this study, the finite difference numerical method is used to study the explosion pressure time history using FLAC3D software [6].

Most researchers who have used numerical methods to solve explosion problems have used the analytical, quasi-analytical and experimental relationships provided by previous researchers to validate the numerical model. In this study, the relationships presented by Smith and Henrington [7] have been used to validate the numerical model. The geometry of the numerical model is 100 meters long in the direction of the x-axis, 20 meters wide in the direction of the y-axis and 65 meters high in the direction of the z-axis and the center of the model geometry is at the center point of the explosive sphere.

Hexagonal cubic zones were used to zoning the geometry of the numerical model. The dimensions of the zones are important for the correct propagation of the wave in the numerical model. The dynamic distortion that can occur in wave propagation in dynamic analysis is a function of the model conditions. Wave frequency and velocity affect the accuracy of wave propagation. Lysmer (1973) showed that for the wave propagation to be correct in the numerical model, the size of the smallest element must be approximately less than one-tenth to one-eighth the input wavelength with the largest frequency component [9]. The dynamic load in FLAC3D software can be applied using the history of acceleration, velocity, stress or pressure and force. In this research, the propagation of explosion waves in a spherical manner by applying explosion pressure on the wall of the explosion sphere with a time history of Figure (1) was considered. Also in this study, Riley damping was used to simulate the damping of wave propagation in soil.

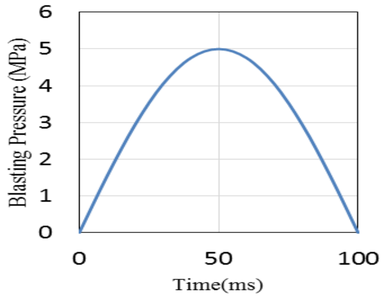

Figure 1. Explosion pressure time history

The values of maximum velocity and maximum induced pressure to the environment around the explosion sphere due to the explosion of 500 kg of TNT have been calculated both numerically and analytically by distances of 10, 15, 20 and 25 meters. The maximum velocity and pressure of the environment around the explosion relative to the distance from the center of the explosion is calculated. The results showed that the numerical model is in good agreement with the values of the analytical results.

3. Results and Discussion

In this study, the effect of two parameters of the distance of the underground structure from the blast site and the diameter of the explosive sphere from the ground surface on stresses, forces and displacement of the tunnel maintenance system to 8 m height, 16 m width and 20 m length with reinforced concrete storage system with specifications Table (1) was modeled and analyzed.

Table 1. Mechanical parameters of underground space storage system

Parameter	Value
System Material	Reinforced concrete
Density (Kg/m^3)	2500
Thickness (cm)	30
Poisson's ratio	0.25
Elastic modulus (GPa)	35
Material behavior	Linear Elastic

For numerical modeling of the maintenance system, three-node triangular shell elements with six degrees of freedom for each node were used. The distance of the crown of the underground structure from the center of the explosive sphere was considered for the values of 5, 10, 15, 20, 25 and 35 meters. The diameter of the explosive sphere was assumed to be one meter and the distance of the center of the explosive sphere from the ground was fifteen meters for all the mentioned values.

The maximum soil pressure on the maintenance system decreases exponentially with increasing distance of the underground structure from the center of the explosion, and up to a distance of 10 meters, the maximum pressure decreases with a high slope. The vertical displacement and velocity of the storage system particles in the tunnel crown just below the center of the explosive sphere is highest after the blast wave reaches the tunnel maintenance system.

The bending moment of the crown and the wall of the tunnel is reduced to a distance of ten meters with a very high slope, and for a distance of more than 10 meters, this slope is significantly reduced, which is more noticeable for the tunnel crown. The values of bending moment in the tunnel wall are higher than the tunnel crown, which are closer at a distance of less than 10 meters and more than 30 meters. Such a result is also observable for the axial force, and therefore the critical state of the induced forces to the retaining system in the tunnel wall, which must be considered in the design. But the trend of shear force changes is different from the axial force and bending moment. The shear force for distance less than ten meters in the crown is much more than the tunnel wall and is reversed for distance more than 10 meters.

To investigate the effect of explosive sphere diameter on the maintenance system, values of 20, 40, 60, 80 and 100 cm were considered for explosive sphere diameter in numerical modeling. The distance of the maintenance system from the center of the explosion was equal to 10 meters and the height of the center of the explosion from the ground was 15 meters. For an explosive sphere with a diameter of 60 to 100 cm, the maximum soil pressure on the underground structure with an almost double slope increases compared to an explosive sphere with a diameter of 20 to 60 cm. As the diameter of the explosive sphere increases, the vertical and horizontal displacements and velocities in the crown and wall of the tunnel increase exponentially, respectively, and the values of horizontal displacements and velocities are very small compared to the vertical displacements and velocities of the tunnel. As the diameter of the explosive sphere increases, the bending torque at the crown and wall of the tunnel increases almost linearly. This slope for the tunnel crown is three times that of the tunnel wall. The inductive axial force in the wall and the crown of the tunnel is equal for the diameter of the explosive sphere less than 40 cm and for values higher than 40 cm the amount of axial force in the tunnel crown increases with a greater slope than the tunnel wall. The same is true for shear force.

4. Conclusions

The results showed that the underground space and the stresses and induced forces in the underground space maintenance system have a significant sensitivity to the forces created by the explosion, which must be considered in the analysis and design of the underground space.

5. References

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