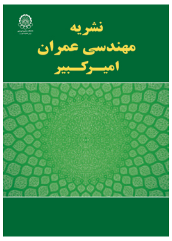

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Sensitivity Analysis of Un-lined Underground Spaces under Dynamic Loading using Numerical Methods

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ABSTRACT: In this study, the effect of explosive penetrating projectiles on the stability of underground spaces is investigated through numerical simulation using FLAC2D software. Considering effect of numerous factors on this issue, sensitivity analysis on parameters such as depth of overburden, the width of opening and stress ratio (ratio of horizontal stress to vertical stress) was carried out. The effect of each parameter on the damage around the location of explosion and underground space and the amount of deformation around the tunnel was investigated. For this purpose, a total of more than 35 numerical model were built and the required results were extracted. According to the results, the damaged zone around the opening is extended with increasing of excavation width and it is reduced with increasing of depth and stress ratio. The most important factor that affects the stability of opening is the depth of overburden such that with increasing depth of opening, the damage affected by explosion is reduced surrounding the excavation. Based on the deformation of the opening roof, the stability has been assessed and the effect of various factors on it has been investigated. Finally, a mathematical equation based on the results of numerical modeling is provided using SPSS software.

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1- Introduction

Explosive penetrating projectiles are among the weapons that can threaten the sustainability of underground spaces and buried structures. Penetrating projectile at high speed collided with the earth and penetrate to a certain depth and then explodes. Bayott simulated an explosion using the DYANA3D software by stress type boundary conditions and studied its effect on a buried concrete structure; he claimed that if the time interval of analysis was small, the application of stress boundary conditions will be appropriate to simulate the explosion [1]. Also, numerical modeling of explosive projectiles and its effect on underground structures have investigated by many researchers such as: Yang using ABAQUS in 2D [2], Castro using PLAXIS-2D [3], Nagy using JWL[1] state equations [4]. In this study, the effect of the GBU-28 explosive penetrating projectile on an unlined underground space, is investigated. Sensitivity analysis is performed on important parameters affecting the simulation results, and finally based on the obtained results, the relationships between the parameters are correlated by the SPSS statistical software and the diagram and its mathematical relation is presented.

2- Modelling and Simulation

In general, the phenomenon of explosion can be simulated in two ways, directly and indirectly; in the first type, the thermodynamic phenomenon of the explosion is directly simulated by numerical solution of the gas state equation. In the second method, the explosion is indirectly simulated by applying boundary conditions of stress or displacement to internal boundaries of a spherical hole with a specific small radius. In this way, a time history (1 ms) is defined with a specific pattern for acceleration or velocity particle at the excavation boundary. To estimate maximum explosion stress, the experimental relationship (Equation 1) [5] provided by the US Army Corps of Engineering was estimated to be about 45 MPa.

$$P_p = 0.407 f \rho_c \left(\frac{R}{Q^{1/3}} \right)^{-n} \quad (1)$$

The explosion pressure (Pp) decreases by increasing the mass of the explosive substance (Q) and increasing the distance from the explosion center (R). Using FLAC2D software, the geometry of the problem is modelled in axisymmetric mode according to Figure 1.

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1 Jones-Wilkins-Lee

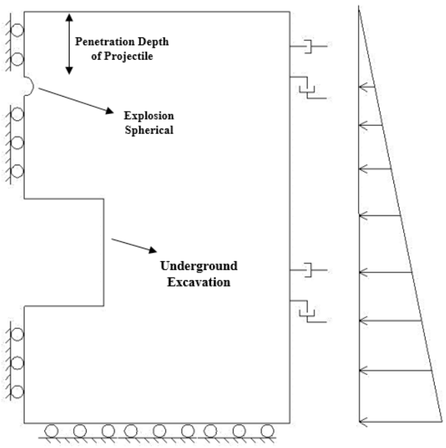

Figure 1. Model geometry and boundary conditions

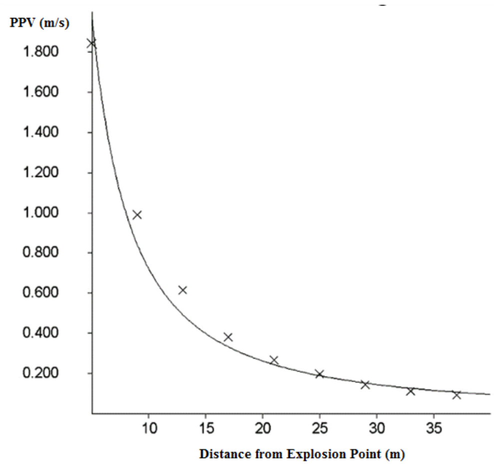

Figure 2. Comparison of PPV numerical model (cross-points) with experimental Equation 3 (continuous curve)

A new code is defined in FLAC2D in which the friction and cohesion of materials are varied related to the shear plastic strain and the tensile strain, in order to modify the softening of the mohr-colomb model, in which, it is assumed that the residual cohesion and friction of each element equal to half its initial value and the tensile strength of each component is zero. To modeling, the characteristics of Karaj rock formations belong to the South Alborz with low joints is used (GSI = 80), which mechanical properties of intact rock was extracted from [6] and the geomechanical properties of rock mass is estimated using the Hook-Brown failure criterion in Roclab software according to Table 1.

Table 1. Properties of intact rock [6] and the rock mass

Parameter	Unit	Intact rock	Rock mass
Density	gr/cm^3	2.5	2.5
Poisson's Ratio	-	0.3	0.3
Compressive Strength	MPa	95	31.2
Tension Strength	MPa	11.1	1.2
Elastic Modulus	MPa	11.4	10
Cohesion	MPa	6	0
Friction angle	deg.	50.4	0

In order to verify numerical model, the values of PPV[1] using an experimental equation presented by Dowding as Equation 2 [7], is investigated:

$$PPV = 18.3\, mm/s \left(\frac{30.5m}{R}\right)^{1.46} \times \left(\frac{Q}{4.54kg}\right)^{0.48} \times \left(\frac{2.4}{\rho}\right)^{0.48} \quad (2)$$

By comparing the PPV values obtained from modeling (cross-points) with Equation 3 (continuous curve), in Figure 2 there is an acceptable match between the numerical response and the empirical relation.

1 Peak Particle Velocity

To sensitivity Analysis, after selecting the most important factors, namely: type of projectile (GBU-28), geomechanical parameters of rock mass, stress ratio (0.5, 1, 2), excavation width (50 m with depth of (3, 5, 7, 10, 15, 22, 30 m), 100 m with depth of (10, 15, 20, 30, 40, 50 m)), totally 40 numerical cases were modelled.

3- Results and Discussion

In this research, the criterion for assessing the stability of excavation, the convergence of roof is selected. If in the static analysis the convergence ratio of the wall and roof to the radius of the opening is less than 2% then a light support system will be needed to ensure its stability [8] which according to this, the convergence of roof is assumed to be 10 cm in stability conditions.

$$RoofConvergence = 2.17\left(\frac{W}{D}\right)^{3.47} \times \frac{1}{K^{0.41}} \quad (3)$$

Then, performing a statistical analysis (SPSS software) on the numerical results, and using a multivariate linearization, a general relationship (Equation 3) was obtained for predicting excavation convergence. In Figure 3, the graph of the above equation is drawn and one can predict the convergence value in terms of various W/D ratio.

4- Conclusions

In this research, the effect of the explosion of penetrating projectile on unlined underground opening has been investigated through sensitivity analysis and its stability in terms of different variables such as depth and dimensions of opening, stress ratio were evaluated. It was concluded that with increasing depth, damage significantly decreases to opening. Also, the excavation stability decreases when its width increases and the stress ratio decreases. Excavation depth is the most important parameter in the stability of underground spaces. Figure 3 illustrates the final output of this research, in which the relationship between excavation width, depth, stress ratio and roof convergence due to explosion of penetrating projectile can be analyzed.

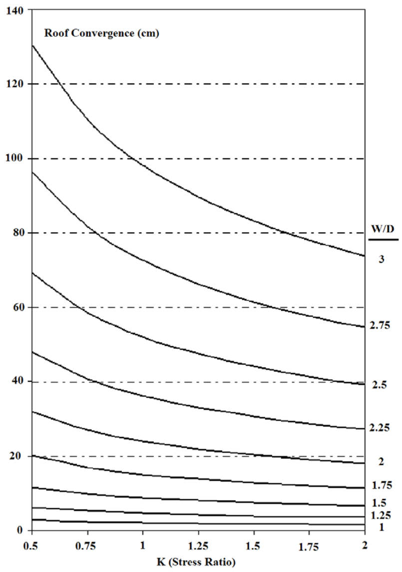

Figure 3. The excavation roof convergence due to projectile explosion vs. its width, depth and stress ratio

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