Effect of Rock Mass Discontinuities on Shock Wave Attenuation Produced by Ground Surface Explosion

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ABSTRACT

The impact of explosive load must be considered in design of civil defense structures. An explosion occurring on or below ground level generates a ground shock wave that affects underground structures. Current knowledge about the spectrum of induced vibrations in underground structures is limited.

The computer code UDEC offers an opportunity to model the propagation of ground shock waves as well as the rock mass discontinuities. This paper presents the rock mass discontinuities effects on the shock waves attenuation.

The studies revealed that discontinuities (with low stiffness parameters) are playing a vital role on reduction of explosion effects on underground structures.

Keywords:Underground structures; Wave propagation; Wave damping; Discontinues media; distinct element method; Dynamic analysis; Crater

1. INTRODUCTION

Analysis of induced vibrations on an underground structure which subjected to explosive loading must be included the shock wave propagation in discontinues rock mass. Surface explosions will create craters of different sizes according to the magnitude, W (weight of charge), and the characteristics of the rock mass.

From physical considerations one may conclude that the same charge W will create higher maximum amplitude of the shock wave when detonated in a confined condition than when detonated on the surface (unconfined). Crater building and energy transmission by surface explosions are thus questions which have been the prime target of investigation over a long period. Unfortunately this field of research is so wide and the results so uncertain that it is beyond the scope of the present text to study it in detail according to the Persen's theory (Persen, 1975). An actual crater replaced with a theoretical one, and then, assumed that the dynamic load, represented as a mechanical pressure acting normal to the crater boundary uniformly distributed. Then with modeling and analyses of such instantaneous loading on the discontinuous rock mass, using UDEC software code, the effect of discontinuities on shock wave dissipation has been studied.

2. CRATER DIMENSIONS AND DYNAMIC LOADING

According to the Persen's theory one can replace the actual crater presented in Fig. 1 with a theoretical one same as Fig. 2.

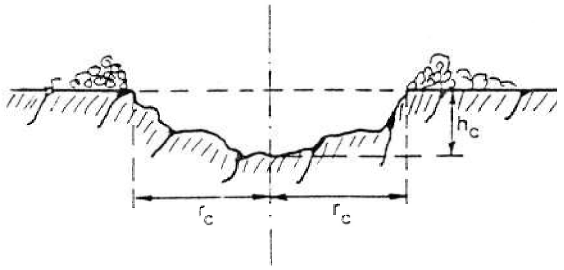

Fig.1 - Crater left by a surface explosion

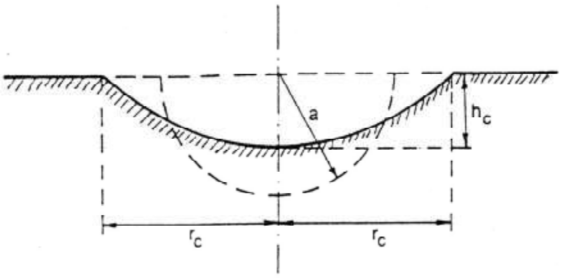

Fig. 2 - The theoretical crater

Volume of the masses "excavated" by the explosion can be computed through an assumed parabolic shape of the crater. The crater volume, V_C, is proportional to the charge weight,W. This means that one has an equivalent half-sphere with the radius, a, is to be determined so that it's volume is V_C.

Thus the relation between a, and, r_c , will be as Eq. 1:

$$a = \frac{2}{3} r_c \tag{1}$$

The situation along the vertical axis through the center of the crater would be similar to that of a confined explosion (Persen, 1975). This statement can be supported from consideration of the analytical solution. Thus it may be acceptable that if measurements are made along the said axis, the results from the solution to the confined explosion problem could still be applicable.

So, the amplitude of shock wave that is produced by surface explosion, along this axis, can be calculated from Eq. 2, that related to confined explosion of a point source in elastic, isotropic and homogeneous, media (Achenbach, 1975).

$$u_i = \frac{1}{4\pi C_p^2} \frac{\partial}{\partial x_i} \left[\frac{1}{r} f(t - \frac{r}{C_p}) \right] \qquad r^2 = x^2 + y^2 \tag{2}$$

Where C_P is the P-wave velocity, and f(t) is the source time history.

If the source time history is assumed as: $f(t) = \begin{cases} 0 & t < 0 \\ 1 & t \geq 0 \end{cases}$

Then by integration of Eq. 2 we have:

$$u = -\frac{1}{2\pi \cdot C_p} \cdot \frac{t}{r^2}\left[\frac{t^2 C_p^2}{r^2} - 1\right]^{-\frac{1}{2}} \qquad t > \frac{r}{C_p} \qquad (3)$$

Where u is the radial displacement, and r is the radial distance from wave source

So the radial velocity time history will be according to Eq. 4:

$$v = -\frac{1}{2\pi C_p} \cdot \frac{1}{r^2}\left[\frac{t^2 C_p^2}{r^2} - 1\right]^{-\frac{3}{2}} \qquad t > \frac{r}{C_p} \qquad (4)$$

According to above assumptions, a shock wave represented in Fig. 3 is acting normal to crater boundary (a semicircular shape of crater is assumed according to the Persen's theory) which is uniformly distributed along it.

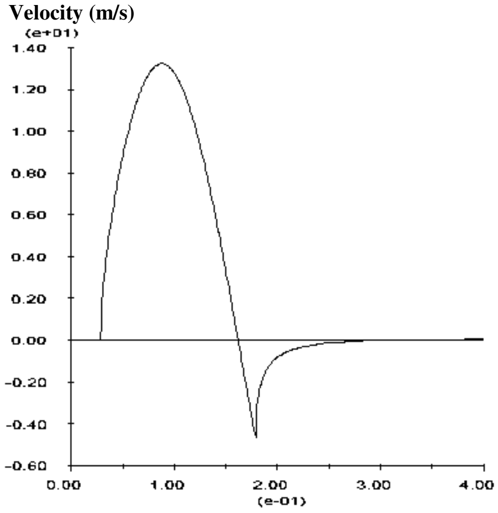

Fig. 3 - Input radial velocity time history

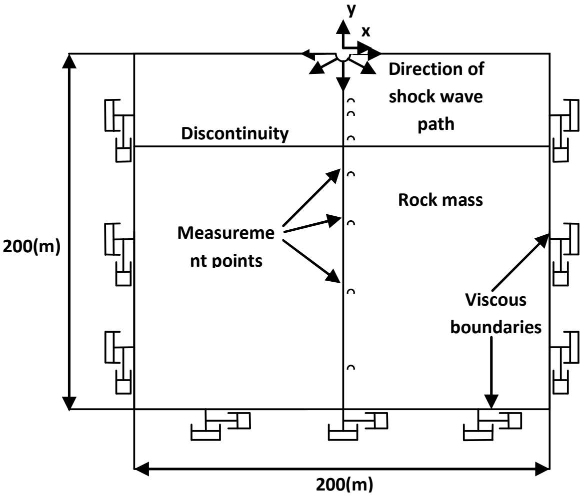

Fig. 4 - Model of geometry and boundary conditions

3. NUMERICAL MODEL

3.1 Model Geometry and Boundary Condition

Model dimensions and boundary conditions are shown in Fig. 4. The crater is considered to have a diameter of 7.0 meters. This value is based on the experiences of the type.

The model size has to be limited by artificial boundaries. For these boundaries a viscous boundary is available in UDEC that can absorb kinetic energy and minimize wave reflections for outward propagating waves. Viscous boundary conditions are applied for the lower horizontal boundary and the left and right vertical boundaries.

3.2 Grid Discretization

Kuhlemeyer & Lysmer (Itasca, 1999) show that for accurate representation of wave transmission through a model, the spatial element size, Δl, must be smaller than approximately one-tenth to one-eight of wavelength of the input wave (dynamic load). This requirement is expressed in the following relation:

$$\Delta l \leq \lambda / 10 \qquad (5)$$

Where λ is the wavelength associated with the highest frequency component that contains appreciable energy.

The time history for the dynamic load multiplier on the crater boundary was estimated by using the Eq. 4.

According to Eqs. 4 and 5, the element size, in the models has been selected equal to five meters.

3.3 Damping

Natural dynamic systems show some degree of damping when subjected to dynamic loading. In rock masses, damping is mainly due to energy loss as a result of internal friction in the material. The damping in a numerical calculation should ideally reproduce the energy losses in the natural system when subjected to dynamic loading. In rock masses, natural damping is mainly hysteretic (i.e., independent of frequency), but this type of damping is difficult to reproduce numerically (Itasca, 1999).

There are two means of supplying damping to a UDEC simulation (i) by use of damping schemes such as Rayleigh damping or local damping and (ii) by use of plasticity constitutive models. During yield, plasticity constitutive models can dissipate a considerable amount of energy. In the calibration modeling, Rayleigh damping was used in combination with Mohr-Coulomb plasticity model.

3.4 Material and Discontinuities Models

The Mohr-Coulomb material model has been used in blocks material modeling. This model has a shear yield surface that is defined by the strength parameters cohesion and friction angle. The discontinuities model is the simple Coulomb shear model.

4. MODELING RESULTS

Three different models are used in this study - (a) a continues rock mass for examining the effect of rock mass strength parameters in propagation of blast wave and critical depth (the depth of surface explosion plastic zone), (b) a rock mass containing a single joint at different location and different stiffness for examining the effect of a single joint in the propagation of blast wave, and (c) a rock mass containing one joint set with 10 meter spacing for investigating the influence of joint angle on blast wave propagation.

To satisfy the accuracy requirement for wave propagation modeling, each block in the UDEC models is subdivided into a mesh of triangular constant strain finite elements.

Figure 5 shows the results of peak velocity distribution along the y-axis. It can be seen that lower rock Young's modulus causes greater attenuation to the blast wave. It shows that in a continuum-based medium, lower rock strength causes greater dissipation to shock wave.

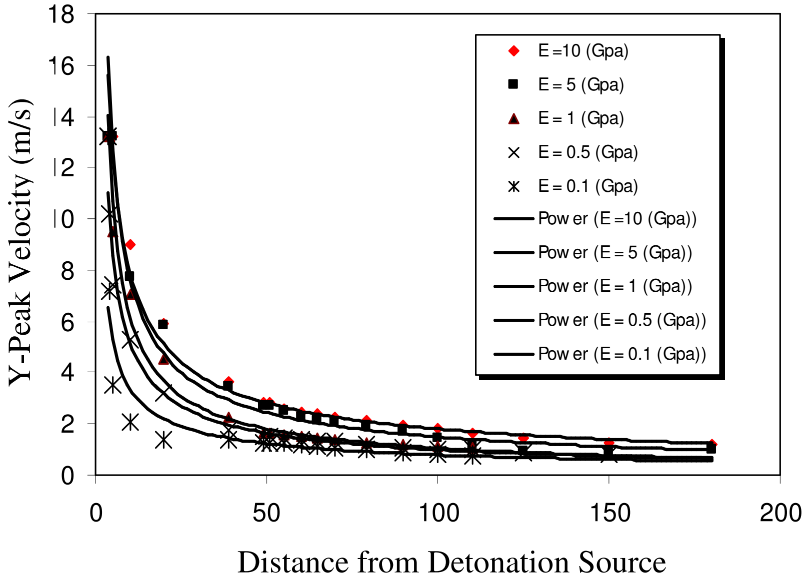

Figure 5 - The effect of rock mass strength parameters on shock wave dissipation

Figure 6 depicts the critical depth versus Young's modulus of rock mass. It can be noticed that in harder rocks with upper Young's modulus, the critical depth is closing to a constant value.

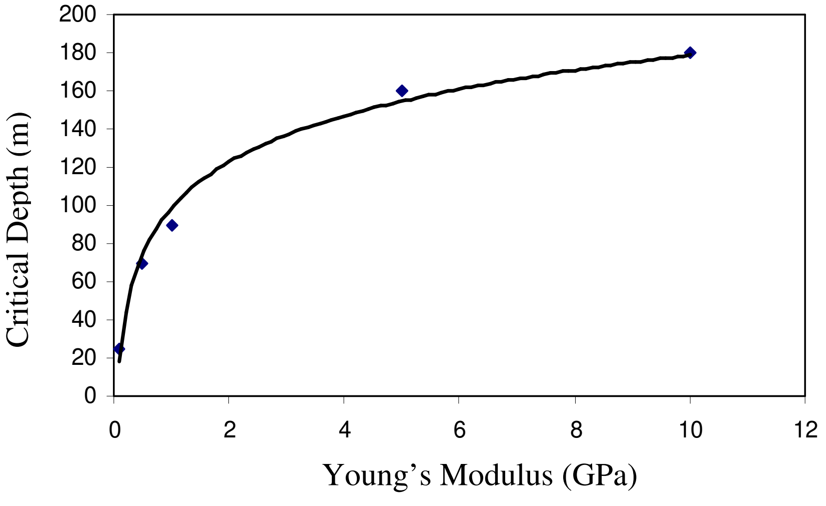

Fig. 6 - Critical depth vs. Young's modulus

4.1 The effect of a single joint

A single joint at distances 15, 30, 40, 60, 80 m from the explosive charge is used in each modeling. Figure 7 shows the results of peak velocity in different joint locations. It can be seen that the joint induces a sudden attenuation in blast wave wherever the joint is located. It follows from the propagation theory that the reflection and transmission occurs and energy of blast wave dissipates when the shock wave reaches a joint.

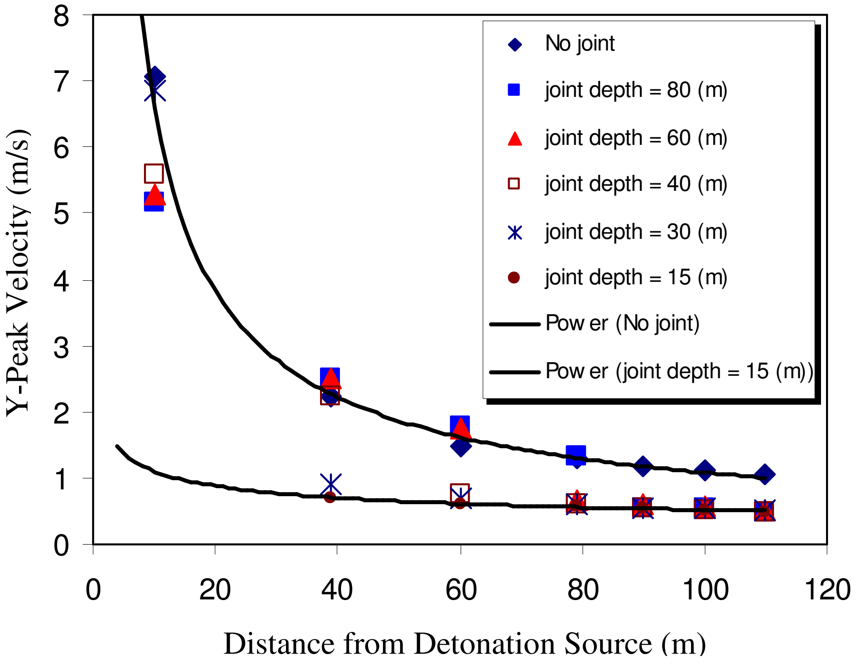

Fig. 7 – The effect of joint distance from explosive charge on shock wave attenuation

Figure 8 shows the joint stiffness which has significant influence on wave attenuation. Lower joint stiffness causes greater attenuation to the blast wave, due to larger deformation and more energy absorption.

4.2 The effect of a single joint set

One joint set is included in UDEC models and computations are carried out by taking the different joint dip angle with ground surface as 0, 20, 40, 45, 60, 75, 90 degree in each modeling.

Figure 9 shows the results obtained for different joint direction. It can be seen that, if the joint trend angle with ground surface, is about 60 degree, then it will be the most suitable condition for shock waves dissipation and reduction in the surface explosion damage effects.

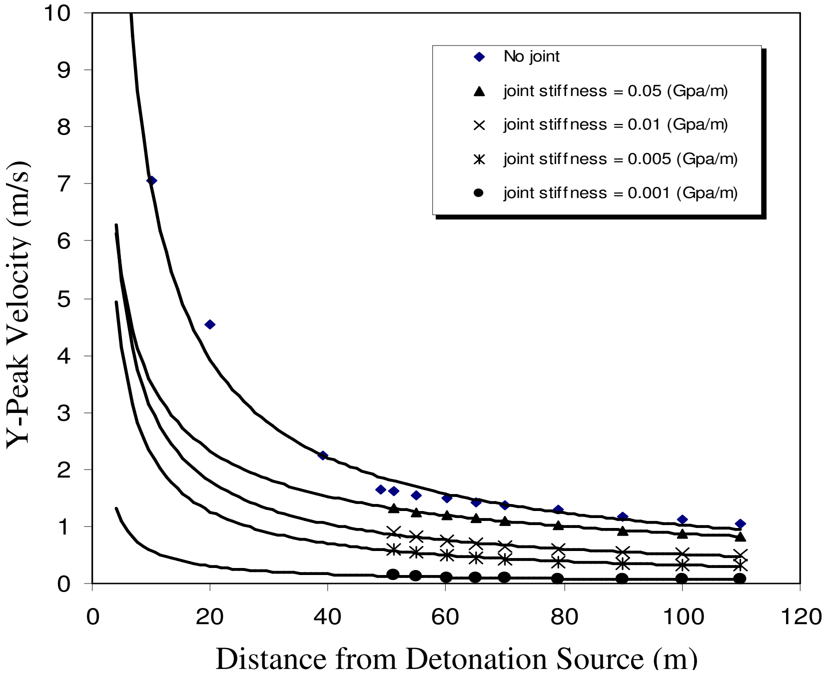

Fig. 8 - The effect of discontinuities stiffness on shock wave attenuation

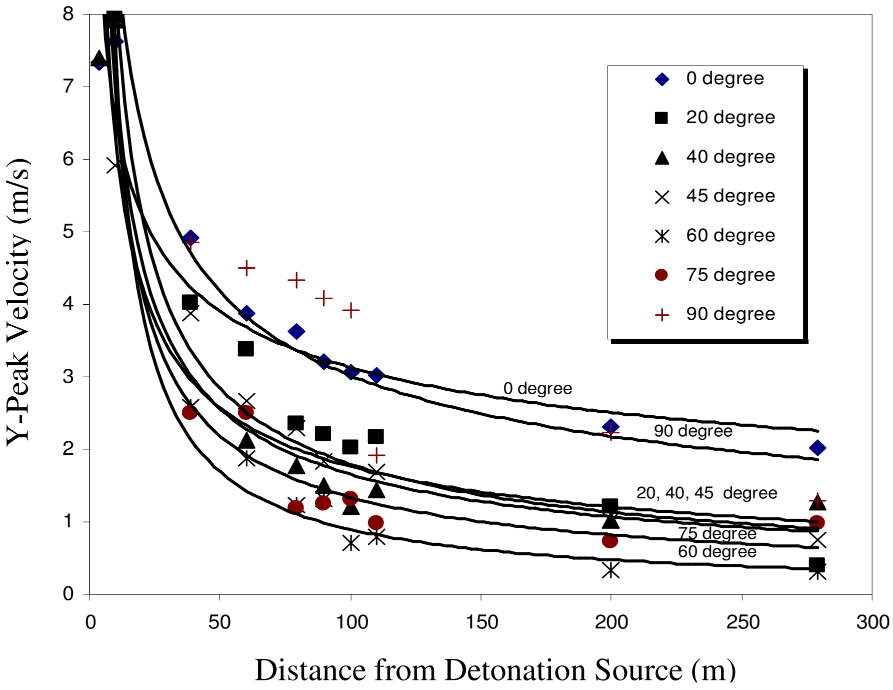

Fig. 9 - The effect of discontinuities dip angle on shock wave attenuation

5. DISCUSSION AND CONCLUSIONS

The discrete element code UDEC is capable of modeling shock wave propagation in jointed rock masses. UDEC offers a distinct advantage in modeling the blast wave propagation and the response of the jointed rock masses, as actual joints are represented in the model. However, UDEC is not able to simulate the explosion process. Explosion input, therefore, needs to be provided to the UDEC modeling. In the UDEC modeling, each deformable block can be subdivided into a mesh of triangular finite elements to satisfy the accuracy requirement.

The effect of the joints on wave attenuation is of great importance in understanding wave propagation in jointed rock masses. The modeling results clearly show that the joints in rock masses produce fast attenuation in wave propagation. In other words, the existence of joints in rock masses may help to attenuate a shock wave produced by surface explosion. This study on the effect of a single joint illustrates that when the shock wave reaches the joint, it will be suddenly attenuated. This is in line with the commonly accepted belief that a joint filters the shock wave due to the wave transmission and reflection at the joint surface and the energy dissipation where the joint is displaced.

The joint stiffness is an important parameter in representing the deformability of the joint. The study on the influence of joint stiffness indicates that a joint with lower stiffness reflects more, and causes greater attenuation to the shock wave. This agrees with the general understanding of the response of joints in wave propagation that the lower joint stiffness (joints with clay filling) produces the more wave attenuation, and the studies about this subject (Chen and Zhao, 1998 and Cai and Zhao (2000) and Fan et al. (2003)).

Furthermore it has been deduced that if the angle between the direction of shock waves path and the discontinuities direction is about 30 degree, then it will be the most suitable for shock waves dissipation and reduction in the surface explosion damage effects.

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