

PREDICTION OF EDZ (EXCAVATION DAMAGED ZONE) FROM EXPLOSIVE DETONATION IN UNDERGROUND OPENINGS

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ABSTRACT

The prediction of damage to the rock mass is a very important factor to evaluate the quality of the excavation process in tunneling, so that it would allow the optimization of explosive charges utilized in successive blasting rounds, as well as lowering risks of instability from rock loosening, less support costs and water inflows.

Upon developing a mathematical approach to evaluate rock damage from underground blasts, practical applications were accomplished to confirm it, both in tunneling excavations and underground mining. Examples of these studies are described in detail.

1. INTRODUCTION

The detonation of explosives confined in boreholes generates a large volume of gases at high temperatures (2000 – 5000 °C) and high pressures (10 – 40 GPa). The sudden application of these effects to the cylindrical surface of the hole generates a compressive stress pulse in the rock, which may be a source of damage in the surrounding zone.

The dimensions of that zone depend on the size of explosive charge detonated, rock's dynamic strength and density, wave velocity propagation, and vibration velocities transmitted to the rock mass.

2. MECHANISMS OF EDZ FROM EXPLOSIVE DETONATION IN UNDERGROUND OPENINGS

When an explosive charge detonate inside a borehole several zones can be distinguished in the surrounding rock: 1) Zone of crushing, 2) Zone of radial cracking, 3) Zone of extension and expansion of fractures and 4) Elastic Zone, where no cracks are formed. The damage that may occur in nearby rock happens behind the elastic zone (Fig.1 left).

Excavation of underground openings by rock blasting methods results in fragmentation within a certain volume that should not exceed the perimeter established in the corresponding design. Deviations of that perimeter from their outside and inside limits are called *overbreak* and *underbreak* respectively, with the word *backbreak* used when overbreak is excessive. The more general concept of *EDZ (Excavation Damaged Zone)* applies to the fractured and fragmented rock volumes that surround a cavity upon blasting, also called *DOW (Damage to the Opening Wall)* by Maerz N.H. et al.,1996 - see Fig. 1.

These deviations are normally undesirable because they generate higher costs in the constructive process of the underground opening.

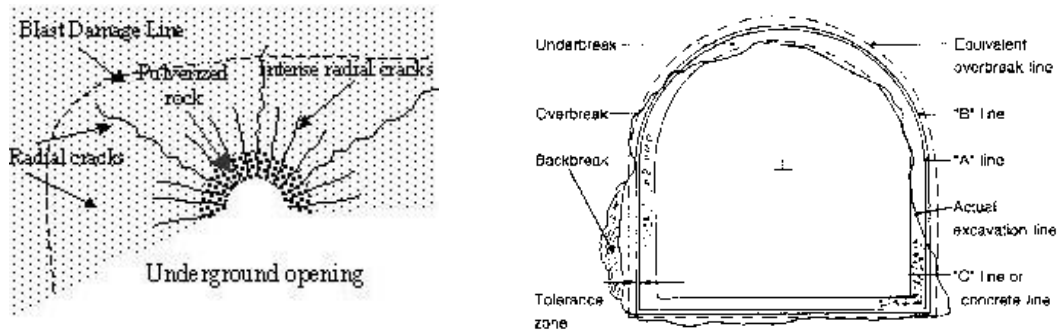


Figure 1: Mechanisms of blast damage to rock around an underground opening cross-section, with EDZ at left and breakage at right

3. PREDICTION OF EDZ FROM EXPLOSIVE ACTION BY PERIMETER POWDER FACTOR (PPF) AND ROCK QUALITY DESIGNATION (Q)

The factors influencing the magnitude of EDZ can conveniently be grouped into two categories, which are rock mass characteristics (geological factors) and explosive (blasting factors) as Table 1 summarizes.

The blasting factors normally result from poor blast design and/or execution. Inadequately design of the perimeter part of the blast-round, i.e., countour holes is likely to result in EDZ, but the central part of the blast (cut) may also cause perimeter damage. Even a well-design blast can give poor results if it is not correctly implemented. Particularly important are the accurate location marking and drilling of blast-holes. Much over-break is caused by blast-holes that diverge or converge, and holes that fail to detonate on time and in sequence.

Table 1- Geological and blasting factors influencing EDZ (Maerz N.H., et al.,1996)

GEOLOGICAL FACTORS	BLASTING FACTORS
Joint orientation	Explosive type and power factor
Joint spacing	Charge concentration
Clay filling and alteration	Delay time
Rock strength	Perimeter blasthole pattern
Ground-stress effect	Drilling deviation
Groundwater effect	Blasthole length and diameter, including empty holes

3.1. Measuring EDZ

There are currently three methods of actually measuring excavation profiles: surveying techniques, both manual or laser based, and photographic light sectioning method (LSM). The last one offers several advantages.

The principle of the method is to project a radial light to the perimeter of the underground opening so that light rays intersect the perimeter contour of the cavity. The image of this perimeter is then saved in digitized form to allow further computerized analysis.

Both graphical and numerical analyses allow the calculation of EDZ values (Overbreak and Underbreak) in a quantitative form, normally expressed as O (%) and U (%) as Table 2 indicates, which may be correlated with explosive powder factor and rock quality.

Table 2 - Quantitative results of graphical and numerical analysis

GENERAL INFORMATION	EDZ PARAMETERS
Name of the underground opening	Excavated volume (m ³ /m)
Exact location of the profile	Overbreak Volume (m ³ /m) and (%)
Date and hour of measurement	Underbreak Volume (m ³ /m) and (%)

3.2. Quantification of blasting parameters

According to AUTOR, ANO evaluation of blast design may be done by a single parameter Perimeter Powder Factor (PPF) (kcal/m³) by a simple equation, defined as the explosive energy contained in the perimeter blastholes and in the next row, divided by the volume of rock within this annulus:

$$PPF = (P_e \cdot E_e) / V_{rp} \quad (1)$$

where P_e is the weight of explosive charges used in the perimeter blast holes (kg), E_e is the unit explosive energy (kcal/kg), and V_{rp} is volume of rock in this annulus (m³). PPF is used instead of the conventional powder factor because this one involves the weight of all explosives loaded in the entire opening heading, but EDZ is more closely related to the explosives located near the perimeter than those at the central part of the opening (Holmberg, 1979).

3.3. Estimating EDZ in Overbreak and Underbreak

The magnitudes of Overbreak and Underbreak are a function of at least two independent variables: rock mass quality (Q) and perimeter powder factor (PPF). The corresponding empirical equations are given by (based on Ibarra, J.A. et al., 1996.):

$$EDZ_o = (-a + b \cdot PPF - c \cdot \log Q) / 100 \quad (2)$$

$$EDZ_u = (a' - b' \cdot PPF + c' \cdot \log Q) / 100 \quad (3)$$

where EDZ_o is Damage for Overbreak (index), EDZ_u is Damage for Underbreak (index) and a , b , c , a' , b' , c' are coefficients whose values are obtained by means of multiple regression statistics correlating Rock Mass Quality Q and Perimeter Powder Factor (PPF) with observed Overbreak and Underbreak.

3.4. Case study of EDZ

An interesting case study was described by J.A. Ibarra et al, 1996 who made EDZ measurements in rhyolites and tuffs found at the Diversion Tunnel No. 2 of Aquamilpa Hydroelectric Project in Nayarit, Mexico. The tunnel was excavated in two stages: a first semi-circular top heading 16 m diameter and 8 m height and a second rectangular bench excavation with dimensions of 8 m by 16 m (Fig. 2).



Figure 2 – Tunnel cross section at Aquamilpa project (J. A. Ibarra et al., 1996)

As for rock mass classification systems, rock quality designation (Q) gave a close correlation with rock mass rating (RMR) resulting:

$$RMR = 19.8\text{Log}Q + 38.5$$

Statistics analyses of EDZ measurements revealed a relationship between Underbreak, PPF and Q, as well as between Overbreak, PPF and Q, with correlation coefficients of 0.860 and 0.913, respectively.

The results of correlation in this case study allowed to obtain the coefficients values indicated in the Table 3 for ANFO unit energy of 920 kcal/kg (C. López Jimeno, 1987).

Table 3 - Coefficients values for Tunnel No. 2 of Aquamilpa Hydroelectric Project in Nayarit, Mexico (based on J.A. Ibarra et al, 1996)

a	b	c	a'	b'	c'
0.12	0.01622	2.55	9.33	0.01991	0.72

With these values and applying equations (5) and (6), the predictive equations for EDZ in this case are:

$$\begin{aligned} EDZ_o &= -0.0012 + 0.0001622PPF - 0.0255\text{Log} Q \\ EDZ_u &= 0.0933 - 0.0001991 PPF + 0.072\text{Log} Q \end{aligned}$$

These predictive equations are site specific, but can readily be calibrated to suit other projects, where the rock and blasting conditions differ from the present case.

4. PREDICTION OF EDZ BY PEAK PARTICLE VELOCITY

4.1. Prediction by distance blast damage

In order to calculate damage magnitudes for any rocky mass around the excavation of underground openings (tunnels) resulting from blasting, Holmberg (1982) established a relation

correlating the peak particle velocity “v” induced by the detonation of explosive charges, by means of the following equation:

$$v = a.Q^b.D^c \quad (4)$$

where a, b, c are numerical coefficients depending on the geologic and blasting factors, that can be determined by statistical processes from “in situ” tests, Q is explosive quantity detonated in simultaneous instant, and D is the distance of the blast damage.

On the other hand, the rock tensile strength σ could be determined by means of the very well known equation:

$$\sigma = \rho . u . v \quad (5)$$

where ρ is the rock mass-density, u is velocity of wave propagation in the rock mass and v is peak particle velocity. Equating equations (4) with (5), C. Dinis da Gama (1998) obtained an evaluation equation (6) that allows to predict the damage distance D_d of blast damage by

$$D_d = [\sigma/(\rho . u . a . Q^b)]^{1/c}$$

4.2. Case study on SANEST tunnels

The study was performed during the excavation of 9.5 km of sanitary tunnels in Portugal, with the use of gelatinous explosives and electrical microdelay detonators. Tunnel section had a 8,5 m² horseshoe shape at depths from the surface between 10 to 50 meters. The typical blast pattern consisted of 46 drillholes of 45 mm diameter per 3 m length, with unloaded holes of 105 mm diameter). A total of 60.86 kg of explosive detonated in normal rounds with rock class ZG1, the most compact of the three defined classes in which rock mass was divided. That represented a powder factor of 2.78 kg/m³ or 3.76 kWh/m³ in energy terms, also giving an average of 2.64 kWh/m³ for rock class ZG2 and 1.05 kWh/m³ for rock class ZG3 (Fig. 3). The dynamic properties of rock mass classes, including their compressive and tensile strengths, are indicated in Table 4.

Table 4: Main properties of rocks types in the Sanest tunnels (C. Dinis da Gama, 2000)

Rock class	Rock type	Density (kg/m ³)	Seismic velocity (m/s)	σ_c (MPa)	σ_t (Mpa)
ZG1	Basalts, compactlimestone and marls	1700 a 3000	4000 a 6000	100	10
ZG2	Basaltic breach, limestone and altered marls	2300 a 2700	1500 a 4000	50	5
ZG3	Altered limestones and marls, clays	1800 a 2300	500 a 1500	0.2	0.02

Measurements of EDZ were accomplished by routinely drilled horizontal holes at the advancing tunnel face, and they were correlated with explosive released energy and rock type.

A typical example of damaged thickness was of 1.3 meters for rocks of the type ZG3, in a blast round with 32 boreholes and 24 kg of explosive, having a maximum load of 0.91 kg per hole.

Using the parameters of that rock, as seen in Table 4, and the coefficients of Johnson (1971), $a = 0.085$ m/s, $b = 0.73$ and $c = -1.87$, the expression (6) gives a value of $D_d = 3.03$ meters, for what the thickness of fractured rock was $3.03 - 1.5 = 1.53$ meters.

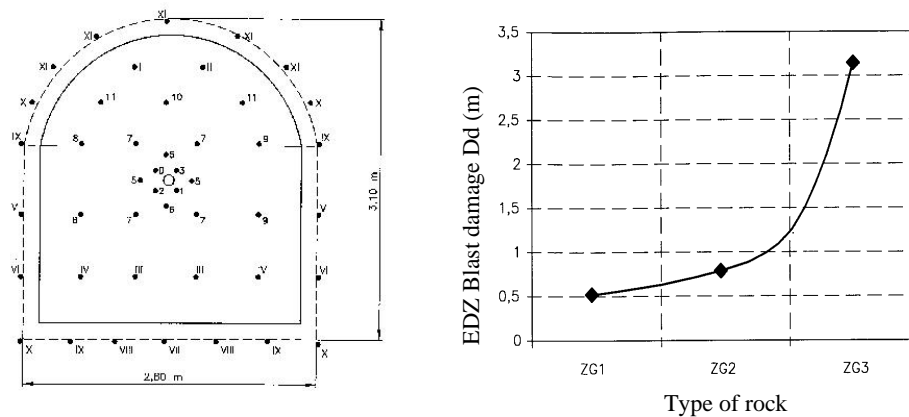


Figure 3: Blast pattern in Sanest tunnels(left) and predictions of blast damage in function of rock type (right) (C. Dinis da Gama, 2000)

4.3. Case study in Panasqueira Mine

The Panasqueira Mine is located in Portugal near the village of Barroca Grande; next to Serra da Estrela mountains, Beira Interior district, and it is still a producing unit of wolfram and tin. The common production blasts of the Mine have a pattern that is depicted in Fig. 4.

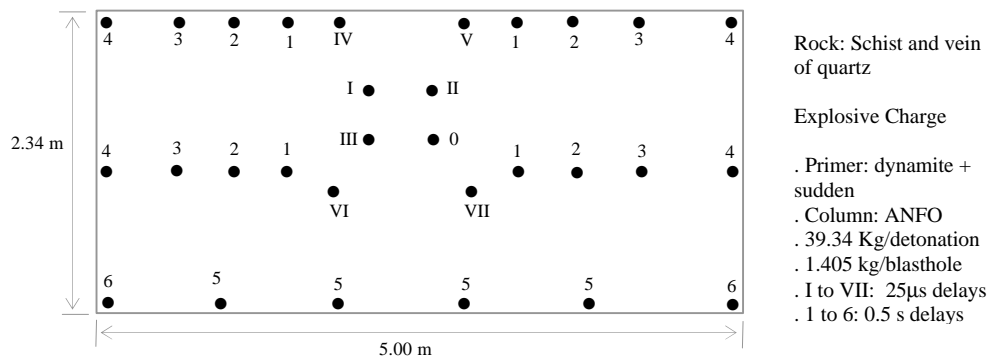


Fig. 4 - Blasting pattern for exploitation with room and pillars method in Panasqueira Mine

For the application of equation (6) to the Panasqueira Mine blasts it was necessary to determine schistose rock's tensile strength σ (through laboratory tests) and coefficients a , b , c

by “in situ” measurements of vibrations from many detonations recorded inside the Mine (see Table 5). These tests were carried out by recording peak particle velocities (v) together with explosive weights per delay and distances, in several stopes: L3.D19.R-3.AW30, L3.D21.R-2.AW33, L3.D19.R-1.AW33 and L3.D21.R-1.AW33.

Table 5: Results “in situ” and laboratory tests

NUMERICAL COEFFICIENTS			SCHISTOSE ROCK PROPERTIES*	
a	B	c	Tensile strength σ (Mpa)	7.62
			Wave velocity u (m/s)	5100
471.49	0.40	-1.58	Rock (schist) density ρ (kg/m ³)	2860

* From C. Dinis da Gama and Yu Xianbin., 1999.

The critical peak particle velocities (v) of the Panasqueira Mine schist were calculated by equation (5) giving a value of 0.51 m/s (or 510 mm/s).

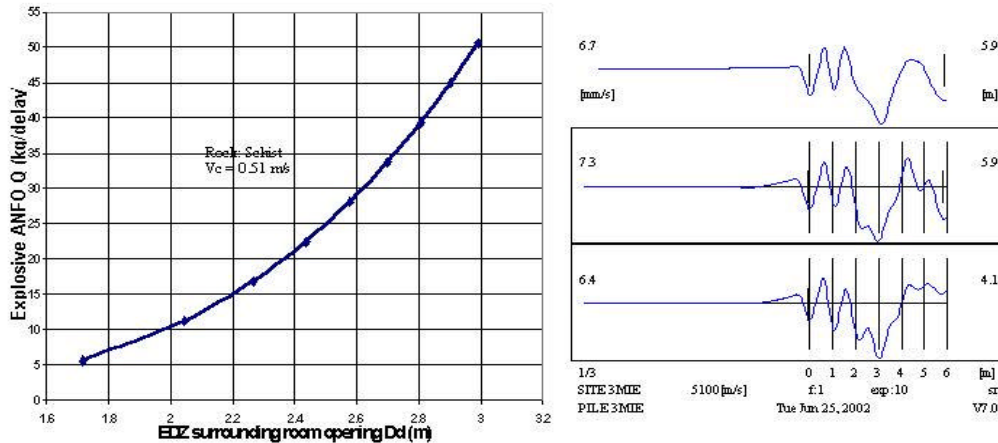


Figure 5: Blast Damage (EDZ) surrounding room opening in Panasqueira Mine (left) and results of measurement process with SIT equipment (right)

With these values and applying equation (6), the particular expression of EDZ from explosive detonation surrounding the rooms of Panasqueira Mine is provided by the following expression of the distance of damage:

$$D_d = 1.108 Q^{0.25316}$$

For confirmation purposes, a series of field tests were conducted inside Panasqueira Mine to measure EDZ. By means of using a Profound Sonic Integrity Testing system (Baby SIT) in underground openings or rooms with 11 m length and 2.40 m high, in the panel of exploitation L3.D19.R-3.AW34 (between the topographical points 31 and 35), a place where rocks were excavated in the exploitation method of room and pillars.

Although the use of SIT methods are mainly proposed for piles evaluation in Civil Engineering to detect pile defects such as cracks, soil incursions and diameter changes in both pre-cast concrete piles and cast-in-place piles, experiments in the Panaqueira Mine rock mass provided encouraging results. The tests were carried out with an input energy of hammer impact for a maximum distance of 5 m and considering a wave propagation velocity of 5100 m/s (Yu Xianbin, 2001). The results of 27 carried out tests gave representations such as that of Fig. 5 right, indicating .

Interpretations of those results show that reflections of waves were originated by fractures within the surrounding rock mass for distances (or thicknesses) of 1.0 m, 2.0m, 3.0m, 3.5 m till 4.1 m, from the surface wall of the stope rooms. It was also found that the reflected waves of 1.0 to 2.0 m are fractures created under the EDZ influence and those of 3.0 m to 4.1 m distances probably due to tectonic fractures.

5. CONCLUSIONS

Prediction of EDZ from explosive detonations in underground openings is possible by alternative methods of Overbreak and Underbreak evaluations or Distance of Damage (D_d).

In the first method, main required parameters are powder factor (PPF) and rock mass quality (Q), while in the predictive equation for D_d rock dynamic proprieties (tensile strength σ , density ρ , wave velocity u) and vibration propagation coefficients a, b, c as well as explosive detonated per delay Q, are necessary. Both these methods for EDZ prediction must be calibrated for each particular project.

Use of Sonic Integrity Testing methods showed interesting possibilities for detecting EDZ dimensions in underground excavations.

6. REFERENCES

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