In situ stress evaluation according to the Drillhole detonation method, applied to the geometric design underground excavations

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ABSTRACT: The rock mass is composed of homogeneous and heterogeneous rocks, generating stresses of different orientation and magnitude. One of the techniques to evaluate the state of stress *in situ* is the Drillhole detonation method; the procedure consists of detonating a drillhole with explosives to obtain radial cracks and with this result analyze the ellipse generated, called stress ellipse. The data to evaluate the magnitude of the stresses σ1, σ3, and σ2; are based on the analysis of the stress ellipse, from which are obtained: the orientation (α) of the major stress σ1, the coefficient *k*, and the Correction factor (CF). The Drillhole detonation method provides the appropriate technique for the design of underground excavations, according to the profile of the horizontal and vertical trend stress ellipse.

Keywords: K coefficient, Design of underground excavations, Drillhole detonation method, In situ stress evaluation, Stress ellipse.

1 DRILLHOLE DETONATION METHOD METHODOLOGY

This The methodology of the Drillhole detonation method consists of interpreting the geometry of the cracks produced by the detonation of drill holes in a point of the rock mass, where it is desired to know the orientation and magnitude of stresses *in situ*; the process consists of: 1) Detonate a drillhole of approximately one meter in length with explosives as a cutting element to obtain radial cracks, and 2) Joining the ends of the radial cracks, an ellipse called stress ellipse is generated, with its major and minor axes with different geometry and position. (Berrocal, 2015)

The length of the fissures produced by the detonated drillhole, the position of the major and minor axes of the ellipse generated, vary according to the homogeneous and heterogeneous rocks of the rock massif, through which the stresses are transmitted; where "the longest cracking represents the largest principal stress σ1, influenced by rock anisotropy, pre-existing cracking and *in situ* stress state" (Hoek, 1985, págs. pp. 431-433) concordant with the stress ellipse.

When the stress ellipse is obtained, its geometry is analyzed to determine: 1) the orientation (α) of the major principal stress, 2) the coefficient *k*, and 3) the Correction factor (CF); data necessary to evaluate the magnitude of the *in situ* stresses: σ1, σ3, and/or σ2 (see Figure 1).

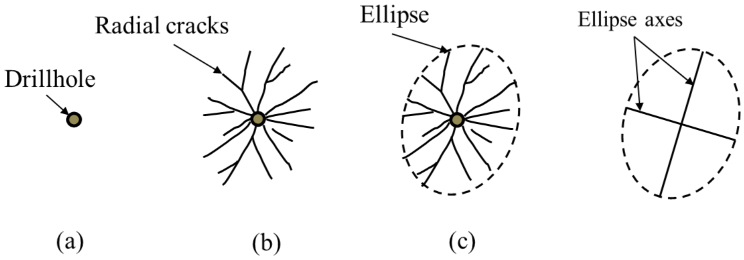

Figure 1. Sequence of processes of the Drillhole detonation method.

1.1 Measurement of the angle (α) of the major stress, according to the Drillhole detonation method

The angle (α) is the orientation of the principal stress *in situ*, at an instant and at a single location in the rock mass; detected by the Drillhole detonation method. The angle (α) is measured from the lower end of the major axis of the ellipse, with the horizontal projection and is measured in degrees. The angle (α) can acquire different values from 0° to 180° (see Figure 2).

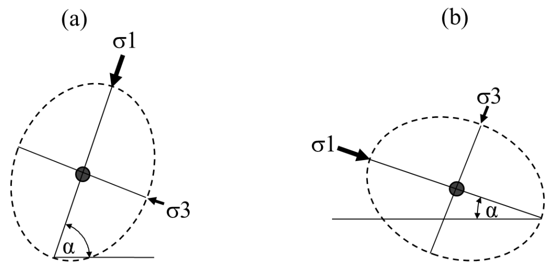

Figure 2. Angle (α) of the principal stress in the ellipse.

1.2 Estimation of coefficient k, by the Drillhole detonation method

The coefficient *k* is a dimensionless numerical value, it is the variable that differentiates the value of the magnitude with respect to the major and minor principal stress. In the Drillhole detonation method, the coefficient *k* is obtained by dividing the horizontal trend length by the vertical trend length in the ellipse (see Figure 3).

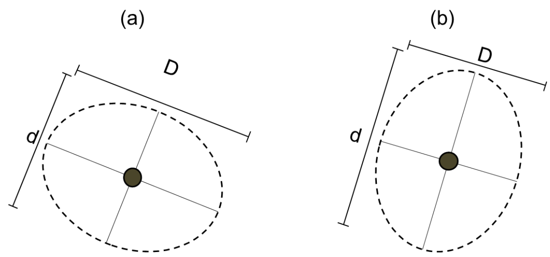

Figure 3. Minor and major axes of the ellipse in different positions.

The structure of equation 1 below shows how to calculate the *k* coefficient.

$$k = \frac{length\ of\ horizontal\ trend\ in\ the\ ellipse}{length\ of\ vertical\ trend\ in\ the\ ellipse} = \frac{D}{d} \qquad (1)$$

1.3 Estimation of the Correction factor (CF) according to the Drillhole detonation method

By the homogeneous and heterogeneous conditions of the rock mass; *in situ* stresses: σ1, σ3, and σ2 are transmitted with their own unique orientations for each condition of the rock mass. The orientation (α) is expressed in degrees with respect to the horizontal line, in that scenario; the angle deviation (α) is correlated with the Correction factor (CF) (Berrocal, 2015). The design of the Correction factor (CF) equations is calculated with the following assumptions: (see Figure 4).

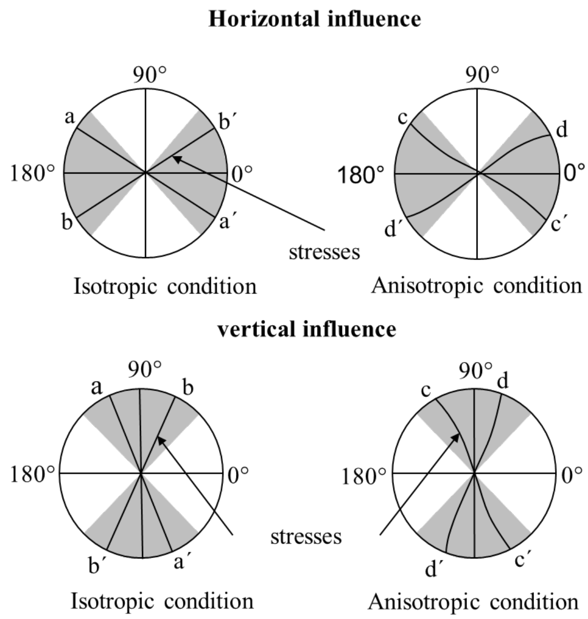

Figure 4. configuration of horizontal and vertical tendency stresses with the planet "earth".

- Lines a-a', b-b', c-c', and d-d', simulating the stresses passing through the center point of the planet "earth" under isotropic and anisotropic conditions.
- Considering the approximate equatorial diameter of the earth of 12,756 km, and dividing this length by the approximate polar diameter of the earth of 12,713 km: 1.003.
- The value of 1.003 is divided between two circular sectors, formed by the two congruent circular sub-sectors of 45° each: 1.003/2 results in 0.5015
- To know the influence from 0° to 90° degrees, of the quadrant where the stress ellipse is located; divide: 0.5015/90 = 0.0056

Compiling the calculated values: 1.003 and 0.0056, we design the general equation of the Correction factor (CF)

$$CF = 1.003 + (0.0056)(angle\ \alpha, of\ the\ stresses\ \sigma1, \sigma3, and\ \sigma3) \qquad (2)$$

According to the quadrant where the stress ellipse is located, the Correction factor (CF) is adapted to the following conditions:

1. For the magnitude σ1, related to the angles (α) of 46°-136°, with the equations:

$$CF = 1.003 + (0.0056)(\alpha) \quad (3)$$

$$CF = 1.003 + (0.0056)(90 - \alpha) \quad (4)$$

2. For the magnitude σ1, related to the angles (α) of 0°-44° and 134°-180°, with the equations:

$$CF1 = 1.003 + (0.0056)(90 - \alpha) \quad (5)$$

$$CF = 1.003 + (0.0056)(\alpha) \quad (6)$$

1.4 Design of equations for stress evaluation σ1 and σ3, according to the Drillhole detonation method.

The equations for in situ stress evaluation are designed based on the lithostatic loading methodology for calculating vertical and horizontal stress, as shown in equations (7) and (8) below:

$$\sigma v = \gamma * z \quad (7)$$

$$\sigma h = k * \gamma * z \quad (8)$$

Due to the condition of homogeneous and heterogeneous rocks of the rock mass, in order to evaluate the magnitude of the major principal stress, the Correction factor (CF) is coupled in the second member of equation (7), transforming into:

$$\sigma 1 = CF * \gamma * z \quad (9)$$

Also; in order to evaluate the magnitude of the minor principal stress, the Correction Factor (CF) is coupled in the second member of equation (8), transforming into:

$$\sigma 3 = CF3 * k * \gamma * z \quad (10)$$

Where:
$\sigma 1 = Major\ principal\ stress$
$\sigma 3 = Minor\ principal\ stress$
$FC = Correction\ factor\ for\ stress\ orientation\ (see\ equations\ 3, 4, 5, and\ 6)$
$k = Coefficient$
$\gamma = Average\ rock\ density$
$z = Depth\ at\ the\ point\ evaluation$

2 *IN SITU* STRESS EVALUATION, BY THE DRILLHOLE DETONATION METHOD

In situ stress evaluation, using the Drillhole detonation method, was applied in the Marañon area of Compañía Minera Poderosa (November 2020). The locations for the tests have been randomly selected nine stations in three operation zones; obtaining the parameters: stress orientation (α) with respect to the horizontal line, length of the ellipse axes, and the coefficient *k* according to formula 1 (see table 1).

Table 1. Summary of the angles (α), length of the axes of the ellipses, and values of the *k* coefficient.

Zone	Station	(α) Degree	(*) cm.	(**) cm.	Coefficient *k*
1	Proj. Lv. 2300, RA Katy-Lola 1	90°	10.0	10.5	0.95
	Proj. Lv. 1915, CR 5000, Choloque	81°	30.0	41.0	0.73
	Proj. Lv. 1467, CR SE, Choloque	89°	30.0	41.0	0.73
2	Proj. Lv. 1450-1400, RA Estrella-Karola techo	74°	30.0	38.0	0.79
	Proj. Lv. 1400, GL N, Karola techo	67°	25.0	35.5	0.70
	Proj. Lv. 1400, ESCM 6205 Karola techo	44°	50.0	48.5	1.03
	Proj. Lv. 1800,CR NW1-ESCM 1010-1, Pajilla	68°	30.0	41.0	0.73
3	Proj. Lv. 1800, CR NW1-ESCM 1025, Pajilla	60°	17.0	24.5	0.69
	Proj. Lv. 1800, CR NW1, Pajilla	86°	10.5	14.5	0.72

(*) Length of horizontal trend in the ellipse
(**) Length of vertical trend in the ellipse

With the data compiled in Table 1, and using equations (1), (3), (4), (9) and (10) of the Drillhole detonation method (Berrocal, 2015), we proceed to evaluate the magnitude of the *in situ* stresses corresponding to the Marañón zone of Compañía mining Poderosa (see Table 2).

Table 2. Summary of compiled data and magnitude of stresses *in situ*.

Station	(α)	z (*) m	γ (*) T/m^3	FC1	FC3	*k*	σ1 MPa	σ3 MPa
Proj. Lv. 2300, RA Katy-Lola 1	90°	766.39	2.72	1.507	1.003	0.95	30.81	19.48
Proj. Lv. 1915, CR 5000, Choloque	81°	1321.51	2.72	1.457	1.053	0.73	51.36	27.10
Proj. Lv. 1467, CR SE, Choloque	89°	324.70	2.72	1.501	1.009	0.73	13.00	6.38
Proj. Lv. 1450-1400, RA Estrella K. t.	74°	619.70	2.72	1.417	1.093	0.79	23.42	14.27
Proj. Lv. 1400, GL N, K. t.	67°	691.30	2.72	1.378	1.132	0.70	25.41	14.61
Proj. Lv. 1400, ESCM 6205 K. t.	44°	635.14	2.72	1.249	1.261	1.03	21.16	22.00
Proj. Lv. 1800,CR-ESCM 1010-1, Pajil	68°	559.20	2.72	1.384	1.126	0.73	20.64	12.26
Proj. Lv. 1800, CR-ESCM 1025, Pajill	60°	554.20	2.72	1.339	1.177	0.69	19.79	12.01
Proj. Lv. 1800, CR NW1, Pajilla	86°	532.20	2.72	1.025	1.025	0.72	21.08	10.48

(*) Data provided by the Geomechanics department of Poderosa mining company

2.1 *Average values of parameters and magnitude of in situ stresses in the Marañón zone of Poderosa mining company*

With the results of table 2, we have proceeded to calculate the average and global values of the parameters and magnitude *in situ*, in the entire rock mass corresponding to the Marañón zone of the Poderosa mining Company. (see Table 3).

Table 3. Average parameters and magnitude of *in situ* stresses in the Marañón zone, Poderosa mining Company.

Marañón zone Poderosa mining company	(α) degrees	*k*	σ1 MPa	σ3 MPa
Average	73°	0.79	25.19	15.40

3 DESIGN OF UNDERGROUND EXCAVATIONS, ACCORDING TO THE DRILLHOLE DETONATION METHOD

By means of the stress ellipse, obtained by the Drillhole detonation method, it is feasible to design the geometry of the underground excavations, based on: the orientation (α) of the major stress, and the magnitude σ1 major principal. Explaining the following figure five: the horizontal lines and angles (0° to 44° and 136° to 180°), suggest underground excavations in profile: horseshoe; the vertical lines and angles (46° to 134°), suggest underground excavations with profile: trunk or chest; and the oblique lines with angles (45° and 135°), suggest underground excavations with profile: circular with height and width of equal magnitude (see Figure 5).

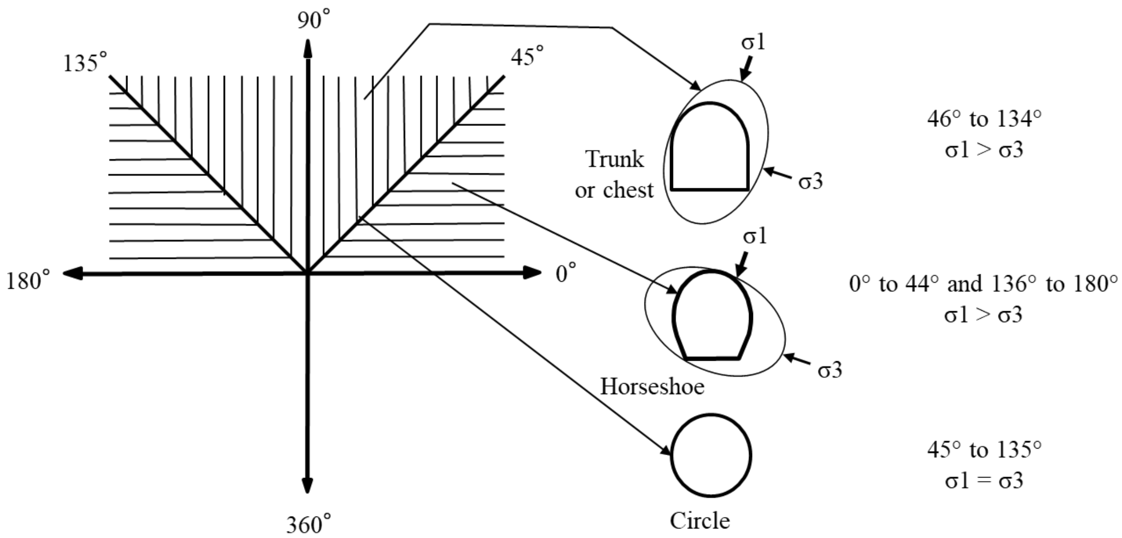

Figure 5. Profiles of underground excavations, related to the orientation (α) of *in situ* stresses.

The Drillhole detonation method allows designing the profile of underground excavations, according to the range of values of the coefficient *k*; where:

- $k > 1$: Horseshoe profile.
- $k = 1$: Circular profile.
- $k < 1$: Trunk or chest profile.

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