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MODIFICATION OF FOUR-SECTION CUT MODEL FOR DRIFT BLAST DESIGN IN RAZI COAL MINE - NORTH IRAN

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ABSTRACT: Four-section cut, a model similar to Swedish method, is an empirical method for blasting design in underground excavations. This method, often, has been used in excavating tunnels with cross section area of more than 10m^2. Using the model for smaller tunnels needs some modifications to achieve proper quantity of the parameters. In this paper, four-section cut method has been modified for designing patterns for tunnels with cross section area of less than 10 m^2. The applicability of the modified version has been examined through several blasting cycles and the ultimate optimized blasting pattern has been obtained. The previous blasting pattern of Razi coal mine, near Ramian city in Golestan Provience, has been replaced by the new pattern which was proved to be much more efficient.

BLASTING PATTERN ALREDY PRACTICED IN RAZI COAL MINE'S DRIFT

The cross section area of Razi coal mine's drift is 9.2 m^2. Rock properties at advance face of the tunnel are as in Table 1. Table 2 introduces the specifications of dynamite types used in this excavation. Table 3 points on blasting properties of the dynamite types. Blasting pattern used in the drift is illustrated in Figure 1. Length of stemming in this pattern is about 0.15- 0.20 m which seems inadequate and has led to long bootlegs and violent air vibration. Therefore, to avoid these outcomes the length of stemming had to be increased to more than 0.2 m. Result of conducting the practiced pattern is shown in Table 4.

Table 1 - Rock properties of drift's advance face in Razi coal mine.

Shear strength (MPa)	13	Specific weigh	2.7
Velocity of blasting wave (m/sec)	4000	Uniaxial compress strength (MPa)	77.5
Specific energy (Mj/m^2)	1.55×10^{-3}	Tensile strength (MPa)	5
Impedance (kg/m^2.sec)	10760×10^{3}	C: Rock constant (kg/m^3)	0.8

Table 2 - Specifications of dynamite cartridges

Type of dynamite	Diameter (mm)	Length (m)	Linear charge concentration
a	25	0.20	0.625
b	23	0.23	0.543
c	22	0.27	0.46

Table 3 - Blasting properties of the dynamite

Specific weight	1.215	Impedance (kg/m².sec)	10760×10^{3}
Velocity of detonation (m/s)	5000	Specific energy (Mj/kg)	4.51
Relative weight strength with respect to ANFO (%)	121	Relative bulk strength with respect to ANFO (%)	181

Table 4 - Results of the practiced blasting pattern

SD: Specific drilling (m/m^3)	4.75
SC: Specific charge (kg/m^3)	1.51
AE: Advance Efficiency (%)	80
Length of bootleg (m)	0.10 - 0.20

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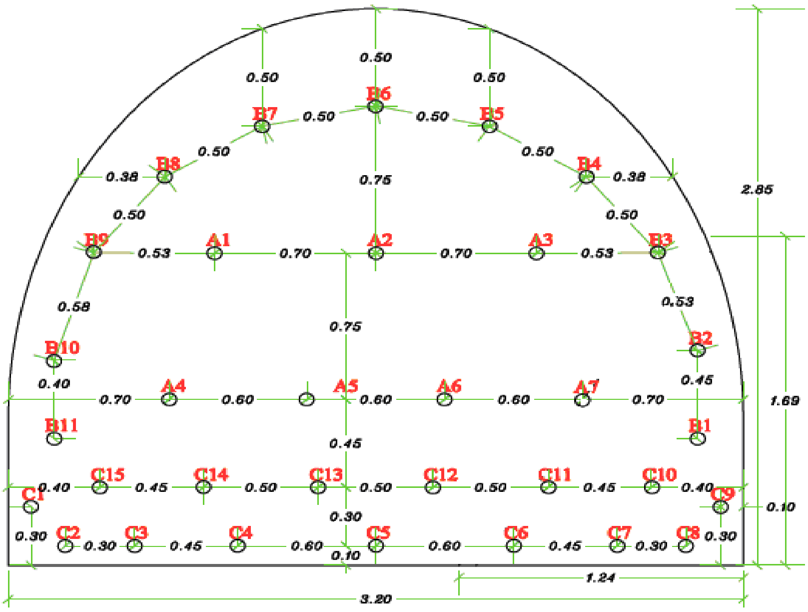

Figure 1 - Blasting pattern used in Razi coal mine drift.

BLASTING PATTERN BASED ON 4-SECTION CUT

The four-section cut which is close to Swedish model is based on the parallel hole cut. This model started with Langefors and Kihlstrom (1963) and has been further developed afterwards. Holmberg published the complete blast design model in 1982 (Holmberg, 1982) and was later updated by Persson *et al* (2001). The method suggests the experimental equations listed in Table 5. In this Table, E and X are drilling error and length of each quadrangle sides respectively. Due to relative easiness and precision in drilling of direct cutting holes E is taken as zero. The value of E for stopping and perimeter holes is calculated by Equation 1 (Konya, 1995):

$$E = \alpha H + \beta \tag{1}$$

$$E = \alpha H + \beta = 0.03 \times 1 + 0.01 = 0.04\,\mathrm{m} \tag{2}$$

Where; E = drilling error, H = blast hole depth (equal to 1m), α = angular deviation (equal to 0.03 m/m) and β = collaring error (0.01 m).

In this model, the holes in the face are divided into separate sections as cutting holes, stopping holes, perimeter (roof, floor and wall) holes.

Four-section cut method includes an empty hole in the centre as shown in Figure 2. If the number of empty holes is more than one, equivalent diameter is calculated by Equation 3 (Konya, 1995):

$$\phi_{e2} = \sqrt{N}\phi_e \tag{3}$$

Where; ϕ_e =empty hole diameter and ϕ_{e2} = Equivalent diameter of empty holes.

Table 5 - Equations for blasting pattern design

Sections	Burden (B)	Spacing (S,X)	Stemming (St)
Firs square cut	$B_1 = 1.5\phi_{e2}$	$X_1 = \sqrt{2}B_1$	$St_1 = B_1$
Second square	$B_2 = \sqrt{2} \times B_1$	$X_2 = \sqrt{2}B_2 \times 1.5$	$\mathrm{St}_2 = \frac{\sqrt{2}}{2}B_1$
third square	$B_3 = \sqrt{2}B_2 \times 1.5$	$X_3 = \sqrt{2}B_3 \times 1.5$	$\mathrm{St}_3 = \frac{\sqrt{2}}{2}(\frac{\sqrt{2}}{2}B_1 + B_2)$
Fourth square	$B_4 = \sqrt{2}B_3 \times 1.5$	$X_4 = \sqrt{2}B_4 \times 1.5$	$\mathrm{St}_4 = \frac{\sqrt{2}}{2}(\frac{\sqrt{2}}{2}(\frac{\sqrt{2}}{2}B_1 + B_2) + B_3)$
Stopping	$B = 0.012\left(\frac{2\rho_C}{\rho_r} + 1.5\right) \times \phi_c - E$	$S = 1.1\mathrm{B}$	$St_S = 0.5\mathrm{B}$
Roof	$B = 0.012\left(\frac{2\rho_C}{\rho_r} + 1.5\right) \times \phi_c - E$	$S = 1.1\mathrm{B}$	$St_r = 0.2\mathrm{B}$
Wall	$B = 0.012\left(\frac{2\rho_C}{\rho_r} + 1.5\right) \times \phi_c - E$	$S = 1.1\mathrm{B}$	$St_w = \mathrm{B}$
Floor	$B = 0.012\left(\frac{2\rho_C}{\rho_r} + 1.5\right) \times \phi_c - E$	$S = 1.1\mathrm{B}$	$St_f = \mathrm{B}$

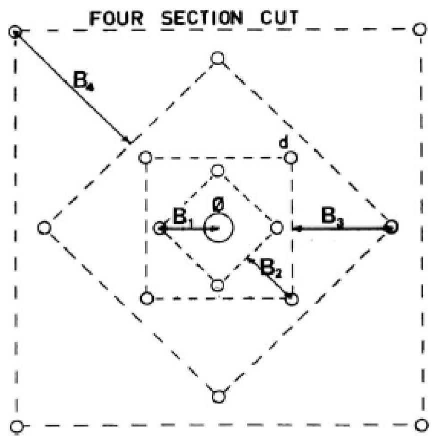

Figure 2 - location of holes in 4-section cut (Persson et al 2001).

This model suggests that the diameter of empty hole to be more than 75 mm. To achieve this diameter three empty holes with 45 mm diameter is drilled. The equivalent diameter of empty holes is calculated using Equation 3 as follows (Konya, 1995):

$$\phi_{e2} = \sqrt{N}\phi_e = \sqrt{3} \times 45 = 78 \text{ mm} \tag{4}$$

The type of dynamites that must be charged into cut holes is determined by Equation 5 (Jimno et al, 1995):

$$q = \frac{55\phi_h}{PRP_{ANFO}}\left[\frac{B_1}{\phi_{e2}}\right]^{\frac{3}{2}}\left(B_1 - \frac{\phi_{e2}}{2}\right)\left(\frac{C}{0.4}\right) \tag{5}$$

Where: q = Lineal charge concentration (kg/m), ϕ_h = drilling diameter (m), ϕ_{e2} = equal diameter of empty holes, B_1 = Maximum distance between empty hole and holes in the first cutting quadrangle (m), C = Rock constant, PRP_{ANFO} = Relative weight strength of explosive with respect to ANFO.

Frequently, the possible values of lineal charge concentration are quite limited as there is not an ample variety of cartridge explosives (Jimno et al, 1995).

It's obvious that quantity of q for stopping holes is less than that of cut holes and quantity of q for roof and wall holes is less than that of stopping holes. Also, the quantity of q for floor holes is more than those of the roof and wall holes. For holes of 1 m length and type of dynamites chosen from Table 6 the values of parameters calculated by Equations in Table5 are listed in Table 7.

Table 6 - Type of dynamites charged in different holes

Dynamite type	a	b	c
Sections	Cutting	Stopping and floor	Roof and wall

Table 7 - Calculated blasting pattern parameters.

Sections	Burden (m)	Spacing (m)	Stemming (m)
Firs square	$B_1 = 0.117$	$X_1 = 0.165$	$St_1 = 0.117$
Second square	$B_2 = 0.165$	$X_2 = 0.351$	$\mathrm{St}_2 = 0.082$
Third square	$B_3 = 0.351$	$X_3 = 0.744$	$\mathrm{St}_3 = 0.175$
Fourth square	$B_4 = 0.744$	$X_4 = 1.578$	$\mathrm{St}_4 = 0.372$
Stopping	$B \approx 0.6$	$S \approx 0.7$	$St_S = 0.3$
Roof	$B = 0.6$	$S = 0.7$	$St_r = 0.12$
Wall	$B = 0.6$	$S = 0.7$	$St_w = 0.6$
Floor	$B = 0.6$	$S = 0.7$	$St_f = 0.6$

DEFICIENCIES OF THE 4-SECTION CUT METHOD FOR SMALL CROSS SECTION TUNNELS

Four-section cut is often applied to large tunnels with cross section area of larger than 10m^2. In order to apply this method to tunnels with area of less than 10m^2 some modifications to the equations was found to be inevitable. Applying the traditional model would lead to some miss estimation of the parameter values some of which was found to be as follows:

- B_1 in first cutting square is very small.
- St_1 is very small. The results of previously performed blasting pattern in Razi Coal Mine's drifts show that the length of St_1 must be larger than 0.2 m. From the other hand St_1 value must be more than $2B_1$ (Ostvar, 1999).
- Quantity of B_2 appears to be small.
- Comparing the values of B_3 and B_4 with smaller dimension of the tunnel cross section reveals that the third and fourth cutting quadrangles are to be eliminated.
- Spacing is estimated from S=1.1B. This amount is not appropriate for tunnels where control blasting is required. In such patterns S<B would be more acceptable.
- The length of stemming for holes of wall and floor with length of 1m seems to have been over estimated.
- Results obtained from previous blasting pattern show that stemming length of floor holes is smaller than required.

MODIFIED MODEL FOR SMALL CROSS SECTION AREA TUNNELS

Taking the above mentioned points into account the traditional model needs to be modified for tunnels with area of less than 10 m^2. Table 8 shows the equations suggested for this purpose. In this Table, stemming lengths of St_r, St_w, St_f and perimeter holes spacing have been taken from Swedish method. The hole depths are 1 m and the type of dynamites are as indicated in Table 6. The parameters calculated from equations in Table 8 are as appear in Table 9.

Figure 3 illustrates the pattern designed based on parameters shown in Table 9. Due to restriction of tunnel dimensions, in practice, burden of stopping and perimeter holes should be reduced to less than those obtained in Table 9. Such a pattern, can be applied for tunnels with area of 8-10 m^2 in rocks having density of about 2.7 kg/m^3. Blasting results of this pattern are shown in Table 10.

Table 8 - Modified equations for small cross section tunnels

Sections	Burden (B)	Spacing (S,X)	Stemming (St)
First square	$B_1 = 1.7\phi_{e2}$	$X_1 = \sqrt{2}B_1$	$St_1 = 10\phi_h$
Second square	$B_2 = \frac{\sqrt{2} \times B_1 + 2X_1}{2}$	$X_2 = \sqrt{2}B_2 \times 1.5$	$St_2 = 10\phi_h$
Stopping	$B = 0.012\left(\frac{2\rho_C}{\rho_r} + 1.5\right) \times \phi_c - E$	$S = 1.1B$	$St_S = 0.5B$
Roof	$B = 0.012\left(\frac{2\rho_C}{\rho_r} + 1.5\right) \times \phi_c - E$	$S = 0.8B$	$St_r = 0.5B$
Wall	$B = 0.012\left(\frac{2\rho_C}{\rho_r} + 1.5\right) \times \phi_c - E$	$S = 0.8B$	$St_w = 0.5B$
Floor	$B = 0.012\left(\frac{2\rho_C}{\rho_r} + 1.5\right) \times \phi_c - E$	$S = 0.8B$	$St_f = 0.5B$

Table 9 - Calculated parameters based on equations in Table 8

Sections	Burden (m)	Spacing (m)	Stemming (m)	No & type of dynamite per hole
Firs square	$B_1 = 0.133$	$X_1 = 0.19$	$St_1 = 0.32$	3.5(a)
Second square	$B_2 \approx 0.29$	$X_2 = 0.6$	$St_2 = 0.32$	3.5(a)
Stopping	$B \approx 0.6$	$S \approx 0.7$	$St_S = 0.3$	3(b)
Roof	$B = 0.6$	$S \approx 0.5$	$St_r = 0.3$	2.5(c)
Wall	$B = 0.6$	$S \approx 0.5$	$St_w = 0.3$	2.5(c)
Floor	$B = 0.6$	$S \approx 0.5$	$St_f = 0.3$	3(b)

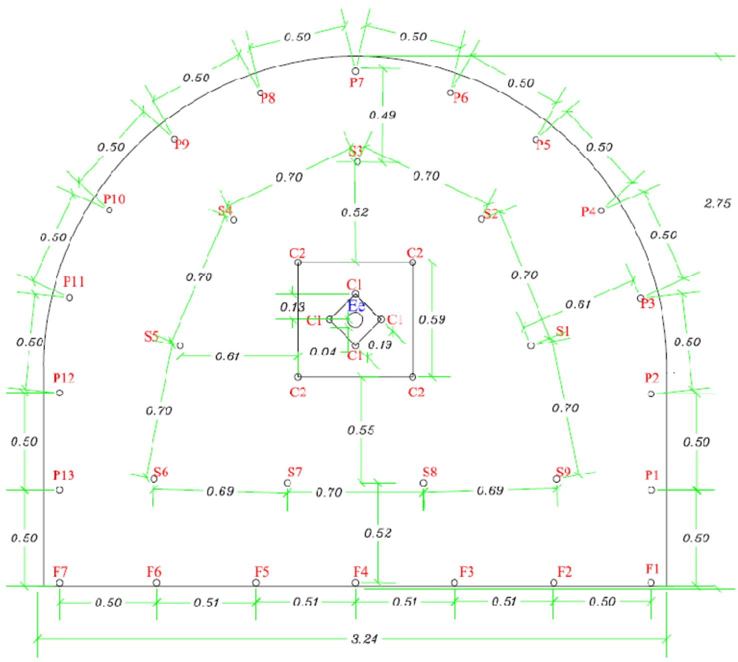

Figure 3 - Blasting pattern based on the modified method

Table 10 - Blasting results of the pattern based on equations in Table 8

SD: Specific drilling (m/m^3)	4.34
SC: Specific charge (kg/m^3)	1.47
AE: Advance Efficiency (%)	90
Length of bootleg (m)	≤0.10

FINAL BLASTING PATTERN

Comparison of Tables 10 and 4 implies that application of the pattern shown in Figure 3 leads to much better results in compare to the pattern previously practiced. Although the model of Figure 3 looks satisfactory, search for getting lower amounts of specific charge and specific drilling continued by gentle practical modifications.

Therefore, the model was improved step by step in consecutive blasting runs. After several blasting cycles, ultimate optimized blasting pattern was obtained (Figure 4). As shown in Figure 4, in ultimate optimized blasting pattern, first cutting square of Figure 3 has been eliminated. As estimation of parameters of second cutting square is done by using the parameters of first square, the later is therefore, determined although not made in practice. Results of ultimate optimized and previously practiced blasting patterns are shown in Table 11. As shown in this table, great improvement has been achieved by the modified model.

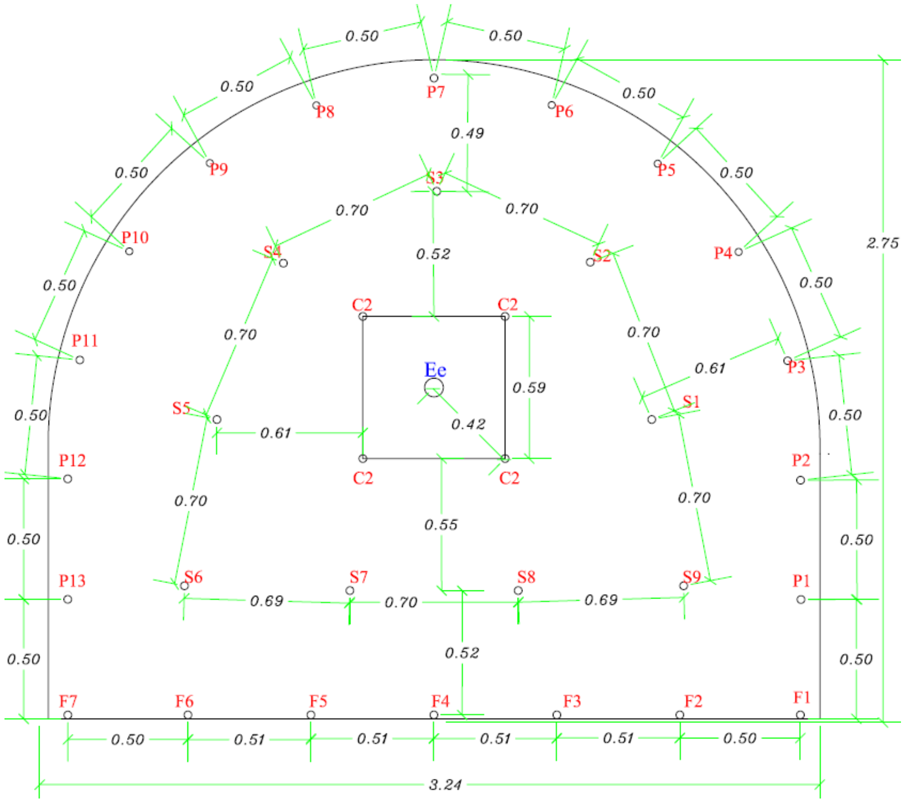

Figure 4 – Final optimized blasting pattern

TABLE 11 - COMPARISON OF FINAL AND PREVIOUS BLASTING PATTERNS

Parameter	previous	ultimate	Improvement,%
Specific drilling (m/m^3)	4.75	3.91	21.5
Specific charge (kg/m^3)	1.51	1.28	18
Advance Efficiency (%)	80	90	12.5
Length of bootleg (m)	0.10-0.20	≤0.10	Average: 50

CONCLUSIONS

- Applying the traditional four-section model to small cross section tunnels would lead to some miss-estimations of the pattern parameters. A modification to the model is inevitable in such tunnels particularly for estimation of stemming, cutting holes burden and perimeter holes spacing.
- In four-section model the proper value of uncharged central hole for tunnels with cross section area of 8-10 m^2 is 75-80 mm.
- In case of small cross section tunnels the third quadrangle of four-section cut is not required.
- Although the specifications of the first quadrangle of the cut are determined, the holes of this quadrangle corners are not drilled.
- The modified model results in great improvement of blasting efficiency and cost saving.

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