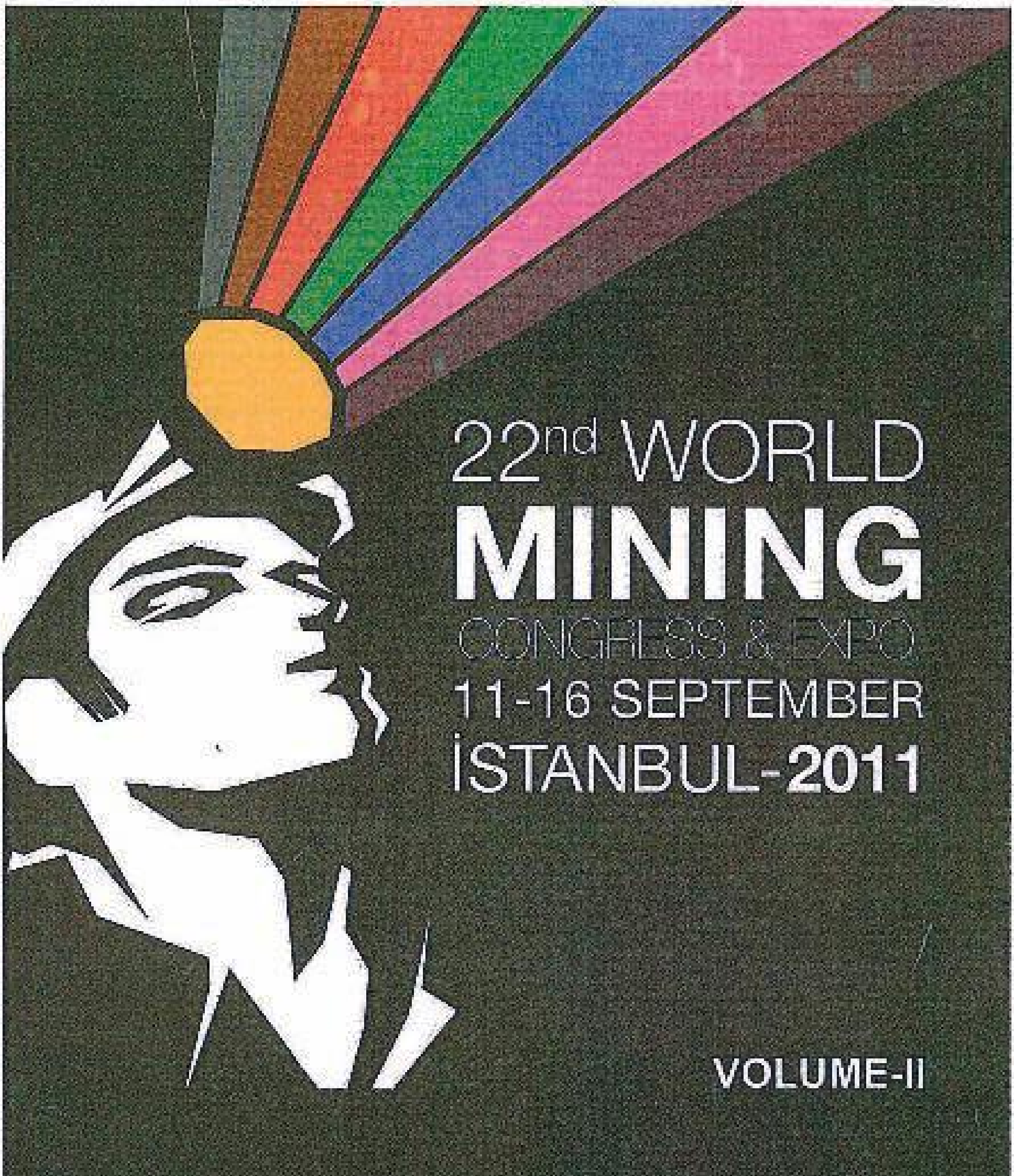

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Dr. Şinasi ESKİKAYA

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SOFTWARE FOR DESIGN OF DRILLING & BLASTING OPERATIONS AT HEPP CONSTRUCTION

[1]U. Kalaycı, U. Ozer, A. Karadogan, *Istanbul University, Engineering Faculty, Mining Engineering Departemant, Istanbul, Turkey*
[2]M.C. Celiksirt, V. Erkan, *Doğuş Inşsaat & Trading Co., Istanbul, Turkey*

ABSTRACT

Drilling and blasting process needs to produce fragment size distributions that are tailored to minimize the production costs and energy consumption including loading, hauling and crushing. This paper presents a part of computer-aided system that can be used for design and planning of open-pit drilling and blasting operations. The case study of software application includes quarry operations in a HEPP Dam construction located at Boyabat / Turkey. To be getting the maximum productivity of the crusher at the quarry, the fragmentation size of the blasted rock material should be inside of the limits of the Passing Size curves of the selected crusher model. The results obtained by the software are compared with actual costs incurred in the field during the construction period and crusher operations. The results of this study, can be used by industry professionals to evaluate different drilling and blasting scenarios.

1. GENERAL INSTRUCTIONS

The below described software for Organization & Analysis of Rock Drilling and Blasting Systems was developed by the authors of this paper. Several Universities and companies in different countries(USA, Australia, Canada, Norway, Italy, Greece, Turkey, Iran) are using the software in MS educational programs and research endeavors. The "Dokuz Eylul University-Turkey" has approved the calculated results of the software with the actual obtained results after a special field experiment.

This software has several parameters which are required at the beginning of design. The included selectable input variable parameters:

1.1. Inputs

- Operating Time

-Volume of rock to be drilled-blasted (m3)
-Operating Time Information (Project duration, Non-working days, working hours per shift etc.)
-Drill Rig and Blasting Labours unit cost, shot firer number and unit cost
-Drill Rig Usage % (Working efficiency, Mechanical availability, drill rig usage)

- Material Characteristics

-Hardness and Density (Swelling factor, Hardness in Moh's scale, Density)
-Joint Orientation (Dominant Joint Plane, Horizontal, vertical, dip into face, dip out of face)
-Water in Borehole (Dry, wet or water level)
-Rock Mass structure (Highly fractured, Blocky, Massive)
-Joint Spacing (Average dominant joint plane spacing)
-Rock Type (Andesit, Basalt, Diorite, Granit etc)

- Fragmentation, Bench dimension, Control Contour Blasting

-Required Fragment Size Distribution (Passing Size 10-150 cm,% by weight)
-Bench Dimensions (Height 4~24m, width 12~150m)
-Control Contour Blasting (Smooth Blasting, Pre-Splitting)

- Drill Rigs & Accessories (selectable from included database)

-Drill rigs
-Drill Steels (Bit, rod, coupling, shank unit costs)
-Charging machinery
-Fuel (diesel) – Lubricating Oil Unit Cost

- Drill Pattern Design

-Drilling Pattern (Rectangular, stagger)
-Row in Drilling Pattern (4~15)
-Hole Inclination (45~90 degree)

- Explosives (selectable from included database)

-Detonator
-Primer
-Bottom Charge
-Column Charge

Drilling pattern and charge in borehole is not an input value it is calculated by the software according to the other selected input values. Both of the calculated values are also editable (bounded by the limits of the software) by the user.

The calculated output parameters:

1.2. Outputs

- Reports

Several different text and graphic reports included drilling-blasting cost results. Some of the calculated report parameters are:

Specific Drilling (m/m3 and m/m2), Yield (m3/m and m3/hole), Specific Charging (kg/m3), Penetrate Rate (m/min), Drilling Capacity (m/h), Amount of drilling (m), Amount of blast-hole (number), Total Detonator (number), Primer charge (kg), Bottom charge (kg), Column charge (kg), Drilling Cost ($/m3), Blasting Cost ($/m3), Burden x Spacing (m2), Velocity of Detonation (m/sec)

- Comparing results with other projects
- Geometry, 3D graphical View of Drilling pattern
- Fragment Size Distribution, numeric and graphic view
- Timing Analyses, Fire Planning, Delay Drill pattern design

Air Shock Wave as a Function of Distance for Each bore hole diameter, Particle Velocity as a function of distance for each hole-diameter, Maximum traveling distance of fly-rock as a function of blast-hole diameter for specific charge

- Schedule plans
- Daily Record results and reports

The software includes; Drilling Pattern, Planning of the project duration, Control Contour Blasting (Smooth & Pre-Splitting) methods, Cost Model, Fragmentation models. Hereafter the Cost model and especially Fragmentation model will be described.

2. COST MODEL

Cost estimation model consists of two entities. First entity includes total drilling cost (TDC) while the second one includes total blasting cost (TBC).

2.1. Drilling Cost

Total drilling cost (TDC) is given by

TDC = DMIC + DMCC + DSC + FC + DLC ($/m3)

where DMIC is drilling machine investment cost, DMCC is drilling machine corrected cost (Tamrock 1987), DSC is drill steels cost, FC is fuel cost, and DLC is drilling labor cost.

2.2. Blasting Cost

Total blasting cost (TBLAST) is given by

TBLAST = MATC + BLASTL + CHMCOST + FUELC + CHMLCOST ($/m3)

Where MATC is blasting material cost, BLASTL is blasting labor cost, CHMCOST is charging machine cost, FUELC is charging machine fuel cost, and CHMLCOST is charging machine labor cost.

3. FRAGMENTATION MODEL

The fragmentation model in the software is based on the original equation which was developed by Kuznetsov, modified by Cunningham for ANFO based explosives and also the size distribution theory of Rosin & Rammler and the rock type correlation of Lilly.

Required fragment size distribution; Passing size (10~150 cm), Percentage by weight (5~99%) are given by the user and after, the Fragmentation model starts the calculation and as result the drilling pattern (Burden and Spacing values) are ready.

Hereafter the fragmentation model is described.

ROCKFAC = 0.05 * (RMD + JF + OF + RDI + HF)
(Lilly, P., 1986)

ROCKFAC is Rock Factor (or Blastability Index) and it's calculated by existing parameters from "Material Characteristics" section. RMD is rock mass description, JF is joint factor, OF is joint orientation factor, RDI is rock density index, HF is hardness factor.

(Rosin-Rammler, 1933)

$$Y = 100\left(1 - e^{-(X/S51)^{RR}}\right)$$

RR is uniformity in the Rosin-Rammler equation.

The RR uniformity range is between 0.75 to 1.50 and the calculated ROCKFAC range is between very poor to good blastability.

If Blastability Index (ROCKFACTOR) is between
7.34 to 8.75 then RR = 1.50 and
4.52 to 7.34 then RR = 1.25 and
1.71 to 4.52 then RR = 1.00 and
0.30 to 1.71 then RR = 0.75

The software calculates the uniformity, according to the selected rock properties.

S51 is the required characteristic size of distribution (m) which is calculated by the software, X is size of material (m) and Y is percentage of material less than the size X (%).

$S50 = ROCKFAC * SC^{0.8} * KGMD^{0.167} * (115/STRENGTH)^{0.633}$
(Kuznetsov 1973)

S50 is average size of material (cm), KGMD is explosive charge weight per blast hole (kg), SC is specific charge (kg/m3), and STRENGTH is effective relative bulk strength in charge length.

STRENGTH = ((COLRBS * HCOL) + (BOTRBS * HBOTT) + (PRIRBS * HPRI)) / CCL

COLRBS is column charge relative bulk strength, BOTRBS is bottom charge relative bulk strength, PRIRBS is primer charge relative bulk strength, HCOL is height of column charge (m), HBOT is height of bottom charge (m), HPRI is height of primer charge (m), CCL is total charge length (m).

3. STUDY FOR DIFFERENT ALTERNATIVES OF "FRAGMENTATION SIZE"

The results shown in Table 1a, 1b, 1c are the previously planned values which are calculated in the office with the software according to the selected condition values.

Table 1a. If as input values, the required fragment size distribution is 90% of material less than passing size 50 cm selected, the below theoretical results are calculated by the software

HD	B	S	ST	CC	CCL	SC	SUD
89	2.27	2.69	2.45	43.38	8.36	0.722	0.73
102	2.43	3.06	2.69	55.72	8.18	0.760	0.78

HD	SD	Y1	Y2	DC	BC	TC
89	0.18	5.53	61.14	0.69	0.65	1.34
102	0.15	6.70	74.37	0.92	0.95	1.87

Table 1b. If as input values, the required fragment size distribution is 90% of material less than passing size 60 cm selected, the below theoretical results are calculated by the software

HD	B	S	ST	CC	CCL	SC	SUD
89	2.29	3.37	2.46	43.38	8.36	0.571	0.73
102	3.06	3.06	2.90	55.72	8.18	0.603	0.98

HD	SD	Y1	Y2	DC	BC	TC
89	0.14	6.99	77.29	0.54	0.73	1.27
102	0.12	8.28	93.66	0.54	0.76	1.30

Table 1c. If as input values, the required fragment size distribution is 90% of material less than passing size 70 cm selected, the below theoretical results are calculated by the software

HD	B	S	ST	CC	CCL	SC	SUD
89	2.77	3.37	2.62	43.38	8.36	0.471	0.69
102	2.98	3.84	2.86	55.72	8.18	0.497	0.95

HD	SD	Y1	Y2	DC	BC	TC
89	0.12	8.34	93.49	0.46	0.61	1.07
102	0.10	10.07	113.59	0.45	0.63	1.08

Explanation for Table 1a, 1b and 1c
HD: Hole Diameter (mm), B: Burden (m), S: Spacing (m), ST: Stemming (m), CC: Column Charge (kg), CCL : Column Charge Length (m), SC: Specific Charge (kg/m3), SUD: Sub Drilling (m), SD: Specific Drilling (m/m3), Y1: Yield (m3/m), Y2: Yield (m3/hole), DC: Drilling Cost ($/m3), BC: Blasting Cost ($/m3), TC: Total Cost ($/m3)

The software was run for different alternatives of fragment size distributions. However, the results in Table 1a, 1b, 1c are eligible and site studies were initiated accordingly.

4. CASE STUDY

"Boyabat Dam and Hydroelectric Power Plant" is located 124 river kilometers from the mouth of the Kızılırmak River, where it discharges into the Black Sea.

The Boyabat Project consists of a concrete gravity dam (approximately 150 m high from riverbed and 195 meters high from the rock foundation), a powerhouse within the body of the concrete dam containing three vertical Francis turbine-generating units with a total installed capacity of 510-MW, an associated switchyard, and appurtenant facilities.

The required aggregate for the concrete production of the dam will be obtained with drilling-blasting method at the rock quarry and by a comprehensive crusher system.

The Case Study is performed during the construction at the HEPP Dam in Boyabat-Turkey.

The fragmentation size of the produced rock material at the T3 quarry is important for crusher feeding.

The max size for the selected (2 x 600 ton/h) crusher jaw model is 90 cm. If the fragmentation size is too big, then the material squeezes in the crusher jaw and cause to delay and increase of total crusher cost.

During the application at the quarry, closer data's to Table 1a, 1b, 1c was applied. The applied data's are shown at Table 2a, 2b, 2c.

Table 2a. The values at this table are the application at the quarry according to Table 1a with 90% of material less than passing size 50 cm

HD	B	S	ST	CC	CCL	SC	SUD
89	2.30	2.70	2.00	42.00	8.00	0.700	0.70
102	2.50	3.00	2.40	55.00	8.30	0.730	0.75

HD	SD	Y1	Y2	DC	BC	TC
89	0.20	5.50	60.00	0.65	0.62	1.27
102	0.15	6.50	75.00	0.80	085	1.65

Table 2b. The values at this table are the application at the quarry according to Table 1b with 90% of material less than passing size 60 cm

HD	B	S	ST	CC	CCL	SC	SUD
89	2.30	3.40	2.00	43.00	8.50	0.450	0.75
102	3.00	3.00	2.70	55.00	8.20	0.340	0.85

HD	SD	Y1	Y2	DC	BC	TC
89	0.15	7.00	75.00	0.50	0.70	1.20
102	0.12	8.00	95.00	0.50	0.75	1.25

Table 2c. The values at this table are the application at the quarry according to Table 1c with 90% of material less than passing size 70 cm

HD	B	S	ST	CC	CCL	SC	SUD
89	2.70	3.50	2.50	43.00	8.00	0.240	0.80
102	3.00	4.00	2.70	56.00	8.40	0.250	0.90

HD	SD	Y1	Y2	DC	BC	TC
89	0.10	8.50	94.00	0.45	0.60	1.05
102	0.10	10.00	114.00	0.40	0.65	1.05

Explanation for Table 2a, 2b, 2c
HD: Hole Diameter (mm), B: Burden (m)
S: Spacing (m), ST : Stemming (m)
CC: Column Charge (kg), CCL: Column Charge Length (m), SC: Specific Charge (kg/m3), SUD : Sub Drilling (m), SD: Specific Drilling (m/m3), Y1 : Yield (m3/m), Y2: Yield (m3/hole), DC: Drilling Cost ($/m3), BC: Blasting Cost ($/m3), TC : Total Cost ($/m3)

The results on Tables 1a, 1b, 1c shows the theoretical values which was calculated by the software but the results on tables 2a, 2b, 2c shows the quarry application data's. After the blasting operations, the fragment size distribution was checked out and was deemed to be appropriate.

The obtained appropriate fragment size distribution result with (90% of material less than passing size 50 cm) for primer crusher jaw is shown at table 2b.

Our experience has shown that at table 2a the fragment size is smaller than required, at table 2c the fragment size was to big and caused several problems at the crusher jaw. Also, for the proposed primer crusher, the maximum and minimum limit of passing size (given by Akzo Nobel Co. / Sweden) for the blasted material is shown in Table 3. The equivalent curve for 102 mm hole diameter, which is calculated by the software and inside the limits is passing size (60 cm), percentage by weight (90%). Numerical values of the graphic at Figure 1 are shown on Table 3.

The most appropriate curve was obtained for 90% of material less than passing size 60 cm.

Table 3 Comparison of three different fragment size distribution values between Akzo Nobel and the software

	Akzo Nobel Co.		Software calculated results for 102 mm hole diameter		
Particle size, m	Passing top limit, %	Passing down limit, %	50 cm, 90%	60 cm, 90%	70 cm, 90%
1,100	100	100	99,264	99,791	98,260
1,000	98	100	98,723*	99,382*	97,257
0,700	92	100	93,870*	97,000*	90,000
0,500	80	95	84,012*	90,000*	77,953
0,200	40	60	44,189*	51,928*	38,183
0,100	21	35	21,745*	26,506*	18,309
0,045	10	19	10,790	8,641	7,182
0,010	5	8	1,716	1,369	1,130

* Values at Table 3 are inside the limits of Akzo Nobel Curves (Fig. 1).
Note: During the construction, 89 mm and 102 mm hole diameters were drilled, therefore the actual data's are only for those two diameters.

5. CONCLUSION

The best fragment size distribution result for the crusher was obtained with the values shown in Table 2b with the 102 mm hole diameter. This result also confirms the suggested fragment size distribution curve for the primer crusher jaw.

The drilling-blasting operation total cost for fragment size distribution with 90% of material less than passing size 70 cm is low (see Table 2c) , but the problems with this fragment size at the primer crusher jaw has become more expensive.

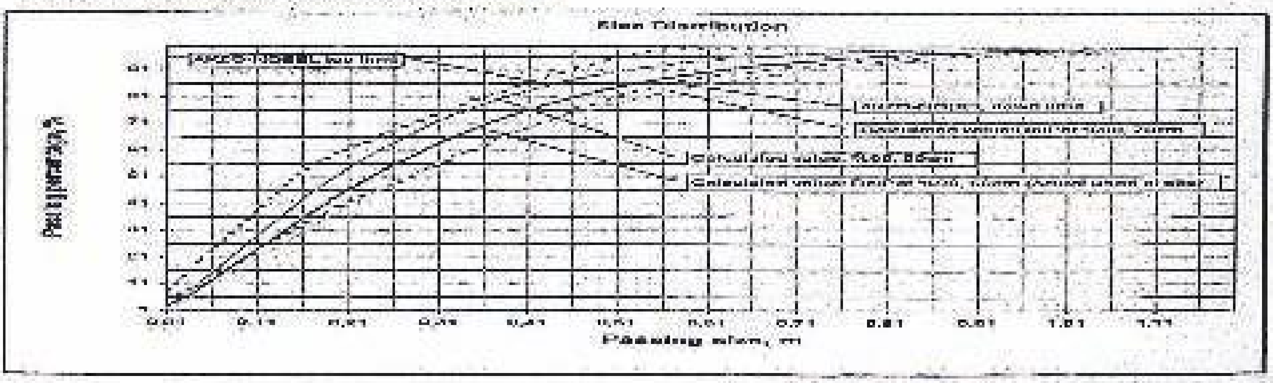

Figure 1 .Size distribution as a function of passing percentage (%) and passing size(m)

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