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# ESTIMATION OF DRILLING AND BLASTING COSTS IN ROAD EXCAVATION

**M.Can ÇELİKSIRT[1], Vural ERKAN[1], Vladislav KECOJEVIC[2]**

[1] DelPat, Doğuş Grubu Binaları-Büyükdere Cad No:65 A-Blok Kat.3 34398 Maslak-Istanbul, TURKEY
info@delpat.com

[2] The Pennsylvania State University, 154 Hosler Building, University Park, PA 16802, USA
vuk2@psu.edu

## ABSTRACT

Drilling and blasting costs represent a significant component in terms of overall costs related to road excavation. Therefore, an accurate and comprehensive costing model should be developed in design stage. This paper presents a part of new integrated computer-aided system called DelPat that can be used for estimation of drilling and blasting costs. The stand-alone version with both metric and imperial units was developed in Microsoft Visual Basic programming language. The database was developed using Microsoft Access system and applies multi–user, open database connectivity for storage and processing of drilling and blasting information. The case study of system application is presented for Tarsus Mersin Motorway Construction in Turkey.

## INTRODUCTION

The major thrust in drilling and blasting operations is to maintain safety and minimize overall costs. Additionally, in road excavation projects the special emphasizes is placed on the final rock wall contours where smooth blasting or pre-splitting is commonly used. Drill holes are charged with special, light explosives to minimize the effect of shock waves and initiation is frequently performed by detonating cords, and pre-split holes are fired simultaneously ahead of the other holes whereas smooth blasting uses the highest number of detonator delay [1].

Estimation of drilling and blasting costs associated with road excavation is one of the crucial steps in a project development. Drilling costs comprise operating and ownership costs while blasting costs include explosives, boosters and primers, initiation systems, labor costs, and the costs of bulk loading. A detailed discussions, principles and the fundamental theoretical background on drilling and blasting related costs can be found in Atlas Powder [2], ICI Explosives [3], Dowding and Aimone [4], Kleine et al [5], Tamrock [6], La Rosa [7], and Kanchibotla [8].

In the last two decades, many efforts have been made to develop models and computer programs to assist the designer in estimation of drilling and blasting costs. Ingersoll-Rand has developed a computer program called Drill Cost Estimating (DCE) to assist users to select proper drilling equipment [9]. The Julius Kruttschnitt Mineral Research Centre

(JKMRC) has developed JKBMS system in attempting to carefully measure costs and use that information to produce calibrated cost models with which to evaluate blast optimization [7]. Dyno Nobel's BLASTEC software tool is focused on planning and cost estimation for drilling and charging [10], while Precision Blasting Services was developed the Blasting Cost Analyst software that compares costs resulting from as many as four different patterns at one time and calculates the cost per volume and the cost per weight for each design [11].

## DELPAT COST MODEL

DelPat main screen contains six different categories that should be defined in design stage. These categories include: Planning (total amount of rock excavation and time roster, labor and associated costs), Machinery (drilling, drill steels, charging, fuel-lubricating oil price), Properties of rock material (rock mass, joint spacing, rock type, hardness and specific gravity, joint orientation, and water case), Drilling arrangement (patterns type–rectangular or staggered, number of rows, and hole inclination), Fragment size distribution and bench dimensions, and Explosives (detonator, primer, bottom charge, column charge).

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

### Drilling Costs

Total drilling costs (TDC) are given by

$$\mathrm{TDC} = \mathrm{DMIC} + \mathrm{DMCC} + \mathrm{DSC} + \mathrm{FC} + \mathrm{DLC} \qquad (5)$$

where DMIC is drilling machine investment cost, DMCC is drilling machine corrected cost [6], DSC is drill steels cost, FC is fuel cost, and DLC is drilling labor cost.

Drilling machine investment cost (DMIC) is given by

$$\mathrm{DMIC} = \frac{\mathrm{DMFC} \times \mathrm{DMAF}}{\mathrm{EDPS} \times \left(365 - \frac{\mathrm{TNWD} \times 365}{\mathrm{PD}}\right)} \qquad (5)$$

where DMFC is drilling machine FOB cost ($), DMAF is drilling machine annuity factor, EDPS is effective drilling per shift, TNWD is number of total non-working days, and PD is project duration in days.

Effective drilling per shift (EDPS) can be calculated by

$$\mathrm{EDPS} = \mathrm{DMC} \times \mathrm{WHPS}$$

where WHPS is number working hours per shift, and DMC is drilling machine drill capacity (m/hour) and can be obtained by

$$DMC = \left( PR \times 60 \times \frac{DMDR}{100} \right) \times \frac{DRU}{100}$$

where DMDR is drilling machine drill rate (%), and DRU is drill rig usage (%) and is given by

$$DRU = \left( \frac{\text{Working efficiency} \times \text{Mechanical availability}}{100} \right)$$

PR is penetration rate and can be obtained by the following equation

$$PR = 31 \times \left( \frac{DMP}{HD^{1.4}} \right)$$

where DMP is drilling machine power (kW), and HD is hole diameter (mm).

Drilling machine annuity factor (DMAF) is given by the following equation

$$DMAF = \frac{NDM \times \frac{DMIR}{100}}{1 - \left( 1 + \frac{DMIR}{100} \right)^{-DMDP}}$$

where NDM is number of drilling machines, DMIR is drilling machine interest rate (%), and DMDP is drilling machine depreciation period.

Number of required drilling machines (NDM) can be calculated as

$$NDM = \frac{\frac{TRE}{NWD}}{EDPS \times VMPL \times SPD}$$

where TRE is total rock excavation ($m^3$), NWD is number of net working days, SPD is number of shifts per day, and VMPL is volume of material per length ($m^3$/m).

Number of net working days (NWD) can be obtained as

$$NWD = PD - TNWD$$

Volume of material per length (VMPL) is given by

$$VMPL = \frac{B \times S \times BH}{HD}$$

where B is burden (m), S is spacing (m), BH is bench height (m), and HD is hole depth (m).

Drilling machine corrected cost (DMCC) can be calculated as [6]

$$DMCC = \frac{abefac}{DMC} \quad (\$)$$

where abefac is a constant which changes according to the total number of working hours of drilling machine (ENGHOUR) within the net working days and has the following values [6]

| | | |
|---|---|---|
| ENGHOUR | <=1500 → | abefac = 3.5 |
| ENGHOUR | 1500 to 3000 → | abefac = 11.5 |
| ENGHOUR | 3000 to 4500 → | abefac = 18.5 |
| ENGHOUR | 4500 to 6000 → | abefac = 31.5 |
| ENGHOUR | >6000 → | abefac = 43.5 |

ENGHOUR can be determined by

$$ENGHOUR = \frac{NWD}{\frac{SD - FD}{365}} \times WHPS \times SHP \times \frac{DMDR}{100} \times \frac{DRU}{100}$$

where SD is start date of the project, FD is end date of the project, and SHP is number of shifts per day.

Drill steel cost (TSC) is given by

$$TSC = GMC + AGCC + TBC + RC + CPC + SC \quad (\$)$$

where GMC is grinding machine cost, AGCC is grinding cup cost, BC is bit cost, RC is rod cost, CC is coupling cost, and SC is shank cost.

Grinding machine cost (GMC) is given by

$$GMC = \frac{GMFOB}{GML \times \frac{TLD}{\frac{PD}{365}}} \quad (\$)$$

where GMFOB is grinding machine FOB cost ($), GML is grinding machine life (year), and TLD is total length of drilling (m) and can be obtained by

$$TLD = TRE \times \frac{1}{VMPL}$$

The grinding cup cost (AGCC) is given by

$$AGCC = \frac{GCC}{\frac{TLD \times \frac{365}{PD}}{GBSL \times GCL}} \quad (\$)$$

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.

Blasting material cost (MATC) is given by

$$MATC = \frac{DETCOST + PRICOST + BOTCOST + COLCOST}{TRE} \quad (\$)$$

where DETCOST is detonators cost ($/detonator), PRICOST is primer cost ($/kg), BOTCOST is bottom charge cost ($/kg), and COLCOST is column charge cost ($/kg).

Blasting labor cost (BLASTL) is given by

$$BLASTL = \frac{(NF \times FW) + (NFA \times AFW) \times NWD \times WHPS}{TRE} \quad (\$)$$

where NF is number of fireman, FW is fireman wage ($/h), NFA is number of fireman assistants, and AFW is fireman assistant wage ($/h).

Charging machine cost (CHMCOST) is given by

$$CHMCOST = \frac{CMFC \times TAEX}{CMCA \times 60 \times B \times S \times BH \times ENGHOURS} \times CMAF \quad (\$)$$

where CMFC is charging machine FOB cost ($), TAEX is total amount of explosives (kg), CMCA is charging machine capacity (kg/min), and CMAF is charging machine annuity factor and can be determined by the similar formula as for drilling machine.

Charging machine fuel cost (FUELC) is given by

$$FUELC = \frac{CMFCON \times MFC \times TAEX}{CMCA \times 60 \times B \times S \times BH \times ENGHOURS} \quad (\$)$$

where CMFCON is charging machine fuel consumption (l/h).

Charging machine labor cost (CHMLCOST) is given by

$$CHMLCOST = \frac{CMOW + CMAW}{CMCA \times 60 \times B \times S \times BH \times NWD \times WHPS} \times TAEX \quad (\$)$$

where CMOW is charging machine operator wage ($/h), and CMAW is charging machine assistant wage ($/h).

## CASE STUDY

The computer-aided system DelPat was used in drilling and blasting design for the construction of a dual three-lane Tarsus Junction Mersin Motorway Construction in Turkey (Fig. 1). More than 73 kilometers of the highway have been completed with 52 million cubic meters of material excavated. This motorway was built in a deep cutting in the limestone that is predominant in this part of Turkey.

where GCC is grinding cup purchase cost ($), GBSL is grinding bit service life (m), and GCL is grinding cup life (grinding/pcs).

Bit cost (BC) can be expressed as

$$BC = \frac{BPC}{SBL} \qquad (\$)$$

where BPC is bit purchase cost ($/pcs) and BL is bit life (m).

Rod cost is given by

$$RC = \frac{RPC}{RL} \qquad (\$)$$

where RPC is rod purchase cost ($/pcs) and RL is rod life (m).

Coupling cost (CC) is given by

$$CC = \frac{CPC}{CL} \qquad (\$)$$

where CPC is coupling purchase cost ($/pcs), and CL is coupling life (m).

Shank cost is given by

$$SHC = \frac{SPC}{SHL} \qquad (\$)$$

where SPC is shank purchase cost ($/pcs) and SHL is shank life (m).

Fuel cost is given by

$$FC = \frac{DMFC \times MFC}{DMC} \qquad (\$)$$

where DMFC is drilling machine fuel consumption (l/h), and MFC is market fuel cost ($/l).

Drilling labor cost is given by

$$DLC = \frac{DMOW + ADM}{DMC} \qquad (\$)$$

where DMOW is drilling machine operator wage ($/h), and ADM is assistant for drilling machine wage ($/h).

**Blasting Costs**

Total blasting costs (TBLAST) is given by

$$TBLAST = MATC + BLASTL + CHMCOST + FUELC + CHBLASTC \qquad (\$)$$

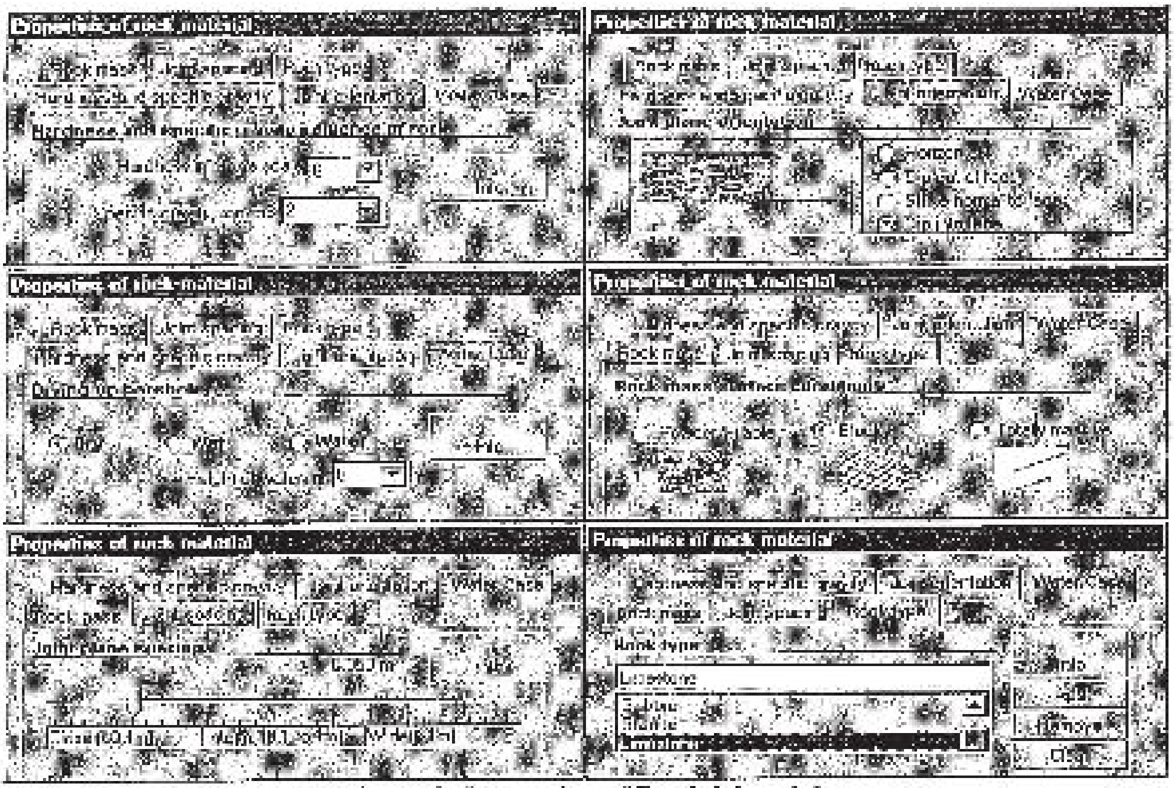
Figure 3. Properties of Rock Material.

An efficient loading and haulage operation requires appropriate fragment size distribution. The major implications of oversized fragments are reduced loading productivity and secondary blasting. For this case study, the fragment size was designed at 60 cm with percentage by weight at 79 % (Fig. 4). The maximal bench height was 10 m, while bench width was 24 m.

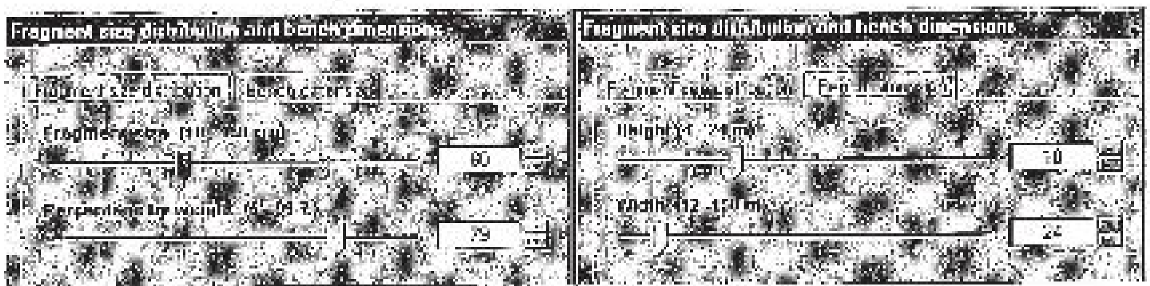
Figure 4. Fragment Size Distribution and Bench Dimensions.

The Tamrock ZOOMTRAK DHA 1000S drilling machine was selected and the following parameters were included: FOB cost of 290 000 USD, depreciation period of 7 years, annual interest rate of 15 %, power class of 18.5 kW, fuel consumption of 24 l/h, minimal hole diameter of 89 mm, maximal hole diameter of 152 mm, rod length of 3660 mm, and drilling rate of 67 %. The machine/fuel cost was 0.35 USD/l and machinery/lubricating oil cost was 0.5 USD/l ((Fig. 5).

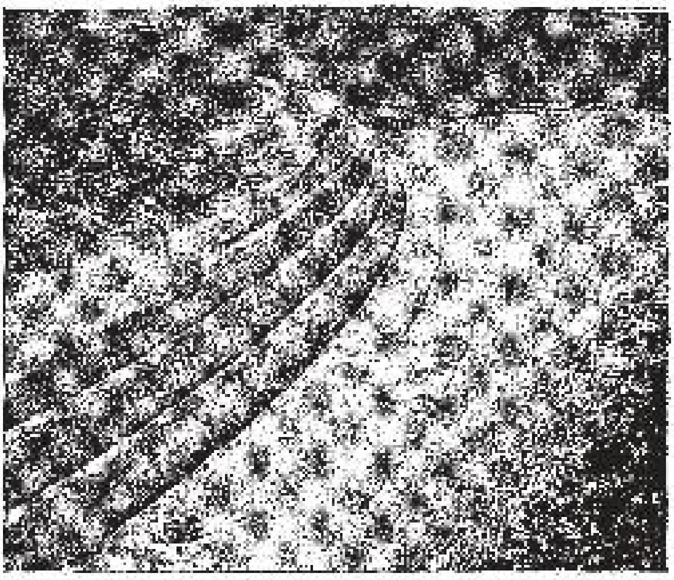

Figure 1. Tarsus Junction Mersin Motorway Construction, Turkey.

Drilling and blasting operations were based on 4.8 million of rock materials to be excavated annually including 4 non-working days per month, 10 working hours per shift, and 2 shifts per day (Fig. 2). Drill rig usage was 67.5 % .

Rock material was limestone with hardness in Moh's scale of 6 and specific gravity of 2 t/m$^3$. Rock mass surface condition was selected as a Blocky, i.e. well interlocked undisturbed rock mass consisting of cubical blocks formed three intersecting discontinuity sets. Joint plane orientation was selected as a Dip into face, borehole case was as Dry, while the Joint plane spacing value was 0.05 m. All the properties of rock material are presented in Fig.3.

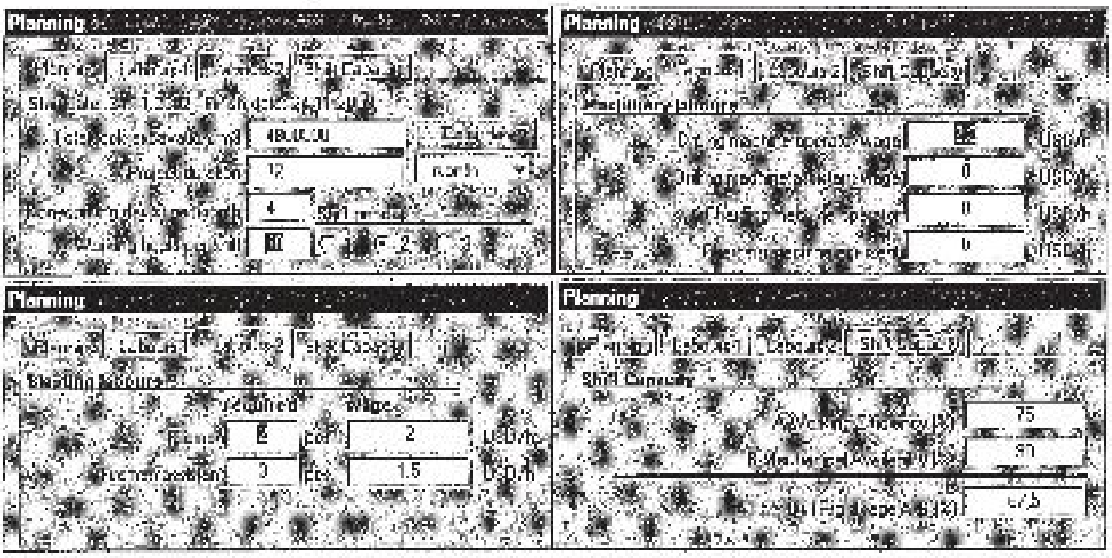

Figure 2. Planning of Drilling and Blasting Operations.

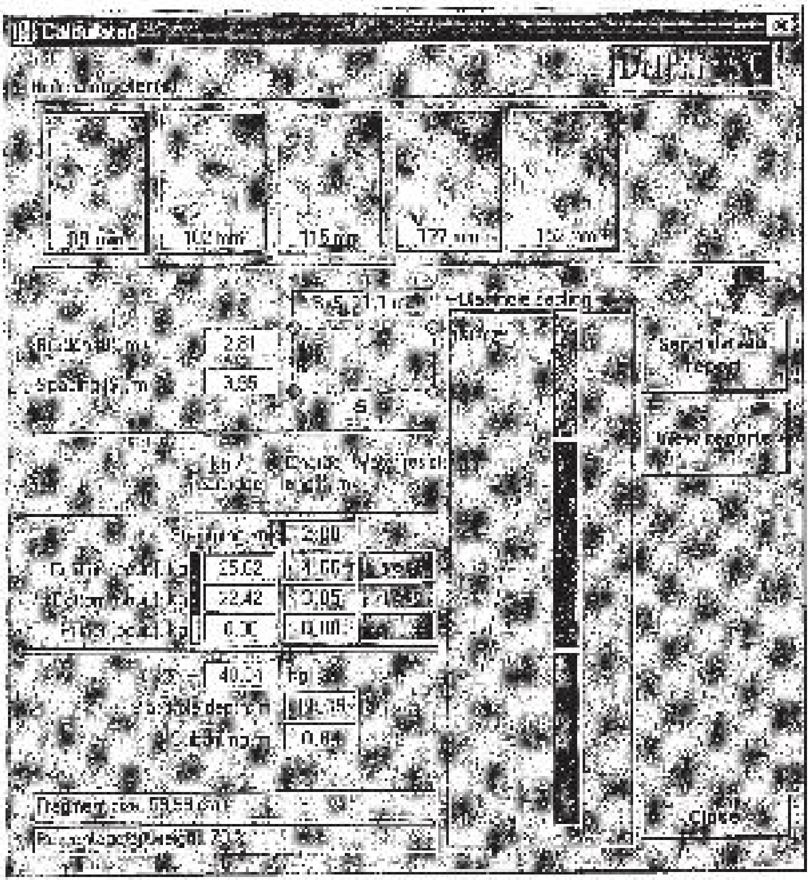

Figure 7. Calculated Values for Hole Diameter of 89 mm.

Table 1. Column and Bottom Charge for Different Hole Diameters.

| Column charge | | | | | | | Bottom charge | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| HD | B | S | BxS | ST | CLK | CLM | CLK | CLM | HDP | SB |
| 89 | 2.81 | 3.95 | 11.10 | 2.88 | 25.62 | 4.66 | 22.42 | 3.85 | 11.39 | 0.84 |
| 102 | 3.04 | 4.49 | 13.64 | 3.10 | 30.39 | 4.21 | 31.73 | 4.15 | 11.46 | 0.91 |
| 115 | 3.24 | 5.03 | 16.28 | 3.36 | 33.31 | 3.63 | 44.05 | 4.53 | 11.52 | 0.97 |
| 127 | 4.21 | 4.45 | 18.75 | 3.83 | 35.39 | 3.16 | 57.38 | 4.84 | 11.83 | 1.26 |
| 152 | 4.51 | 5.38 | 24.25 | 4.31 | 32.22 | 2.01 | 95.09 | 5.60 | 11.92 | 1.35 |

Table 2 shows specific drilling, yield, and specific charge for various hole diameters. The following abbreviations were introduced: HD–hole diameter (mm), BH–bench height (m), HL–hole length (m), SD–specific drilling ($m/m^3$), yield in ($m^3/m$) and ($m^3$/hole), TC–total charge (kg), and SC-specific charge ($kg/m^3$).

Through the project the special emphasizes was placed on studying the relationship between the cumulative amounts of fragments (%) passing different meshes size. A fragment size distribution was quantified by mesh sizes with 10, 50 and 100% of the mass passing ($S_{10}$, $S_{50}$, and $S_{100}$). Upon calibration, validation and sensitivity analysis, the prediction of fragment size distributions was based on formulas such as Kuznetsov-Rosin-Rammler [12], Cunningham [13], and the Swedish Detonic Research Foundation formula [14].

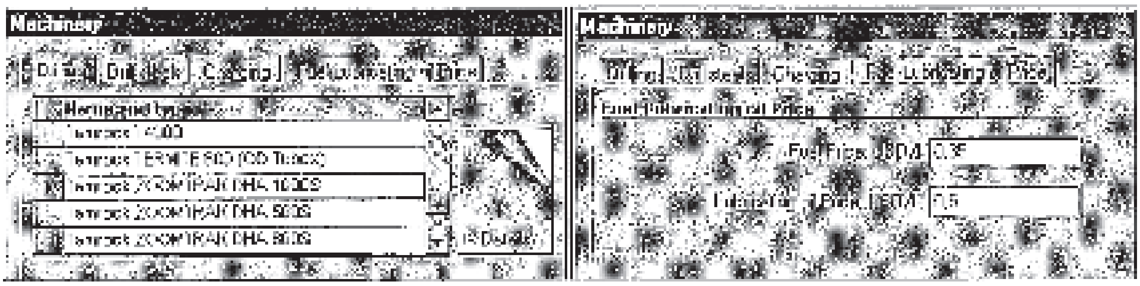

Figure 5. Machine Selection.

Drilling pattern was selected as "Rectangular" with 4 rows, and hole inclination of 3/1 or 72 degree (Fig. 6). The DetEx1 detonator was selected from the Explosives/Detonator database including 2 detonators per hole and cost of 3.4 USD/pcs. The BottEx1 was selected from the Explosives/Bottom charge database including the following properties: absolute weight strength of 900 cal/g, density of 0.9 g/cm$^3$, velocity of detonation of 2500 m/sec, cost of 1.15 USD/kg, cartridge diameter of 0 mm (pouring), and cartridge length of 0 mm (pouring). The ColEx1 column charge was used with the following properties: absolute weight strength of 912 cal/g, density of 0.85 g/cm$^3$, velocity of detonation of 2500 m/sec, cost of 0.5 USD/kg, cartridge diameter of 0 mm (pouring), and cartridge length of 0 mm (pouring). Primer was not used in this project.

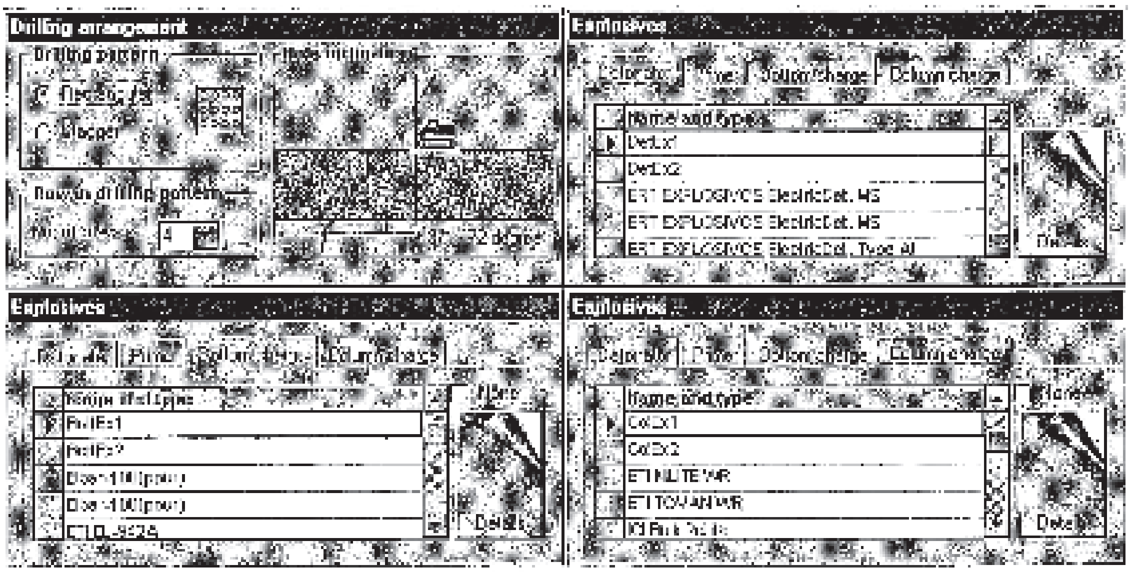

Figure 6. Selection of Drilling Arrangements and Explosives.

Based upon the input parameters, the various alternatives were considered. Fig. 7 shows calculated values for burden, spacing, stemming, column and bottom charge, hole depth and sub-drilling for hole diameter of 89 mm.

Table 1 shows column and bottom charge for various hole diameters applied in the project. The following abbreviations were introduced: HD–hole diameter (mm), B-burden (m), S–spacing (m), ST–stemming (m), CLK–column (kg), CLM–column (m), HDP-hole depth (m), and SB–sub-drilling (m).

- The mesh sizes with 10% of the mass passing as block size (P10) is 0,041 m
- The mesh sizes with 25% of the mass passing as block size (P25) is 0,111 m
- The mesh sizes with 40% of the mass passing as block size (P40) is 0,197 m
- The mesh sizes with 50% of the mass passing as block size (P50) is 0,267 m
- The mesh sizes with 75% of the mass passing as block size (P75) is 0,535 m
- The mesh sizes with 90% of the mass passing as block size (P90) is 0,888 m

The histogram of weight passing- block size for 89 mm hole diameter is shown in Fig. 9, while Fig. 10 shows calculation of S50 according to block size. Table 4 shows these values for various hole diameters where S50s is start value of S50, S50f is end value of S50, SCs is start value of specific charge, and SCf is end value of specific charge.

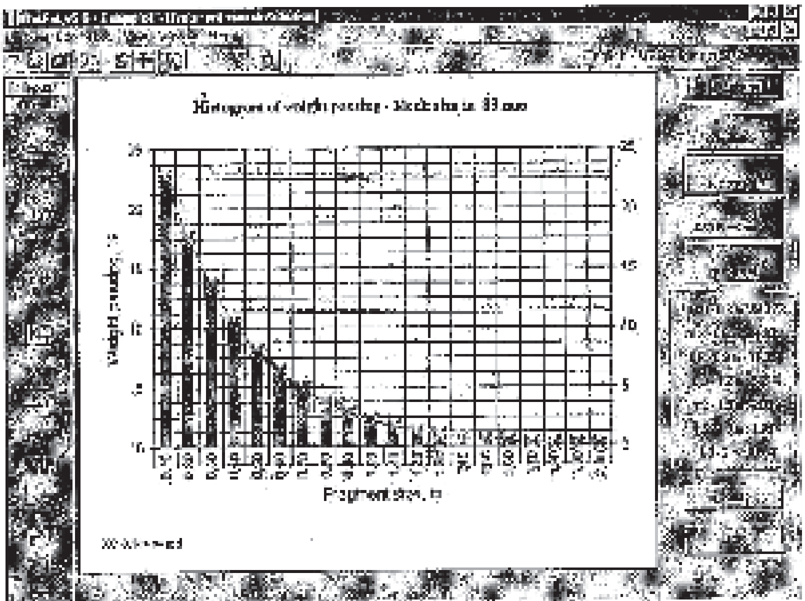


Figure 9. The Histogram of Weight Passing- Block Size for 89 mm Hole Diameter.

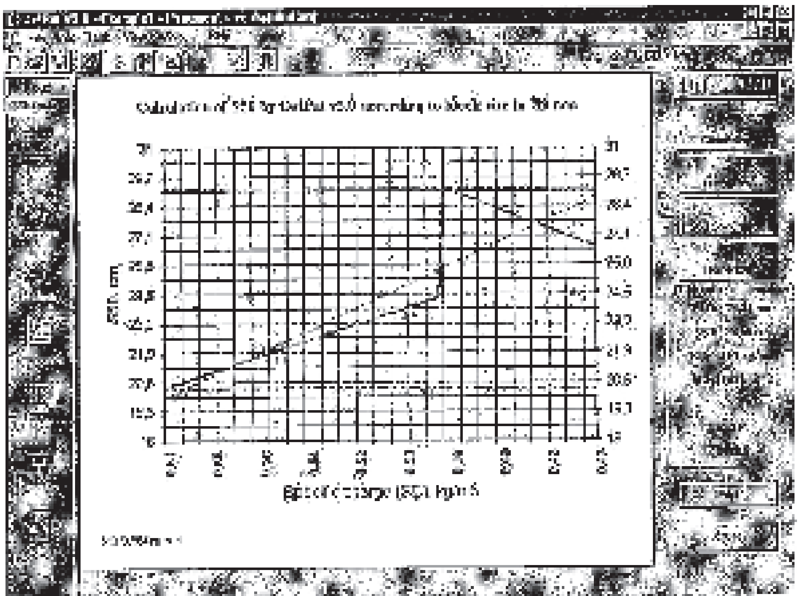

Figure 10. Calculation of S50 According to Block Size for 89 mm Hole Diameter.

Table 2. Specific Drilling, Yield, and Specific Charge for Various Hole Diameters.

| HD (mm) | BH (m) | HL (m) | SD ($m/m^3$) | Yield ($m^3/m$) | Yield ($m^3$/hole) | TC (kg) | SC ($kg/m^3$) |
|---|---|---|---|---|---|---|---|
| 89 | 10 | 11,39 | 0,103 | 9,75 | 110,99 | 48,04 | 0,433 |
| 102 | 10 | 11,46 | 0,084 | 11,91 | 136,42 | 62,12 | 0,455 |
| 115 | 10 | 11,52 | 0,071 | 14,13 | 162,81 | 77,36 | 0,475 |
| 127 | 10 | 11,83 | 0,063 | 15,86 | 187,53 | 92,77 | 0,495 |
| 152 | 10 | 11,92 | 0,049 | 20,34 | 242,45 | 127,32 | 0,525 |

Fig. 8 shows cumulative graph of weight passing block size in 89 mm hole diameter while Table 3 shows fragment size distribution for various hole diameters studied through the project.

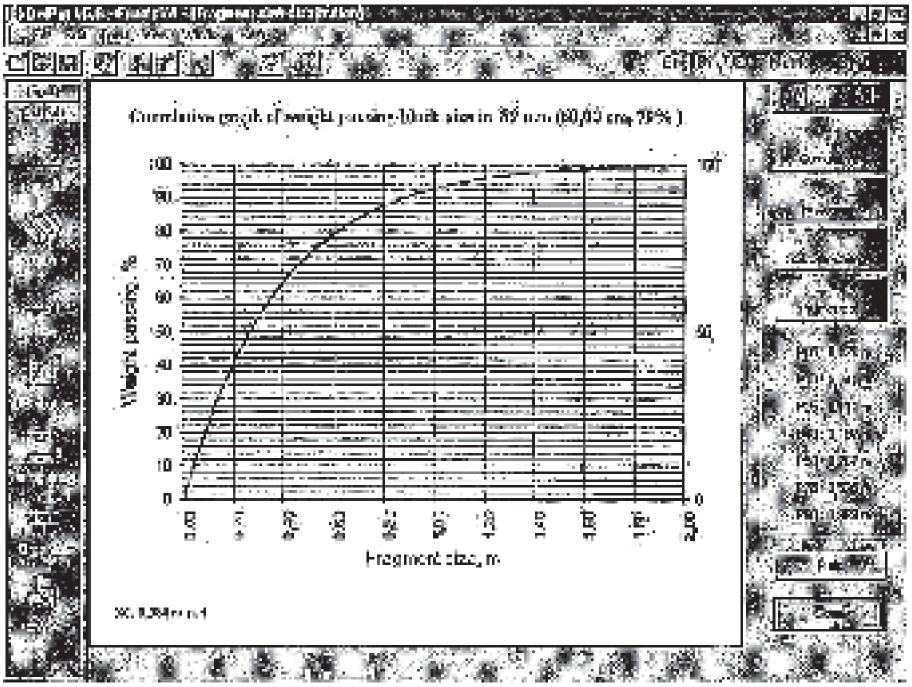


Figure 8. Cumulative Graph of Weight Passing Block Size in 89 mm Hole Diameter.

Table 3. Fragment Size Distribution for Various Hole Diameters.

| Hole diameter (mm) | Burden (m) | Spacing (m) | Fragmentation size (mm) | Percentage by weight | S50 | Burden/Spacing |
|---|---|---|---|---|---|---|
| 89 | 2,81 | 3,95 | 60 | 79 | 0,266 | 1,41 |
| 102 | 3,04 | 4,49 | 60 | 79 | 0,266 | 1,48 |
| 115 | 3,24 | 5,02 | 60 | 79 | 0,266 | 1,55 |
| 127 | 4,21 | 4,45 | 60 | 79 | 0,266 | 1,06 |
| 152 | 4,51 | 5,38 | 60 | 79 | 0,266 | 1,19 |

The following mesh sizes were obtained:

- The mesh sizes with 5% of the mass passing as block size (P05) is 0,020 m

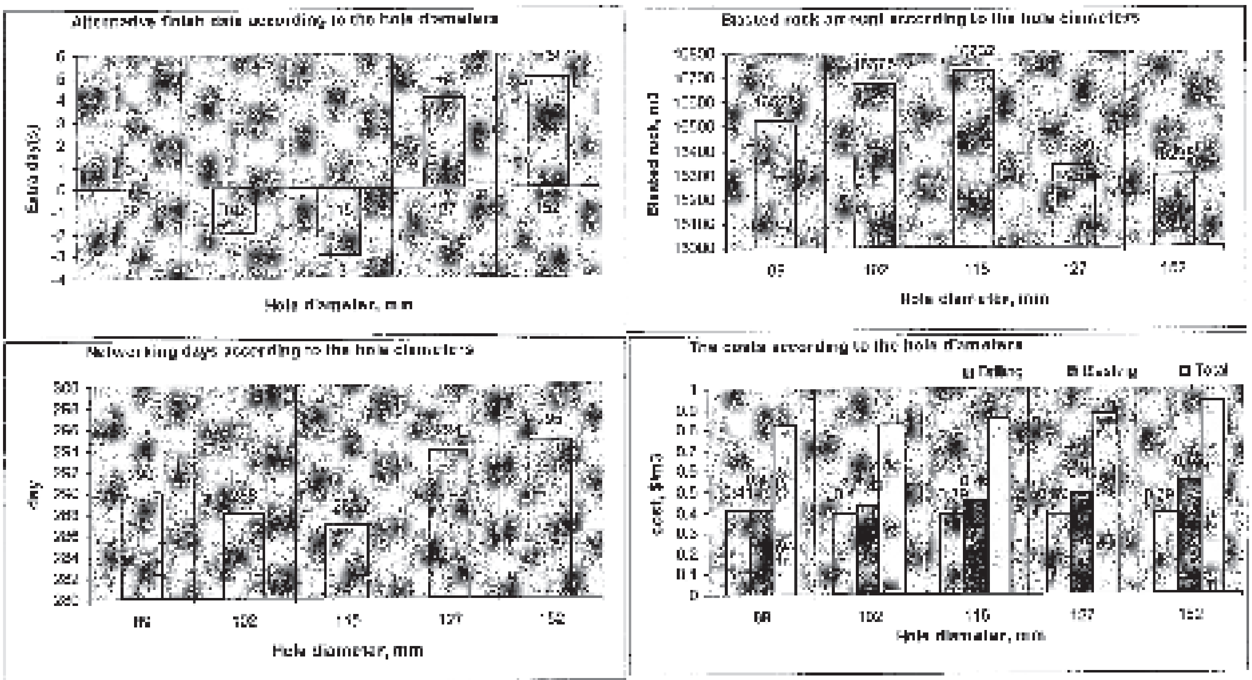


Figure 12. Time Schedule, Total Amount of Rock Material, Number of Net-Working Days, and Total Drilling and Blasting Costs.

## CONCLUSIONS

Drilling and blasting operations are critical in any rock excavation process. They affect overall excavation costs, thus it is important to realize that keeping safe working conditions and minimizing these costs are the primary goals. The discussion presented here addressed a comprehensive drilling and blasting cost model that can be used in development of different blasting strategies.

The various factors should be considered in trying to achieve a reliable cost estimation including a knowledge of rock properties, selection of appropriate explosives and drilling machinery, pattern arrangement, fragment size distribution, time schedule and labor management.

The application presented here was based on road excavation project in Turkey and had served as a case study to illustrate the methodology of cost modeling with DelPat system. This cost estimation approach revealed the simplicity and effectiveness in modeling complex construction project.

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Table 4. Values of S50 and Specific Charge for Various Hole Diameters.

| Hole diameter (mm) | Ø 102 | Ø 115 | Ø 127 | Ø 152 |
|---|---|---|---|---|
| S50s (cm) | 21,25 | 22,14 | 23,23 | 25,6 |
| S50f (cm) | 26,62 | 26,64 | 26,55 | 26,59 |
| SCs (kg/m3) | 0,6 | 0,6 | 0,58 | 0,55 |
| SCf (kg/m3) | 0,46 | 0,48 | 0,49 | 0,53 |

Analysis of costs associated with drilling and blasting operations was performed for various hole diameters, and rectangular blasting patterns. Fig. 11 presents a summary of drilling and blasting data for hole diameter of 89 mm while Table 5 shows blasting cost report for various hole diameters where the following abbreviations were introduced: HD-hole diameter (mm), DC-detonator costs, PC-primer costs, BC-bottom costs, CC-column costs, and BCS-blasting costs.

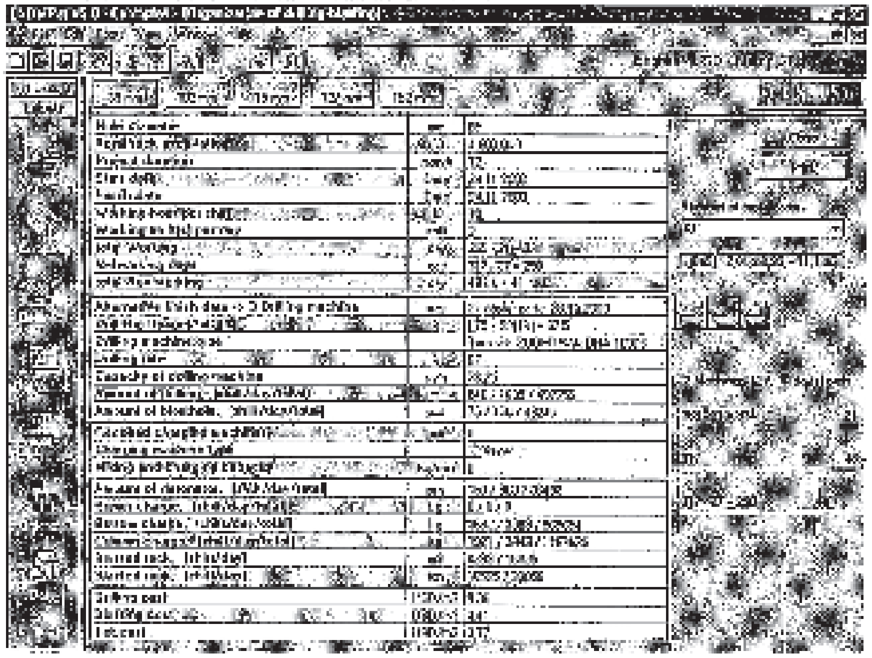

Figure 11. A Summary of Drilling and Blasting Costs for 89 mm Hole Diameter.

Table 5. Blasting Cost Report for Various Hole Diameters.

| HD (mm) | DC (USD) | PC (USD) | BC (USD) | CC (USD) | BCS (USD/m$^3$) |
|---|---|---|---|---|---|
| 89 | 294,067.31 | 0 | 1,115,103 | 553,912.33 | 0,42 |
| 102 | 239,261.11 | 0 | 1,283,993 | 534,603.20 | 0,44 |
| 115 | 200,479.09 | 0 | 1,493,408 | 491,085.40 | 0,46 |
| 127 | 174,053.36 | 0 | 1,689,055 | 452,940.57 | 0,49 |
| 152 | 134,625.68 | 0 | 2,165,077 | 318,992.47 | 0,55 |

Fig. 12 presents time schedule, total amount of rock material, number net working days, and the total drilling and blasting costs associated with Tarsus Junction Mersin Motorway Construction project.

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