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Minimising Mucking Time by Prediction of Muckpile Top Size in Tunnel Blasting: A Case Study

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MINIMISING MUCKING TIME BY PREDICTION OF MUCKPILE TOP SIZE IN TUNNEL BLASTING: A CASE STUDY

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ABSTRACT: Drilling and blasting is widely used in underground excavation projects. Timing is considered to be the most important factor in construction projects. In cyclic operations such as drilling and blasting, losing time in each cycle will cause a delay in operation for all cycles and can impose huge amounts of budget loss because of the significance of fixed costs. Therefore, this investigation tries to minimise the mucking time in drilling and blasting operations of the Alborz Tunnel in Iran via controlling the topsize of muckpile in order to eliminate the need for time consuming secondary blasting. Using the Split-Desktop system, the size distribution curve for 25 blasting rounds in Alborz Tunnel were obtained from which the topsize of the muckpile for each round was calculated. 16 datasets were used to develop a multiple linear regression model. The other nine datasets were used to validate the model. Comparing the actual and predicted values of topsizes, R^2 and RMSE for the model were obtained as 0.73 and 0.14 respectively, showing that the proposed model can be used for controlling topsize of muckpile. Specific drilling and the ratio of amount of charge to the burden in contour holes are revealed to be the most important parameters in controlling the topsize of the muckpile in this particular case. The proposed model was successfully used and can be used in future excavations as long as the condition of rock mass is not changed.

INTRODUCTION

Drilling and blasting is the most satisfactory tool for excavation of rocks because of a high progress rate and the need for low capital investment (Mandal and Singh, 2009). Since relocation of the site of a tunnel is rarely possible, engineers have to cope with the quality of encountered rock mass as it is (Ryu, *et al.*, 2006). However a standard design of practice has not been set in this area because of the complexity of the operation in which many factors contribute to the obtained results (Afeni, 2009).

The fragmentation degree (specifically the percentages of oversize and fines), displacement and looseness of muckpile can significantly affect the overall costs in mining and construction industries. Therefore, there is a strong tendency to design primary blasts in order to gain optimum muckpiles (Hagan, 1979).

The ratio of the real and theoretical pull of the round, geometry of the contour in the cross-profile, powder factor and size distribution of rock fragments along with the muckpile profile are the factors that can be used in verification of the quality of blasting operations. The fourth parameter can be used as an indicator of possibility of easiness in carrying out the created muckpile (Innaurato, *et al.*, 1998). The degree of fragmentation and the muck profile are important indicators of blast performance, particularly in open pit mining operations. However, these parameters impact the mucking operation and generally do not pose severe problems in tunnel blasting activities (Chakraborty, *et al.*, 2004). The most important factor in tunneling is time and under any circumstances, time should not be loosed (Kolymbas, 2005).

Considering the aforementioned reasons, the degree of fragmentation created in blasting operations in tunnels, will be important mainly because of muck pile top size. Creation of topsizes which can't be solved without need for secondary blasting, means losing time and a decrease in monthly advance rate. The consequence will be a significant loss of money because of huge budgets in tunneling projects. Therefore, the present paper focuses on prediction statistical methods. of the topsize of muckpile created in the Alborz Tunnel blasting operations.

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CASE STUDY

Albroz Tunnel is one of the largest tunnels which is going to be excavated along the Tehran-Shomal freeway in Iran. The length of tunnel is approximately 6400 meters. The rock mass type blasted during this study was anhydrite with constant physical and mechanical characteristics for about a 70 m length. As the rock mass condition was constant, its characteristics were not considered in the prediction of topsize. The parameters of blasting design used in this study, were powder factor, specific drilling, ratio of the amount of charge to burden in lifter and contour holes, drilling density (number of holes per square meter) and charge type (ratio of ANFO to Emulsion) from which a reliable equation was acquired in order to predict the topsize of muckpile created after each blast.

The explosive used in the blasting operations was a combination of ANFO and Emulsion cartridges with diameter of 35mm. Compacted clay was employed as the stemming material. The area of the tunnel face was 65 m^2, the diameter of drill holes 57 mm and detonation caps with half second delay were used. An example of blasting patterns used in the Alborz Tunnel is shown in Figure 1. Figure 2 shows the location of the Alborz Tunnel. The parameters used for construction of the regression model are shown in Table 1.

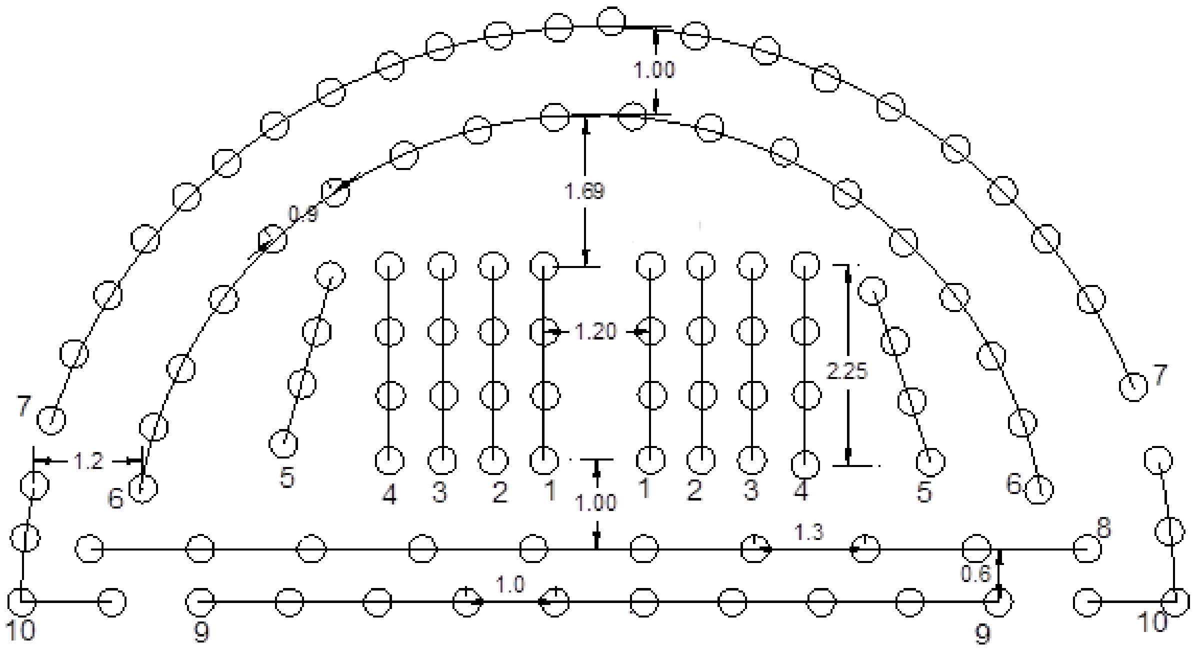

Figure 1 - An example of blasting patterns used in Alborz tunnel

IMAGE ACQUISITION AND ANALYSIS

Size distribution of the muckpile can be assessed directly with sieving a representative sample or indirectly based on production statistics or image analysis techniques (Kanchibotla, *et al*., 1999). Several softwares namely Split-Desktop, WipFrag, GoldSize, FragScan, TUCIPS, CIAS, PowerSieve, IPACS, KTH and WIEP. can be used in order to quantify size distribution of the muckpile. The accuracy of these systems varies from 2 to 20 percent (SiddiquI, *et al.*, 2009). In this study, the Split-Desktop system is used for computation of size distribution of the muckpile from which topsizes were obtained.

Split-Desktop is an image-processing program designed to compute the size distribution of rock fragments with analysing digital images. Digital images can be gained manually using a digital camera, individual frame capture from video or scanned (digitised) photos.

Using the Split-Desktop system, size distribution and topsize of muckpile for 25 blasting operations were obtained. An example of digital images and size distribution curve is shown in Figures 3 and 4.

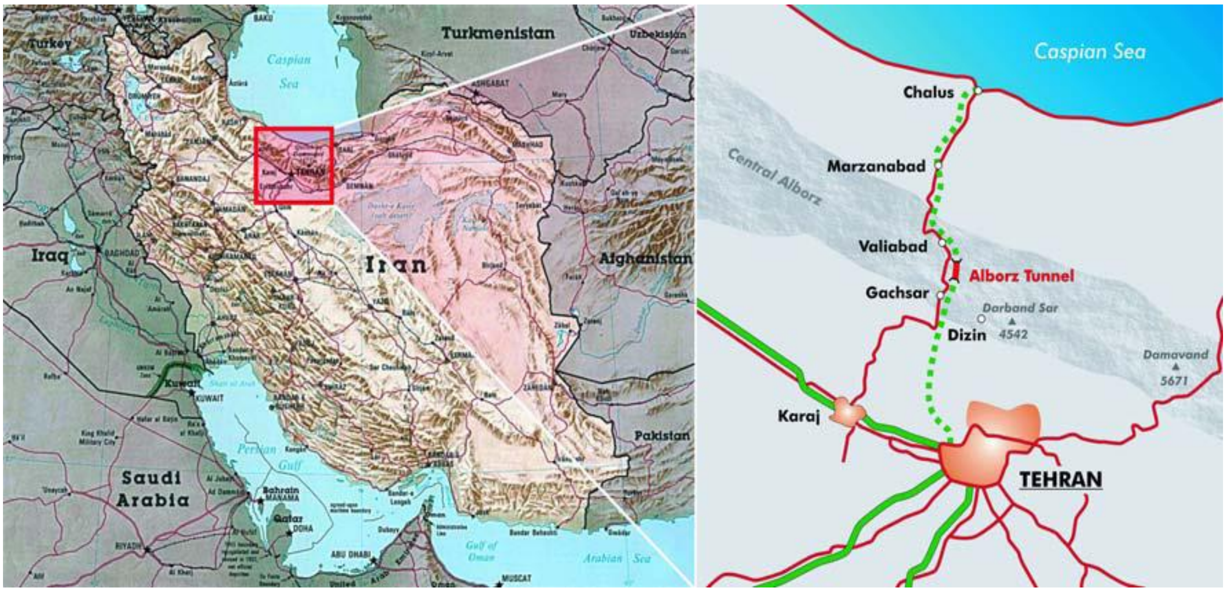

Figure 2 - Location of Alborz tunnel (Wenner and Wannenmacher, 2009)

Table 1 - Description of input and output parameters used in establishing the regression model

Type of parameter	Parameter	symbol	Min.	Max.
Input	Powder factor (kg/m^3)	P_f	1	2.54
	Specific drilling (m/m^3)	S_d	1.4	1.94
	ratio of amount of charge to burden in lifter holes (kg/m)	Wl	32	100
	ratio of amount of charge to burden in contour holes (kg/m)	Wc	67.6	97.6
	Drilling density or number of holes per square meter	N	1.21	1.49
	charge type (ratio of ANFO to Explosive Emulsion)	AM	1.31	2.5
output	Topsize (m)	TS	0.47	2.66

Figure 3 - An example of acquired digital image for calculating size distribution

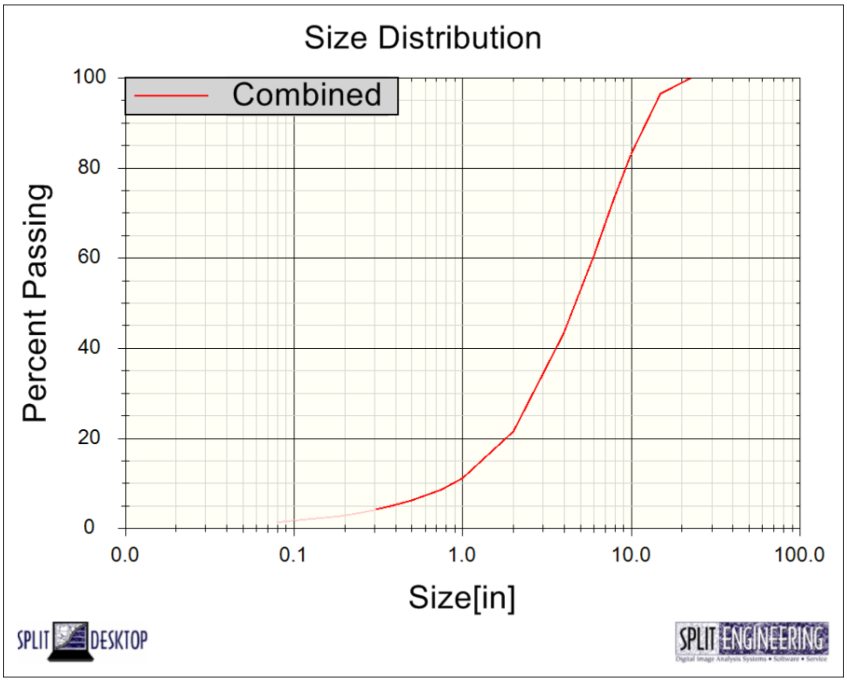

Figure 4 - Size distribution curve obtained from Split-Desktop

STATISTICAL ANALYSIS

In order to study or determine the relationship between different independent and dependent variables, analysing data and generating predictive models, the multiple linear regression method (MLR) can be used (Eskandari, *et al.*, 2004). This method has been used by many researchers in mining fields (Monjezi, *et al.*, 2009). The structure of the multiple linear regression model is as shown in equation 1 (Rodríguez del Águila and Benítez-Parejo, 2011).

$$Y = \beta_0 X_0 + \beta_1 X_1 + \ldots + \beta_n X_n + \varepsilon \quad (1)$$

Where Y = dependent variable, X_0, X_1, X_2, …, X_n are independent variables, β_0, β_1,β_2, …, β_n are regression coefficients (constants),and ε is the error term. Parameters used for MLR have different units and their range varies widely. Therefore, using equation 2, all these parameters should be normalized (Chakraborty, *et al.*, 2004).

$$X_n = \frac{X}{X_{max} - X_{min}} \quad (2)$$

Where, X_n is the normalised value, X is the original value and X_{max} and X_{min} are the maximum and minimum values of that particular parameter.

Using 16 out of 25 datasets, the linear regression model is developed and the relationship between input and output parameters is described in Equation 3.

$$TS = 3.535 + 0.164P_f - 0.64S_d + 0.248W_l - 0.503W_c + 0.36AM - 0.11N \quad (3)$$

Where, $P_f =$ powder factor, $S_d =$ specific drilling, $W_l =$ ratio of amount of charge to burden in lifter, $W_c =$ ratio of amount of charge to burden in contour holes, $AM =$ drilling density (number of holes per square meter) and $N =$ charge type (ratio of ANFO to Emulsion).

Other nine datasets were used to test the accuracy of the model. The actual and predicted topsizes are compared and shown in Figure 5. Coefficient of determination and root mean square error (RMSE) are 0.73 and 0.14 respectively showing that the proposed model can be used reliably in order to prevent creation of topsizes that can cause difficulty in the mucking operation. The proposed model was used in a 70 meter length of the Alborz Tunnel to control creation of topsizes. Also, the exact condition of the rock mass is repeated in some sections of Alborz Tunnel which will be excavated in future. The developed model can be used in these parts of the tunnel to control the topsize of muckpile. Specific drilling and the ratio of the amount of charge to the burden in contour holes are revealed to be the most important parameters in controlling of topsize of the muckpile. The burden of the contour holes is larger compared to other sections of the blasting patterns. This can be the reason for importance of the ratio of the amount of charge to the burden in the contour holes in creation of topsize.

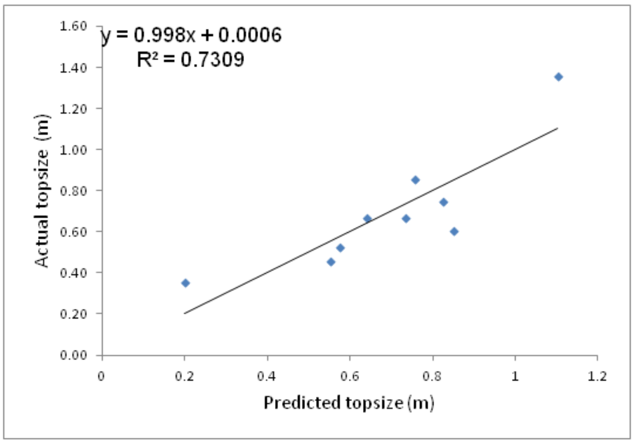

Figure 5 - Actual topsize versus predicted topsize from regression model

CONCLUSIONS

As time is the most important factor in underground excavation projects, delay in any cycle of blasting in tunnel excavation could cause considerable loss of money. Therefore, the mucking time in the Alborz tunnel is considered to be kept to its minimum, through controlling muckpile topsize with no need forsecondary blasting.

In this investigation, with the above aim, the following conclusions are drawn:

- Using Split-Desktop software, the size distribution of the muckpile for 25 blasting rounds of the Alborz Tunnel were obtained from which the topsize of the muckpile was found for each round.
- The actual and predicted values of topsize were compared. Coefficient of correlation and root mean square error (RMSE) for the model were 0.73 and 0.14 respectively.
- The proposed model can be used reliably to control the topsize of the muckpile and consequently keep the mucking time to its minimum.
- Specific drilling and the ratio of the amount of charge to the burden in contour holes were revealed to be the most important parameters in controlling the topsize of the muckpile in this particular case.
- The burden of contour holes is larger compared to other sections of blasting patterns which can be the reason for the importance of the ratio of the amount of charge to the burden in the contour holes in creation of topsize.
- The proposed model can be used in the remaining sections of the Alborz tunnel, to be excavated later, where the condition of the rock mass is repeated.

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