EFFECTS OF BLAST-HOLE DEVIATION ON DRILLING AND MUCK-PILE LOADING COST

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Abstract

Effect of blast-hole deviation on drilling and muck-pile loading cost at Hwange Colliery Mine, Zimbabwe was investigated. Samples were obtained from the mine and tested for point load strength index using point load tester. Uniaxial compressive strength was estimated from the result obtained from point load strength index of the samples. Blast-hole depth and deviation were measured on the field. Blasting parameter, volume of blast, drilling cost and excavation cost were determined using empirical equations developed by researchers. Six scenarios were to analyze excavation cost for bucket capacity of 4 m^3 and 5.5 m^3 respectively. The results of point load strength index varied from 1.43 – 2.10 MPa and 34.27 – 89.49 MPa respectively. The drilling cost varied from \$0.13/m for operator's cost to \$7.35/m for total operating and ownership cost. Extra cost of drilling varied from \$1,728 for 7.07% blast-hole deviation to \$4, 218 for 21.58% blast-hole deviation. Excavation cost varied from \$3.47/m^3 - \$4.25/m^3, \$3.55/m^3 - \$4.35/m^3, \$3.57/m^3 – \$4.41/m^3, \$3.49/m^3 - \$4.25/m^3 and \$3.50/m^3 – \$4.28/m^3. The correlation between extra cost and blast-hole deviation produce high value of coefficient of determination and it varies from 0.9941 – 0.9952.

Keywords: Effect, blast-hole, muck-pile, strength, excavation, loading, mine

Introduction

Drilling is one of the critical elements in the process of rock breakage. A blast hole is merely a cylindrical vehicle drilled and strategically situated to hold and contain an explosive charge. When detonated in the most efficient and optimum manner possible, it can give good rock fragmentation which can be measured for evaluation of blasting performance (Muhammad, 2009). Many researchers have established significant relationship between blast-hole deviation and cost of drilling and blasting in surface mines. On the other hand, rock fragmentation is arguably the most important process in mineral exploitation as it has direct effect on the costs the extraction-loading and ore dressing. Adebayo and Aladejare (2013) researched on the effect of the rock properties on excavation loading operation and establish the relationship between excavation -loading and rock properties. Rock fragmentation is dependent on two main factors; (i) the rock properties which are uncontrollable and (ii) the blasting parameters that can be changed to give maximum efficiency (Muhammad, 2009). Bondai (2013) investigated the effects of rock properties and blasting parameters on blasting performance and he found out that there is a strong correlation between blasting parameters and blasting performance. It means that if blast-hole deviation is experienced, this will alter the blasting parameters and consequently affect the blasting performance. The blasting parameters can be adjusted in an attempt to increase blasting efficiency, it mostly depends on the execution of the drilling process. Fewer studies have been done that correlate the cost incurred by inaccurate drilling and the blast-hole deviations (Sarma *et al.,* 2001). Better setup and selection of drilling method and equipment will help minimize deviation, improving the whole rock breaking operation (Atlas Copco, 2008).

Kangwa (2001) stated that many operators do not have a good grasp of their actual drilling costs per metre, most do not capture all costs, and do not consider pattern deviation to be a major issue. The impact of blast-hole deviations can be felt throughout the production cycle, such as excavating, hauling and mineral processing. The consequences of blast-hole deviation include build-ups, hang-ups and poor rock fragmentation and will normally lead to extra drilling, loss of drill strings, ore dilution, ore loss, increased explosive consumption, time wastage and delays in the chain of production operations. Rock drilling deviation is usually divided into four different classes as follows: Collaring deviation, alignment deviation (horizontal direction and vertical inclination), drilling deflection and depth. In case of feed with indicator the error is reduced to 0.5 – 1.0% and further to 0.2 – 0.5% with careful working and this error is more related to operating personnel (Atlas Copco, 2002). Penetrating structured rock with strong foliation and bedding properties can cause deviations of up to 5-10% (Oslen, 2009). In view of this many mines avoid drilling holes deeper than 20 m, unless guide rods are added directly behind the bit, or drill tubes are used. In these cases, the deviation can be expected to decrease to 3-5% Atlas (Copco, 2000) and top hammer holes are normally restricted to 30 m. According to Zvonimir (2005) "Blasting of explosive charge in blasting hole creates significant amount of energy released, shock-wave of great force in explosive and surrounding rock-formation and gases of high temperature and pressure. Crushing process in blasting affects the average size of the fragmented rock and the discharge affects the muck-pile geometry which is crucial to the loading process (Akande, 2014). Digability is the ease at which at a loader bucket is filled. Fill factor refers to how well a container such as a loader bucket or truck tray is filled. Fill factor is directly related to the size distribution of the rock being loaded (Cottee, 2001). The objectives of this paper therefore are to determine the rock strength parameters, deviations of blast-holes from the designed blast pattern and evaluate drilling and muck pile loading cost at different blast-hole deviations.

MATERIALS AND METHOD

Scenarios Adopted in the Study

This study was conducted at Hwange Colliery Mine. Coal production is carried out after the supplementary stripping and overburden removal at JKL and CHABA and the scenarios used are presented in Table1.

Table 1: Scenarios used

Scenario	Design Burden	Design Spacing	Explosive	Bit diameter
1	4	4.6	ANFO	191
2	4	4.6	ANFO	311
3	4	4.6	Heavy ANFO	191
4	4	4.6	Heavy ANFO	311
5	4	4.6	Emulsion	191
6	4	4.6	Emulsion	311

Blast-hole depth measurement

Blast-hole depth was measured by lowering a metal ball tied to a string down the blast hole. The ball was let to reach the bottom of the hole and the string collar position was marked. The ball would then be taken out and the length of the string measured to the collar position.

Determination of Point load strength index and uniaxial compressive strength

The Point Load Strength Index $I_s(50)$ was determined in accordance with standard method suggested by the International Society of Rock Mechanics (ISRM, 1989). The point load was evaluated using Equations 1 and 2.

$$f = \left(\frac{D}{50}\right)^{0.45} \quad \text{.......... (1)}$$

$$I_{s50} = f\left(\frac{P}{D^2}\right) \quad \text{.......... (2)}$$

Where; I_{s50} is Point load index, P is failure load (N) and D is the distance between the plates

The UCS was derived from the results of the point load strength index. This was done using the calculated point load strength index of the rock and the correlation factor C, in accordance with ISRM (1981) and the value of the correlation factor C used is 24.

$$UCS = CI_{s(50)} \quad \text{.......... (3)}$$

Where, UCS is Uniaxial Compressive Strength, $I_{s(50)}$ is the correlated point load index and

C is the correlation factor between UCS and $I_{s\,(50)}$

Measuring of blasting parameters

The blasting parameters which are the burden and spacing were measured after drilling using a tape measure. The burden and spacing for each hole measured to come up with the collar deviations.

Determination of planned and Actual volume of blast

Planned volume of blast was determined using Equation 4.

$$Volume\ of\ Blast = L_{avg} \times b \times s \quad \text{.......... (4)}$$

Where; L_{avg} = Average hole length, b is burden, s is spacing and n is number of holes

The Area to be blasted was measured using a GPS device and the volume of blast was then obtained using Equation 5.

$$Volume\ of\ Blast = A \times L_{avg} \quad \text{.......... (5)}$$

Where; A is the area (m^2) and L_{avg} is average hole length

Determination of cost of drilling

Atlas Copco DM 45 900 was the drilling machine used. Drilling cost per meter was determined using Equation 6 proposed by Jimeno *et al.* (1995). All the parameters in the equation where obtained from the mine planning department and from the drill manual.

$$C_{TD} = \frac{C_A + C_I + C_M + C_O + C_E + C_L + C_B}{P_r} \left(\frac{\$}{m}\right) \quad \text{.......... (6)}$$

C_A Is depreciation (\$/h), C_I is interest rate and insurance (\$/h), (indirect costs), C_M is maintenance cost (\$/h), C_O is labour (\$/h), C_E is fuel or energy, C_L is cost of lubrication and filters (\$/h), C_B cost of bits, rods and shanks (\$/h) (direct costs) and P_r is drilling productivity (m/h)

Determination of excavation cost

Precise stopwatch was used to determine the cycle time. The bucket filling rate was determined from equation (4).The bucket filling rate was determined using Equation 7.

$$Bucket\ filling\ rate = \frac{Bucket\ capacity}{Cycle\ time}\left(\frac{m^3}{s}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Excavation cost was determined using Equation 8.

$$C_{EX} = \left[\frac{C_A + C_I + C_M + C_{FE} + C_{LUB} + C_{LAB}}{B_{FR}(\frac{m^3}{h})}\right] + C_{BA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where C_{EX} is cost of excavation (\$/m^3), C_A Is depreciation (\$/h), C_I is interest rate and insurance (\$/h), (indirect costs), C_M is maintenance cost (\$/h), C_{LAB} is labour (\$/h), C_{FE} is fuel or energy, C_{LUB} is cost of lubrication and filters (\$/h), C_{BA} cost of bucket teeth and hydraulic consumables (\$/h) (direct costs)

Determination of extra costs

The cost of extra cost was determined using Equations 9-11.

$$Hole\ per\ 100\ 000\ bcm = \frac{100\ 000\ bcm}{Burden \times Spacing \times Hole\ length\ (m)} \ldots\ldots\ldots\ldots\ldots (9)$$

$$Drilling\ Shifts\ per\ 100000\ bcm = \frac{Holes\ per\ 100000\ bcm}{Drilling\ metre\ per\ shift} \ldots\ldots\ldots\ldots\ldots (10)$$

$$Extra\ cost = Extra\ Shift \times Labour/shift + Extraholes \times D\&B\ cost\ per\ hole \ldots (11)$$

Results and Discussion

The results were obtained from the Hwange Colliery Company JKL and Chaba open cast mines. An excel model was used to model the changes in costs due to hole deviation. Six scenarios were developed, and each scenario`s blasting patterns were varied from the designed.

Analysis of Strength Parameter

Table 2 shows the results of the strength parameter for Chaba and JKL Pits. The point strength index varied from 1.49 - 3.73 MPa while the uniaxial compressive strength varied from 34.27 -89.49 MPa.

Table 2 Strength Parameters Chaba and JKL Pits $I_{s(50)}$

Specimen	Diameter mm	Failure Load (kN)	D^2 (mm^2)	Point Load Strength ($I_{s(50)}$) MPa	UCS (MPa)
1	45	4.48	2025	2.10	56.19
2	45	4.15	2025	2.02	48.47
3	45	3.05	2025	1.43	34.27
4	45	7.97	2025	3.73	89.49
5	45	3.85	2025	1.80	45.62
6	45	3.81	2025	1.79	43.01
7	45	3.18	2025	1.49	35.85

Drilling cost per metre

Table 3 presents summary of the estimate of the drilling cost per meter of a 191mm hole using Atlas Copco MD 45 900. The total operating cost of $5.97/m was estimated for the drilling rig. Also, total operating and ownership cost was calculated to $7.35/m. The cost variables varied from $0.13/m for operator's cost to $3.14/m for fuelling.

Table 3 Drilling Costs per Metre

Summary of Costs Per Metre	Cost ($/m)
Fuel Cost per metre	3.14
Operator Cost per metre	0.13
Maintenance Cost per metre	1.72
Consumable Cost per metre	0.98
Total Operating Cost per metre	5.97
Total Owning Cost per metre	1.38
Total Operating and Owning Costs	7.35

Table 4 presents extra cost incurred due to collar deviation for three different blasts. The percentage deviation recorded varied from 7.07% for blast 2 to 21.58%. The incurred for blasts 1, 2and 3 are $3,456:00, $1,728:00 and $4, 218:00. The third blast with highest collar percentage deviation of 21.58% incurred highest extra cost for drilling and blasting (D & B). This confirmed that cost drilling and blasting increases and collar hole deviation increases.

Table 4 Extra cost due to collar deviation from observed three blasting cycles

Blast-hole No.	**No.of drilled holes**	**Average depth (m)**	**Average Actual Burden (m)**	**Average Actual Spacing (m)**	**% Deviation**	**Extra Costs (D&B) ($)**	**Volume of Blast (m^3)**
1	94	11.4	3.7	4.1	17.55	3,456.00	16250
2	76	11.7	3.8	4.5	7.07	1,728.00	15205
3	88	12.3	3.7	3.9	21.58	4,218.00	15619

Analysis of Cost Drilling, Blasting and Excavation from Six Scenarios formulated.

Tables 5-7 present cost of drilling, blasting and excavation-loading for the six scenarios. Scenarios 1 and 2 use design pattern of 4 x 4.6 m, ANFO, deviation (0 to – 0.5) with bit diameter of 191 mm for scenario 1 and 311 mm for scenario 2. The size of fragments (X 50) varied from 122 – 149 mm and 117 – 142 mm for scenario 1 and 2 respectively. This reveal that as the deviation increases the size of fragment increases. The cost of drilling and blasting increase from $1.58/m^3 – 2.02/m^3 as the deviation increases form (0 - 0.5). The excavation cost varied from $4.20 - 4.25/m^3 and $4.30 – 4.35/m^3 for scenario 1 and 2 using bucket capacity 4 m^3. In addition, excavation cost varied from $3.47 – 3.50 4/m^3 and $3.55 – 3.59/m^3 for scenario 1 and 2 respectively using bucket capacity of 5.5 m^3. It could be deduced with lager diameter blast-holes could lead smaller fragment size.

Table 5: Cost Drilling, Blasting and Excavation for Scenarios 1 and 2

Description	Scenario 1 – Design Pattern (4 X 4.6), 191 mm bit and ANFO						Scenario 2 – Design Pattern (4 X 4.6), 311 mm bit and ANFO					
Deviation	0	-0.1	-0.2	-0.3	-0.4	-0.5	0	-0.1	-0.2	-0.3	-0.4	-0.5
Burden (m)	4.0	3.9	3.8	3.7	3.6	3.5	4.0	3.9	3.8	3.7	3.6	3.5
Spacing (m)	4.6	4.5	4.4	4.3	4.2	4.1	4.6	4.5	4.4	4.3	4.2	4.1
X 50 (mm)	149	144	138	133	128	122	142	137	132	`127	122	117
P. F (kg/m^3	1.69	1.77	1.86	1.95	2.15	2.16	2.86	3.00	3.15	3.31	3.48	3.67
D& B. Cost ($/m^3)	1.58	1.66	1.74	1.83	1.92	2.02	2.23	2.34	2.45	2.58	2.71	2.84
Exca Cost 4 m^3 ($/m^3)	4.25	4.24	4.23	4.22	4.21	4.20	4.35	4.34	4.33	4.32	4.31	4.30
Exca Cost 5.5 m^3 ($/m^3)	3.50	3.49	3.49	3.48	3.47	3.47	3.59	3.58	3.58	3.57	3.56	3.55

From Table 6 the cost of drilling and blasting varied from $1.09 – 2.33 /m^3 and $3.66 – 4.69/m^3 for scenario 3 and 4 respectively. The excavation varied from $4.33 – 4.41/m^3 and 4.22 – 4.25 $/m^3 using bucket capacity of 4 m^3 for scenarios 3 and4. Using the bucket capacity of 5.5 m^3 the excavation ranged from $3.57 – 3.62/m^3 and $3.49 – 3.51/m^3 for scenarios 3 and 4 respectively. It could be observed using excavator with larger bucket capacity is capable of reducing cost of excavation as could be observed in Tables 5-7.

Table 6: Cost Drilling, Blasting and Excavation for Scenarios 3 and 4

Description	Scenario 3 – Design Pattern (4 X 4.6), 191 mm bit and Heavy ANFO						Scenario 4 – Design Pattern (4 X 4.6), 311 mm bit and Heavy ANFO					
Deviation	0	-0.1	-0.2	-0.3	-0.4	-0.5	0	-0.1	-0.2	-0.3	-0.4	-0.5
Burden (m)	4.0	3.9	3.8	3.7	3.6	3.5	4.0	3.9	3.8	3.7	3.6	3.5
Spacing (m)	4.6	4.5	4.4	4.3	4.2	4.1	4.6	4.5	4.4	4.3	4.2	4.1
X 50 (mm)	207	200	192	185	177	170	102	99	95	91	87	84
P. F (kg/m^3	1.09	1.15	1.20	1.26	1.33	2.16	4.47	4.49	4.92	5.17	5.44	5.73
D& B. Cost ($/m^3)	1.04	1.09	1.15	1.20	1.27	2.33	3.66	3.86	4.03	4.23	4.45	4.69
Exca Cost 4 m^3 ($/m^3)	4.41	4.39	4.37	4.36	4.34	4.33	4.25	4.24	4.23	4.23	4.22	4.22
Exca Cost 5.5 m^3 ($/m^3)	3.62	3.61	3.60	3.59	3.57	3.56	3.51	3.51	3.50	3.50	3.49	3.49

Comparing the performance the explosive used ANFO performance was the best with blast-hole diameter of 191 mm having the maximum fragment size of 144 mm in the distribution while heavy ANFO recoded the best performance with blast-hole diameter of 311 mm having maximum fragment size of 102 mm in the distribution.

Table 7: Cost Drilling, Blasting and Excavation for Scenarios 5 and 6

Description	**Scenario 5 – Design Pattern (4 X 4.6), 191 mm bit and Emulsion**						**Scenario 5 – Design Pattern (4 X 4.6), 311 mm bit and Emulsion**					
Deviation	0	-0.1	-0.2	-0.3	-0.4	-0.5	0	-0.1	-0.2	-0.3	-0.4	-0.5
Burden (m)	4.0	3.9	3.8	3.7	3.6	3.5	4.0	3.9	3.8	3.7	3.6	3.5
Spacing (m)	4.6	4.5	4.4	4.3	4.2	4.1	4.6	4.5	4.4	4.3	4.2	4.1
X 50 (mm)	167	161	154	148	142	137	114	110	106	102	98	94
P. F (kg/m^3	1.66	1.74	1.83	1.92	2.06	2.13	4.46	4.61	4.84	5.09	5.36	5.64
D& B. Cost (\$/m^3)	1.60	1.68	1.76	1.85	1.95	2.05	3.72	3.90	4.09	4.30	4.52	4.77
Exca Cost 4 m^3 (\$/m^3)	4.28	4.28	4.27	4.26	4.25	4.24	4.28	4.27	4.26	4.25	4.25	4.25
Exca Cost 5.5 m^3 (\$/m^3)	3.53	3.53	3.52	3.51	3.50	3.45	3.53	3.53	3.52	3.52	3.51	3.51

From Figures 1 to 6, the correlation equations between blast-hole deviations and extra costs, it is evident that the blast-hole deviation has strong correlation with extra cost incurred. This is consistent with hypothesis and the findings of (Kangwa, 2001).

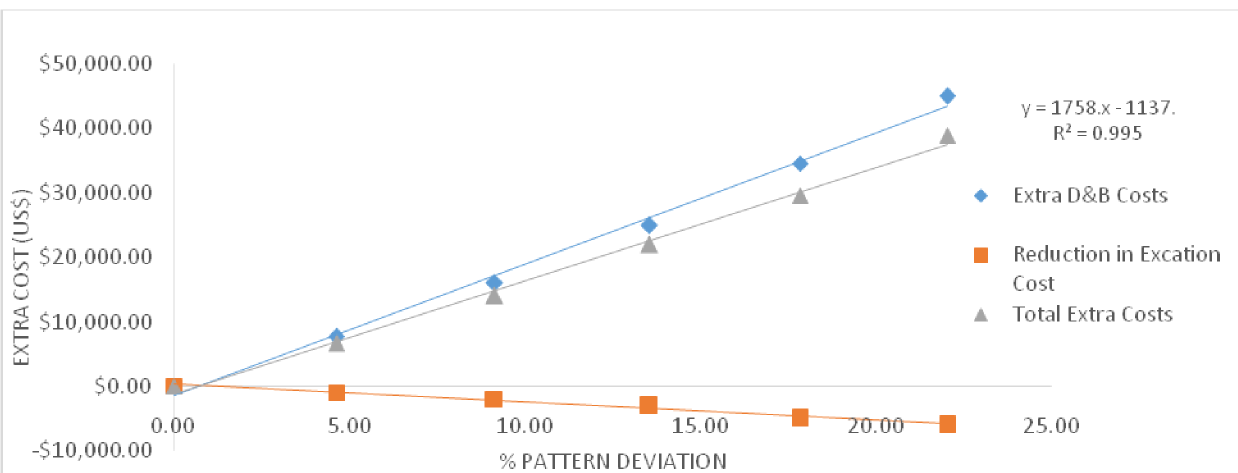

Figure 1: Total extra cost, extra D&B cost and Reduction in excavation cost against % pattern deviation for Scenario 1

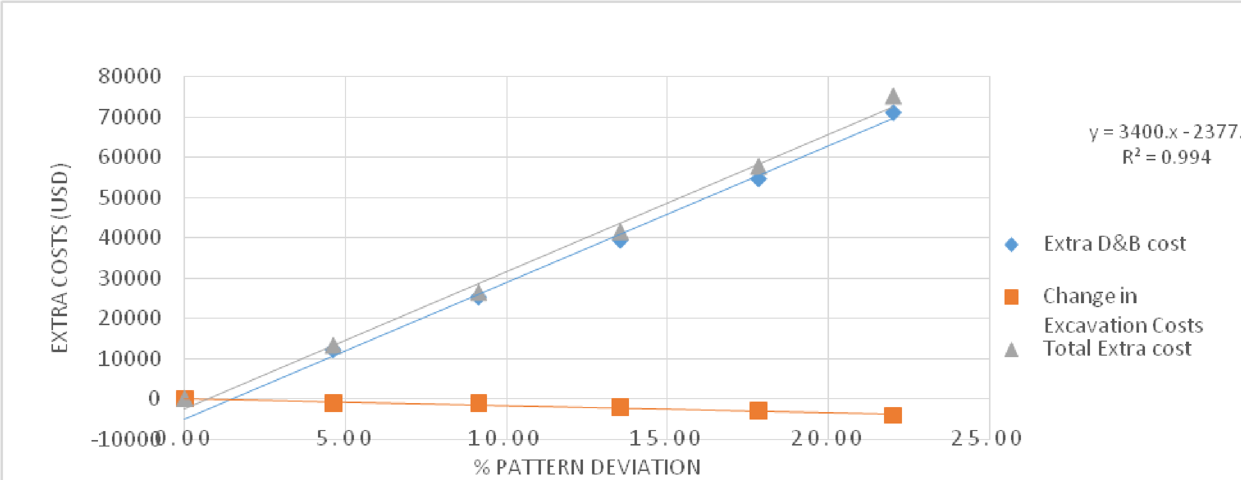

Figure 2: Total extra cost, extra D&B cost and Reduction in excavation cost against %o pattern deviation for Scenario 2

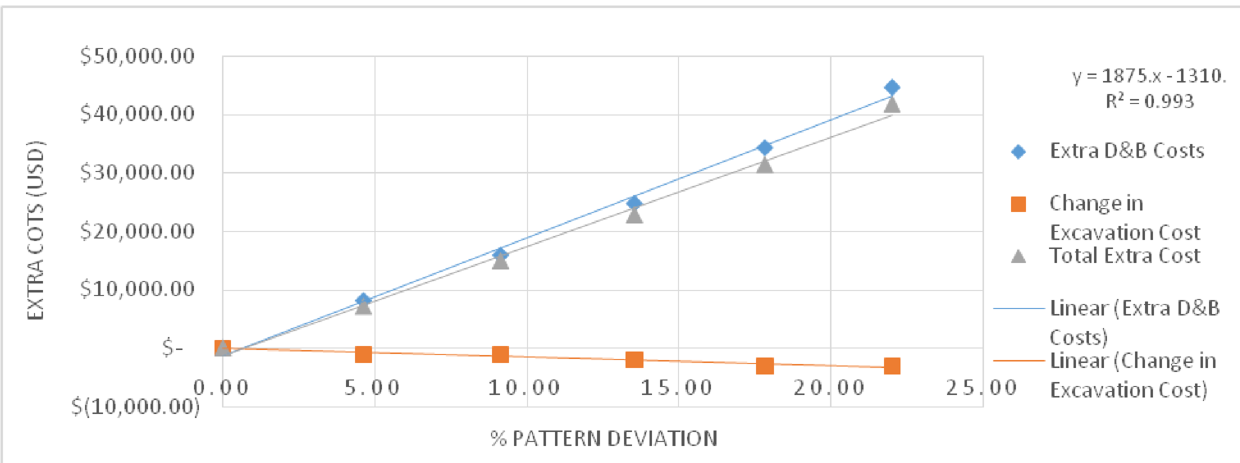

Figure 3: Total extra cost, extra D&B cost and Reduction in excavation cost against % pattern deviation for scenario 3

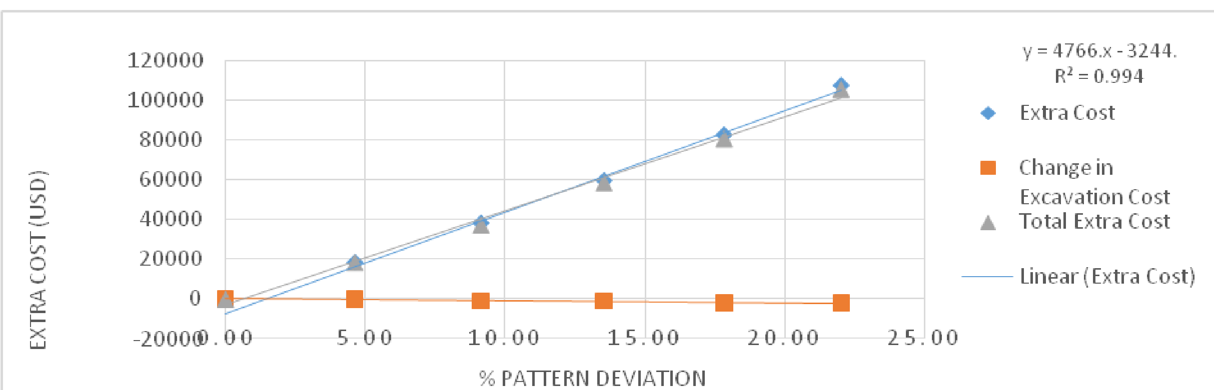

Figure 4: Total extra cost, extra D&B cost and Reduction in excavation cost against % pattern deviation for scenario 4

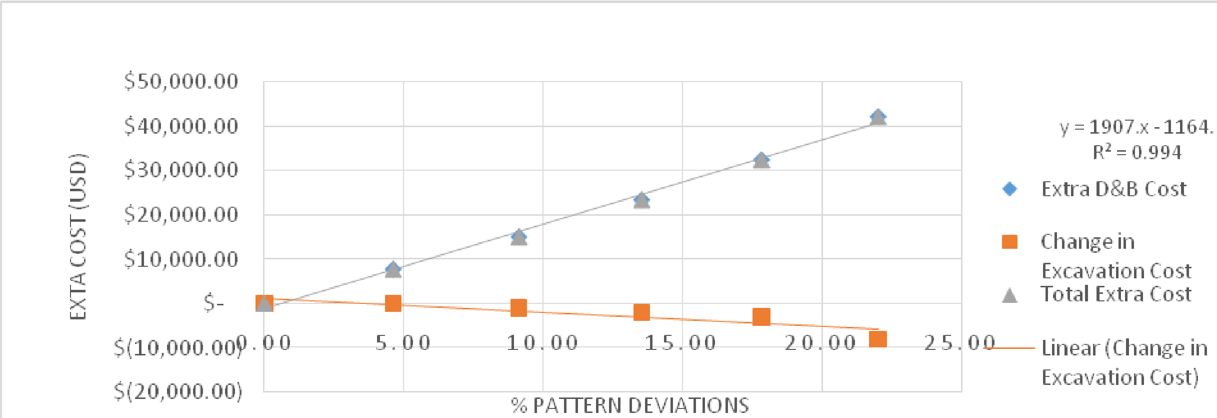

Figure .5: Total extra cost, extra D&B cost and Reduction in excavation cost against % pattern deviation for Scenario 5

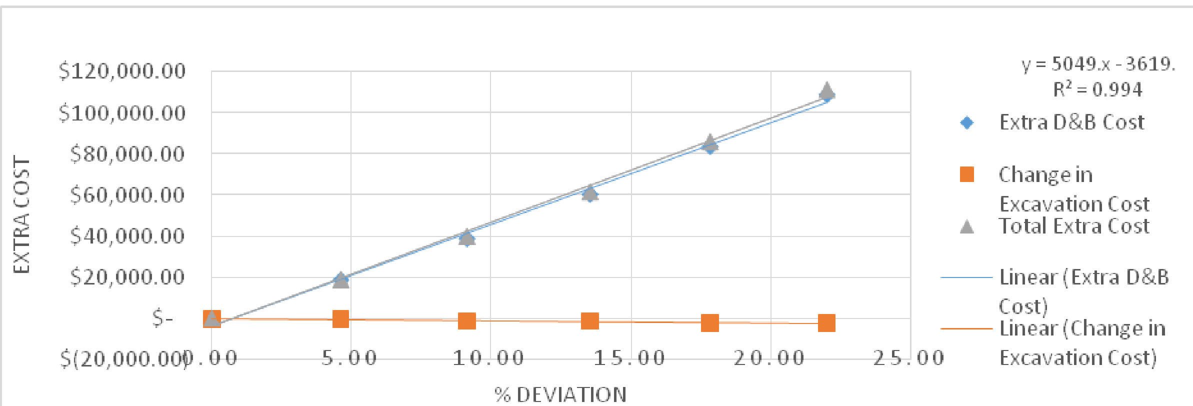

Figure 6: Total extra cost, extra D&B cost and Reduction in excavation cost against % pattern deviation for Scenario 6

Conclusion

A clear quantification of the extra costs as a result of the consequences is useful in targeting the unit operations (drilling and charging and excavation-loading) for improvement. Elimination or reducing the casual effects of uneven toe of bench platform and blast-hole inclination would make significant savings in the overall mining operational cost. The results obtained agree with the research of Muhammad [1]. He found out that when there is a change in drillhole diameter or fragmentation specification, changes in the blast design parameters are required affecting the cost of a drilling and blasting operations. The correlation equations generated from each scenario may be used as a quick or on the spot estimates of the extra cost due to the hole-deviation. This will enable prompt decision towards minimizing operational costs. ANFO performance was the best with blast-hole diameter of 191 mm while heavy ANFO recoded the best performance with blast-hole diameter of 311 mm.

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References

Adebayo, B. and Aladejare, A. E. (2013). Effect of Rock Properties on Exacavation-loading in Selected Quarries, *Advanced Materials Research ,* vol. 824(2013), pp. 89-90, 2013.

Akande J. M. (2014): "Evaluation of Environmental Impacts of Blasting in Okorus Fluorspur Mine, Namibia," *Internatonal Journal of Engineering and Technology,* vol. 2, no. 4, pp. 1-8, 2014.

Atlascopco (2008): Surface Drilling, Ulf Linder, Stockhom, 2008.

Atlascopco (2002) "A Technical Reference Edition of Atlas Copco," Ulf Linder, Stockholm

Atlascopco (2000) "Underground Mining Equipment," Ulf Linder, Stockhom, 2000.

Bondai, O. T. (2013) "Effects of Selected Rock Properties and Blasting Parameters on Blasting Performance," University of Namibia, Ongwediva, pp. 1-79

Cottee, S. (2001). Impact of Fragmentation on Truck and Loader Productivity, University of Queensland, Queensland.

ISRM, (1989). Rock Characterization testing and Monitoring: International Society for Rock Mechanics Commission. Ed. E.T. Brown, Pergamon press pp. 75-105.

Jimeno, C.L., Jimeno, E.L., Ayala, F.J. and De Ramiro, Y.V. (1995). Drilling and Blasting of Rocks, Taylor and Francis Publisher, pp. 1-391.

Kangwa, S. (2001). "Economic consequecies of hole deviations in mining operations.," University of Zambia, Lusaka, 2001.

Muhammad, A. R. (2009). The effects of fragmentation specifications on cost, Queens University, Kingston, 2009.

Oslen, V. (2009). Rock Quarrying: Prediction Models and Blasting Safety," Norwegian University of Science and Technology, Norwegian, 2009.

Sarma, K. Valery, S, W. and Steve, M. (2001): "Modelling fines in Blast fragmentation and its impact implication on crushing and grinding, Julius Kruttschunitt Mineral Research Center, Queensland.

Wells, B. (2006). The Latest Developments in Laser Profiling, Borehole Deviation and Laser Enhanced Videometry, Measurement Device Ltd, York, 2006.

Zvonimir, D. M, B. (2005). Measurement in Blast-hole Stem and Influence of Steming Material on Blasting Quality," *University of Zagreb, Faculty of Mining,* vol. 2, p. 1