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Comparison of Tunnel Construction Cycle with NTNU Model for the Headrace Tunnel of Seti Khola Hydropower Project

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Abstract

Achieving smooth and efficient blasting of tunnel walls is a challenging task. Tunneling performance and advancement can best be performed with proper and effective blasting techniques in drill and blast techniques. In this manuscript, the Seti Khola hydropower project's headrace tunnel's real-time statistics are used to compare the overall performance of tunnel excavation for the widely used blasting approach. The headrace tunnel's 663 meters of observed and recorded length comprises rocks with weak to medium blastibility. According to the Q-system, this tunnel section's rock mass quality class ranges from good to bad. The rock type found has a monotonous sequence of metasandstone and phyllite with quartz partings and discontinuities filled with clay to silt. A variation in the excavation cycle is observed in relation to the presence of different rock mass classes. Ultimately, the NTNU model is compared and analysis is done on the drilling patterns and cycles of tunnel building. It was discovered that using the NTNU model for tunnel excavation presents a significant opportunity to enhance performance.

Keywords: Blasting Pattern; Drill-holes, Specific Charge; Specific Drilling

1. Introduction

Tunneling is a repetitive (cyclic) process of a sequence of activities consisting of excavation, mucking, and support application. The drill and Blast method (DBM) of tunneling has over 60 years of history in Nepal. The DBM is extremely flexible, especially true regarding the shape and size of tunnel cross-sectional geometry and the geology along the alignment [1].

The basic principle of the DBM method is to blast the rock mass to advance the tunnel face. Huge force is required to create the free space, which is done with the help of explosives. In the present scenario of Nepal, Emulsion explosives with electric or non-electric detonators are widely used.

One of the most difficult aspects of tunnel blasting is the excavation that must be done in a small space surrounded by parent material that should hardly be impacted by it. The drill and Blast Method of tunneling is divided into parallel cut and angular (wedge) cut. This paper compares the blasting model used in the Seti Khola Hydropower Project (SKHP) and the NTNU model. The data and observation records of a 663m length tunnel have been used in this manuscript. The rocks encountered are mainly Phyllite and Metasandstone and the rock mass class, according to the Q-system, varies from poor to good rock mass quality.

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2. Literature Review

The criteria for the selection of cut is vested in parameters such as the size of the tunnel, diameter of drill holes, preferred advance rate, and use of equipment besides the character of rock and rock mass [2]. The proper blast design should be used [3]. Parallel cuts tend to have longer round lengths. On the other hand, the angular (wedge) cut is relevant for small-sized tunnels, poor quality rock mass, and less use of mechanization, which influences the drilling round length [4]. The development of mechanized methods has made the parallel cut method more popular than angular, which eases the difficulty of accuracy required for drilling.

Similarly, Angular (V-cut) requires more drill holes than parallel for similar rock conditions, as studied by Soroush et al. [5]. Additionally, the increase in diameter of blast holes for better blastibility of rock mass. While V- cuts are more productive for small tunnels (<10 sq.m), with drill holes less than 2.5m, whereas parallel cuts are more productive for medium to large tunnels.

The advance rate per round tunnel excavation for parallel cut holes depends upon the size of the relief holes [6]. The auxiliary cut holes depend upon the drill length and drilling angle, only in the charging length < Drill length x cosθ [7].

Niches are pockets in the tunnel wall to reduce congestion and facilitate mucking. The distance between the tunnel face and the niche should not exceed 250 meters as the traveling time will increase, making it difficult and time-consuming for efficient mucking.

NTNU Model [8]

The experience developed by the Department of Civil and Transport Engineering at the Norwegian University of Science and Technology (NTNU) is the foundation for the NTNU model. The parallel cut holes are the method's primary focus. A distinct approach is taken to the drill holes in the tunnel face. The distance between successive holes and the charging duration is varied to provide a smooth blasting surface.

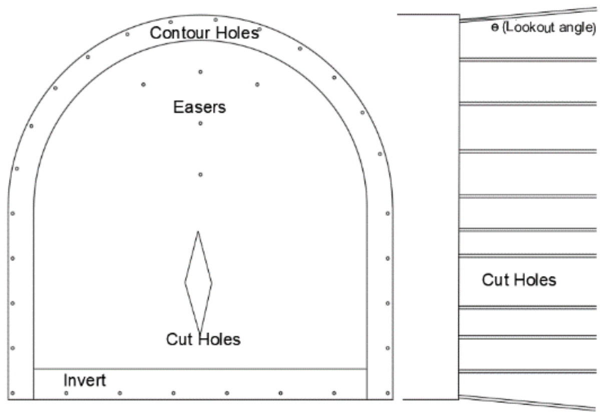

Figure 1: Arrangement of drill holes in NTNU Model

Some other models are the Swedish model and the Energy balance model. Four more models have been developed with parallel and angular cut holes based on the Swedish model.

3. Methodology

Much research was done to acquire comprehensive knowledge of the blasting pattern before fieldwork began. The blasting pattern failed to give smooth blasts.

Daily log sheets and real-time data were gathered from the SKHP to conduct the analysis. The data in chainage 0+627 to 1+294 m was used. Among these, 125m of data was collected via direct observation on the site. Only the data falling within statistical ranges were used to analyze after the collected data were filtered. For the filtration range, mean ± standard deviation was used. A comparative analysis was conducted after the data were further examined and contrasted with the NTNU model.

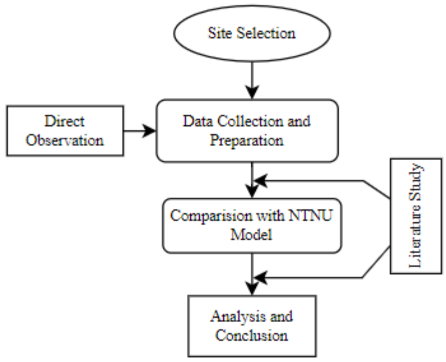

Figure 2: Flowchart for Methodology of work

The NTNU model was chosen for the comparison since it is one of the most globally recognized models. The recommendation is made with a 90% pull efficiency in mind for 48mm drill holes.

3.1. Case study: SKHP

The project is located on the Seti River's bank in the midland. The Headrace Tunnel is 3105 meters long and features a cross-section formed like an inverted "D." The headrace tunnel is under construction. Under the observed section, a monotonous succession of phyllite and metasandstone was transverse with quartz parting. The filling material within the joints is clay to silty sand material. The primary joint sets are oriented toward the southwest at a dip angle of 25–40 degrees and a strike of 106–110 degrees. With a drill length of 2.65 meters and a drill-hole diameter of 45 millimeters, the angular (wedge) cut blasting technique is used (Table 1). The apparatus being utilized for tunnel excavation is listed below.

Table 1: Details of Equipment/ resources for SKHP

Cross-section	32.21 sq.m (6x6)
Drilling	Boomer 282; AC COP 1838
Charging	Emulsion Φ32mm; 0.85g/cc charge Density
Ventilation	Serpent; AVH90
Loading	Wheel loader (1.5 cumec)
Hauling	Trucks (7.5-10 cumec)

4. Results and Discussion

The drill and blast method of tunneling is a widely used method in Nepal. The blasting patterns are varied as per the Rock class. Q-system is one of the most often used rock mass classification systems. Following is the summary of the blasting pattern being adopted. The chart below shows the randomness of drill holes and the charge used.

Table 2: Summary of Blasting Pattern at SKHP

Q- Value	1-4	0.4-1	0.1-0.4	0.02-0.1
Drill holes	91	91	81	80
Specific Drilling (m/m^3)	2.7	2.7	2.43	2.41
Explosive (Kg)	187	181	137	147
Specific Charge (Kg/m^3)	2.57	2.46	1.81	2.05

4.1 Drilling Pattern

The arrangement of lifters, contour holes, and cut holes is shown in the NTNU model. The blastibility of the rock mass determines the burden and spacing (B&S) between the holes (SPR). The SPR depends on the characteristics of the explosives being used, the specific gravity, and the sonic velocity of the rocks.

In SKHP, B&S continued to consider the classification of rock masses and the evaluation of rock quality (RQD). The range is 0.5–0.7 meters.

Figure 3: Marking for drilling

Burden is determined by empirical models. The specific drilling for the NTNU model is for 3m of round length, and variation in the specific drilling is due to the number of drill holes employed.

4.2 Charging

Table 3: Comparison of drilling pattern

	NTNU	SKHP
No drill holes	65	80-91
Specific Drilling(m/m^3)	2.08	2.4-2.7

The type of explosive assumed in the NTNU model is ammonium nitrate with a charge density of 0.85g/cc, whereas the SKHP emulsion type explosive has been used with a similar charge density.

Table 5: Comparison of Loading and hauling time

	NTNU	SKHP
Mucking Time(hour)	1.7	3.1-3.5

In SKHP, the 32mm diameter emulsion packet is inserted with the detonators, tamped and packed with packet soil to seal the drill holes. For smooth blasting, only 0.5-0.6m charge length is maintained for contour holes and 0.88-0.9m charge length is maintained for invert holes and middle holes. Six delayed detonators have been used. Planning the firing pattern is necessary to ensure that every hole, or set of holes, has the best possible confinement and throw conditions.

Center wedges are blasted first and the inverted holes are blasted at the end where 25 milliseconds delay is used.

Table 4 Comparison of Specific charge

	NTNU	SKHP
Explosive	ANFO	Emulsion 32mm
Sp. Charge (Kg/m^3)	1.6	2.4-2.7

4.3 Mucking and Hauling

Tunnel size could accommodate one-way traffic at a time only. Provision of niches is done within 250-300m. Following is the relation of loading distance and time for the wheel loader. The graph shows the linear increment of loading time with the increase in distance of tunnel face and niche position.

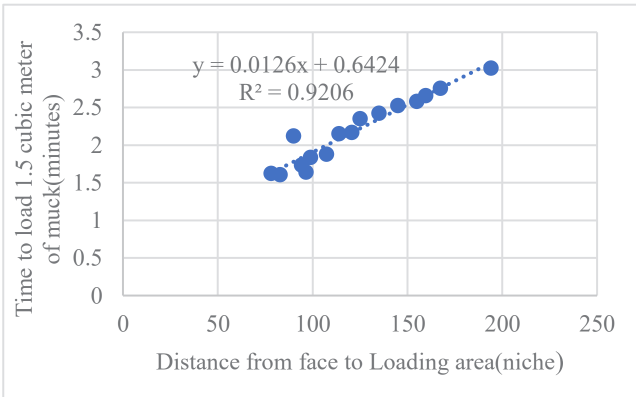

Figure 4: Variation of loading time with niche distance

According to the observation, loader time should not be idle for which an adequate number of transporting vehicles needs to be employed and hauling time should be equal to the loading of (n-1) vehicles where n is the number of vehicles.

$$\text{Mucking time} = (\text{Blasted volume} * \text{expansion factor}) / ((\text{Loading time for transporting vehicle})) * \text{incidential lime loss factor}$$

The number of vehicles deployed and the distance of muck disposal are interrelated for the mucking.

The table above shows a significant difference in time due to the assumption made for the NTNU model, for which wheel loader capacity is almost double that used in SKHP.

4.4 Tunnel Construction Cycle

Observed Tunnel construction cycles for SKHP have been presented in Table 6. The data presented in the table are the average values of the tunnel cycle from change 0+627 to 1+294 m. The data include traveling time and set-up time. The averaging of the data from chainage 0+627 and 1+294 has some limitations as the travel distance varies.

Therefore, for comparison, the basic tunnel construction cycle for 800m has been presented in Table 7. Here the basic cycle time refers to exclusive final support time.

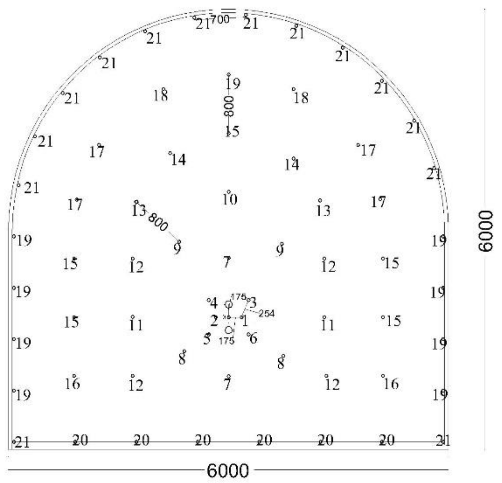

Figure 5: Parallel holes for SKHP

In the above drilling pattern, 2 large empty holes of 127 mm have been used. Burden and Spacing are maintained between 0.7-0.8m ±1% deviations. The drilling pattern has been designed based on the 2007 edition of the NTNU model [7]. The penetration rate for Phyllite rock is considered 2.58m/min for the design of the blasting pattern and the specific charge required is adopted as 1.6kg/sm^3. The cycle time is calculated for the same resources used in the SKHP now but with the modified drilling pattern. Travel time and setup time have been included in calculating the time required for different activities. The velocity of the different vehicles was measured during the field observation work. The number in Figure 5 represents the blasting sequence. During blasting, the rock mass is assumed to expand 1.8 times.

Table 6: Observed details of Drilling and charging

Q-Values	1-4	0.4-1	0.1-0.4	0.02-0.1
Marking for Drilling (hour)	0.6	0.6	0.6	0.6
Drilling (hours)	2.54	2.58	2.26	2.26
Blasting (hours)	1.44	1.42	1.3	1.27
Ventilation (hour)	0.45	0.52	0.63	0.56
Mucking(hours)	3.20	3.01	3.5	N/A
Pre-Scaling (hour)	0.59	0.64	0.68	0.68
Surveying (hour)	0.56	0.56	0.56	0.56
Post Scaling (hour)	0.68	0.69	0.79	0.60
Shotcrete (hour)	0.91	0.82	0.82	0.65
RB drilling (hour)	0.41	0.45	0.52	0.56
Preparation time(hour)	0.3	0.3	0.3	0.3
RB installation (hour)	0.37	0.40	0.47	0.51
Total time per cycle (hours)	12.05	11.99	12.43	

The above table is the observed time required to accomplish different activities. These are the mean values of the data obtained from the daily log sheet. There are more ways to reduce the effective time of the tunnel construction cycle.

Table 7: Predicted Cycle time for parallel cut holes

For distance between the face and the station is 800 m and niche distance 125m				
Activities	Q- Values			
	1-4	0.4-1	0.1-0.4	0.02-0.1
Drilling	2.23	2.23	2.23	2.23
Charging	0.64	0.64	0.64	0.64
Ventilation	0.28	0.28	0.28	0.28
Loading	3.27	3.31	3.40	3.23
Scaling	0.78	0.78	0.78	0.78
Survey	0.33	0.33	0.33	0.33
Shotcrete	0.92	0.82	0.82	0.67
RB installation	1.34	1.44	1.63	1.73
Total (hours)	9.81	9.85	10.13	9.90
Inc. 5% incidental loss	10.3	10.34	10.63	10.39

During the calculation, incidental time loss was added as an overall 5%. Each activity has been broken down into traveling time, preparation time, and others as per the nature of the work. The calculation of the time was using the same resources that have been used in SKHP. Also, the calculation is done considering that the survey time and marking time should overlap with the surveying time. The calculation of blasted volume, 1.8 times the blasted rock mass, is considered for mucking.

In addition to that, for ventilation, an air velocity of 1.5m/s has been adopted. Scaling time is calculated with the help of the NTNU model. Similarly, the Shotcrete time is observed in SKHP, Furthermore, the rock bolting time is adopted from the observed value in SKHP.

4.6 Advance Rate

The advance rate is a function of resources available and effective working hours. The following advancement of the tunneling is done with 1 set of Boomer, wheel loader (1.5 cu.m bucket capacity), and trucks.

Table 8: Time consumed to complete 663 m of tunnel excavation

Effective working hours/ week=144 hours				
Q-Values	1-4	0.4-1	0.1-0.4	0.02-0.1
Tunnel length (%)	19	51	23	8
Weeks	3.7	10.8	4.6	1.5
Total	20 weeks			

However, the NTNU model suggests that for the 32.21 sq.m of cross-section, 3 drilling hammers with wheel loader bucket capacity of approximately 3.72 cu.m will have an advance rate of 86-88 meters per week.

Meanwhile, in SKHP, the excavation time for the stated chainage length is about 34 weeks; deducting holidays and other uncovered sections of length and shift changes gives about 27 weeks. But also, the time includes delays and breakdown of machineries.

The study also concludes that the effective working hours in the project are less, and the idle time of machinery due to various reasons has enormously impacted the projects' time.

4. Conclusions

This study aims to adopt a smooth and efficient tunnel blasting pattern and analyze tunneling trends in Nepal by comparing them to a world-recognized model. Every activity of a tunnel excavation cycle was thoroughly compared in terms of time consumption.

In SKHP drilling pattern is V- cut and the NTNU model opted for parallel holes; time consumption for the V-cut is more than for the parallel-cut drilling pattern, ultimately increasing the time. Similarly, the increased number of holes will require more charging powder.

In addition to that, ventilating time can also be reduced by measuring air quality after blasting.

5. Recommendations

The cost comparison is not in the scope of this paper, which is one of the crucial aspects of the analysis. It is essential to find the best-suited blasting pattern per location, which should be prioritized and not just depend on empirical methods, designs, and research.

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References

[1] Guo, S.J., Analysis of cycle excavation and productivity of large-scale rock tunnel projects - Lesson learned in Taiwan. *Canadian Journal of Civil Engineering,* .28. (2001) 26–34.

[2] Yilmaz, O., Drilling and Blasting designs for parallel hole cut and V-cut method in excavation of underground Coal mine galleries, *Scientific Reports*, 13:2449 (2023)

[3] Adhikari, G. R., Burden calculation for partially changed blast design conditions. *International Journal of Rock Mechanics and Mining Sciences*, 36. (1999) 253-256.

[4] Holmberg, R., Charge calculations for tunneling underground Mining Methods Handbook, *New York: Society of Mining Engineers, American Inst. of Mining Met. & Pet. Eng*. (1982) 1580-1589

[5] Soroush, K., Mehdi, Y. and Arash, E., Trend analysis and comparison of basic parameters for tunnel blast design models, *International Journal of Mining Science and Technology,* 25 (2015) 595-599.

[6] Chakraborty, A.K., Roy, P.P., Jethwa, J.L. and Gupta, R.N., Blast performance in small tunnels – a critical evaluation in underground metal mines. *Tunnelling and Underground Space Technology*, 13(3) (1998) 331-339.

[7] Lou, X., Wang, B., Wu, E., Sun, M., Zhou, P., Wang, Z., Theoretical and Numerical Research on V cut Parameters and Auxiliary Cuthole criterion in Tunnelling. *Advances in Materials Science and Engineering.* (2020)

[8] Zare, S, and Bruland, A., Prediction Model and Simulation Tool for Time and Costs of Drill and Blast Tunnelling. Department of Civil and Transport Engineering, NTNU, (2007).