BLAST DESIGN MODIFICATIONS TO IMPROVE RATES OF EXCAVATION OF UMA OYA PROJECT LINK TUNNEL

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ABSTRACT

In Uma Oya hydropower project, which is currently under construction in Sri Lanka, a Link Tunnel (LT) is being developed for transferring water from Puhulpola reservoir to Dyaraaba reservoir. The LT is 3869.4m long, 4.95m high and 4.7m wide. It has a horse-shoe shape and was excavated by conventional drill and blast methods. As with most other drill and blast excavated tunnels, Burn-Cut blast design is adopted for the LT. However, due to the presence of adverse geological structures, which are pre-existing planes and zones of weakness within some of the gneissic rocks, the conventional burn-cut blast design yielded only poor rates of excavation advance in some intervals of the LT and resulted in very slow progress. This was largely due to the loss or escape of blast energy through the pre-existing planes and zones of weakness in the rock mass. To overcome this problem, several modifications to the blast design were trialed. The trials revealed that a non-conventional burn-cut blast design with no relief holes was best suited to the problematic rock mass conditions, and this yielded good results. This paper describes the details of the original blast design, the ground conditions that led to the slow rates of excavation advance, the modifications made to the blast design and the results achieved.

Key words: Umaoya, Link Tunnel, Blast Design

1. INTRODUCTION

The Uma Oya Project Link tunnel (LT) is being constructed to transfer water from Puhulpola reservoir to Dyaraaba reservoir. The LT is 3869.4m long, 4.95m high and 4.7m wide. It is a horse shoe-shape tunnel, excavated by conventional drill and blast methods. The tunnel has a 1.32‰ gradient towards the outlet portal, and is excavated from that end.

Geologically, the project area is situated within the highland complex of Sri Lanka. The highland complex rocks in the project area belong to the inter-banded metamorphic granulite facies. The common rock types in the area are Charnockitic gneiss, Marble, Quartzite, Quartzofeldspathic gneiss and Garnet biotite sillimanite graphite gneiss. The regional major geological structures are synclines, anticlines, escarpments and faults. Geological structures found within the tunnel are fault zones, fracture zones and shear zones.

Lithological condition in the project area is most suitable for conventional drilling and blasting method of excavation. The rock types in the area are very hard and competent, hence the well-known Burn-Cut blast design is adopted for the LT. This blast design is also suitable for the heading dimensions (width and height) of the LT.

However, due to the presence of adverse geological structures, which are pre-existing planes and zones of weakness within some of the gneissic rocks, the conventional burn-cut blast design yielded only poor rates of excavation advance in some intervals of the LT and resulted in very slow progress.

To overcome this problem, several modifications to the blast design were trialed. The trials revealed that a non-conventional burn-cut blast design with no relief holes was best suited to the problematic rock mass conditions, and this yielded good results.

Generally, burn-cut blast design with no relief holes is considered as unsuitable for any type of rock mass, because the relief holes provide the much needed second free face for the rock mass to break into when the first few blast holes in the cut are fired. Nonetheless, in these rock mass conditions, the modifications yielded the desired results.

2. METHODOLOGY

Blast Design

The main difference between tunnel blasting and surface blasting is that the former is done towards one free surface while the latter is done towards two or more free surfaces. Olofsson [1] explained that the rock is more constricted in the case of tunneling and a second free face has to be created early in the blast, so that the rock can break towards it and be thrown away from the surface. This second free face is created by a cut in the tunnel face and can be a parallel hole cut, a V-cut or a fan cut.

2.1. Standard Burn-Cut Blasting Design

In conventional burn-cut blast design the cut is usually created by drilling closely spaced holes parallel to the tunnel axis. The cut holes are blasted sequentially, one by one, towards one or two large diameter empty hole(s), which act as an opening and are called relief holes. A typical burn-cut blast design used for the LT is presented in Figure 1. The area marked by red lines in Figure 1 is the cut and the blue dots represents the relief holes. Diameter of the relief holes used for the LT are 64mm and that of the blast holes are 45mm. The drill hole numbers shown in Figure 1 are assigned according to the firing sequence that can be used for the relevant drilling pattern. The length of blast holes is 3m.

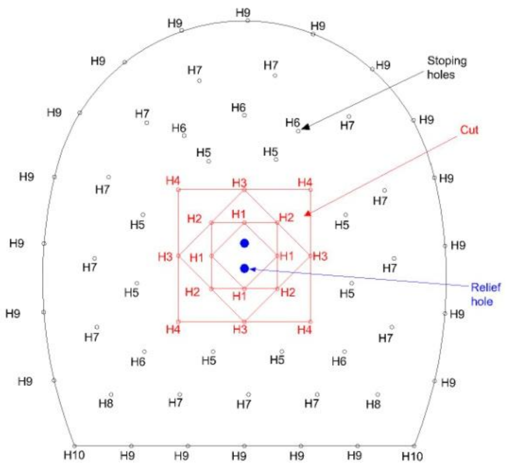

Figure 1: Drilling pattern and hole numbers

Drilling pattern, explosives type and amount and the delay sequence are designed to achieve the maximum possible progress in each blast.

Detonators with different delay times are used to ensure progressive breakage of rock with minimal unwanted damage to the perimeter of the tunnel and also to minimize ground vibration which could cause an adverse effect on the surrounding environment.

Normally the delay sequence used in LT did not change from time to time. But, sometimes the delay numbers were changed because detonators with the correct delays were not available on site. The changed delays numbers did not alter the firing sequence, and it only increased the time lag between some detonators by a few milliseconds. This did not to have any adverse effect on the efficiency or the progress of those blasts. Further, this change did not last long as a new stock of detonators were brought within one or two days.

2.2. Blast Design Changes for Geological Conditions

For each and every blast, drilling pattern, delay sequence, and explosive amount have been recorded. After each blast the performance of the blast was recorded. Simultaneously, each blasted area of the LT has been geologically mapped.

Subsequently, the blast design records, the blast performance reports and the geological mapping reports have been studied, particularly with respect to the extent, orientation and properties of geological structures present on each tunnel face. When major geological structures present on the tunnel face were construed to be the cause of poor blast performance the drilling pattern for burn cut was slightly adjusted, initially by shifting the cut away from geological structures as illustrated in Figure 2.

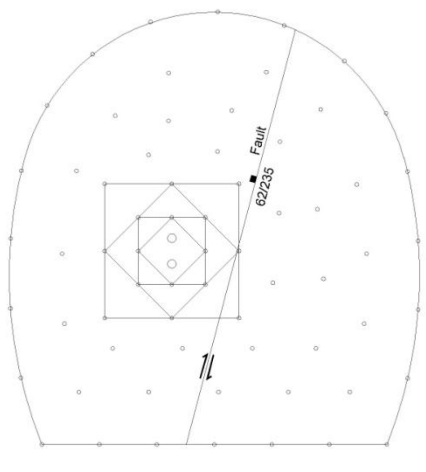

Figure 2: Changed drilling pattern for fault zone

Further, when highly fractured rocks are present on the tunnel face the relief holes were not drilled. Thus, the burn-cut blast design in some areas of the LT were implemented without relief holes as illustrated in Figure 3

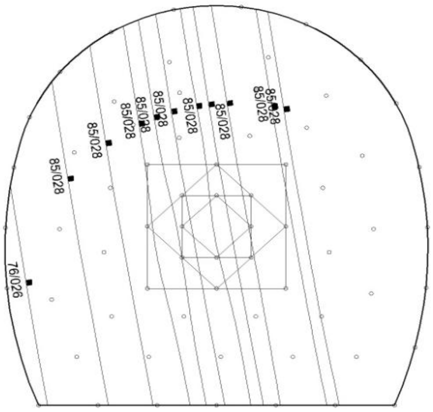

Figure 3: Changed drilling pattern for fractured and sheared zone

3. RESULTS

Closer to the outlet end of the LT, from chainage 2+904.7 to 2+899, rock mass is highly fractured with a closely spaced joint set in the middle of the tunnel face. This joint set is sub-parallel to the tunnel axis and its average dip and dip direction is 64/241. With the standard burn-cut blast design, blasting progress in this area was low as shown in the Table 1. (The progress is a measure of actual tunnel advance against the expected advance for each blast, expressed as a percentage.)

Table 1: Blasting progress in fractured zone from chainage 2+904.7 to 2+

Starting Chainage	Progress (%)
2+904.70	83
2.902.20	33
2+901.20	70
2+899.10	46

From chainage 2+897.7 to 2+869.3 a highly jointed fault zone was intersected. Again, the fault zone was sub-parallel to the tunnel axis. Initially, the blast pattern was not changed in this area, and found that the blast performance was low as shown in Table 2.

Table 2: Blasting progress in fault zone from chainage 2+897.7 to 2+891.7

Starting Chainage	Progress (%)
2+897.70	66.7
2.895.70	83.3
2+893.20	60.0
2+891.70	48.0

Later the blast design was changed taking into account the adverse geological conditions. From chainage 2+890.5 to 2+881.10, the cut-holes were shifted to the left side of the fault on the tunnel face, as shown in Figure 2. Blasting progress for new blast pattern in this area was excellent as can be seen from Table 3.

From chainage 2+878.45 to 2+805.5, relief holes were not drilled in the cut, but all other cut holes were drilled and charged as usual, as illustrated in Figure 3. In this area, within chainage 2+878.45 and 2+869.30 there was a fault zone, and from chainage 2+869.30 to 2+835.2, there was a highly fractured, shear zone.

Table 3: Blasting progress in fault zone from chainage 2+890.50 to 2+881.10

Starting Chainage	Progress (%)
2+890.50	80.0
2+888.50	92.8
2+886.20	96.0
2+883.80	106.0
2+881.10	107.6

By elimination of relief holes for this area a good blasting progress was achieved. Out of 16 blasts in the area from chainage 2+878.45 to 2+835.5, 15 blast rounds achieved more than 90% progress as listed in Table 4. The performance of just one blast out of 16 was only 50%.

Table 4: Blasting progress in fracture zone from chainage 2+878.45 to 2+835.2

Starting Chainage	Progress (%)
2+878.45	105
2+875.30	107
2+872.10	93
2+869.30	97
2+866.40	100
2+863.40	100
2+860.40	100
2+857.40	100
2+854.40	103
2+851.30	103
2+848.20	97
2+845.30	100
2+842.30	93
2+839.50	93
2+836.70	50
2+835.20	90

After passing through the fractured and faulted zones mentioned earlier, another several blasts were conducted without using relief holes in the cut, even though only a small number of joint sets were present in the tunnel face. Blast progress in these areas was low as shown in Table 5. In this area, out of 9 blasts, progress of 4 blasts was less than 67%. Subsequently a decision was taken to include relief holes for each blast round from chainage 2+803.5. Since then only few drill and blast rounds were completed. More data will be collected and analyzed as excavation is progressed.

Table 5: Blasting progress in fracture zone from chainage 2+824.3 to 2+805.5

Starting Chainage	Progress (%)
2+824.30	90.0
2+821.60	66.7
2+819.60	93.3
2+816.80	90.0
2+814.10	90.0
2+811.40	96.6
2+808.50	66.0
2+806.50	33.0
2+805.50	66.0

4. RESULTS

The result of this study indicated that geological condition, particularly the geological structures such as faults, shears and joints and their orientation and physical properties, affect the blasting progress. Good blasting progress can be obtained by shifting cut holes away from significant geological structures mentioned above. In fault zones and highly fractured zones, good blasting results were achieved without relief holes in the cut.

Usually, relief holes are a critical element of the conventional burn-cut blast design. They create the second free face for rock to break into when the first blast hole in the cut is fired. It is widely known in the tunneling industry, without relief holes the blasting progress is very low in tunnels excavated through strong massive rocks. However, in this study it was observed that when tunnels are excavated through rocks with fracture and fault zones which are sub-parallel to the tunnel axis, the conventional burn-cut blast design with relief holes yielded very poor blast performance and the tunnel excavation progress was low. The study also showed that under these geological conditions, good blasting results can be achieved with no relief holes. The elimination of relief holes is a cost and time saving in each round of tunnel blast. This in turn results in a reduction in the total cost of tunneling.The shifting of the cut away from the geological structures also yielded good blasting results. But, this does not involve any cost or time saving.

As already mentioned, the purpose of the relief holes is to create a second free face for rock to break into when the first blast hole in the cut is fired. When the first blast hole is fired the rock between the blast hole and the relief hole is broken towards the relief hole, and then broken rock is thrown out through the relief hole. To achieve this outcome the blast energy in the first hole and other holes in the cut must work as per the design expectations. However, the adverse geological structures present in some areas of the LT, create an imbalance in the distribution of blast energy (shock energy and gas pressure). The shock energy suffers greater attenuation in a jointed rock mass as damping capacity increases with joining. This reduces the effectiveness of the cut in the blast pattern.

Further, gas pressure can escape through the geological structures oriented sub-parallel to the blast holes. This in turn reduces the gas pressure available for crack propagation and throwing out the broken rock through the relief holes.

From the observations made up to now, it can be stated that, when the relief holes are eliminated, the geological structures sub-parallel to the tunnel axis may act as a second free surface. They may also provide a path for the broken rock to be thrown out when the cut holes are fired. These may be the reasons for achieving better blast performance without the use of relief holes in the geological conditions described earlier.

5. CONCLUSSIONS

For drill and blast excavated tunnels, relief holes are a critical element of the conventional burn-cut blast design. Without relief holes the blasting progress is very low in tunnels excavated through strong massive rocks. However, this study showed that, in rock masses with fractured and faulted zones sub-parallel to the tunnel axis, the conventional burn-cut blast design with relief holes yielded very poor blast performance. In contrast, in these rock mass conditions much better blasting results were achieved with no relief holes. The elimination of relief holes is a cost saving.

REFERENCES

[1] S. O. Olofsson, "*Applied Explosives Technology for Construction and Mining*," pp. 131-146, 1990.