Tunnel "Daylighting" on the Alaska Railroad

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In June 1984 routine scaling of loose rock from above the north portal of the 175-ft-long Tunnel 5 on the Alaska Railroad's Seward-Anchorage line revealed some large cracks and very unstable rock. Before stabilization work could be started, a 10-ft length of the tunnel collapsed, burying the track. Traffic was stopped for 48 hr while the track was cleared and an assessment was made of stability conditions. In this paper are described the emergency procedures that were undertaken during the next month to correct the hazardous rock stability conditions in this area. The stabilization procedure consisted of blasting to daylight the 150-ft-long tunnel, thus forming a steep rock cut as much as 120 ft high. Because of the very unstable condition of the rock, it was necessary to remove the tunnel in a single blast consisting of about 600 holes. Most of the holes, with lengths of up to 80 ft, were drilled on the slope above the tunnel on a 6-ft-square pattern. Exceptions were the shear line holes, which were drilled on 2-ft centers, and two rows of holes drilled from the tunnel into the outside rib pillar. The holes were laid out in rows at 45 degrees to the track centerline and were detonated at 25-msec intervals using an electronic sequencer. The rib holes were detonated last in the sequence. The blast produced a stable face that required no stabilization and the total track closure time for loading and mucking was 50 hr.

Tunnel 5 is one of six tunnels on a half-mile length of track, running on the west side of Placer Canyon about 50 mi north of Seward (Figure 1). The canyon is about 250 ft deep and the side slopes are as steep as 70 degrees. Construction of the railroad through this terrain required the excavation of almost continuous rock cuts and six tunnels with lengths of between 150 and 600 ft. The original construction was carried out in about 1910, and only minor remedial work has been required on the slopes and tunnels since that time.

On Thursday, June 21, 1984, a collapse occurred involving a 10-ft length of the north portal, with a volume of about 1,000 yd^3, that buried the track to a depth of 12 ft. A front-end loader was immediately mobilized to remove the fallen rock, and by Saturday morning the track was cleared. However, observation of the new portal face revealed areas of very loose, hazardous rock, and there was concern that vibration produced by the passage of a train could cause a further collapse. This loose rock occurred both in the rib on the outer side of the tunnel and on the slope surface above the portal where there were a number of open tension cracks as much as 10 in. wide (Figure 2). Fortunately, the area of instability was confined to the north portal; the rest of the tunnel was stable.

FIGURE 1 Site location plan.

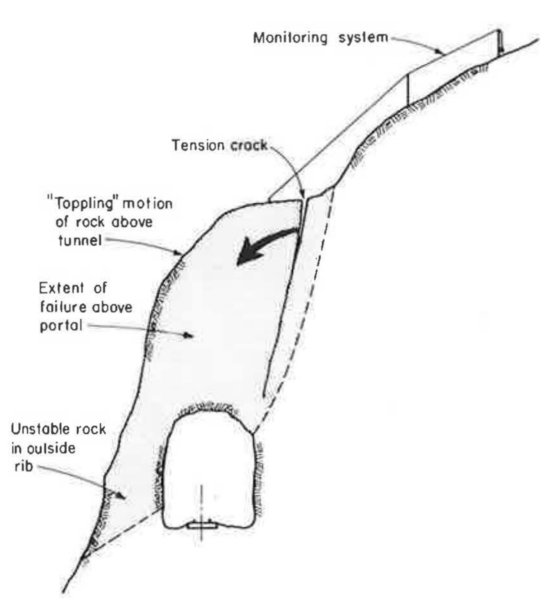

FIGURE 2 Extent of instability above portal.

Careful observations of rock conditions and measurement of the width of the tension cracks made on June 23 showed no evidence of new movement. Consequently, it was decided that it would be safe to open the track to traffic under strictly controlled conditions. The first train was a northbound (down-grade) freight that idled through the tunnel and produced no movement of the rock.

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To open the track to southbound (upgrade) traffic that operates under power, it was necessary to have a monitoring system that would detect movement of the rock and give a warning to train operators that traffic should be stopped. The warning system consisted of a tensioned cable anchored in the unstable rock above the portal and fixed to a stable reference point on the slope above the tunnel (Figure 2). A microswitch was set up on the reference point such that if more than ½ in. of movement occurred, a signal light at track level would be set off. When this system had been established and all measurements of crack widths showed that no movement was occurring, normal traffic was restored. However, all trains operated at very low speed to minimize vibration of the rock.

The primary cause of the instability at the portal was the partial failure of the narrow rib of rock on the outside of the tunnel. The canyon wall at this point is as steep as 70 degrees, and the outer rib varied in width between about 10 and 20 ft. The rock in this pillar had been somewhat damaged by blasting in the original construction, and at the portals the rock had loosened and relaxed as a result of the pillar being unconfined on three sides. This weakening of the rock in the pillar resulted in a "toppling" of the rock above the tunnel into the canyon.

Tunnel 5 was originally about 175 ft long, but progressive small failures over the years had reduced its length to about 150 ft. Ground support consisted only of some timber sets at the south portal that were carrying a considerable load of loose rock, and progressive loosening of the ground was occurring. The rock is a moderately strong greywacke with near vertical bedding planes striking at approximately right angles to the tunnel axis. The rock is somewhat susceptible to weathering and blocks of rock tend to loosen with time.

STABILIZATION MEASURES

Although traffic was operating within 2 days of the collapse of the portal, it was clearly evident that extensive remedial work would be required to ensure long-term safety. During assessment of the options available, consideration was given to a number of factors.

First, traffic frequency was one train per day, so there was ample track time available for remedial work. However, this work could not cause a continuous track closure of more than 72 hr. Second, seepage into the tunnel often produced severe icing during the winter that required time-consuming and expensive deicing operations. Third, the track had to be made safe before winter weather stopped construction work, that is, within about 4 months.

The instability at both portals was so extensive that a major stabilization program was required to make the track safe. The only two alternatives considered were either to construct reinforced concrete portals at both ends of the tunnel or to remove the tunnel entirely to form a 120-ft-high slope. The merits of these two alternatives are discussed next.

Concrete Portals

Portals would provide a high degree of safety against instability and require little maintenance in the future. However, design of a structure to withstand eccentric loading applied by the toppling motion of the rock above the tunnel would have been a complex and time-consuming task. Also, some blasting would have been required to provide the necessary clearance, and this might have caused further instability. Furthermore, it was unlikely that construction could have been completed before the onset of winter.

Tunnel "Daylighting"

The removal of the tunnel, which was estimated to take about 1 month to complete, would eliminate the need to stabilize the portals. However, it was decided that it would not be possible to carry out the blasting in a series of benches, because it was likely that vibration from the first blasts would cause further falls at the portals that would disrupt traffic. Therefore, the daylighting would have to be done in a single blast. This introduced a certain risk into the work because the one blast would have to remove the entire tunnel and form a stable slope under which equipment could work to clean away the broken rock within the 72-hr track closure. Access to the slope after the blast to trim areas of unstable rock would be difficult and time consuming. The major disadvantage of this alternative was that a high, steep slope would be formed that would require maintenance in the future.

A further potential danger was to a 30-ft span bridge located about 100 ft to the south of the tunnel. It would be necessary to protect this structure from both flyrock and ground vibration.

It was decided that the daylighting option would be adopted, mainly because it could be done within a month with no disruption to traffic while the blastholes were drilled. Another important factor in this decision was that examination of the rock showed that it would be possible to cut a steep slope in the rock and minimize the volume of the blast.

EXCAVATION DESIGN

The slope was designed at an angle of ¼:1 (76 degrees) with a 25-ft-wide ditch at the toe. This steep slope served two purposes. First, it minimized the height of the cut and the volume of rock to be excavated because no cutting was done back into the steeply sloping ground above the tunnel. Second, a steep slope reduces the rockfall hazard in comparison with a flatter one because, on a steep face, rocks tend to fall close to the toe and do not bounce outward onto the track. Also, the ditch was designed to be wide enough to catch most rocks that might fall from the slope.

It was decided that it would be possible to cut the slope at the steep angle of ¼:1 after a close examination of the rock conditions (Figure 3). The bedding planes have continuous lengths of as much as 100 ft, but they are nearly vertical and strike across the tunnel. Therefore it was not possible for any large blocks of rock to slide on these fractures. The joints have continuous lengths of only 2 to 3 ft, so they will have no effect on overall stability. Any small, loose blocks formed on the joint surfaces could be readily scaled from the slope.

BLAST DESIGN

To remove the tunnel in a single blast and then reopen the track within 72 hr, it was essential that the blast produce the following results:

- The slope face should be safe so that cleanup of the broken rock could begin immediately. This would also allow trains to operate as soon as the track was cleared.
- The rock should be uniformly broken so that no secondary blasting or slope trimming would be necessary.
- The detonation sequence should be arranged such that the impact of the falling rock and the ground vibrations would damage neither the track bed nor the bridge to the south of the tunnel.

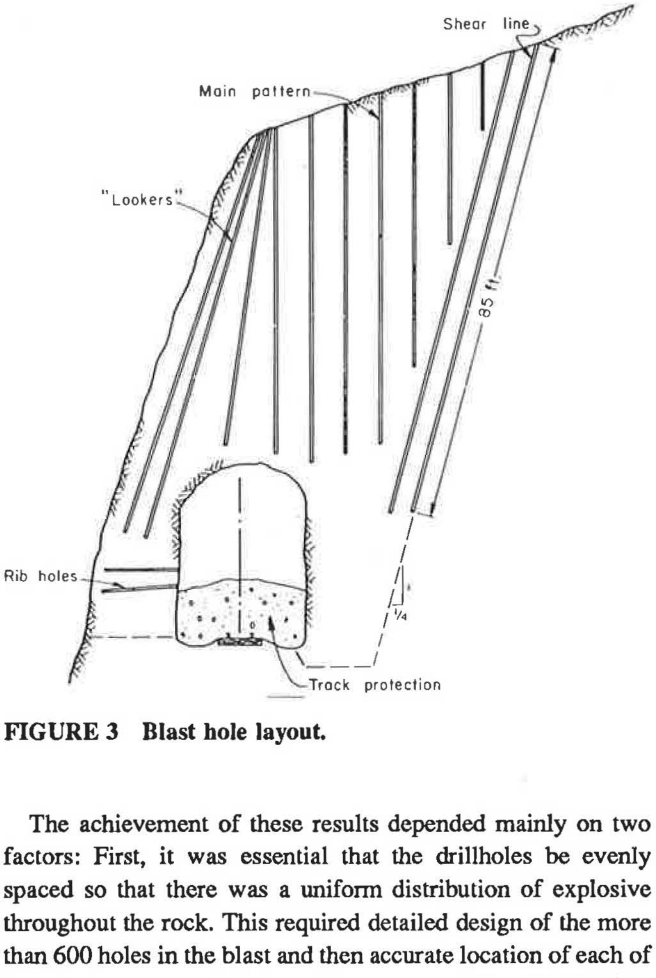

FIGURE 3 Blast hole layout.

The achievement of these results depended mainly on two factors: First, it was essential that the drillholes be evenly spaced so that there was a uniform distribution of explosive throughout the rock. This required detailed design of the more than 600 holes in the blast and then accurate location of each of these holes on the hillside with survey stakes, each marked with the inclination and depth of the hole. Also, drills would have to be carefully positioned and aligned to keep deviation to a minimum. It was decided that the maximum hole depth should be about 80 ft, because at greater depths deviation was likely to be excessive. Figure 3 shows a typical drillhole layout; note that the holes, except for the "lookers," extend only as far as the springline of the tunnel (i.e. a depth of about 80 ft). The rib pillar beside the tunnel was broken with two rows of holes drilled from the tunnel on 2-ft centers.

The total drillhole length was about 25,000 ft and was drilled during a period of 24 days by four drill rigs working 12-hr shifts.

The second factor influencing the blast results was the detonation sequence of the blastholes. Millisecond electric delay caps were used to arrange the holes in a series of rows at approximately 45 degrees to the track centerline (Figure 4). Because the blast was initiated at the cut face to the north of the tunnel and the rows were detonated on 25-msec delays, every row broke to a free face. This delay sequence also moved the rock away from the bridge at the south end of the tunnel.

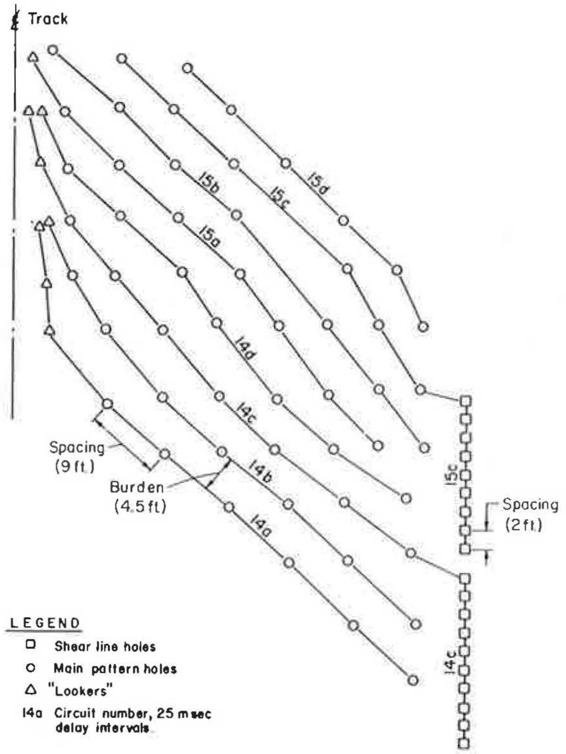

FIGURE 4 Blast hole detonation sequence.

The shear line was detonated as a "cushion blast" with each 20-ft length of the shear line detonated with every fourth row of the main pattern. In this way, the shear line fired after the pattern holes in front of it. It was decided that a "pre-shear" would not be used because there was a high risk that concussion produced by the detonation of this back row of holes might displace the rock and cause cutoffs in holes of the main blast.

Correct sequencing of the detonation of all 600 holes was achieved by the use of an electronic sequential timer. Four rows of holes were wired into each circuit of the timer, and the interval between timer circuits was set to 100 msec. This created a uniform 25-msec delay between each row of holes.

The final holes to be detonated were the two rows in the tunnel rib that were detonated with 4,000-msec caps but were energized with the first timer circuit so that they would not be cut off by the main blast above. The rib holes were detonated last in the sequence so that the rib formed a buttress to protect the track from the impact of the blasted rock. A summary of the explosive loads follows:

- Shear line: Atlas Kleen Kut Type F, 1⅜ in. × 36 in. powder, load factor 0.19 lb/ft.
- Production hole: Atlas Gelmax, 2 in. × 16 in. powder loaded to 8-ft collar, powder factor approximately 1.25 lb/yd^3.

Total weight of powder was approximately 32,000 lb, and total volume of the blast was about 25,000 yd^3. The track was

FIGURE 5 North portal showing tension crack and track protection.

FIGURE 6 Blast detonation initiated above north portal.

protected during the blast with a 6-ft-thick layer of gravel (Figure 5), and a bridge about 50 ft from the south portal was protected with heavy timbers.

All holes were double primed and had a continuous string of primer cord to avoid any breaks in detonation of the long column loads.

Loading of the explosives started on Saturday, July 21, using five two-man crews and was completed by midafternoon on July 22, after about 18 hr of working time. It was decided that no trains would operate while the loading was in progress as a precaution against accidental detonation. The blast was finally detonated at about 6:19 p.m. on Sunday, July 22 (Figure 6).

FIGURE 7 Removing broken rock from track.

RESULTS

The results of the blast were entirely satisfactory. The final face was formed exactly along the designed shear line, and there was virtually no cracking of the ground behind this line. The overall slope was stable, but there was some loose rock on the face where hole deviation had produced concentrations of explosives. The timber placed on the bridge piers proved to be quite adequate protection against the impact of flyrock, and there was no vibration damage to the concrete abutments. The only area of major instability was on the slope below the track bed, where a 30-ft-long block of rock, bounded by continuous joint planes, slid into the river. Fortunately, this failure did not undermine the track.

As soon as the dust had cleared, two bulldozers (a D6 and a D8) and a loader started to clear the broken rock, which had formed a muckpile about 30 ft high, from the tracks. These three pieces of equipment operated throughout Sunday night, and by 10 a.m. Monday morning the track was clear—after a total closure time of about 50 hr (Figure 7).

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