Strata Reinforcement with Cable Bolts*

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ABSTRACT

Long-term stability of the salt roof strata above a new underground mill was required at the Goderich Mine. A civil engineering method of grouted cable bolts was used. The design criteria for this support system required that: it be capable of supporting a roof section 8 ft thick; the anchorage of the cable bolts be in competent ground; and that boreholes should preferably not penetrate a dolomite bed some 25 ft (7.6 m) above the roof horizon. These requirements were met by installing three tendon cables in boreholes 30 ft (9 m) long, 9 ft (2.7 m) apart, and inclined at an angle of 45° over the pillars. The top 10 ft (3 m) of the cable located over the pillar edge provided the anchorage.

Difficulties were experienced with the borehole seals, which were resolved first by pouring a grout plug at the borehole collar and subsequently filling the rest of the borehole with grout. In some boreholes the grout migrated through cracks in the salt formation. This required drilling adjacent boreholes which intersected the grout-filled cracks. In all, 250 cable bolts were installed and about 75% of these were tensioned to the specified load, at a cost of about $200 per cable bolt.

The load is being monitored on six of the cable bolts. Initially a tension of about 55 tons was applied to each cable bolt. This tension then relaxed due to the flow characteristics of the salt and then stabilized. The average load, at present, on the cable bolts is about 47 tons. A year and a half after starting the installation the whole support system appears to be functioning as it was designed to function.

INTRODUCTION

The Goderich Mine of the Sifto Salt Division of Domtar Chemicals Limited is located at Goderich in the Province of Ontario, Canada. Goderich is a small town on the eastern shore of Lake Huron. The mine is close to the north-eastern rim of the "Michigan Salt Basin," referred to in geological reports. This basin contains several distinct beds of salt. Mining operations of Goderich are confined to a nearly flat bed 80 ft (24 m) thick at a depth of 1760 ft (540 m).

The salt is being recovered by the room-and-pillar system. Room widths were originally 60 ft (18 m), but because of roof failures this dimension has been reduced to 45 ft (14 m). Room heights are 43 ft (13 m) and pillars are 150 ft (46 m) square. Production exceeds 1.75 million tons** per year. The blasted salt is separated into four sizes in a complete underground crushing and screening plant.

The salt bed, particularly the upper portion, is composed of coarse crystals of nearly pure salt and thin layers of impurities spaced at 1 to 2-ft (0.3 to 0.6-m) intervals. There is little interlocking or cohesion between the salt crystals or between the layers of impurities and the salt. Roof falls have been a problem since the start of operations nearly 13 years ago. Initially, these falls were thin slabs, up to 2 ft (0.6 m) thick. The use of 5-feet (1.5 m) roof bolts, subsequently reduced to 4 ft (1.2 m), spaced 5 ft (1.5 m) apart, has prevented falls of this type. Later, despite the use of these bolts, heavier falls occurred both in the rooms and in the intersections. These falls have been up to 8 ft (2.4 m) thick and in some instances, if allowed to continue, penetrated the overlying dolomite about 25 ft (7.7 m) above the mine roof. The room falls extend across almost the full width of the room and are at least 100 ft

**Short tons (2000 lb = 809 kg)

(30 m) long, terminating at the intersection. The intersection falls extend across the complete intersection and progress a short distance into the rooms. Next to the pillar sides and corners, the failure surface is very steep, being approximately 70 degrees. The tops of the falls are flat and occur at one of the impurity layers.

These falls are often associated with a leakage of connate brine. Some warning of an impending fall is given by bolts breaking near to the pillars. Also, steep cracks are observed in the roof next to the pillar edge and corners. Most falls occur 9 to 36 months after mining.

The reduction in room widths from 60 to 45 ft (18 to 14 m) and the use of bastion-type pillars at the intersections have largely overcome the heavier roof falls, but the problem has not been entirely eliminated. This experience with roof conditions was kept in mind when it was decided to erect a new, large, underground crushing and screening plant, concentrated in one of the recently excavated rooms and its adjoining intersections. The area had been bolted with the conventional 5-ft (1.5-m) bolts but additional support appeared desirable to ensure long-term roof stability in this area.

Several methods of support were studied and it was finally decided to try to adapt the civil engineering method of tying potentially unstable strata to competent ground by the use of post-tensioned steel cables grouted in boreholes drilled into competent ground. In this paper, the assembly of the various components making up an individual support is referred to as a cable bolt. This type of support is being used in a few underground mines (McLeod and Schwartz, 1970) and has been tried in an open pit (Barron et al., 1971).

DESIGN OF CABLE BOLT SYSTEM

Soon after the start of mining operations, a comprehensive program of roof and pillar measurements was initiated under the direction of the Mining Research Centre, Department of Energy, Mines and Resources. The roof deformation measurements have a specific bearing on the layout of the cable bolts.

In one instrumented 45-ft (14-m) wide room, it was observed that the roof strata in the central half-span was expanding up to a depth of about 15 ft (4.6 m). In the quarter-span next to the pillars, the depth of the expansion zone was reduced and contraction was measured at greater depth. A flat-bottomed, arch-like profile can be drawn, intersecting the pillar-roof corners with a depth of 15 ft (4.6 m) at mid-span, separating the roof into expansion and compression zones (for vertical deformation). At mid-span the maximum movement occurs at a depth of 8 ft (2.4 m), whereas near the pillar the maximum movement is within the first 5 ft (1.5 m) of roof. This distribution of deformation is consistent with the shape and depth of the falls in the rooms which are usually 8 ft (2.4 m) thick.

These measurements in conjunction with the experience of existing roof falls indicate that the roof strata above the central half-span is unsuitable for anchoring the cable bolts, at least to a depth of about 40 ft (12 m) equivalent to the deepest roof fall. The roof strata over the pillar edge is under compression and is suitable for anchoring the cable bolts.

These and other criteria for design of the cable bolt system can be summarized as follows:

1. cable bolts must be capable of supporting an 8-ft (2.4-m) thick potential roof fall;
2. anchorage of cables must be in competent ground;
3. boreholes for cable bolts should preferably be drilled in salt and not penetrate the overlying dolomite.

The last criteria is to facilitate the use of existing rotary drilling equipment, whereas percussive drills would be required for the dolomite. Also, connate brine could be encountered at the dolomite/salt interface. The dolomite is at least 25 ft (7.6 m) above the roof horizon, but its actual position is not known.

The layout of the cable bolts and the potential roof fall which requires support is shown in Fig. 1. Previous roof falls are known to start about 2 ft (0.6 m) from the pillar edge with a failure surface about 70° to the horizontal (Fig. 1). The second and third criteria are satisfied if the anchorage is outside the central roof zone bounded by the 70° lines and below the dolomite. This necessitates inclined boreholes with the anchorage located beyond the

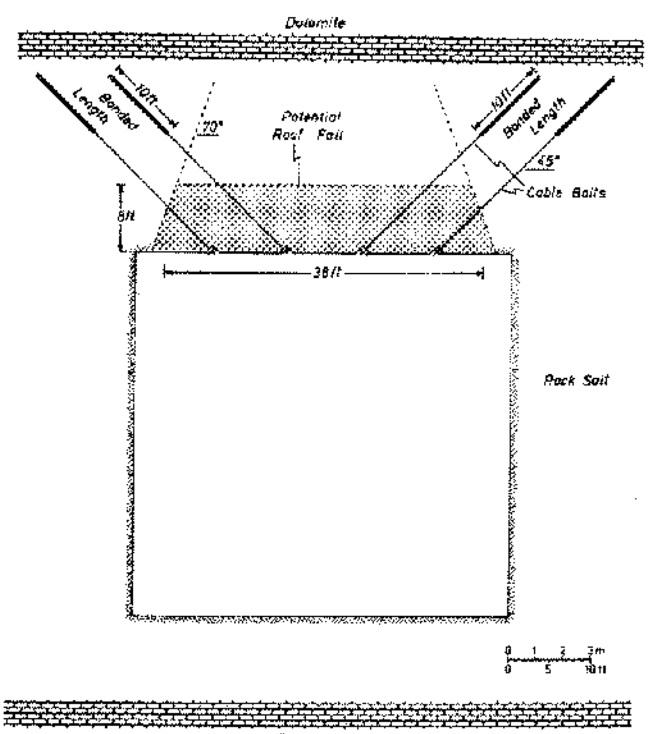

Figure 1. Design and layout of cable bolts in a room.

70° lines. It was decided that four cable bolts per row, spaced at 9-ft (2.7-m) centres, and drilled upwards at 45° and 30 ft (9 m) in length would fulfill the design requirements.

The weight of the potential roof fall per unit foot along the room is,

$$38 \times 8 \times 1 \times \frac{135}{2000} = 20.5 \text{ tons per ft,}$$

where, lateral extent at mid-height of fall is 38 ft (11.5 m), depth of fall is 8 ft (2.4 m), density of salt is about 135 lb/cu ft (2150 kg/cu m).

The distance between rows of cable bolts is 9 ft (2.7 m), so the load to be supported by one row is,

$$20.5 \times 9 = 184.5 \text{ tons.}$$

Hence, the vertical load to be supported by each cable bolt is 184.5/4 = 46 tons. The cable bolts are inclined at 45°, so the load which has to be applied to a cable to produce a vertical component of 46 tons is 46/cos 45° = 65 tons.

Used hoisting cable was considered for the cable bolts but was rejected in favour of Freysinnet high-tensile steel cable. Each cable assembly consists of a number of tendons, 0.6 in. (15 mm) in diameter, each of which consists of 7 twisted strands of wire. The ultimate strength of the steel is 270,000 psi (19,000 kg/sq cm) which for each tendon is 29 tons. These tendons are usually tensioned to 80% of their ultimate strength, which is 23 tons. Hence three of these tendons per cable bolt would provide an applied load of 69 tons and an ultimate load capacity of 87 tons. This load capacity was considered sufficient to support a roof section 8 ft (2.4 m) thick. A three-inch (76-mm)-diameter borehole is sufficiently large to accommodate the three tendons.

In the intersections, the layout of the cable bolts had to be modified, otherwise the anchorage would be in the unstable zone of the intersecting room. It was necessary to anchor each cable over the pillar corners by drilling slightly longer boreholes. A plan view of an intersection (Fig. 2) shows the direction and length of each cable bolt. The longest borehole is 38 ft (11.5 m).

The total area of roof requiring support in the room and two intersections is about 15,000 sq ft (1400 sq m). It was planned to install 176 cable bolts in this area.

CABLE BOLT INSTALLATION

In the cable bolt system, expensive mechanical anchors are not used. Instead, cement grout is pumped into the borehole after the cable has been inserted. The bond between the cement, cable and walls of the borehole provides the anchor. In order to establish the bonded length of cable required in salt strata, several test holes were drilled into one of the pillars. Cables with various bonded lengths were installed in these holes and after seven days were tensioned to 69 tons. These tests showed that a bonded length of 10 ft (3 m) would be adequate.

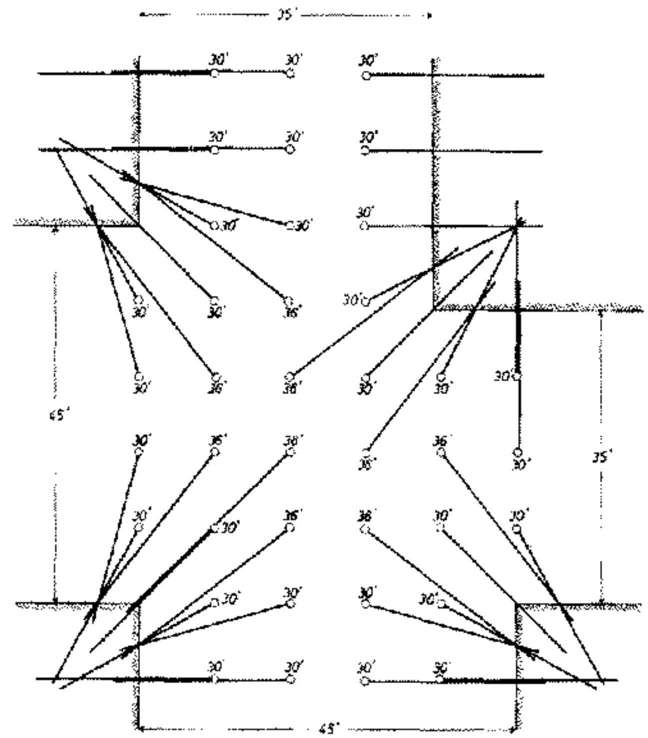

Figure 2. Layout of cable bolts at an intersection.

The problem arose as to how to do this work safely and efficiently in a room which had already been excavated to a height of 43 ft (13 m). This was accomplished by dumping 25,000 tons of waste salt in this area to within 15 ft (4.6 m) of the roof. This gave an excellent solid base for the men, equipment and materials.

Boreholes up to 38 ft (11.5 m) in length and 3 in. (76 mm) in diameter were driven without undue difficulty with one of the regular drills. These holes did not penetrate the overlying dolomite. A special tool was made in the mine maintenance shop to cut a 12-inch (305-mm)-diameter smooth face normal to each borehole. In a diagrammatic sketch of the components making up the cable bolt assembly (Fig. 3), only one tendon of the cable, instead of three, is shown inside the borehole, for clarity.

The first 20 ft (6 m) of each tendon was sheathed in plastic hose so that this section would not be in contact with the grout and could be stretched during the tensioning operation. Three spacers were inserted along the 10-ft (3-m) anchor section to hold the tendons in their relative positions and insure that all the tendon surfaces would be embedded in grout. The tendons were also banded at the top to permit easy insertion in the holes.

As expected, difficulties arose in developing a tight seal at the borehole collar. Any leakage of grout lowers the level of the grout at the top of the borehole, which is the anchor portion of the cable. The seal must prevent the leakage of the thin grout, yet allow passage of the three tendons, one air-escape tube and at least one grout tube.

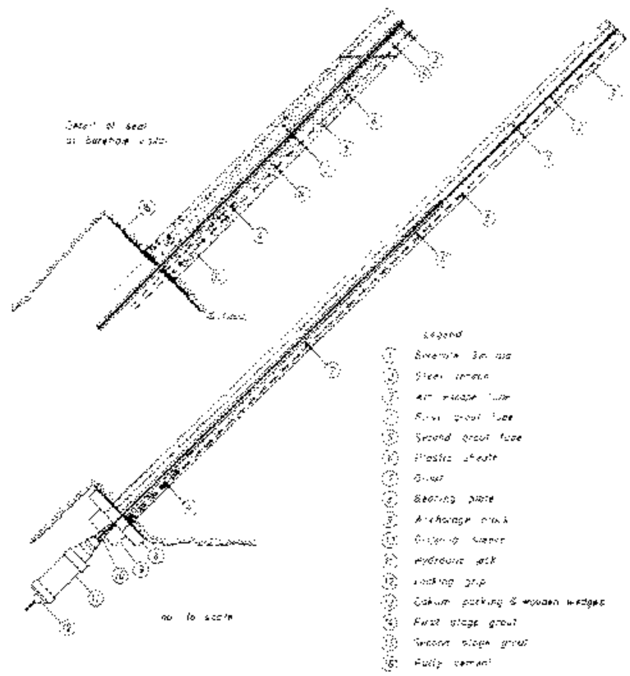

Figure 3. Cable bolt components.

An air-inflated type of seal was tried first but proved unsatisfactory. The next attempt was to use oakum packed into the holes with wooden wedges to hold the tendons in place.

The air-escape and grout tubes consisted of plastic hose and to avoid collapsing, were connected to 1/4-inch (6-mm)-diameter steel pipes for the section through the oakum pack. The air tubes were carried to the top of the holes. The grout tubes in the first few holes were about 4 ft (1.2 m) long.

The grout, of necessity, had to be thin to permit pumping through the small-diameter steel pipe. It consisted of one 80 lb bag of high-early-strength cement to 5 gallons of water. A standard expanding agent was added to the mix.

The oakum seal as originally developed appeared encouraging but did not completely eliminate the leakage of grout. On the next few holes, a stiff putty mix of cement, water, and fast-acting hardener was plastered around the tendons and tubes. This resulted in a further improvement, but some leakage continued to occur. It was then decided to grout in two stages. A second grout tube was run to the top of each hole using the shorter one to make a cement plug on top of the oakum. This gave a tight seal. After one day setting time, the remainder of the hole was completely filled with grout, including the air and grout tubes.

The grout was allowed to set for seven days before the tensioning process was initiated. In this process, the grout and air tubes were first cut off square with the borehole. The components used to hold the tendons under tension are shown in Fig. 4. An 8 X 8 X 1 1/2-in. (200 X 200 X 38-mm) thick mild-steel bearing plate with a 3-in. (76-mm) central hole was slipped over the cable and held by hand against the square cut face. An anchorage block with a separate tapered hole for each tendon was then slipped over the three tendons and held against the bearing plate. Tapered, split, gripping sleeves were then inserted over the tendons and tapped in place in the tapered holes on the anchorage block. This served to loosely hold the anchorage block and bearing plate on the tendons. A hollow hydraulic jack was then slipped over one of the tendons and held by hand against the gripping sleeve. Next, a smaller block was run over the tendon and locked in place with a tapered sleeve against the back of the jack. The hydraulic jack was then extended by means of either a hand or motor-driven pump until a load of 23 tons was indicated by a pressure gauge. This tension stretches the 20-ft (6-m) sheathed portion of the tendon about 1 3/4 in. (44 mm). Immediately on release of the hydraulic pressure, the tapered sleeve grips the tendon and locks it in place in the anchorage block. This process was repeated for the other two tendons of the cable.

As expected, in addition to the leakage problems at the borehole seal, further difficulties arose from the loss of grout through cracks which had already developed in the overlying formation. In some cases, the grout escaped to adjacent roof bolt holes and in other instances, into crevices in the salt. In these problem holes, only partial anchor strength could be attained. It was then necessary to install one or more adjacent cable bolts, which penetrated grout-filled crevices from the previous operation, until one proved to have adequate anchor strength.

At six locations, it was particularly difficult to obtain satisfactory anchorage. Finally, the problem was overcome by increasing the anchor length from 10 to 15 ft (3 to 4.6 m) and by using small mechanical anchors attached to the top ends of the tendons. These mechanical anchors consisted of a combination of 1 1/2-in. (38-mm) pipe cou-

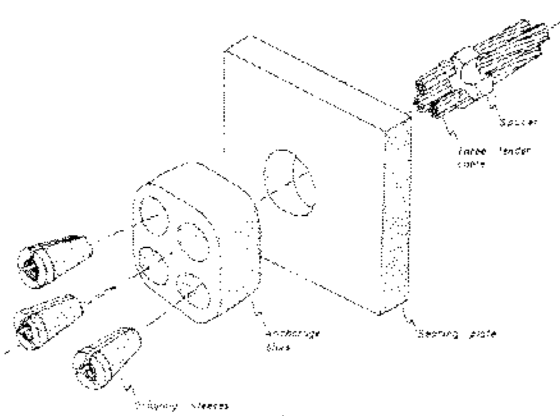

Figure 4. Method of anchoring cable at borehole collar.

plings and regular tendon gripping sleeves. The couplings served as collars which forced the sleeve to tighten on the tendon when any slippage occurred.

When the project was finally completed, 250 cable bolts had been installed. Of this number, 182 were tensioned to the specified amount. The remainder developed varying amounts of resistance to slip, to provide some support to the strata.

The cable was purchased in reel lengths and originally this cable was cut to the specified lengths and assembled on surface. Later, because of transportation difficulties, this work was done underground.

The cost of each completed cable bolt was about $200., which was close to the original estimate. On completion of the cable bolting, wire mesh was installed to hold any minor loss between the cable bolts.

LOAD MONITORING

Long-term (at least 15-year) roof stability is required in the new mill area, so it was decided that the load on several cable bolts would be monitored in order to continuously assess their performance. Six vibrating-wire load cells with a capacity of about 100 tons were manufactured at the Mining Research Centre at Elliot Lake. Smaller vibrating-wire load cells have been used to measure the loads on conventional rock bolts at this mine over a period of 2 1/2 years without any major maintenance. A battery-operated comparator unit is used to measure the frequency of vibrating wires and in conjunction with laboratory calibrations the load can be determined.

The six load cells were installed on three adjacent pairs of cable bolts located in an intersection, in the middle of the room, and adjacent to an intersection. Two 1 1/2-in. (38-mm) thick bearing plates were placed either side of the load cell, and this was the only difference from the regularly installed cable bolts. The load was monitored during the tensioning and subsequently at about 1-month intervals.

The graph (Fig. 5) shows the location of the instrumented cables, the variation of load with time and mining activity, and indicates that the load on all the cable bolts relaxed immediately after installation, then stabilized, and subsequently increased. The relaxation and load stabilization pattern of behavior is similar to that of the conventional rock bolts. The increase in load coincided with

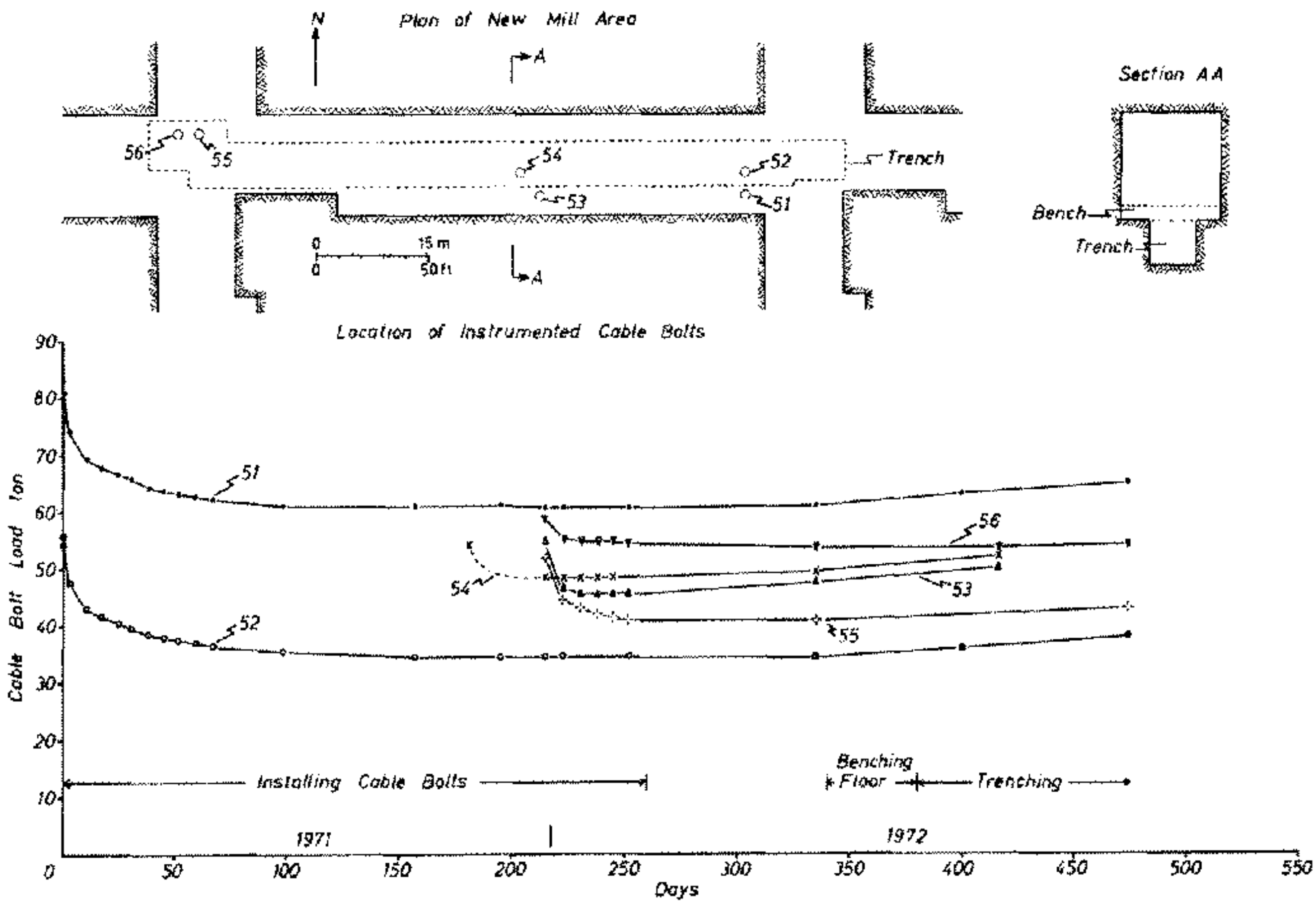

Figure 5. Variation of load on cable bolts.

mining a 5-ft (1.5-m) bench in the floor and then excavating a 20-ft (6-m) deep trench. It is thought that these excavations affected the deformation of the roof strata resulting in an increasing load on the cable bolts.

The high installed load of 83 tons for Cell 51 is probably erroneous because it is very near the capacity of the cable. The probable reason for this high indicated load is eccentric and uneven loading on the cell. Load Cells 53, 55 and 56 had thin lead washers on them to overcome this problem. However, the measurements on Cell 51 are still valid in terms of a percentage change in load.

The installed load on the other five load cells is between 52 and 58 tons which is reasonable. During tensioning, 23 tons is placed on each of the three tendons which gives a total theoretical load of 69 tons per cable. However, during setting of the clamping wedges, between 4 and 5 tons is lost per tendon; hence, the actual installed load is about 55 tons.

The drop off in load on Cells 53, 54, 55, and 56 is much less than on Cells 51 and 52. The probable reason for this behavior is that Cells 51 and 52 were on the first set of cables installed. The collar of the boreholes had been faced off with a plate containing cutter picks which produce small concentric ridges. The bearing plate rests on the top of these ridges and when load is applied they slowly crush, causing a reduction in load. Later practice was to put a skim of putty-like cement at the bearing surface, to increase the contact area for the bearing plate; this results in less drop off in load.

The average load, at present, on the cable bolts is about 47 tons which is less than the 65 tons required to support a roof section 8 ft thick. However, as mentioned previously, the cable bolts are capable of taking more load up to an ultimate of about 87 tons.

SUMMARY

The civil engineering technique of reinforcing ground with post-tensioned steel cables has been successfully adapted as a system of support in underground mines. Cable bolts were considered the most practical means for ensuring long-term stability of the roof of the new mill area because of the thickness of strata requiring support, the nature of the salt, and the obstructed space required for the mill installations. Some problems such as developing an adequate borehole seal were soon solved. A year and a half after installation of the first cable bolt the whole system appears to be functioning as it was designed to function.

ACKNOWLEDGEMENTS

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