■ OPERATING IDEAS

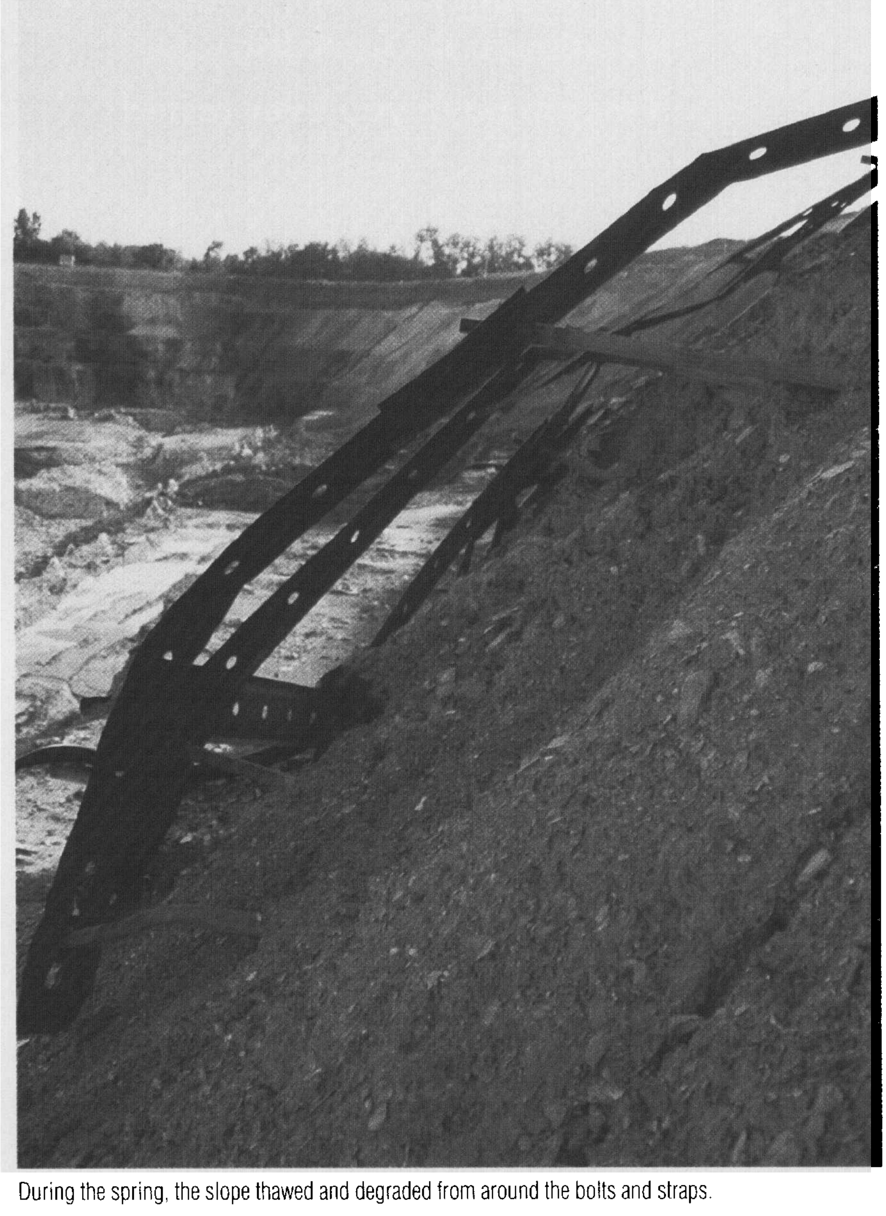
Rock Bolting at the Flambeau Open-Pit Mine

By Raymond Yost

In autumn of 1995, the Flambeau Mining Co. began a rock-bolting program on the hanging wall of the open pit to control the bench-scale instability that had occurred throughout the life of the mine. A bolting program was initiated after displacements continued despite two redesigns: the first, decreasing the inter-ramp angle and bench height and the second, reducing the bench-face angle and bench width.

The Flambeau mine, located near Ladysmith, Wisc., began operations in March 1993 that were scheduled to be concluded during February 1997. The Precambrian massive sulphide deposit averages 10% copper with a minor gold and silver content. The orebody lies between highly fractured and strongly altered lava flows and tuffs that have been overturned to an average dip of 70°. The pit measures approximately 760 m in length and averages 165 m in width. Total planned depth is 70 m. The inter-ramp slope design in the Precambrian bedrock is at 45° and ranges from 27° to 36° in the overburden.

Bench-scale instability, as opposed to overall wall displacement, began early in the mine life. Although feasibility studies indicated that the bedrock could support a bench height of 18 m, several displacements occurred on the footwall after only 12 m of the final wall had been excavated. As a remedy, the bench height was reduced to 9 m throughout the pit, but bench-scale instability continued to occur on the hanging wall due to unexpected low rock strengths. A further redesign of the hanging wall flattened the bench-face angle, but despite the reduction in both bench height and bench face angle, the hanging wall continued to experience displacements. At that time, a ground support program consisting of rock bolting was instigated.



During the spring, the slope thawed and degraded from around the bolts and straps.

The rock bolting program was first targeted for a short section of the hanging wall located immediately below a haul road. The initial stage of the program focused on determining the type of rock bolt best suited for the ground conditions and designing a basic pattern for bolt installation.

The first question to address was which type of bolt would function best in the strongly altered and highly fractured rock. The hanging wall of the mine is composed primarily of schists, which are differentiated on the basis of primary alteration products. The three principal rock types are quartz augen schist, biotite andalusite schist, and meta-dacite. The meta-dacite readily breaks down upon exposure and exhibits uniaxial compressive strengths of 3.5 to 7MPa. The quartz augen schist and andalusite biotite schists are generally stronger, but uniaxial compressive strengths are still low, ranging from 10.5 to 17MPa.

Given the abundance of clay and a high fracture frequency, a mechanically anchored rock bolt was preferred over resin or cement-grouted bolts. Friction rock stabilizer-type bolts were considered but were eliminated due to their length limitation. The maximum length of the friction rock stabilizers, 3.6 m, was inadequate to reach beyond and support the potential zone of displacement. Atlas Copco Swellex bolts were available in lengths up to 8 m and offered the required mechanical anchoring capability.

After choosing the type of bolt, determining an installation pattern was the next step in the trial program. In the absence of a well-defined limit to slope instability, the design was based on an analysis of such factors of rock strength, fracture frequency, average block size, the orientation of structure, and an assumed instability limit.

To support the assumed displacement mass, 8-m Standard Swellex bolts were installed on a 1.5 x 1.5-m pattern. Additionally, wire mesh was fastened to the bolts to contain rockfall, and straps were placed between bolts to contain larger blocks and further restrain the rock mass.

Two problems were encountered during and after the initial test installation. The first was discovered when the bolts were subjected to non-destructive pull tests and would only achieve a load of 3-4 st as opposed to the expected load of 7 st. The probable cause was that the outer several feet of the drill hole was subjected to excessive wear from the repeated passing of the drill rod couplings. The ground easily eroded beyond the maximum recommended hole diameter for the Standard Swellex, but it was impossible to reduce the size of the bit and drill-rod system. When the bolt was inflated within the hole, a gap between the drill hole wall and the inflated bolt existed for the outer 1-1.5 m of the hole. To correct the situation, 1.5 m lengths and 12 mm steel cable were inserted in the holes to fill the extra space. Pull tests performed on bolts installed in this manner verified that the bolts met design specifications for a non-destructive pull-out resistance of 7 st.

The second problem did not become evident until several months after the bolts and mesh had been installed. During the spring thaw, the rate of near-surface rock breaking accelerated dramatically and loaded the mesh with loose material. In areas where the mesh was fastened to the front of the bolt plate with a special mesh washer, the washer would break, allowing the mesh to pull away from the bolt and the accumulated debris to fall onto the benches below. A number of bolts had been installed with the mesh fastened in front of the bolt plate to secure the bolt to the uneven face of the slope as tightly as possible rather than installing the mesh behind the bolt plate, which often resulted in a gap of 15-30 cm between the slope and the bolt plate.

Both remediation of the affected area and a change in the mesh installation procedure were required to redress this problem. In areas where the mesh had begun pulling away from the bolts, a geofabric was installed to contain any secondary rockfall. To prevent any reoccurrence, the mesh was installed under the bolt plate and Ingersoll Rand Split Set friction stabilizers were used to anchor the chain link securely to the slope.

Standard Swellex bolts were used in the initial bolting program because of their immediate availability. A switch to Super Swellex bolts was made as soon as these could be delivered. The Super Swellex bolt had more than twice the strength rating, 220nK, as the Standard Swellex, which meant that the spacing between the bolts could be expanded without decreasing the support of the bolts. The larger diameter of the Super Swellex bolts also meant that a larger drill string, bit, and coupling system could be used. Although the couplings would still wear the hole beyond the diameter of the bit, there was a smaller difference between the drilled hole and the recommended hole diameter for the Super Swellex bolt, and a better bond between the bolt and the rock could be established.

The bolts were installed with an Ingersoll Rand LM 500 drill, but several modifications were necessary to optimize the drill performance. The first change was made for safety. The drill controls were moved from the mast to the main body of the drill to reduce the highwall exposure to the operator. A rod changer was also added so that one person could operate the drill without the need for a helper.

Drilling was a challenge, however, when bolts were installed in one of the weakest rock types of the mine: the metadacite. The nature of the material presented several problems for the bolting program.

Ingersoll Rand drills were used to install the bolts throughout the pit.

During installation, the high clay content made drilling difficult, and bits were often plugged. The varying strength of the rock also allowed the drill bit to wander to the point that insertion of the 8-m bolt often had to be accomplished with the aid of heavy equipment. Furthermore, many bolts were installed during the winter months when the wall was frozen solid. In the spring, the ground thawed and rapidly degraded around the bolts, rendering the straps virtually useless.

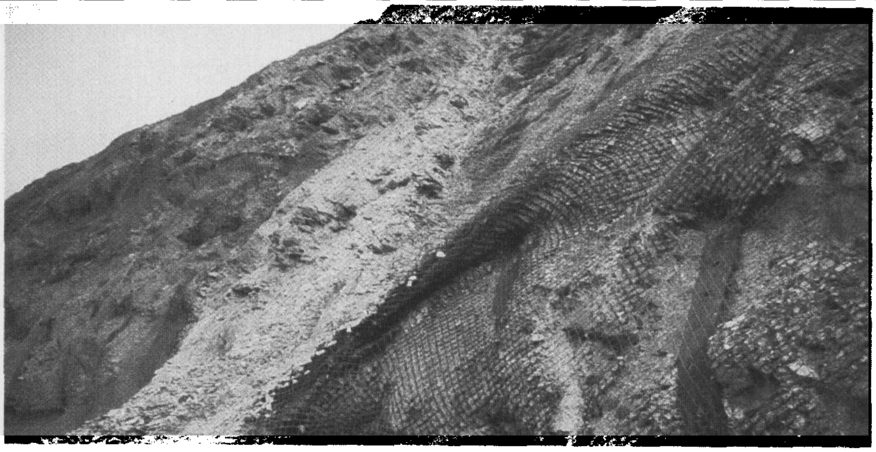
A standard PSP 300 pneumatic pump was used to inflate the bolts. The pump suffered considerable maintenance problems given the less-than-ideal conditions under which the bolts were installed. On average, the air temperature ranged between -23°C and 10°C with operations continuing until the temperatures dropped to -23°C. The floor of the pit was usually waterlogged and coated with a viscous mud. Due to such conditions, the pump would seize periodically and have to be torn down, lubricated, and rebuilt. The frequency of seize-ups was reduced by adding a water separator to the air compressor to prevent the introduction of water into the pump cylinder. To keep the pump warm, it was mounted next to the air compressor, and to prevent clogging any moving parts, a longer air hose was added between the installation wand and the pump. In extreme temperatures, a deicer oil was periodically applied to the piston. Although adding the oil appeared to help in the short term, it caused the pump seals to break down more quickly, which meant that the entire pump had to be overhauled after every 500-750 bolts.

The initial installation of bolts demonstrated a significant decrease in the incidence of bench-scale instability. To optimize the associated wall stabilization costs, a series of four test patterns were designed to minimize the number of bolts required to achieve stability. In the first test area (Pattern 1), bolts were spaced evenly over the height of the bench face on a staggered 1.5 x 3-m pattern with additional bolts to secure the crest. Overall, the pattern required 40% fewer bolts than the 1.5 x 1.5-m pattern. In the next test area (Pattern 2), bolts were concentrated on the upper third of the slope with additional bolts installed at mid-slope. The bottom 4.5 m of the bench was left unbolted. The resulting configuration required 50% fewer bolts than the 1.5 x 1.5-m pattern. In the third test area (Pattern 3), only the crest of the bench was bolted, leaving the bottom 6 m unsecured and using 60% fewer bolts than the 1.5 x 1.5-m pattern. The final alternative involved a presplit blasting test (the presplit), where the bench was excavated at a shallow angle (52°) to determine if this would eliminate the bench-scale displacements and consequently the need to bolt the slope. No bolts were installed initially in this test area.

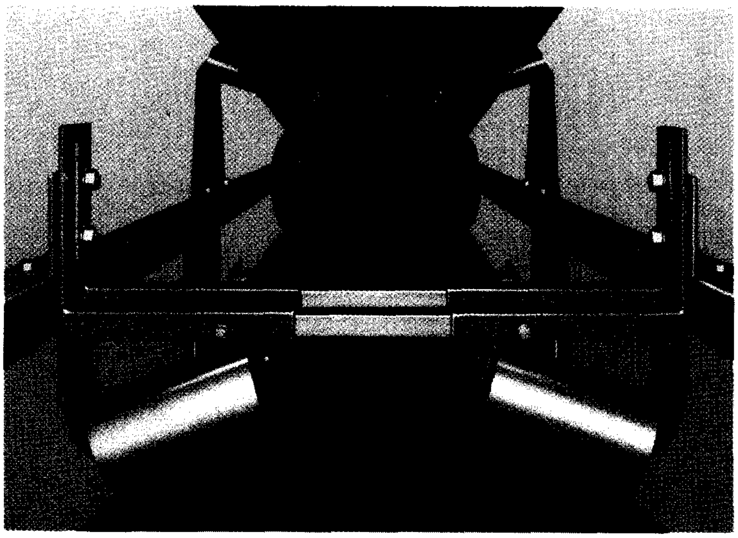
To evaluate the performance of the test, survey prisms were installed on the bench above each of the test areas to determine if differential rates of movement were associated with any of the patterns. The extent of backbreak both into the slope and along the bench and the quantity of rockfall from the slope were also compared for each of the test areas.

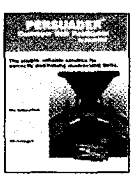
All of the bolted test areas performed well. Bolts spaced evenly over the entire height of the bench (Pattern 1) virtually eliminated backbreak and reduced rockfall rates to minimal amounts. The second area (Pattern 2) also experienced minimal backbreak, but some rockfall of larger blocks from the unsecured area of the bench face did occur. Bolting only the crest of the bench (Pattern 3) allowed a greater volume of rockfall from the unsecured portion of the bench face and some backbreak. The shallow angle test area (the presplit) fared worst of all. Excavation of the first 10 ft indicated that the presplit blast had caused excessive backbreak along the crest. The area was then bolted with two rows of bolts on a 1.5 x 1.5-m pattern to prevent further degradation.

No significant differential rates of movement were observed among these test areas. Differences between movement rates



Area where mesh washers failed, allowing accumulated debris to fall onto bench. The majority of such failures occurred where no straps were installed.





The Flambeau mine near Ladysmith, Wisc., looking northeast with the hanging wall to the left and the footwall to the right.

for each area roughly correspond to the degree of bolting in the slope below, but these are not statistically significant.

Based on the test results, it was decided that areas with relatively high-rock strengths would be bolted with a minimum of two rows of bolts at the crest installed on a 1.5 x 1.5-m pattern. A bolting program for the remainder of the mine was generated based on geologic cross sections that identified future rock mass conditions. Much of the pit would ultimately be bolted with either three or five rows of Super Swellex bolts installed on a 1.5 x 3-m spacing.

Despite the initial uncertainty regarding the slope displacement mechanism, a rock-bolting program was successfully developed that has effectively controlled bench-scale instability. Backbreak and rockfall have also diminished. Testing and subsequent modification of the first installation pattern and method have optimized the ground support generated by the Swellex bolts. Pull tests conducted both soon after bolt installation and up to six months afterward have indicated that the Swellex bolt has proven to perform as specified in weak rock masses that are intensely fractured and highly altered.

A minimum of two rows of bolts will be installed along the remaining benches throughout the Flambeau mine hanging wall to maintain the stability of the bench crests. The bolting and meshing program will continue to play a key role in achieving an aggressive mine design in weak rock. ■