CASE EXAMPLES OF STABILITY ON SURFACE MINING PROJECTS

By

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INTRODUCTION

Stability on surface mining projects is primarily controlled by five factors. These include structural geology, the most important of the factors, the existence of weak layers, primarily clayey gouge or clay infill, groundwater, blasting and weathering. Case examples of stability on many surface mines including some coal mines are presented. The experience and lessons learned are applicable in some way to stability of surface coal mines.

EXAMPLES INVOLVING STRUCTURAL GEOLOGY

1. Hammersley Iron Mine, West Australia. Figure 1 illustrates the through going bedded structure dipping at about 45 degrees out of the slope. This dip angle was continuous across to the other side of the pit. The angle of friction along the joints was in the order of 30 degrees. Whenever the dip bedding angle out of the slope exceeds the angle of friction, the potential of instability is very real.

In this instance the benches that had originally been developed failed along the bedding. This resulted in severe problems with raveling rock and maintaining the haul road. This became aggravated during infrequent high intensity rain storms. In this instance the geologist on the project during the feasibility and original design should have insisted that the haul road be located on the other side of the pit where the potential of instability and the potential of bench loss would have been minimal.

Fig. 1 - Dip angle of bedding exceeds the angle of friction along the bedding. As a result the benches have failed.

2. Morwell Open Cut, State Electrical Commission, Victoria, Australia. Figure 2 shows a through going joint dipping at about 55 degrees out of the slope. The face angle being excavated by the bucketwheel excavator was approximately 70 degrees. The angle of friction along the joint in the coal was in the order of 25-30 degrees. When the bucketwheel excavator excavated the base cut, it undercut the wedge formed by the joint in the face and a 200 tonne block of coal slid down onto the wheel. This supplied sufficient load and force to break the bucketwheel arm and to cause the bucketwheel to partially tip on its side (Figure 3). As a result of this

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failure a continuous mapping program was developed around the open pit to map all joints. Where joints dip out of the slope flatter than 70°, and near parallel to the slope it is advisable that the design face be cut at the angle of the dip of the joints.

3. Chambishi Pit, Roan Consolidated Mining Co., Zambia. A major slide on an argillaceous layer 15 cm thick which dipped toward the pit face disrupted the only haul road into the pit. (Figure 4) The movement of the highwall was in the order of 20m. The existence of this adversely oriented weak layer was not known prior to mining. Subsequent drilling showed that the water pressure behind this argillaceous layer was 13m higher than in front, indicating that the layer was acting as a dam. The recommendations for stabilization involved an adit to be excavated through the argillaceous layer, then to follow parallel behind this layer in the direction of mining. From this underground adit, a series of percussion drain holes were recommended to increase the effective diameter of drainage.

Fig. 2 - A block of coal failed on a joint dipping at 55° out of the slope. The bench face was being cut at 70°.

Fig. 3 - Bucketwheel excavator tipped on its side due to 200 tonne block of coal falling on the excavating wheel.

Fig. 4 - Disruption of the haul road by failure on a thin continuous argillaceous layer dipping out of the slope.

Very recently the technique of vacuum drainage for mining stability was developed by the author in North America. The recommendation today would include installation of an air-tight bulkhead about 15m from the entrance of the adit and placement of the adit under a vacuum. This will greatly improve the rate of drainage and develop negative pore water pressures within the slope which will have a significant
influence on improving stability.

It is strongly recommended on all projects that several boreholes be drilled deeper than the base of the ore zone to determine whether or not structural geologic surprises, weak materials or very high groundwater pressures exist.

4. Exshaw Limestone Quarry, Alberta, Canada. This is an example of mining to the slope angle of the bedding. (Figure 5) If benches had been developed it is likely that they would fail. The height of this slope is about 130m, the dip angle of the bedding is 45 degrees, and the angle of friction along the bedding with moderate roughness is about 35 degrees.

In order to mine this face at the angle of the bedding two options are available concerning blast control. The first is to drill angle holes along a dip of the bedding at about 1/2 meter in front of the face. The second option is to step out 3m, drill a 3m hole, step out 6m, drill a 6m hole, step out 9m and drill a 9m hole with the base of the blast hole maintained about 1/2 meter above the bedded face.

There is one major problem with respect to this procedure in North America where heavy snow fall occurs. During the winter time there is the potential of snow avalanches. Mine planning must be such that no mining is performed below this face when a heavy snow fall is occurring, when snow exists on the face and when the temperature warms up substantially such that melting will occur.

5. Kennecott Copper Ltd., Liberty Pit, Nevada, U.S.A. Figure 6 shows a failure involving some 4 million cubic meters which has occurred as a very large wedge with joints on one side and a through going fault on the other side. The angle of intersection of the two major discontinuities was 19 degrees. It is this angle which controls the stability. The angle of friction of the material was about 26 degrees which indicates that some other factor had to cause the failure. Observation of photographs prior to the failure indicated that considerable seepage was noted in the lower area where the wedge daylighted on the slope. This indicates the likelihood of high pore water pressures acting on this wedge. This failure took a number of months to occur. It could likely have been stopped had subsurface drainage such as the installation of horizontal drains just below the failure surface, been installed. It is now recognized that wedges of relatively large magnitude can occur on mining projects.

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Examples of Instability Related to Thin Layers of Very Weak Material

1. Strip Coal Mine, Queensland, Australia. A block failure involving an overburden sedimentary sequence occurred directly in front of the dragline. The failure took place in a clayey carbonaceous, bentonitic layer directly above the coal. As a result of stress relief which occurs rapidly during mining with the dragline, discrete tension cracks open up beyond the highwall. These can become filled with water during periods of very high rainfall. The water pressure in the tension crack is sufficient to cause the block to move laterally into the pit when the friction angle along this weak material is in the order of 10-15 degrees or less. The problem is compounded because during the rapid mining, differential strain due to the differential stress relief occurs along this weak contact. Large strains can develop to the point that the peak strength of the material is exceeded. In this instance, the back of the failure undercut the walking pad and a small portion of the tub. Had the failure extended another 5-6m the dragline could have moved into the pit.

Fig. 7 - Block failure on a weak clayey carbonaceous layer which almost undercut a dragline.

2. Exxon Highland Uranium Mine, Wyoming U.S.A. Two problems developed on this project. (Figure 8) The first involved shrinkage which occurred within the shale layers due to the high temperatures on the face which reached 60 degrees C. The shale shrank and pulled away support for the sandstone blocks directly above. This resulted in ravelling of the sandstone blocks and a gradual change from a 55 degree designed slope angle to a 37 degree angle of repose for the failing sandstone blocks. The recommended solution to this problem was to spray the exposed shale layers with an asphalt emulsion to reduce the evaporation and shrinkage within the shale layers.

The second problem was that water was caught on the surface of each of the shale layers where there was a depression in the shale and a perched water table developed. This perched water table resulted in a increase in moisture content on the upper layer of the shale and a reduction in the cohesive strength. As a result of the stress relief and opening of tension cracks behind the face, water pressure caused block failure to develop along the top of the shale layers. There were 8 shale layers that were believed to be contributing to this potential block failure mechanism. It is impossible to drain these layers with horizontal drains which is normally the most inexpensive and successful subsurface drainage method available to the mining engineer. The technique that was developed was to drill vertical holes 45cm in diameter, to a depth slightly below the base of the ore body and fill the holes with a clean sand and fine gravel. Horizontal drains are then drilled in from the toe of the slope to intercept the well and to drain off the water that had been collected in each of these wells. This turned the system into a gravity system which did not require pumps within the wells.

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3. Syncrude Tar Sand Project, Alberta, Canada. The thickness of the tar sand being mined is up to 35m thick with the draglines on the highwall bench. It is very important that this highwall bench remain stable. Within the sequence of the tar sand are channel deposits which occasionally contain thin clay layers whose dip angle may range up to a maximum of about 25 degrees. Wherever these dipping clay beds exist dipping out of the slope there is a potential for failure of the block on which the dragline is located. Mapping of all of the exposed faces is performed each day during a maintenance period of the dragline. However, since some of these channel deposits can be cut off by other channel deposits it is essential that the dip angle be monitored in behind the slope face. At the author's recommendation the Schlumberger Co. was asked to consider developing a down the hole dip meter which utilised four resistivity meters around the probe and would fit in a maximum 10cm hole. This has been successfully developed. The dipmeter is capable of determining the dip and dip direction of clay layers down to a thickness of 6mm. As a result of this system 17 of 18 failures which occurred along channel deposits were predicted in advance and a suitable mining program was developed to maintain stability. In one instance the dip meter data was disregarded and a failure occurred. Fortunately both the dragline operator and a geologist at that dragline noticed a tension crack developing. The dragline immediately turned around and moved off the site. Within 10 minutes of leaving the site, a failure had occurred. (Figure 9) Had the dragline remained on the bench the dragline would have fallen into the pit.

4. Trans Alta Utilities, Highland Mine, Alberta, Canada. A series of bentonitic clay layers exist in the overburden of the coal. Perched water tables exist on practically all of these bentonitic layers. Friction angles in the bentonitic clays are in the order of 10-12°. Inadequate control of subsurface and surface water existed on this project and as a result a number of highwall failures developed such as shown in Figure 10. A program to improve stability on this project has been to divert surface water, to slope the benches to shed the water off the surface, particularly during periods of high rainfall and snow melt in the spring. Increasing the bench elevation on which the dragline operates also is
effective because it increases the normal force which develops friction and improves stability. The highwall face is kept as steep as possible in order to maintain a high normal load. It is to be noted that increasing the bench elevation and increasing the slope angle is contrary to what might normally be considered requirements to improve stability.

Fig. 10 - Block failure on a weak horizontal bentonite layer. Water pressure in tension cracks precipitated the movement.

3. Lornex Mining Co., Highland Valley, Canada. A series of parallel clay infilled shear zones ranging from 10-20m apart extend nearly parallel to the west face of the Lornex pit. These discontinuities dip at approximately 70 degrees into the slope. At the toe of the slope, the major Lornex fault which is about 30m wide is infilled with zones of clayey gouge. This also dips at 70 degrees into the slope. The approximate slope height is 350m. Figure 11 shows the toppling failure that has developed near an intermediate haul road about half way up the slope. Slope indicator installations indicate that the depth of toppling is in the order of 110m. The total volume is estimated at about 30 million tonnes. Groundwater pressures exist in the slope. In addition the Lornex fault is acting as a major dam in the toe area of the slope. Toppling has resulted in break up of the haul road and extensive ravelling of all the bench faces such that the overall slope is about 33 degrees. The influence on stability of groundwater pressures is aggravated during periods of high rain fall and spring melt when the water seeps into the shear zones and develops high pressures at the back of each of the blocks near the surface. The moment arm developed by the water pressure is very high.

The least expensive way to develop stability for this condition is to dewater the slope. Because of the large number of clayey shear zones, some of which are also near horizontal, a large number of confined aquaclasses exist which require multi-level drainage. It was therefore recommended that horizontal drains at several levels be installed in the slope to reduce the water pressures. It is essential that the stabilization commence at the bottom to stabilize the toe first. Drainage is then installed progressively upward. All of the drain water that is intercepted must be collected and not allowed to flow back into the slope where it simply moves the high groundwater pressures from farther in the slope to near the outer surface of the slope.

Fig. 11 - Large toppling failure occurring in a pit highwall. Stabilization by drainage is the most cost effective procedure. The drainage must start at the bottom.

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Influence of Groundwater on Stability

1. Canadian Johns Manville, Quebec, Canada. A major slide involving approximately 55 million tonnes of rock and overburden dropped about 2m as a result of breakage of the main water main that ran into the town near the crest of the open pit. Figure 12 shows the open pit slope and adjacent town. The slide continued at about 7cm per day and extended well into the town. Approximately 100 structures were damaged as a result of the movement. An immediate program of stabilization was developed at the same time as an evaluation of the depth of failure, depth of the water table, etc. commenced. The movement at the top dropped vertical and the toe pushed out near the toe. This indicated a curvelinear failure surface was involved. As a result, a major unloading program at the crest utilizing 180 tonne trucks was instituted. This resulted in excavating one year in advance what normally would be the mining cycle. In addition a number of horizontal drains were drilled through a major fault zone in the slope to reduce the water pressures behind that zone and also near the toe of the slope.

It was found that an old underground exploration and development adit existed directly underneath the slide. Arrangements were made to dewater this adit and to reinstall the ventilation system. Vertical percussion drain holes were drilled up into the slide zone to bleed off water pressure. After a three month period of stabilization the slide was brought under control.

2. Syncrude, Alberta, Canada. A water bearing sand aquifer exists underneath the tarsand. When the tarsand is excavated to full depth there is an imbalance of water pressure in the bottom of the excavation. The pit bottom will either blow as a result of the imbalance of the water pressure or piping will occur which will carry sand out and take away support for the slope.

The original design at this operation was to install approximately 800 pumping wells to dewater the entire area in advance of mining. This is a very expensive procedure. It is also difficult with respect to disruption of the drainage during dragline tarsand pile and conveyor moves.

Fig. 12 - 55 million tonne slide caused by broken water main. Slope 300m high.

Fig. 13 - Four horizontal drains connected to a header and vacuum pump. The drainage rate increased 5 fold.

A procedure that was recommended and was installed on an experimental basis was to install long horizontal drains from the toe of the tarsand into the sandy layer. Some of the drains were up to 250m in length. A new was...
constructed along the outer 10-13m of the horizontal drain between the outside of the pipe and the inside of the hole. The entire system was then placed under a vacuum. The flow from the drains increased approximately 5 fold with the result that there was a much more rapid depressurization of the aquifer. This technique was developed by the author three years ago and has now been used at Afton, Lonex Mines, and Gibraltar Mines in British Columbia, at a tailings dam at Union Carbide in the U.S. and to stabilize a major landslide along the California coast at Malibu.

3. Lake Asbestos of Quebec, Canada. A major failure extending about 250m high occurred in an area where two steeply dipping faults exist. (Figure 14) Extensive ravelling developed, a portion of the toe moved out and toppling occurred at the top of the slide. A drainage ditch existed along the top of the slope which was required to intercept water being drained into the area from a highway and railway. Unfortunately, this ditch excavation was not lined and continuous seepage occurred all along the highwall slope. Water was obviously a main factor in the instability. One borehole with two piezometers was installed behind the scarp to measure the water pressures. Two water tables were located. The slope was still moving in the center. Two horizontal drains 125m long were installed at each side of the slide. All four drains were effective in draining the slope, one of which amounted to 80,000 liters per day. Shortly after the installation of the four drains was complete, the movement stopped.

**Controlled Blasting to Improve Stability**

1. Cleveland Cliffs, Michigan, U.S.A. The country rock in the iron range of Michigan is extremely hard with relatively few through-going discontinuities. Those that do exist are of random orientation. As a result of this, a closely controlled blasting program was developed along the contact of the ore and the hard waste rock by utilizing line drilling, minimum explosives along that line and buffer lines between the line and production blasts. An overall slope angle of 80 degrees has been developed for a slope that is approximately 150m high (Figure 15).

Fig. 14 - Highwall failure bounded by two steep faults and triggered by high pore water pressures from ditch seepage.

Fig. 15 - Excellent blasting for wall control to develop a slope at 80 degrees.

2. Carrdrum Mine, Ireland. A modified program of blasting control was developed along this final face utilizing 15m diameter holes spaced 2m apart. This follows the...
general rule of spacing for line control drilling with larger holes. It will be noted that the dip angle of the face of each bench was also excavated at about 75 degrees. The author recommends that when new drills are being purchased for any mining operation that they should be obtained with the ability to drill at an angle of 15 degrees off the vertical. A combination of good blasting control along this face has resulted in good highwall stability. It is likely that the final walls could have been steepened by 8 - 10 degrees.

Fig. 16 - Good wall control with 15cm diameter line holes and angled drilling at the face.

On many projects the blasting foreman is placed in charge of the drill and blast program. As a result the author has found that very little experimentation and incentive to develop new blasting techniques exist to improve stability. It is recommended for larger mines that an engineer be made responsible for all the blasting with complete authority to develop and evaluate new blasting programs and techniques that will reduce the cost of drilling and blasting, reduce seismic acceleration forces, improve stability and allow the steepening of rock slopes. Major financial benefits will result.

Weathering and Stability
Atlas Consolidated, Philippines. In

Tropical areas were glaciation has not removed weak rock which has developed as a result of weathering, failures can develop to a considerable depth. A typical example is the Atlas Consolidated mine in the Philippine Islands. A slide involving approximately 40 million cubic meters was activated by mining which undermined the lower elevation of the mountain slope. The failure was aggravated by groundwater pressures. Figure 17 shows the mountain slope and pit wall which was failing.

Fig. 17 - Major slide in weathered rock involving about 40 million cu. m.

A program to determine the depth of the failure zone, the depth of the water table, and the rate of movement was developed. The mining company wished to deepen this portion of the pit an additional 150m. The depth of the failure surface was found to be approximately 100m which was the contact between the weathered rock and the essentially unweathered rock below. The depth of the water table was found to be approximately 60m. The only practical means of improving the stability of this project would be to lower the groundwater table. Analysis indicated that the stability could be
increased by about 16% with full water level drawdown. Two drainage adits were installed 300m long with two cross cut drainage adits 60m long. Percussion drain holes were drilled upward from the tunnel to the failure zone to increase the effective diameter of the tunnels.

Evaluation of Stability

In recent years a considerable number of geotechnical engineers have been offering services to mining companies to perform investigations, analysis and recommend stabilization programs or programs to increase slope angles.

It is very important when selecting a consultant to provide such specialist services that the selection be based on experience relative to that specific type of problem rather than for the selection to be based on price.

The author also recommends that a semi-annual to annual inspection of mining projects by a stability specialist be adopted by mining companies to evaluate their existing structural geologic program, groundwater and dewatering program, blasting program and monitoring program to evaluate existing stability, potential stability, and pit slope angles. If a single review consultant is used he should have an overall background in all of these areas. On very large mining projects it is strongly recommended that a Review Board be utilized to provide this service. This board would typically be made up of three widely experienced stability engineers. For hard rock, a specialist in structural geology and stability, a specialist in groundwater and drainage and an engineer specialist in blasting procedures, blasting damage and blast design is suggested. For soft rock the blasting engineer can be replaced by a mine stability specialist.

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