Preliminary Data Collection for Pit Slope Design

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Progress in the technology of slope design over the past 15 years now permits the selection of rational slope angles if suitable data on geology, hydrology, and rock properties are available for a specified project. Although a full-scale slope design study remains the best course of action, there are situations where an extensive study is not feasible due to time or budget constraints. Two typical examples are: (a) selecting pit slope angles for a preliminary feasibility study at the exploration stage; and (b) coping with a slope failure in an operating mine. In both instances, slope angles must often be chosen on the basis of data that are currently available or can be readily obtained.

All too often during exploration programs, a feasibility study is initiated shortly before the decision deadline to drop the property or proceed to purchase. If the only existing data at this point are a few cross-sections at odd angles showing ore and waste contacts or a dog-eared map of the surface geology, there may not be time to collect and organize sufficient information for the design of slope angles. On the other hand, if during the drilling program geologic cross-sections were constructed and the structural data compiled in tabular form, rational slope angles could be computed within the allotted time.

Certain types of data can be collected only at specific times during a project. Two prime examples: logging fracture intensity, and sample collection for rock testing before the core is split. It is particularly disheartening to ask to examine the core and to be shown a tattered cardboard box filled with plastic bags of sample pulps.

Similarly, when a rock mechanics specialist is asked to give advice on an active slide in an operating pit, his effectiveness can be enhanced by providing him with the data he needs, including slide geometry, geologic structure, rock types (strength), and water conditions. For example, rather than having the consultant pace out the geometry of the slide, the survey crew could map the slide before he arrives.

Fabric diagrams are standard tools for a structural analysis. It is more cost-effective to have the mine geologist plot the geologic structure on a fabric diagram than to have the consultant measure strikes and dips from a map while the mine manager looks on, waiting for advice on the relationship between geologic structure and pit geometry.

The lack of appropriate data is largely due to uncertainty as to what's required and not to the inability or unwillingness to provide the information. The following guidelines will explain the type of data required for preliminary slope studies, along with some suggestions for an efficient format in which to present the data.

Gather Data During the Exploration Stage

The primary concern during mapping and drilling of an exploration target is the economics associated with the estimated tonnage and grade of the ore body. Until a potential ore body is indicated, there is little justification for specific slope stability investigations. However, a large amount of data pertinent to slope design can be compiled during this stage without appreciably increasing the exploration budget. For example:

Base Maps. A logical point for data compilation is the development of a suitable set of topographical base maps. The following three map scales are appropriate:

(1) Regional—A general site location map covering an area of five to 15 km around the mine. An appropriate scale would be 1:50,000 or USGS 15-minute or 7.5-minute quadrangle maps.

(2) Mine area—A map covering the proposed pit, dumps, and crusher sites. Recommended scale is 1:6000.

(3) Pit—A map covering the proposed pit for approximately one pit-depth around the edge of the pit. This will be the basic pit planning scale. An appropriate scale would be 1:2400 for large pits or 1:600 for small pits.

Reproducible film copies or sepias of these maps should be made for use as base maps for plotting other data.

Geology. The surface geology should be compiled on the regional, mine area, and pit base maps. An outcrop map showing actual observations and a separate interpretive geology map are also needed for each scale. The temptation to put interpretation on the only outcrop map should be resisted. As new geologic information becomes available and concepts change, the interpretive map can be discarded and a new interpretation can be constructed from the outcrop map. It is important to distinguish between what the geologist observes and what he thinks might be there, not to mention the drafting problems of modifying a combined interpretive and factual map.

Factual and interpretive cross-sections should also be prepared with the fact in mind that a slope design study is most concerned with the rock left in the pit wall after the ore is removed. Thus, the cross-sections must be extended to include the pit walls. As a rule of thumb, the cross-sections should include an area at least one pit-depth from the edge of the ore body.

Geologic maps and cross-sections are usually the most important documents for slope design, since the rock types, major structures (faults), and minor structures (joints) determine the modes of failure and their locations.

When mapping major structures and jointing it is preferable to supplement conventional plotting of strike and dip by recording the location, attitude, and characteristics of fracture sets (length, spacing, thickness, and waviness angle) on a tabular data sheet. This procedure will save time—since the information is ready for data processing—and avoids the inaccuracies inherent in replotting and remeasuring strikes from geologic maps. Lower hemisphere Schmidt plots should be made to summarize the fracture orientation data.

Drilling. During the excitement of discovery and the rush to obtain assays, the drill core is commonly split after a minimal logging effort. Photographing the core *before* splitting could furnish information on the intensity and orientation of the fracturing.

Rock strength testing requires unsplit core. If nine pieces of core with a length of two or three times the core

Checklist for Preliminary Slope Stability Data

MAPS AND SECTIONS

Regional (1: 50,000 or USGS quadrangles)

- Surface topography ☐
- Surface geology
  - Outcrop ☐
  - Interpretation ☐
- Typical geologic cross-sections ☐
- Hydrology
  - Drainage areas and surface flow ☐
  - Ground water
    - Water levels in drill holes and springs ☐
    - Contour map of piezometric surface ☐

Mine Area (1:5000 or 1:10,000)

- Surface topography ☐
- Surface geology
  - Outcrop and drill hole locations ☐
  - Interpretations ☐
- Geologic cross-sections
  - Surface and drill hole data ☐
  - Interpretations ☐
- Ground water
  - Water levels in drill holes and springs ☐
  - Contour map of piezometric surface ☐

Pit (1:1000 or 1:2000)

- Surface topography ☐
- Trial pit plans ☐
- Geology
  - Surface outcrop ☐
  - Surface interpretations ☐
  - Grid cross-sections
    - Drill data ☐
    - Interpretations ☐
  - Radial cross-sections
    - Drill data ☐
    - Interpretations ☐
- Level maps ☐
- Structure contour maps ☐

GRAPHS

- Precipitation ☐
- Water levels in drill holes ☐
- Stream flow ☐
- RQD of drill core ☐
- Natural slope height vs. slope angle ☐

TABLES

- Surface fracture data ☐
- Drill core fracture attitude ☐
- RQD of drill core ☐

SAMPLES

Type samples for each rock type

- Uniaxial compression (2½ core diam long, 6 per rock type) ☐
- Triaxial compression (2½ core diameters long, 6 per rock type) ☐
- Disc tension (½ to 1 core diameter long, 3 per rock type) ☐
- Direct shear (1 core diameter long, 3 per rock type) ☐

PHOTOGRAPHS

- Drill core before splitting ☐
- General views of pit ☐
- Typical outcrops ☐
- Major structure exposures ☐
- Aerial photographs ☐

OPERATING PITS SHOULD ADD THE FOLLOWING:

MAPS AND SECTIONS

Unstable areas (pit scale)

- Topography
  - Before movement ☐
  - After movement ☐
- Plan showing unstable areas ☐
- Tension cracks and displacement vectors ☐
- Geologic cross-sections through slide ☐
- Ground water
  - Surface seepage and water levels in drill holes and blast holes ☐

GRAPHS

- Displacement measurements ☐
- Bench face angle vs. mine coordinates ☐

TABLES

- Displacement measurements ☐
- Bench face angle data ☐
- Blasthole data ☐
- Production data ☐
- Mining Costs ☐
- Stockpile capacities ☐
- Rock strength data ☐

PHOTOGRAPHS

- Unstable slopes ☐

diameter are saved from each 100-m interval, redrilling to obtain samples for strength testing can be avoided.

The drill hole that misses the ore body may be a disappointment for the exploration geologist, but it can be just what the rock mechanics engineer needs since his major concern is obtaining samples of the rock in the pit wall. Rather than throwing away the barren core, it should be saved for logging and sampling for rock strength tests.

Ground water has a significant and sometimes critical effect on slope stability; therefore, drill-hole water levels, lost circulation during drilling, and artesian flows should be recorded. After a hole is finished, the collar pipe should be left in place to establish a piezometer for recording changes in water level over a period of time.

Surface Hydrology. A skillful evaluation of ground water recharge requires that drainage basins be outlined and precipitation records compiled. Surface flows should be measured and the location of springs plotted. These procedures are usually required for the environmental impact statement and can serve a dual purpose by providing input to the stability study.

Operating Pit Instability Calls for Quick Action

Evidence of instability in an operating mine may include cracking, raveling, and in many cases, significant displacement. A rock mechanics specialist called in at this time is under great pressure to suggest remedial action, and he will need all the help he can get to avoid or reduce production delays.

Slide Geometry and Displacement. The geometry of the failure and the nature of the displacement are essential factors in planning strategy to minimize the impact of slope instability. To obtain this needed information, the survey crew can effectively map the boundaries of a failure and construct cross-sections. Surface cracks should be mapped, since they may indicate that a failure is only a small part of a larger impending failure. Survey stakes should be placed at the ends of existing cracks to determine whether the cracks are lengthening or if new cracks are developing.

Simple wire or bar extensometers should be placed across the cracks and displacement pins installed in the unstable area. The movement of these pins is usually well within the range of accuracy obtained from standard surveying equipment, and can be measured by simple resection with a theodolite. Graphs of total displacement and rate of displacement should be plotted, along with precipitation, quantities mined in the area, and flow from any drain holes. All graphs should have the same time scale to assess the influence of different parameters.

Geology. Rock types and geologic structure should be plotted on the surface map and cross-sections to correctly evaluate geologic factors affecting a slide. If a routine mapping program has been maintained, little or no supplemental mapping may be required.

Pit geology maps often contain a wealth of structural information. However, hundreds of dip and strike symbols on a map are confusing, and the classic lower hemisphere Schmidt plot is still one of the best ways to summarize structural data. Comparison of these plots with the slide geometry and displacement vectors will usually define the structural features controlling the failure.

Hydrology. Some indication of ground water levels can be obtained if the exploration drill holes have been maintained as piezometers. Such data is invaluable in assessing the potential for stabilizing slopes by dewatering.

Mine Planning. The potential cost of slope failure should be considered, including costs involved in removing failed material, interruption of mining, increased haulage due to haul road cutoff, and the value of ore covered by a slide. Keep in mind that the objective in mining is the most economic removal of ore, not the creation of stable slopes. It is often possible to mine unstable areas provided a suitable monitoring system is maintained.

In one case, a quantity of ore representing several months' production was exposed beneath an unstable area involving several million tons of material with movement rates of up to 30 mm per day. The mine management's initial approach involved stripping the top of the failure to stabilize it, shifting mining to another area with a higher stripping ratio, and deferring mining of the exposed ore to a salvage operation which would be conducted near the end of the mine's productive life, some ten years off. Following a review of the displacement data and history of the failure (which included an unsuccessful attempt to stabilize the slide by stripping), it was recommended that no stripping be done and the exposed ore be mined until the displacement rate accelerated beyond the rate of 30 mm per day. The suggestion was carried out and 80% of the ore was recovered before unacceptable movement occurred. The result of this failure was a month-and-a-half of high-grade ore production with no stripping, which gave a much better cash flow than the original plan of stripping and deferred mining. □

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James P. Savely, a geotechnical engineer with Pincock, Allen & Holt, has been engaged in slope studies for mines in the US, Canada, Mexico, and Africa. He has also been involved with an in situ fragmentation study for a copper property requiring new data collection methods and development of data analysis techniques. Mr. Savely graduated from South Dakota School of Mines and Technology with a B.S. in geological engineering, and obtained his M.S. degree in that field from the University of Arizona. He is a member of SME-AIME and the International Society of Rock Mechanics.

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