A Progress Report on Stope Optimization

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The optimization of the geometry of stopes and the sequencing of multiple stopes is a longstanding problem that is ready for a thorough treatment with the latest optimization and computer techniques. Initial work in this area was reported last year. Some additional results are reported this year. Proper integration of stope optimization into a mine's planning will result in stopes yielding the highest possible return based on the available exploration data. Previously, stope optimization was performed in a simplified context where stopes were defined using 8-noded solids. This note focuses on advances to be made to the stope optimization algorithm to produce a much more realistic outcome.

Introduction

A stope optimization algorithm has been developed for very simple cases where a stope is defined by 8 vertices, is aligned with the underlying grid, and is unaffected by any neighboring stopes. This optimization program could be of interest to CCG members involved in underground mining since these assumptions are often reasonable; please contact the author or CCG staff for assistance with the current program. The significant advantages of optimization is (1) a trade-off between lost ore and dilution, (2) an ability to account for multiple realizations, (3) repeatable results, and (4) fast sensitivity analysis and adjustment for changing economic conditions. Although the current software is useful, there are a number enhancements that are planned to yield results that more accurately reflect the complexity of underground mining.

The underlying principal of stope optimization remains the same in that a stope providing maximum return based on an economic model is found; however, the database of parameters that are to be considered in producing more representative and accurate results will be significantly larger than with the simple case. Better geometrical modeling techniques will have to be employed for describing stopes and the limitations imposed on them by neighboring stopes, geotechnical insight, and physical characteristics of the mining method.

Current Approach

The current approach to stope optimization considers a simplified 8-noded case. Stopes are defined by the following set of parameters, see Figure 1:

- 8 vertices – the corner points of the stope
- Minimum allowable mining width – this is imposed by characteristics of the mining method such as degree of mechanization and ventilation needs.
- Maximum stope size – results from a geotechnical analysis would reveal the allowable span prior to collapse.
- Minimum allowable dip of the stope – this may be limited by the use of gravity-fed extraction or drilling equipment.

These parameters along with a grade model are read into the program where an expected profit model is generated and an optimal stope found. The economic model is generated using input cost parameters including commodity price, recovery factor, and operating cost. The shape of the stope was altered until an optimal economic return is found.

Optimization is accomplished by randomly varying the positions of the stope corner points in the dip direction. Blocks are determined to be inside the stope based on block centers. Partial blocks are not used. Stope length and height remained unchanged in the optimization process. Width and dip limitations are checked and any attempt that violates input constraints are discarded.

An example of stope optimization for the 8-noded case is provided using a disseminated deposit that is to be mined using sublevel stoping. 51 realizations were made and the expected grade and economic models calculated, see Figure 2. Note that the block model was clipped to be the same width and height as the stope to be optimized. The economic profile involved operating costs of 35 $/tonne and a metal price of 14 $/gram. Ore recovery was set at 85 %.

An initial stope was created with the intention to observe the differences once optimized rather than to create the best stope by hand. The final stope adheres to any input limitations such as mining width and dip, and also accounts for planned dilution. The initial profit was $797,340 whereas the optimized profit was $3,076,649 – an improvement of 286 %. A comparison of the profit and designed dilution is shown in Figure 3.

Framework for a New Stope Optimization Algorithm

The optimization algorithm developed for 8-noded stopes works fast and accurately based on the precision it offers; however, a more complex algorithm is needed to handle a wider variety of stope designs and a more intricate environment. With complexity comes higher computational demand so to keep the optimization process fast, efficient geometric algorithms will need to be employed, especially for clipping the block model inside the stope. Below is a list of requirements for the development of a more realistic and flexible stope optimization algorithm:

1. Incorporation of more geometrical information
    a. Accept any stope design, not just those defined by 8 nodes. Various file formats should be supported as well such as data exchange files (DXF from AutoCAD) and 3D-Studio files.
        i. Stopes may be defined by 3-dimensional rings and tie lines (as in Gemcom), as sets of polygons or other surface meshes.
    b. Optimize stopes in multiple directions, not just in the dip direction. Restrictions on length and height would have to be imposed here otherwise the stope could end up being the size of the entire deposit. However in the case of cut-and-fill stoping for example, this may be desired.
    c. Clip the block model inside the stope using three user-defined levels of precision, see Figure 4:
        i. Least precision, fastest run: block centers and full blocks are used
        ii. More precision, slightly slower: Partial blocks with axis-aligned cuts are used
        iii. Most precision, slowest run: Exact or near-exact intersection of blocks with the stope object are used

2. Account for more geotechnical and mining related considerations
    a. Consider allowable stope size prior to collapse in all directions. It may also be pertinent to consider the hydraulic radius of various open faces for stability purposes, see Figure 5.
    b. If stope size along strike is to be optimized, there may be a minimum allowable pillar size between stopes. This may also be important in the dip direction if multiple stopes exist there.
    c. Support requirements such as cable bolting, which may be a function of stope size. Cost of support should be considered if this is the case.
    d. Depending on the degree of mechanization and ventilation needs, a minimum space requirement for working will be maintained.
    e. If it is possible, additional dilution (over-break) should be modeled or at least estimated.
3. Account for the presence of neighboring stopes and any limitations they may impose on the stope being optimized.
    a. Deviations in dip and/or strike from one stope to the next
    b. Allowable changes in span. Perhaps no abrupt changes in span can be tolerated along dip because of the risk of ore hang-ups in gravity-fed extraction.
    c. Account for any space required for development between stopes such as pillars, extractions cones, and drifts.

Conclusion

The current stope optimization program handles a stope defined by 8 vertices and ensures the solution adheres to minimum and maximum span and overall dip limitations. The stope must also be aligned with the grid in the dip direction, which is also the only direction that vertices are shifted in the optimization process. There are many limitations inherent in this stope optimization algorithm to deal with more realistic situations.

An 8-noded stope may work for some sublevel stoping cases, but will not be applicable to most situations such as vertical crater retreat or any case where more flexibility can be incorporated along strike or dip. A more flexible algorithm is needed to accept variation in stope design observed in underground mining operations. My plans in this area are described.

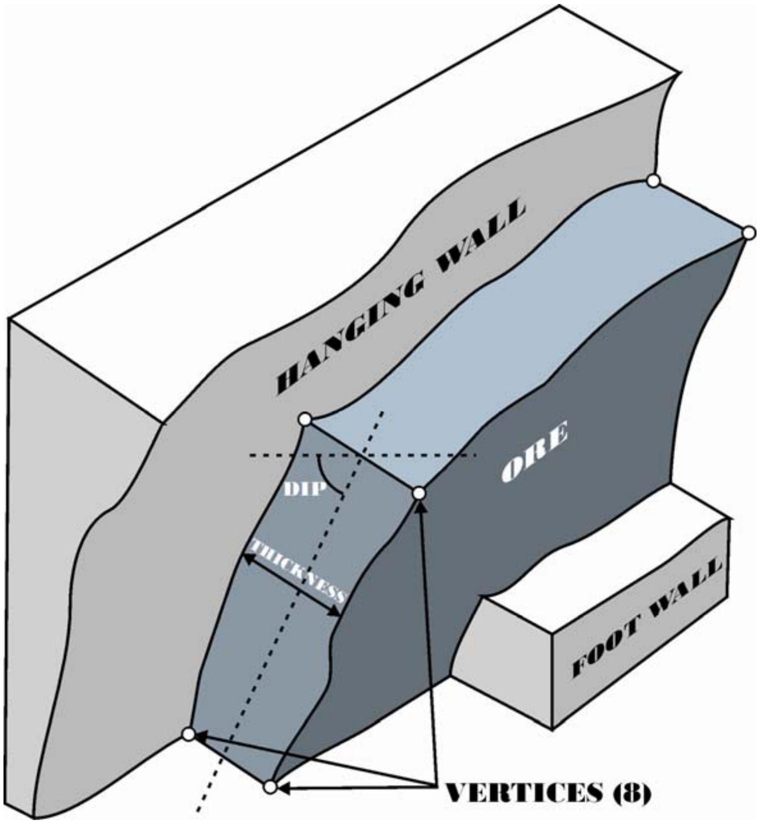

Figure 1: Stope parameters

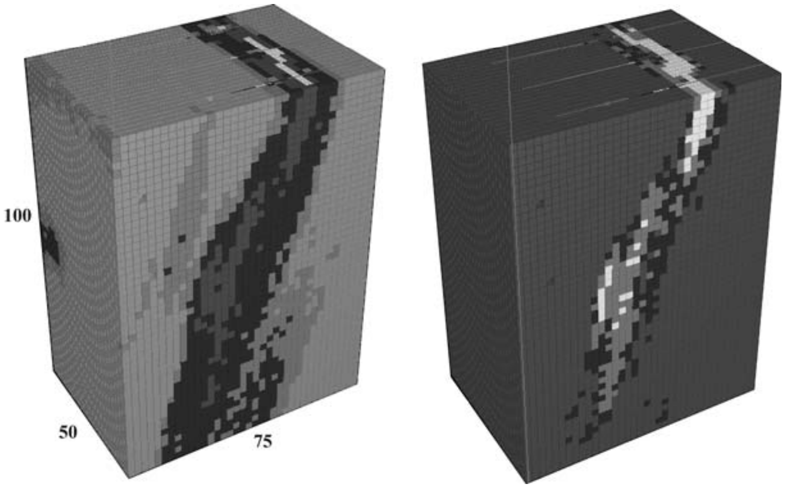

Figure 2: Expected grade model (left) and expected profit model (right) from 51 realizations

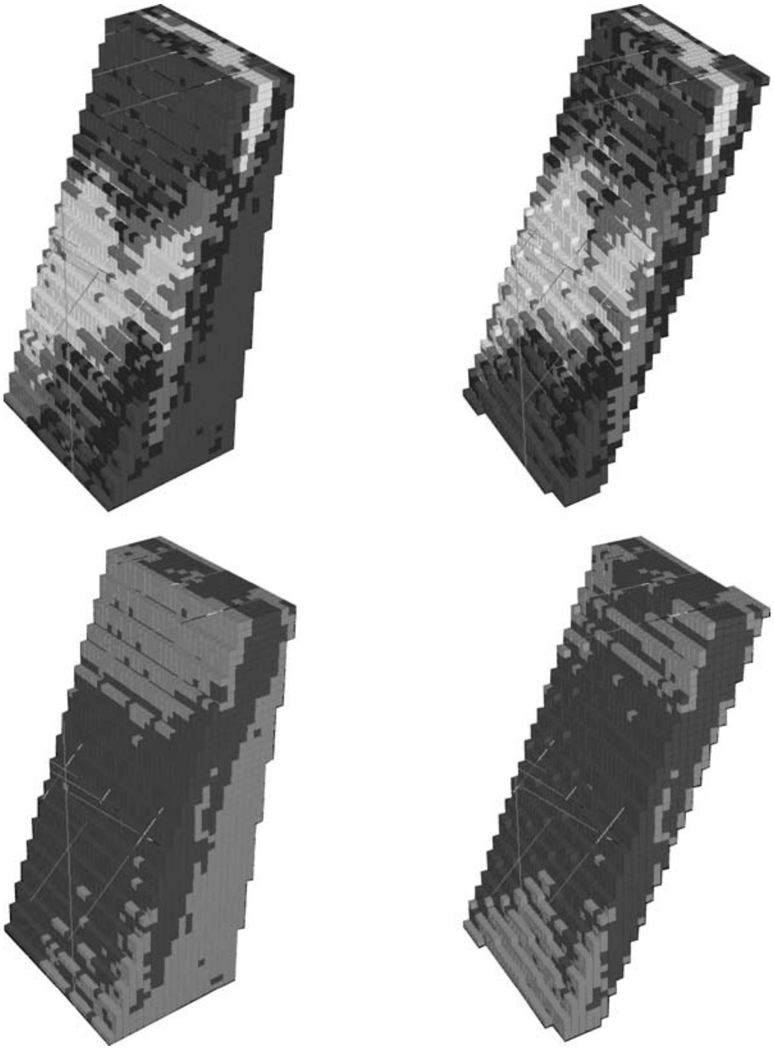

Figure 3: Designed (left) and optimal (right) stopes. Economics (top) and designed dilution (bottom) are shown. Dilution is indicated by material below a cutoff grade of 3.0 g/tonne (light gray).

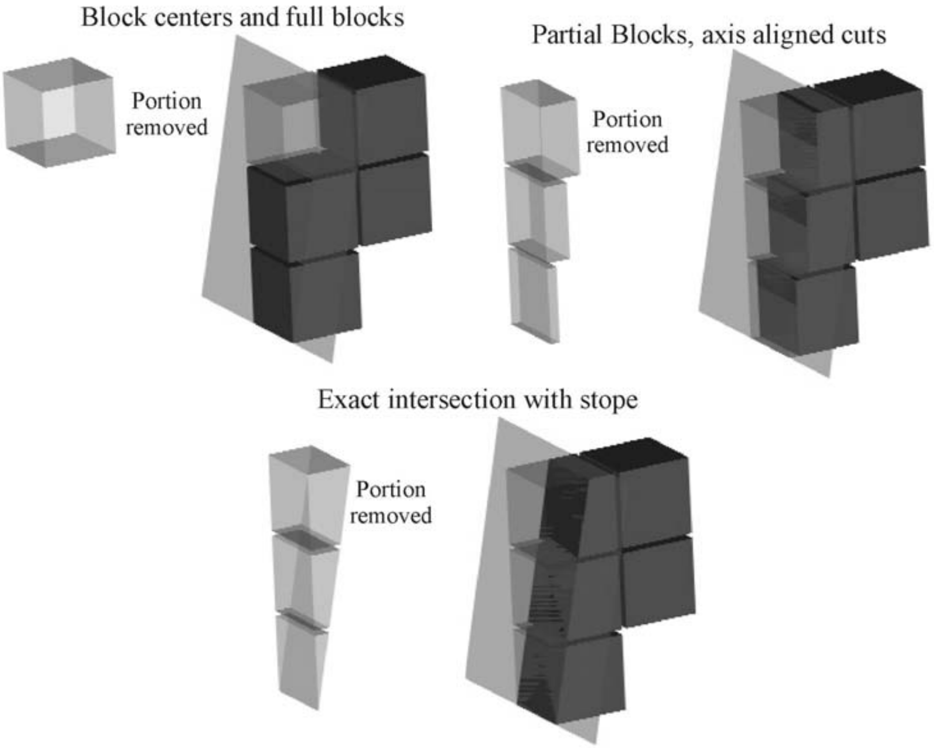

Figure 4: Various accuracy levels for clipping the block model inside the stope.

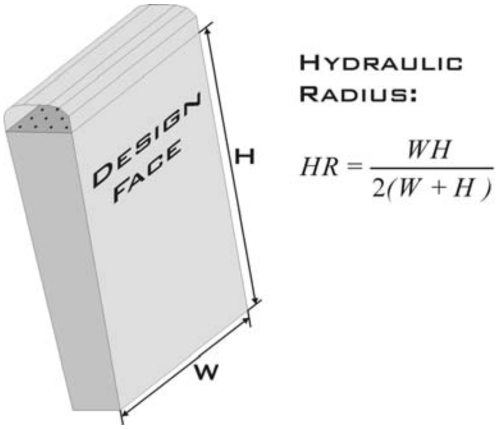

Figure 5: Hydraulic radius of a stope face.