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PROGRAM INFORMATION BULLETIN NO. P09-03

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SUBJECT: General Guidelines for the Use of Numerical Modeling to Evaluate Ground Control Aspects of Proposed Coal Mining Plans

Scope
Coal mine operators, miners and miners' representatives, and Mine Safety and Health Administration (MSHA) enforcement personnel should receive this bulletin.

Purpose
The purpose of this program information bulletin (PIB) is to provide the mining community with general guidelines when utilizing numerical modeling to evaluate ground control aspects of proposed mining plans. Assessing the stability of mined areas and the compatibility of mining plans with existing conditions are essential elements in assuring a safe working environment at a given mine site.

Background
Effective mine design has long been recognized as an essential element in establishing safe and productive mining operations. Over the years, numerous empirical and analytical techniques (e.g. Analysis of Retreat Mining Pillar Stability (ARMPS) and Analysis of Longwall Pillar Stability (ALPS) computer programs) have been developed to analyze pillar stability. These methods can provide a reasonable estimate of pillar strength and stability under specific conditions and relatively simple mining geometries. In practice, however, situations often arise where areas of concern contain

pillar configurations with varying entry and crosscut orientations and widths in addition to differing pillar dimensions. Additional factors such as non-uniform pillar lines, remnant stumps scattered throughout irregularly shaped gobs and multiple seam mining can further complicate an analysis. In such instances, application of empirical and analytical methods to evaluate ground stability is difficult. In order to evaluate mining configurations and sequences not easily treated by simplified empirical or analytical methods, numerical modeling methods (i.e. boundary element, finite element) can be employed.

<u>Information</u>

Simulation Process

The following is an eight-step process developed by MSHA, Technical Support, Roof Control Division for the simulation of underground mining systems[1]. While it is specifically directed to numerical modeling applications, it can also be used in conjunction with empirical or other analytical methods.

1. **Observe Underground Areas** - This is an essential first step in solving ground control problems regardless of the methodology employed. Mine conditions should be categorized in a number of areas where differing pillar sizes, panel configurations and overburden levels are found. A deterioration index rating system, discussed later in this PIB, can aid in the description of in-mine ground conditions.

2. **Estimate Model Parameters** - Coal, rock and gob properties must be established consistent with the requirements of a particular numerical method. Ideally, those properties will be based on coal and rock tests of the specific mine site. In the absence of that data, published properties of adjacent or same seam mines can be used. It should be noted that laboratory values tend to overstate the actual in-situ properties. Consequently, it is appropriate to apply a reduction factor, based upon specimen size, to the laboratory values. As an example: strength reduction factors of 1/5 for 2-inch cubes and 1/4 for 3-inch cubes have been used to estimate in situ coal strength from test data. When no site-related data is available, general coal and mine roof rock properties can be utilized, or the default values offered in the software, can be employed. Regardless of the source of data, it cannot be overemphasized that they represent only a <u>first estimate</u> of mine roof and rock properties that must be validated.

3. **Model Observed Areas** - The third step of the process involves modeling each of the areas observed underground. The properties estimated above are tested

[1] Karabin, G.J., and M. A. Evanto. Experience with the Boundary Element method of Numerical Modeling as a Tool to Resolve Complex Ground Control Problems. Proceedings of the 13th International Conference on Ground Control in Mining, WV Univ., August 1994, pp. 201-213.

under various geometric and overburden conditions to determine their suitability to accurately model observed areas. Successfully modeling many areas under a variety of different conditions increases confidence in the properties used.

4. **Verify Model Accuracy** - This is the most critical step in the entire simulation process. Each of the areas modeled must be closely examined to ensure that the results correlate with observed conditions. If reasonable correlations cannot be made, the model must be recalibrated (material properties adjusted) and the process repeated. It should be noted that relating the output of numerical models (stress, convergence, etc.) to observed conditions (pillar sloughing and roof or floor deterioration) is often difficult given the complexities of the underground environment. The use of a deterioration index rating system, discussed later in this PIB, can simplify the task of verifying model accuracy.

5. **Establish Threshold Limits** - Once the accuracy of the model is verified, threshold limits delineating acceptable and unacceptable mining conditions must be established in order to evaluate the effectiveness of proposed design alternatives. Stress or convergence levels corresponding to deteriorating ground conditions can be identified. Other factors such as the extent of pillar yielding or predicted pillar, roof and floor conditions can also be utilized.

6. **Model New Configurations** - Having established an effective model and a means of evaluating the results of analyses, new mining techniques can be simulated. Generally, several alternatives are modeled under the conditions expected at the mine location where the design will be implemented.

7. **Evaluate New Configurations** - The various alternatives can be evaluated relative to the threshold limits established. For instance, if specific stress and convergence values were found to correspond to deteriorating ground conditions, an alternative that produces levels lower than those values would be desired. However, if none of the configurations evaluated meet the threshold requirement for stable conditions, then new alternatives must be developed and analyzed.

8. **Implement Best Alternative** - Once the best alternative is identified (either meeting the threshold criteria or providing the most favorable conditions), it can be <u>cautiously</u> implemented. The level of confidence in achieving a successful design is directly proportional to the breadth of the evaluation and the degree of correlation noted in the model verification process. In any event, conditions should be closely monitored as the design is implemented, and any deviations from the expected behavior would warrant reassessing the mining plan and recalibration of the model.

Deterioration Indices

As mentioned previously, the most critical phase of the simulation process is verifying the accuracy of a model through correlation with actual underground conditions. To aid in the evaluation of in-mine ground conditions and verification of model accuracy, a set of deterioration indices should be established to quantify pillar, roof and floor behavior. For example, observed in-mine locations could be assigned a numerical rating on a scale of 0 - 5 (0 being the best condition and 5 the most severe) in each of the three categories: pillar, roof and floor. The deterioration index levels should be reasonably well defined to minimize subjectivity of observations and promote consistency in ratings from site to site and from observer to observer.

Guidelines for the Boundary Element Method

While the above simulation process and deterioration indices can be applied to numerical modeling in general, the following topics specifically address the boundary element method (BEM) of numerical modeling for coal mining applications.

Mining Geometry

An essential step when using the boundary element method is creating a model grid that duplicates the in-mine geometry. The seam must be broken into elements of a size that allows the entry, crosscut and pillar dimensions to be accurately reproduced. Seam elements must be small enough to model details of the mine geometry and produce discernable differences in performance, yet large enough to allow broad areas of the mine to be included in the simulation.

As a general rule, setting the element size at one half the entry width has provided acceptable results in most coal mining applications. A 10-ft. element width (for a 20-ft.-wide entry/crosscut configuration) should enable a large area to be modeled and yet provides the stress and convergence detail needed to effectively evaluate conditions. Both larger (1-entry width) and smaller (1/4-entry width) element sizes can be used for specific applications, but are limited in application to scenarios where detail (small elements) or influence area (large elements) are considered critical for the analysis.

A number of other geometric guidelines have been identified that can aid in creating an effective boundary element model:

- To the extent possible, locate model boundaries over solid coal or known stable areas to reduce the likelihood of erroneous loading conditions (transferred stress from adjacent yielded areas not propagating into the zone of interest).

- Orient the model such that the primary areas of interest are positioned away from the model boundaries to minimize end effects.

- Known or potential yielding pillars should not contain linear-elastic elements which could erroneously affect the stress transfer to adjacent areas.

- Known or potential yielding pillars should contain an odd number of elements across the minimum dimension to ensure accurate pillar strength and peak core stress calculations.

- Care should be taken when entries or crosscuts are not oriented at 90° angles to ensure that the effective widths and percent extraction match the actual mine geometry.

Rock Properties

The rock mass properties needed for BEM modeling are minimal since the assumption of a linearly elastic material is inherent and in most BEM models the rock mass is composed of a single unit. Initially, it would appear that treating a complex rock structure in such a simplistic manner would not be appropriate. However, considering that stresses on pillars within the seam are generated through massive main roof loading (generally remaining in elastic compression), it is not unreasonable to expect an effective representation of pillar loading.

One widely used BEM program, LaModel, represents the rock mass as a stack of layers piled atop one another. The layered formulation in LaModel utilizes an additional input parameter, layer thickness, that can be adjusted to allow more flexible and realistic strata behavior. In LaModel, it is important to recognize the effect of layer thickness. Using thin laminations will result in roof which tends to sag readily into the mine openings and load the edges of pillars. As a result, the rock mass is less apt to span across openings or failing pillars and does not transfer load over a long distance.

Coal Properties

Establishing representative coal properties for a BEM analysis is the most critical step in model formulation. Yielding seam capability is needed to accurately simulate the complex underground environment where localized coal failure results in the redistribution and concentration of stress into adjacent areas. The suitability of assigned coal properties can be assessed by comparing the simulation output to observed pillar conditions. Test models should include underground areas (varying depths and pillar sizes) where definite observed pillar behavior can be documented and reflects the differences in depth and pillar size. For instance, if a model with 8-ft.-wide elements predicts corner yielding, significant sloughing and crushing for a length of 8 ft. from the pillar corner should be obvious. A similar condition would be expected along the sides of pillars if perimeter yielding were projected. In general, more observed pillar deterioration than projected by the model suggests that the coal strength has been overestimated and less sloughing than predicted indicates it has been underestimated. There are occasions, however, where the element size itself can contribute to erroneous interpretations. For example, a model using 10-ft. elements may indicate elevated stress at the pillar corners, but no yielding. However, underground observations reveal 4-ft. crushed zones at the pillar corners, suggesting that the model coal strength has been overestimated. Remodeling the area using 4-ft. elements (with corresponding recalculation of element properties) may result in the prediction of corner yielding that would match the in-mine conditions.

When constructing calibration models to verify coal strength, it is essential that:

- the element size selected is appropriate to illustrate phenomena (yielding) observed underground;
- element properties are recalculated when element sizes are changed, as smaller elements have lower strength values than larger ones because of their proximity to the free face.

Gob Properties

When numerical models contain large mined areas such as longwall or pillar line gobs, some mechanism must be employed to simulate caving and stress relief associated with those areas. Without it, the full weight of the overburden would be transferred to adjacent areas and result in a significant overestimation of abutment loads. The stress redistribution process is complex and is comprised of caving, bulking and subsequent compaction of the gob material. As with other material properties, the suitability of the gob material properties that essentially treat the gob as a backfill must be verified. The use of a gob material that is too stiff will result in excessive gob loading and reduced abutment loads. Conversely, a gob material that is too soft will generate excessive abutment loads and low-gob stress. The modulus of elasticity of the rock mass and other geometric parameters (panel width, lamination thickness, etc.) can have a significant impact on gob backfill loading and must be considered. Examining gob backfill stress can indicate the amount of stress redistribution simulated by the model and can be compared to known or anticipated cave heights associated with those areas.

Summary

Successful numerical simulation requires a substantial effort including the observation of in-mine conditions in many areas and the often repetitive process of calibrating model parameters. The use of techniques such as a deterioration index can facilitate the linking of observed and simulated mine conditions. It cannot be over-emphasized, however, that in order to be of value, a numerical model must be validated and provide a realistic representation of the underground environment for which it is applied.

Authority
The Federal Mine Safety and Health Act of 1977, as amended, 30 U.S.C. § 801 et seq.; 30 C.F.R. §75.203.

Internet Availability
This PIB may be viewed on the Internet by accessing the MSHA home page at http://www.msha.gov "Compliance Info" and "Program Information Bulletins."

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