Introducing the New Windows ARMPS–LAM Program

Christopher Newman, Ph.D. Student
Zach Agioutantis, Professor of Mining Engineering
Department of Mining Engineering
University of Kentucky
Lexington, KY

Keith Heasley, Professor of Mining Engineering
Department of Mining Engineering
West Virginia University
Morgantown, WV

ABSTRACT

Previously, in 2013, a laboratory version of the computer code ARMPS-LAM, introduced at the 32nd International Conference of Ground Control in Mining, successfully integrated the laminated overburden model of LaModel into an ARMPS-style pillar stability analysis. The ARMPS-LAM analysis has now been fully integrated into the ARMPS program allowing users to more accurately classify the stability of a given mine design utilizing a laminated overburden model for the determination of pillar loading within the AMZ.

This paper introduces the new Windows-based ARMPS-LAM program. The program's ease of use, output result generation, and limitations are highlighted through the parametric analysis of three hypothetical case studies where traditional ARMPS output is compared to output generated by LaModel. As mining operations continue to produce at greater depths and in more complex geometric and geological conditions, flexible and efficient analyses of mine stability for underground room and pillar mining has become more and more essential. The ARMPS-LAM program provides the mining industry with an empirically backed, numerical design tool for the evaluation of underground room and pillar mine plans.

INTRODUCTION

In the Southern Appalachian coal fields of the United States, retreat room-and-pillar methods have allowed mining operations to maintain high rates of production in the face of adverse geologic conditions and shrinking coal reserves. Over the years, research has been dedicated to understanding and mitigating mining-related dangers due to second mining practices, such as: pillar squeezes, floor heave, roof falls, pillar bumps, etc. However, as mining operations continue at deeper depths and with more complex geometric and geologic conditions, there is an inherent industry need for more accurate, flexible, and faster evaluations of stability for underground room-and-pillar mining.

The original, laboratory-oriented, computer code, referred to as the ARMPS-LAM program was first introduced in 2013 and successfully utilized the laminated overburden of LaModel (LAM) for the generation of an Analysis of Retreat Mining Pillar Stability (ARMPS) style analysis (Zhang and Heasley, 2013). Using the basic geometric inputs and empirically derived parameters for defining the mine plan and loading conditions as in ARMPS, the ARMPS-LAM computer code allowed one to conduct a LaModel analysis for the determination of pillar stability factors within the Active Mining Zone (AMZ), barrier pillar stability factors, as well as other loading and strength data (Zhang et al., 2014). Previous research compared the accuracy of the ARMPS-LAM program and the accuracy of the ARMPS 2010 program through an analysis of the stability factor calculations for each of the 645 case histories within the NIOSH ARMPS database. Results indicated that the new ARMPS-LAM code had a slightly better classification accuracy of 71% when including the AMZ stability factor, barrier pillar stability factor, seam thickness and depth in the analysis compared to a 63% classification accuracy provided by ARMPS when only using the AMZ stability factor (Zhang and Heasley, 2013).

This paper introduces the new Windows-based ARMPS-LAM program. Windows ARMPS-LAM will convert any ARMPS mine plan into a LaModel input file, execute a custom LaModel calculation and display stability results next to the traditional ARMPS 2010 results. This paper showcases its capabilities through a parametric analysis of three hypothetical case studies that highlight the ease of operation, the generation of output results, and the current limitations of ARMPS-LAM. With ARMPS-LAM, mining operators and consultants have been provided with an empirically backed, numerical design tool for investigating and optimizing pillar plans and mine layouts with respect to the overall safety and stability of underground works.

ARMPS BACKGROUND

Since its release in the mid-1990s, the Analysis of Retreat Mining Pillar Stability (ARMPS) program has been widely used by mining engineers in the United States for the evaluation of the stability of room-and-pillar retreat mining layouts. The true strength of the program lies in its statistical calibration against a database of 645 case histories (Mark, et al., 2011). The aim of the ARMPS program is to prevent pillar squeezes, collapses, and/or bumps by designing an appropriate stability factor for the Active Mining Zone (AMZ). The stability factor calculation is accomplished by utilizing basic geometric input parameters such as mining height, depth of cover, and pillar dimensions for calculating the load bearing capacity of the AMZ pillar system and the total applied load, as determined by tributary area and abutment loading. The calculated AMZ pillar stability factor is then compared to a large database of successful and unsuccessful case studies in order to statistically determine the potential success of the chosen mine design.

In 2010, following the Crandall Canyon disaster, the ARMPS load transfer mechanism was revised and a pressure arch factor was included in addition to the tributary area and abutment angle loading (Mark, 2010). Based on the latest statistical analysis of the ARMPS database, the 2010 design criteria simply requires a minimum ARMPS stability factor for the AMZ of 1.5 for depths less than 650 ft, but requires both a minimum ARMPS stability factor for the AMZ of 1.5 and a minimum barrier pillar stability factor of 1.5 for depths greater than 650 ft (Mark, 2010). Using this design criterion to evaluate the case history database, ARMPS 2010 is able to correctly classify 82% of the failed case histories and 59% of the successful case histories for an overall classification accuracy of 63% (Zhang and Heasley, 2013).

BACKGROUND OF ARMPS-LAM

As discussed by Zhang and Heasley (2013), a computer code was developed, successfully implementing the laminated overburden model, or LaModel, into an ARMPS style of analysis. The initial research code was designed with two capabilities: a) to be run in a batch mode for analyzing multiple case studies (i.e. the ARMPS database) or b) to be invoked by an interactive wrapper program to run a specific case study. As presented in this paper, the production version of ARMPS-LAM for Windows has been created based on the latest version of the ARMPS program. Basically, the capabilities of ARMPS 2010 have been extended by adding the necessary functionality to call the LaModel code in the background and perform a full LaModel numerical analysis of a given case study alongside the traditional ARMPS 2010 calculations. This fully functioning Microsoft Windows-based program is ready to be released to the general public.

As shown in Figure 1, the ARMPS-LAM input parameter forms are very similar to that of ARMPS 2010, allowing users to define their mining layout with respect to geometric parameters such as mining height, panel depth, center-to-center pillar dimensions, etc. as well as the various loading conditions: development, active gob, one-side gob, and two-side gob. However, at the bottom of the main input parameter form, a new, "Overburden Model," input parameter has been defined allowing users to select between the traditional ARMPS 2010 analysis or an ARMPS analysis utilizing the laminated overburden model as well as a means of calculating and comparing both model outputs within a single run.

Upon user completion of the input parameter forms, if a laminated overburden analysis is desired, the LaModel part of the ARMPS-LAM code is invoked. The code initially calibrates the overburden, coal, and gob material properties using the deep-cover calibration method (Heasley, et al., 2010). Then, utilizing a series of new algorithms and formulas (Zhang and Heasley, 2013), ARMPS -LAM automatically replicates the user-defined geometric and loading conditions into a fully functional LaModel3.0 input file (*.inp) containing boundary conditions, element sizing, yield zone materials, etc. A comparison of sample geometric mine plans between ARMPS 2010 and ARMPS-LAM is provided in Figure 2.

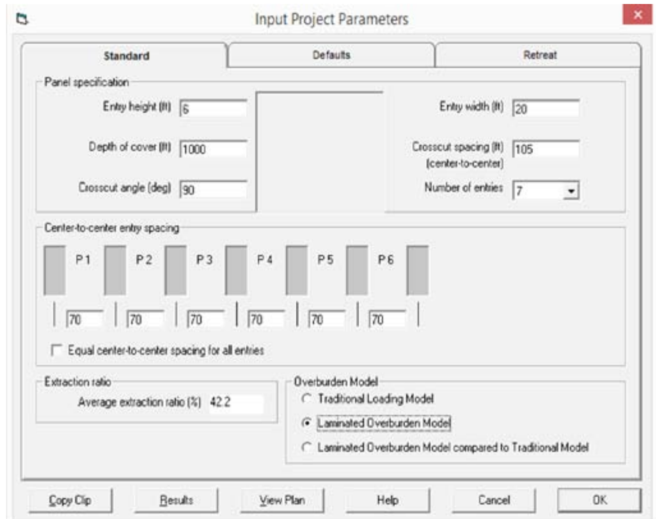

Figure 1. ARMPS-LAM input parameter form.

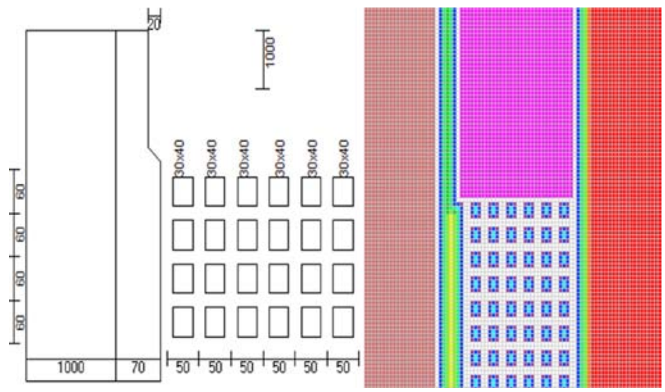

Figure 2. Mine Plan Generation (a) ARMPS (b) LaModel.

With the LaModel input file developed, the numerical module of ARMPS-LAM solves the fundamental differential equations of the laminated overburden model producing a classic LaModel output file (*.f1) for the given mining scenario. The ARMPS-LAM post-processing module then extracts data from this output file and calculates the stability factor of the AMZ and barrier pillars. Finally, ARMPS-LAM reports the model output information to the user in a fashion similar to that seen in ARMPS 2010 (Figure 3).

As previously discussed, based on the value of the user-defined Overburden Model input parameter, ARMPS-LAM can generate analysis results for the traditional loading model of ARMPS, the laminated overburden model of LaModel, or a comparison of results generated by both overburden models.

Initial testing of the laboratory version of the ARMPS-LAM code found that the program allowed for the accurate classification of 82% of the failed case histories within the ARMPS databases and 69% of the successful case histories for an overall classification accuracy of 71% (Zhang and Heasley, 2013). Both programs utilize the Mark-Bieniawski pillar strength formula for determining pillar strength as well as a 21-degree abutment angle for the calculation of the magnitude of the abutment loading; however, ARMPS-LAM utilizes the laminated overburden model and the relative

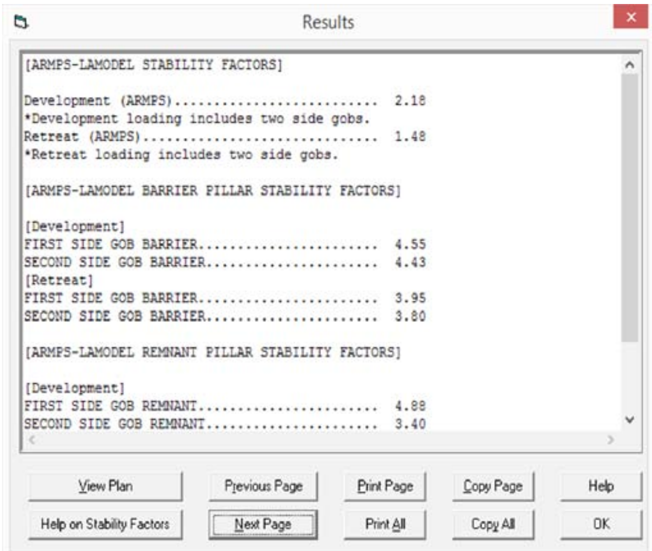

Figure 3. ARMPS-LAM results form.

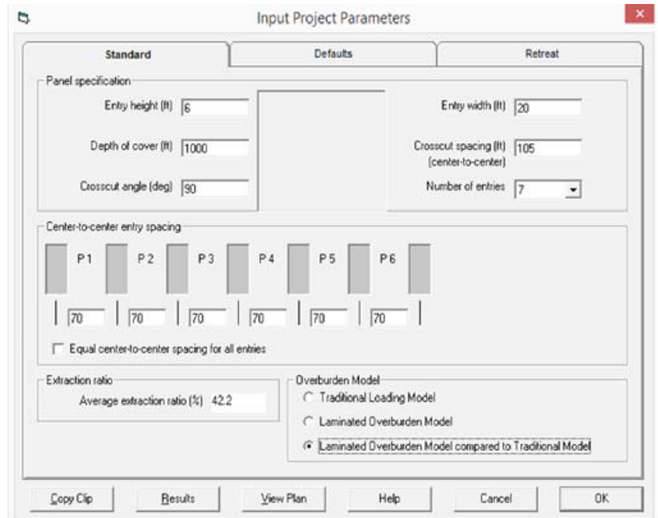

Figure 4. Case 1 ARMPS-LAM input parameter form.

stiffness of the pillars and gob to distribute the overburden load to the AMZ, gob and surrounding pillars. In the previous research, linear regression analyses indicate that stability factors calculated by ARMPS-LAM are, on average, 8% higher than that of ARMPS. Further analysis showed that the difference in the stability factors between ARMPS and ARMPS-LAM was strongly correlated to the overburden depth. In particular, it was found that ARMPS-LAM typically provided larger AMZ stability factors than ARMPS for low cover (<1000 ft) scenarios and lower AMZ stability factors than ARMPS for high cover (>1000 ft) scenarios (Zhang, et al., 2014).

CASE STUDIES

The following three hypothetical case studies have been developed to provide users with an overall understanding of ARMPS-LAM operations while highlighting the capabilities and limitations of the program with respect to a traditional ARMPS analysis. These models have been developed for investigating the stability factor of the AMZ with respect to both shallow cover (<1000 ft) and deep cover (>1000 ft) scenarios. Each case study has been developed using program-defined, default input parameters for the insitu coal strength (900 psi), density of overburden material (162 pcf), width of AMZ, and the ARMPS pressure arch factor. The ARMPS-LAM lamination thickness and the final gob modulus are automatically set by LaModel code executed by ARMPS-LAM. By varying the depth of cover within each case study, further comparisons could be made between the stability factor results of ARMPS-LAM and that of ARMPS 2010.

In Case 1, a seven entry room-and-pillar panel has been defined with pillars on 70-foot entry and 105-foot crosscut spacing (center-to-center), at a depth of 1000 feet, and an excavation thickness of 6 feet (See Figure 4). On retreat, Loading Condition 4 (one active section and two side gobs) was selected with a 1000-foot extent of active gob, 1000-foot extent of side gob 150-foot barrier pillars, and a 35-foot slab cut defined for both the first and second side gobs. From the results shown in Figure 5, the stability factor for the AMZ was 2.18 on development and 1.48 on retreat as determined by ARMPS-LAM. These results are compared to 2.38 on development and 1.50 on retreat as determined by ARMPS 2010.

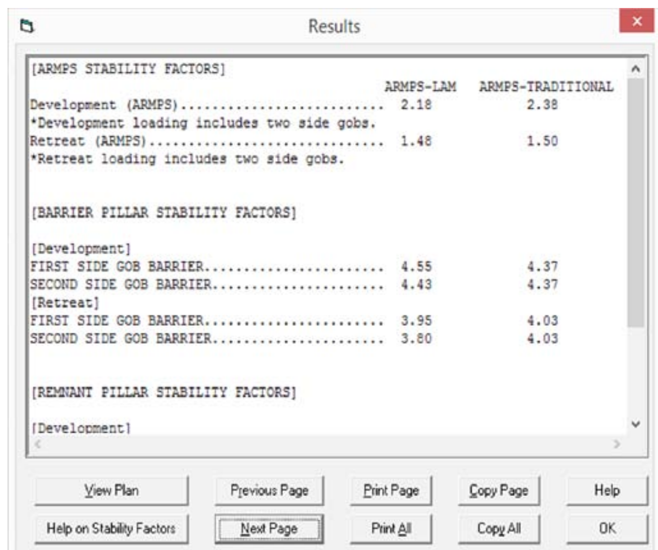

Figure 5. Case 1 ARMPS-LAM vs ARMPS analysis results.

In further comparing the ARMPS-LAM and ARMPS results for Case 1, the graphing function within the program was used to evaluate development and retreat stability factors with varying depths of cover (see Figure 6). From this graph, one finds that as depth increases, deep cover (>1000 ft) results determined by ARMPS-LAM are, on average, 10.5% less within the AMZ on development and 3% less within the AMZ on retreat. As depth decreases, shallow cover (<1000 ft) results determined by ARMPS-LAM are, on average, 7.2% higher within the AMZ on development and 11.4% higher within the AMZ on retreat. These results confirm the conclusions previously made by Zhang (2013).

In Case 2, a seven entry room-and-pillar panel has been defined on pillars with 50-foot entry and 60-foot crosscut spacing (center-to-center), at a depth of 400 feet and an excavation thickness of 6 feet (See Figure 7). On retreat, Loading Condition 3 (one active section and one side gob) was selected with a 1000-foot extent of active gob and a 1000-foot extent of side gob, 70-foot barrier

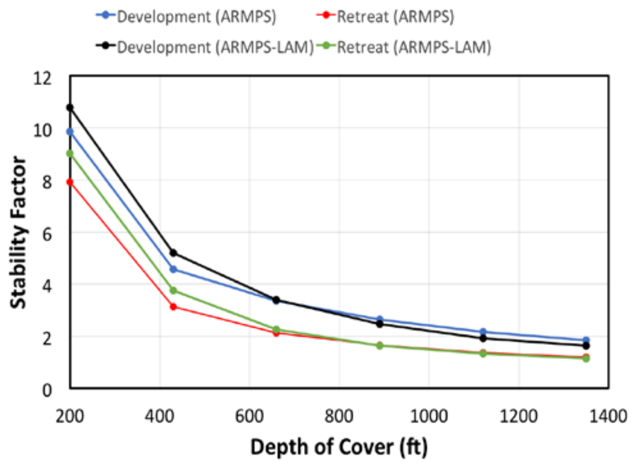

Figure 6. Case 1 Stability factors vs depth of cover for ARMPS-LAM and ARMPS.

pillar, along with a 20-foot slab cut. From the results shown in Figure 8, the stability factor of the AMZ as determined by ARMPS-LAM was 2.87 on development and 1.94 on retreat, as compared to the stability factors determined by ARMPS 2010 of 2.21 on development and 1.50 on retreat.

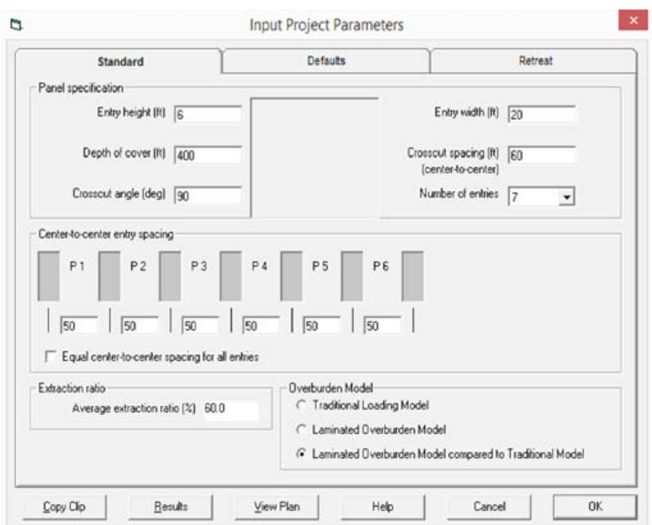

Figure 7. Case 2 ARMPS-LAM input parameter form.

In further comparing the ARMPS-LAM and ARMPS 2010 results for Case 2, the graphing function within the program was used to evaluate the development and retreat stability factors with varying depths of cover (see Figure 9). From this graph, one finds consistent differences between the results of ARMPS-LAM and ARMPS 2010 in both shallow and deep cover scenarios as ARMPS-LAM produces, on average, a 23.7% higher stability factors within the AMZ on development and 30.8% higher stability factor within the AMZ on retreat as compared to ARMPS 2010 for the overburden depth range shown.

In Case 3, a five entry room-and-pillar panel has been defined with pillars on 60-foot entry and 70-foot crosscut spacing (center-to-center) at an angle of 60degrees, with a depth of 1500

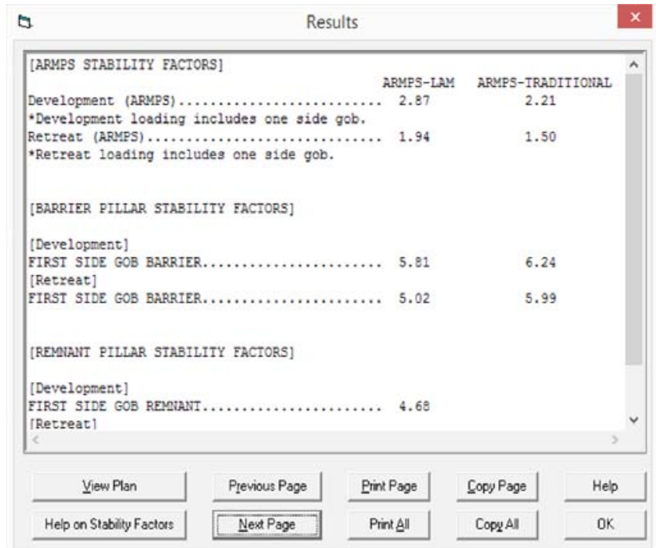

Figure 8. Case 2 ARMPS-LAM vs ARMPS analysis results.

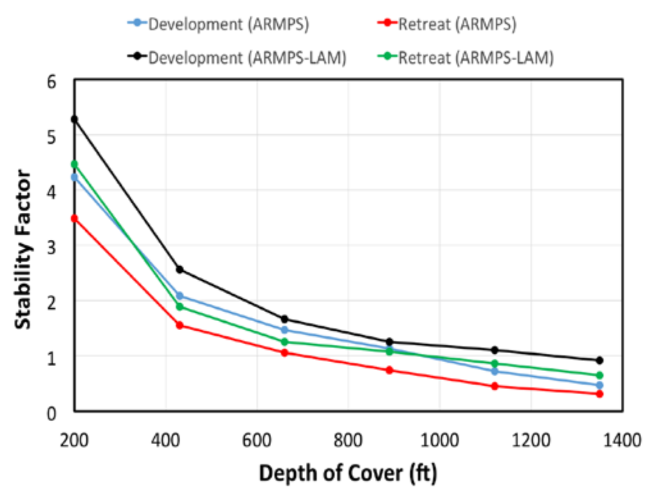

Figure 9. Case 2 Stability factors vs depth of cover for ARMPS-LAM and ARMPS.

feet, and an excavation thickness of 5 feet (See Figure 10). On retreat, Loading Condition 3 (one active section and one side gob) was selected with a 1000-foot extent of active gob, a 180-foot extent of side gob, and a 90-foot barrier pillar. From the results shown in Figure 11, the stability factor for the AMZ was 1.16 on development and 1.07 on retreat as determined by ARMPS-LAM. These results are compared to 1.61 on development and 1.31 on retreat as determined by ARMPS 2010.

In further comparing the Case 3 results of ARMPS-LAM versus those of ARMPS 2010, the graphing function within the program was used to evaluate development and retreat stability factors with varying depths of cover (see Figure 12). From the graph, one finds that in both shallow and deep cover scenarios ARMPS-LAM calculates, on average, a 29% lower stability factor within the AMZ on development and a 21.5% lower stability factor within the AMZ on retreat as compared to ARMPS 2010 for the overburden depth range shown.

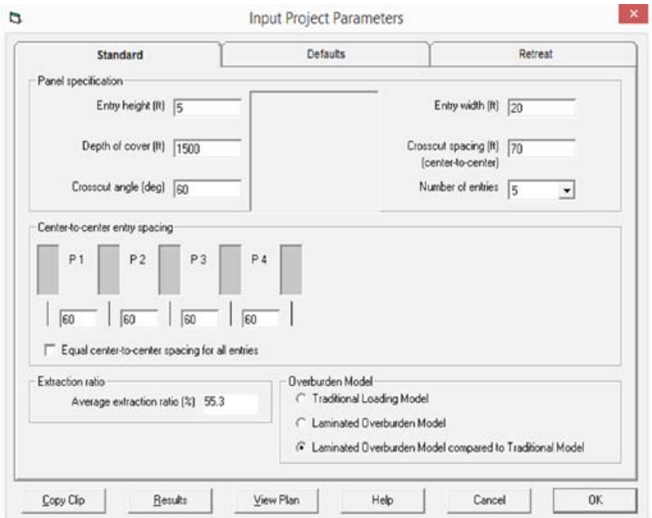

Figure 10. Case 3 ARMPS-LAM input parameter form.

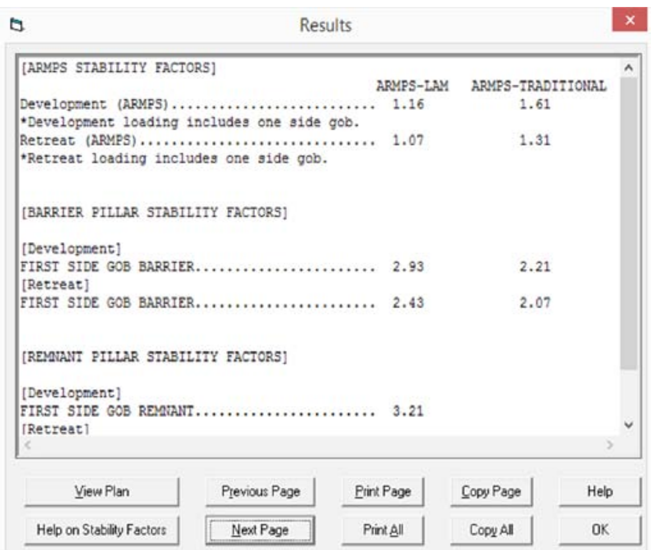

Figure 11. Case 3 ARMPS-LAM vs ARMPS analysis results.

SUMMARY AND CONCLUSIONS

This paper introduces the new Windows-based ARMPS-LAM program, which functionally implements an additional laminated overburden loading model into the ARMPS 2010 program. In previous research (Zhang and Heasley, 2013), it was determined that the present version of the laminated overburden model more accurately classifies the ARMPS database in comparison to ARMPS 2010 (71% versus 63% respectively). From the hypothetical case studies presented in this paper, the ARMPS-LAM program sometimes calculates an AMZ stability factor higher or lower than that determined by ARMPS. While work done by Zhang (2013) indicated that the ARMPS-LAM provided higher stability factors for shallow cover and lower stability factors in deep cover, these hypothetical case studies indicate that differences between stability factors may also be a function of other parameters than depth.

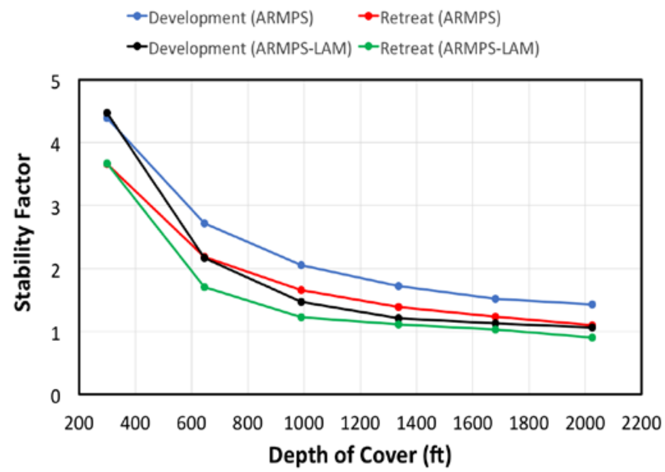

Figure 12. Case 3 stability factors vs depth of cover for ARMPS-LAM and ARMPS.

Currently, the laminated overburden model is not seen to offer any significant advantages over ARMPS 2010. However, present research is being done to investigate the functional differences between the two loading mechanisms in order to more fully understand the disparities and to determine how the laminated overburden model accuracy can be improved. The laminated overburden implemented in ARMPS-LAM provides significant opportunities for the incorporation of improved models for overburden flexibility, gob loading, and pillar behavior. In particular, the improved abutment angle loading suggested by Tulu and Heasley (2012) could be implemented into the program and/or the more accurate strain-softening pillar behavior as suggested by Li and Heasley (2014) could be used. In the future, the plan is to implement these improved models with the goal of increasing the accuracy of ARMPS-LAM and improving retreat mining pillar design in the process.

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