**ALPHA FOUNDATION FOR THE IMPROVEMENT OF MINE SAFETY AND HEALTH**

# Final Technical Report

**Project Title:** Enhanced Ground Control Assessment for Improving Safety in Mine Design
**Grant Number:** AFC 215-13
**Organization:** University of Kentucky Research Foundation
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# 1.0 Executive Summary

Over the last 20 years, NIOSH has developed and validated a number of software tools addressing safe coal mine design with respect to ground control. These tools are available free of charge to the mining industry to help design safer mining environments with respect to pillar stability in longwall and room and pillar mines, formation characterization, support requirements, etc. More specifically, these tools are available as stand-alone PC based software packages (Windows) and complement each other with the ultimate goal of achieving a safer mine design. Mine design, especially with respect to ground control, is a complex procedure, may require multiple iterations and may have to be modified for different panels within the same mine. As cloud computing gains momentum, there is a definite need to develop internet-based applications for mine design that would be easily accessible by mine personnel at all times, even underground where permitted. Mining industry professionals deserve to have up-to-date tools for safer mine design.

webGroundControl provides the mining industry with a web-platform from which one is able to access ground control design programs as well as previous analyses through a web browser. Due to current industry utilization of NIOSH ground control software packages, webGroundControl was developed as an online web-platform providing users with access to existing NIOSH ground control applications (ARBS, ALPS, ARMPS, ARMPS-HWM and AHSM). Each mine design application not only allows users to easily access and input site-specific input parameters, but also provided multiple output options such as scenario results (HTML and PDF formats), parametric analyses, as well as a scenario plan view of user defined geometries. Furthermore, webGroundControl has been structured such that it can be easily expanded for future inclusion of additional mine design applications. Additionally, webGroundControl allows users to store maps, pictures, and other supporting information pertaining to a specific design defined within the platform. Similarly, to aid in project collaborations as well as maintaining transparency, webGroundControl allows for Project sharing between users with full editing rights or “read-only” access. webGroundControl is available with respect to both free public and private (corporate) licenses.

webGroundControl allows for faster and easier access to existing mine designs, in field calculations (if needed), and instant online collaboration between planning personnel and operations engineers. The shared webGroundControl platform allows for more transparent calculations and analyses in cases of variable conditions as well as the easy recognition of problematic areas under a specific design scenario. Due to the potential impact to underground safety, industry professionals have embraced webGroundControl as a means of directly and quickly accessing and sharing design analyses and is seen as a new paradigm for mining engineering computer applications. Furthermore, it is expected that new needs will emerge within the industry resulting in further populating the web platform with additional applications and tools for mine design.

# 2.0 Problem Statement and Objective

The webGroundControl project directly relates to the Focus Area of "Health and Safety Interventions" and the sub area of "Ground Control" as outlined in the call for proposals. For organizational purposes, this major heading has been divided into two separate subheadings; Statement of Problem and Objectives.

## 2.1 Statement of Problem

Over the last 20 years, NIOSH has developed and validated a number of software tools addressing safe coal mine design with respect to ground control. These tools are available free of charge to the mining industry to help design safer mining environments with respect to pillar stability in longwall and room and pillar mines, formation characterization, support requirements, etc. More specifically, these tools are available as stand-alone PC based software packages (for the Windows environment) and complement each other with the ultimate goal of achieving a safer mine design. The ground control software available by NIOSH are heavily utilized by the industry both during planning of underground coal operations as well as during operations, e.g., when conditions change. NIOSH offers training courses on this material and many mining college programs have incorporated instruction on a number of these tools into their curriculum.

Due to the increase in design intricacies as mining operations continue to develop reserves at deeper depths and in more complex geologic and geometric conditions, there has been an industry and regulatory demand for mine designs to better replicate site-specific conditions for the evaluation of support performance, pillar stability, stress conditions, etc. with respect to ground control. Mining personnel are provided with a suite of ground control design programs for the evaluation of underground coal mines which has been developed, validated, and are distributed (free of charge) by the National Institute of Occupational Safety and Health (NIOSH). These NIOSH programs, for example Analysis of Roof Bolt Stability (ARBS), Analysis of Longwall Pillar Stability (ALPS), Analysis of Retreat Mining Stability (ARMPS), Analysis of Retreat Mining Stability – Highwall Mining (ARMPS-HWM), Analysis of Horizontal Stress in Mining (AHSM), etc., have become instrumental in obtaining mine plan approvals from United States federal and state authorities for underground longwall, room-and-pillar, multiple-seam and surface highwall mining operations (MSHA, 2013; Skiles and Stricklen, 2008).

ARBS (Analysis of Roof Bolt Stability) provides users with a means of evaluating the performance of a given roof bolt system with respect to the depth of cover (stress), intersection span, roof condition and quality, bolt/cable location, geometries and strength, etc. In utilizing this program, one is able to quickly compare the effectiveness of the given roof bolt system against an extensive and verified case history database. ALPS (Analysis of Longwall Pillar Stability) estimates the applied loading conditions and evaluates the stability of the longwall pillar system with respect to the development and extraction of a longwall panels. ALPS analyses the longwall pillar system with respect to mining depth and geometries as well as the condition of the roof and further compares calculations results against a database containing 100 case histories. ARMPS (Analysis of Retreat Mining Stability) aids mine operators and planning personnel in the sizing of pillars for development and retreat mining operations. ARMPS has become the most widely used pillar design methodology in the United States coalfields and has resulted in a dramatic reduction in the number of pillar squeezes, collapse, and bumps during the development and retreat

phases of single seam underground coal mining operations (Mark and Gauna, 2017). The ARMPS program estimates pillar loading and stability with respect to mining depth and geometries and compares stability calculation results against a large (> 600) case history database (Mark, 2015). ARMPS-HWM (Analysis of Retreat Mining Stability – Highwall Mining) evaluates the stability of both web and barrier pillars with respect to highwall geometries in a similar manner to the ARMPS program previously discussed. AHSM (Analysis of Horizontal Stress in Mining) estimates horizontal stress magnitudes and evaluates mine panel layout and mining direction with respect to underground stress orientations (NIOSH, 2005).

While the NIOSH suite of ground control design programs provide the mining industry with a reliable means of evaluating underground stability, their "stand alone" or "single-tier" architecture often becomes a hindrance when updating design parameters with respect to new site-specific conditions observed or measured in the field. Similarly, the inherent limitations of the single-tier architecture, as described in Newman, et al., (2017), are further compounded when collaborating with multiple mine design personnel as files are emailed back-and-forth without a reliable mechanism of documenting user changes and versions. Currently, these programs require an individual or workgroup computer equipped with a Microsoft Windows operating system on which all program data resides. Recently, taking advantage of web-based computing technologies, a new online platform has been developed for mine design applications called webGroundControl (webGC). Through the adoption of a multiple-tier architecture, webGC provides multiple users on-demand access to ground control mine design applications across multiple devices and operating systems (OS) by means of an internet connection (Figure 1).

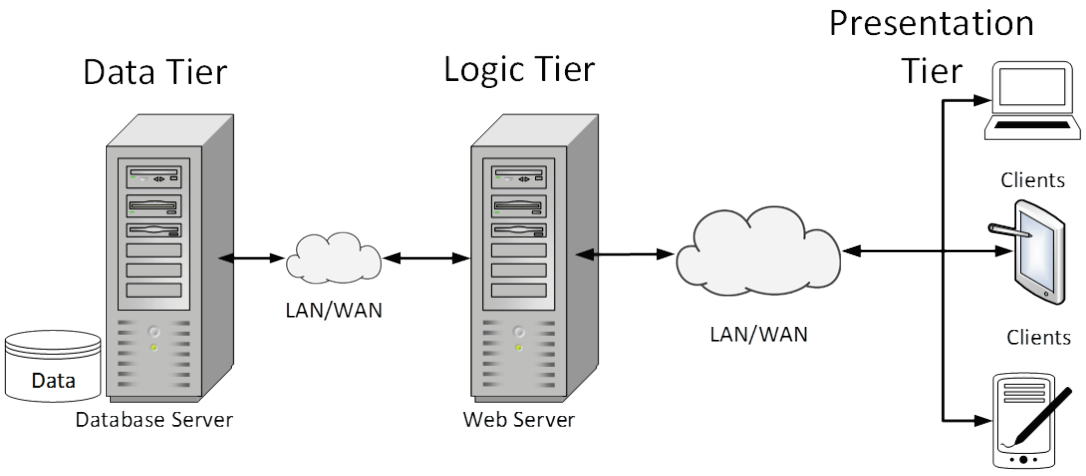



**Figure 1: Multiple-tier architecture as implemented by the webGroundControl platform**

webGroundControl is directly related to the focus area of "Health and Safety Interventions" and the subcategory of "Ground Control" as outlined by the call for proposals. With the expansion of Internet connectivity on the surface and underground, webGC will provide users with the means of performing on-demand design calculations in the field with respect to varying site-specific underground mining conditions, observations, and measurements as well as facilitate online collaboration between mine operations and planning personnel.

Furthermore, webGroundControl has been developed to further enhance the design methodology by not only incorporating a suite of ground control related mine design applications, but also allowing for comprehensive mine planning. Here users are not only able to calculate pillar stability, loading, and strength with respect to their design, but are also able to easily collaborate with other users on the same project as well as the ability to upload design pertinent information (mapping, core logs, photographs, etc.) to everyone involved in the mine design process. Additionally, state-of-the-art charting and graphical interfaces enhance engineering design decisions and allow for better mine plan solutions fulfilling the overall goal of the Alpha Foundation of developing, "Better engineering of mining systems for improved safety."

## 2.2 Objectives

The overarching objective of this research project was the development of a web platform (webGroundControl) providing users with instantaneous access to design plans and analyses through a web browser. Due to the complexity and difficulty in the development of the web platform as well as updating current mine design software for deployment in a web environment, the project has been broken down into a series of manageable objectives detailed below.

1. *Development of a server-side module for a new web-based software product (webGroundControl)*. This module "runs" either on a stand-alone PC or on a server computer. The server-side module is responsible for user authentication, managing the data, performing the calculations and generating results. In addition, this module is responsible for maintaining the integrity of the database storing the data. Prior to development, existing tools were analyzed and an optimum approach to the development of the web platform was designated. Public domain tools were used where appropriate so that no licensing fees will be associated with the distribution of this product.
2. *Development of a front-end web brwser module.* This module "runs" on standard web browsers and communicates with the server-side module via an internet connection. webGroundControl includes the following web-based applications: Analysis of Roof Bolt Systems (ARBS), Analysis of Longwall Pillar Stability (ALPS), Analysis of Retreat Mining Pillar Stability (ARMPS), Analysis of Retreat Mining Stability – Highwall Mining (ARMPS-HWM), and Analysis of Horizontal Stress in Mining (AHSM). These applications, as well as future applications, will be available to users under the umbrella of webGroundControl given the appropriate user authentication. The users have access to any previous projects run under that application and archived in the database. The web browser module is installed along with the server-side module in the "server" computer and comprises the front-end of webGroundControl. Prior to development, existing cloud computing tools were analyzed and an optimum approach for designing the web platform was selected and implemented.
3. *Generation of web-based help files for the above software products.* The files are based on the existing PC based files. The information will be accessible through the new platform that will be developed and will be deployed with the server-side module.
4. *Development of installation instructions of webGroundControl on a server or a stand-alone PC as well as a quick reference guide that includes step-by-step instructions on how to install and/or uninstall the product*. The installer is a separate software package that facilitates the installation of webGroundControl in any contemporary

windows-based system that can act as a server. The installer downloads all the necessary modules or software components to run the product.

# 3.0 Research Approach

The research approach is divided into four subsections; Backend Development, Frontend Development, Platform and Application Help Files, and webGC Install/Uninstall.

## 3.1 Introduction

The development of the webGroundControl online platform as well as its associated design applications is segmented with respect to the overall architecture. With the advent of cloud computing, web-based applications have become more popular with their adoption of multiple-tier, or n-tier, architecture containing independently operating tiers. webGroundControl utilized a three-tier application architecture containing a Data Tier (Data Server), a Logic Tier (Logic/Application Server), and a Presentation Tier (Web Server) as shown in Figure 2. The separation of the software platform into a series of tiers greatly increases the maintainability and scalability allowing for the adoption of new technologies that can be applied to a single tier without redesigning the entire software package.

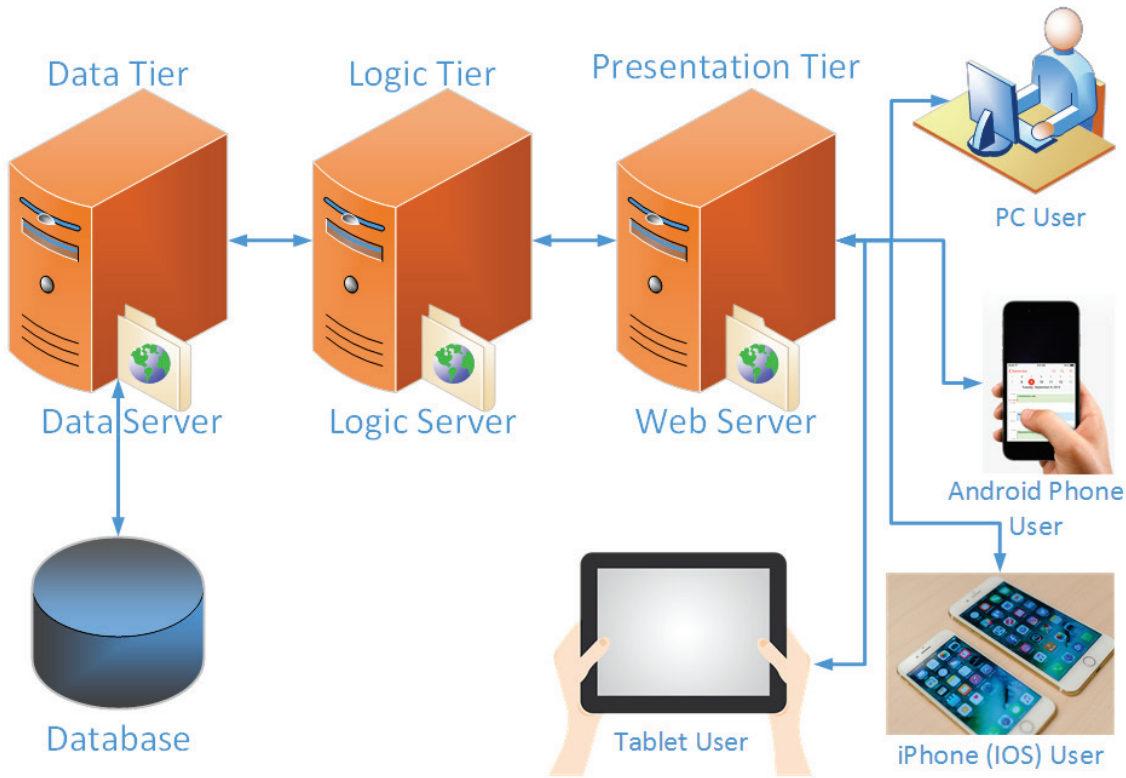



**Figure 2: Schematic of the three-tier web application architecture**

The Data Tier authenticates user requests, and given the appropriate authentication rights, retrieves queried information from the database and reports information back to the Logic Tier. The Data Tier has been developed with respect to Firebird, an open source SQL relational database management system. The database is accessed and maintained through robust data management mechanisms. Utilizing these storage mechanisms preserve data security as well as reduce data discrepancies within the database. The utilization of these

storage mechanisms also allow for updates and changes to occur within the database without affecting either the Logic or Presentation tiers.

The Logic Tier provides a means of communication between the Presentation and Data tiers as well as performing all necessary calculations for scenario analysis. User requests are sent from the Presentation Tier to the Logic Tier that completes the request by making queries to and processing the results from the Data Tier. The Logic Tier has been developed with respect to the Python coding language allowing for seamless interactions between both the Presentation (HTML and JavaScript) and Data (SQL) tiers. Through the creation of a form-based structure, the Logic Tier is able to quickly receive, process, and distribute information throughout the application framework of webGroundControl. Through the creation of a robust Logic Tier, this server is able to effectively enforce the routes and methods by which data sets are accessed and updated.

The Presentation Tier maintains the user interface translating client requests (through a web server) and displaying results (through a web browser). The Presentation Tier allows for on-demand access from multiple users and compatibility with a variety of personal computers, Smartphones, tablets, etc. on different operating systems. The Presentation Tier has been developed with respect to the HTML and JavaScript languages. Through the utilization of CSS, a coding language which describes the style of an HTML document, the webGroundControl display is able to spontaneously adapt to any browser and any screen. The development of the Presentation Tier will be discussed in more detail in subsequent sections of this report.

## 3.2 Back-end Development

The back-end essentially controls the flow of data between the user and webGroundControl. Prior to the development of the back-end data transfer and storage mechanisms, the research team investigated existing tools and design methodologies with respect to user authentications, project management, and data management mechanisms as well as deployment across multiple OS (PC, tablet, smartphone, etc.). From these investigations it was determined that the platform could be based on a combination of the Flask environment under Python 2.7 for data storage/retrieval, Object-relational mapping (ORM) for data queries, as well as an underlying SQL translator for the management of data to and from the application.

The initial task in the development of the webGroundControl back-end was the creation of a user authentication mechanism, i.e., the protocol for logging into the web platform with a username and password, password authentication procedures, as well as a protocol allowing for password changes. This was achieved through the development of a database table which holds usernames, encrypted passwords, and the user's role (regular or administrator) (Figure 3).

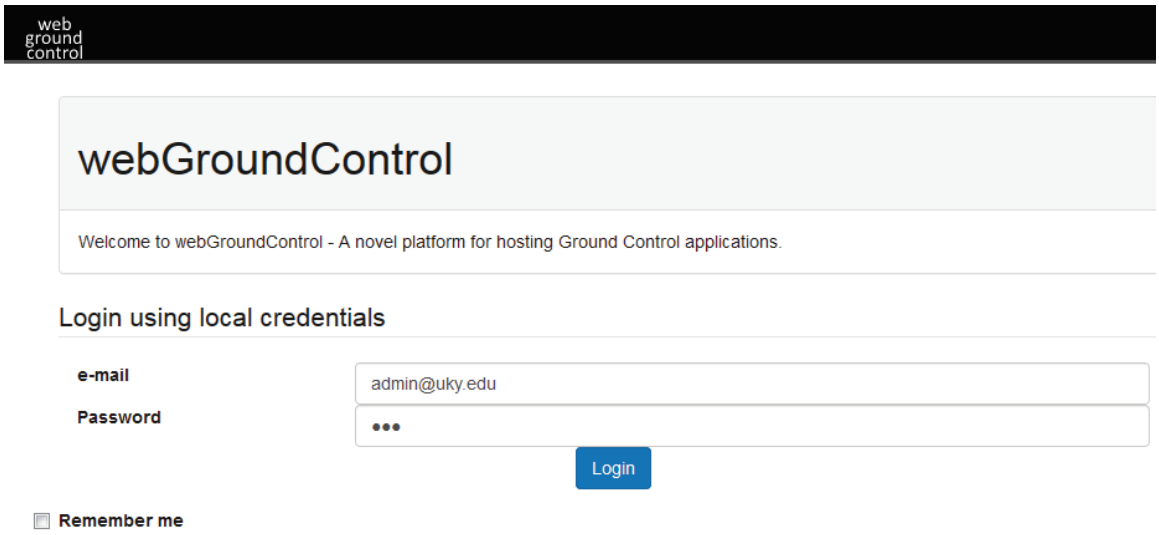



**Figure 3: Login for webGroundControl**

Following the development of the user authentication mechanism, the design team began the development of the project management mechanism within the back-end (Figure 4). Here, users are able to archive their previous analyses for future web access. Projects will be accessible to only the user who created them as well as any users identified for group collaboration (i.e. project sharing). Several tables were included in the back-end to manage where each project corresponds to a given mine location. Under each project, users are able to define a series of scenarios. Each scenario is composed of different ARBS, ALPS, ARMPS, ARMPS-HWM, or AHSM data sets. Upon logging into webGroundControl, the available projects (mines) and scenarios within each project are displayed and can be accessed and/or modified.

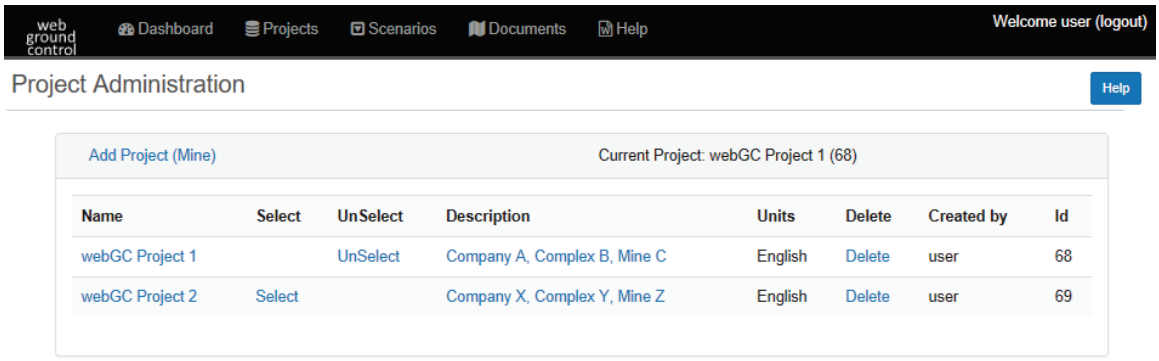



**Figure 4: Project management mechanism as presented to the user**

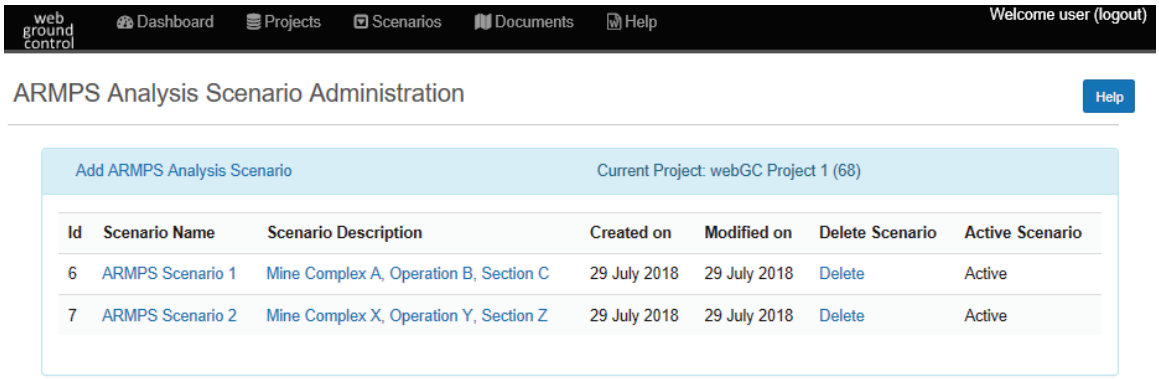



**Figure 5: ARMPS scenario management mechanism as presented to the user**

Furthermore, a data management mechanism was developed for each project defined within the back-end allowing for the storing and retrieval of data on a per scenario basis (Figure 6). Upon creating or selecting a previously saved scenario, a web form will be populated with either default or user defined parameters (Figure 6). Additionally, a document management mechanism was developed allowing users to upload design supporting documentation such as mine mapping (.dwg), core logs, photos, etc. (Figure 7).

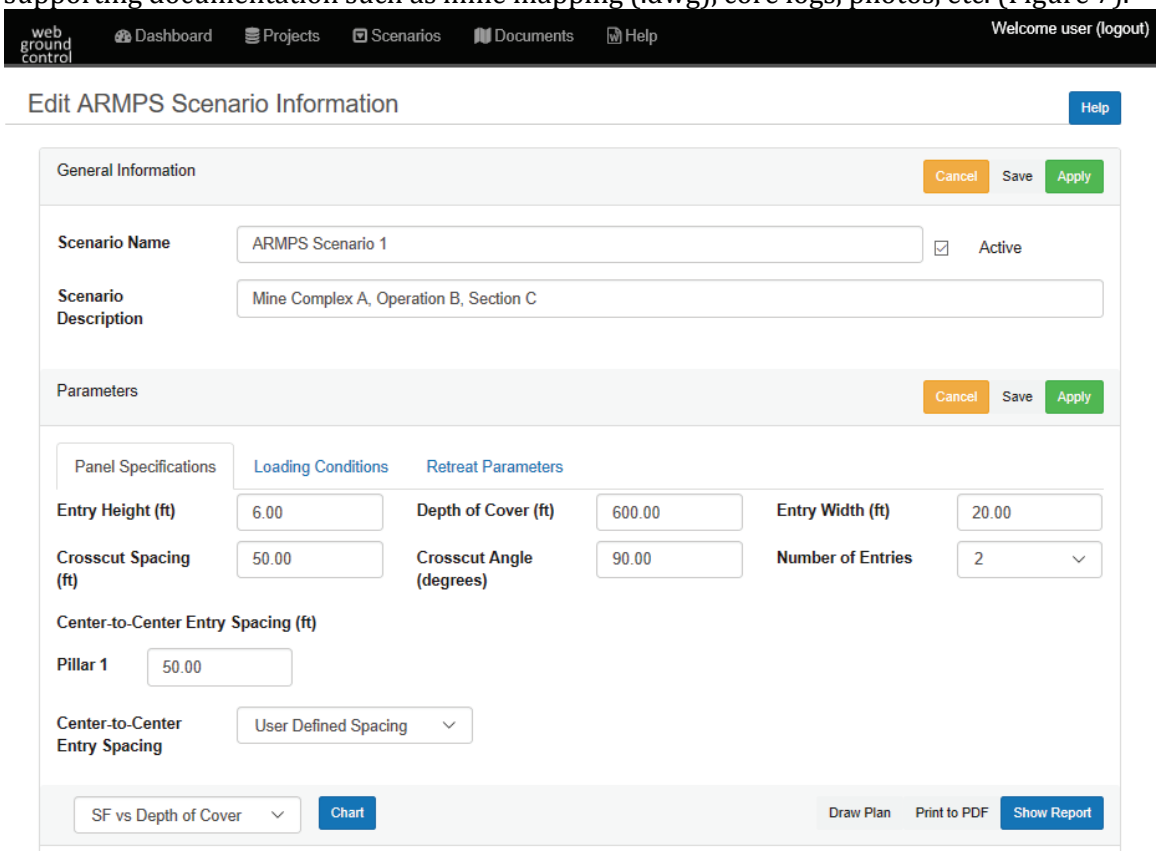



**Figure 6: ARMPS data management mechanism as presented to the user**

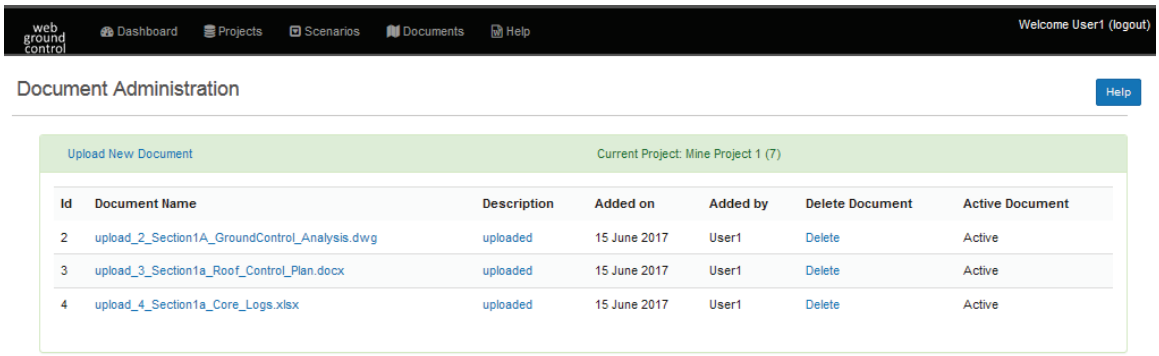



**Figure 7: Document management mechanism for a given project as presented to the user**

With all the back-end mechanisms developed, the design team rigorously tested the back-end to ensure data integrity and stability. Utilizing a local area network server, the back-end mechanisms were accessible by Windows, Apple and Android clients (Figure 8).

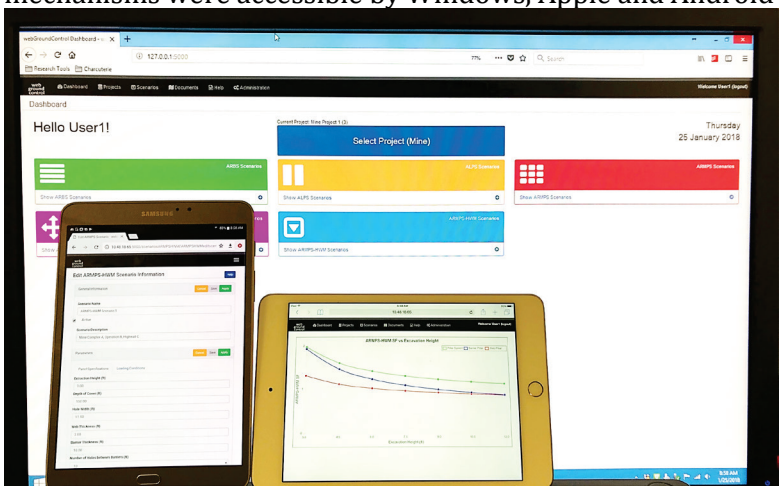



**Figure 8: Demonstration of platform access across multiple OS and devices**

## 3.3 Front-end Development

With the development of a generic back-end database work could be initiated on the front-end or Presentation Tier. Creation of the front-end user-application interface was subdivided into three parts; user authentication, user dashboard, and scenario modules. The creation of the front-end user authentication mechanism involved the creation of forms and queries for username and password login, password authentication, and utilities for password changes. Given the appropriate authentications, users are able to access and update data sets through project management and data management mechanisms with respect to the front-end user-application interface. As shown in Figure 9, when users login to webGroundControl they will first be directed to the main user dashboard with navigation buttons located in the menu bar along the top of the display and access to project management (Select Project) as well as data management (ARBS Scenario, ALPS Scenario, ARMPS Scenario, ARMPS-HWM Scenario, and AHSM Scenario) mechanisms.

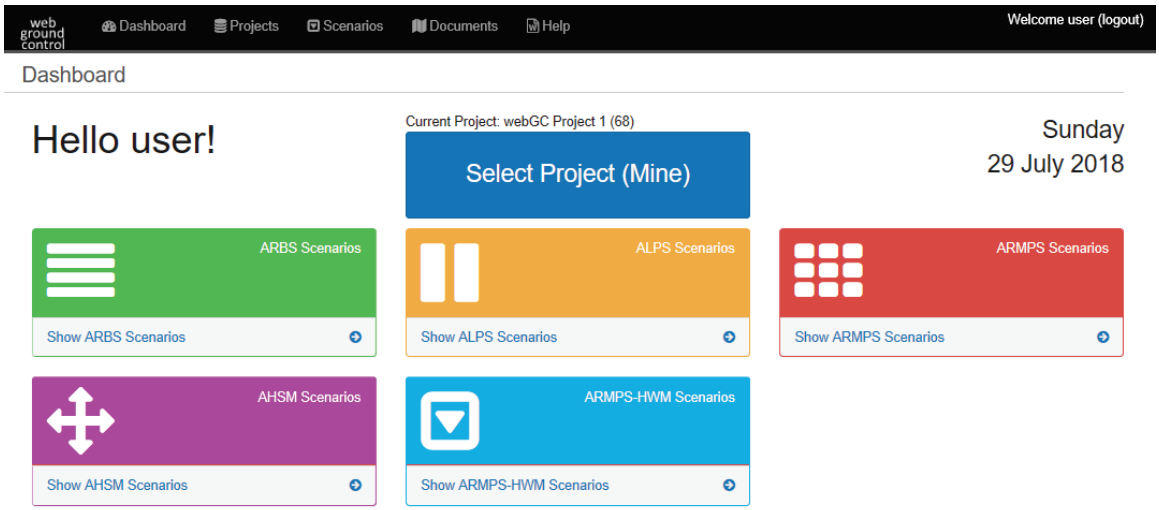



**Figure 9: User dashboard for the webGroundControl platform**

Users are initially required to select a project (mine) to which their ABRS, ALPS, ARMPS, etc. scenarios will apply by selecting the "Select Project (Mine)" button located both in the main display and menu bar. Users are then redirected to the Project Administration page (front-end project management mechanism) as shown in Figure 4. Here users are able to add, delete, and select different mine projects to which the scenarios will apply. With a project selected, users are now able to create, edit, or delete scenarios related to that project (front-end data management mechanism). The front-end aspect of all module scenarios have been developed as a series of forms with each containing appropriate result generation and charting mechanisms available to the user for in-depth analysis of the given scenario.

### 3.3.1 Analysis of Longwall Pillar Stability

By selecting the ALPS module from the dashboard, users will be directed to the scenario administration page. Here users are able to create a new, modify an existing, or delete a scenario for either ALPS Analysis or ALPS Design (Figure 10). Within ALPS Analysis, users are able to evaluate the stability of a given or proposed pillar layout while ALPS Design allows users to determine the minimum pillar dimensions with respect to a user defined pillar stability factor. If a user decides to create or edit a given scenario, they would be directed to the Edit Scenario Information page. Here users can make and save edits to default scenario parameters as shown in Figure 11.

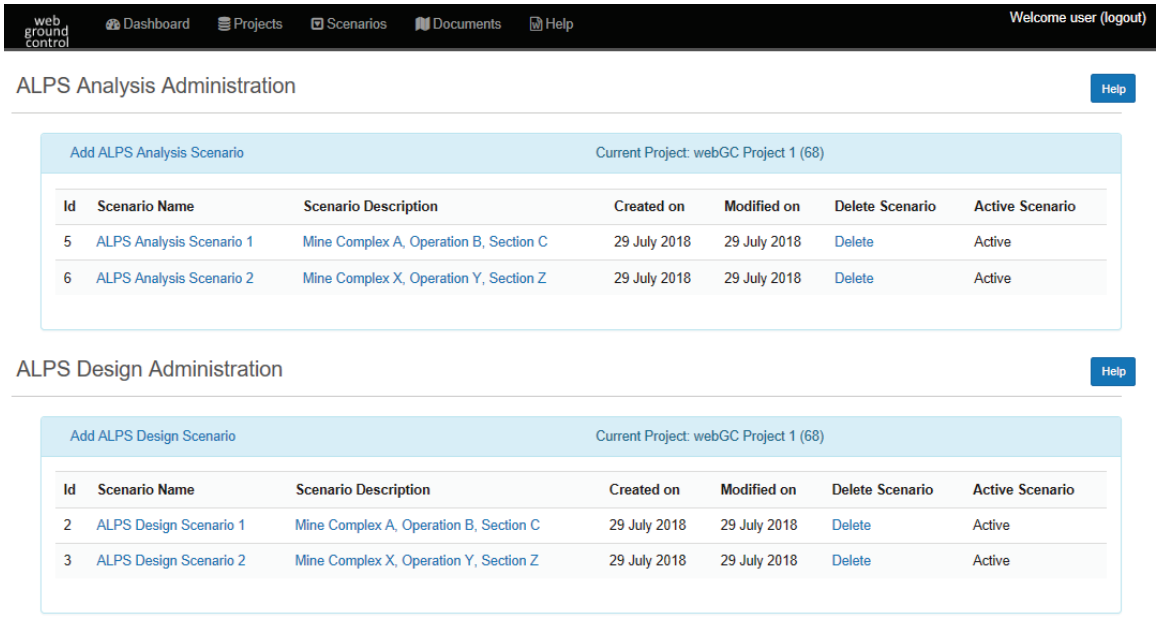



**Figure 10: ALPS scenario administration**

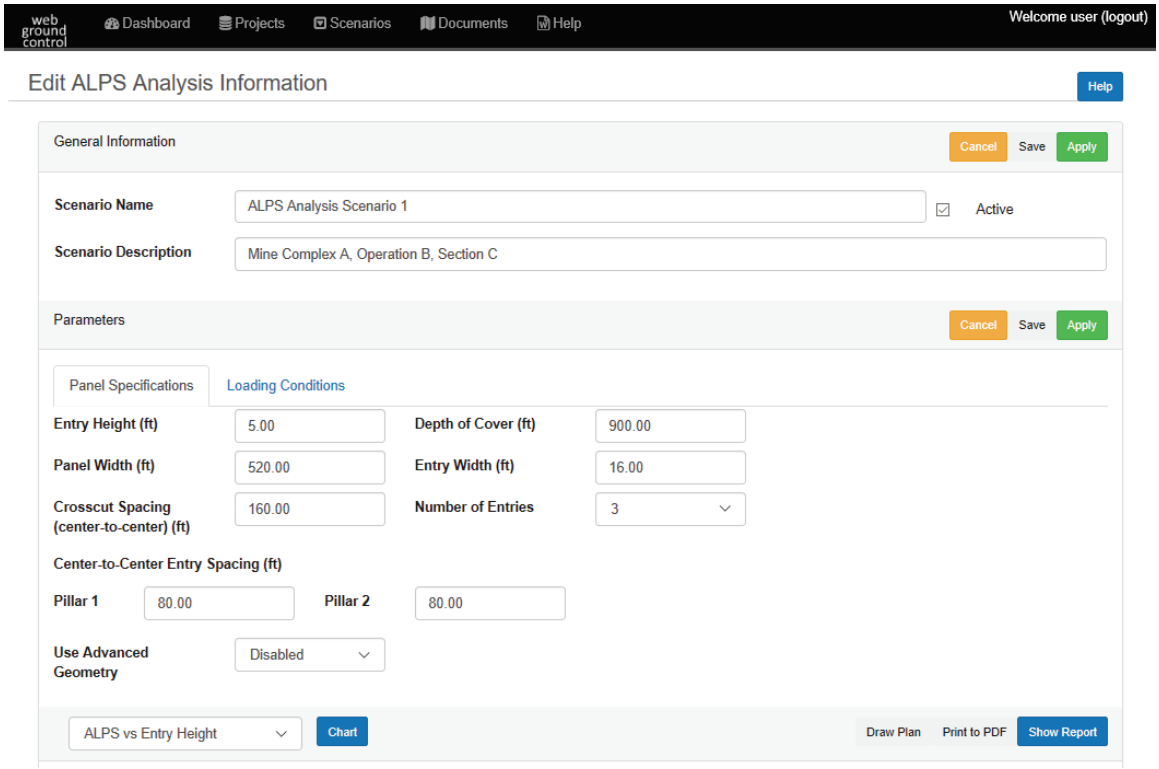
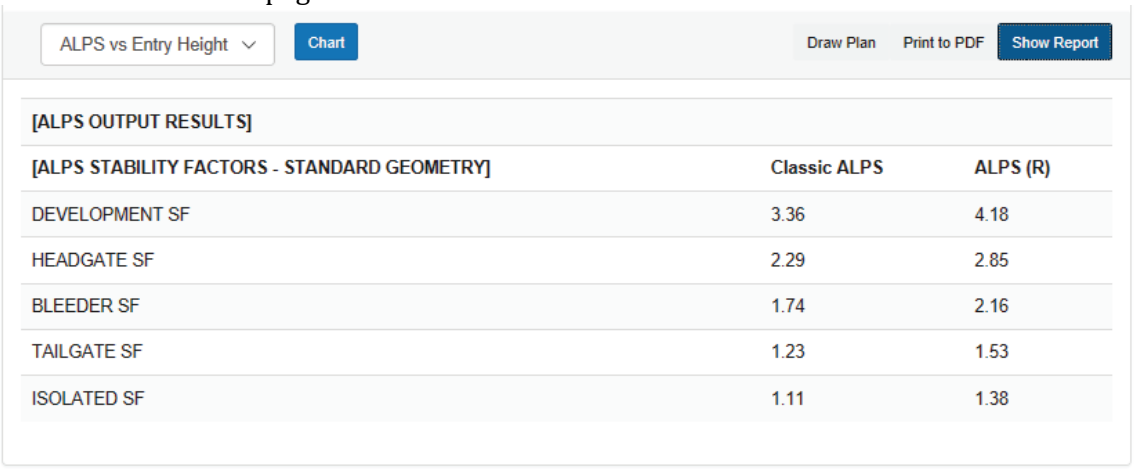



**Figure 11: ALPS analysis scenario information form**

This input parameter form has been created through a series of HTML groups and tables. Each input parameter group has been defined with its own unique parameter tab. By selecting a given tab, users are able to view and edit tab related input parameters. The Cancel, Save, and Apply buttons at the top of each parameter group will either scratch user edits and return them to the Scenario Administration page, save user edits and return them

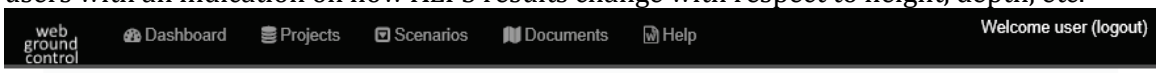
to the Scenario Administration page, or Apply (submit) user edits while remaining in the current Scenario Edit page.




| [ALPS OUTPUT RESULTS] | | |
|---|---|---|
| **[ALPS STABILITY FACTORS - STANDARD GEOMETRY]** | **Classic ALPS** | **ALPS (R)** |
| DEVELOPMENT SF | 3.36 | 4.18 |
| HEADGATE SF | 2.29 | 2.85 |
| BLEEDER SF | 1.74 | 2.16 |
| TAILGATE SF | 1.23 | 1.53 |
| ISOLATED SF | 1.11 | 1.38 |

**Figure 12: ALPS analysis scenario output results**

Scenario output results are displayed and can be accessed at the bottom of the input parameter form as shown in Figure 12. Here users are provided with the most basic scenario outputs. If more detailed results are required, users can select Show Report which will direct them to the scenario output results page containing all input parameters and output results for the given scenario, see Figure 13. Further, users can print out this report by selecting Print to PDF (Figure 14). Additionally, users are provided with a parametric graphing utility (Figure 15) where users can evaluate how ALPS results change with respect to specific input parameters. Parametric graphs are included in ALPS Analysis that provide users with an indication on how ALPS results change with respect to height, depth, etc.

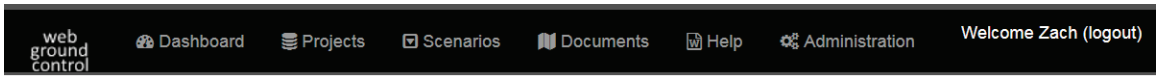



| [GEOMETRY PARAMETERS] | |
|---|---|
| Entry Height | 5.0 (ft) |
| Depth of Cover | 900.0 (ft) |
| Panel Width | 520.0 (ft) |
| Entry Width | 16.0 (ft) |
| Number of Entries | 3 |
| Center-to-Center Distance #1 | 80.0 (ft) |
| Center-to-Center Distance #2 | 80.0 (ft) |
| Crosscut Spacing | 160.0 (ft) |
| **[DEFAULT PARAMETERS]** | |
| InSitu Coal Strength | 900.0 (psi) |
| Abutment Angle | 21.0 (degrees) |
| Unit Weight of Overburden | 162.0 (pcf) |

**Figure 13: ALPS analysis scenario report**

| | |
|---|---|
| **[ALPS OUTPUT RESULTS]** | |
| ALPS Module Build: | VERSION 3.0 |
| Date | 29 July 2018 |
| **[ALPS SCENARIO INFORMATION]** | |
| Project File | webGC Project 1 (68) |
| Scenario Name | ALPS Analysis Scenario 1 |
| Scenario Description: | Mine Complex A, Operation B, Section C |
| Project Units | English Units (ft) (psi) |
| **[GEOMETRY PARAMETERS]** | |
| Entry Height | 5.0 (ft) |
| Depth of Cover | 900.0 (ft) |
| Panel Width | 520.0 (ft) |
| Entry Width | 18.0 (ft) |
| Number of Entries | 3 |
| Center-to-Center Distance #1 | 80.0 (ft) |
| Center-to-Center Distance #2 | 80.0 (ft) |
| Crosscut Spacing | 160.0 (ft) |
| **[DEFAULT PARAMETERS]** | |
| InSitu Coal Strength | 900.0 (psi) |
| Abutment Angle | 21.0 (degrees) |
| Unit Weight of Overburden | 162.0 (pcf) |

**Figure 14: ALPS analysis scenario PDF report**



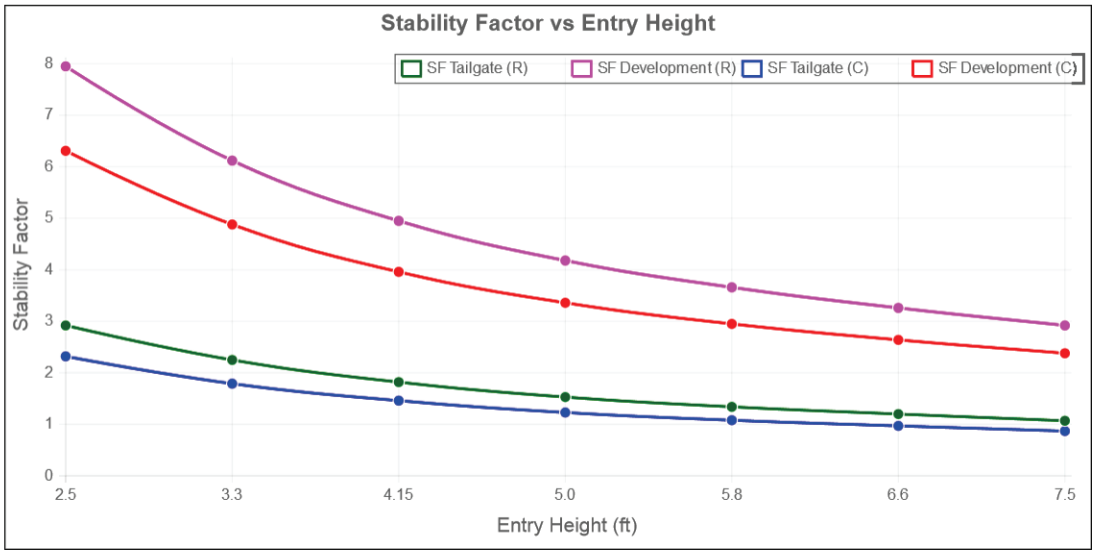




**Figure 15: ALPS analysis scenario parametric charting**

Within ALPS Analysis, users are provided with a plan view of their chain pillar configurations by selecting the View Plot action button (Figure 16). Additionally, a Help button has been included at the top of the ALPS scenario administration page (Figure 10) as well as both the ALPS and ALPS Design Scenario Information pages (Figure 11). Upon selecting the Help button, users will be directed to the respected analysis or design scenario

help file. For more information on the help files implemented in the ALPS module of webGroundControl, please see Section 4.4 below.

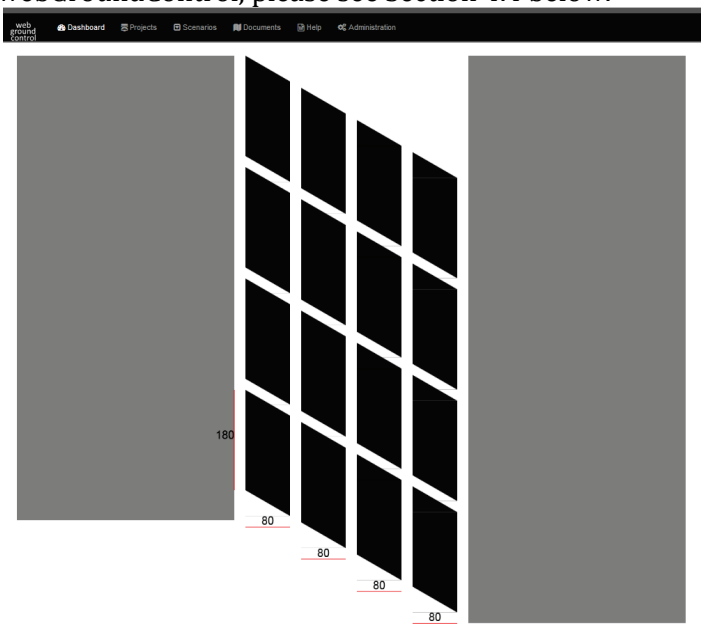



**Figure 16: ALPS analysis scenario (advanced geometry) plan view**

### 3.3.2 Analysis of Retreat Mining Pillar Stability (ARMPS)

By selecting the ARMPS module from the dashboard, users will be directed to the scenario administration page. Here users are able to create a new, modify an existing, or delete a scenario for ARMPS Analysis (Figure 17). Within ARMPS Analysis, users are able to evaluate the stability of a given or proposed pillar layout with respect to loading conditions encountered during secondary mining operations. If a user decides to create or edit a given scenario, they would be directed to the Edit Scenario Information page. Here users can make and save edits to default scenario parameters as shown in Figure 18.

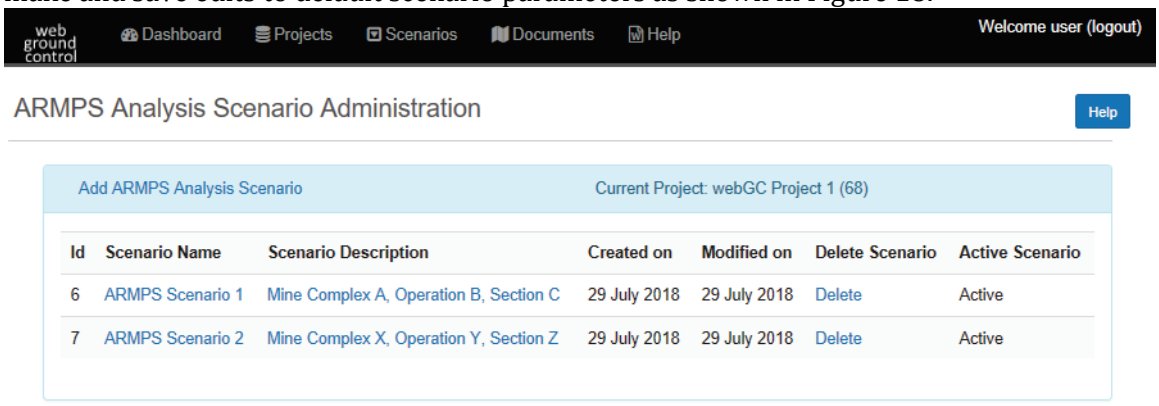



**Figure 17: ARMPS scenario administration**

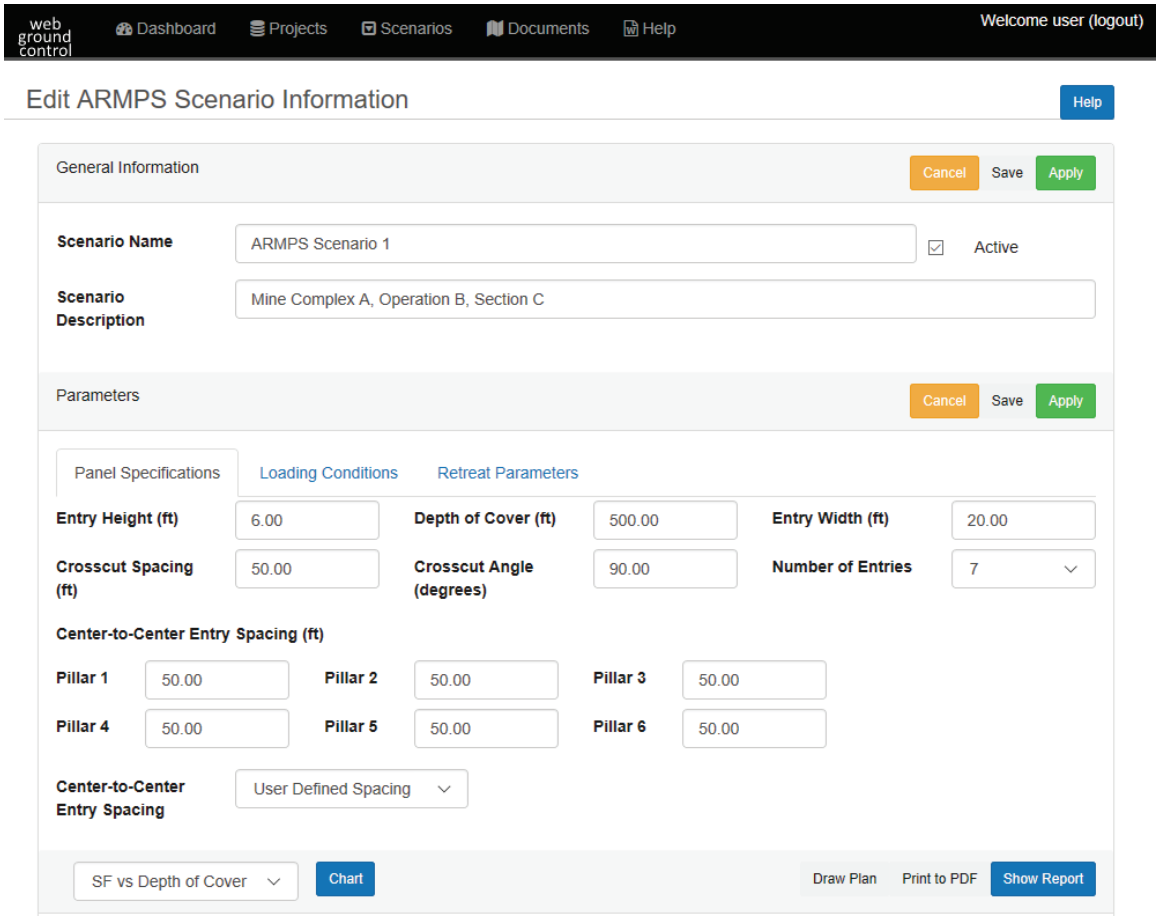



**Figure 18: ARMPS analysis scenario information form**

This input parameter form has been created through a series of HTML groups and tables. Each input parameter group has been defined with its own unique parameter tab. By selecting a given tab, users are able to view and edit tab related input parameters. The Cancel, Save, and Apply buttons at the top of each parameter group will either scratch user edits and return them to the Scenario Administration page, save user edits and return them to the Scenario Administration page, or Apply (submit) user edits while remaining in the current Scenario Edit page. Scenario output results are displayed and can be accessed at the bottom of the input parameter form as shown in Figure 19. Here users are provided with the most basic scenario outputs.

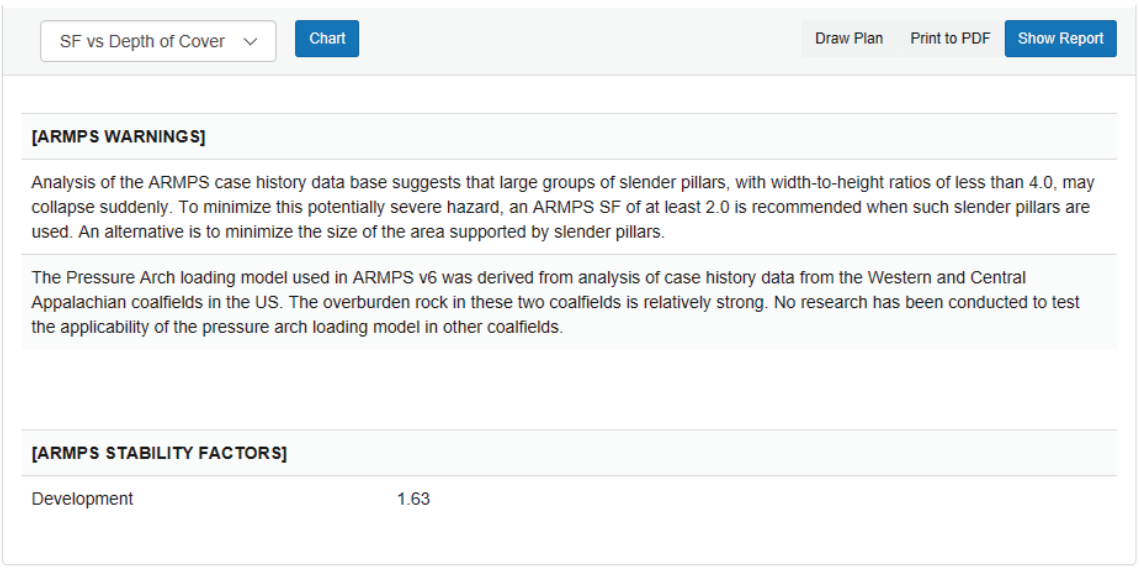



**Figure 19: ARMPS analysis scenario output results**

Furthermore, within the results, users will be provided with a series of ARMPS Warnings which are used to inform the user of potential design hazards as well as the limitations of the ARMPS database. While these basic results are available at the bottom of the Edit ARMPS Scenario page a more detailed report on input parameters and output results are available to users by selecting the Full Report, which will direct them to the scenario output results page for the given scenario (Figure 20). Furthermore, users can print out this report by selecting Print to PDF (Figure 21). Additionally, users are provided with a parametric graphing utility (Figure 22), where users can evaluate how ARMPS results change with respect to specific input parameters. Parametric graphs are included in ARMPS Analysis that provide users with an indication on how ARMPS results change with respect to height, depth, etc.

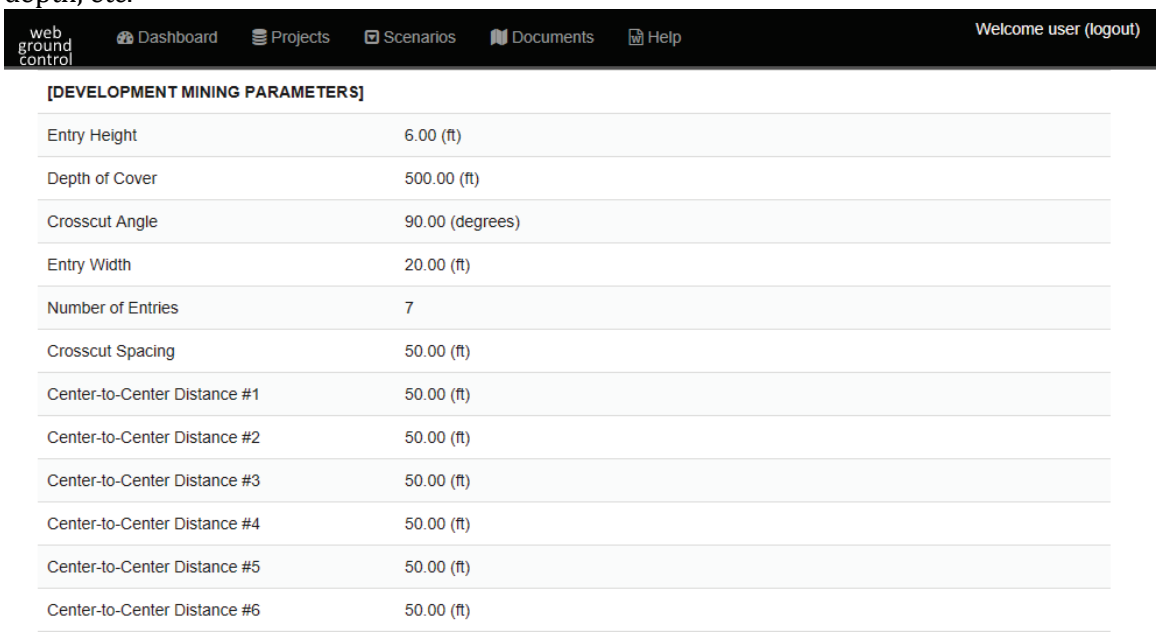



**Figure 20: ARMPS analysis scenario report**

| | |
|---|---|
| **[ARMPS OUTPUT RESULTS]** | |
| ARMPS Module Build: | VERSION 3.0 |
| Date | 30 July 2018 |
| **[ARMPS SCENARIO INFORMATION]** | |
| Project File: | webGC Project 1 (68) |
| Scenario Name | ARMPS Scenario 1 |
| Scenario Description | Mine Complex A, Operation B, Section C |
| Project Units | English Units (ft) (psi) |
| **[ARMPS INPUT PARAMETERS]** | |
| **[DEVELOPMENT MINING PARAMETERS]** | |
| Entry Height | 6.00 (ft) |
| Depth of Cover | 500.00 (ft) |
| Crosscut Angle | 90.00 (degrees) |
| Entry Width | 20.00 (ft) |
| Number of Entries | 7 |
| Crosscut Spacing | 50.00 (ft) |
| Center-to-Center Distance #1 | 50.00 (ft) |
| Center-to-Center Distance #2 | 50.00 (ft) |
| Center-to-Center Distance #3 | 50.00 (ft) |
| Center-to-Center Distance #4 | 50.00 (ft) |
| Center-to-Center Distance #5 | 50.00 (ft) |
| Center-to-Center Distance #6 | 50.00 (ft) |

Figure 21: ARMPS analysis scenario PDF report

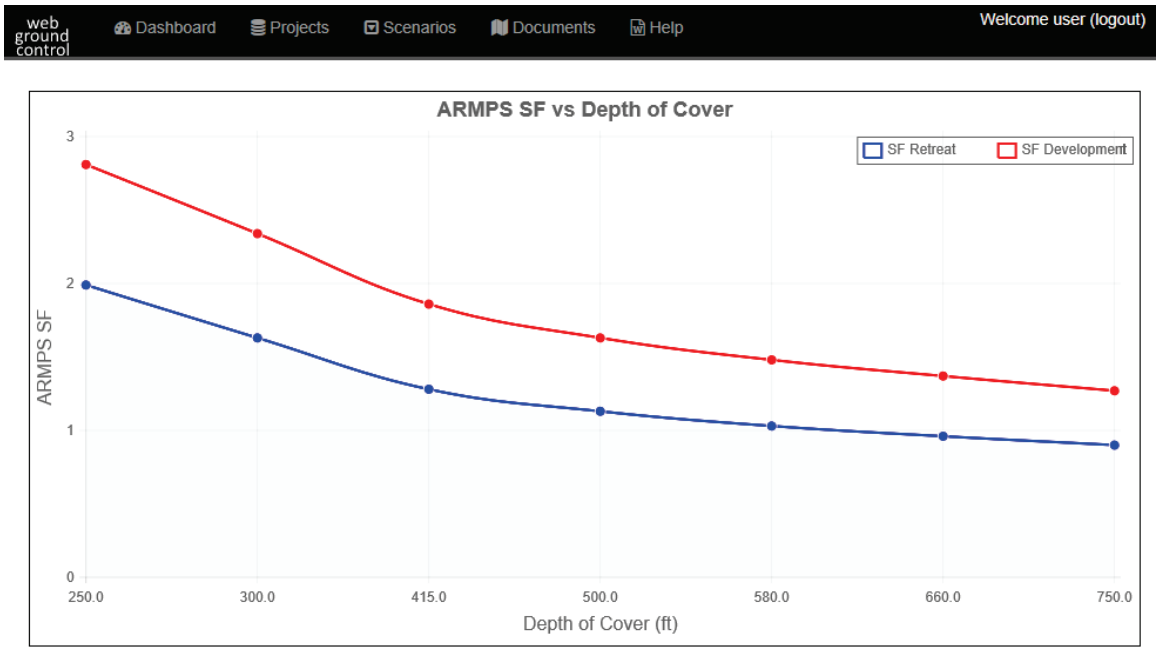



Figure 22: ARMPS analysis scenario parametric charting

Within ARMPS Analysis users are provided with a plan view of their pillar configurations by selecting the View Plot action button (Figure 23). Additionally, a Help button has been included at the top of the ARMPS scenario administration page (Figure 17) as well as the ARMPS Scenario Information page (Figure 18). Upon selecting the Help button, users will be

directed to the respected analysis or design scenario help file. For more information on the help files implemented in the ARMPS module of webGroundControl, please see Section 4.4 below.

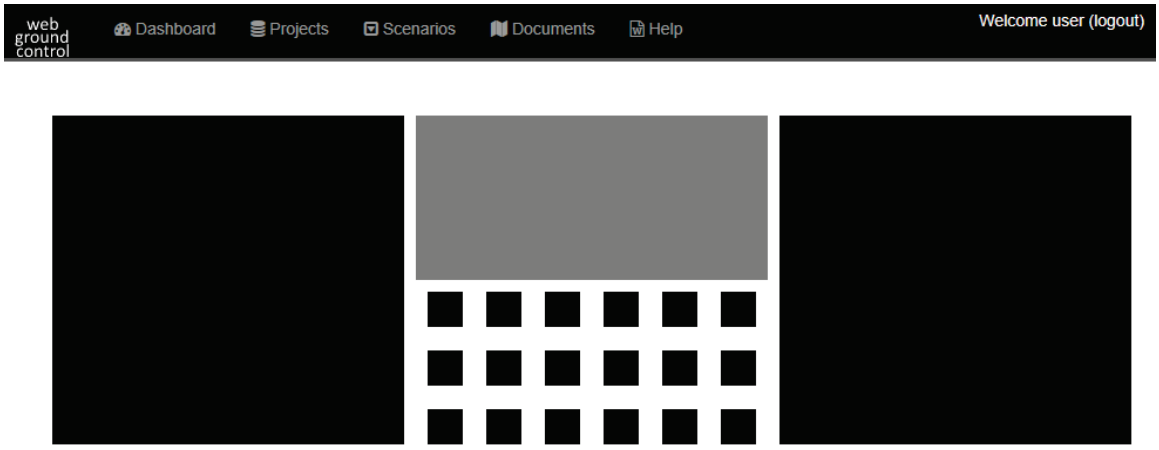



Figure 23: ARMPS analysis scenario plan view

### 3.3.3 Analysis of Roof Bolt Stability (ARBS)

By selecting the ARBS module from the dashboard, users will be directed to the scenario administration page. Here users are able to create a new, modify an existing, or delete a scenario for either ARBS Analysis or ARBS Cost (Figure 24). While ARBS Analysis determines the stability of the roof support system(s) system with respect to bolt densities within the immediate roof, the ARBS Cost module provides users with a means of estimating costs associated with a given roof bolt design with respect to input parameters such as labor, material, machinery, etc. If a user decides to create or edit a given scenario, they will be directed to the Edit Scenario Information page. Here users can make and save edits to default scenario parameters as shown in Figure 25.

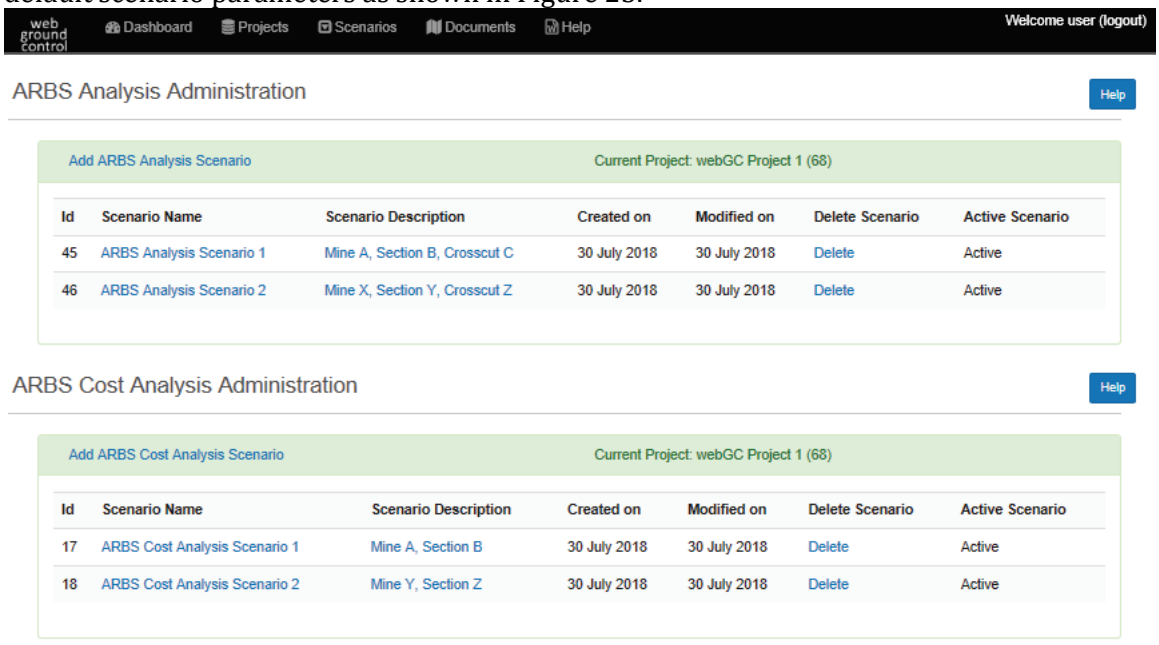



Figure 24: ARBS scenario administration

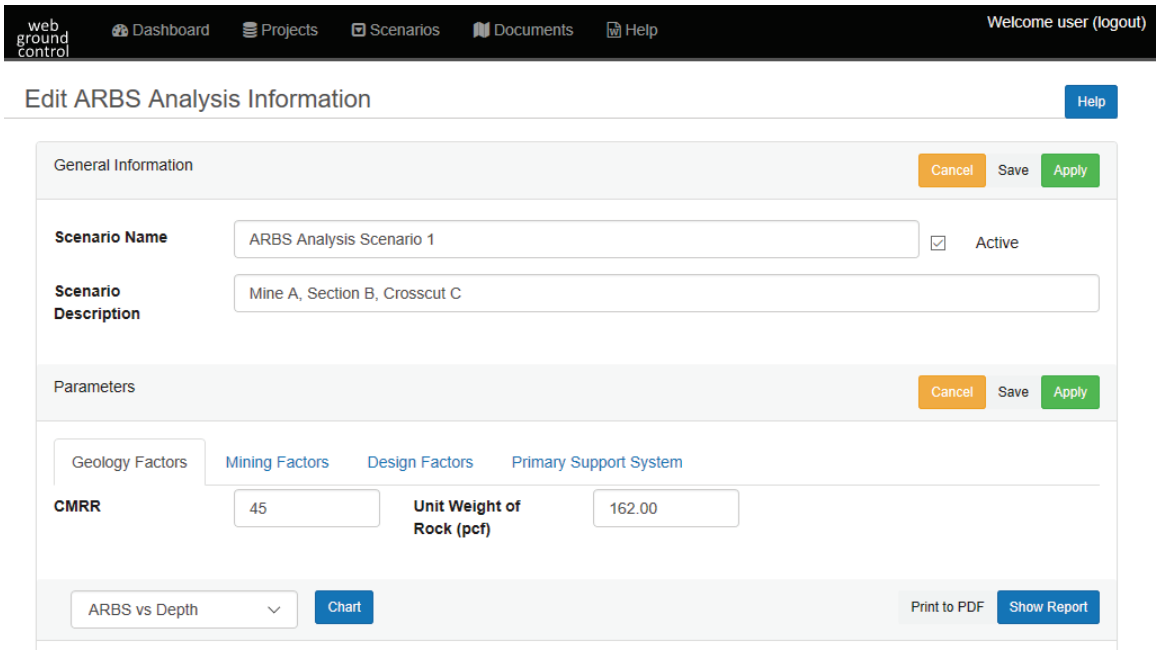
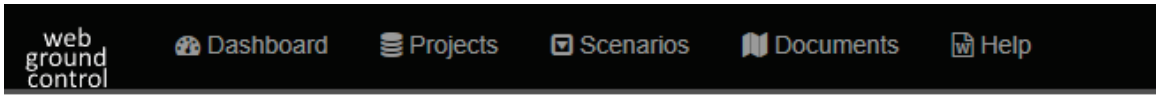



**Figure 25: ARBS analysis scenario information form**

This input parameter form has been created through a series of HTML groups and tables. Each input parameter group has been defined with its own unique parameter tab. By selecting a given tab, users are able to view and edit tab related input parameters. The Cancel, Save, and Apply buttons at the top of each parameter group will either scratch user edits and return them to the Scenario Administration page, save user edits and return them to the Scenario Administration page, or Apply (submit) user edits while remaining in the current Scenario Edit page. Scenario output results are displayed and can be accessed at the bottom of the input parameter form as shown in Figure 26. Here users are provided with the most basic scenario outputs.


**Figure 26: ARBS analysis scenario output results**

If more detailed results are required, users can select Show Report which will direct them to the scenario output results page containing all input parameters and output results for the given scenario, (Figure 27). Further, users can print out this report by selecting Print to PDF (Figure 28). Additionally, users are provided with a parametric graphing utility (Figure 29) where users can evaluate how ARBS results change with respect to specific input parameters. Parametric graphs are included in ARBS Analysis that provide users with an indication on how ARBS results change with respect to height, depth, etc.




| | |
|---|---|
| **[GEOLOGY PARAMETERS]** | |
| CMRR | 45.0 |
| Depth of Cover | 400.00 (ft) |
| Unit Weight of Rock | 162.00 (pcf) |
| **[MINING PARAMETERS]** | |
| Actual Intersection Span | 30.00 (ft) |
| Entry Width | 20.00 (ft) |
| **[SUPPORT PARAMETERS]** | |
| Stability Factor | 1.20 |
| Number of Support Systems | 1 |

Figure 27: ARBS analysis scenario report

| | |
|---|---|
| **[ARBS OUTPUT RESULTS]** | |
| ARBS Module Build: | VERSION 3.0 |
| Date | 30 July 2018 |
| **[ARBS SCENARIO INFORMATION]** | |
| Project File: | webGC Project 1 (68) |
| Scenario Name | ARBS Analysis Scenario 1 |
| Scenario Description | Mine A, Section B, Crosscut C |
| Project Units | English Units (ft) (psi) |
| **[GEOLOGY PARAMETERS]** | |
| CMRR | 45.0 |
| Depth of Cover | 400.00 (ft) |
| Unit Weight of Rock | 162.00 (pcf) |
| **[MINING PARAMETERS]** | |
| Actual Intersection Span | 30.00 (ft) |
| Entry Width | 20.00 (ft) |

Figure 28: ARBS analysis scenario PDF report

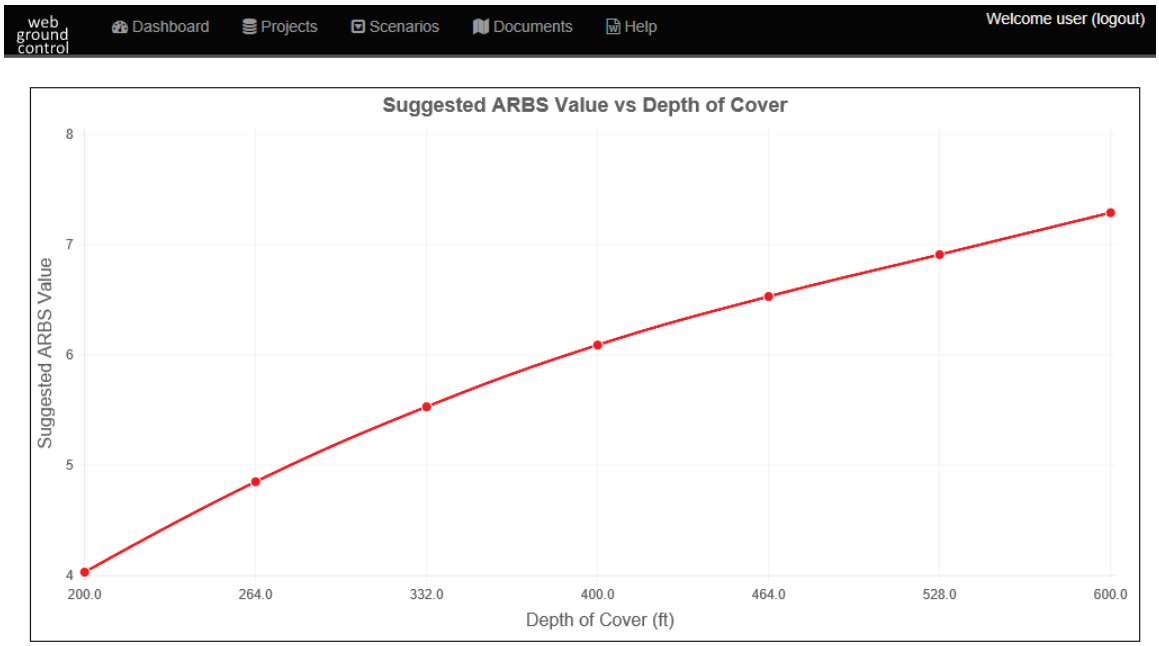



**Figure 29: ARBS analysis scenario parametric charting**

Additionally, a Help button has been included at the top of the ARBS scenario administration page (Figure 24) as well as both the ARBS and ARBS Design Scenario Information pages (Figure 25). Upon selecting the Help button, users will be directed to the respected analysis or design scenario help file. For more information on the help files implemented in the ARBS module of webGroundControl, please see Section 4.4 below.

### 3.3.4 Analysis of Retreat Mining Pillar Stability – Highwall Mining (ARMPS-HWM)

By selecting the ARMPS-HWM module from the dashboard, users will be directed to the scenario administration page. Here users are able to create a new, modify an existing, or delete a scenario for ARMPS-HWM (Figure 30). Within ARMPS-HWM Analysis, users are able to evaluate the stability of a given or proposed barrier and web pillar layout for highwall mining operations. If a user decides to create or edit a given scenario, they will be directed to the Edit Scenario Information page. Here users can make and save edits to default scenario parameters as shown in Figure 31.

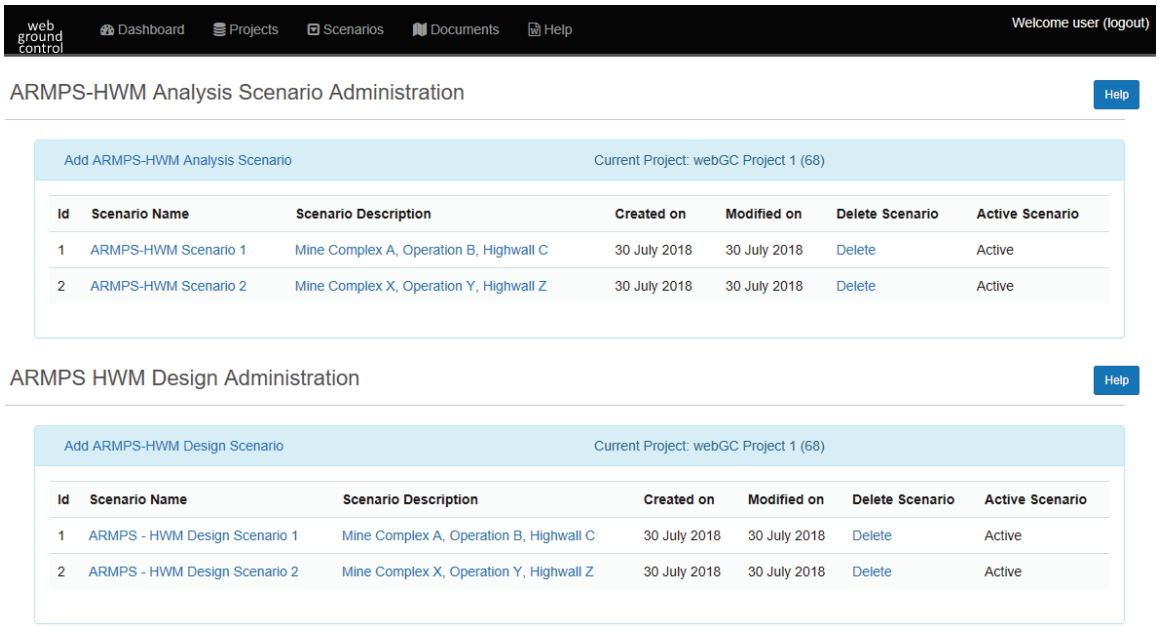



**Figure 30: ARMPS-HWM scenario administration**

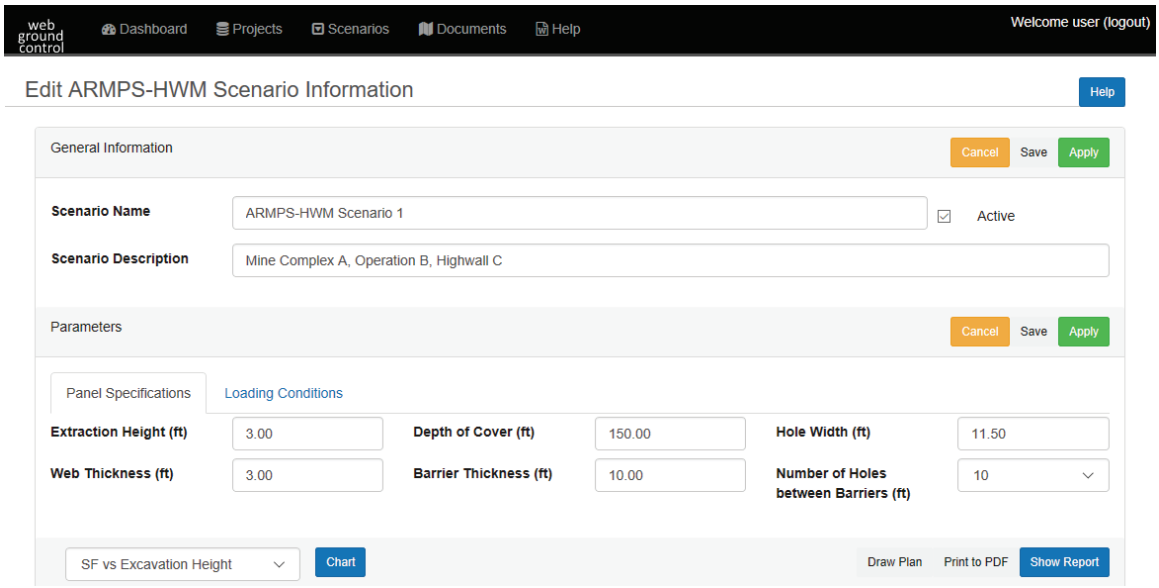



**Figure 31: ARMPS-HWM analysis scenario information form**

This input parameter form has been created through a series of HTML groups and tables. Each input parameter group has been defined with its own unique parameter tab. By selecting a given tab, users are able to view and edit tab related input parameters. The Cancel, Save, and Apply buttons at the top of each parameter group will either scratch user edits and return them to the Scenario Administration page, save user edits and return them to the Scenario Administration page, or Apply (submit) user edits while remaining in the current Scenario Edit page. Scenario output results are displayed and can be accessed at the bottom of the input parameter form as shown in Figure 32. Here users are provided with the most basic scenario outputs.

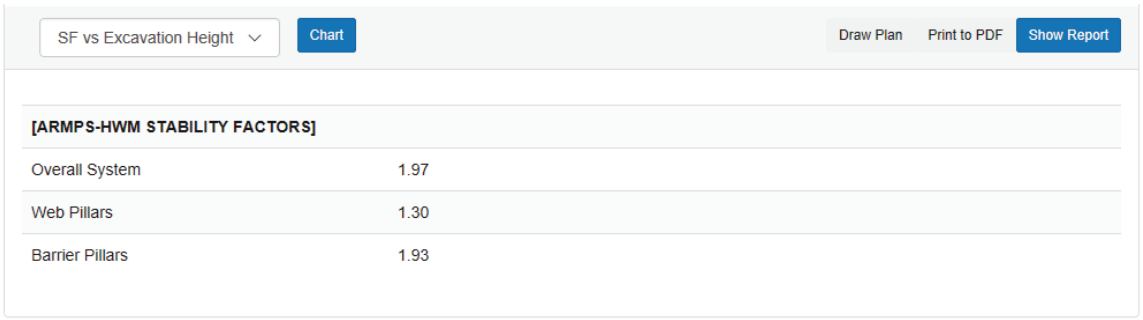



**Figure 32: ARMPS-HWM analysis scenario output results**

If more detailed results are required, users can select Show Report which will direct them to the scenario output results page containing all input parameters and output results for the given scenario, (Figure 33). Further, users can print out this report by selecting Print to PDF (Figure 34). Additionally, users are provided with a parametric graphing utility (Figure 35) where users can evaluate how ARMPS-HWM results change with respect to specific input parameters. Parametric graphs are included in ARMPS-HWM Analysis that provide users with an indication on how ARMPS-HWM results change with respect to height, depth, etc.

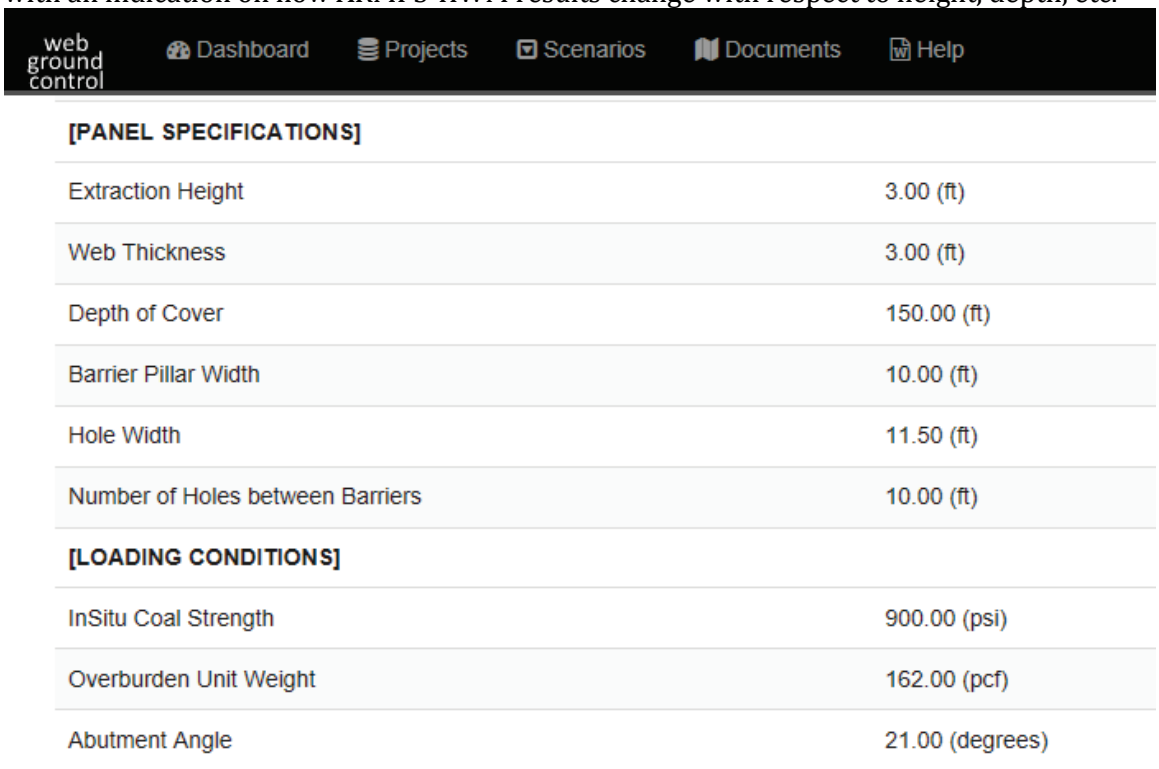



**Figure 33: ARMPS-HWM analysis scenario report**

**[PANEL SPECIFICATIONS]**

| | |
|---|---|
| Extraction Height | 3.00 (ft) |
| Web Thickness | 3.00 (ft) |
| Depth of Cover | 150.00 (ft) |
| Barrier Pillar Width | 10.00 (ft) |
| Hole Width | 11.50 (ft) |
| Number of Holes between Barriers | 10.00 (ft) |

**[LOADING CONDITIONS]**

| | |
|---|---|
| InSitu Coal Strength | 900.00 (psi) |
| Overburden Unit Weight | 162.00 (pcf) |
| Abutment Angle | 21.00 (degrees) |

**Figure 34: ARMPS-HWM analysis scenario PDF report**

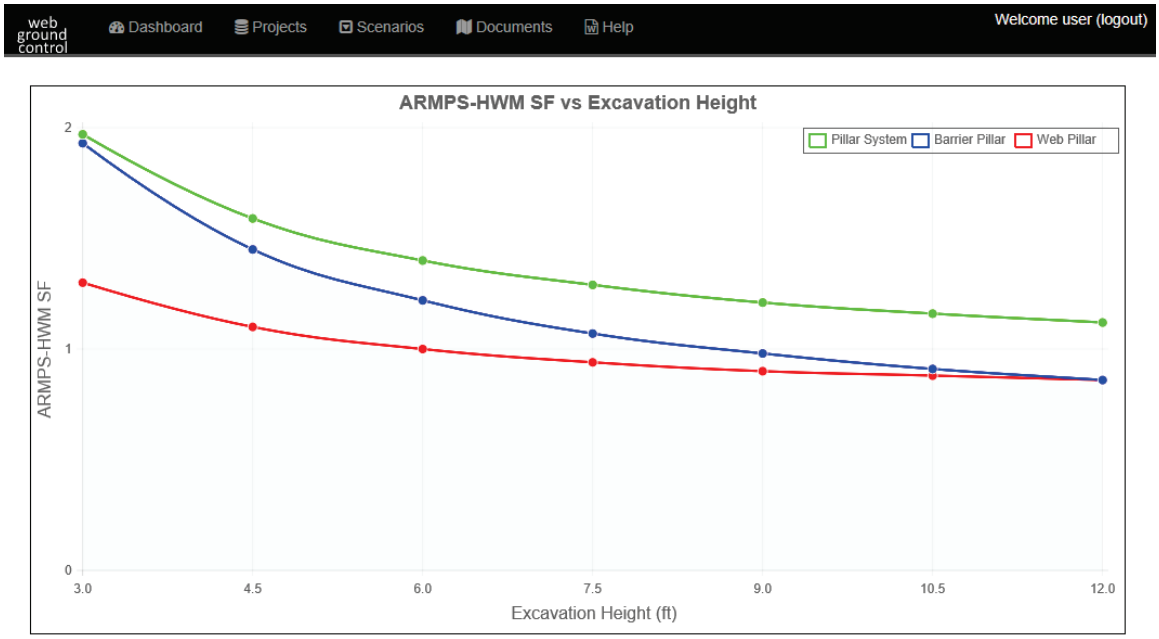



**Figure 35: ARMPS-HWM analysis scenario parametric charting**

Within ARMPS-HWM Analysis users are provided with a plan as well as cross-sectional view of their highwall pillar configurations by selecting the View Plot action button (Figure 36). Additionally, a Help button has been included at top of the ARMPS-HWM scenario administration page (Figure 30) as well as both the ARMPS-HWM Analysis and ARMPS-HWM Design Scenario Information pages (Figure 31). Upon selecting the Help button, users will be directed to the respected analysis scenario help file. For more information on the help files implemented in the ARMPS-HWM module of webGroundControl, please see Section 4.4 below.

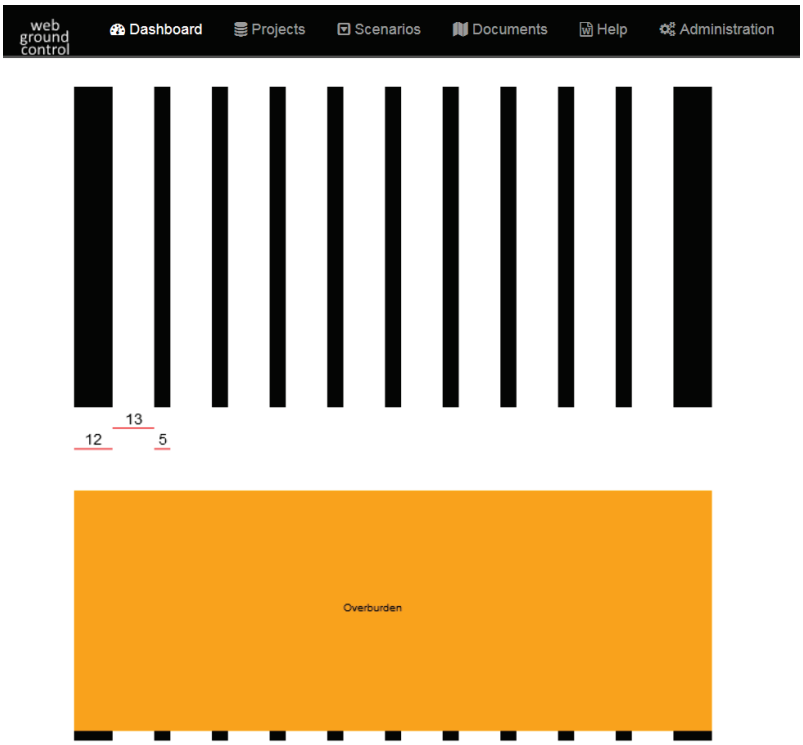



Figure 36: ARMPS-HWM analysis scenario plan view

### 3.3.5 Analysis of Horizontal Stress in Mining (AHSM)

By selecting the AHSM module from the dashboard, users will be directed to the scenario administration page. Here users are able to create a new, modify an existing, or delete a scenario for AHSM Analysis (Figure 37). Within AHSM Analysis, users are able to evaluate the relative direction and magnitude of the horizontal stress with respect to mining azimuths for both room-and-pillar and longwall mining operations. If a user decides to create or edit a given scenario, they will be directed to the Edit Scenario Information page. Here users can make and save edits to default scenario parameters as shown in Figure 38.

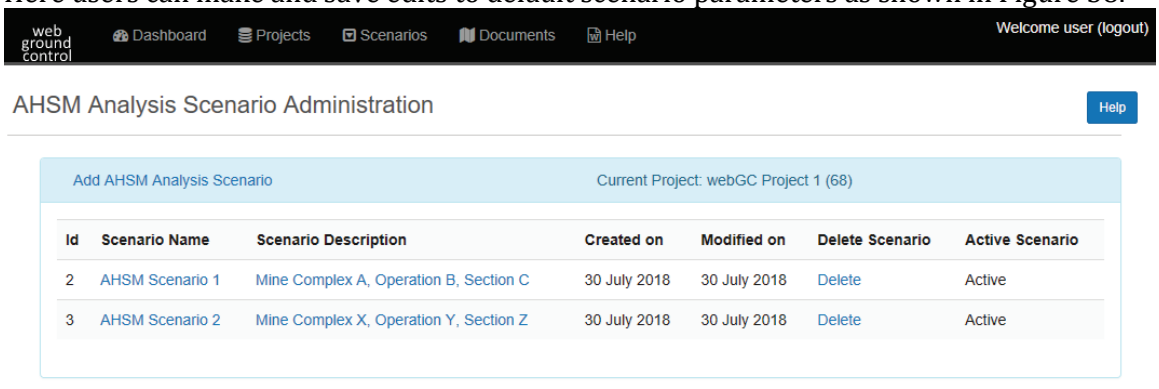



Figure 37: AHSM scenario administration

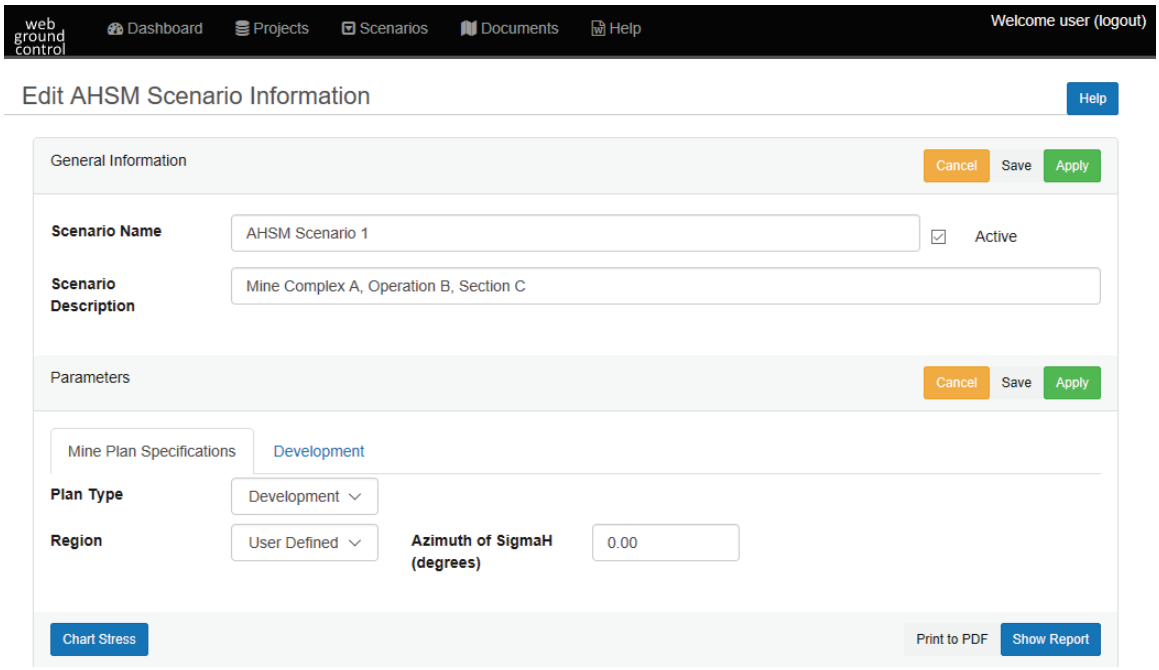



**Figure 38: AHSM analysis scenario information form**

This input parameter form has been created through a series of HTML groups and tables. Each input parameter group has been defined with its own unique parameter tab. By selecting a given tab, users are able to view and edit tab related input parameters. The Cancel, Save, and Apply buttons at the top of each parameter group will either scratch user edits and return them to the Scenario Administration page, save user edits and return them to the Scenario Administration page, or Apply (submit) user edits while remaining in the current Scenario Edit page. Scenario output results are displayed and can be accessed at the bottom of the input parameter form as shown in Figure 40. Here users are provided with the most basic scenario outputs.

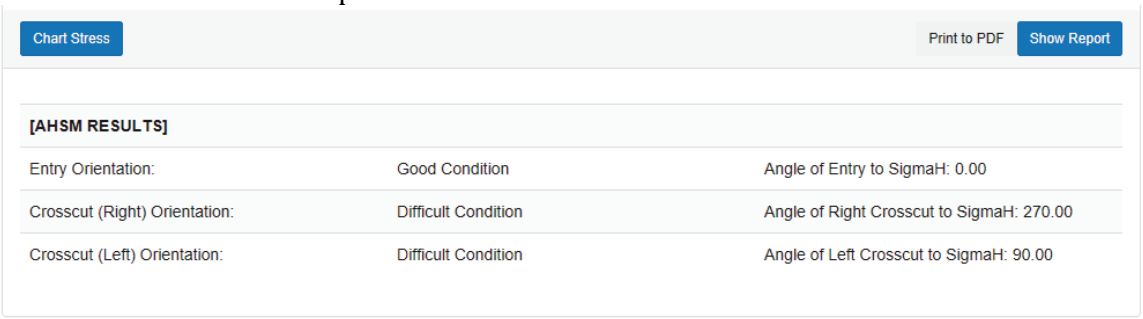
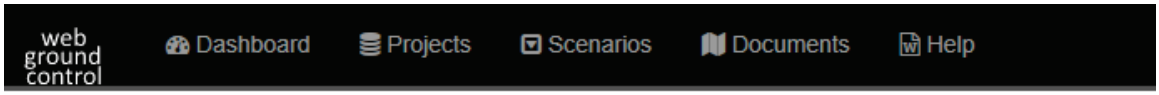



**Figure 39: AHSM analysis scenario output results**

If more detailed results are required, users can select Show Report which will direct them to the scenario output results page containing all input parameters and output results for the given scenario, see Figure 40. Furthermore, users can print out this report by selecting Print to PDF (Figure 41).




| | |
|---|---|
| **[AHSM OUTPUT RESULTS]** | |
| AHSM Module Build: | VERSION 3.0 |
| Date | 30 July 2018 |
| **[AHSM SCENARIO INFORMATION]** | |
| Project File: | webGC Project 1 (68) |
| Scenario Name | AHSM Scenario 1 |
| Scenario Description | Mine Complex A, Operation B, Section C |
| Project Units | English Units (ft) (psi) |

**Figure 40: AHSM analysis scenario report**

| | | |
|---|---|---|
| **[AHSM OUTPUT RESULTS]** | | |
| AHSM Module Build: | VERSION 3.0 | |
| Date | 30 July 2018 | |
| **[AHSM SCENARIO INFORMATION]** | | |
| Project File: | webGC Project 1 (68) | |
| Scenario Name | AHSM Scenario 1 | |
| Scenario Description | Mine Complex A, Operation B, Section C | |
| Project Units | English Units (ft) (psi) | |
| **[AHSM INPUT PARAMETERS]** | | |
| Plan Type | Development | |
| Region | User Defined | |
| Azimuth of SigmaH | 0.00 (degrees) | |
| Azimuth of Entries | 0.00 (degrees) | |
| Azimuth of Right Crosscut | 90.00 (degrees) | |
| Azimuth of Left Crosscut | 270.00 (degrees) | |
| **[AHSM OUTPUT]** | | |
| Entry Orientation : | Good Condition | Angle of Entry to SigmaH : 0.00 |
| Crosscut (Right) Orientation : | Right Crosscut to SigmaH : 0.00 | |
| Crosscut (Left) Orientation : | Angle of Left Crosscut to SigmaH : 0.00 | |

**Figure 41: AHSM analysis scenario PDF report**

Additionally, a Help button has been included at the top of the AHSM scenario administration page (Figure 37) as well as top of the AHSM Analysis Scenario Information pages (Figure 38). Upon selecting the Help button, users will be directed to the respected analysis scenario help file. For more information on the help files implemented in the AHSM module of webGroundControl, please see Section 4.4 below.

## 3.4 Platform and Application Help Files

Help files have been developed in HTML for both platform navigations and features as well as currently available mine design applications (ARBS, ALPS, ARMPS, etc.). The webGroundControl platform help file can be accessed by users through the menu bar at the top of each web page and form. Selection of this Help button will direct users to a help file which discusses and outlines platform features, such as project, scenario, document administration, as well as platform navigations (Figure 42). Application specific help files can be accessed within their respective Edit Scenario Information web pages by selecting the Help button at the top of the page. These help files provide users with details on input parameter definitions, calculations, as well as suggested values (Figure 43). While the information within each help file is different, help file access and layouts remain constant throughout the webGroundControl platform.

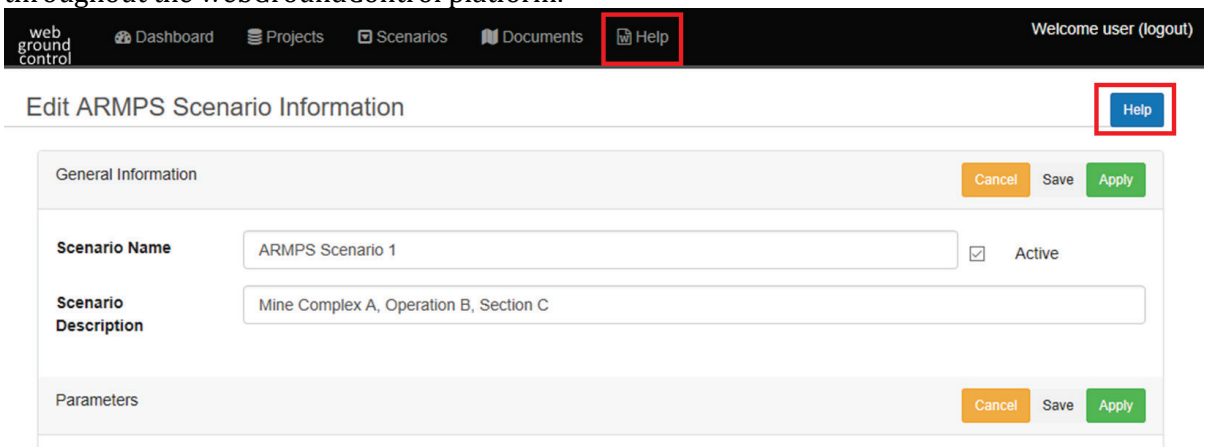



**Figure 42: ARMPS help file available at the top of the scenario information form**

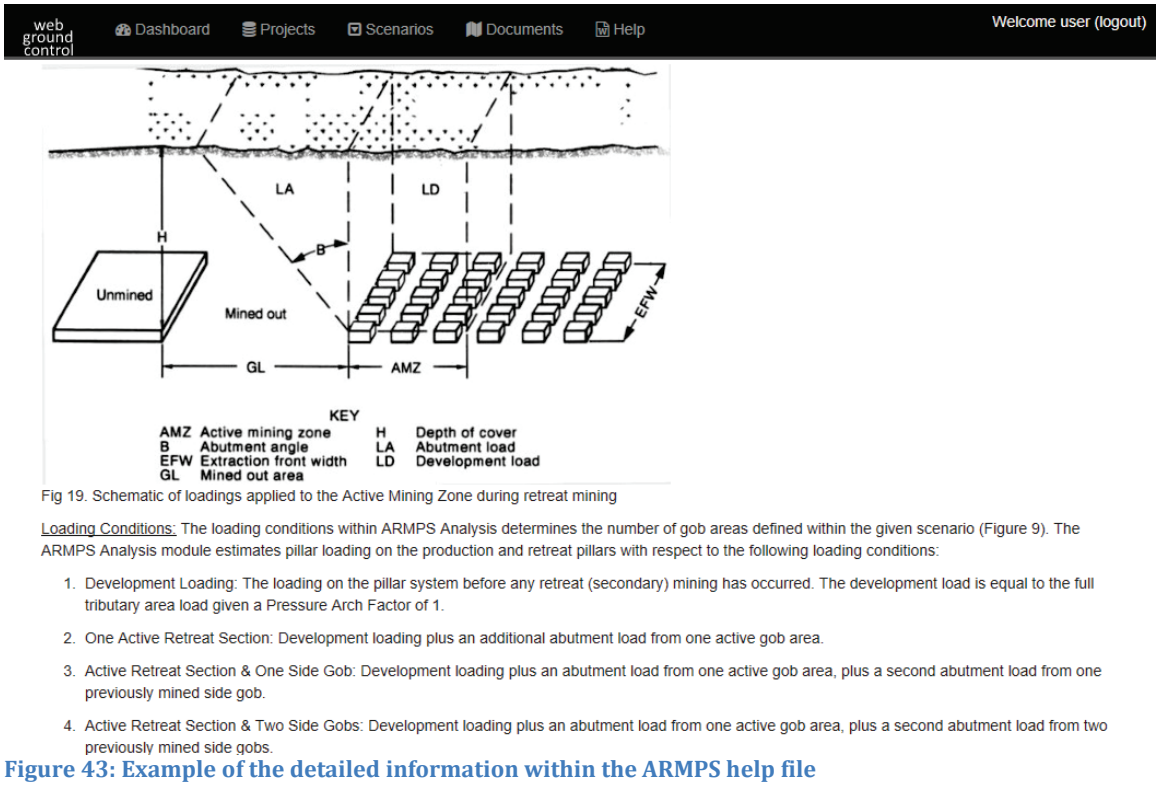



**Figure 43: Example of the detailed information within the ARMPS help file**

## 3.5 Logic Controller

In developing both the back-end database and front-end user-application interfaces, a significant amount of time was devoted to the development of a central controlling mechanism (Logic Controller or Controller) to seamlessly manage the request, retrieval, display, and storage of data sets. The flow chart shown in Figure 44 provides a simplified representation of the processes within the webGC application and the role of the Controller in orchestrating the transfer of information between back- and front-end mechanisms.

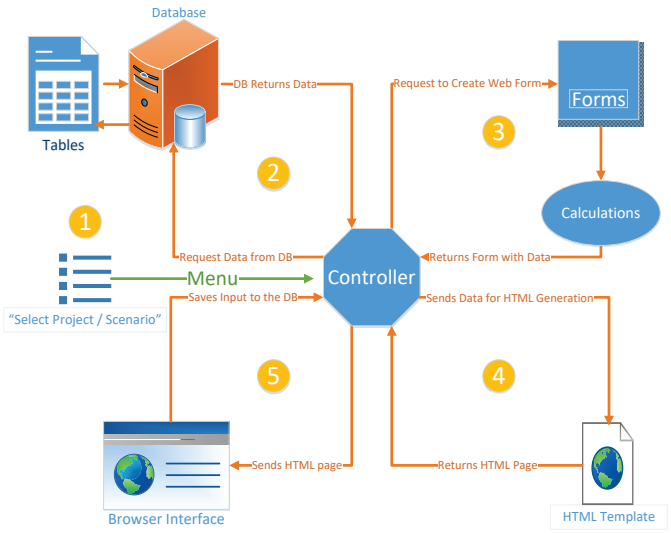



**Figure 44: Schematic of logic controller utilized within webGroundControl**

Through a web browser, the user initially selects a Project as well as a module Scenario (ARBS, ALPS, ARMPS, etc.) within the given Project. This information is then passed to the Controller. Given the Project and Scenario information received by the Controller, data is requested from the Database. If the authentication rights are valid, information can be retrieved from the database. This information has been organized as a series of data tables. The Database then returns the appropriate data back to the Controller.

Once the Controller has finished communications with the Database, a web form request is then submitted, and a web form is created with respect to the initial Project and Scenario selection by the user. The web form is then populated with the data received from the Database. With the data set imported into the web form, a series of calculations are performed with respect to the initial Project and Scenario selection providing Scenario output results. The populated web form as well as the results from the Scenario calculations are then returned to the Controller. Upon receiving these new datasets from the web form, an HTML template page is requested. An HTML template is selected with respect to the initially selected Project and Scenario. This HTML template is then populated with the data from the web form and calculations results and returned to the Controller. In receiving the populated HTML template, the Controller sends the html page to be displayed in the web browser. Information provided by the user through the web browser interface is then returned and processed by the Controller and further requests are made to the Database. The processes for each module within webGC (ALPS, ARBS, and ARMPS) are very similar. Slight processing differences can be found in the types of forms requested by the Controller and the calculations executed with respect to the given web application (ARBS, ALPS, ARMPS, etc.)

### 3.6 webGC Install / Uninstall

The webGroundControl online platform has been deployed to a cloud server and is accessible through app.minegroundcontrol.com. At the time of writing the final report, any user can log-in using an email and password. webGroundControl and its associated mine design application are available free to the public through this domain. Here users can create their own unique username and password given a valid email address. Through the public server, user accounts, projects, scenarios, and documents are monitored by domain administrators. A typical authentication sequence will be implemented in a few weeks.

If one would like to maintain control of their data, webGroundControl is available with respect to a corporate license which can be installed within a company or personal network, i.e. the webGroundControl platform can be run on a private (i.e., corporate) server. The server needs to have the following specifications

- Windows environment
- Installation of Python 2.7
- Installation of the Firebird database server (2.5.x)

The webGC modules will then be deployed through a binary distribution file that will be supplied depending on the platform. Binary distribution files are created using the following syntax:

```
python setup.py bdist --formats=wininst
```

The online platform can be accessed through the following URL:
http://app.minegroundcontrol.com/
Users can login using a username and password. When the platform was initially released users were automatically registered upon entering a username and password without user email verification. Once the product is finalized, a proper email verification procedure will be implemented for new users.

For detailed information on installation of the web platform within a secure network, users should contact Dr. Zach Agioutantis, PI of this project.

## 4.0 Research Findings and Accomplishments

Due to the three-tier architecture of the webGroundControl platform as well as the dedication of the design team, three web applications (ARBS, ALPS, and ARMPS) were developed and deployed as originally proposed as well as an additional two web applications (ARMPS-HWM and AHSM). While the development of the web platform as well as the current mine design applications within three years is a significant accomplishment itself, it is our belief that the significance of webGroundControl is best measured through its pre-launch acceptance before and anticipation of the release of the webGroundControl product in the Fall of 2018. In the October 2017 issue of Mining Engineering, webGroundControl appeared as a featured article and was similarly invited to be presented during the 2018 Society of Mining Engineers (SME) “Best of Ground Control” at the annual conference and exposition.

Building upon the anticipation of the product release, as well as ensuring the stability of the webGroundControl platform as well as data securities, several beta testing sessions were

utilized to get feedback from the mining community. Questionnaires were provided to participants with respect to the ARBS, ALPS, ARMPS, ARMPS-HWM, and AHSM as the platform applications and features were developed. Initial beta testing for the ARBS module was performed at the 2016 International Conference on Ground Control in Mining (ICGCM) in Morgantown, WV and continued to the following year (2017). In the Fall Semester of 2016, initial classroom testing of the platform applications and features began in the Rock Mechanics (MNG 551) course and Graduate Student Seminar (MNG 771) at the University of Kentucky. This continued into the 2017 Fall and Spring semesters. Three UK students (one undergraduate and two graduate) were independently asked to use the software and to try to discover bugs and problems. A final presentation of the platform was done during 2018 ICGCM with over 30 participants actively participating during the presentation. User feedback was not collected from the 2018 ICGCM participants.

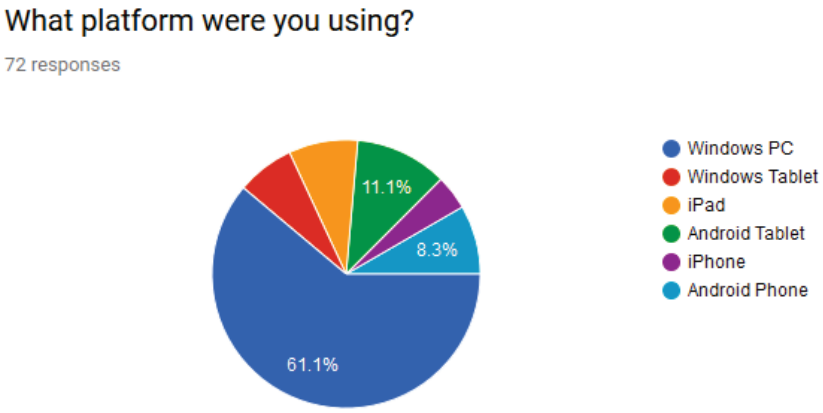



**Figure 45: Beta testing questionnaire results for device utilized in accessing webGC**

To date, over 70 participant responses have been gathered within the previously outlined beta testing sessions. The majority of participants accessed webGC through a local Windows PC device (61%) providing a significant amount of data for a base comparison of the "traditional" NIOSH ground control programs and the "web" applications provided within the webGC platform (Figure 45). Of the data collected through beta testing sessions showed 26% of participation coming from industry professionals and regulatory agencies with 39% of all participants accessing the web platform through a mobile device.

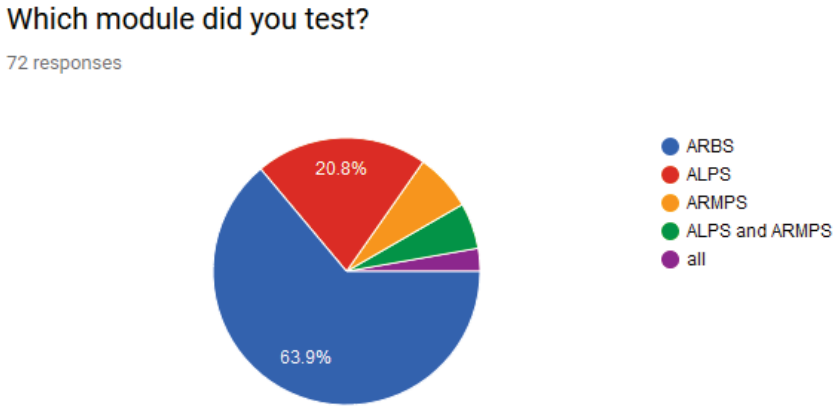



**Figure 46: Beta testing questionnaire results for module tested**

In further reviewing that data, a significant amount was collected with respect to the ARBS design application (Figure 46). While this is a significant percentage (64%), it should be stated that the ARBS design application, and associated modules ARBS Analysis and ARBS Cost, was the initial application developed within the web platform. As such, a significant amount of beta testing effort was initially performed post ARBS development as a means of ensuring platform and application stability as well as data securities before further building upon the foundation of the backend architecture. Furthermore, as more applications became available in subsequent beta testing sessions, ARBS was similarly tested against the new applications.

The utilization of a continual beta testing regime throughout the development of webGroundControl (webGC) has been instrumental in the development of a rigid back-end database and logic controller as well as a user-friendly front-end user-platform interface. Of the responses collected, 14 provided information on critical errors while 54 provided insights into platform and/or applications improvements. Some of these improvements included on-change updating of the HTML from and calculation results, modified charting mechanisms, and more user-friendly navigation through the webGroundControl web-platform.

# 5.0 Publication Record and Dissemination Efforts

The following section lists all publications and presentations throughout the development of webGroundControl and its various components.

## 5.1 Summary of Publications

1. Agioutantis, Z. and Newman, C. (2016). The Development of a Web-based Platform for Ground Control Applications. SME Preprint 16-121, SME Annual Meeting and Exposition. Phoenix, AZ.
2. Barczak, T., Agioutantis, Z., and Restrepo, J. (2016). The Contributions of the Alpha Foundation to Ground Control Research and Development. 35th International Conference on Ground Control in Mining. Morgantown, WV. (peer reviewed)
3. Newman, C., Agioutantis, Z., and Schaefer, N. (2017). Current Progress in the Development of the webGroundControl Application. SME Preprint 17-032, SME Annual Meeting and Exposition. Denver, CO.
4. Newman, C., Agioutantis, Z., and Schaefer, N. (2017). A New Web-based Platform for Ground Control Applications. Preprint 2017-0011, 51st US Rock Mechanics Symposium. San Francisco, CA. (peer reviewed)
5. Newman, C., Agioutantis, Z., and Schaefer, N. (2017). A New Generation of Web-Based Applications for Mine Design. 36th International Conference on Ground Control in Mining. Morgantown, WV. (peer reviewed)
6. Newman, C., Agioutantis, Z., and Schaefer, N. (2017). Development of a New Web-based Platform for Ground Control Applications. Mining Engineering. 69(10): pp. 34-44.
7. Newman, C., Agioutantis, Z., and Schaefer, N. (2018). Development of a Web-platform form Mining Applications. International Journal of Mining Science and Technology. https://doi.org/10.1016/j.ijmst.2017.11.016 (peer reviewed)

## 5.2 Summary of Presentations

1. Agioutantis, Z. and Newman, C. (2016). The Development of a Web-based Platform for Ground Control Applications. SME Annual Meeting and Exposition. Phoenix, AZ.
2. Newman, C., Agioutantis, Z., and Schaefer, N. (2017). Current Progress in the Development of the webGroundControl Application. SME Annual Meeting and Exposition. Denver, CO.
3. Newman, C., Agioutantis, Z., and Schaefer, N. (2017). A New Web-based Platform for Ground Control Applications. 51st US Rock Mechanics Symposium. San Francisco, CA.
4. Newman, C., Agioutantis, Z., and Schaefer, N. (2017). A New Generation of Web-Based Applications for Mine Design. 36th International Conference on Ground Control in Mining. Morgantown, WV.
5. Newman, C., Agioutantis, Z., and Schaefer, N. (2018). Addition of ARMPS-HWM and AHSM into the webGroundControl Platform. SME Annual Meeting and Exposition. Minneapolis, MN.
6. Newman, C. and Agioutantis, Z. (2018). webGroundControl: A Live Walk-through. 37th International Conference on Ground Control in Mining. Morgantown, WV.

## 5.3 Dissemination to the Participants of the International Conference of Ground Control, 2018

While beta testing of the webGroundControl project was performed within the classroom, with individual students at UK as well as during previously attended conferences, a soft release of the webGC product to the mining industry was conducted during the 2018 International Conference on Ground Control in Mining. Within the conference schedule, time was allotted for a webGC information session as well as live demo of the web-platform and its associated application modules, document upload, result mechanisms, etc. (Figure 47) The total attendance at the 2018 ICGCM Conference was 170 people associated with either mining operations, regulatory agencies, academia, or consultants. Following a 12-minute information session in which the audience was encouraged to participate during the webGC platform walk-through, over 31 users actively participated in the live demo accounting for 18% of conference attendance.


**Figure 47: Active participation during the 2018 ICGCM live walk-through**

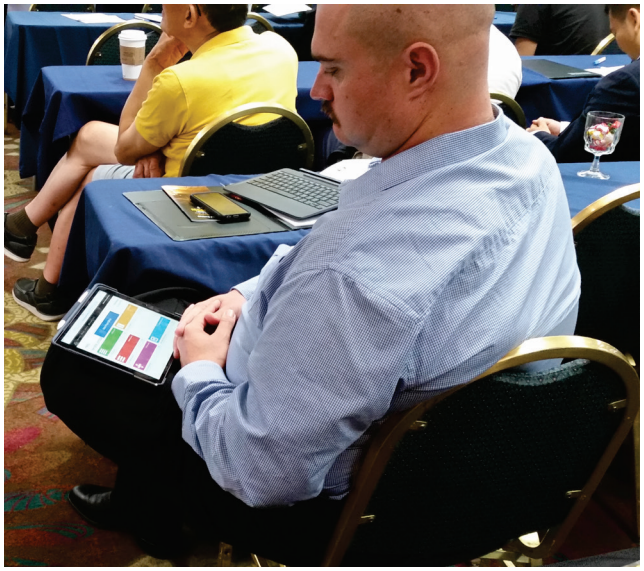


**Figure 48: ICGCM participant following along with the live walk-through presentation**

Furthermore, following the information session, multiple audience members quickly approached the webGC design team asking for more information on current and future work within the web-platform. Each ICGCM participant (Figure 48) was emailed a questionnaire to document their experience with the mine design applications as well as navigation through the platform. The results of this questionnaire will be used for further improvement of the platform, The participation in the live demo as well as the questions to the developers indicate the industry need as well as enthusiasm with the webGroundControl mine design platform.

# 6.0 Conclusions and Impact Assessment

As modern mining practices continue to develop reserves at deeper depths and in more complex geologic and geometric conditions, there has been an industry as well as regulatory demand for mine designs to better replicate site-specific conditions for the evaluation of support performance, pillar stability, stress conditions, etc. with respect to ground control. For the past 20 years, the National Institute of Occupational Safety and Health (NIOSH) developed, validated, and distributed (free of charge) a number of software tools addressing safe coal mine design with respect to ground control. These NIOSH programs, for example Analysis of Roof Bolt Stability (ARBS), Analysis of Longwall Pillar Stability (ALPS), Analysis of Retreat Mining Stability (ARMPS), Analysis of Retreat Mining Stability – Highwall Mining (ARMPS-HWM), Analysis of Horizontal Stress in Mining (AHSM), etc., have become instrumental in obtaining mine plan approvals from United States federal and state authorities for underground longwall, room-and-pillar, multiple-seam and surface highwall mining operations (MSHA, 2013; Skiles and Stricklen, 2008).

Mine design, especially with respect to ground control, is a complex procedure, may require multiple iterations and may have to be modified for different panels within the same mine. While the NIOSH suite of ground control software has provided industry professionals with tools aiding in the design of safer mining environments with respect to pillar stability in longwall and room and pillar mines, formation characterization, support requirements, etc. As cloud computing gains momentum, there is a definite need to develop internet based applications for mine design that would be easily accessible by mine personnel at all times, even underground where permitted. Mining industry professionals deserve to have up-to-date tools for safer mine design.

webGroundControl provides the mining industry with a web-platform from which one is able to access ground control design programs as well as previous analyses through a web browser. Due to current industry utilization of NIOSH ground control software packages, webGroundControl was developed as an online web-platform providing users with access to existing NIOSH ground control applications (ARBS, ALPS, ARMPS, ARMPS-HWM and AHSM). Each mine design application not only allows users to easily access and input site-specific input parameters but also provided multiple output options such as scenario results (HTML and PDF formats), parametric analyses, as well as a scenario plan view of user defined geometries. Furthermore, webGroundControl has been structured such that it can be easily expanded for future inclusion of additional mine design applications. Additionally, webGroundControl allows users to store maps, pictures, and other supporting information pertaining to a specific design defined within the platform. Similarly, to aid in project collaborations as well as maintaining transparency, webGroundControl allows for Project sharing between users with full editing rights or “read-only” access. webGroundControl is available with respect to both free public and private (corporate) licenses.

The significant impact webGroundControl will have on the mining industry is providing industry professionals with faster and easier access to existing mine designs, in field calculations (if needed), and instant online collaboration between planning personnel and operations engineers. The shared webGroundControl platform allows for more transparent calculations and analyses in cases of variable conditions as well as the recognition of problematic areas under a specific design scenario. Due to the potential impact to underground safety, industry professionals have embraced webGroundControl as a means of directly and quickly accessing and sharing design analyses and is seen as a new paradigm

for mining engineering computer applications. This was further confirmed by the number of live participants at the 2018 ICGCM technical information session and live walk -through. Furthermore, it is expected that new needs will emerge within the industry resulting in further populating the web platform with additional applications and tools for mine design.

# 7.0 Recommendations for Future Work

As previously stated within this report, one of the significant features of the webGroundControl mine design platform is its ability to easily integrate future mine design software with respect to the current and future needs of the mining industry.

As an example, at the 2018 ICGCM, the new Analysis of Coal Pillar Stability (ACPS) software was presented and released to the mining industry. The Analysis of Coal Pillar Stability (ACPS) integrates the Analysis of Longwall Pillar Stability (ALPS), Analysis of Retreat Mining Pillar Stability (ARMPS), and Analysis of Multiple Seam Stability (AMSS) software packages into a single pillar design framework. ACPS encapsulates significant advances have been achieved in the science of pillar design during the past 30 years. ACPS utilizes the previously validate NIOSH ground control programs but also incorporates the latest research with respect to pillar design, an expanded multiple seam case history database, and a new method to evaluate room and pillar panels containing multiple rows of "leave" blocks and bleeder pillars left in place during pillar recovery operations. By integrating ALPS, ARMPS, and AMSS into a single pillar design framework, ACPS represents the logical next step for pillar design.

Once ACPS is fully debugged and operational the plan is to integrate it into the webGroundControl.

## 8.0 References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