Analysis of Coal Pillar Stability Manual

Thursday, April 27, 2023

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1   ACPS Overview

Help File Updated: Thursday, April 27, 2023

1.1   Overview

Pillar design is one of the fundamental elements of mining engineering. Pillars are necessary to control the great weight of the overburden during all phases of underground mining. Without stable pillars, ground control is impossible.

Thirty years ago, the Analysis of Longwall Pillar Stability (ALPS) inaugurated a new era in coal pillar design. ALPS was the first empirical pillar design technique to consider the abutment loads that arise in retreat mining, and the first to be calibrated using an extensive database of longwall mining case histories. ALPS was followed by the Analysis of Retreat Mining Stability (ARMPS) and the Analysis of Multiple Seam Stability (AMSS). These methods incorporated other innovations including the Coal Mine Roof Rating (CMRR), the Mark-Bieniawski pillar strength formula, and the pressure arch loading model. They also built upon ever larger case history databases and employed more sophisticated statistical methods.

The Analysis of Coal Pillar Stability (ACPS) now integrates all three of the older software packages into a single pillar design framework. ACPS also incorporates the latest research findings in the field of pillar design, including an expanded multiple seam case history database and a new method to evaluate Room-and-Pillar panels containing multiple rows of pillars left in place during pillar recovery. ACPS also includes updated guidance and warnings for users, and features upgraded Help files and graphics.

References

1.2   Structure of ACPS

ACPS users begin with the "Input Project Description" screen. Two basic project types can be defined. The "Development/Room-and-Pillar" module is used for the design of main headings and production panels. Options for this type of project are "multiple seam" and "pillar recovery." The other type of project, a "Longwall Gate," also has the multiple seam option, though it is only applicable to the development phase of a gate entry's service life.

The standard ACPS input screen for Development/ Room-and-Pillar projects allows the user to input the depth of cover, the mining height, and other mining parameters that define the pillar geometry. The new "advanced geometry" option allows all entry spacings, crosscut spacings, and crosscut angles to be specified for each individual pillar in a pillar row (Figure 1).

When the Retreat Option is selected, the user can specify (Figure 2):

- Whether there is just the active retreat mining in the pillar system being evaluated, or if there are pre-existing worked-out panels (side gobs) on one or both sides of the active panel,
- The extent of the active gob, and the width of any side gobs,
- The width(s) of the barrier pillar(s) separating the active panel from the side gobs,
- The depth of any slab cuts taken from the barrier pillars, and
- Whether a row of bleeder pillars has been left within a side gob, and the width of those bleeder pillars.

ACPS' most significant new feature for retreat mining is that it can now simulate a wide variety of leave pillar configurations within the active panel (Figure 3).

The Multiple Seam Option provides two distinct evaluations of potential effects of a multiple seam interaction. The first is a pillar Stability Factor (SF) calculation that incorporates the multiple seam loads. This calculation requires data relating to the previous seam mining, such as the interburden distance and the type of remnant structure.

The second multiple seam evaluation is of the entry stability, focusing on the expected integrity of roof and rib conditions. The ACPS calculations for this evaluation are slightly different from the former AMSS calculations because they are based on an expanded database and a new statistical analysis.

A new feature of ACPS is a "CMRR estimator" that helps users select appropriate values of this critical entry stability parameter. The tool can be used when reliable geologic data is available from core logs or underground observations, but no strength testing has been conducted. The ACPS CMRR estimates are conservative and coalfield-specific, and based on experience with the most common roof geologies throughout the US. For example, the CMRR of Central Appalachian shale is estimated to be about 45, while the estimates for weaker Illinois Basin shales are 38-40.

The Longwall Gate project module closely resembles the former ALPS program on which it is based. The primary purpose of the module is to help size pillars to maintain the stability of the longwall tailgate. A new feature of the Longwall Gate module is that panel widths and abutment angles can now be specified for individual longwall panels. The CMRR estimator can also be used to help obtain input CMRR values, which are needed to help determine the appropriate tailgate pillar SF.

The multiple seam option is only available for the development phase of an ACPS longwall gate entry project. In fact, an equivalent analysis of a longwall gate development can be conducted using either the Longwall Gate module or the Development/Room-and-Pillar module. The calculations for the longwall "bleeder," and "isolated" loading conditions are likewise now consistent in both modules.

1.3   ACPS Calculations Overview

Pillar design fundamentally consists of three basic steps:

- Estimating the loading that will be applied to the pillars during all the phases of mining;
- Estimating the load-bearing capacity of the pillar system, and;
- Calculating "stability factors" (SF) by comparing the load to the load-bearing capacity.

A final step is interpreting the SF. In ACPS, the interpretation is founded in statistical analysis of large databases of real world mining case histories.

ACPS determines the SF for a *pillar system*, not individual pillars. Experience has shown that a single pillar may be undersized, but if it can shed its excess load to adjacent pillars, then overall stability can be maintained. In the Longwall module, the gate pillar system is evaluated. In the Development/Room-and-Pillar module, the pillar system is defined with a width equal to the width of the mains or panel being evaluated, and a breadth equal to five times the square root of the depth of cover (DEPAMZ = 5 * SQRT(H)) (Figure 5). For a pillar system beneath 900 feet of cover, for example, its breadth is (5 * 30) = 150 feet.

In a retreat project, when leave pillars are employed within the active retreat panel, ACPS re-defines the retreat pillar system to include only those pillars on the active pillar line (Figure 3).

The ACPS load bearing capacity calculation begins by determining the sizes of all the pillars. Then the strength of each pillar is determined, using the Mark-Bieniawski pillar strength formula (Figure 4). The pillar strength is then multiplied by the pillar's area to obtain the pillar's load bearing capacity.

In an ACPS Longwall Gate project, the individual pillar strengths are added together to determine the total load-bearing capacity of the longwall gate entry pillar system, expressed per foot of longwall gate. The load bearing capacity of the pillar system in a development / room -and-pillar project is determined by adding together the capacities of all the pillars within the pillar system. Projects using the Retreat Mining option also require the calculation of the load bearing capacities of the barrier pillars.

The ACPS pillar load calculation begins with the tributary area approximation, which states that the pillars carry the entire weight of the overburden directly above them (Figure 6a). When the pillar system is at least 80 feet deeper than it is wide, however, a "pressure arch" is assumed to form (Figure 6b). The pressure arch transfers some of the tributary area load to presumed solid coal or barrier pillars on either side of the pillar system. For a Development project, the pillars carry the load within the pressure arch.

Retreat mining causes abutment loads to be transferred to the pillars. The "abutment angle" concept is used to estimate the magnitude of these abutment loads in both Retreat and Longwall Gate projects (Figure 7). In the Multiple Seam module, a simple two-dimensional numerical model that is incorporated into ACPS is used to estimate the multiple seam loads. The total load applied to the pillars is the sum of the development, abutment, and multiple seam loads.

The SF is determined by dividing the load-bearing capacity of the pillars within the pillar system by the total applied load. The design criteria suggested by NIOSH are still considered to be appropriate.

1.4   Origins of ACPS

Pillars have been used since the earliest days of mining. The first scientific pillar design method for US coal mines was developed more than a century ago. Yet as late as the 1980's no design technique had achieved wide acceptance, and few pillars were truly engineered (Mark, 2006). Most mines sized their pillars using local rules of thumb that were based on past experience. Pillar failures (or "squeezes") occurred relatively frequently, particularly during pillar recovery, and were considered an inevitable part of mining.

The advent of modern longwall mining added to the difficulties. Longwall gate pillars were expected to maintain access to the longwall face, including the tailgate side of the panel. Early pillar design methods did not consider the heavy abutment loads that are generated by longwall mining, however. The 1984 Wilberg Mine Disaster, in which 27 miners were trapped by a headgate fire and could not escape because roof falls blocked the tailgate entry, tragically illustrated the potential consequences of inadequate gate entry ground control.

The Analysis of Longwall Pillar Stability (ALPS) was developed in direct response to the Wilberg Mine Disaster. The two dimensional "abutment angle" concept was developed to provide estimates of retreat mining abutment loads, based on an extensive stress measurement research program (Mark, 1990). ALPS used the Bieniawski formula to

estimate pillar strengths, though that formula is only appropriate for square pillars. A Stability Factor (SF) was then calculated by comparing the load to the load-bearing capacity of the longwall pillar system.

When applied to the few available case histories, however, it was clear that the ALPS pillar SF could not predict tailgate stability on its own. Roof support, entry width, and most critically, roof geology needed to be considered as well. The Coal Mine Roof Rating (CMRR) rock mass classification was therefore developed so that geologic factors could be quantified and integrated into the longwall pillar design process (Mark and Molinda, 2005). Ultimately, a large database of case histories was collected during visits to longwall mines throughout the US, and modern multi-variate statistical techniques were used for the first time to analyze the data (Mark et al., 1994). The study resulted in simple ALPS design guidelines that considered all the key elements of the tailgate stability problem.

Pillar design for room-and-pillar retreat mining was pursued next. During the decade before 1994 pillar recovery operations had been associated with about 25% of all roof fall fatalities underground, and in addition at least 12 massive pillar collapses had occurred (Mark et al., 1997a; Mark et al., 1997b). The Analysis of Retreat Mining Pillar Stability (ARMPS) was developed as a first step towards addressing these retreat mining hazards. ARMPS employed the same "abutment angle" loading model as ALPS, but extended it to three dimensions (Mark and Chase, 1997). It also modeled a wide variety of mining geometries, including both production pillars and barrier pillars. The original ARMPS database included 140 room-and-pillar mining case histories, and the method explained the data very well up to depths of 650 feet or so. Two subsequent research projects added another 500 cases to the database, mainly from mines with depths of cover exceeding 750 feet. ACPS now incorporates the pressure arch loading model, which was derived from statistical analysis of the case history data (Mark, 2010).

After more than a century of underground coal mining, many of the remaining coal reserves in the US are affected by multiple seam interactions. These very complicated phenomena can result in subsidence or stress transfers that cause roof falls, rib failure, floor heave, and even coal bursts. The Analysis of Multiple Seam Stability (AMSS) was developed to help mine planners assess the likelihood and potential severity of such interactions. The AMSS database included 344 case histories representing the most difficult conditions encountered in the Western and Central Appalachian coalfields (Mark et al., 2007). Each of the case histories was defined by 22 variables, and a two dimensional version of the numerical model LaModel (Heasley and Akingube, 2004) was employed to estimate the multiple seam loads arising from an interaction. Logistic regression was used to winnow these down to six key parameters which were then combined into a design equation. AMSS has two components, one that predicts pillar failures and the other entry stability issues.

By 2018, the ALPS, ARMPS, and AMSS pillar design methods were used in nearly every underground coal mine in the US. Their success can be attributed to three main factors (Mark, 2015):

- They are reliable because they are based on case histories which represent the broad range of actual mining experience in the US,
- They are transparent because they employ concepts that can be easily understood even by non-specialists, and
- They are user-friendly because the input parameters are readily at hand, and because they have been available on high quality, easy-to-use computer platforms.

Although no statistics on pillar failures are collected on a regular basis, it is clear that improved pillar design has greatly reduced their incidence in US coal mines. Longwall tailgate blockages have been rare in recent years, and typically only affect short segments of the gateroad. Squeezes are very unusual today during pillar recovery, and massive collapses are almost unheard of. The near-universal use of barrier pillars, particularly under deep cover, has significantly reduced the risk of coal bursts.

Better pillar design has also contributed to the greatly improved overall ground control safety record of the US industry. The connection is clearest in the case of pillar recovery. Once miners realized that squeezes resulted from inadequate pillars, and not from "poor caving," they were free to install more roof support and leave large final stumps. With more effective ground control only one miner has been killed by a pillar recovery roof fall in the decade since 2007, compared with 19 in the decade prior (Mark and Gauna, 2016).

There has been one significant blemish on this record, however. In 2007, the catastrophic pillar failure at the Crandall Canyon Mine resulted in the deaths of six miners and three rescuers. MSHA's investigation found that a root cause of the disaster was that the "dimensions of pillars within the active workings, as well as dimensions of the adjoining barrier pillars, did not provide sufficient strength to withstand stresses" (MSHA, 2008). The investigation further found that the process used to design the pillars was flawed because the "ARMPS analysis of the pillar dimensions was inappropriately applied" and the numerical model analysis was "faulty."

The Crandall Canyon disaster confirmed the need for reliable, user-friendly pillar design techniques for coal mining. In the initial wake of the disaster, the ARMPS program was strengthened with new pop-up user warnings and an expanded help file. Significant technical improvements, notably the pressure arch loading model, were also made. AMSS and ALPS were also upgraded, but not to the same extent. ACPS now integrates all three of the older packages into a single pillar design framework.

Part II

2 The File Menu

Description:

Use the File menu option to access various file management operations such as:

Creating New Files

Opening Existing Files

Saving Files

Saving Files under Different Names (Save As)

Setting up the Printer

Printing Files

Print Preview

Browsing Text Files

Exiting the Program

2.1 Creating New Files

Description:

Use the New option to delete the existing project (if any) from memory and create a new (blank) project. All related fields are set to their initial (default) values.

Notes:

- The program will prompt the user whether to save the current file to disk.

2.2 Opening Existing Files

Description:

Use the Open option to load a file (project) into the program.

To use Open:

- Select the Open option from the File menu. The program displays a listing of the available files in the current data directory.
- Optionally, select a different drive or directory using the mouse or the cursor control keys.
- Select or enter a filename.

Notes:

- If the file extension is omitted, the default extension will be appended.
- If the current project is not saved, the program will prompt whether to save changes or not before discarding the current project data.

2.3   Saving Files

Description:

Use the Save option to save an existing file (dataset) to the drive or directory from which it was originally loaded. Any changes that were made since the last time the file was loaded will be saved back on the drive by overwriting the previous instance of that file. The filename remains the same and the project information remains loaded into the program.

To use Save:

Select the Save option from the File menu.

Notes:

- If the file has never been saved using the Save As option, choosing Save automatically displays the Save As dialogue box, which prompts for a filename before saving it.

2.4   Saving Files under Different Names (Save As)

Description:

Use the Save As option to save a file and give it a new name.

To use Save As:

- Select the *Save As* option from the File menu. The program displays a listing of the available files in the current data directory.
- Optionally, select a different drive or directory.
- Select or enter a file name.

Notes:

- If the file exists, the program will prompt whether to overwrite the existing file.
- Saving an unnamed file will default to *Save As.*

2.5   Import ARMPS Project

Description:

Use the Import ARMPS Project option to load an ARMPS data file (project) into the program.

To use Import ARMPS Project:

- Select the Import ARMPS Project option from the File menu. The program displays a listing of the available files in the current data directory. *.ARM files are filtered by default.
- A different drive or directory may be selected using the mouse or the cursor control keys.
- A different file extension may be selected.
- Select or enter a filename.

Notes:

- ARMPS project files should be saved with the latest ARMPS program version.
- Importing an ARMPS project (file) will override any information already entered into the ACPS program.

2.6   Import ALPS Project

Description:

Use the Import ALPS Project option to load an ALPS data file (project) into the program.

To use Import ALPS Project:

- Select the Import ALPS Project option from the File menu. The program displays a listing of the available files in the current data directory. *.ALP files are filtered by default.
- A different drive or directory may be selected using the mouse or the cursor control keys.
- A different file extension may be selected.
- Select or enter a filename.

Notes:

- ALPS project files should be saved with the latest ALPS program version.
- Importing an ALPS project (file) will override any information already entered into the ACPS program.

2.7   Import AMSS Project

Description:

Use the Import AMSS Project option to load an AMSS data file (dataset) into the program.

To use Import AMSS Project:

- Select the Import AMSS Project option from the File menu. The program displays a listing of the available files in the current data directory. *.AMS files are filtered by default.
- A different drive or directory may be selected using the mouse or the cursor control keys.
- A different file extension may be selected.
- Select or enter a filename.

Notes:

- AMSS project files should be saved with the latest AMSS program version.
- Importing an AMSS project (file) will override any information already entered into the ACPS program.

2.8   Setting Up the Printer

Description:

Use this option to select the printer to use for printing output and graphics. This printer becomes the Windows default printer.

To use this option:

Select the appropriate Printer from the drop-down list and click on OK.

2.9   Printing Files

Description:

Use the Print option to print the current dataset (file) from program memory to the default Windows printer. The default printer may be set using the Setting Up the Printer menu option.

Notes:

- The file is sent directly to the printer, without preview. Use the Print Preview option to preview the file and then send it to the printer.

2.10   Print Preview

Description:

The user may navigate through the Print Preview window by using the vertical scroll bar.

The text in the window can be sent directly to the printer, or it can be copied to the Windows clipboard for use in other applications.

Notes:

- This operation does not send any control characters to the printer. All output is ASCII text. The text prints in "Courier" or "Courier New" font in size 9. If these fonts are not available to the printer, then printed text will appear in the default printer font.
- Each printed page is formatted with preset margins as follows:
  ✓ left margin = 1 inch
  ✓ top margin = 1 inch
  ✓ bottom margin = 1 inch
  ✓ right margin = variable

2.11   Browsing Text Files

Description:

Use the browse option to view a text (ASCII) file in a specified directory. No editing is allowed during browsing.

Use the pattern field to specify a file pattern (i.e. *.txt). The file window will be reset to conform to the specified pattern. The default pattern is *.ACP. More than one pattern can be applied using ";" as delimiter (e.g. *.txt;*.dxf).

Use the Set Font command button to specify the type and size of font for the displayed text. These settings are saved in the ACPS.INI file.

Use the cursor control keys and vertical scroll bar to move within the browse window.

Use Ctrl-A to select all text and Ctrl-C to copy text to clipboard.

2.12   Exiting the Program

Description:

Use the Exit option when ready to exit this program and return to the original environment. The program will prompt the user to save the current file to disk, if not already saved.

Part III

3   Input Parameters

Description:

Use the Edit menu option to access various parameter input/edit forms such as:

Project Description

Development / Room-and-Pillar Parameters

Longwall Gate Parameters

3.1   Project Description

This is an arbitrary 300-character description of the model being generated. It is a recommended to make this a fairly detailed description of the specifics of the input file. This text may be a single line of characters or may contain carriage returns.

The user can select the Project Type (Development / Room-and-Pillar or Longwall Gate) and then the appropriate project options for each project type, i.e. Retreat Mining and/or Multiple Seam. The current setup can also be set as the default setup by checking the "Set as Default" checkbox.

In addition, the user can set the type of units that will be used in the current project. The program is designed to use two different sets of units:
- ft and lbs
- m and kN

Click on "Next form" to access the input forms for either Development / Room-and-Pillar or Longwall Gate.

3.2 Development / Room-and-Pillar Input Parameters

Development / Room and Pillar Input Parameters: Development

Development / Room and Pillar Input Parameters: Defaults

Development / Room and Pillar Input Parameters: Retreat

Development / Room and Pillar Input Parameters: Multiple Seam

3.2.1 Input Parameters: Development

Entry Height
The entry height is the mining height or coal seam thickness (in feet or meters). Note that the value entered here is the mined height of the pillars, which is not necessarily equal to the seam thickness. Some engineering judgment may be exercised when the seam contains a lot of rock.

The rock that is mined with the coal usually falls into one of two categories. The first is weak claystone which should be considered part of the entry height, and includes:

- most in-seam rock,
- most floor rock, and

- most draw rock beneath a rider seam.

On the other hand, competent roof rock that is mined solely for equipment clearance is often stronger than the coal. The thickness of such "cap rock" can be reduced by 50% in the entry height calculation. In other words, if 12 inches of competent cap rock is mined, only 6 inches should be added to the seam thickness to obtain the entry height. This guideline was used in the analysis of the ACPS database.

A special case might be a thick parting that includes some strong rock. In that case, the strong portion of the parting could be subject to the "50% rule" described above. A geologist or ground control professional could help determine how much of the parting is actually competent rock.

Depth of Cover
Determining the depth of cover to use in an ACPS analysis can be problematic in mountainous terrain. A study using the numerical model code LAMODEL indicated that a good estimate of the average pillar system stress could be achieved by computing the average depth of the elements within the pillar system. Based on this finding, the recommended procedure for estimating depth of cover for an ACPS analysis is:

1. Locate the point within the panel or section being analyzed where the depth of cover is greatest.
2. Draw a perpendicular line across the row of pillars that includes the point of the maximum depth of cover.
3. Define a zone that extends 200 feet (60 m) inby and 200 feet (60 m) outby the deepest cover line and determine the minimum depth of cover within that zone.

The ACPS depth of cover (H) is then the arithmetic average of those minimum and maximum depths (Figure 8a). This guideline was used in the analysis of the ACPS database.

Entry Width
The entry width is the width of the entries. Crosscuts are assumed to be the same width as the entries (in feet or meters). Note that when the case histories in the ACPS database were analyzed, the nominal entry widths were used, rather than widths adjusted for rib sloughage.
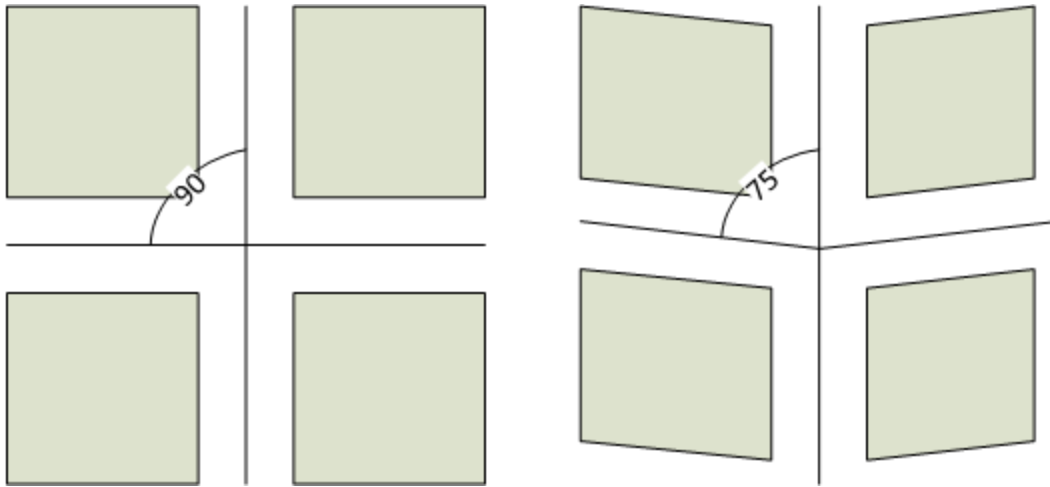
Crosscut Spacing
The center-to-center crosscut spacing helps define the pillar dimensions. Only one spacing is normally entered (in feet or meters). When the "advanced geometry" option is enabled different crosscut spacings can be specified for each column of pillars (Figure 1).

Crosscut Angle
The crosscut angle is measured between the entry and the crosscut. When the crosscuts are perpendicular to the entries, the crosscut angle is 90 degrees. Under the

"Advanced Geometry" option (Figure 1), the user may specify angles different than 90 degrees (typically 60 or 75 degrees) as shown in the sketches below.

Although, different crosscut angles may be specified for each column of pillars, it should be noted that the orientation of the crosscut angle is not significant, only the actual angle to the entries. For example a crosscut angle of 75 degrees and a crosscut angle of 105 degrees are equivalent with respect to pillar stability.

Also note that the ACPS program will try to automatically determine the belt entry (Figure 2) and plot the crosscuts appropriately around the belt entry. See examples in Figure 26.

Number of Entries
The user should specify the number of entries within the pillar system. When setting this number, the corresponding number of center-to-center spacing input boxes automatically appears. The maximum number of entries is limited to eleven in a Development/Room-and-Pillar project.

Entry Spacings
The center-to-center entry spacings help define the pillar widths. The entry spacings are entered in order. Note that pillar column #1 is the column between the first and second entry, pillar column #2 is the column between the second and third entry, and so on (in feet or meters). Changing the numbering sequence will not affect the stability factors calculated by ACPS, but it can change which leave pillars are specified in a retreat project.

Advanced Geometry
When the Advanced Geometry option is checked, the user can specify different crosscut spacings and different cross cut angles for every pillar row.

Retreat Mining

The *Retreat Mining* option should be checked to provide access to the "Retreat" tab of the input form. When the *Retreat Mining* option is not enabled, stability factors are calculated for the development case only. See Input Parameters: Retreat.

Multiple Seam

The *Multiple Seam* option should be checked to provide access to the "Multiple Seam" tab of the input form. When the *Multiple Seam* option is not enabled, stability factors are calculated for the single seam case only.

3.2.2   Input Parameters: Defaults

Note: Users generally should not adjust the values of the default parameters. The statistical analysis that went into the development of the ACPS design criteria assumed the default values for all the case history data. Using different values invalidates the design criteria.

In Situ Coal Strength

The in situ coal strength is expressed in psi or MPa. The default value is 900 psi or 6.2 MPa. Research (Mark and Barton, 1997) has shown that 900 psi is a better approximation than can normally be obtained from coal testing. In general, the only valid reason to adjust the in situ coal strength is if back-analysis of numerous site-specific case histories indicates that it is significantly different from 900 psi.

Breadth of the Pillar System

The default value of the breadth of the pillar system is five times the square root of the depth of cover (DEPAMZ = 5 * SQRT(H)).

Unit Weight of the Overburden

The unit weight of the overburden is expressed in pcf or kN/m^3. The default value is 162 pcf or 25.47 kN/m^3.

Pressure Arch Factor (Fpa)

The Pressure Arch Factor (Fpa) determines how much of the load is initially transferred from the production pillars in the pillar system to the solid coal or barrier pillars. The

default value of the Fpa is 1.0 when the pillar system width plus 80 feet (24.4 m) is greater than the depth of cover. For narrower pillar systems, i.e., when the pillar system width plus 80 feet (24.4 m) is less than the depth of cover, the default value is:

Fpa = 1 - [0.28 * Ln(H / Wt)]

3.2.3   Input Parameters: Retreat

Loading Condition
The loading condition (LC) defines the number of gob areas. Four possible loading conditions can be modeled in ACPS, as illustrated in Figure 9.

- LC1: Development Load: First mining only, no gob is present.
- LC2: One Active Retreat Section: Development load plus a front abutment load from pillar recovery in the active panel.
- LC3: Active Retreat Section and One Side Gob: Development load plus a front abutment load from the active gob, plus a side abutment load from one previously-mined side gob.
- LC4: Active Retreat Section and Two Side Gobs: Development load plus an abutment load from the active gob area, plus two additional abutment loads from two previously-mined side gobs.

Note that if there is no active pillar recovery, the effects of previously-mined side gobs may be modeled by setting the extent of the active gob equal to zero.

Leave Pillars in the Active Retreat Panel
Columns of "leave pillars" can be left in the active retreat panel gob as shown in Figure 3. One or more pillars can be left on either or both sides of the panel by checking the appropriate boxes on the input screen.

Leave Pillars in Previously Extracted Side Gobs
Pillars can also be left in previously extracted side gobs (Figure 10). Row "A" can be left in the first side gob, and row "B" in the second side gob. The width of the pillars in rows "A" and "B" are input on the "Retreat" screen. These widths are of solid coal, not center-to-center. The crosscut spacings for rows "A" and "B" are assumed to be the same as the other production pillars (or pillar row number one if advanced geometry is employed), and the crosscut angle is fixed at 90 degrees. ACPS assumes that the row "A" and row "B" leave pillars may add to the load-bearing capacity of the adjacent barrier pillars. Therefore, they cannot be enabled unless a solid barrier pillar is left in place. See Barrier Pillar Calculations for more information.

Extent of Gob (Active Gob)
The extent of the active gob is measured perpendicular to the pillar line (i.e., it is normally the length of the gob, from the start of pillar recovery to the active pillar line).

Extent of Side Gobs

For the side gobs, the gob extents are measured parallel with the pillar line (i.e., they are normally the panel widths, minus any leave pillars that may have been left within them). In both cases, they are measured outside-rib-to-outside-rib (not entry center-to-center).

Barrier Pillar Width

The width of the barrier that should be entered is solid coal, not entry center-to-center (in feet or meters). The width that is entered is the width prior to taking any slab cuts (Figure 2).

Depth of a Slab Cut

The slab cut in ACPS is taken from a barrier pillar (Figure 2). Slab cuts may only be input in Loading Conditions 3 and 4, because there are no barrier pillars in Loading Condition 2. Studies have shown that when a slab cut is taken from solid coal, little additional load is applied to the pillar system. Since a slab cut from the solid doesn't affect the SF, ACPS does not include the option to directly input a slab cut from the solid. While it is not recommended, slab cuts from the solid may be modeled indirectly by entering Loading Condition 3 or 4, and then setting the extent of the gob on the solid side to zero. Slab cuts also cannot be taken from a barrier pillar if leave pillars are adjacent to it.

Abutment Angles

The abutment angle determines how much load is carried by gob and how much is transferred to the adjacent pillars or solid coal. Figure 7 shows the abutment loading for subcritical and supercritical gob widths. The abutment angle has been calibrated from measurements of longwall abutment stresses, not from observations of caving angles or subsidence. These stress measurements indicated that an abutment angle of 21° is appropriate for normal caving conditions as shown by Mark (1990) and Colwell et al. (1999). Although the value of 21° was used to analyze all the case histories in the ACPS database, in rare cases it may be appropriate to change the abutment angle. For example, if it is known that no caving has occurred, then the abutment angle may be set to 90° to simulate zero load transfer to the gob. Other research on the abutment angle can be found in Tulu et al. (2012) and Hill et al. (2015).

3.2.4 Input Parameters: Multiple Seam

Active UNDER Previous Mining (Undermining)

Undermining occurs when the upper seam has been mined first and the lower seam is the active seam (Figure 11).

Active OVER Previous Mining (Overmining)

Overmining occurs when the upper seam is extracted after mining is complete in the lower seam (Figure 12).

Interburden Thickness

The thickness of the strata separating the active seam from previously mined seam.

Seam Thickness (Previous Seam)

The previous seam thickness is the mining height (in feet or meters). Note that the value entered here is the mined height of the pillars, which is not necessarily equal to the coal thickness. This value is used as an input to the Lam2D calculation of the multiple seam stress.

Type of Remnant Structure in Previous Seam

Remnant Structures encountered in multiple seam mining can generally be classed as either:

- gob-solid boundaries, with gob on one side, or;
- isolated remnant pillars that are surrounded by gob on two or more sides

Figure 13 shows that while a gob-solid boundary carries a single, distributed abutment load, an isolated remnant pillar is subjected to two, overlapping abutments. As a result, the stress concentration on an isolated remnant pillar is usually significantly larger than that on a gob-solid boundary, and its impact on underlying seams proportionally greater. In many cases, it is obvious how to classify a remnant structure. In other cases, some engineering judgment is required to determine whether the structure should be treated as a gob-solid boundary or an isolated remnant pillar. Two common examples:

- Development pillars adjacent to a mined-out area: The boundary between a gob area and several rows of development pillars is normally considered a gob-solid boundary.
- Longwall chain pillars between two mined-out longwall panels are normally modeled as an isolated remnant pillar. In AMSS, a chain pillar system can be approximated by combining the chain pillars into a single remnant pillar. For example, if the chain pillar system consists of two, 80-ft wide pillars, it can be modeled in AMSS as one 160-ft wide remnant. Keep in mind that the purpose of AMSS is to provide a simple first-pass analysis, so there is no need to model details like the middle entries or crosscuts of the chain pillar system.

Sometimes it is difficult to determine if a wide remnant pillar should be treated as one isolated remnant or as two gob solid boundaries. The rule of thumb used in AMSS is that if the pillar's width exceeds 5 times the square root of the depth of cover, then the pillar is so large that the abutment loads probably do not overlap, and it should be considered as two gob solid boundaries. Another problem can arise with a thin isolated remnant. If its Stability Factor is less than about 0.5, then it may have yielded and may not be able to transfer significant loads. Figure 14 shows the approximate minimum and maximum dimensions for a pillar to be considered an isolated remnant.

Width of Remnant

The width of the remnant pillar is generally the smallest dimension of the remnant. Where the remnant's dimensions are highly irregular, some engineering judgment may be required.

Supplemental Support

Supplemental Support can be cable bolts, trusses, superbolts, steel posts, or some other type. In the ACPS database, the density of the supplemental support was generally sufficient to carry 5-8 feet of rock load. For example, two, 30 ton capacity cable bolts every 4-8 feet along the entries.

Gob Width

The gob width is the least dimension of the gob in the previously-mined seam. For an old longwall gob, the width is almost always the face length. Room-and-pillar gob areas can assume many shapes, and so some engineering judgment may be necessary to select the appropriate minimum gob width.

Coal Mine Roof Rating (CMRR)

The Coal Mine Roof Rating (CMRR) is a 0-100 rating scale that measures the structural competence of mine roof. The CMRR can be calculated from underground exposures, or from exploratory drill core using a combination of geotechnical logging and point load testing. A NIOSH program to help in calculating the CMRR is available at http//www.cdc.gov/niosh/mining/. The "CMRR Estimator" provides some general values for some of the most common roof geologies found in the different US coalfields.

If *CMRR Manual Setting* is checked, the user can enter a value for CMRR. If *CMRR Manual Setting* is not checked then the CMRR estimator can be used to select a value for CMRR depending on the mining region. The value selected through the CMRR estimator can not be changed without checking *CMRR Manual Setting.*

3.3   Longwall Gate Input Parameters

Longwall Gate Input Parameters: Development

Longwall Gate Input Parameters: Defaults

Longwall Gate Input Parameters: Longwall Retreat

Longwall Gate Input Parameters: Multiple Seam

3.3.1   Input Parameters: Development

Entry Height

The entry height is the mining height or coal seam thickness (in feet or meters). Note that the value entered here is the mined height of the pillars, which is not necessarily equal to the seam thickness. Some engineering judgment may be exercised when the seam contains a lot of rock.

The rock that is mined with the coal usually falls into one of two categories. The first is weak claystone which should be considered part of the entry height, and includes:

- most in-seam rock,
- most floor rock, and
- most draw rock beneath a rider seam.

On the other hand, competent roof rock that is mined solely for equipment clearance is often stronger than the coal. The thickness of such "cap rock" can be reduced by 50% in the entry height calculation. In other words, if 12 inches of competent cap rock is mined, only 6 inches should be added to the seam thickness to obtain the entry height. This guideline was used in the analysis of the ACPS database.

A special case might be a thick parting that includes some strong rock. In that case, the strong portion of the parting could be subject to the "50% rule" described above. A geologist or ground control professional could help determine how much of the parting is actually competent rock.

Depth of Cover

Determining the depth of cover to use in an ACPS analysis can be problematic in mountainous terrain. The recommended procedure for estimating depth of cover for an ACPS longwall analysis is:

1. Locate the point within the gate entry system being analyzed where the depth of cover is greatest.
2. Draw a perpendicular line across the row of pillars that includes the point of the maximum depth of cover, and find the center point of that line.
3. Define a square, centered on that point, with sides that measure (400 feet (120 m) + Wgs), where Wgs is the width of the gate entry system (center-to-center).
4. Determine the minimum depth of cover within that zone.

The ACPS longwall depth of cover (H) is then the arithmetic average of those minimum and maximum depths (Figure 8b).

Entry Width

The entry width is the width of the entries. Crosscuts are assumed to be the same width as the entries (in feet or meters). Note that when the case histories in the ACPS database were analyzed, the nominal entry widths were used, rather than widths adjusted for rib sloughage.

Crosscut Spacing

The center-to-center crosscut spacing helps define the pillar dimensions. Only one spacing is normally entered (in feet or meters). When the "advanced geometry" option is enabled different crosscut spacings can be specified for each column of pillars (Figure 1).

Crosscut Angle

The crosscut angle is measured between the entry and the crosscut. When the crosscuts are perpendicular to the entries, the crosscut angle is 90 degrees. Under the

"Advanced Geometry" option (Figure 1), the user may specify angles different than 90 degrees (typically 60 or 75 degrees) as shown in the sketches below.

Although, different crosscut angles may be specified for each column of pillars, it should be noted that the orientation of the crosscut angle is not significant, only the actual angle to the entries. For example a crosscut angle of 75 degrees and a crosscut angle of 105 degrees are equivalent with respect to pillar stability.

Also note that the ACPS program will try to automatically determine the belt entry (Figure 2) and plot the crosscuts appropriately around the belt entry. See examples in Figure 26. In addition, the user has the option to instruct ACPS to place the belt entry on the #1 entry (see plot options) and, therefore, angled crosscuts will be plotted as shown below:
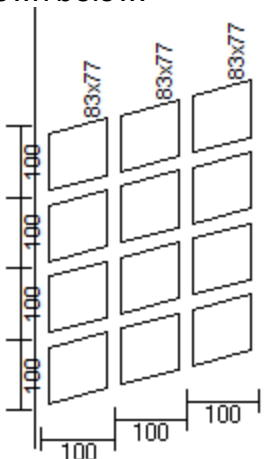
Number of Entries

The user should specify the number of entries within the gate entry system. When setting this number, the corresponding number of center-to-center spacing input boxes automatically appears. The maximum number of entries is limited to five in a longwall gate project.

Entry Spacings

The center-to-center entry spacings help define the pillar widths. The entry spacings are entered in order, starting from the first longwall panel or side gob. Note that pillar column #1 is the column between the first and second entry, pillar column #2 is the column between the second and third entry, and so on (in feet or meters).

Advanced Geometry

When the Advanced Geometry option is checked, the user can specify different crosscut spacings and different cross cut angles for every pillar row

Multiple Seam

The *Multiple Seam* option should be checked to provide access to the "Multiple Seam" tab of the input form. When the *Multiple Seam* option is not enabled, stability factors are calculated for the single seam case only. Note that the Multiple Seam option only applies to Development of the gate entries.

3.3.2   Input Parameters: Defaults

Note: Users generally should not adjust the values of the default parameters. The statistical analysis that went into the development of the ACPS design criteria assumed the default values for all the case history data. Using different values invalidates the design criteria.

In Situ Coal Strength

The in situ coal strength is expressed in psi or MPa. The default value is 900 psi or 6.2 MPa. Research (Mark and Barton, 1997) has shown that 900 psi is a better approximation than can normally be obtained from coal testing. In general, the only valid reason to adjust the in situ coal strength is if back-analysis of numerous site-specific case histories indicates that it is significantly different from 900 psi.

Unit Weight of the Overburden

The unit weight of the overburden is expressed in pcf or kN/m^3. The default value is 162 pcf or 25.47 kN/m^3.

Pressure Arch Factor (Fpa)

The Pressure Arch Factor (Fpa) determines how much of the load is initially transferred from the production pillars in the pillar system to the solid coal or barrier pillars. The default value of the Fpa is 1.0 when the pillar system width plus 80 feet (24.4 m) is greater than the depth of cover. For narrower pillar systems, i.e., when the pillar system width plus 80 feet (24.4 m) is less than the depth of cover, the default value is:

$$Fpa = 1 - [0.28 * Ln(H / Wt)]$$

3.3.3   Input Parameters: Longwall Retreat

Panel Widths

The panel width is the width of the longwall panel (or face length), measured from panel rib to panel rib (in feet or meters). Panel widths can be specified individually for the first and second panels.

Note1: In ACPS, the "first longwall panel" refers to the panel on the belt entry side of the gate system being evaluated (the headgate entry side), and the "second panel" refers to the panel on the other side (the tailgate entry side) of the same gate system.

Note2: When the first panel width is set to zero, the second panel width automatically defaults to zero and input is disabled.

Abutment Angles

The abutment angles may be specified for each individual panel. The default value is 21 degrees (Figure 7).

Users generally will not need to adjust the abutment angle, which determines the magnitude of the abutment loads, and the in situ coal strength, which is used in the calculation of the pillar load-bearing capacity. The research that went into the development of ALPS indicated that these two variables should be set at 21 degrees and 900 psi, respectively (Mark, 1990). In particular, research has found that there is no correlation between the performance of longwall pillars and the uniaxial compressive strength of coal specimens (Mark and Barton, 1997; Mark 1999).

Coal Mine Roof Rating (CMRR)

The Coal Mine Roof Rating (CMRR) is a 0-100 rating scale that measures the structural competence of mine roof. The CMRR can be calculated from underground exposures, or from exploratory drill core using a combination of geotechnical logging and point load testing. A program to help in calculating the CMRR is available at http//www.cdc.gov/niosh/mining/. The "CMRR Estimator" provides some general values for some of the most common roof geologies found in the different US coalfields.

Stability Factor (SF) for a Longwall Gate Project

The suggested ACPS SF for a Longwall Gate project is supplied by ACPS, not input by the user. Research suggests that, all else being equal, weaker roof requires larger pillars (Mark, 1999). The suggested ACPS Longwall Gate SF is determined by the Coal Mine Roof Rating (CMRR):

$$SF = 2.00 - 0.016 \; CMRR$$

3.3.4   Input Parameters: Multiple Seam

Active UNDER Previous Mining (Undermining)

Undermining occurs when the upper seam has been mined first and the lower seam is the active seam (Figure 11).

Active OVER Previous Mining (Overmining)
Overmining occurs when the upper seam is extracted after mining is complete in the lower seam ([Figure 12](#)).

Interburden Thickness
The thickness of the strata separating the active seam from previously mined seam.

Seam Thickness (Previous Seam)
The previous seam thickness is the mining height (in feet or meters). Note that the value entered here is the mined height of the pillars, which is not necessarily equal to the coal thickness. This value is used as an input to the Lam2D calculation of the multiple seam stress.

Remnant Structures
Remnant Structures encountered in multiple seam mining can generally be classed as either:

- gob-solid boundaries, with gob on one side, or;
- isolated remnant pillars that are surrounded by gob on two or more sides

[Figure 13](#) shows that while a gob-solid boundary carries a single, distributed abutment load, an isolated remnant pillar is subjected to two, overlapping abutments. As a result, the stress concentration on an isolated remnant pillar is usually significantly larger than that on a gob-solid boundary, and its impact on underlying seams proportionally greater. In many cases, it is obvious how to classify a remnant structure. In other cases, some engineering judgment is required to determine whether the structure should be treated as a gob-solid boundary or an isolated remnant pillar. Two common examples:

- Development pillars adjacent to a mined-out area: The boundary between a gob area and several rows of development pillars is normally considered a gob-solid boundary.
- Longwall chain pillars between two mined-out longwall panels are normally modeled as an isolated remnant pillar. In AMSS, a chain pillar system can be approximated by combining the chain pillars into a single remnant pillar. For example, if the chain pillar system consists of two, 80-ft wide pillars, it can be modeled in AMSS as one 160-ft wide remnant. Keep in mind that the purpose of AMSS is to provide a simple first-pass analysis, so there is no need to model details like the middle entries or crosscuts of the chain pillar system.

Sometimes it is difficult to determine if a wide remnant pillar should be treated as one isolated remnant or as two gob solid boundaries. The rule of thumb used in AMSS is that if the pillar's width exceeds 5 times the square root of the depth of cover, then the pillar is so large that the abutment loads probably do not overlap, and it should be considered as two gob solid boundaries. Another problem can arise with a thin isolated remnant. If its Stability Factor is less than about 0.5, then it may have yielded

and may not be able to transfer significant loads. Figure 14 shows the approximate minimum and maximum dimensions for a pillar to be considered an isolated remnant.

Gob Width
The gob width is the least dimension of the gob in the previously-mined seam. For an old longwall gob, the width is almost always the face length. Room-and-pillar gob areas can assume many shapes, and so some engineering judgment may be necessary to select the appropriate minimum gob width.

Coal Mine Roof Rating (CMRR)
The Coal Mine Roof Rating (CMRR) is a 0-100 rating scale that measures the structural competence of mine roof. The CMRR can be calculated from underground exposures, or from exploratory drill core using a combination of geotechnical logging and point load testing. A NIOSH program to help in calculating the CMRR is available at http//www.cdc.gov/niosh/mining/. The "CMRR Estimator" provides some general values for some of the most common roof geologies found in the different US coalfields.

If *CMRR Manual Setting* is checked, the user can enter a value for CMRR. If *CMRR Manual Setting* is not checked then the CMRR estimator can be used to select a value for CMRR depending on the mining region. The value selected through the CMRR estimator can not be changed without checking *CMRR Manual Setting.*

Part IV

4   CMRR Estimator

A new feature of ACPS is a "CMRR estimator" that helps users select appropriate values of this critical entry stability parameter. The tool can be used when reliable geologic data is available from core logs or underground observations, but no strength testing has been conducted. The ACPS CMRR estimates are conservative and coalfield-specific, and based on experience with the most common roof geologies throughout the US. For example, the CMRR of Central Appalachian shale is estimated to be about 45, while the estimates for weaker Illinois Basin shales are 38-40. The estimator does not consider water. It is the "dry CMRR."

The CMRR estimator can be accessed from the Multiple Seam tab of either the Development / Room-and-Pillar or the Longwall Gate input forms. In addition the estimator can be accessed through the Longwall Retreat tab of the Longwall Gate input form.

Part

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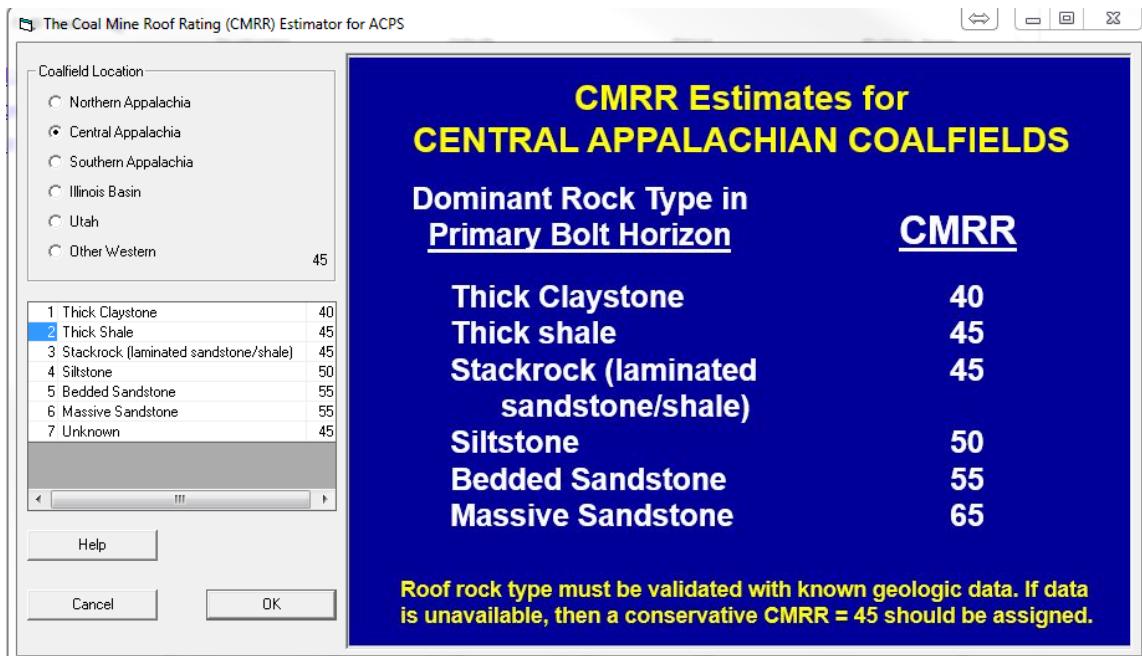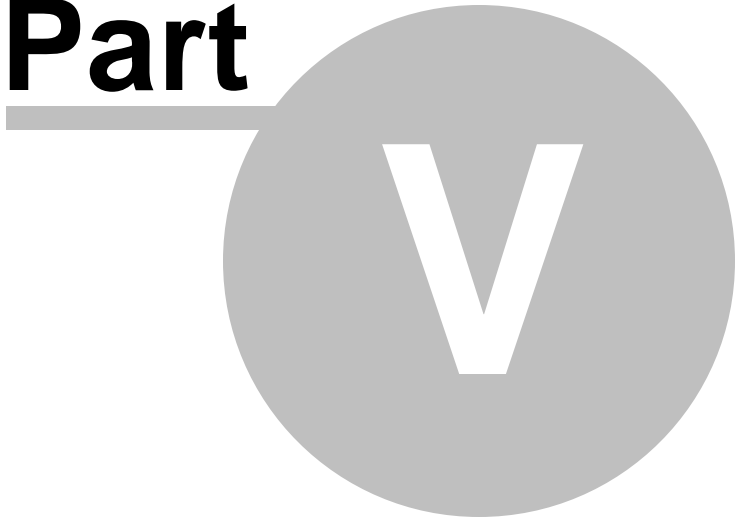
5 Interpretation of ACPS Stability Factors and Output

5.1 Types of Ground Control Failure

ACPS can help prevent ground control failures that are responsible for hazardous conditions underground, including:

- **Pillar Squeezes**, which are non-violent events that may take hours, days, or even weeks to develop. Squeezes are the most common type of pillar failure, and generally result in significant roof-to-floor convergence over a large area. They are also commonly associated with roof instability, floor heave, and rib falls. Because they develop slowly, however, the affected area is usually abandoned before there are any injuries. MSHA fatality reports show that no mineworkers have been killed by a pillar squeeze in at least the past 35 years.
- **Pillar Collapses**, which are relatively rare events that occur when a large number of overloaded pillars fail almost simultaneously. Pillar collapses often result in a destructive airblast. Most collapses in the US have occurred under low cover (less than 500 feet (150 m)), and they have been associated with the slender pillar remnants that have been left in worked-out gob areas after partial pillar recovery operations.
- **Multiple Seam Interactions**: A multiple seam interaction may occur even when the pillar SF is adequate (for example, a single-entry tunnel with solid coal on either side can be affected by an interaction). The severity of a multiple seam interaction depends on a number of factors, including the location of the past mining relative to the active mining, the type of remnant, and the roof quality and installed support in the active mine.
- **Longwall Tailgate Blockages**, which may be caused by roof instability, floor heave, and/or rib falls, and are often associated with inadequately sized pillars.
- **Coal Bursts**, which can affect just a small portion of a single pillar, or may destroy many pillars at once. The likelihood of a large burst affecting multiple pillars can be greatly reduced when properly sized pillars and barrier pillars are used. Bursts have

many causes, however, and not all of them can be eliminated by pillar design. A pre-mining burst risk analysis should be conducted whenever a potential for coal bursts exists (Mark and Gauna, 2015).

5.2   Stability Factor for the Development/Room and Pillar Module

ACPS stability factors (SF) are obtained by dividing the total load-bearing capacity of the pillar system by the total load applied to it. The critical step is the interpretation of the SF. ACPS has been verified through back analysis of mining case histories. Three separate databases have been collected:

- **Development and retreat mining**: More than 600 case histories were obtained from 10 states, almost all from mine visits (Mark, 2010). They cover an extensive range of geologic conditions, roof rock cavability characteristics, extraction methods, depths of cover, and pillar geometries. Ground conditions in each case history have been categorized as being either satisfactory or unsatisfactory.
- **Multiple seam**: The original database included 344 case histories from 36 coal mines, all from the Western or Central Appalachian coalfields (Mark et al., 2007). In 2018, 53 cases from three Northern Appalachian mines were added (Mark and Agioutantis, 2018).
- **Longwall tailgates**: Verified by back-analysis of more than 100 actual longwall mining case histories (Mark et al., 1994).

Stability Factors for the Development/Room-and-Pillar Module

The original ARMPS database, published in 1997, consisted of approximately 150 case histories, representing a broad range of cover depths. About half of these were considered "successful" because the entire retreat panel was recovered without significant ground control incident. Analysis indicated that when the depth of cover was less than 650 ft, an SF of about 1.5 was a reasonable starting point. However, for deep cover cases, two discrepancies were apparent:

- Many retreat panels with an SF well below 1.5 were successful, and;
- No single SF was able to separate the successful from the unsuccessful cases.

Later research showed that the "pressure arch" theory adequately explains these discrepancies (Mark, 2010). The "pressure arch" can reduce the load applied to the pillar system, while increasing the load applied to the barrier pillars (see Figure 6b). When the loads in the case history database were adjusted to account for the pressure arch, an SF of about 1.5 appears to be appropriate for the deeper cover conditions as well as shallow ones (see Figure 17). These suggested design guidelines are shown in Table 1.

Table 1. ACPS suggested design guidelines.

Depth of Cover (ft)	Pillar System SF	Barrier Pillar SF

< 650	1.5	-
> 650	1.5	1.5

In the ACPS Retreat option, barrier pillar behavior is directly linked to the pillars in the pillar system. If the barrier pillars are too small, large loads are transferred back to the pillar system (Figure 18), resulting in low ACPS SF values. Therefore, the barrier pillar SF is an integral part of the design criteria as shown in Table 1.

The data also show that when deep cover pillar systems are adequately shielded from side abutment loads with barrier pillars, the overall likelihood of success is greatly increased. Therefore, alternative criteria are suggested in Table 2 and Figure 19. To provide added assurance that the pressure arch is functioning effectively, it is recommended that these alternative criteria only be used where the development pillar system width is limited to 425 ft, and where the barrier pillar has been reinforced by increasing its SF to at least 2.0.

Table 2. Alternative ACPS suggested design guidelines with narrow pillar systems and reinforced barrier pillars.

Depth of Cover (ft)	Pillar System Width (ft)	Pillar System SF	Barrier Pillar SF
650 - 1,000	< 425	1.5-[0.20*((Depth-650)/350)]	> 2.0
> 1,000	< 425	1.30	> 2.0

It is important to note that the ACPS model misclassifies some pillar failure case histories as successes. All of these misclassifications were pillar squeezes, not the more hazardous collapses. Pillar collapses represent a much more direct threat to miners because they occur with little or no warning. The pillar design method should therefore provide a higher margin of safety for collapses than is necessary for squeezes.

Preventing Massive Pillar Collapses

Most of the pillar failures included in the ACPS database are "squeezes" in which the section converged over hours, days, or even weeks. Another important subset is the group of 13 massive pillar collapses (Mark et al., 1997). These occurred when undersized pillars failed and rapidly shed their load to adjacent pillars, which in turn failed. The consequences of such chain reaction-like failures typically include a powerful, destructive, and hazardous airblast.

Data collected at 12 massive collapse sites revealed that the ACPS SF was less than 1.5 in every case. What really distinguished the sudden collapses from the slow squeezes, however, was the pillar's w/h ratio. Every massive pillar collapse involved slender pillars whose w/h was 3.0 or less.

Two alternative design strategies are available to prevent massive pillar collapses:

- **Prevention**: With the prevention approach, the pillar system is designed so that collapse is highly unlikely. This can be accomplished by increasing either the SF of the pillars to exceed 2.0, or increasing their w/h ratio to be at least 4.0.
- **Containment**: In this approach, high-extraction is practiced within individual compartments that are separated by barriers. The size of the area supported by slender pillars should not exceed 3.2 acres (about 140,000 square ft), and the minimum dimension of the area should not exceed 300 ft. The slender pillars are less likely to collapse within such a small compartment, but even if they do, the consequences are not great. The barriers must be strong enough to truly isolate the compartments from each other (though the barriers may consist of rows of development pillars that are not split on retreat).

Additional information for preventing gob collapse during retreat mining is in the Resource Files. The reference is in the material under "Pillar Design for Development and Retreat Mining" titled "Preventing Massive Gob Collapse from Pillar or Floor Recovery Mining".

5.3   Stability Factor for the Longwall Gate Module

The ACPS Longwall Gate SF used in design should be based on the structural competence of the mine roof, measured by the Coal Mine Roof Rating (CMRR). The research showed that, all else being equal, weaker roof requires larger pillars. The suggested ACPS Longwall Gate SF to maintain tailgate stability is:

SF = 2.00 - 0.016 CMRR

This equation was also derived from statistical analysis of the longwall tailgate case history database (Mark, 2001). The data from the longwall case histories also showed strong relationships between the CMRR and entry width (Figure 20), and between the CMRR and primary support (Figure 21). Because the case histories only address tailgate stability, ACPS does not suggest SF values for other applications (such as bleeder entry stability).

If the ACPS Longwall Gate SF is not adequate over some portion of its length (typically where the cover is deepest), it may be possible to adjust the crosscut spacing in that area to increase the SF. Additional tailgate support may also be installed to compensate for the low SF.

5.4   Multiple Seam Evaluation

The goal of the ACPS multiple seam option is to help identify the location and likely severity of multiple seam interactions. The Multiple Seam Option provides two distinct evaluations of potential effects of a multiple seam interaction. The first is a pillar Stability Factor (SF) calculation that incorporates the multiple seam loads. Many of the failed

cases in the multiple seam database involved pillars whose Multiple Seam Pillar Stability Factors appeared inadequate.

The second multiple seam evaluation is of the entry stability, focusing on the expected integrity of roof and rib conditions. The ACPS design equation predicts the critical thickness of the interburden (INTcrit) required to minimize the likelihood of a multiple seam interaction:

INTcrit = 83*TVS – 63*UO – 54*EX + 51* REMPIL – 105*(lnCMRR20) + 340

where:

INTcrit = critical interburden (ft)
TVS = Total vertical stress on the critical pillar (thousands of psi)
UO= 1 for undermining, 0 for overmining
EX = 1 for supplemental support, 0 for none
REMPIL = 1 for isolated remnant pillar, 0 for gob-solid boundary
lnCMRR20 = ln (CMRR-20)

In some cases the INTcrit equation can predict a negative value of the critical interburden thickness. Therefore, a logistic regression model was determined using the log of the critical interburden (INTcritLN) in place of the interburden per se:

INTcritLN = EXP[0.914*TVS – 0.66*UO – 0.64 *EX + 0.546* REMPIL – 1.30*(lnCMRR20) + 7.58]

Three predicted outcomes are possible:

a) **GREEN**: If INTcrit is significantly less than the actual interburden without supplemental support, then a major multiple seam interaction can be considered unlikely.
b) **YELLOW**: If the actual interburden is less than INTcrit without supplemental support, but greater than INTcrit with supplemental support, then adding a pattern of cable bolts or other equivalent supplemental support could greatly reduce the probability of a major interaction.
c) **RED**: If INTcrit even with supplemental support is greater than the actual interburden thickness, then a major interaction should be considered likely, and it may be desirable to avoid the area entirely.

The results of this analysis are printed in the output, and they are also displayed visually on the ACPS Output window.

This equation has been incorporated into a step-by-step ACPS multiple seam design procedure that allows mine planners to evaluate each potential interaction and take steps to reduce the risk of ground control failure (Mark et al. 2007).

5.5 ACPS Warnings

WARNINGS: INPUT PARAMETERS

Warnings: Pressure Arch Factor

The ACPS case history database was analyzed with the Pressure Arch Factor (Fpa) calculated automatically (Fpa = [1-0.28 times the natural log of the depth-to-pillar system-width ratio]). Stability Factors (SF) obtained with a different Fpa may not be comparable to the suggested SF values obtained from ACPS's analysis of the database.

The Pressure Arch loading model used in ACPS was derived from analysis of case history data from the Western and Central Appalachian coalfields in the US. The overburden rock in these two coalfields is relatively strong. No research has been conducted to test the applicability of the pressure arch loading model in other coalfields.

Warnings: Retreat mining under extreme conditions

The ACPS database includes only 7 retreat mining cases where the depth of cover exceeded 2,000 feet and three of those were failures. Retreat mining should be avoided when the depth of cover exceeds 2,000 feet.

In the ACPS database, of the 19 case histories of Active Retreat and Two Side Gobs under deep cover, only 7 were successful. This extraction sequence should be accompanied by substantial side barrier pillars, or otherwise avoided.

The ACPS database includes 44 failures that occurred where the depth of cover exceeded 1,000 feet (300 m). Of these, 20 were caused by coal bursts. The authors recommend that deep cover room-and-pillar retreat coal mines conduct regular burst hazard assessments for any areas where retreat mining is proposed and the depth of cover exceeds 1,000 feet.

Warning: Massive pillar collapse

Analysis of the ACPS case history database suggests that large groups of slender pillars, with width-to-height ratios of less than 4.0, may collapse suddenly. To minimize this potentially severe hazard, an ACPS SF of at least 2.0 is recommended when such slender pillars are used. An alternative is to minimize the size of the area supported by slender pillars.

Warnings: Multiple seam

The ACPS multiple seam database contains few cases where the depth of cover exceeds 1500 feet (450 m). The ACPS predictions may not be valid.

The width of the remnant pillar is greater than 5*SQRT(H). Consider conducting analysis as gob-solid boundary.
*Note: H = Depth of cover in feet. When H is in m, then use 2.77*SQRT(H).*

The ACPS multiple seam database contains few overmining cases where the interburden thickness is less than 50 feet (15 m). The ACPS predictions may not be valid.

The ACPS multiple seam database contains few undermining cases where the interburden thickness is less than 30 feet (10 m). The ACPS predictions may not be valid.

When the interburden is less than 30 ft (10 m), an ultra-close interaction is possible. Consider stacking the pillars and assessing the stability of the interburden.

When the interburden thickness is less than 10 times the lower seam height, the upper seam may be in the fracture zone of subsidence. Special precautions may be necessary.

The ACPS multiple seam database indicates that interactions are more likely when development in the active seam is parallel with the remnant structure.

The ACPS multiple seam database contains few cases where the CMRR is less than 40. The ACPS predictions may not be valid.

The ACPS multiple seam database contains few cases where the CMRR is greater than 75. The ACPS predictions may not be valid.

WARNINGS: DEFAULTS

The ACPS case history database was analyzed with the breadth of the pillar system calculated automatically as five (5) times the square root of the depth of cover. Stability Factors (SF) obtained with a different value may not be comparable to the suggested SF values obtained from ACPS's analysis of the database.

The ACPS case history database was analyzed with an overburden unit weight of 162 pcf (2.6 g/cc). Stability Factors (SF) obtained with a different overburden unit weight may not be comparable to the suggested SF values obtained from ACPS's analysis of the database.

The ACPS case history database was analyzed with an in situ coal strength of 900 psi (6.3 MPa). Stability Factors (SF) obtained with a different in situ coal strength may not be comparable to the suggested SF values obtained from ACPS's analysis of the database. Also, ACPS research has shown that the reliability of the ACPS design method decreases substantially when laboratory coal strengths were used in place of the default value. For more information, see Help/Resources/In situ strength of coal.

The ACPS case history database was analyzed with abutment angles of 21 degrees. Stability Factors (SF) obtained with different abutment angles may not be comparable to the suggested SF values obtained from ACPS's analysis of the database.

WARNINGS: OUTPUT

Warnings related to Pillar System Stability Factors (single seam analyses)

Analysis of the ACPS case history database suggests that the risk of pillar failure is increased when the ACPS SF is less than 1.5.
Note: Applies when Depth of Cover is less than 650 feet (200 m), or where either the pillar system width exceeds 425 feet (130 m) or the Barrier Pillar SF is less than 2.0.

Analysis of the ACPS case history database suggests that when the depth of cover is H, the pillar system width is less than 425 ft, and the Barrier Pillar SF is greater than 2.0, the risk of pillar failure is increased when the ACPS SF is less than [1.5 - 0.2*((H-650)/350)] (where H is the Depth of Cover and the equation is solved for the given H).
Note: Applies when Depth of Cover is between 650 and 1,000 feet (200-300 m)

Analysis of the ACPS case history database suggests that when the depth of cover is greater than 1,000 ft, the pillar system width is less than 425 ft, and the Barrier Pillar SF is greater than 2.0, the risk of pillar failure is increased when the ACPS SF is less than 1.3.

Pillar System SF warning for multiple seam analyses

Development pillar SF is less than the suggested value of 1.50

Retreat pillar SF is less than the suggested value of 1.50

The pillar design may be inadequate to prevent a major multiple seam interaction. Consider increasing the pillar size by changing the entry spacing, the crosscut spacing, and/or the pillar width.

The ACPS pillar calculations assume that the load-bearing capacity of the barrier pillar has not been compromised by undermining or overmining. If it may have been, then additional analysis may be required.

Warnings related to Barrier Pillar Stability Factors

Analysis of the ACPS case history database suggests that when the depth of cover is greater than H the risk of pillar failure is increased when the Barrier Pillar SF is less than 1.5.
Note: Applies to single seam analyses when depth of cover (H) less than 650 feet (200 m), and to multiple seam analyses

Analysis of the ACPS case history database suggests that when the depth of cover is H, the ACPS SF is between 1.5 and 1.5 - 0.2*((H-650)/350)] (where the equation is actually solved for the given H), and the pillar system width is less than 425 ft, the risk of pillar failure is increased when the Barrier Pillar SF is less than 2.0

Note: Applies to single seam analyses when depth of cover (H) is between 650 and 1,000 feet (200-300 m)

Analysis of the ACPS case history database suggests that when the depth of cover is greater than 1,000 ft, the ACPS SF is between 1.5 and 1.3, and the pillar system width is less than 425 ft, the risk of pillar failure is increased when the Barrier Pillar SF is less than 2.0

Warning: Longwall Tailgate SF

Analysis of the ACPS longwall database suggests that the risk of tailgate blockage is increased when the Tailgate SF is less than the suggested Tailgate SF based on the CMRR.

Warning: Multiple Seam

The ACPS multiple seam database contains few cases where the total vertical stress is greater than 3500 psi (25 MPa). The ACPS predictions may not be valid.

5.6   Example 1

The following example illustrates the two separate analyses that ACPS conducts under multiple seam conditions. Adequate pillar size is a necessary, but not sufficient, condition for multiple seam stability. Even if pillars are sized adequately and the stability factor is above the recommended thresholds, a multiple seam interaction could still damage the entries.

The scenario shown below has a typical 5-entry development case with no retreat, but close to previously mined seams.

Results show that although the development stability factor exceeds the suggested value, multiple seam conditions may adversely impact the stability of these workings.
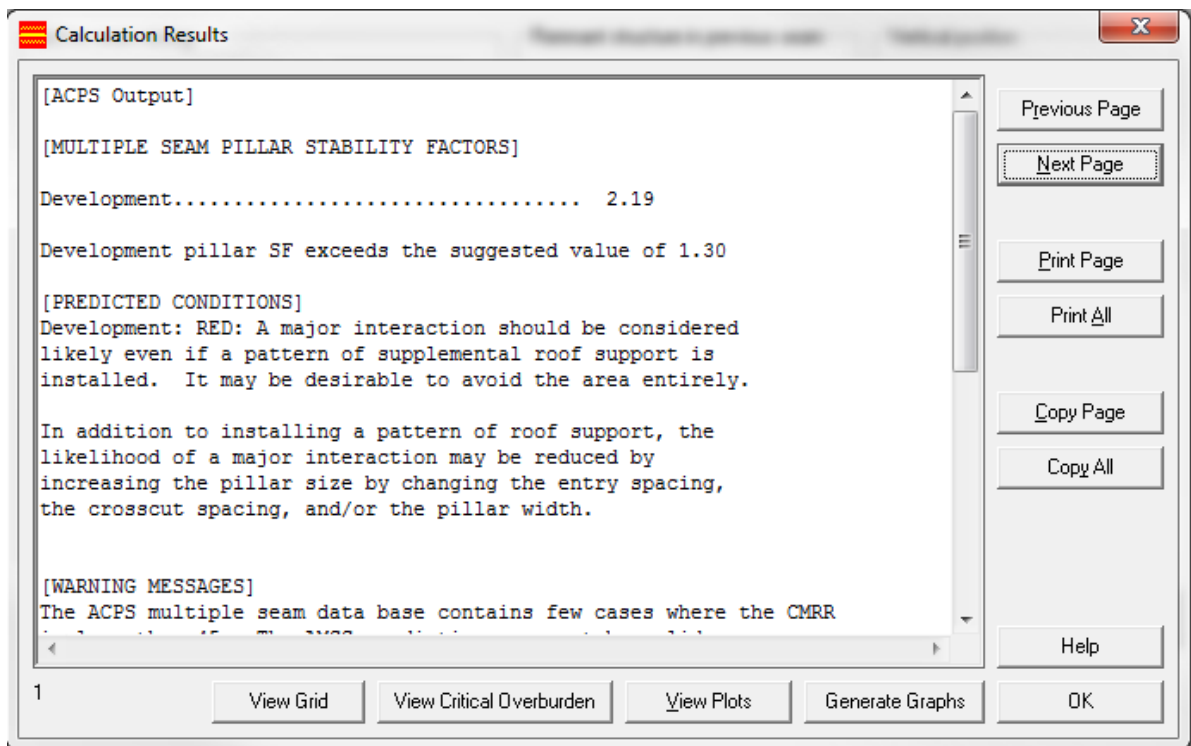
5.7   Example 2

Question:

ABC Mining company plans to do multiple seam mining. They want to mine the X seam underneath the previously mined Y seam.

What should be the input for the gob extent since there are no pillared out areas in the Y seam? The Y seam was only developed (no pillaring). The program will not take zero as gob extend. Also, is it possible roof falls in the Y seam could cause remnant issues?

Should this be handled as a Gob Solid layout or a Remnant Pillar layout?

Answer:

In general if there is only development mining in the previous seam, then there is no need to conduct a multiple seam analysis. So long as the pillars in the previous seam are intact and carrying load, and the interburden is greater than 30 feet or so, then the vertical stress in the active seam should be pretty uniform just as if no previous mining had taken place. The caveats are:

1. Is it possible that the pillars in the previous seam not be carrying their load? This can occur if the pillars are small (check their SF) or if the floor could have failed. If a squeeze has developed in the previous seam, then the old pillars might be behaving as a pseudo gob, transferring remnant loads to the active seam. In this case ACPS

(multiple seam) can be used, treating the extent of the squeezed area (pseudo gob) as the gob extent. In general, the edges of the pseudo gob would be considered gob-solid boundaries.

2. If the seams are quite close together (less than 30 feet or so), there may be an "ultra close" interaction. ACPS (multiple seam) does not address ultra close interactions; a special analysis needs to be performed.

Roof falls do not normally cause multiple seam interactions, so long as the pillars are intact.

5.8   Example 3

The following example discusses the vertical stresses calculated for a room-and-pillar retreat scenario with leave pillars under multiple seam conditions (undermining a remnant pillar). Input data are presented below as screen shots.

The calculated stresses are given below.


```
Calculation Results                                                    x

[WARNING MESSAGES]
The ACPS multiple seam data base contains few cases where the CMRR
is less than 45.  The AMSS predictions may not be valid.


[CALCULATED STRESSES]
Single seam development stress...................1423 (psi)*
Multiple seam stress.............................932 (psi)*
Development abutment stress.......................39 (psi)*
Total vertical stress (Development)..............2394 (psi)
Retreat abutment stress..........................624 (psi)*
Total vertical stress (Retreat)..................3017 (psi)

[SUGGESTED CRITICAL INTERBURDEN]
  Critical Interburden for Development...........220 (ft)
If a pattern of supplemental roof support is installed, then:
  Critical Interburden for Development...........170 (ft)

  Critical Interburden for Retreat...............266 (ft)
If a pattern of supplemental roof support is installed, then:
  Critical Interburden for Retreat...............216 (ft)
```

Previous Page | Next Page | Print Page | Print All | Copy Page | Copy All | Help

Lam2D Output | View Grid | View Critical Interburden | View Plots | Generate Graphs | OK

The average stresses on the pillar system are calculated using Lam2D as shown below.

Analysis of Coal Pillar Stability
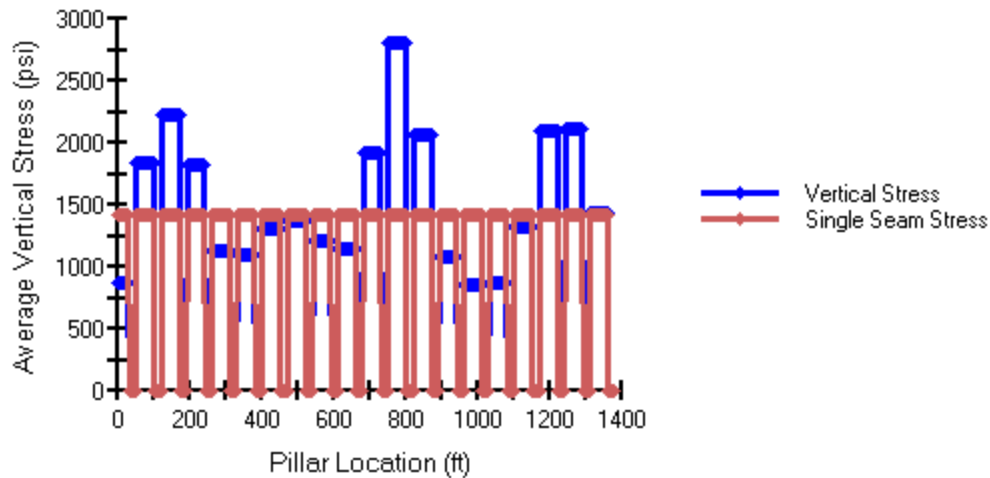
The 2D Lamodel grid essentially assumes that the panel (pillar system) is infinitely wide, and so is the remnant pillar. The grid looks like the cross section below, with everything extending infinitely out of the page.
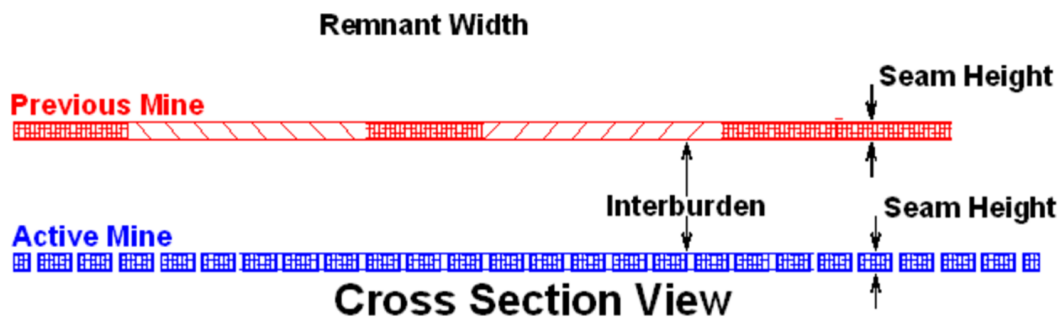
Irrespective of the number of entries that are actually in the pillar system, Lam2D gives the identical result for the "raw" multiple seam stress. ACPS multiplies that stress by the Pressure Arch Factor (Fpa) to obtain the multiple seam stress that is used in the Stability Factor calculation. Also, ACPS assumes that for a given number of entries, the Fpa is the same regardless of how many pillars are extracted (i.e., the number of leave pillars does not affect the Fpa). This also means that changing the number of leave pillars does not change the multiple seam stress. However, changing the number of entries does change the Fpa, and thus the multiple seam stress, regardless of the number of leave pillars.

This would appear to create an anomalous situation, where the multiple seam stress is higher with six (6) entries mined and just one pillar retreated than it is with five (5) entries mined and all pillars retreated. However, some of the same overburden may be responsible for both the multiple seam and the retreat load (i.e., it is double counted).

That would depend on the actual orientation and direction of the retreat mining relative to the remnant structure. (In fact, if the situation is the one modeled by the Lam2D grid as shown above, essentially all the multiple seam stress is counted again as part of the retreat stress, see figure below). So in the big picture, the ACPS simplification is probably the best approach given the actual variety of situations that are modeled.
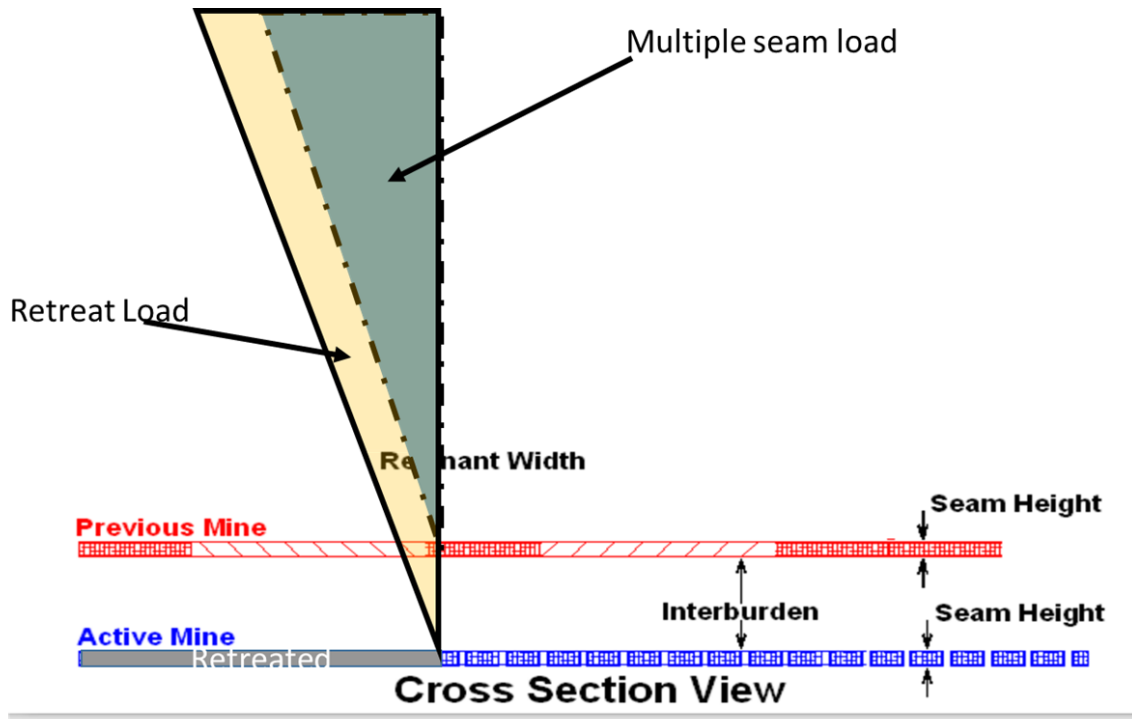
5.9   Example 4

Question:

Is it possible to calculate the SF for a 14-entry wide panel that is being retreated wall-to-wall?

Answer:

The steps are below, and the necessary output is attached.

1. Check the barrier pillars, ensure that the barrier pillar SF is adequate and that minimal side abutment load is being transferred to the active panel.
2. Set the Pressure Arch Factor to 1.0.
3. Complete the first run, using the appropriate pillar sizes and 11 entries (10 pillars extracted). The load bearing capacity of the full panel of n pillars (n=13 in the example) is then the calculated LBC of the pillar system times (n/10). In the example (see data below), it is (1.33E7 tons) times (13/10) = 1.73E7 tons (or 17,300,000 tons).

4. Complete the second run, modeling the actual gob width, to obtain the loads applied to the pillar system. A two-entry system can be used, with its width equal to the width of actual gob. In this case, the gob width is 13*70 = 910 feet. Be sure to input the correct "Extent of the Active Gob."
5. From the results of the second run, the tributary area load is 1.73E7 tons and the retreat load is 0.92E7 tons. The total load applied to the pillar system is then 1.73+0.927=2.08E7 tons.
6. The SF = 1.73/2.08 = 0.83. (Compare with SF = 0.88 which was obtained with the 11 entry run).

Note also that a very close approximation can be obtained by simply extrapolating the results from runs with 10 and 11 entries. In this case, the SF values for 10 and 11 entries are 0.90 and 0.88, for a difference of 0.02. Therefore we can estimate that adding three more pillars will reduce the SF by 0.02 times 3, or 0.06. The estimated SF for 14 entries is then 0.88-0.06 = 0.82, which is very close to the actual value of 0.83. Note that for this method to work, the extent of the gob must be at least twice the actual width of the 14 entry gob.

Example data

```
[DEVELOPMENT GEOMETRY PARAMETERS]
Entry Height.........................................6 (ft)
Depth of Cover.......................................1000 (ft)
Crosscut Angle.......................................90 (deg)
Entry Width..........................................20 (ft)
Number of Entries....................................11
Crosscut Spacing.....................................70 (ft)
Advanced Geometry Mode...............................OFF
Center to Center Distance #1.........................70 (ft)
Center to Center Distance #2.........................70 (ft)
Center to Center Distance #3.........................70 (ft)
Center to Center Distance #4.........................70 (ft)
Center to Center Distance #5.........................70 (ft)
Center to Center Distance #6.........................70 (ft)
Center to Center Distance #7.........................70 (ft)
Center to Center Distance #8.........................70 (ft)
Center to Center Distance #9.........................70 (ft)
Center to Center Distance #10........................70 (ft)

[DEFAULT PARAMETERS]
In Situ Coal Strength................................900 (psi)
Unit Weight of Overburden............................162 (pcf)
Breadth of Pillar System.............................158 (ft)
Breadth of Pillar System Mode.........Set automatically
Pressure Arch Factor.................................1
Pressure Arch Factor ModeSet by the User (not automatically)

[RETREAT MINING PARAMETERS]
Loading Condition..................ONE ACTIVE RETREAT SECTION
[Active Gob]
```

```
Extent of Active Gob..................................2000 (ft)
Abutment Angle of Active Gob..........................21 (deg)
```

Part VI

6 Calculations

- [ACPS Development/Room-and-Pillar Projects](#)
- [ACPS Longwall Gate Module Calculations](#)
- [Multiple Seam Option: LAM 2D](#)
- [Output](#)

6.1 ACPS Development/Room-and-Pillar Calculations

6.1.1 Pillar System

ACPS calculates the Stability Factor for a pillar system, rather than stability factors for individual pillars, because experience has shown that the pillars within a system work together. Thus, if an individual pillar is overloaded, it will normally transfer its excess load to adjacent pillars. If those pillars are adequately sized, the process ends there. A pillar squeeze occurs only when the adjacent pillars are also undersized. Then they fail in turn,

resulting in a "domino" of load transfer and pillar failure. The ACPS SF is therefore a measure of the overall stability of the pillar system.

The area of the pillar system is its breadth multiplied by its width. The breadth of the pillar system is five (5) times the square root of the depth of cover (DEPAMZ = 5 * SQRT(H)). This breadth was selected because measurements of abutment stress distributions (Mark, 1990) show that during retreat mining 90% of the front abutment load falls within its boundaries. In ACPS, for ease of computation, the breadth of the pillar system has the same dimensions for development mining as for retreat mining.

The width of the pillar system is the sum of all entry center-to-center spacings. If any leave pillar rows are left in an active retreat panel, the width of the retreat pillar system (RPS) is reduced to the width of the extracted area.

See also: Abutment Load Distribution.

6.1.2   Pillar Calculations

Pillar Area

The pillar area is necessary to determine the load-bearing capacity and the average stress. When angled crosscuts are employed, the pillar's area is a parallelogram, and the program accurately calculates the pillar's least dimension, length, and area.

The area of an individual pillar is calculated as follows:

CPD is the length of the pillar between crosscuts (ft). For square pillars, it is the crosscut spacing (XC) minus the entry width.

EPD is the length of the pillar between entries (ft). For square pillars, it is the entry spacing minus the entry width.

PHI is the crosscut angle.

CPD = (XC-(WE/SIN(PHI)))*SIN(PHI)
EPD(X) = (ECTR(X)-WE)*(1/SIN (PHI))

PILAREA is the area of an individual pillar (sq. ft).

PILAREA(X) = CPD*EPD(X)

Mark-Bieniawski Pillar Strength Formula

ACPS calculates the unit strength of the pillars using the Mark-Bieniawski pillar strength formula that considers the effect of pillar length:

SP = S1 * [0.64 + (0.54 w/h - 0.18 (w*w)/(h*L))]

where:

S1 = in situ coal strength, assumed = 6.2 MPa (900 psi),
w = pillar width,
h = pillar height, and
L = pillar length.

The strength of rectangular pillars can be significantly greater than square pillars, due to the greater confinement generated within them. The Mark-Bieniawski formula was derived from analyses of the pillar stress distributions implied by empirical pillar strength formulas. The formula is equivalent to the original Bieniawski formula when pillars are square. A complete discussion of the Mark-Bieniawski formula is included in Mark et al., 1995.

See also: Figure 4

Pillar Strength
First, each pillar's least dimension (WW(X)) and maximum dimension (LL(X)) are determined for use in the pillar strength formula:

```
IF CPD > WW(X) THEN
        WW(X) = W(X)
        LL(X)=CPD(X)
ELSE
        WW(X)=CPD
        LL(X) = EPD(X)
ENDIF
```

SP(X) is the strength of an individual pillar (psi) determined by the Mark-Bieniawski formula:

$$SP(X) = S1*(.64+((.54*(WW(X)/HH)) - (.18 *((WW(X)^2)/(HH*LL(X))))))$$

Pillar Load-Bearing Capacity
The load-bearing capacity of an individual pillar (PLBC(X), in lbs) is determined by multiplying the pillar strength (SP(X)) by the pillar area (PILAREA(X)):

$$PLBC(X) = SP(X) * PILAREA(X) * 144$$

Load-Bearing Capacity of the Pillar System
The load-bearing capacity of the pillar system (LBC, lbs) is determined by first calculating the load-bearing capacity of one column of pillars (the sum of all the PLBC(X)), and then multiplying that sum by the fractional number of rows of pillars within the pillar system (DEPAMZ/XC). Then load bearing capacities of all the columns of pillars are combined to obtain the total LBC of the pillar system.

6.1.3 ACPS Loads

The loadings applied to the pillar system include development loads, retreat abutment loads, and multiple seam loads. The development loads are determined by the depth of cover and the extraction ratio. Abutment loads occur as a result of retreat mining and gob formation. They are determined by the depth of cover, the width of the extraction front, the gob extents, and the abutment angles. Multiple seam loads are determined primarily by the type of remnant, the distance between the seams, and the depth of cover. All these loads may be adjusted by the pressure arch factor.

ACPS uses simple empirical equations to estimate the development and retreat loads. The numerical model LAM2D (Heasley and Akinkugbe, 2004) is used to estimate multiple seam loads.

Development Load Applied to the Pillar System
The tributary area load is simply the area of the pillar system (AMZ), multiplied by the depth of cover and the unit weight of the overburden:

LDev = H * Gamma * AMZ

Pressure Arch Factor (Fpa)
The Pressure Arch Factor (Fpa) determines how much of the load is initially transferred from the production pillars in the pillar system to the solid coal or barrier pillars. The default value of the Fpa is 1.0 when the pillar system width plus 80 feet (24.4 m) is greater than the depth of cover. For narrower pillar systems, i.e., when the pillar system width plus 80 feet (24.4 m) is less than the depth of cover, the default value is:

Fpa = 1 - [0.28 * Ln(H / Wt)]

Figure 23 shows the range of values for Fpa.

Note that when leave pillars are employed within the active panel, and the width of the retreat pillar system is reduced accordingly, Fpa is still calculated using the full panel width and not the reduced value.

6.1.4 ACPS Retreat Module Calculations

Leave Pillar Calculations
The ACPS Retreat Module allows the user to leave bleeder pillars next to the barrier pillars within the active panel and/or in the previously mined panel(s).

Leave Pillars Within the Active Retreat Panel
Leave blocks that are within the active panel reduce the front abutment load because they reduce the width of the gob, and they reduce the width of the pillar system. For example, if a panel is developed with 5 rows of pillars on 60-ft centers, then the width of the pillar system is 300 feet. If one row of pillars is left during retreat, then the front gob

width will be 240 feet and the width of the retreat pillar system is also reduced to 240 feet ([Figure 3](#)).

Leave pillars do not affect the Pressure Arch Factor (Fpa), however. In the example above, the Fpa would be calculated using the full 300 feet pillar system width. Leave pillars within the active panel also do not affect the load-bearing capacity of the barrier pillars.

Leave Pillars Within Previously Mined Panels
Rows of leave blocks in the previously extracted panel(s) can increase the effective load-bearing capacity (LBC) of the barrier pillars. In essence, any "excess" LBC that is left over from what is needed to carry the tributary area load (TribLdLvBlk) is added to the LBC of the barrier pillars.

For leave blocks on either side gob (x = 3 and/or 4):

$SPLvBlk(x) = S1 * [0.64 + ((0.54 * (WLvBlk(x) / HHEntryHeight)) - (0.18 * ((WLvBlk(x) ^ 2) / (HHEntryHeight * L))))]$

$PLBCLvBlk(x) = SPLvBlk(x) * 144 * WLvBlk(x) * LTribLdLvBlk(x) = (WLvBlk(x) + we) * Xc * H * Gamma$

$PLBCLvBar(x) = (PLBCLvBlk(x) - TribLdLvBlk(x)) * (DepAMZ / Xc)$

where PLBCLvBar is the excess LBC that will be added to the LBC of the barrier pillars.

Barrier Pillars
The strength of the barrier pillars is determined using the Mark-Bieniawski pillar strength formula, assuming that the barrier's least dimension is WBAR, and that it is a long strip pillar. Note that slab cuts have a negligible effect on the barrier pillar strength, and so slab cuts are ignored in the barrier pillar strength calculation.

SPBAR is the strength of the barrier pillar, and PLBCBAR is its load-bearing capacity.

$SPBar(x) = S1 * (0.64 + ((0.54 * (WBAR(x) / HHEntryHeight))))$

If $WBAR(x) < HHEntryHeight$ Then $SPBar(x) = 0$

$PLBCBar(x) = SPBar(x) * WBAR(x) * DepAMZ * 144$

If there is any excess load-bearing capacity from a row of leave pillars in the adjacent side gob (PLBCLvBar), then the excess is added to PLBCBAR to obtain the total effective LBC of the barrier pillar.

Remnant Barrier Pillars
The remnant barrier pillar is the portion of the barrier pillar that is inby the Retreat Pillar System (RPS). Its width (WRem) is equal to that of the barrier pillar, except when it has

been reduced by a slab cut. The effective length of the remnant, LRem, depends on the geometry of the active gob. RemStrn is the remnant barrier's strength, and PLBCREM is its load-bearing capacity:

ReMStrn(x) = S1 * [0.64 + (0.54 * (WRem(x) / HHEntryHeight))]

PLBCREM(x) = ReMStrn(x) * 144 * LRem * WRem(x)

If there is a row of leave pillars adjacent to the remnant pillar in the previous panel gob, and if those pillars have any excess load-bearing capacity (PLBCLvBar), then that excess capacity is added to PLBCREM.

6.1.5   Retreat Loads

When a gob area is created by full extraction mining, abutment loads are transferred to the adjacent pillars or solid coal. The magnitude and location of these loads depend upon a number of factors, including the depth of cover, the abutment angle, and the geometry of the gob areas. The loads are also distributed between the barrier pillars and the production pillars. If the barrier pillars are too small to carry their assigned loads, some of those loads may be transferred to the production pillars.

6.1.6   Loading Conditions

The loading condition defines the number of gob areas. Four possible loading conditions can be modeled in ACPS, as illustrated in Figure 9.

1. Development Load: Development load, no gob is present.
2. One Active Retreat Section: Development load plus an abutment load from one active gob area.
3. Active Retreat Section & One Side Gob: Development load plus an abutment load from one active gob area, plus a second abutment load from one previously mined side gob.
4. Active Retreat Section and Two Side Gobs: Development load plus an abutment load from one active gob area, plus two additional abutment loads from two previously mined side gobs.

6.1.7   Abutment Angles

The abutment angle determines how much load is carried by gob. Figure 7 shows the abutment loading for subcritical and supercritical gob widths. The abutment angle has been calibrated from measurements of longwall abutment stresses, not from observations of caving angles or subsidence. These stress measurements indicated that an abutment angle of 21° is appropriate for normal caving conditions as shown by Mark (1990) and Colwell et al. (1999). The value of 21° was used to analyze all the case histories in the ACPS database.

6.1.8 Abutment Load Distribution

When a gob area is created by full extraction mining, abutment loads are transferred to the adjacent pillars or solid coal. The abutment stresses are greatest near the gob, and decay as the distance from the gob increases.

Peng and Chiang (1984) determined from stress measurements that the extent of the abutment influence zone (D), defined as the distance from the gob edge to the point of zero stress increase, is 9.3 times the square root of the depth of cover:

D=9.3*(H^0.5)

Mark (1990) compiled another series of stress measurements, and determined that within the abutment influence zone the abutment stress (Sa) decays as the square root of the distance from the gob edge (see Figure 5). Since the total abutment load can be estimated (see abutment angle), the abutment stress distribution can be calculated explicitly.

See also: Abutment Angle, R-Factors

6.1.9 R-Factors

The front abutment load is reduced if some of the load is distributed to pillars outby the Retreat Pillar System (RPS). The R-Factor is the percentage of the total front abutment that is applied to the RPS (see Figure 5).   It is calculated as follows:

R = 1 - (((D - DepAMZ) / D) ^ 3)

Where D is the extent of the abutment influence zone, D = 9.3 * (H^0.5).

R cannot be greater than 1.0 or be less than zero. The default value for the R-factor for the active gob is 0.9, meaning that 90% of the front abutment load is applied to the RPS. This is because the default value for the breadth of the RPS is 5 * SQRT(H).

A second R-factor, called RBar(x), is determined for the side abutment load due to a previously extracted panel.   RBar(x) depends upon the width of the barrier pillar (WBar(x)):

RBar(x) = 1 - (((d - (WBAR(x) + (we / 2))) / d) ^ 3)

RBar(x) determines how the side abutment load is shared between the barrier and the RPS. Its value also cannot exceed 1.0 or be less than zero.

6.1.10 Front Abutment Loads

In retreat mining, the creation of a mined-out gob area generates abutment loads. The abutment loads are applied to the unmined coal or pillars adjacent to the gob. The front

abutment load generated by the active gob that is applied to the RPS is called LABUT(2). LABUT(2) is determined following three rules:

1. The total volume of the overburden above the mined-out area is the depth of cover multiplied by the gob area.
2. The portion of this volume whose weight is carried by the gob is determined by the abutment angle (Figure 7).
3. The weight of any element within the remaining volume is carried by the unmined coal or pillars that is nearest to it.

The calculation of LABUT(2) assumes that substantial remnant barrier pillars are present to carry a portion of the front abutment. The load generated by the active gob that is carried by the remnant barriers is called LFTBAR(X). If subsequent calculation shows that remnant barriers are too small to carry LFTBAR(X), then some of LFTBAR(X) will be transferred back to the RPS and/or to the outby barrier pillar.

Note: In the following equations, the subscript (2) refers to the front, active gob.

TBETA is the tangent of the abutment angle for the front gob: TBETA=TAN(BETA(2))

HCRIT (ft) is the distance into the gob that the influence of a panel edge would be felt, if no other panel edges interfered. If HCRIT<GEXT/2, the panel is considered supercritical. Otherwise, it is subcritical.

HCRIT=H*TBETA=H*TAN(BETA(2))

LS(2) is the weight of the wedge of overburden whose weight is responsible for the abutment load, conceptualized in two dimensions. Its units are lbs/ft. Its calculation depends on whether the panel is supercritical or subcritical. Figure 7 illustrates the two possible shapes of the side abutment.

If HCRIT < GEXT(2)/2 THEN
        LS(2)=(H^2)*(TBETA)*(GAMMA/2)
ELSE
        LS(2)=((H*GEXT(2)/2)-((GEXT(2)2)/(8*TBETA)))*GAMMA
ENDIF

The conceptualized three-dimensional volumes of overburden responsible for the front abutments are illustrated in Figure 9.

Front Abutment, Case 1
In this case, HCRIT is the minimum gob dimension. This case is a "supercritical" panel in both width (WT) and gob extent (GEXT). In other words, the front abutment is fully developed. LABUT(2) is the total front abutment load.

LABUT(2)={[(WT-(2*HCRIT))*LS(2)] + [(2/3)*H*HCRIT2*GAMMA]} * R

Front Abutment, Case 2
In this case, GEXT/2 is the minimum gob dimension. The front abutment is truncated by a short mined-out area (only several rows of pillars extracted).

LABUT(2)={[LS(2)*(WT-GEXT(2)] + [GAMMA*(H-((GEXT/2)*(1/TANBETA)))*(GEXT(2)/2)2] + [GAMMA*(2/3)*(1/TANBETA)*(GEXT(2)/2)3]} * R

Front Abutment, Case 3
In this case, WT/2 is the minimum gob dimension. Case 3 is a narrow gob, and the abutment load is truncated in both directions.

LABUT(2)= R * GAMMA * {[(H-((WT/2)*(1/TBETA)))*(WT/2)2] + [(2/3)*(1/TBETA)*(WT/2)3]}

6.1.11 Effect of the Slab Cut on the Front Abutment Load

A slab cut has the effect of increasing the width of the active panel. An increased panel width results in an increased front abutment load applied to the RPS (LABUT (2)).

ACPS only considers this effect when there is a side gob present. When a slab cut is taken from solid coal, the solid coal is assumed to be strong and stiff enough to absorb the additional load. This is why, in the "active panel only" condition (loading condition 2), ACPS does not have a slab cut option.

The slab cut does have the effect of causing a portion of the front abutment load to be applied to the outby barrier pillar. LaBarSlb(x) is this load.

6.1.12 Side Abutment Loads

Side abutment loads derive from the previously mined side gobs. The abutment angle and the gob extent determine the magnitude of the load. Figure 7 shows two cases: subcritical and supercritical panels.

The side abutment loads are shared between the barrier and the RPS. The R-factor RBar(x) determines how the load is shared. Note: In the following discussion, the subscript (X) can either be (3) or (4). A value of 3 always refers to the first side gob, while (4) refers to the second side gob.

The first step is to determine whether the side gobs are subcritical or supercritical. LS(X) is the cross-section area of the side abutment loading.

For supercritical gobs
LS(X)=(H^2)*TAN(BETA(X))*(GAMMA/2)

For subcritical gobs
LS(X)=((H*GEXT(X)/2)-((GEXT(X)^2)/(8*TAN(BETA(X)))))*GAMMA

LABUT(X) is the initial side abutment loading applied to the RPS (lbs). If the barriers are overloaded, additional side abutment load may be transferred to the RPS.

LABUT(X) = DEPAMZ * LS(X) * (1-RBAR(X))

6.1.13 Front Abutment Loads Transferred from Remnant Barriers

Once all of the initial loads applied to the RPS, the barrier pillars, and the inby remnant barrier pillars have been calculated, then the next step is to determine if some load transfers are necessary because the barriers are not large enough to carry the loads that are initially assigned to them. ACPS first evaluates the inby remnant barrier pillars, and may transfer excess loads to the outby barrier and/or the RPS.

The total load initially applied to the remnant barrier pillar is the sum of its portion of the front abutment load, its side abutment load, and its tributary area load:

RemLd(x) = (LftBar(x) + (Ls(x) * LRem) + (H * Gamma * WRem(x)) * LRem

The load-bearing capacity of the remnant barrier (including any contribution from bleeder pillars left in the previous gob) has already been calculated (PLBCRem(x)). Now a Stability Factor for the remnant barrier can be calculated as:

RemSF(x) = PLBCRem(x) / RemLd(x)

Now some of LFTBar(x) that is transferred back to the RPS (LTransRem(x)) if RemSF<1.5:

LTransRem(x) = ((0.67 * (1.5 - ReMSF(x))) * LftBar(x))

Finally, if the remnant SF is less than 1.5, then some load is also transferred to the outby barrier pillar. This load is called LFBar(x).

LFBarMax = ((WBAR(x) + (we / 2)) * Ls(2) * r) - (LaBarSlb(x))

If ReMSF(x) < 1.5 Then LFBar(x) = (0.67 * (1.5 - ReMSF(x))) * LFBarMax

where LFBarMax is the maximum allowable load transfer.

6.1.14 Pressure Arch Loads Applied to Barriers

The pressure arch loadings, LPABar(x), are the portion of the RPS loads that are initially applied to the barriers if the panel is deep and narrow enough that a pressure arch is formed. These loadings may later be re-applied to the RPS if the barriers do not have sufficient capacity to carry them.

In order to calculate the pressure arch loadings applied to the barriers, it is necessary to calculate the total RPS loadings prior to any load transfer from the barriers. For example, for loading condition 3, the total RPS load is the tributary area load (LDEV), plus the front abutment (LABUT(2)), plus the side abutment transferred across the barriers (LABUT(3)), plus any loads transferred from the inby remnant barriers (LTRANSREM(3)). The Pressure Arch Factor (Fpa) determines how much of these RPS loads are transferred to the barrier. Also, because in reality a barrier pillar will always carry some pressure arch load even when the pillar system is very wide, the LDEV portion of LPABar(x) is held constant once H/WT<2.7. The same logic applies to the second barrier for loading condition 4.

IF (H/WT) > 2.7 THEN
      LPABar(3) = [LDev + LAbut(2)] * [(1 - Fpa) / 2)]
ELSE
      LPABar(3) = LDev*(H*0.37)/WT*0.139 + [LAbut(2)] * [(1 - Fpa) / 2)]
ENDIF

LPABar(3) = LPABar(3) + (LAbut(3) + LTransRem(3)) * (1 - Fpa)

6.1.15   Barrier Pillar Loads

The total load applied to a barrier pillar (LTOTBAR) is the sum of the tributary area load (LDBAR), the front abutment load due to a slab cut (LaBarSlb(x)) or due to yielding of the inby barrier (LFBAR), the side abutment applied to the barrier (LSBAR), and the pressure arch load transferred from the pillar system (LPABar):

LDBar(x) = H * Gamma * (WBAR(x) + (we / 2)) * DepAMZ

LSBar(x) = Ls(x) * RBar(x) * DepAMZ

LTotBar(x) = LDBar(x) + LFBar(x) + LSBar(x) + LPABar(x)

LTotBar(x) = LTotBar(x) + LaBarSlb(x)

6.1.16   Loads Transferred from the Barrier Pillars to the RPS

If the outby, solid barrier pillar cannot carry the entire load assigned to it (LTotBar), then some load is transferred to the RPS. The amount of load that is transferred is called LTRANSBAR(x). In addition, LTRANSBAR(x) includes the pressure arch loads (LPABar) that cannot be carried by the barrier and are returned to the RPS.

The size of LTRANSBAR depends upon the Stability Factor for the barrier pillar (SFBAR(x)).

SFBar(x) = PLBCBar(x) / LTotBar(x)

The maximum amount of load that can be transferred is the same as if the barrier were gob (in other words, equal to a full side abutment). There are three possibilities:

1. If SFBAR is greater than 1.5, then no load transfer occurs.
2. If SFBAR falls between 1.5 and 0.5, then a portion of the side abutment and pressure arch loads are transferred to the RPS.

$$\text{LTransBar}(x) = (1.5 - \text{SFBar}(x)) * (\text{LSBar}(x) + (\text{LPABar}(x)))$$

3. If SFBAR is less than 0.5, then the entire side abutment and pressure arch loads are transferred to the RPS.

If $\text{SFBar}(x) < 0.5$ Then $\text{LTransBar}(x) = (\text{LSBar}(x) + \text{LPABar}(x))$

6.1.17 Final Pillar System Loadings

The system loadings, LTOT, are the final total loadings applied to the pillar system. The total development load applied to the pillar system is the tributary area load multiplied by the pressure arch factor:

$$\text{LTot}(1) = \text{LDev} * \text{Fpa}$$

For loading condition 2, LTOT is the tributary area load plus the front abutment, both reduced by the pressure arch factor:

$$\text{LTot}(2) = (\text{LDev} + \text{LAbut}(2)) * \text{Fpa}$$

For loading conditions 3 and 4, the total load is the tributary area load, plus the front abutment, plus the side abutment transferred across the barriers (LABUT(3 OR 4)), plus any loads transferred from the barriers (LTRANSBAR and LTRANSREM) (see Figure 24).

LTransBar may include pressure arch loads that were initially applied to the barriers.

$$\text{LTot}(3) = \text{LTot}(2) + ((\text{LAbut}(3) + \text{LTransRem}(3)) * \text{Fpa}) + \text{LTransBar}(3)$$
$$\text{LTot}(4) = \text{LTot}(3) + ((\text{LAbut}(4) + \text{LTransRem}(4)) * \text{Fpa}) + \text{LTransBar}(4)$$

6.1.18 Calculation of ACPS Stability Factors

The Pillar System Stability Factor, SF, is simply the total load-bearing capacity of the pillars within the pillar system (LBC) divided by the total load (LTOT).

$$\text{ACPSSF}(x) = \text{LBC} / \text{LTot}(x)$$

ACPS reports SF for two conditions: development and retreat. To obtain the development SF, ACPS models the conditions that exist during the development of the panel (in other words, without any active panel gob or slab cuts, but including the effect

of any previously mined side gobs). The retreat SF models the conditions as the panel is extracted, including the active gob and any slab cuts.

6.2   ACPS Longwall Gate Module Calculations

Pillar Calculations

ACPS Longwall Loads

Abutment Angles

Side Abutment Load

Abutment Load Distribution

R-Factors

Headgate and Tailgate Loading Factors

Loading Conditions

6.2.1   Pillar Calculations

The calculations of the **pillar area**, the **pillar strength** (using the Mark-Bieniawski pillar strength formula) and the **pillar load bearing area** are identical to those used in the Development/Room-and-Pillar Module. See Pillar Calculations for Development/Room and Pillar for details.

Load Bearing Capacity of the Gate Entry Pillar System

The load-bearing capacity of the Gate Entry Pillar System (LBC, lbs per foot of gate entry) is determined by calculating the load-bearing capacity of each individual pillar (PLBC(x)) per foot of gateroad. This is accomplished by dividing PLBC(x) by the appropriate crosscut spacing XC(x). Then the individual load bearing capacities are combined to obtain the total LBC of the gate entry pillar system.

6.2.2   ACPS Longwall Loads

Pressure Arch Factor (Fpa)

The Pressure Arch Factor (Fpa) determines how much of the load is initially transferred from the production pillars in the pillar system to the solid coal or barrier pillars. The default value of the Fpa is 1.0 when the pillar system width plus 80 feet (24.4 m) is greater than the depth of cover. For narrower pillar systems, i.e., when the pillar system width plus 80 feet (24.4 m) is less than the depth of cover, the default value is:

Fpa = 1 - [0.28 * Ln(H / Wt)]

Development Load Applied to the Gate Pillar System

The development load is the tributary area load (the width of the gate pillar system (Wt), multiplied by the depth of cover (H) and the unit weight of the overburden (Gamma)), multiplied by the pressure arch factor (Fpa):

LDev = H * Gamma * Wt * Fpa

Longwall Abutment Loads

When a longwall panel is mined, abutment loads are transferred to the gate pillars. The magnitude and location of these loads depends on the depth of cover, the abutment angle, and several factors that affect the how the load is divided between the gate pillars and the adjacent unmined panels.

6.2.3   Abutment Angles

The abutment angle determines how much load is carried by gob. Figure 7 shows the abutment loading for subcritical and supercritical panel widths. The abutment angle has been calibrated from measurements of longwall abutment stresses, not from observations of caving angles or subsidence. These stress measurements indicated that an abutment angle B of 21° is appropriate for normal caving conditions as shown by Mark (1990) and Colwell et al. (1999). The value of B=21° was used to analyze all the case histories in the ACPS longwall database.

6.2.4   Side Abutment Load

For the supercritical panel case (Figure 7a) the side abutment load per foot of gate entry can be calculated as:

Ls = H2 * tan(B) * Gamma/2

For the subcritical panel case (Figure 7b) the side abutment load per foot of gate entry can be calculated as:

Ls = [(H*P)/2 – (P2 / (8 * tan(B)))] * Gamma

6.2.5   Abutment Load Distribution

The abutment stresses are greatest near the gob, and decay as the distance from the gob increases. Peng and Chiang (1984) determined from stress measurements that the extent of the abutment influence zone (D), defined as the distance from the gob edge to the point of zero stress increase, is 9.3 times the square root of the depth of cover (H):

D=9.3 * SQRT(H)

Mark (1990) compiled another series of stress measurements, and determined that within the abutment influence zone the abutment stress (Sa) decays as the square root of the distance from the gob edge (see Figure 5). Since the total abutment load can be

estimated (see Abutment Angles), the abutment stress distribution can be calculated explicitly.

See also: Abutment Angles, R-Factors

6.2.6   R-Factors

The load carried by the gate pillars is reduced if some of the load is distributed to solid coal that will be the second longwall panel. The R-Factor is the percentage of the total headgate abutment that is applied to the gate pillars. It is calculated as follows:

R = 1 - [((D - Wt) / D) ^ 3]

where:
D is the extent of the abutment influence zone, D=9.3 * SQRT(H).
R cannot be greater than 1.0 or less than 0.

6.2.7   Headgate and Tailgate Loading Factors

The approach used in ACPS assumes that the headgate abutment load (Lhg) and tailgate abutment load (Ltg) are fractions of the full side abutment load (Ls). They can be represented as:

Lhg = Fhg * Ls or
Ltg = Ftg * Ls

where Fhg and Ftg are front abutment factors. Stress measurements were again used to determine appropriate values of Fhg and Ftg for ALPS (Mark, 1990):

Fhg = 0.5
Ftg = 0.7

The actual magnitudes of Fhg and Ftg are probably affected by local geology, but typical values should be sufficient for design purposes.

6.2.8   Loading Conditions

The loading condition defines the number of gob areas. Five possible longwall loading conditions can be modeled in the longwall gate module, as illustrated in Figure 25.

Development loading (Ldev)
The development load was defined in ACPS Longwall Loads.

Headgate loading (Lhg)
The pillar loading adjacent to headgate corner of the longwall face, which is equal to the development load plus the headgate abutment. Because the headgate side panel is

being extracted, it is assumed that only the tailgate panel is available to carry pressure arch loads.

Lhg = (Ldev * (1 + Fpa)/2) + (Ls) * (Fhg) * (R)

Bleeder loading (Lb)

The loading on a pillar system adjacent to a mined-out panel, which equals the development load plus the full side abutment.

Lb = (Ldev * (1 + Fpa)/2) + (Ls) * (R)

Tailgate loading (Ltg)

The loading on a double-use gate entry pillar system when it is adjacent to the tailgate corner of the longwall face, equal to the development load plus the first side abutment plus the tailgate abutment. It is assumed that no pressure arch can develop under this condition.

Ltg = Ldev + (Ls) (1 + Ftg)

Isolated loading (Li)

The loading on a pillar system located between two mined-out panels, equal to the development load plus two side abutments.

If the two side abutments are equal then
Li = Ldev + 2 Ls

If the two side abutments are different then
Li = Ldev + Ls1 + Ls2

6.3   Multiple Seam Option: LAM 2D

Introduction

Multiple Seam Option Analysis Process

Lam 2D

Lam2D Output

6.3.1   Introduction

ACPS can be used to evaluate the potential for multiple seam interactions, and provide guidance for pillar sizing, supplemental support, and other aspects of mine design. **The Multiple Seam Option provides two distinct evaluations of potential effects of a multiple seam interaction.** The first is a pillar Stability Factor (SF) calculation that incorporates the multiple seam loads.

The second multiple seam evaluation is of the entry stability, focusing on the expected integrity of roof and rib conditions. The ACPS design equation predicts the critical

thickness of the interburden (INTcrit) required to minimize the likelihood of a multiple seam interaction.

6.3.2   Multiple Seam Design Procedure

The suggested step-by-step process for using the ACPS multiple seam module is:

1. Identify critical remnant structures on the maps of mining in seams above and below the target seam. Every remnant structure that may be crossed by active mine workings should be evaluated.
2. For each potential remnant structure crossing, determine these ACPS multiple seam input parameters using the maps and core logs:
   - Depth of cover to the target seam (the seam where the mining is currently active);
   - Interburden thickness;
   - Seam heights (both seams)
   - CMRR for the roof of the target seam.
3. Check that the parameters of the case being considered fall within the limits of the ACPS multiple seam database. If the roof of the active seam is very weak (CMRR<40) or the stress is very high (>5,000 psi) then ACPS should be used with caution. The same is true if the case involves overmining and the lower coalbed thickness to interburden ratio is less than 10. If the interburden thickness is less than 30 feet in either undermining or overmining, then potential for an ultra-close interaction should be the primary consideration.
4. Determine whether the remnant structure is a gob-solid boundary or an isolated remnant pillar. A longwall chain pillar system should be modeled as a single isolated remnant pillar. See Multiple Seam Parameters for more details.
5. Enter the ACPS multiple seam parameters in the multiple seam tab of the input form. These parameters include:
   - Whether the active mining is longwall or room and pillar;
   - Whether the case is undermining or overmining;
   - The interburden thickness;
   - The type of remnant structure;
   - The active seam CMRR;
   - The previously mined seam thickness;
   - The width of gob areas, and;
   - The width of the isolated remnant pillar (if present).
6. ACPS will automatically conduct a LAM2D analysis of the remnant structure crossing to determine the multiple seam stress applied to the critical pillar in the target seam. AMSS will also determine the total vertical stress by adding the multiple seam stress to the single seam stress determined from the ACPS Development or Longwall Gate modules.
7. Check that the pillar design is adequate for the multiple seam loads. ACPS will determine the multiple seam pillar stability factor (SFMS) for the active seam, and compare it to the recommended value (see Stability Factor for the Development/Room and Pillar Module).

8. ACPS will calculate the critical interburden (INTcrit) using the design equation (see Multiple Seam Evaluation).
9. If desired, the pillar design in the target seam can be adjusted before running the program again. Changing the pillar size changes the value of the TVS, which can reduce the INTcrit. Finally, if the INTcrit falls within the "Yellow" range, it might be desirable to conduct a more detailed analysis using LaModel 3D.

See also: ACPS multiple seam Design Equation

6.3.3   Lam2D

A key difficulty in multiple seam analysis is obtaining estimates of the multiple seam stresses. Running 3-dimensional models of multiple seam situations is difficult and time consuming. Fortunately, a simple 2-dimensional model LAM2D (Heasley and Akinkugbe, 2004) was available for incorporation into ACPS. Some simplifications are necessary in order to create 2-D grids of a case history:

- Gob widths are defined by their *least dimension*;
- The remnant structure is defined as either a *gob-solid boundary* or an *isolated remnant*;
- *Standard LAM2D* defaults for the rock and coal moduli, lamination thickness, gob stiffness, and yielding properties of the previously mined seam were employed;
- Coal elements in the target seam are modeled as elastic (*non-yielding*) to better estimate the loads that the ground was attempting to apply to the critical pillars, and;
- An *out of seam extraction ratio* is applied to the target seam to account for the crosscuts.

Figure 15 shows a portion of a typical LAM2D model grid. The most important variable value that is derived from the LAM2D model incorporated into ACPS is the average **multiple seam stress** on the critical pillar. This value is then used to determine the total vertical stress and the multiple seam pillar stability factors.

6.3.4   Lam2D Output

This command button is only available when the "*Results*" command button has been invoked and a solution is available.

When the "*Lam2D Output*" command button is invoked, a child form is presented and the user can select to view the three type of output files generated by the Lam2D-AMSS solution module:
- The solution log file generated by Lam2D-AMSS, i.e. the file that shows the detailed solution steps in the Lam2D-AMSS program.
- The file generated by Lam2D-AMSS to be used as input to the original Lam2D program.
- The output file generated by Lam2D-AMSS.

6.4   ACPS Output

The text is organized in pages. By default, the user views the first output page, which is usually the second page. The first page is reserved for printing the input data.

The user may navigate through the text of a single page using the vertical scroll bar and the arrow keys. No editing is allowed.

Text can be selected (block select) and copied to the clipboard using Ctrl-C. Use Ctrl-A to select all text in a page.

In addition, use the command buttons below for additional output navigation and/or printing operations:

Previous Page: Display the previous page of output (if any).

Next Page: Display the next page of output (if any).

View Plot: Display a plot of the geometry of the mining plan with options to display dimensions or pillar properties.

View Critical Overburden: Display a color bar where the current interburden between two seams is compared to the critical values calculated by ACPS. A separate color bar for retreat will be displayed where appropriate. **Note:** This button will only appear if the multiple seam option is enabled.
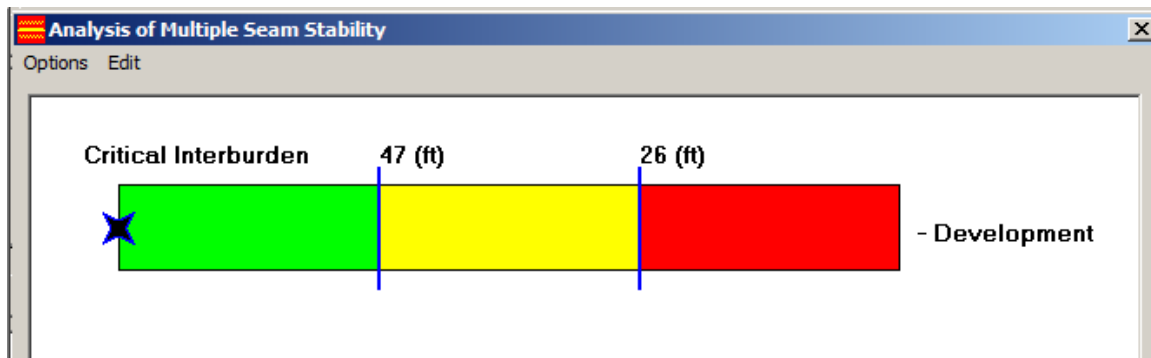
Lam2D Output: display a form that allows the user to view the output generated by the Lam2D code; the visibility of this command button is controlled by the *Enable viewing of Lam2D output file(s)* setting in the ACPS Options. **Note:** This button will only appear if the multiple seam option is enabled.

View Grid: Display the grid that is used by Lam2D for multiple seam calculations; the plot displays on grid for the upper and one for the lower seam. **Note:** This button will only appear if the multiple seam option is enabled.

Generate Graphs: A number of parametric graphs are available. The types of graphs that can be generated for each project depend on the options set for the project, i.e.,

pillar recover, advanced geometry, multiple seam. Below is a list of graphs for a multiple seam scenario.

```
Stability Factor vs Depth of Cover
Stability Factor vs Entry Height
Stability Factor vs Crosscut Spacing
Critical Interburden vs Depth of Cover
Average Vertical Stresses vs Pillar Location
Average Vertical Stresses vs Pillar Location - Detail
Vertical Stresses vs Pillar Location
Vertical Stresses vs Pillar Location - Detail
```

Print Page: Print current page to any Windows printer.

Print All: Print all pages to any Windows printer.

Copy Page: Copy current page to the clipboard.

Copy All: Copy all pages to the clipboard (pages separated by carriage return characters).

Summary of Page Layout
Screen #1 is a listing of case study input parameters

Screen #2 lists the Stability Factors for
- Development, i.e. Room-and-Pillar without any retreat mining or Longwall gate development
- Development and retreat where appropriate, i.e. Room-and-Pillar with retreat mining
- With and without multiple seam loads (multiple seam option)
- Development, headgate, bleeder, tailgate, and isolated, i.e., Longwall gate with longwall panel retreat

In the multiple seam option, Screen #2 also lists the multiple seam output (predicted entry conditions and critical interburden values for development and retreat where appropriate).

Note that the output display starts from screen #2. The user can click on "previous page" to view the input data used in the analysis and on "next page" to see the remaining screens. The user has the option to print any single screen, all screens and also to copy the contents of the output buffer to the clipboard for importing to other applications (such as a word-processing program).

Screen #3 is the design loadings screen. In the Development/Room and Pillar module, screen #3 also includes the dimensions and other characteristics of the pillar system.

Screen #4 is the pillar load-bearing capacity screen that includes the following:
- Pillar width,
- Width-to-height ratio

- The unit pillar strength calculated using the Bieniawski formula,
- The load-bearing capacities of the individual pillars, and
- The total pillar system load-bearing capacity, which is the sum of the load-bearing capacities of the individual pillars, for the gateroad (tons per foot of gateroad) or the development/room-and-pillar system (tons).

In the Development/Room and Pillar module, Screen #5 contains data on the on the barrier pillars, and Screen #6 shows data on the remnant barrier pillars.

6.4.1   Parametric Graphs

The user can create up to 12 types of parametric graphs:

- **Stability Factor vs Depth of Cover:** Separate curves are plotted for Development and Retreat or Tailgate Loading.
- **Stability Factor vs Entry Width:** Separate curves are plotted for Development and Retreat or Tailgate Loading.
- **Stability Factor vs Crosscut Spacing:** Separate curves are plotted for Development and Retreat or Tailgate Loading. This graph option is available only when the crosscut spacing is constant.
- **Critical Interburden vs Depth of Cover:** Separate curves are plotted for Development and Tailgate Loading or Retreat for the cases with and without extra support. This graph option is available only under multiple seam conditions.
- **Average Vertical Stress vs Pillar Location:** Two curves are plotted. One for the average total vertical stress and one for the average single seam stress. This graph option is available only under multiple seam conditions.
- **Average Vertical Stress vs Pillar Location - Detail:** Two curves are plotted. One for the average total vertical stress and one for the average single seam stress. The x-coordinate of the graph focuses in the area around the critical pillar. This graph option is available only under multiple seam conditions.
- **Vertical Stress vs Pillar Location:** Two curves are plotted. One for the total vertical stress and one for the single seam stress as calculated for each element in the 2D grid. This graph option is available only under multiple seam conditions.
- **Vertical Stress vs Pillar Location- Detail:** Two curves are plotted. One for the total vertical stress and one for the single seam stress as calculated for each element in the 2D grid. The x-coordinate of the graph focuses in the area around the critical pillar. This graph option is available only under multiple seam conditions.
- **Multiple Seam Stress vs Interburden Thickness:** The chart shows how the multiple seam stress changes with interburden thickness. This graph option is available only under multiple seam conditions.
- **Multiple Seam Stress vs Remnant Pillar Width:** The chart shows how the multiple seam stress changes with the width of the remnant pillar. This graph option is available only under multiple seam conditions where a remnant pillar option is specified.

In all cases the variation of the x-coordinate ranges between the values set in the ACPS Options settings:

See also: Graph Options

6.4.2   Graph Options

The user can set the basic graph formatting parameters as detailed below:

Graph Title

The graph title is a text string placed over the graph.

Graph X-axis Title

The x-axis titles selection includes twelve text fields, one for each type of parametric graph that can be specified. Note that not all graphs are available for a given analysis. These twelve fields are initially populated using the text in bold from the list below. When editing the x-axis title for a particular graph, the user is only given access to that field, while the remaining fields are disabled.

- Stability Factor vs **Depth of Cover**
- Stability Factor vs **Entry Height**
- Stability Factor vs **Crosscut Spacing**
- Stability Factor vs **First Barrier Width**
- Stability Factor vs **Second Barrier Width**
- Critical Interburden vs **Depth of Cover**
- Average Vertical Stress vs **Pillar Location**
- Average Vertical Stress vs **Pillar Location - Detail**
- Vertical Stress vs **Pillar Location**
- Vertical Stress vs **Pillar Location - Detail**
- Multiple Seam Stress vs **Interburden Thickness**
- Multiple Seam Stress vs **Remnant Pillar Width**

Graph Y-axis Title

The y-axis titles selection includes twelve text fields, one for each type of parametric graph that can be specified. Note that not all graphs are available for a given analysis. These twelve fields are initially populated using the text in bold from the list below. When editing the y-axis title for a particular graph, the user is only given access to that field, while the remaining fields are disabled.

- **Stability Factor** vs Depth of Cover
- **Stability Factor** vs Entry Height
- **Stability Factor** vs Crosscut Spacing
- **Stability Factor** vs First Barrier Width
- **Stability Factor** vs Second Barrier Width
- **Critical Interburden** vs Depth of Cover

- **Average Vertical Stress** vs Pillar Location
- **Average Vertical Stress** vs Pillar Location - Detail
- **Vertical Stress** vs Pillar Location
- **Vertical Stress** vs Pillar Location - Detail
- **Multiple Seam Stress** vs Interburden Thickness
- **Multiple Seam Stress** vs Remnant Pillar Width

Grid Style

Four grid styles are available: Horizontal lines, vertical lines, horizontal and vertical lines, no grid lines.

Graph Style

Three graph styles are available: lines, symbols, lines and symbols.

Curve Legend

This option enables or disables the legend box in the graph.

Symbol Size

With this scroll box the user can set the size of the symbols used by the graph object. The scroll box is enabled only for a graph type of "symbols" or "lines and symbols".

Default Formatting Parameter Options

There are two options for the basic formatting parameters:

- To set the formatting parameters (i.e., graph title, x-axis title, etc.) every time the graph options form is invoked.
- To set the formatting parameters to the ones used in the previous graphing session. These values are saved in the ACPS.INI file.

See also: The Graph Form

Notes:
- Graphics support is provided by Component One which is an independent graph control not included in the Microsoft Visual Basic 6.0 package.

6.4.3 The Graph Form

This form is used to display a graph generated by the calling program. The menu options available are:

File-Print

This option prints the graph to the default printer.

File-Export to Excel

This option exports the data to an Excel spreadsheet.

File-Exit

This option closes the graph form. On some occasions, the option to either keep the graph or to clear the graph is available.

Edit-Copy

This option copies the graph box to the clipboard for use in other applications.

Options-Basic Options

This option loads the graph options form which includes basic graph formatting options.

Options-Point ID

When this feature is enabled, the graph object will display the coordinates of each point graphed on the graph form. Just click on any point of any curve on the graph and the coordinates of this point will be displayed in the appropriate boxes. This feature is active when a graph is displayed.

Notes:

- Graphics support is provided by Component One which is an independent graph control not included in the Microsoft Visual Basic 6.0 package.

See also: Graph Options, Parametric Graphs

6.4.4 Display Grid

The user can view the grid that is automatically generated and passed to Lam2D for the multiple seam calculations. There are two options for the grid:

- Full Grid: where the user can view the full extend of the grid.
- Detail Grid: where the user can only view part of the grid around the critical element in the critical pillar.

It should be noted that although the horizontal extend of the grid is viewed to scale (i.e., entry widths are related to pillar lengths, etc.), the vertical scale of the grid is only indicative of the Depth of Cover and the Interburden Thickness.

The location of the critical element is also shown, when the user pans to that area.

The zoom function allows the user to zoom in and out of the grid.

See also: Grid Colors

Part VII

7 The Utilities Menu

Clear History Window
This option clears the history (activity) window.

Close/Restore History Window
This option closes or restores the history (activity) window according to the current window status.

Copy History Window
This option copies the contents of the history window to the clipboard. You can then paste them to any text handling program for further processing.

7.1 Settings

This form is used to define a number of default parameters and settings for the AMSS program:

Default Units
This setting controls the default units for a new or blank project file by configuring the Units field in the Project Description form. Upon entering and accepting project input parameters, the default setting in the Project Description form cannot be changed. This setting is saved in the ACPS.INI file.

Default File Extension for Input Files
This setting is the default 3-letter extension used in the Open and Save dialog boxes in the File Menu. This setting is saved in the ACPS.INI file.

Data Path
This setting is the default path used in the Open and Save dialog boxes in the File Menu. This setting is saved in the ACPS.INI file.

Show Disclaimer
This parameter controls whether the disclaimer message will be displayed when loading the ACPS program. This setting is saved in the ACPS.INI file.

Maximize Main Menu Window

This parameter controls whether the main menu window will be maximized when loading the ACPS program. This setting is saved in the ACPS.INI file.

Keep Recent File List

This parameter controls whether the program will keep the four (4) recently accessed data files (opened or saved) as menu items in the File Menu. This setting is saved in the ACPS.INI file.

Reminder of Annual Updates

This parameter controls whether the program will display a warning that a year has elapsed since the last update of the program. The update date is internally stored and it is not related to the install date. Annual updates ensure that any bugs that have been discovered are fixed regularly. This setting is saved in the ACPS.INI file.

Display Command History Window

This parameter controls whether the program will display recently executed commands (and their resulting actions). This setting is saved in the ACPS.INI file.

Maximum Characters in Command History Window

This parameter sets the maximum number of characters displayed in the command history window, before it is cleared. This setting is enabled only if the Display Command History Window option is enabled. This setting is saved in the ACPS.INI file.

History Font

This button sets the type and size of font used in the command history window. This setting is enabled only if the Display Command History Window option is enabled. This setting is saved in the ACPS.INI file.

Enable Toolbar

This settings controls whether the program will display a toolbar under the main menu options or not. The toolbar is not editable. This setting is saved in the ACPS.INI file.

Short Names in File List

This parameter controls whether the program will display the filenames in the recently accessed list in a short or long format (i.e. including the whole path). This setting is saved in the ACPS.INI file.

Load Last Input File

When this setting is enabled, the program will automatically load the most recently saved datafile (i.e. the top in the recently accessed files). This setting is saved in the ACPS.INI file.

Copy Example Files

When this setting is enabled, the program will automatically copy all example files from the "Program Files" directory to the user home directory (i.e. MyDocuments/MyGroundControl). This procedure runs upon every program invocation

unless disabled. The modified files will not be overridden, but missing files will be replaced. This setting is saved in the ACPS.INI file.

External Viewer

This option allows the user to specify the external ASCII viewer/editor that will be used when displaying ASCII data. The default setting in this option is to use the Notepad editor. This setting is saved in the ACPS.INI file.

7.1.1   ACPS.INI

Description:

This file is automatically created by the ACPS program the first time it is executed. It should reside in the default document directory for this program, i.e. in the MyGroundControl subdirectory of the (My) Documents directory in the computer where the program is installed (\Documents\MyGroundControl\). Note that in a network environment the Documents directory may reside on a different hard drive. The INI file contains entries such as the ones shown below (the sequence and parameter values may be different in the actual file):

[Settings]
DefaultUnits=0
DisplayActionWin=1
MaxDisplaySize=300
KeepFileNames=1
ShowDisclaim=0
DataPath=C:\Users\User\Documents\MyGroundControl\ACPS\
FileExtension=ACP

[FileMenu] MaxLastFiles=4
LastFile1=C:\Users\User\Documents\MyGroundControl\ACPS\S1.ACP
LastFile2=C:\Users\User\Documents\MyGroundControl\ACPS\S2.ACP
LastFile3=C:\Users\User\Documents\MyGroundControl\ACPS\S3.ACP
LastFile4=C:\Users\User\Documents\MyGroundControl\ACPS\S4.ACP

[TextBrowse]
BrowseFontName=Courier New
BrowseFontSize=10
BrowseFontBold=0
BrowseFontItalic=0

Note: If this file is deleted, it will be automatically reconstructed the next time the program is executed, but the various settings will default to their original values.

7.2   ACPS Options

This form is used to define a number of default parameters and settings for the AMSS program:

[Edit/Print Options](#)

[View/Plot Options](#)

[Output Options](#)

[Multiple Seam Options](#)

7.2.1   Edit/Print Options

Load the Input Form on File Open
If this option is enabled, the input project parameters form will be automatically loaded in the following situations:

* File - New is selected.
* File - Open is selected and a file is loaded.
* An existing file is loaded from the recent file list.

Default Project Type
This option allows the user to select the default project type (Room and Pillar / Development or Longwall Gate) in the ACPS Project description form.

Default Project Options
This option allows the user to select whether the Retreat option would be enabled by default for Room and Pillar / Development projects and whether the multiple seam option would be enabled for either project type.

Issue Warning when Discarding Changes in Input Form(s)
If this option is enabled, then a warning message will be displayed when the user discards changes from the input form(s), by clicking on Cancel or by closing the window form.

Create a File Association
Use this option to create an association between the program executable and the extension of the project files. Thus, double-clicking on a project file will invoke the ACPS program.

Print Module Version Information
If this option is enabled, then whenever the input data are printed, a three-line header is prepended with the program version, filename, etc.

Default CMRR Value

This option allows the user to enter a default values for the CMRR estimator and/or for the CMRR value to be used in a new project.

7.2.2   View/Plot Options

View Project File in Child Window
If this option is enabled, then the View button in the ACPS parameter entry form will launch a separate view window with a sketch of the mine plan. The image in this window can be copied or printed.

Plot Entry Spacing Dimensions
If this option is enabled, then the entry spacing dimensions will be plotted on any output plot.

Plot Crosscut Spacing Dimensions
If this option is enabled, then the crosscut spacing dimensions will be plotted on any output plot.

Dimension Crosscut Spacing ONCE
If this option is enabled, then the crosscut spacing dimension will only be plotted ONCE.

Dimension Barriers and Pillars
If this option is enabled, then the dimensions of the barriers and the gobs will also be plotted.

Longwall: Plot Belt Entry as Entry #1
If this option is enabled, then the belt entry will be entry #1, otherwise the belt entry will be the middle entry.

Plot Gob Width Options
This option controls plotting of the gob width. The gob width may be plotted in the same scale as the rest of the mine plan, or schematically (i.e., not to scale). If the "Plot gob width to scale" option is selected, then the gob width will be plotted in the same scale as the rest of the mine plan.

7.2.3   Output Options

Output Units (Strength)
If the imperial unit system is selected, the user has two options regarding the strength (pressure) units used in the output forms:

- psi [pounds (force) per square inch]
- psf [pounds (force) per square foot]

Output Units (Pressure Gradient)

If the imperial unit system is selected, the user has two options regarding the pressure gradient units used in the output forms:

- lbs/ft [pounds (force) per foot]
- tons/ft [tons (force) per foot]

Range of Parametric Analysis
These numbers control the range (minimum and maximum) of the X-Axis values to be generated when parametric graphs are requested. Default values are 80% for minimum and 120% for maximum. For example, if the x-axis of a parametric graph refers to the overburden depth, and the entered value is set to 500 (ft), then for the above values the parametric graph will be generated for x-values in the range of 400-600 as follows:

- xmin = 500 * 80/100 = 400
- xmax = 500 * (120/100) = 600

Rounding of ACPS SF
The user can select how the Stability Factors calculated by ACPS will be rounded.

- Rounded to two decimals using standard rounding procedures (e.g., 1.496 = 1.50)
- Truncated to two decimals (e.g., 1.496 = 1.49)
- Not rounded (e.g., 1.496 = 1.496)

7.2.4   Multiple Seam Options

Lam2D Cell Size
Specify the Cell Size to be used when creating the grid for the Lam2D module (in feet and m).

Single Seam Plot Stress Options
The user can select one of two options when plotting the average single seam stress under multiple seam conditions (a) Plot average single seam stress per pillar (Longwall Gate / Room-and-Pillar) or (b) Plot average single seam stress per pillar including stress shedding (Lam 2D).

Enable Viewing of Lam2D Progress Information (Parameter Forms)
If this option is enabled, then the user will be able to follow the progress of invoking and calculating stresses using Lam2D in a window at the bottom of both the "Input Longwall Gate Parameter" and the "Input Room-and-Pillar Parameter" forms. This window will only appear when the multiple seam option is selected.

Enable Viewing of Lam2D Output File(s)
If this option is enabled, then the user will be able to invoke the access three files generated by Lam2D during the calculation process as shown below. All such files are in ASCII format and they can be viewed through an ASCII file editor such as notepad.
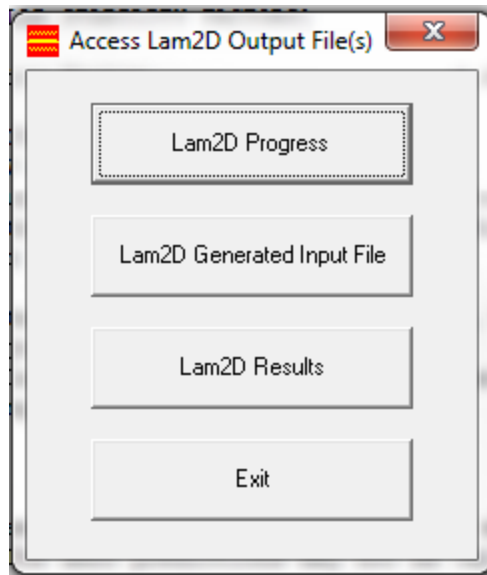
view in an ASCII editor the output generated by Lam2D. This consists mainly of two files. One file can be used as input to the standalone Lam2D program and the other is the log file generated by Lam2D_AMSS to track solution progress.

- The "Lam2D Progress" option will show the log file generated by the Lam2D which includes a listing of the input data as well as a summary of the iterative procedure.
- The "Lam2D Generated input file" option will show the actual input file that was generated and used by Lam2D to analyze the specific project.
- The "Lam2D Results" option will show the output generated by the Lam2D program that is subsequently used by the ACPS multiple seam module to calculate the multiple seam interaction.

Temporary File Location

Multiple seam calculations require the use of a number of temporary files. The user can select the location of the temporary files for multiple seam runs. This setting should not be changed for the average user. There are four available options:

- Application Directory (may not be allowed), i.e., the directory where the application has been installed.
- User Temporary Directory (Hidden) [default option], i.e. the directory under "\Documents\User\AppData\Local Settings\Temp", where User is the windows login name of each user. This directory is automatically available for each user logging into a computer, but it may be hidden from the user.
- Root Directory (may not be allowed), i.e., the C:\ directory.
- MyGroundControl Temp Directory (not Hidden) (this directory is automatically created as "Documents\MyGroundControl\Temp" during program startup if it does not already exist).

7.3   Grid Colors

This form is used to define the background and foreground colors for inseam material codes that are used in Lam2D to generate the multiple seam stress regime. These colors are used when viewing the Lam2D grid using the View Grid command button of the ACPS Output window (see below).

The program sets default colors upon initiation as shown below. The user can change these colors to custom settings. These custom settings are saved in the ACPS.INI file.
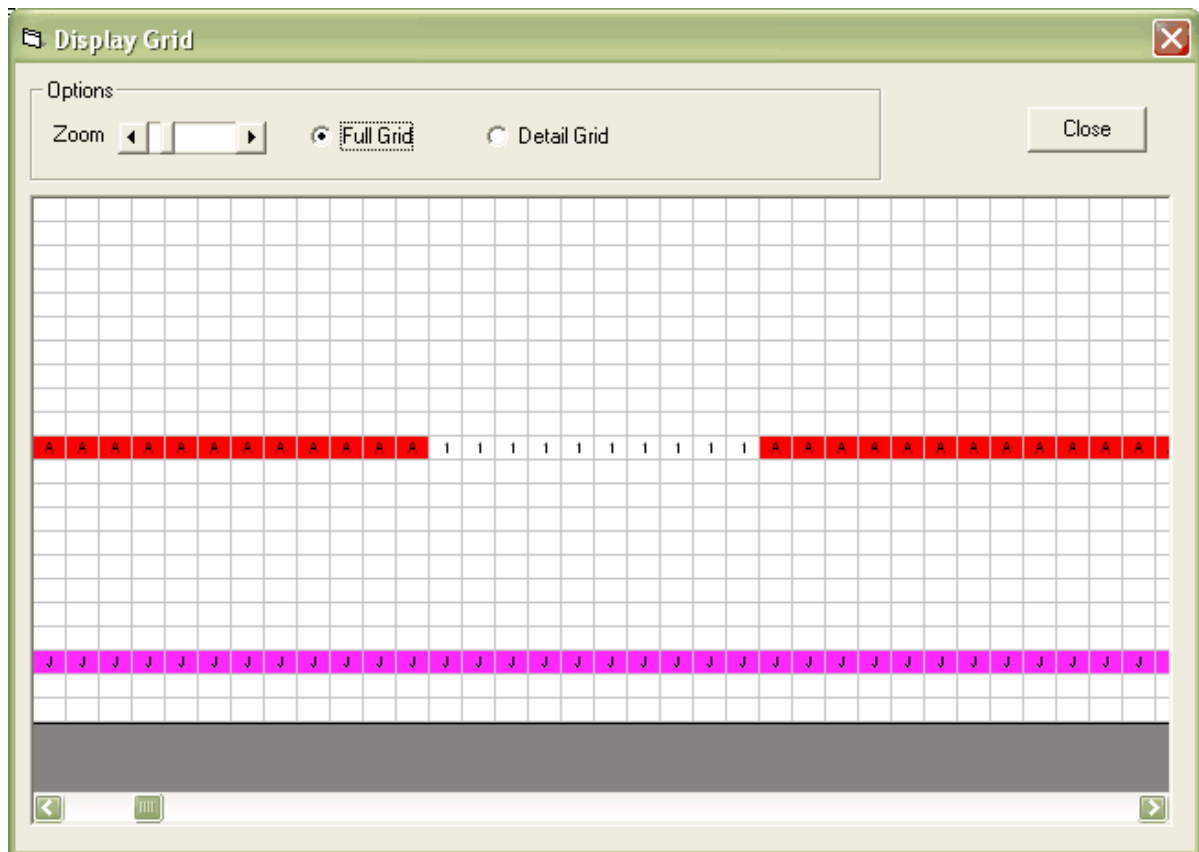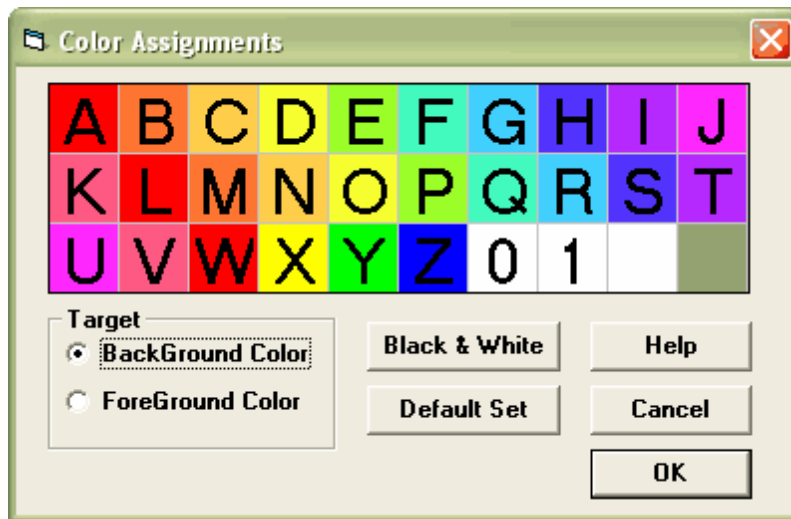
7.4 Unit Conversions

This utility can be used to convert between English and metric units for 4 types of units:

Pressure
Conversion between psi (pounds per square inch), Pa (Pascals) and MPa (MegaPascals) is supported.

Length
Conversion between feet, inches, meters and centimeters is supported.

Stress (Pressure) Gradient
Conversion between psi/ft (psi per foot), psi/in (psi per inch), MPa/m (MegaPascal per meter) and Pa/m (Pascal per meter) is supported.

Load Gradient
Conversion between lbs/ft (pounds per foot), lbs/in (pounds per inch), kN/m (kiloNewton per meter) and MN/m (MegaNewton per meter) is supported.

Notes:
- 1 Pa = 1 Newton per square meter
- 1 psi = 1 pound per square inch

7.5 File Conversion

This utility can be used to convert the **current** file to a different set of units. If the file is in English units, then it can only be converted to metric and vice versa.

Notes:
- The current file should already be saved before accessing the conversion option.

- After conversion, the converted file becomes the current file.
- A prefix is added to the name of the converted file.

Part VIII
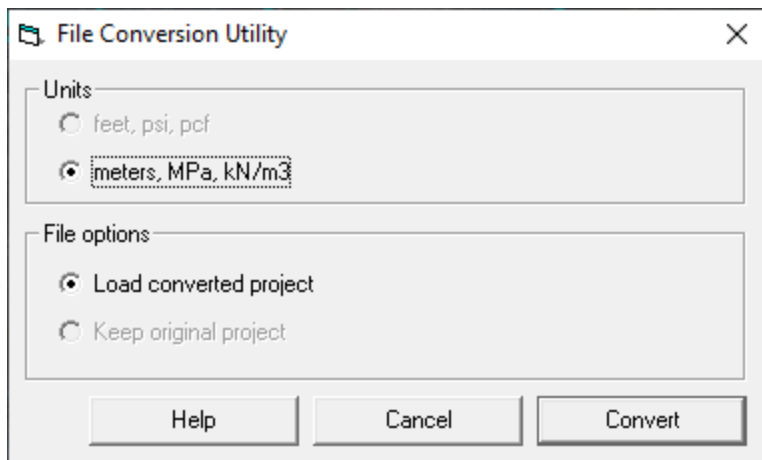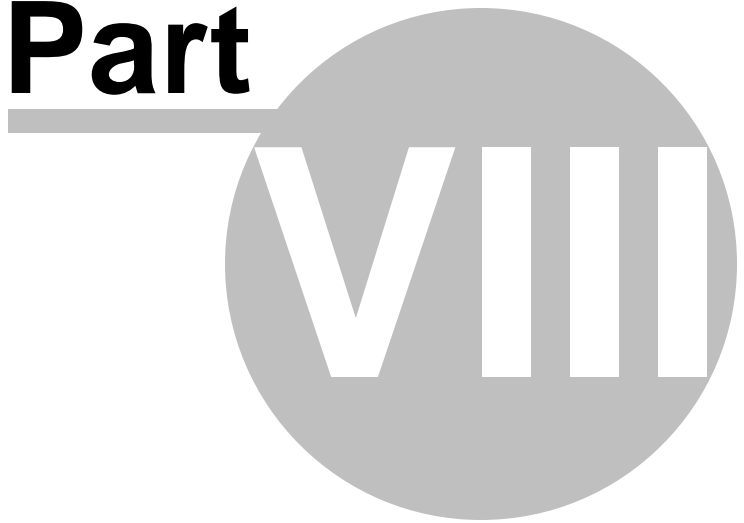
8 The Help Menu

Use the Help menu option to access various Help options, such as

- example files and related documents
- resource files
- the program disclaimer
- information on program updates
- information on the program authors

8.1 Examples

A number of examples are distributed with ACPS. The examples are divided into six groups:
1. Development
2. Side gob bleeder
3. Longwall gate
4. Well pad
5. Pillar recovery, and
6. Multiple seam
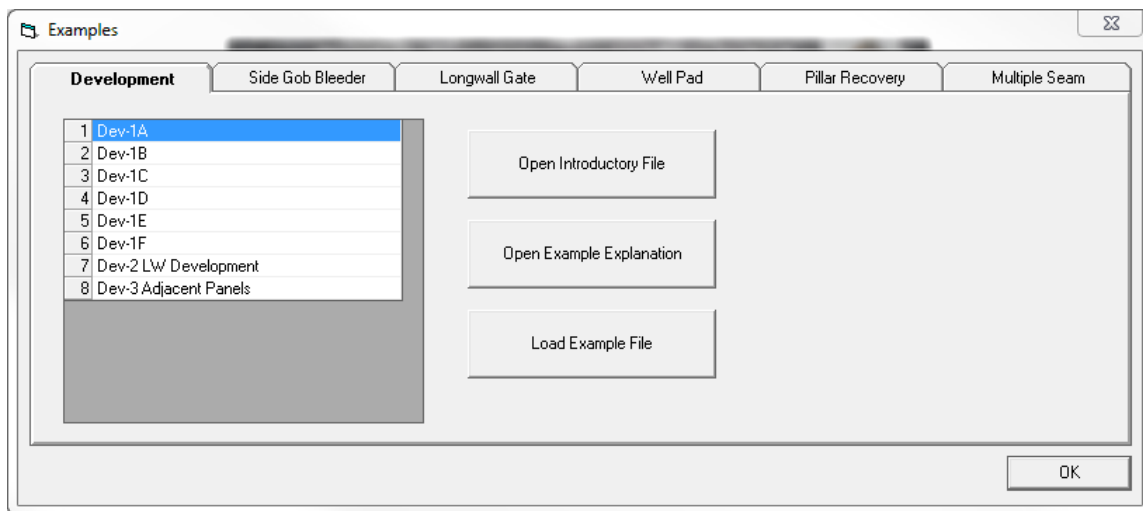
Each group includes several different examples. An introductory file for each group as well as individual PDF files detailing each example can be displayed by clicking on the appropriate button.

The user can also load a specific example file. Once the example file is loaded, control will be transferred to the parameter edit form.

Before the example file is loaded, a copy of the original ACP file is placed under Documents\MyGroundControl\ACPS\Examples. An changes to the example file made by the user, are saved on the copied file. If the user selects that example again through the ACPS example form, the original example file will be copied again to Documents\MyGroundControl\ACPS\Examples and any file with the same name will be overwritten.

Dev-1A
Dev SF = 1.98

7 entries
Depth of cover = 630 ft
5 ft x 20 ft mining
90° crosscut angles
55 ft crosscut centers
55 ft entry centers
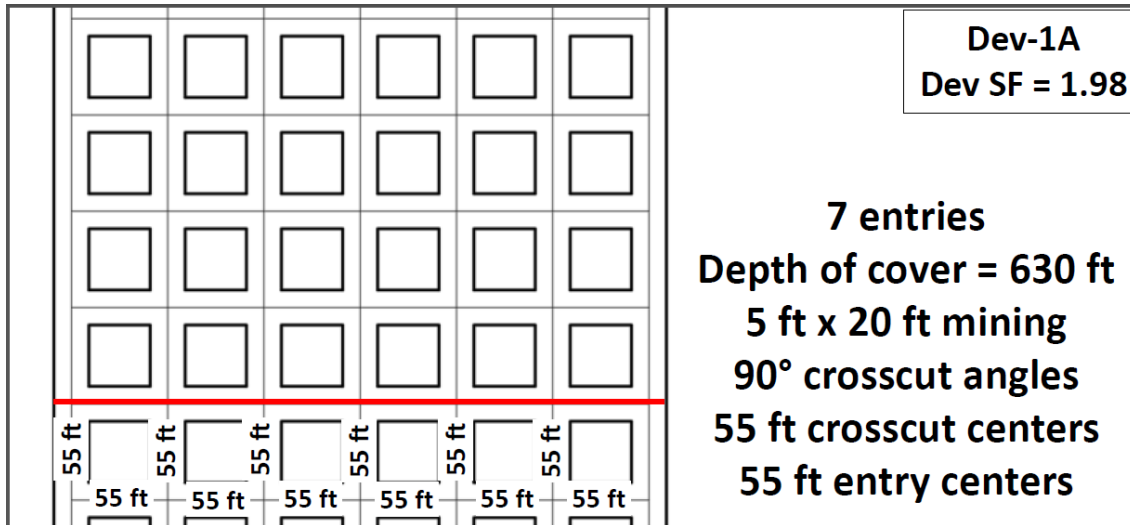
8.2   Resource Files

A number of resource files is distributed with the ACPS program.

Four groups of resource files are available as shown below.

The user can access these files by clicking on the respective command button.
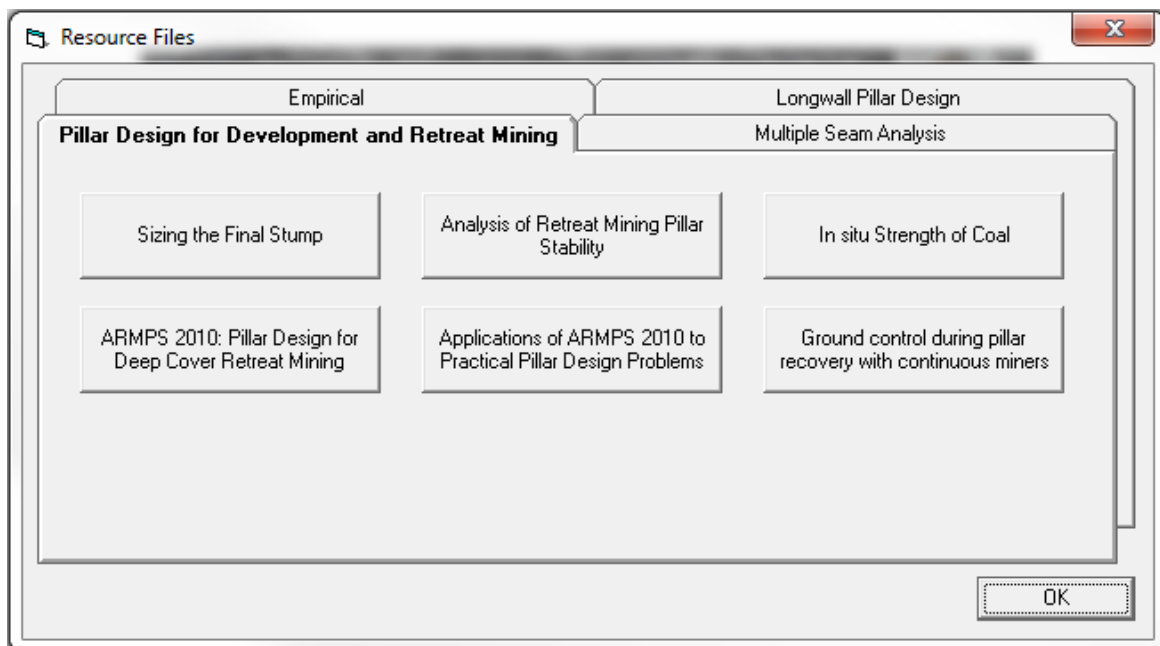
8.3   Disclaimer

This software is provided 'AS IS' without warranty of any kind including express or implied warranties of merchantability or fitness for a particular purpose. By acceptance and use of this software, which is conveyed to the user without consideration by the developers, the user expressly waives any and all claims for damage and/or suits for personal injury or property damage resulting from any direct, indirect, incidental, special or consequential damages, or damages for loss of profits, revenue, data or property use, incurred by the user or any third party, whether in an action in contract or tort, arising from access to, or use of, this software in whole or in part.

See also: Program Updates

8.4   Program Updates

ACPS features an automatic update mechanism. Each time the ACPS program is executed and the computer is connected to the internet, ACPS automatically checks whether a new release is available. The user is then asked whether to download and install the new release.

Users may opt out of the automatic program updates (not recommended).

Users may manually check whether there are updates available that can be downloaded and installed by clicking on *Check for Updates* on the form below.

The ACPS program was officially released in November 2018. Minor updates may be issued periodically.
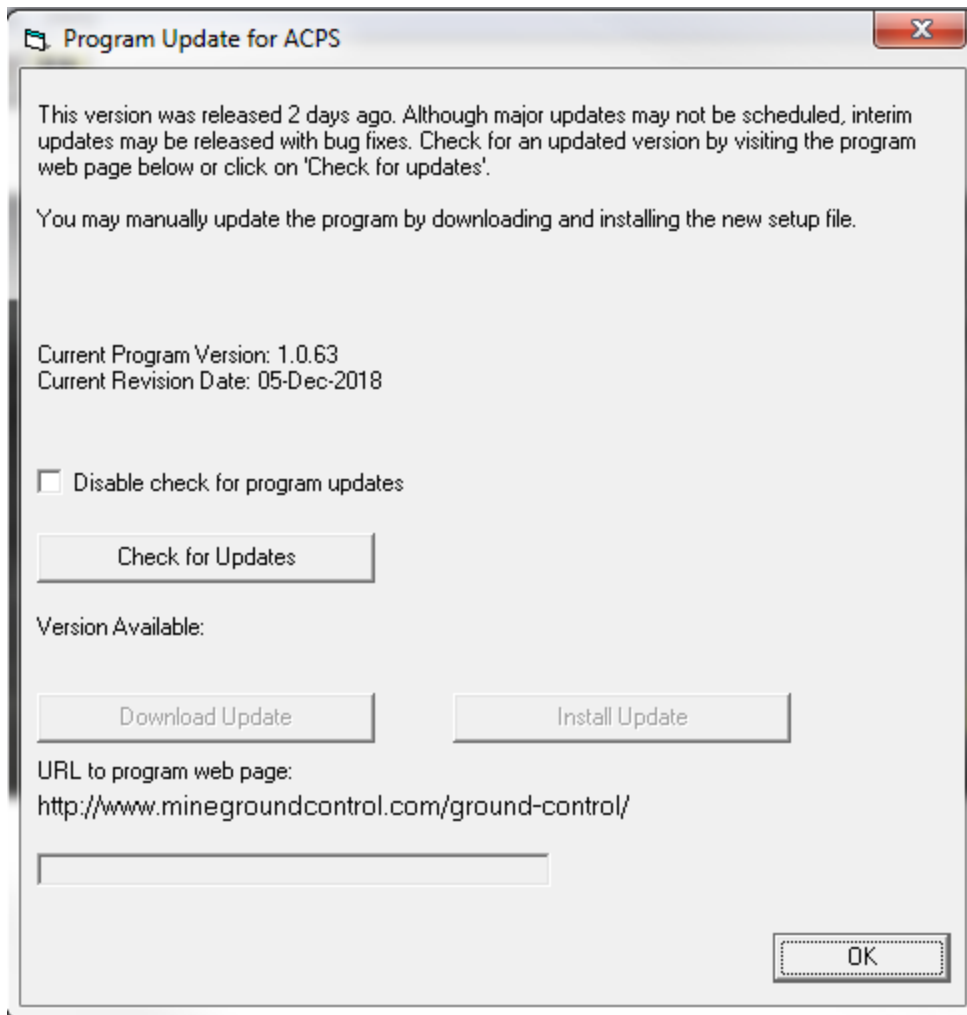
8.5   About ACPS

The concept of the "Analysis of Coal Pillar Stability" (ACPS) program was developed by Dr. Christopher Mark.

This Windows implementation (version 1.0) was developed by Dr. Zach Agioutantis, University of Kentucky. The Lam2D DLL file was developed by Dr. Keith Heasley, West Virginia University.

The help and support of Dr. Christopher Mark during all stages of this project is greatly appreciated.

8.6   ACPS References

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Tulu IB, Heasley KA (2012). Investigating Abutment Load, Proceedings of the 31st International Conference on Ground Control, Morgantown, WV, pp. 150-159.

8.7   HelpButton

Position the cursor on any item on the form and press F1 for context sensitive help.

Part IX
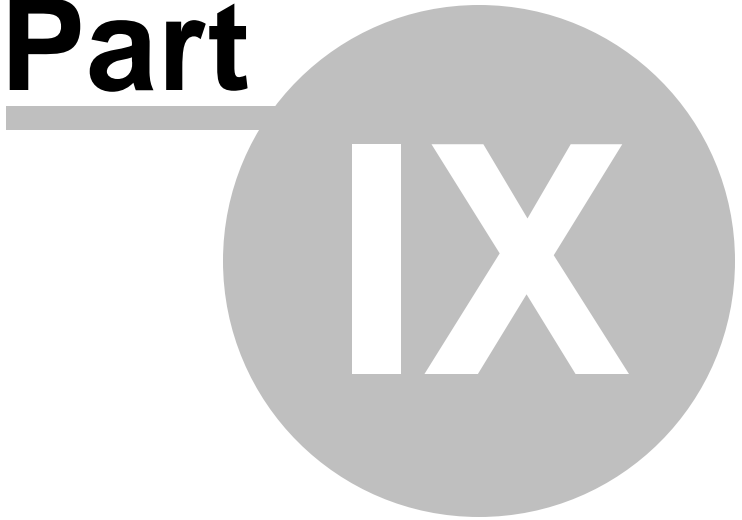
9   ACPS Figures

9.1   ACPS Figure 1

Figure 1. ACPS Advanced Geometry input parameters.

9.2   ACPS Figure 2

Figure 2. Other ACPS input parameters for the Development/Room-and-Pillar module

9.3 ACPS Figure 3

Figure 3. Leave Pillars within the active retreat panel.

9.4   ACPS Figure 4
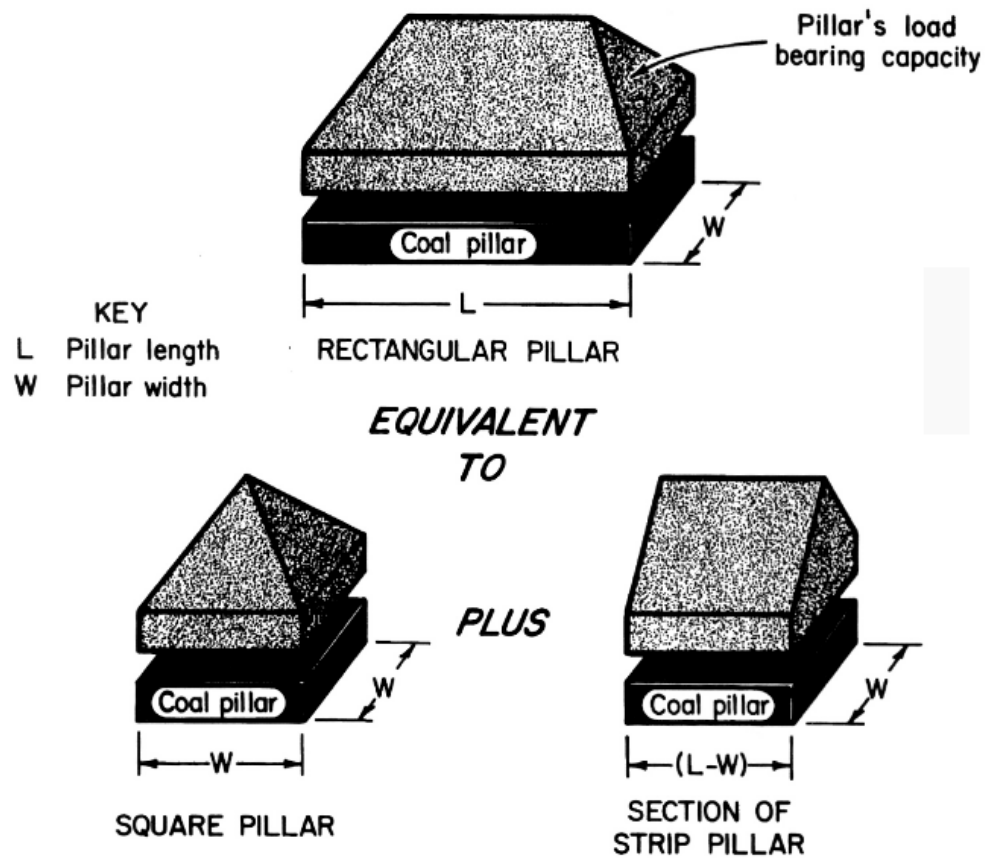
Figure 4: The Mark-Bieniawski formula for the strength of rectangular pillars.

9.5   ACPS Figure 5
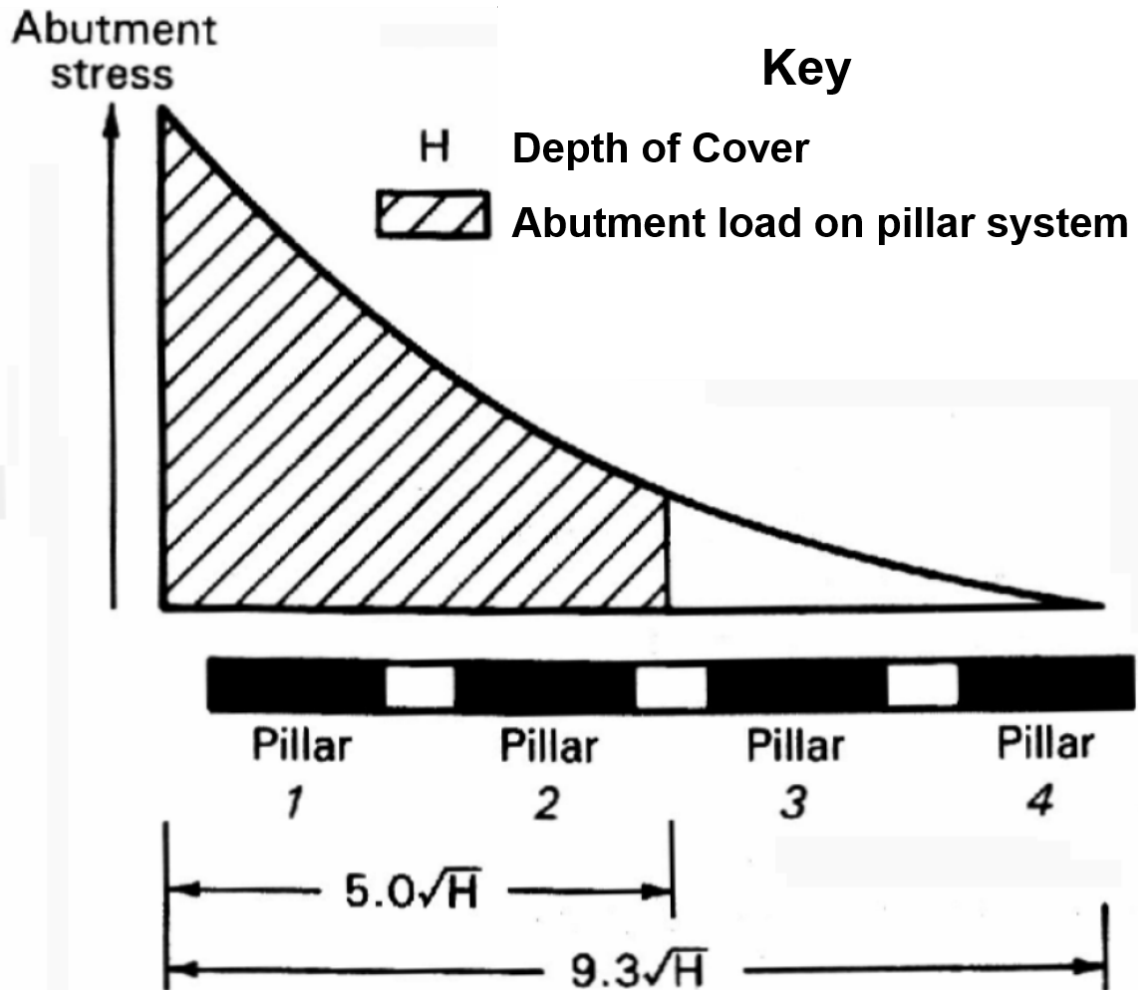
Figure 5. Distribution of the abutment load. Note that 90% of the total abutment load is applied to pillars within 5*SQRT(H) of the gob edge.

9.6 ACPS Figure 6
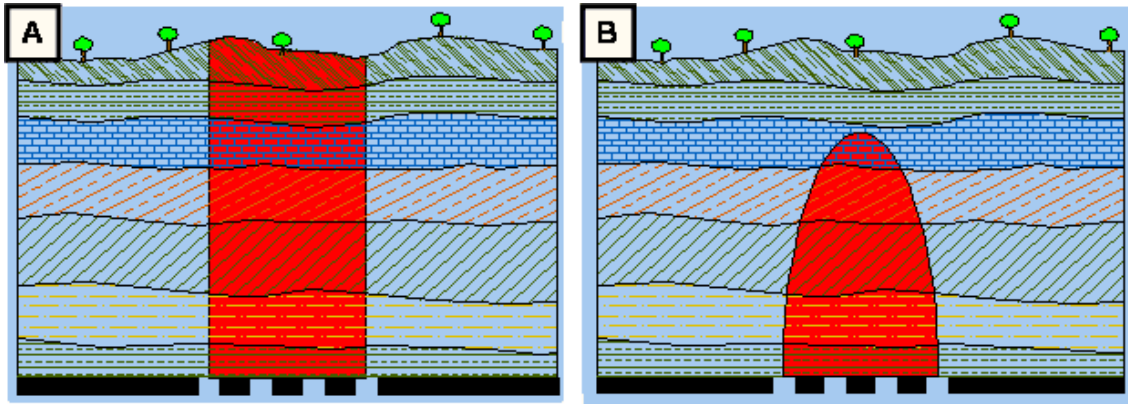
Figure 6: ACPS standard loading models. (a) Tributary area. (b) Pressure arch.

9.7 ACPS Figure 7
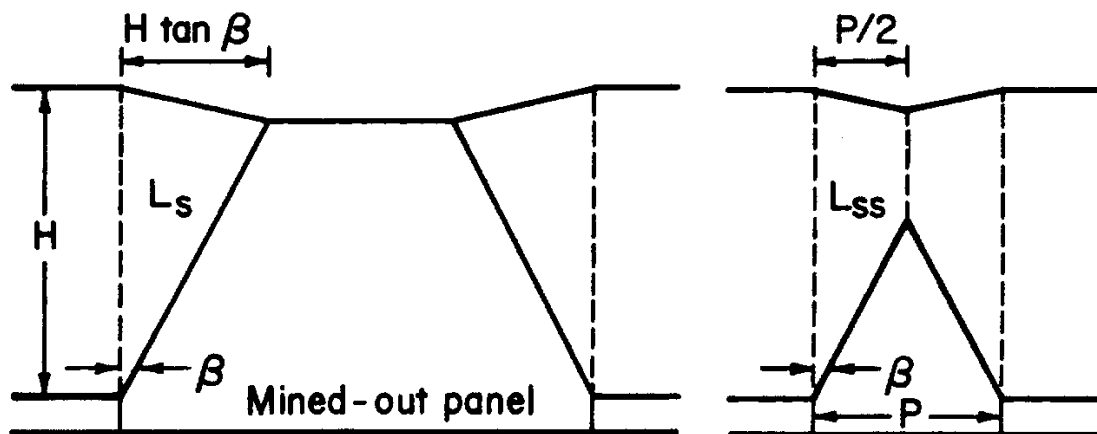
β = Abutment angle
H = Depth of cover
L_s = Side abutment for critical panels
L_{ss} = Side abutment for supercritical panels
P = Panel width

Figure 7: The abutment angle concept in ACPS.

9.8   ACPS Figure 8
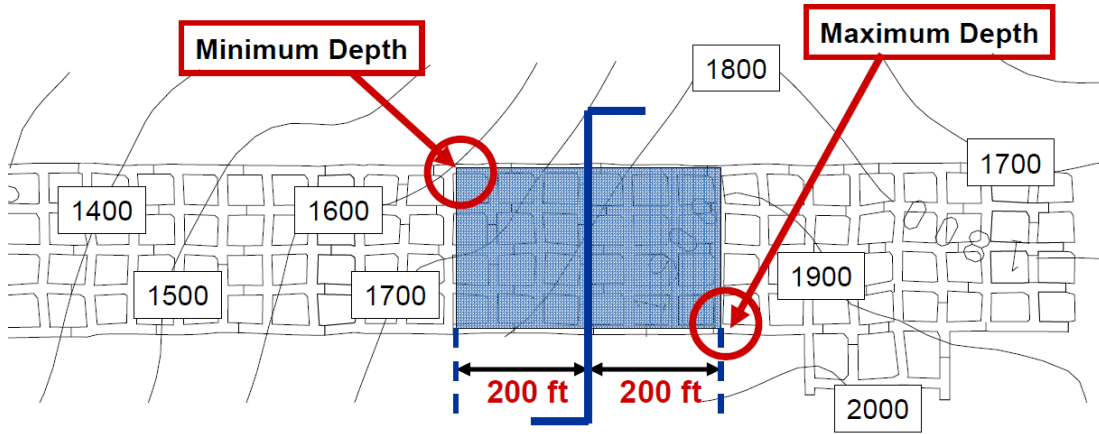
Figure 8a. Estimation of the depth of cover for ACPS development / room-and-pillar input.
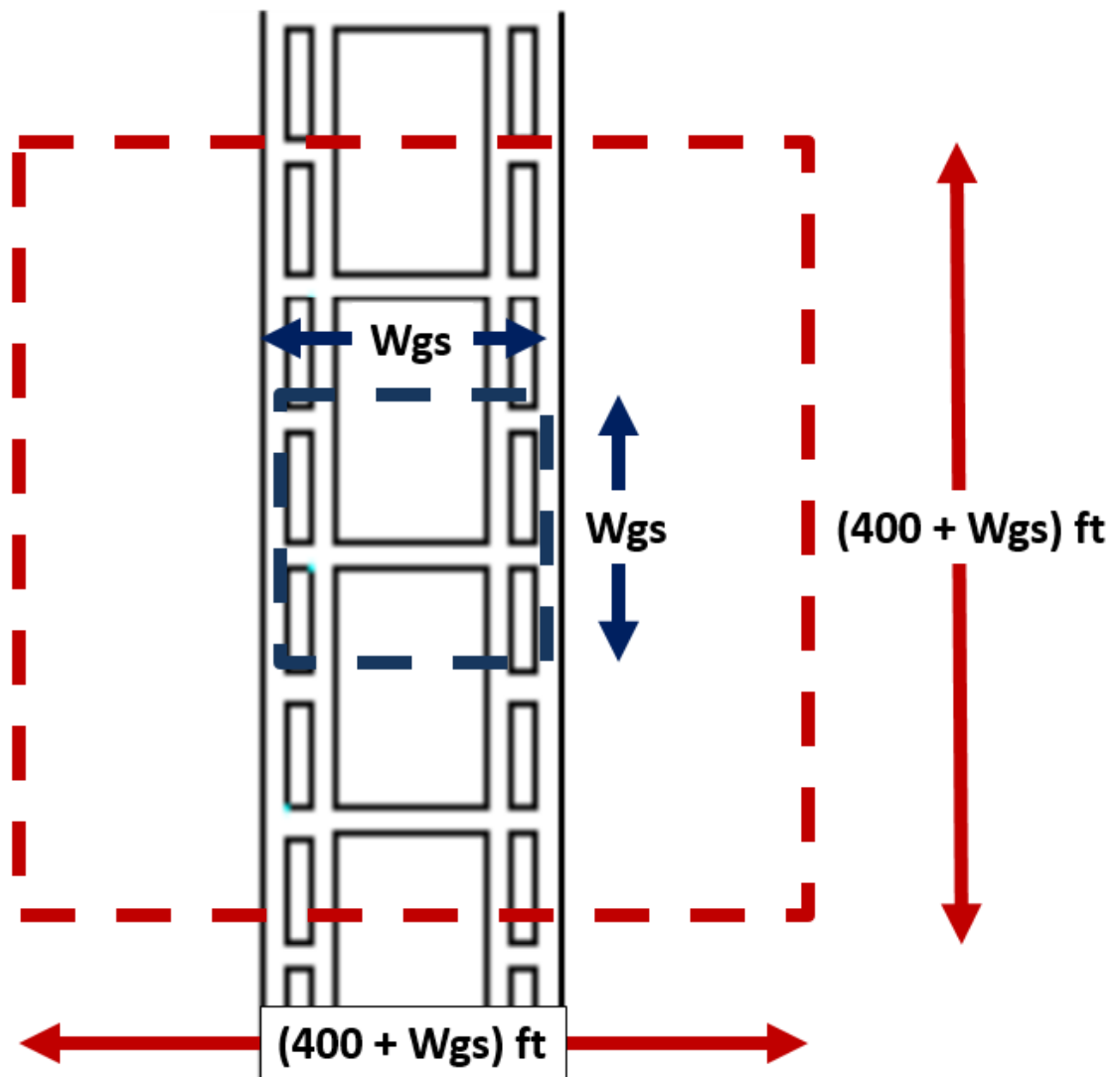
Figure 8b. Estimation of the depth of cover for ACPS longwall gate input.

9.9   ACPS Figure 9
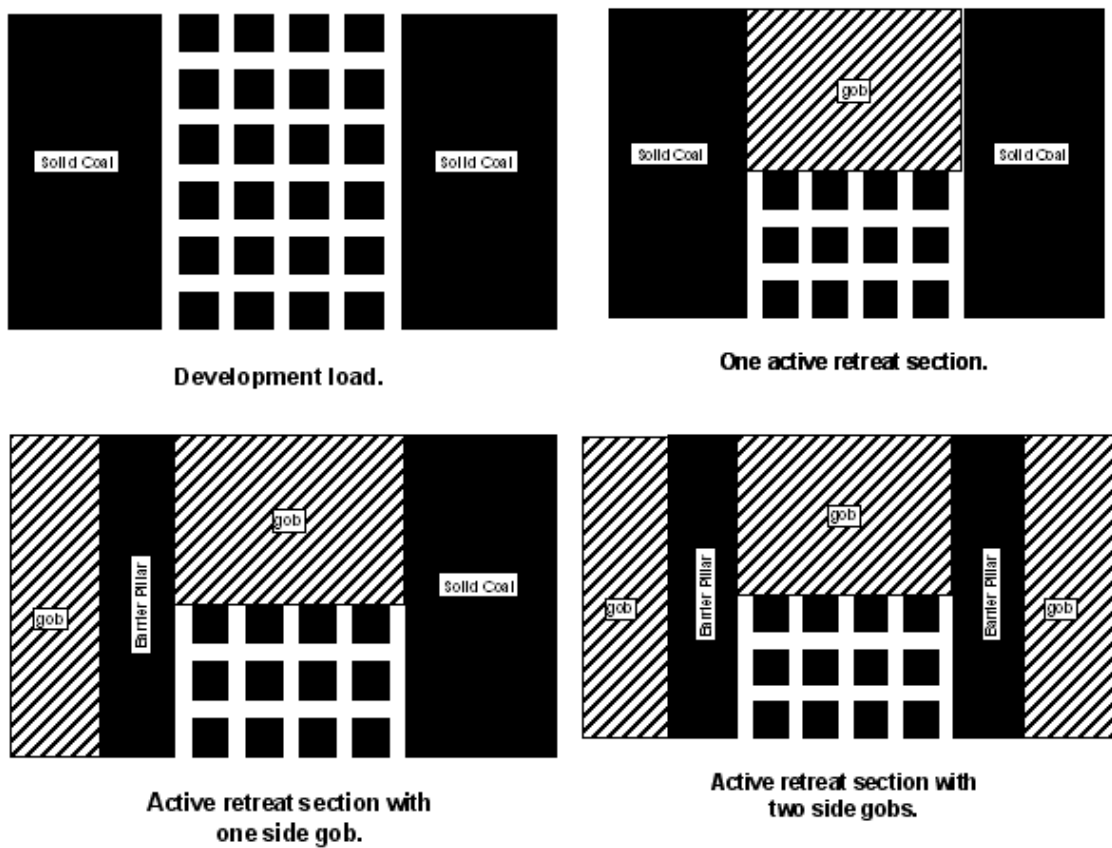
Figure 9. Loading conditions for room-and-pillar retreat mining in ACPS.

9.10 ACPS Figure 10
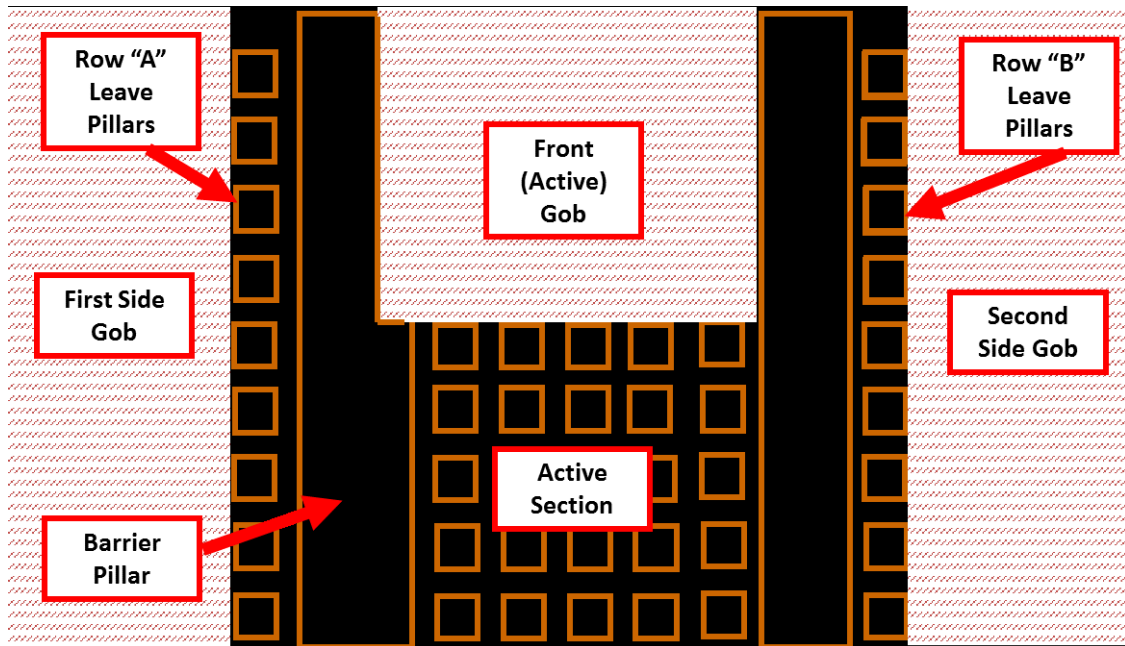
Figure 10: Leave pillars (bleeder pillars) in the previous panels (side gobs).

9.11 ACPS Figure 11

UNDERMINING
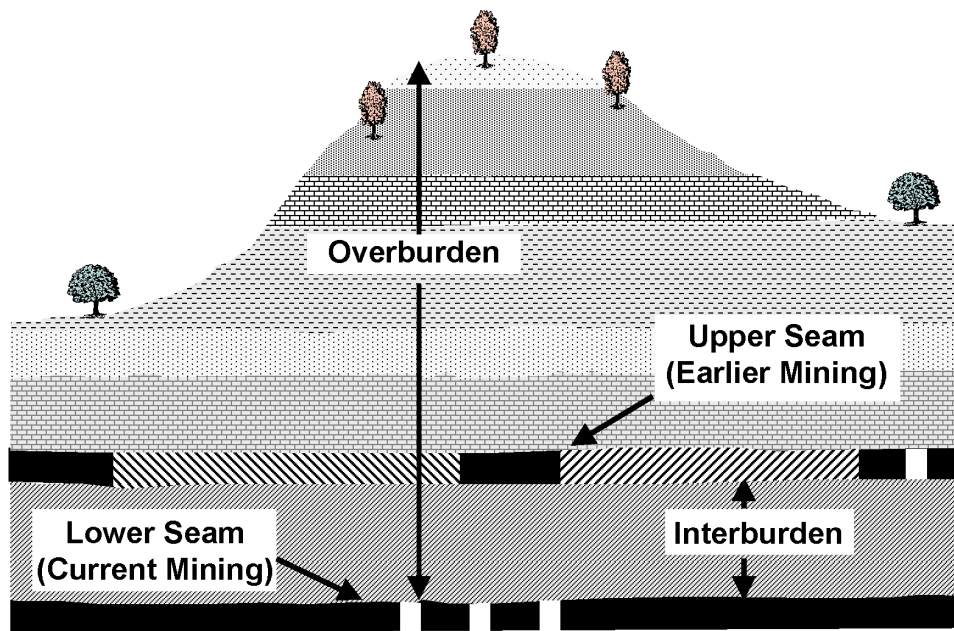
Figure 11: Undermining.

9.12 ACPS Figure 12

OVERMINING

Overburden

Upper Seam
(Current Mining)

Lower Seam
(Earlier Mining)

Interburden
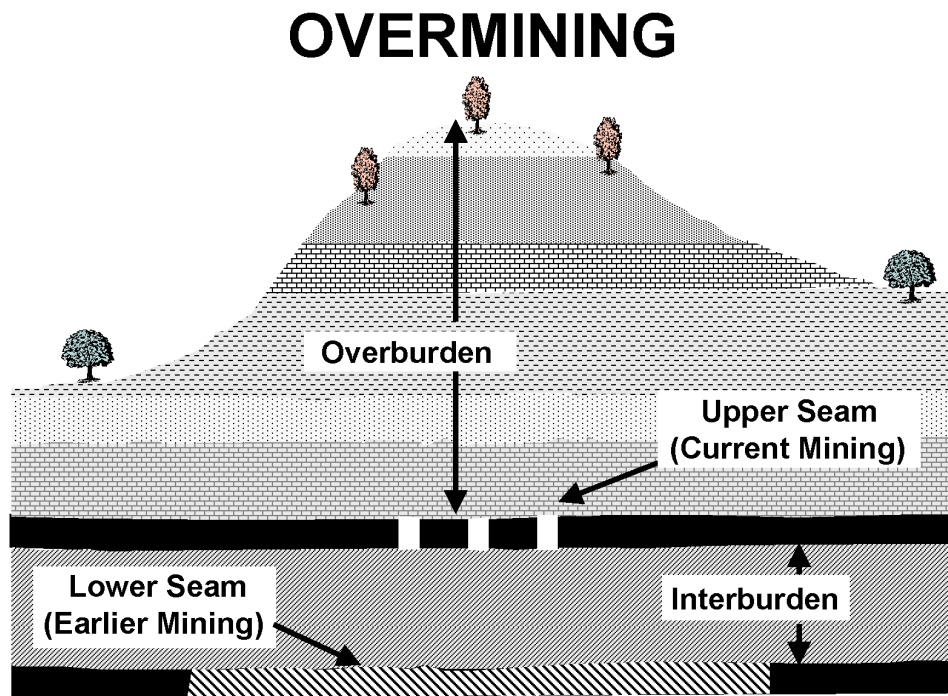
Figure 12: Overmining.

9.13 ACPS Figure 13

A

B
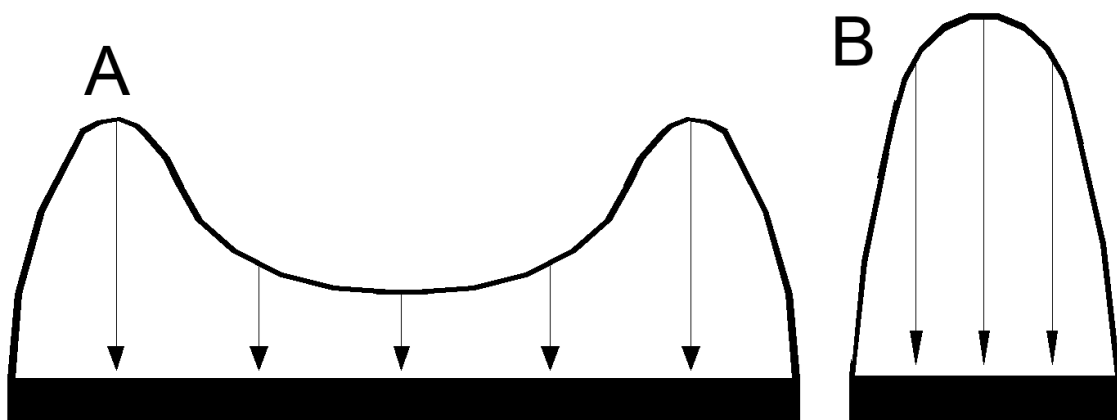
Figure 13: Remnant structures in multiple seam mining. (a) Gob-solid boundaries associated with a very large pillar and (b) remnant pillar isolated in the gob.

9.14   ACPS Figure 14
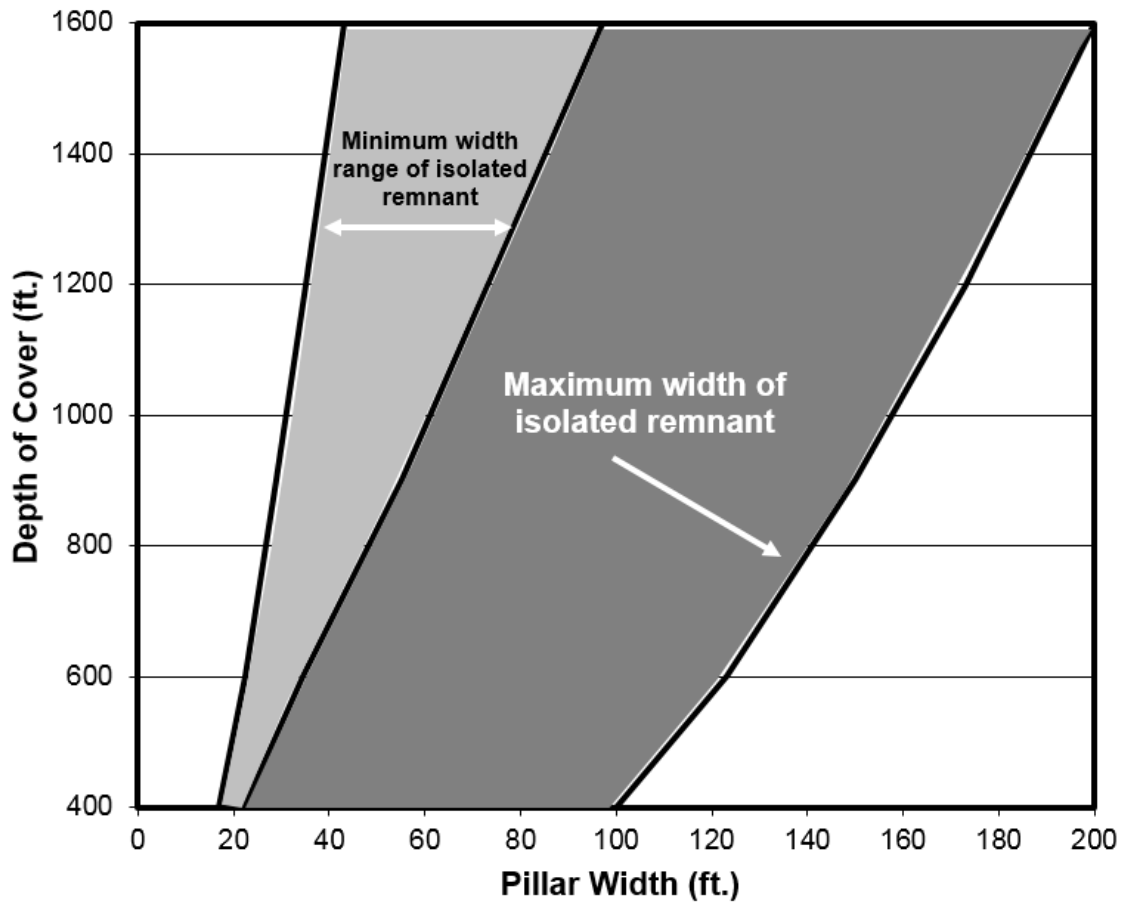
Figure 14: Upper and approximate lower limits for determining whether a remnant structure is an isolated remnant or a gob-solid boundary.

9.15   ACPS Figure 15
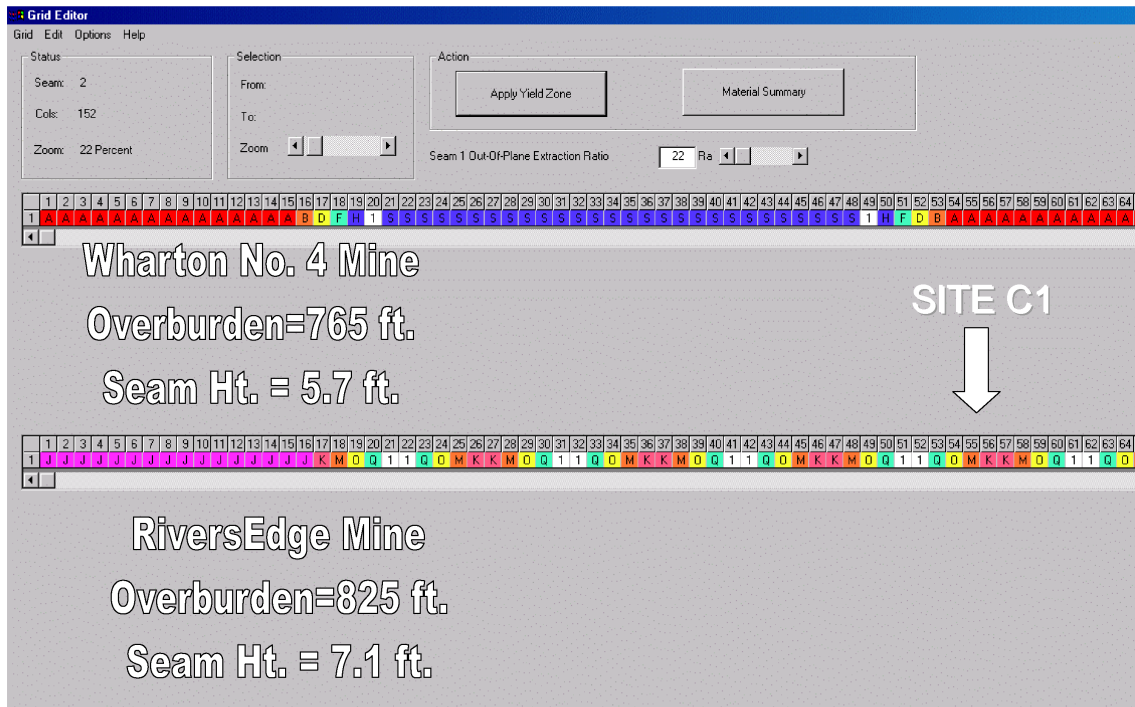
Figure 15: Portion of a typical Lam2D model grid used to determine the multiple seam stress and total vertical stress.

9.16 ACPS Figure 16
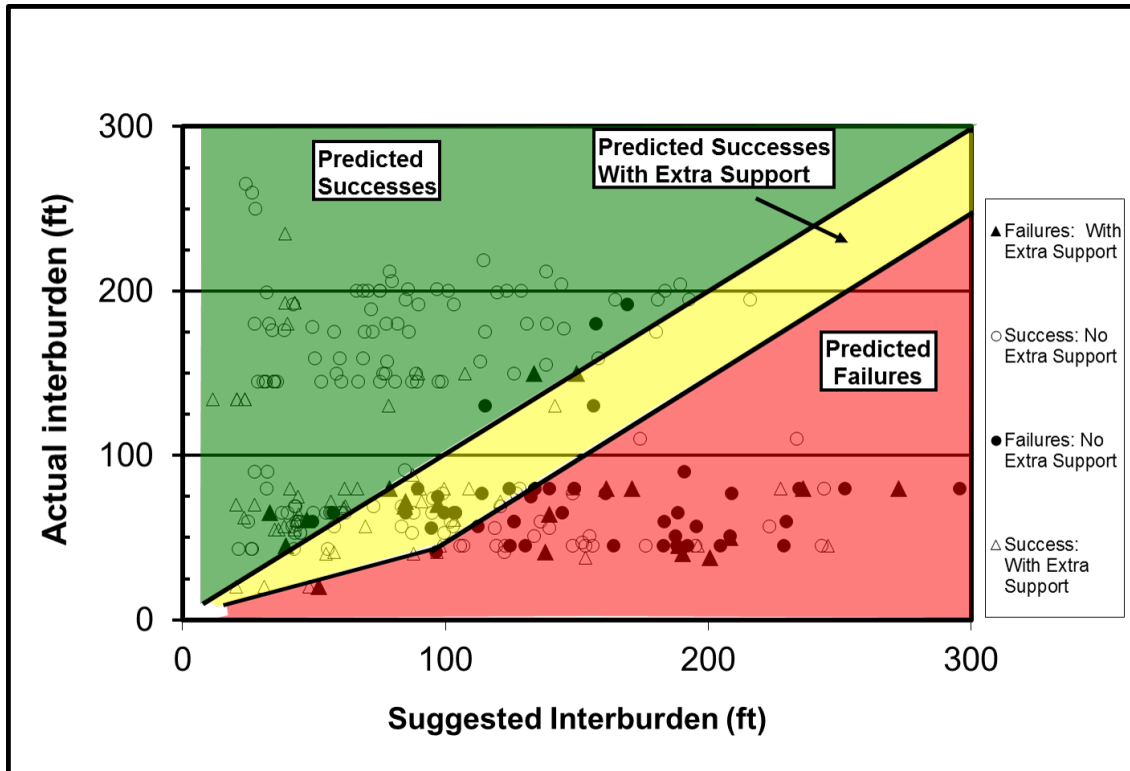
Figure 16a: Performance of the design equation, comparing the suggested critical interburdens with the actual interburdens in the case histories (complete data set)
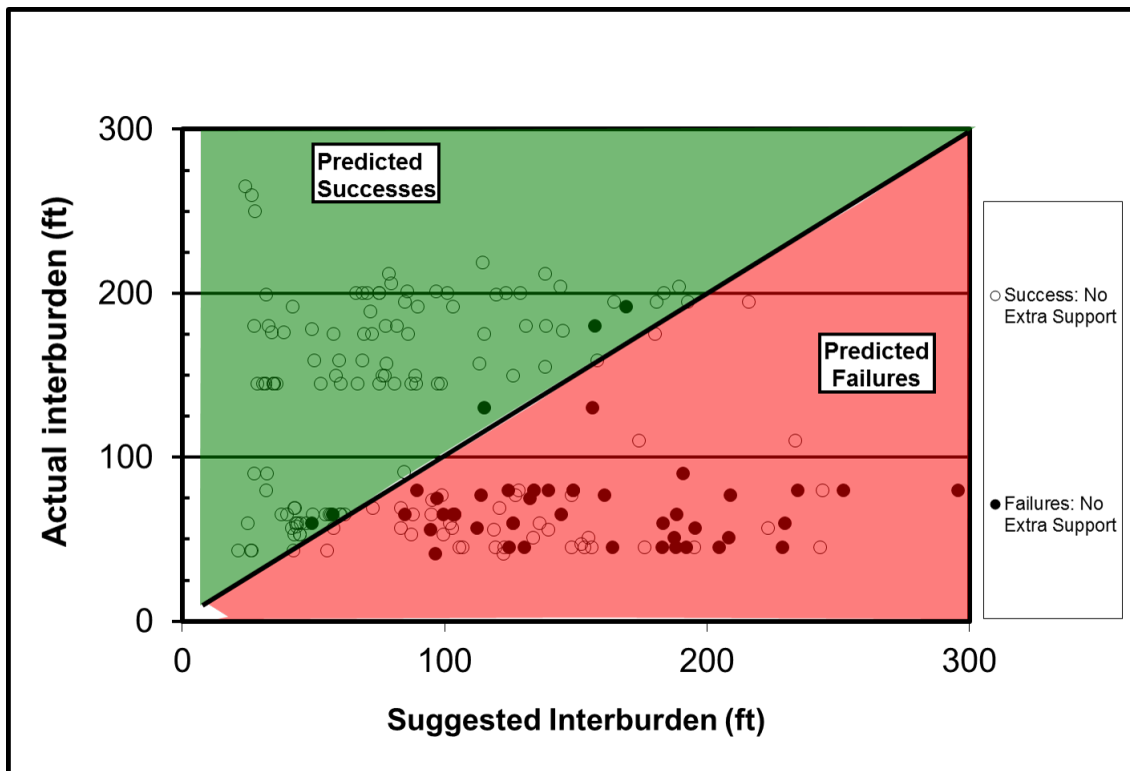
Figure 16b: Performance of the design equation, comparing the suggested critical interburdens with the actual interburdens in the case histories (cases without supplemental support)
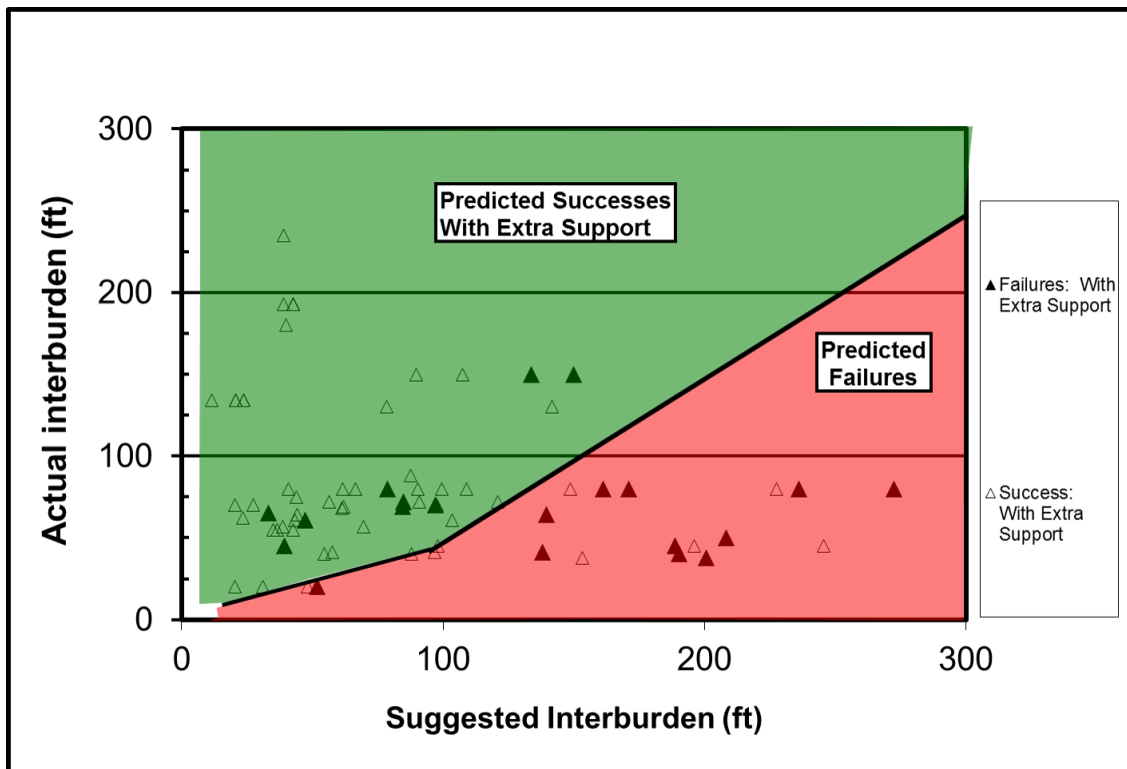
Figure 16c: Performance of the design equation, comparing the suggested critical interburdens with the actual interburdens in the case histories (cases with supplemental support)

9.17   ACPS Figure 17
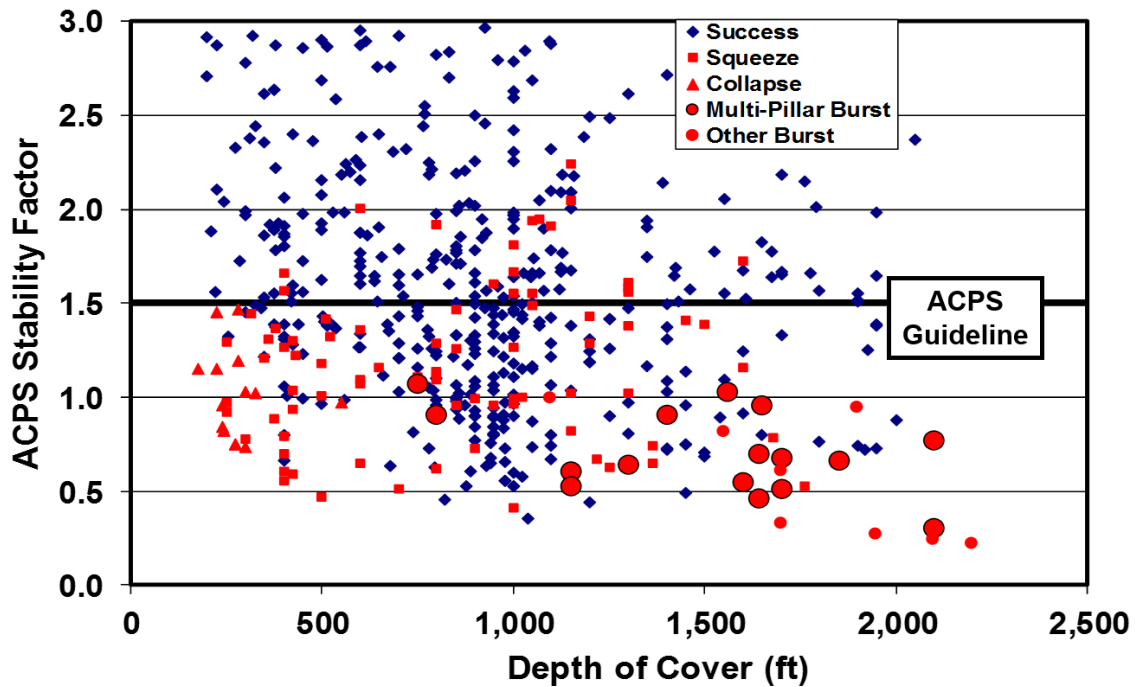
Figure 17: ACPS room-and-pillar case history database, showing the recommended ACPS SF of 1.5 for production pillars.

9.18   ACPS Figure 18
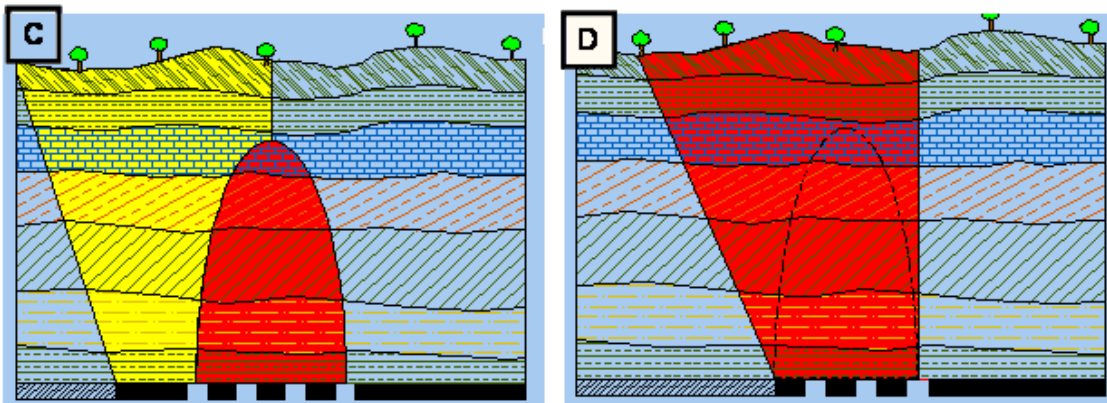
Figure 18: The role of barrier pillars in room-and-pillar retreat mining. The load applied to the pillar system is shown in red. (c) Pressure arch, with side gob and adequate barrier pillar. (d) Side gob without adequate barrier pillar.

9.19 ACPS Figure 19
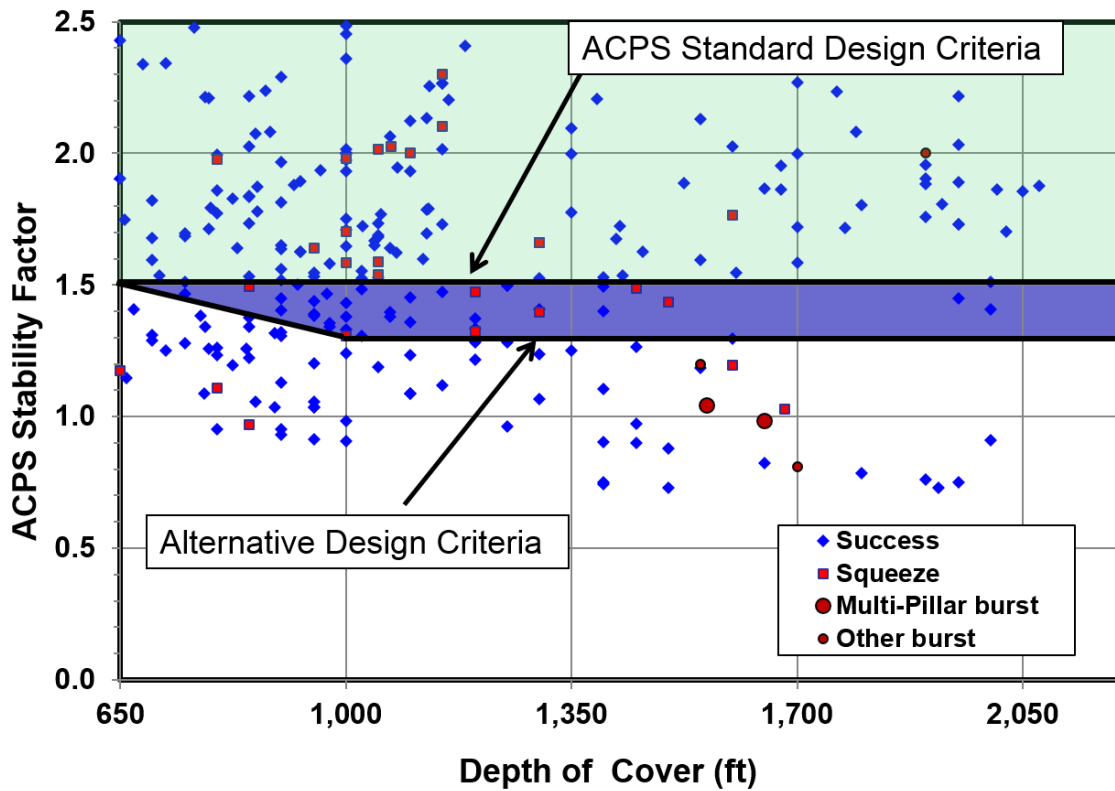
Figure 19: Alternative ACPS design criteria for for narrow pillar systems and reinforced barrier pillars.

9.20 ACPS Figure 20
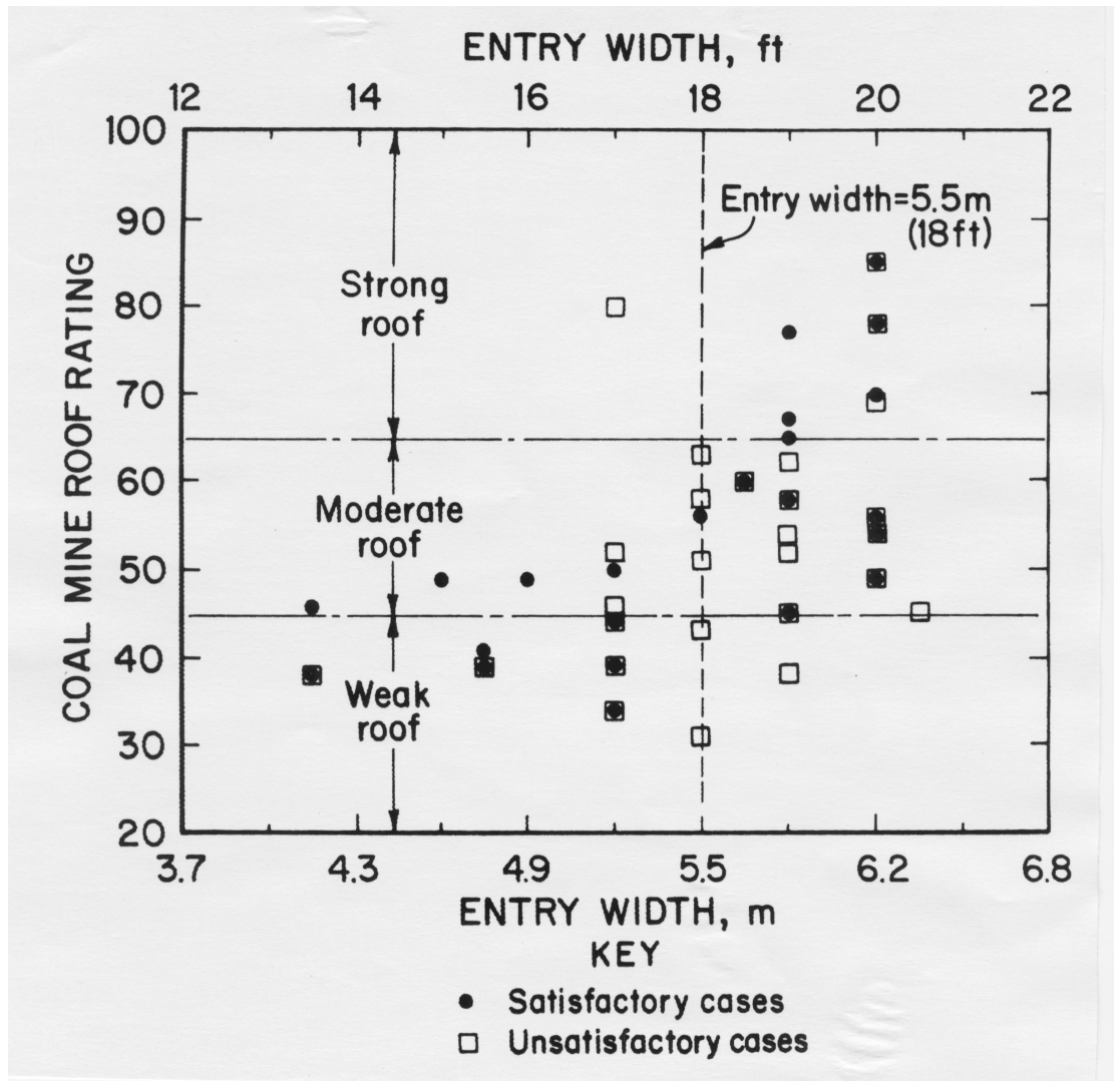
Figure 20: Relationship between entry width and CMRR in the longwall case history database.

9.21 ACPS Figure 21
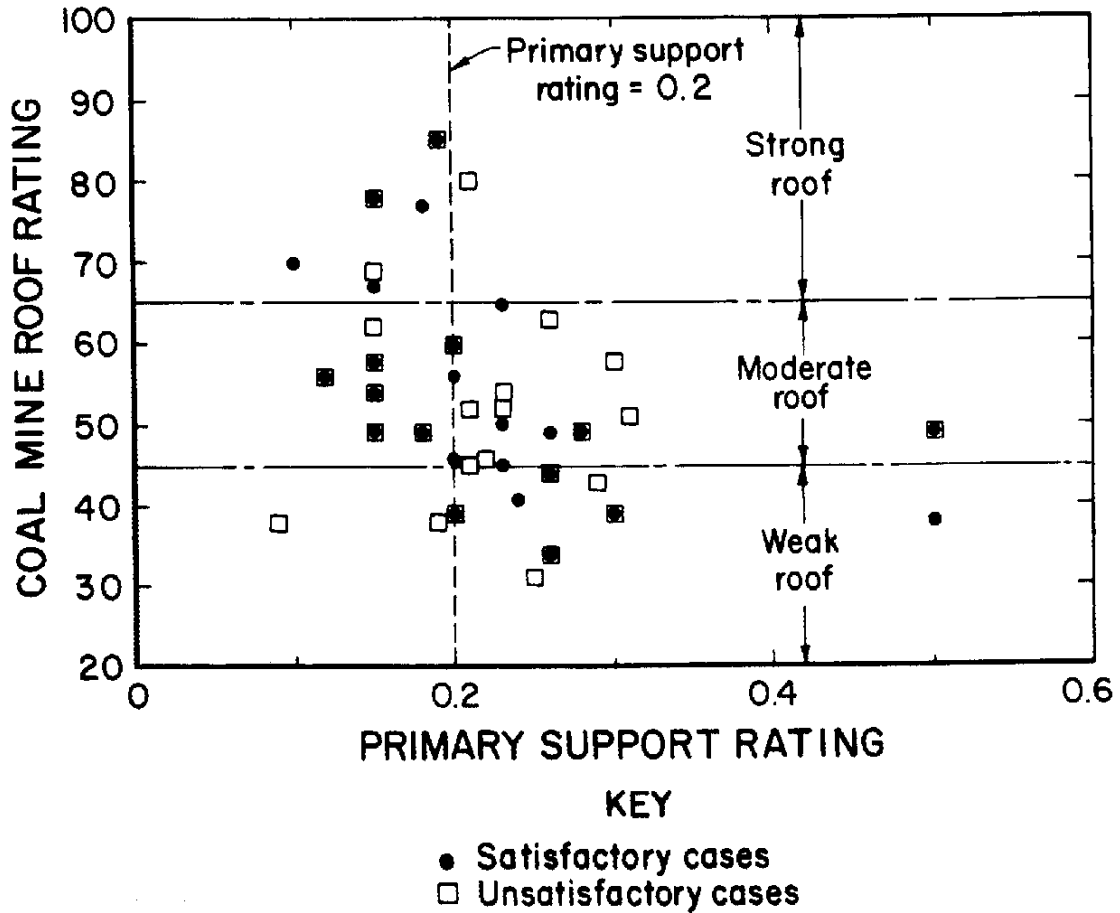
Figure 21: Relationship between primary roof support and CMRR in the longwall case history database.

9.22 ACPS Figure 22
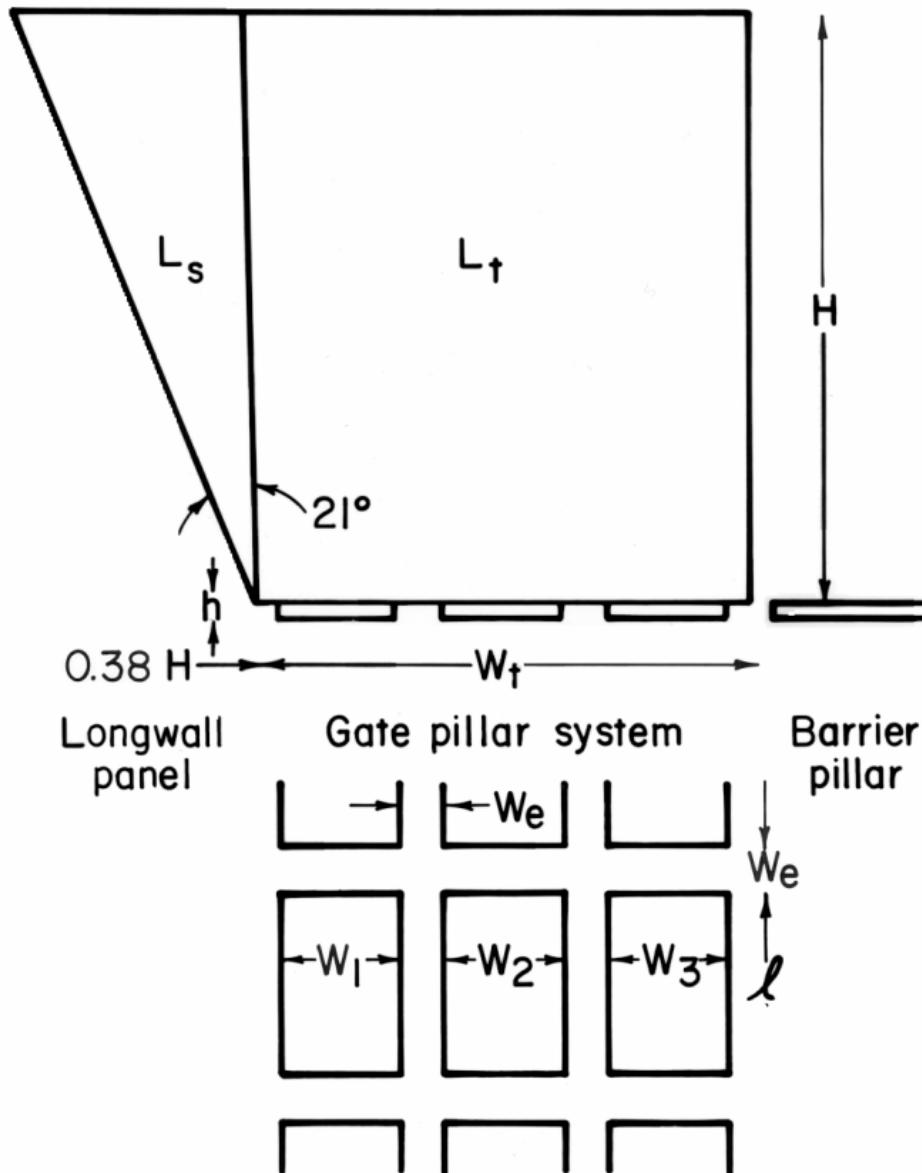
L_t = Tributary Area Load
L_s = Abutment Load

Figure 22: Schematic of the loadings applied to a longwall gate pillar system.

9.23 ACPS Figure 23
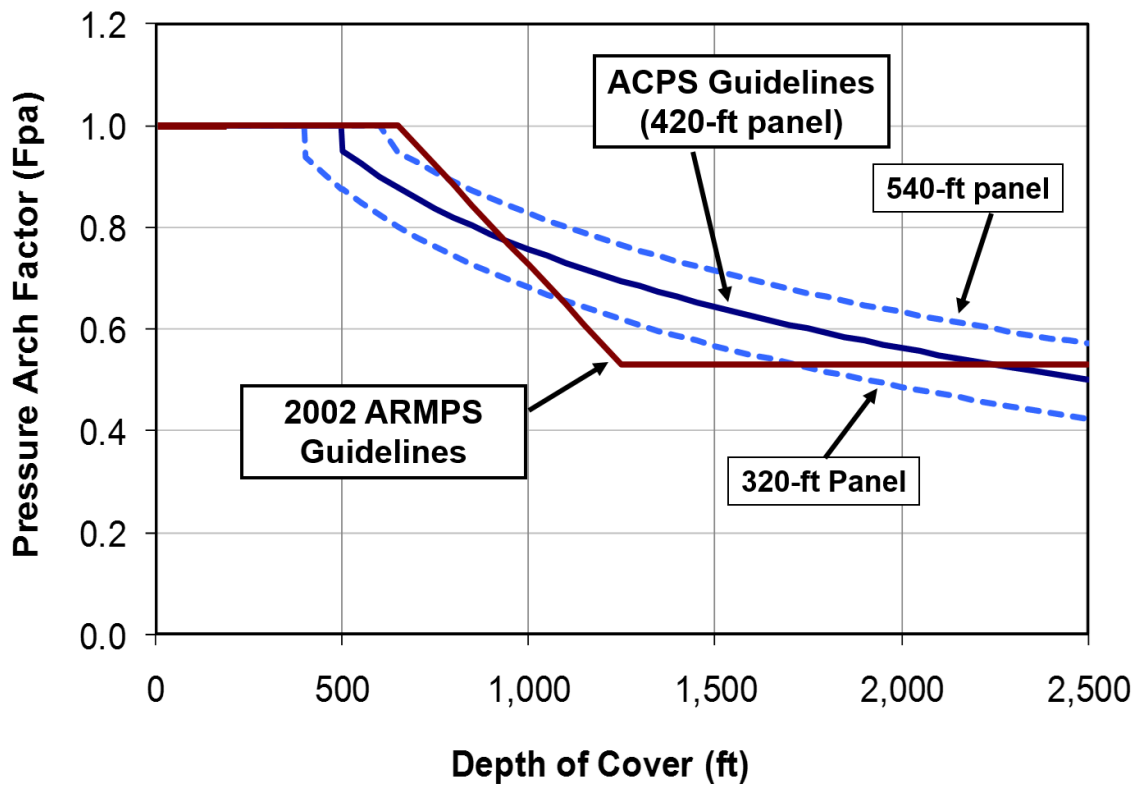
Figure 23: The Pressure Arch Factor (Fpa) as a function of depth for three different pillar system widths.

9.24   ACPS Figure 24
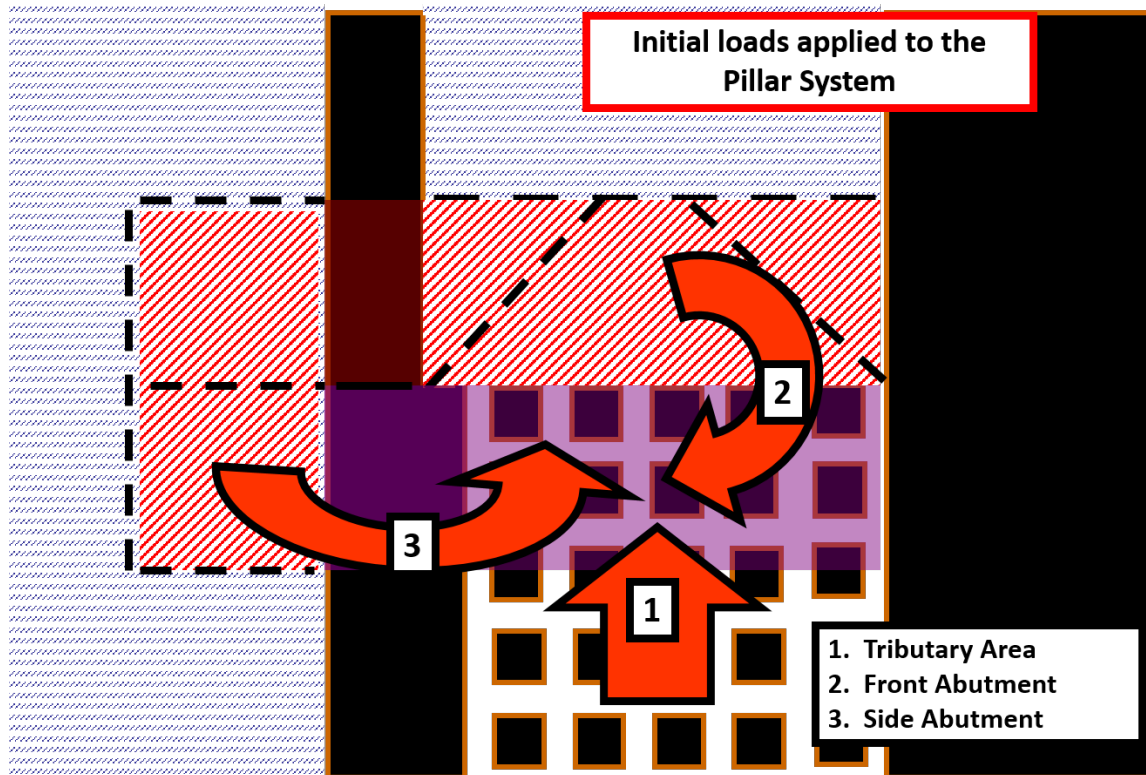
Figure 24: Loads applied to the pillar system: (1) is the tributary area load, (2) is the front abutment load, and (3) is the portion of the side abutment load that extends across the barrier pillar.

9.25 ACPS Figure 25
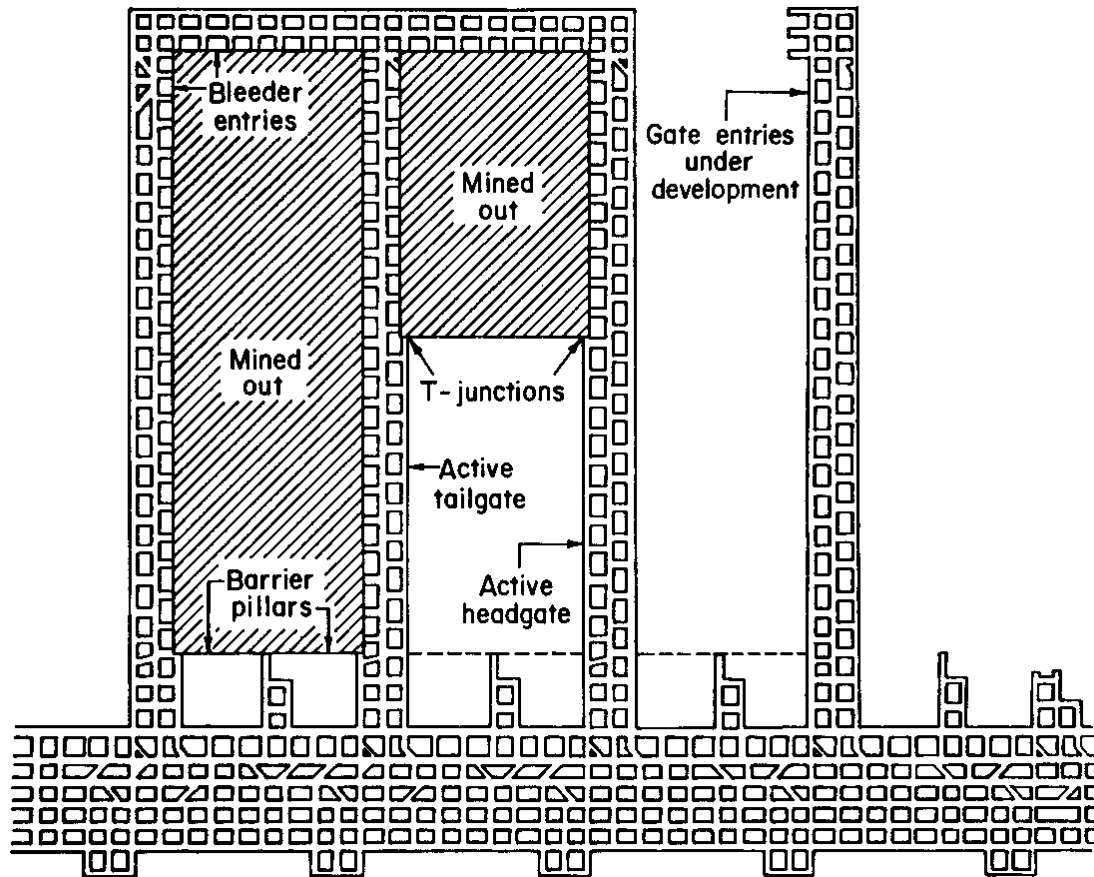
Figure 25: Stages in the service life of longwall gate pillars.

9.26   ACPS Figure 26

Figure 26: Examples of angled crosscuts for room and pillar panels (1-3) and longwall gates where the belt in usually on one side of the entry system (4).

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