ALTS II – A longwall gateroad design methodology for Australian collieries

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Abstract

This paper summarises the development and application of the ALTS (Analysis of Longwall Tailgate Serviceability) Design Methodology for longwall gateroad design associated with Australian collieries. ALTS is an empirical technique, which recognises that several geotechnical and design factors affect gateroad performance and in addition that operational and safety issues essentially dictate the level of performance required.

The original ALTS Design Methodology (Colwell, 1998) was primarily a chain pillar design technique that also provided guidelines in relation to the installed level of primary support. However subsequent research clearly revealed that chain pillars should not be designed without considering the level and type of ground support installed along the gateroads as well as a colliery's operational requirements. In developing ALTS II, the significant leap forward for the Australian coal industry is that the interaction between roof quality, ground support and chain pillar size has been quantified in terms of satisfactory gateroad performance such that roof support levels can be assessed ***in combination with*** *rather than independently of the chain pillar design.*

INTRODUCTION

In many cases, chain pillars in Australia had been designed utilising a process similar to that used for pillars within bord-and-pillar operations, which applies a Factor of Safety in relation to pillar collapse. As discussed by Colwell et al. (1999) this approach was inadequate and there was a clear need for a design method uniquely developed for Australian longwall chain pillars. In 1997 with ACARP (Australian Coal Association Research Program) and colliery support a research program (ACARP Project C6036, Chain Pillar Design – Calibration of ALPS) commenced to develop such a method.

The starting point or basis of that research program was ALPS, i.e. Analysis of Longwall Pillar Stability. The ALPS methodology (Mark 1990; Mark et al. 1994) was chosen because of its operational focus, as it uses tailgate performance as the determining chain pillar design criteria rather than simply pillar stability. Furthermore, ALPS recognises that several geotechnical and design factors, including (but not limited to) chain pillar stability, affect that performance.

Based on this initial research the ALTS Design Methodology was developed (Colwell 1998, 1999). During the initial ALTS research, it was identified that a compromise between pillar size, primary roof support and secondary roof support is possible and necessary to efficiently achieve satisfactory gateroad conditions. The original database (1997–8) was of sufficient size to confidently make recommendations for pillar size and to provide guidelines in relation to the installed level of primary support. However it was only possible to make a subjective assessment in relation to secondary support requirements. Funding from individual collieries and mining companies allowed for the expansion of the database in 2000, from which the ALTS II Design Methodology was developed.

In developing ALTS II, the significant leap forward for the Australian coal industry is that the interaction between roof quality, ground support and chain pillar size has been quantified in terms of satisfactory gateroad performance such that roof support levels can be assessed in combination with rather than independently of the chain pillar design.

DATA COLLECTION

In developing the ALTS technique and database, information was collected in two stages. The original database (1997–98) represented 19 collieries or approximately 60% of the Australian longwall mines operating at that time. Subsequently and during 2000, 29 longwall mines were visited with several mines being visited on more than one occasion. At each mine, information was collected via underground inspections and discussions with colliery personnel.

The aim of the industry review (via the site inspections) was to construct both a contemporary and historical database of gateroad and chain pillar performance. The combined database (i.e. information collected in 1997–98 and 2000) now represents 31 collieries involving some 140 data sets. The case history data was supplemented with an extensive underground monitoring program associated with the initial research (Colwell 1998) that included six sites across three coalfields and was further supplemented with 14 chain pillar loading investigations previously undertaken by several collieries and made available to the project(s). The monitoring sites were critical to the success of the original project and subsequent research in establishing the variability (between collieries and coalfields) in the longwall abutment loading of chain pillars.

DESCRIPTION OF DATABASE

Each complete data set (or case study) was defined by approximately 30 individual data fields, which in turn were used to define eight summary variables or ratings. The first of these variables is Tailgate Condition, which is the outcome or dependent variable in the analysis. The other seven are explanatory or dependent variables and are listed below:

- Coal Mine Roof Rating (CMRR) – roof quality rating.
- Tailgate Stability Factor (TG SF) – the chain pillar rating.
- Primary (tendon) Support Rating (PRSUP).
- Ground (tendon) Support Rating (GRSUP).
- Standing Secondary Support Rating (SSUP).
- Roadway Width (w_e).
- Adverse Horizontal Stress Index (HORST) – classified on a yes/no basis.

The Outcome - Tailgate Condition

The case histories in relation to the earlier research (Colwell 1998) were initially classified as satisfactory and unsatisfactory, utilising the same criteria provided by Mark et al. (1994) in relation to the ALPS research program. To be classified as unsatisfactory, a case had to meet at least one of four criteria:

- Management changed the pillar design or the entry support in response to the poor tailgate conditions.
- The panel was abandoned owing to poor conditions.
- Unacceptable conditions developed in the areas of deepest cover.
- Several falls above the bolt anchorage occurred in the tailgate, resulting in tailgate blockages and significant longwall delays.

Satisfactory cases, in contrast, were those in which:

- The design was used for at least three successive panels.
- Tailgate blockages were very rare or nonexistent.
- Good conditions, with minimal delays attributable to ground control, were reported.

Using the above classification only six of the original 52 cases actually satisfied the unsatisfactory criteria. An initial change that was made in analysing the Australian data was to include *borderline* tailgates within the unsatisfactory category. This modification is consistent with the Australian underground coal industry's desire to have in place strata management plans that design against both borderline and unsatisfactory gateroad conditions. It also added to the otherwise small pool of unsatisfactory cases available for analysis.

Furthermore, in relation to the statistical (discriminant) analyses it was difficult to quantify the impact of standing secondary support on the tailgate condition as compared to pillar size and primary tendon support. Mark et al. (1994) faced similar problems in assessing the impact of standing support in relation to the US database. However 59 of the 62 cases, which formed the US database, utilised some level of standing support and therefore the use of standing secondary support along the length of the tailgate is basically <u>intrinsic to</u> the ALPS chain pillar design equation.

As less than 50% of Australian mines use standing secondary support along the full length of the tailgate, it is reasonable to assume that tailgates which incorporated standing secondary support in this manner would become unsatisfactory if it were removed. A major modification in analysing the Australian data was to include all collieries utilising standing secondary support in a modified-unsatisfactory category of tailgate conditions. Therefore the outcome used within the discriminant analysis for both the earlier and subsequent ALTS research was as follows:

1. **<u>Modified Satisfactory</u>**: This category includes all tailgates that were assessed as being satisfactory, while excluding any of those satisfactory tailgates that incorporated the routine installation of standing secondary support along the length of the tailgate.
2. **<u>Modified Unsatisfactory</u>**: This category includes all tailgates that were assessed as being unsatisfactory/borderline, while also now including any tailgate that incorporated the routine installation of standing secondary support along the length of the tailgate.

Dependent Variables

The CMRR was calculated using both underground and borehole information as outlined by Mark and Molinda (2003). The calculation of the TG SF and the HORST classification remains unchanged from that previously published and the interested reader is referred to Colwell (1998) and Colwell et al. (1999). The roadway width (w_e) used is the nominal roadway width typically designated within a colliery's Support Rules or Strata Management Plan (SMP).

A significant improvement to the earlier research is replacing the primary support rating, PSUP (see Colwell 1998), with PRSUP and GRSUP and the subsequent development of a Standing Secondary Support Rating (SSUP). The development of secondary support ratings that would better reflect the broad range of hardware used in Australia for such purposes (i.e. various tendon and standing support systems) was a major objective of the subsequent research program.

Primary and Secondary Support Ratings

At some collieries, longer tendons (i.e. flexibolts, HI TENS etc.) are being installed off the continuous miner as part of the primary support pattern or process. The PSUP was not originally designed to deal with such situations as it does not account for bolt capacity. This deficiency in the PSUP is somewhat overcome with the use of the PRSUP as proposed by Mark (2000)*. The PRSUP is a modified version of the PSUP rating that includes the bolt capacity in place of the bolt diameter. The PRSUP rating considers all support installed at the face from the continuous miner (or mobile bolter where place changing is used) and is calculated as follows:

$$PRSUP = \frac{L_b \,.\, N_b \,.\, C_b}{14.5 \,.\, S_b \,.\, w_e} + \frac{L_b \,.\, N_t \,.\, C_t}{14.5 \,.\, S_t \,.\, w_e} \qquad (1)$$

where

- L_b = Length of bolted horizon defined by primary bolt type (m)
- N_b = Average number of bolts in row
- N_t = Average number of longer tendons in row
- C_b = Ultimate tensile strength of the primary bolt (kN)
- C_t = Ultimate tensile strength of the longer tendon (kN)
- S_b = Spacing between rows of the same bolt type (m)
- S_t = Spacing between rows of the same longer tendon type (m)
- w_e = Roadway width (m)

*note: Mark (2000) uses the yield capacity. This research uses the tendon's UTS capacity.

Where some support elements may be longer than the primary bolt type, only the length of the primary bolt type is considered (i.e. where 2.1 m bolts are being installed and some longer tendons are also being used, a simulated value of 2.1 m is assigned as the length of the longer tendon(s), i.e. L_b remains constant). The longer tendons were found to unfairly influence the rating if their entire length was included in the calculation.

The PRSUP values can be summed because the PRSUP essentially calculates the deadweight support capacity per square metre of roof and simply weights the value according to the height of the bolted horizon. In calculating the PRSUP in this manner, it is considered to be consistent with that of the CMRR, which focuses on the bolted horizon.

The GRSUP rating incorporates all the tendon support installed within the roof of a roadway into a single rating, regardless of when it is installed. This includes all roof bolts, longer tendons, cables and trusses. The GRSUP is calculated in a similar manner to that of the PRSUP; in fact if no additional support is installed within the roof subsequent to that installed off the miner or mobile bolter then GRSUP will equal PRSUP.

Standing Secondary Support Rating

The SSUP rating considers all standing support installed along the roadway. The SSUP rating is calculated as follows:

$$SSUP = \frac{N_S \cdot C_S}{10 \cdot S_S \cdot w_e} \qquad (2)$$

where

- N_s = number of standing supports within the same row
- C_s = load bearing capacity of standing supports (kN)
- S_s = spacing (centre to centre) between rows of supports (m)
- w_e = roadway width (m)

The SSUP effectively calculates the maximum load bearing capacity offered by the standing support in kN per square metre. Therefore different types of standing support can simply be summed to give a single SSUP value. Unless otherwise provided by the mine, the values for the load bearing capacity of the various standing support elements where taken from the suppliers' product catalogues and for timber chocks from ACARP Final Report C6034 (Offner et al. 1999).

STATISTICAL ANALYSES

The goals of the statistical analyses were to:

- Determine which parameters are significantly related to tailgate performance.
- Classify each case history or data set as a success or failure using a predictive model (or classification rule) based on those parameters.
- Develop a series of equations as part of a design methodology that can be used for chain pillar and ground support design.

The statistical technique of discriminant analysis (or logistic regression) was used to distinguish which parameters are significant predictors of the tailgate condition. Discriminant analysis is a regression method that classifies observations into two (or more) populations. In this case the classified populations being the Modified Satisfactory and Modified Unsatisfactory Tailgate Condition. The statistical software package SPSS was used in relation to these analyses.

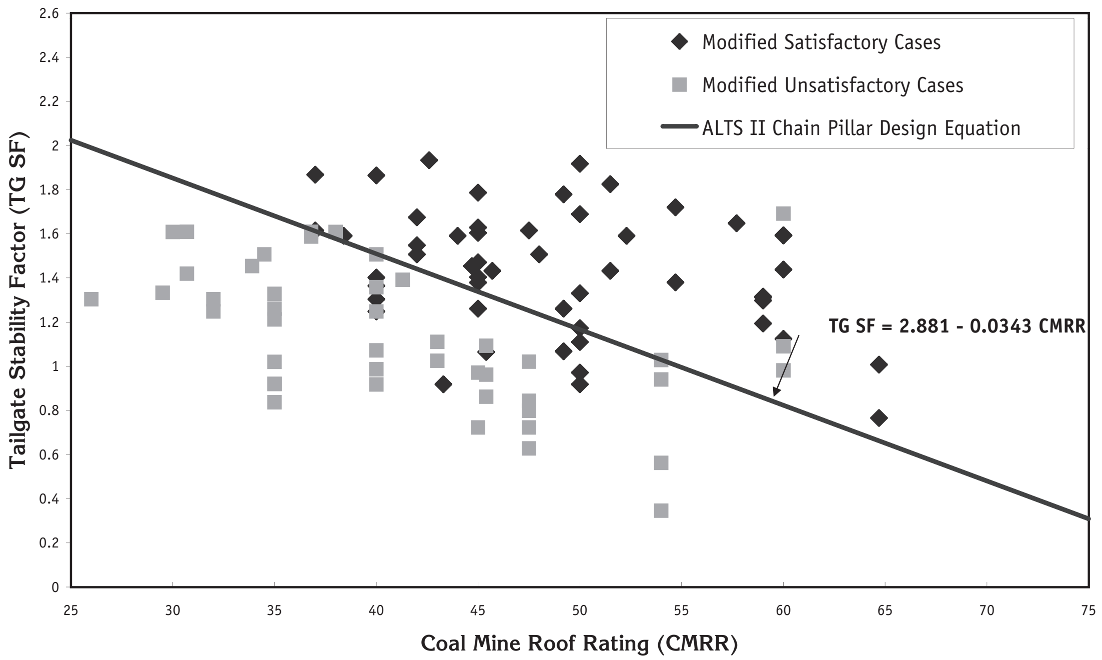
The initial series of analyses revealed that all the dependent variables, except roadway width, were significant predictors of the outcome. In relation to roadway width this was initially a surprising result; however it was found that the variation in the nominal roadway width associated with Australian collieries was simply not sufficient to have a predictive impact on the tailgate condition. This in no way implies that roadway width does not affect gateroad performance, simply that the variance in relation to Australian collieries is insufficient to have a significant impact in terms of the database analyses.

Following a series of discriminant analyses incorporating various combinations of the parameters that affect gateroad performance, it was found that the most practical chain pillar design equation could best be determined solely in terms of the CMRR and the TG SF. While both variables are significant predictors of the outcome they are essentially independent of one another, which allows for SPSS to produce a *line of best separation* between the two populations in terms of predictive success. This results in the recommended chain pillar design equation relating the TG SF to the CMRR, which is displayed on Figure 1 and is expressed as:

$$TG\ SF = 2.881 - 0.0343\ CMRR \qquad (3)$$

The above equation results in a predictive success rate of 84.5% with 11 misclassified modified satisfactory cases and only four misclassified modified unsatisfactory cases. The discriminant analyses also suggested that there were strong relationships between the CMRR and the various ground support ratings that could be better analysed using standard regression techniques.

Figure 1 Discriminant Analysis – ALTS II Chain Pillar Design Equation



Standard Regression Analyses

The linear regression analyses conducted as a part of the original research (Colwell 1998) were extremely useful in examining the strong relationship between the PSUP and the CMRR. That relationship allowed for the provision of guidelines on the level of primary support, compatible with the CMRR and eventually the TG SF, as part of the original ALTS design methodology.

A further and more detailed examination of the relationship(s) between the CMRR and all stages of the ground support process was a principle objective of the subsequent research. The subsequent research also examined the support utilised within the tailgate–cut-through intersections, as it is these zones that tend to be more problematic during the course of the longwall retreat. Figures 2 to 4 illustrate the relationship between the three ground support ratings and the CMRR in relation to headings.

Figure 2 PRSUP vs CMRR – Headings

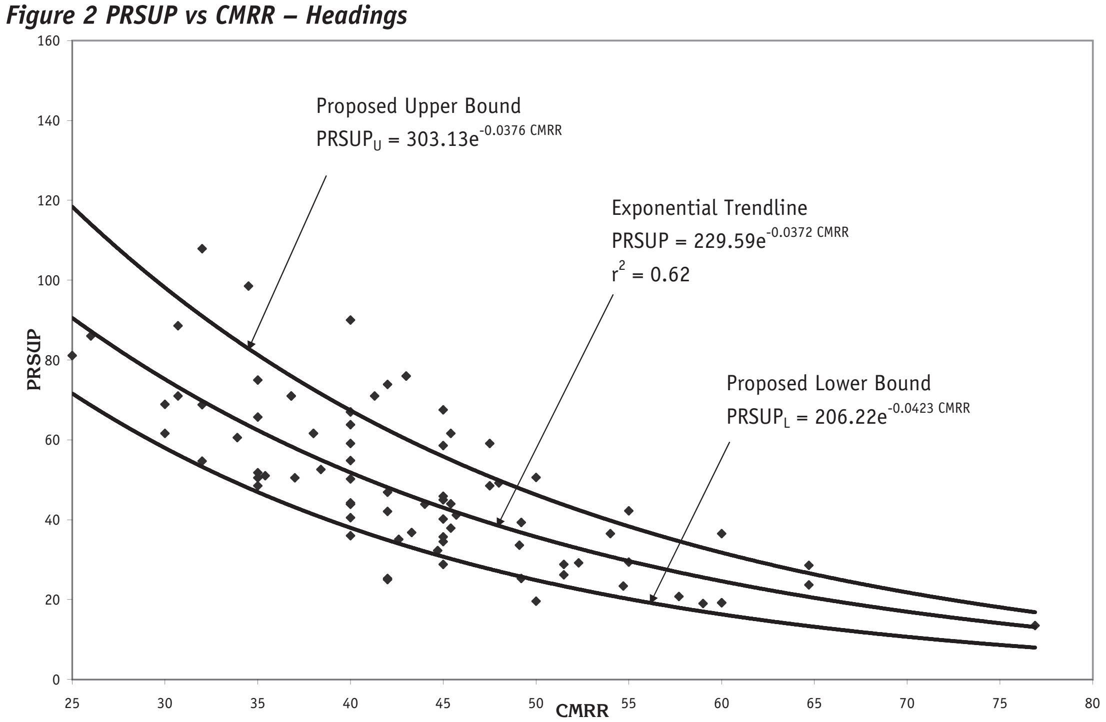


Figure 3 GRSUP vs CMRR – Headings

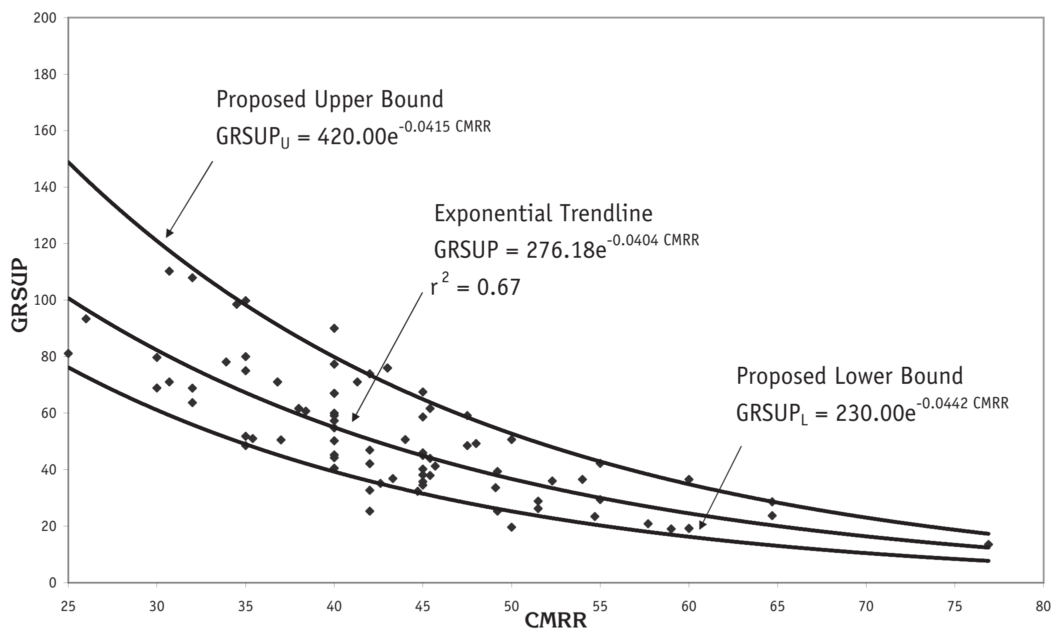
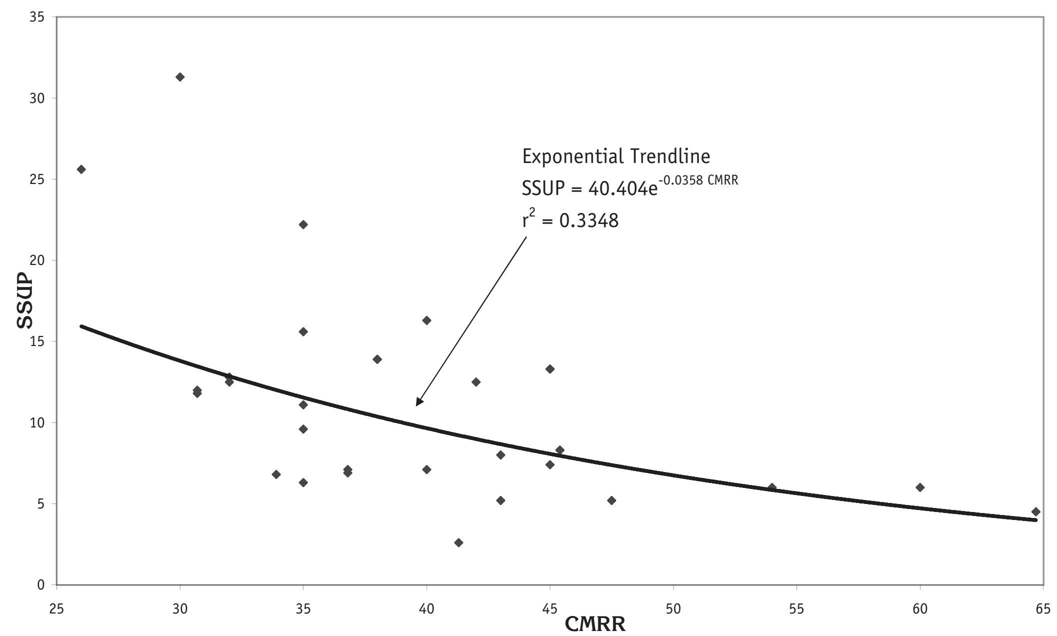


Figure 4 SSUP vs CMRR



There is clearly a strong exponential relationship between the level of primary support and the CMRR, which is further strengthened with the inclusion of the secondary tendon support (i.e. Figure 3 GRSUP vs CMRR). However the standing secondary support relationship (see Figure 4) is inconclusive, with one simple reason being fewer data sets as less than half of Australian collieries routinely utilise standing support along the length of the tailgate. In addition collieries that utilise standing secondary support do not tend to vary the density of that support in the same way that primary and secondary tendon support density is varied for different CMRRs along the length of a tailgate. To assist with the design process in relation to the probable level of SSUP required for satisfactory tailgate conditions, a further series of statistical analyses were conducted which are represented in Figures 5, 6 and 7.

Figure 5 Standing Secondary Support Usage – Headings

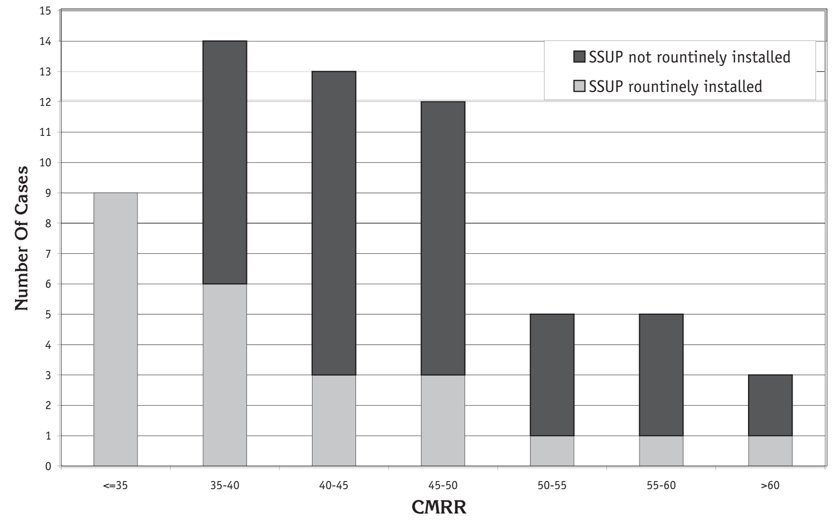


Figure 6 Standing Secondary Support Cumulative Percentage Usage – Headings

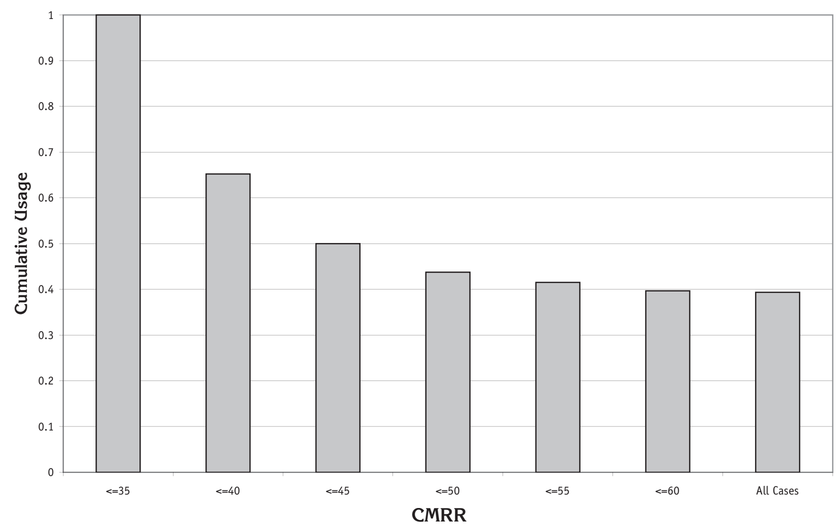
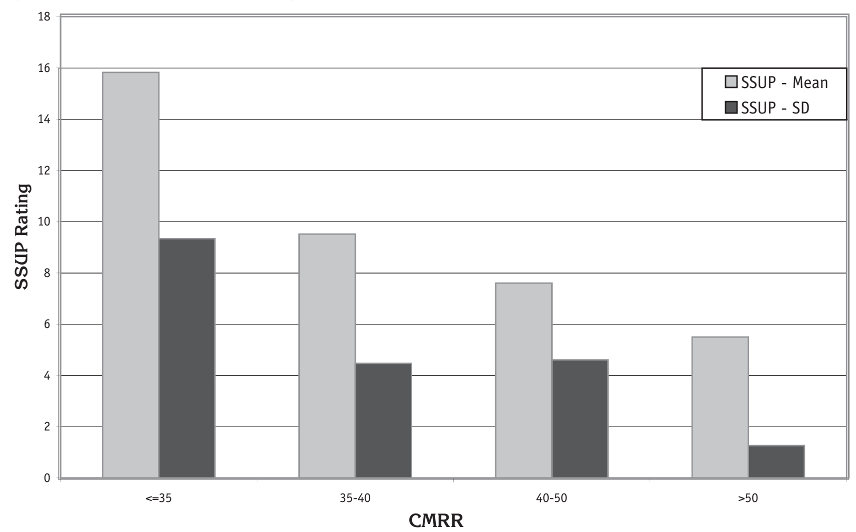


Figure 7 SSUP Mean and Standard Deviation – Headings (for mines utilising SSUP)



From Figure 5 there is clearly a distinct change in colliery attitude to the use of standing support between a CMRR of 35 and 40. Some level of standing secondary support is routinely utilised when the CMRR is ≤ 35 and yet becomes less than a 50:50 *proposition* between 35 and 40. In relation to those collieries utilising standing secondary support it was assessed that in terms of the SSUP mean and standard deviation there are essentially three categories of SSUP usage that could be used in design, being a CMRR ≤ 37.5, 37.5 to 50 and > 50.

Figure 8 (GRSUP + SSUP) vs CMRR – Headings

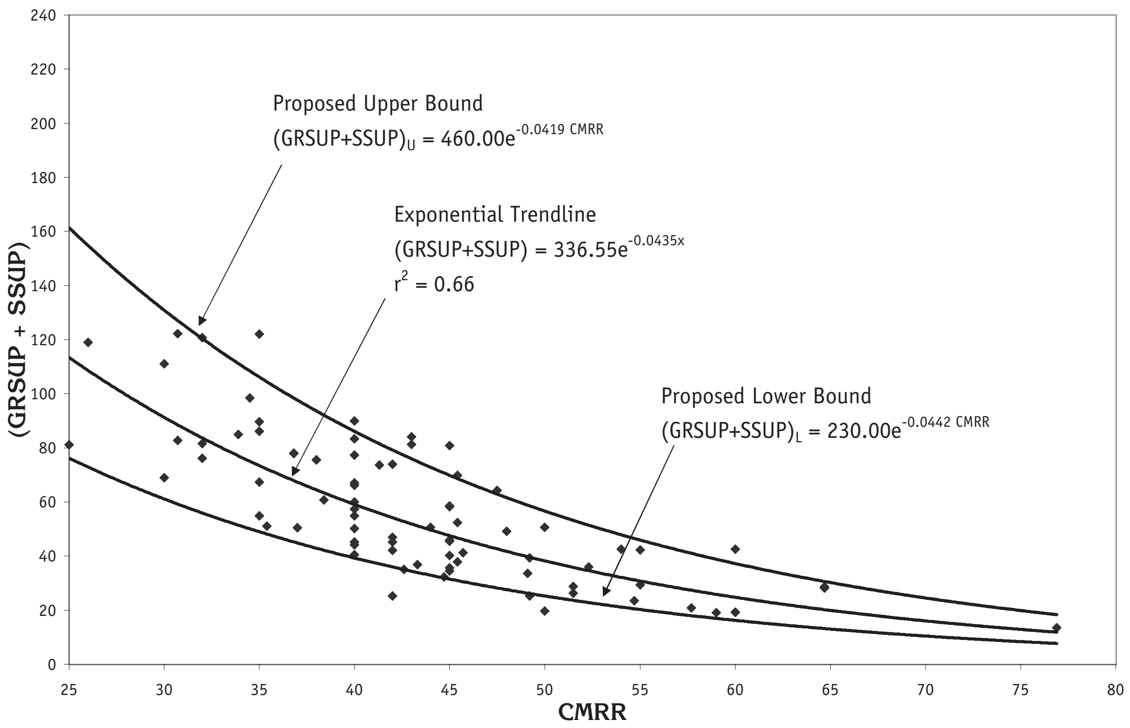
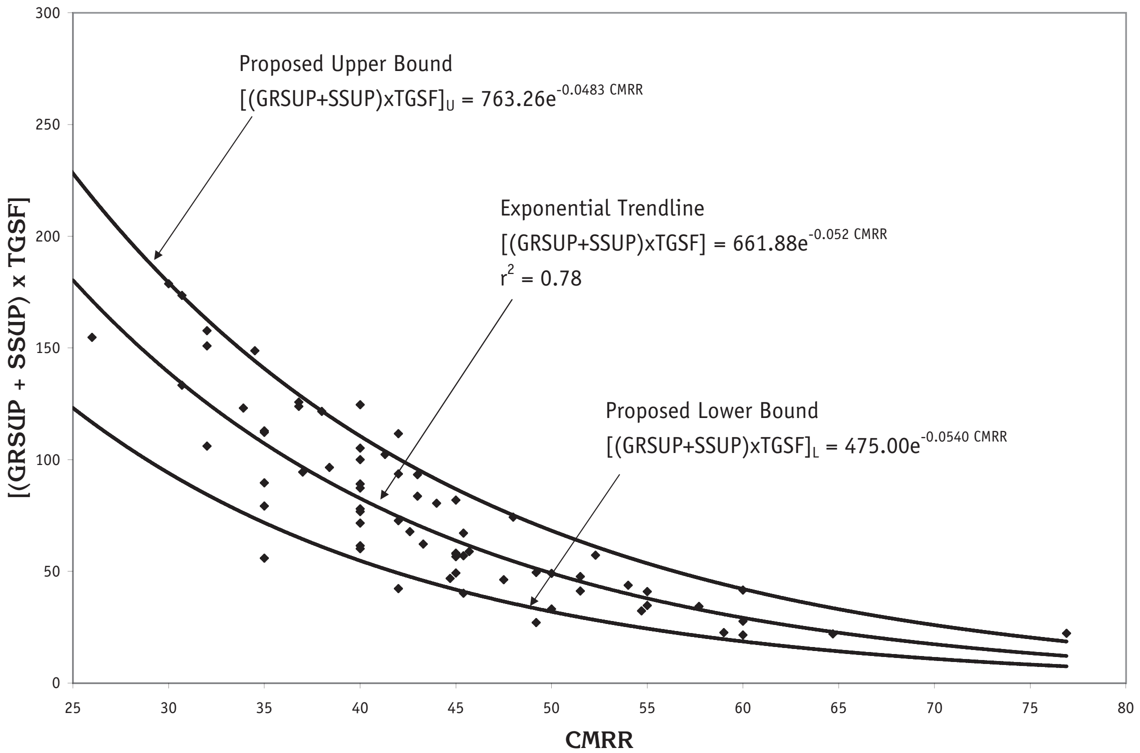


Figure 9 (GRSUP + SSUP) x TG SF vs CMRR – Headings



Figures 8 and 9 illustrate the effect of incorporating the SSUP with the GRSUP to reflect a total support capacity in relation to the CMRR and then using TG SF as a multiple. Once a colliery has decided on the orientation of the longwall panels, the TG SF, GRSUP and SSUP incorporate the majority of the geotechnical design parameters required of the colliery other than timing of ground support installation. When combining these three design parameters the level of correlation with the CMRR (i.e. $r^2 = 0.78$) is exceptionally high. Essentially 78% of the variability in gateroad design is accounted for by the regression equation of Figure 9 and the CMRR.

In developing a longwall gateroad design methodology using the relationships between the various parameters and the CMRR, the critical aspect is to delineate an acceptable and practical range in which each can be varied. Upper and lower boundaries need to be established and in doing so consideration needs to be given to the impact of horizontal stress. A large proportion of that impact is mitigated with the use of the CMRR in the analyses, as the impact of horizontal stress is largely proportional to the roof's material properties and therefore the CMRR.

DESIGN LIMITS

Figures 2, 3, 8 and 9 detail initial upper and lower boundaries for each stage of ground support and finally in combination with the TG SF. Figures 10 and 11 are versions of Figure 9 that specify upper and lower design boundaries for (GRSUP + SSUP) ´ TG SF in terms of HORST. Similar design boundaries are applied to the GRSUP + SSUP relationship with the CMRR (see Figure 8) to ensure there is a safeguard if either large or small values for TG SF are used which could result in impractical levels of ground support. However to prevent such an occurrence, Figure 12 details the limits in relation to chain pillar design utilising the TG SF and CMRR. Figure 12 is a modification of Figure 1.

Figure 10 Upper and Lower Boundaries for Design – HORST is Yes

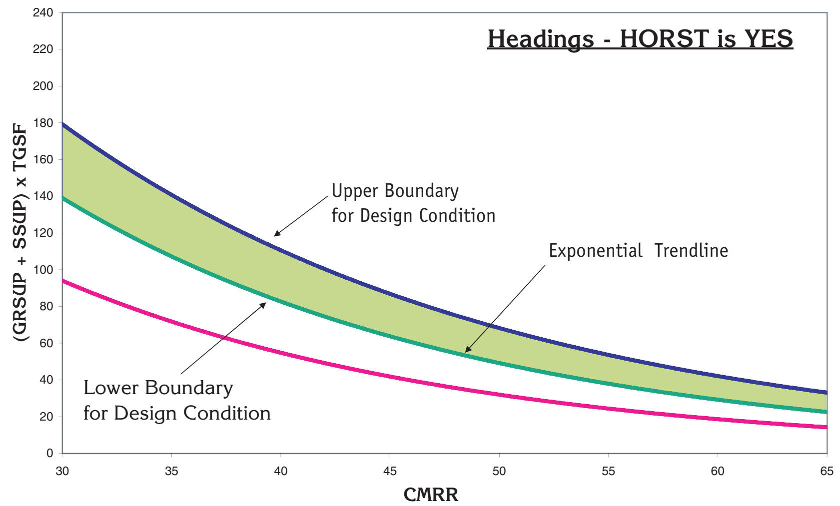


Figure 11 Upper and Lower Boundaries for Design – HORST is No

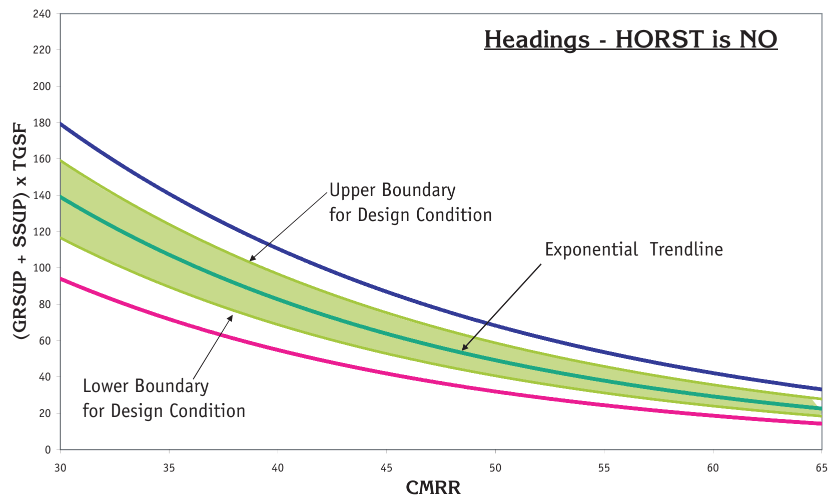
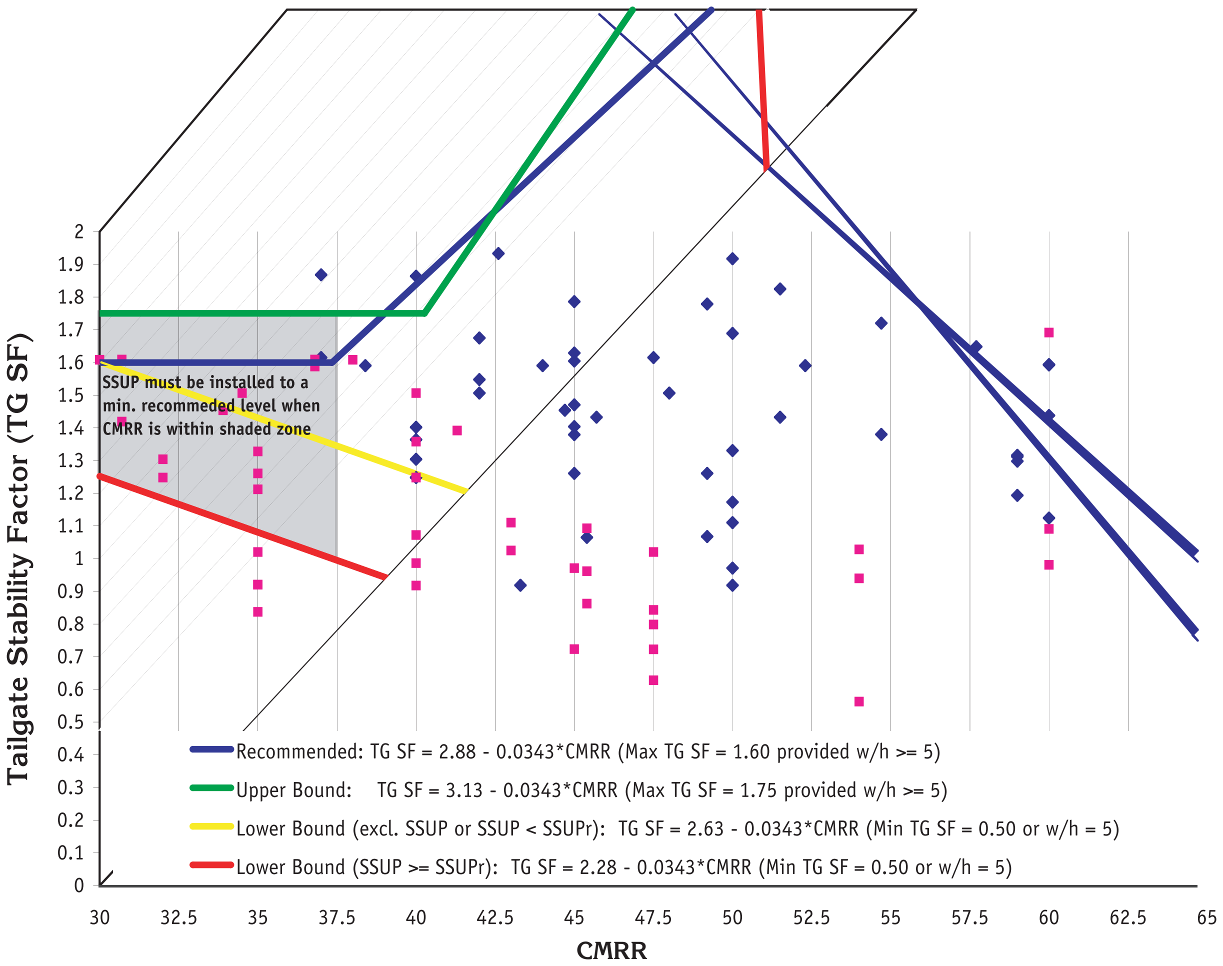


Figure 12 Upper and Lower Boundaries for Design – TG SF vs CMRR



The blue line of Figure 12 is the *line of best separation* from Figure 1 or the recommended design line. The yellow line represents the lower boundary when standing secondary support is not to be installed or will be installed at a level less than the recommended value. The red line represents the absolute lower bound when SSUP ≥ $SSUP_R$ (the recommended SSUP level) for both headings and cut-through intersections. The green line represents the upper bound for which any practical benefit in terms of gateroad performance is derived from the pillar size. An important aspect in relation to pillar sizing is that the minimum allowable TG SF is 0.5 and the minimum allowable pillar width/height is 5.

In relation to standing secondary support five cases are considered in terms of the three CMRR categories previously discussed and HORST. It should be noted that if a colliery wishes to use ALTS II for design and the CMRR ≤ 37.5 then standing support must be used to at least the minimum level of the recommended support range. However, when the CMRR > 37.5 then it is the colliery's decision on whether or not to install standing secondary support and at what level. The proviso is that if the colliery decides to install standing support, then SSUP is to be ≥ 5. It was assessed that at a lower level there would be negligible interaction between the individual supports in relation to overall roof control i.e. SSUP effectively becomes 0.

The level of standing support chosen (as measured by the SSUP) will directly impact on which of the two TG SF lower bounds is used for chain pillar design. The five cases for consideration when a colliery utilises standing support along the length of the tailgate are:

Case 1. CMRR ≤ 37.5 & HORST is Yes (SSUP must be ≥ 10)
$SSUP_R$ (Headings & Intersections) = 17
Recommended Range 10 to 25 (Headings & Intersections)

Case 2. CMRR ≤ 37.5 & HORST is No (SSUP must be ≥ 5)
$SSUP_R$ (Headings & Intersections) = 12
Recommended Range 5 to 20 (Headings & Intersections)

Case 3. 37.5 < CMRR ≤ 50 & HORST is Yes
$SSUP_R$ (Headings) = 13
Recommended Range 5 to 18 (Headings)
SSUPR (Intersections) = 16
Recommended Range 5 to 21 (Intersections)

Case 4. 37.5 < CMRR ≤ 50 & HORST is No
$SSUP_R$ (Headings) = 8
Recommended Range 5 to 13 (Headings)
SSUPR (Intersections) = 11
Recommended Range 5 to 16 (Intersections)

Case 5. CMRR > 50 & HORST is Yes or No
$SSUP_R$ (Headings & Intersections) = 5
Recommended Range 5 to 8 (Headings)
Recommended Range 5 to 11 (Intersections)

It should be noted the study concluded that there was minimal benefit in using standing support along the length of a tailgate when the CMRR>50 except at depths of cover greater than ≈ 350 m. In addition ALTS II makes no recommendations in relation to the use of standing support within the confines of the cut-throughs or adjacent to seals.

ALTS II DESIGN METHODOLOGY

For practical design, the most significant conclusions from the research are:

- Gateroad design is primarily based on the structural integrity of the roof being characterised by the CMRR.
- The four key design parameters determining tailgate performance are pillar sizing, primary and secondary tendon roof support and standing support.

The first step in using ALTS II is to evaluate and/or delineate the required data input, being:

- Coal Mine Roof Rating (CMRR)
- Primary Support Bolt Length (L_b)
- Assessment for HORST
- Assessment for SSUP
- Geometric Data
  - Depth of Cover (m)
  - 1st Panel Width (m, centre)
  - 2nd Panel Width (m, centre)
  - Roadway Width (m)
  - Development Height (m)
- Pillar Loading Parameters (refer Colwell 1998)
  - Overburden Density (t/m^3)
  - Abutment Angle (°)
  - ΔTG:ΔMG

In terms of conventional gateroad panel development, it is proposed to use the CMRR that would typically represent the major portion of the tailgate in question. In pragmatic terms this will relate to previous colliery experience and available borehole information. In evaluating HORST the colliery is encouraged to use empirical, anecdotal or numerical techniques to assist in that assessment. Also if in doubt, HORST can be used to evaluate best and/or worst case scenarios.

Using the guidelines provided, a colliery needs to decide on whether it will incorporate the routine installation of standing support along the length of the tailgate and at what level. The ultimate load bearing capacity of the support element should be assessed and the intended SSUP calculated.

Step 2 is to select an initial pillar size that satisfies both operational issues and the recommended TG SF range that can be ascertained using Figure 12.

Step 3, having assessed all of the above, use is then made of Figures 10 and 11 to evaluate the recommended GRSUP range.

Step 4 is then to use an iterative process (if necessary) varying pillar size and ground support levels to finalise the overall gateroad and chain pillar design. For example it is up to the colliery to decide on what combination of primary and secondary tendon support will be used to satisfy the selected GRSUP. The selection of the GRSUP will essentially be dependent on a risk assessment which amongst other aspects should include level of experience with the intended ground conditions (e.g. greenfield site or not), level of geological knowledge, intended level of monitoring and assessment, the setting of ground behaviour *trigger* levels and the ability of the colliery to respond to said trigger levels as a part of the colliery's SMP.

Step 5, having decided on the chain pillar width and assessed the ground support requirements along the headings, the final step is to assess the appropriate or corresponding levels of GRSUP and SSUP for heading/cut-through intersections. (Due to space constraints the corresponding relationships with the CMRR for intersections have not been included within this paper, however they are available from Colwell Geotechnical Services.)

APPLICATIONS FOR ALTS

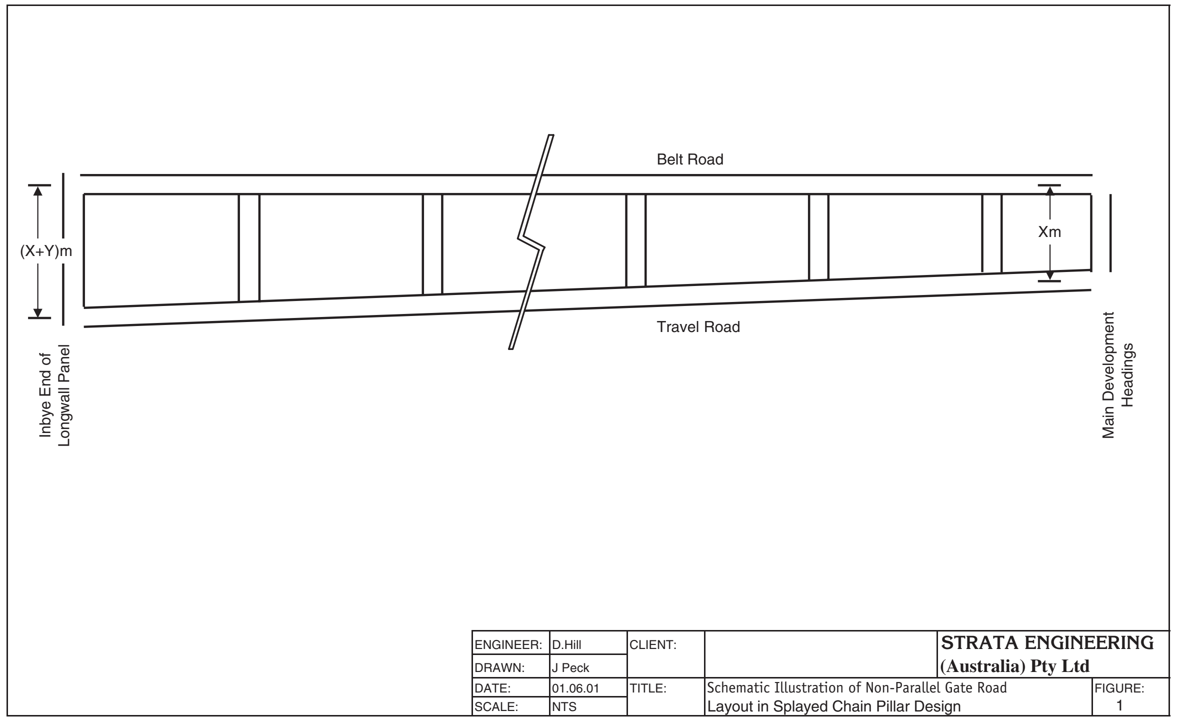
During the last four years ALTS has been used on numerous occasions in the design of chain pillars for collieries in both Queensland and New South Wales. A major goal of the research was to develop a design methodology and software that could be utilised directly by the collieries. A series of workshops conducted in 1999 (ALTS) and 2002 (ALTS II) provided training for both the collieries and the inspectorate in the technique's use and application. Several collieries now utilise ALTS II directly as either their primary or supplementary means of assessing gateroad design. In recent years the technique has also been utilised in a unique manner in the design of tapered gateroad panels.

Tapered Chain Pillar Design

One of the innovative applications of ALTS in recent years has been in the area of tapered chain pillar designs (see Figure 13). A tapered pillar design involving non-parallel gateroads is feasible wherever the mining layout is unconstrained by existing development and there is a reasonably consistent and defined change in one or more variables, most commonly roof quality (defined by the CMRR) or depth of cover, from one end of the panel to the other. It should be noted that:

- The dimensions of the longwall block itself do not change, such that the longwall panel will be rotated by a fractional amount.
- Usually the rate of change in the pillar width is practically imperceptible underground, as the splay angle is typically less than 1º (i.e. the individual pillars are practically rectangular).
- Where the pillars narrow towards the mains development, as shown in Figure 13, there is also a reduction in mains drivage.

Figure 13 Splayed Chain Pillar Design Concept



The net saving in drivage generally amounts to several hundred metres over individual gateroads and can total several kilometres over a series of gateroads. Although the tapered pillar approach could potentially be adapted to any chain pillar design methodology, the speed of application of ALTS facilitates the ready analysis and quantification of a range of geotechnical scenarios, such that the process does not become unwieldy and remains both cost and time effective.

Furthermore, the development of ALTS II opens up further scenarios whereby the pillar configuration and roof support system can be finessed to better address potential localised anomalies, such as the effect on tailgate serviceability of a surface ridge or escarpment. The hazards associated with such features can now be more fully assessed using the derived pillar width/ground support relationships.

This design approach has been applied on several occasions over the last three years (e.g. Hill 2000, 2001, 2002). To date, two tapered gateroad panels have been developed and one longwall extracted. The successful gateroad panel tapered from 26 m to 42 m (centres) from outbye to inbye, on the basis of increasing depth and reducing CMRR; this equates to an average width of 34 m, as against an earlier proposal based on a standard 40 m (a net drivage saving of approximately 200 m in one gateroad panel). The drivage of tapered gateroads at a second major longwall project has now commenced.

CONCLUSIONS

ALTS II provides the means by which a compromise between roof quality, chain pillar width and gateroad roof support can be assessed in terms of satisfactory roadway performance throughout the longwall extraction cycle. Furthermore ALTS II can be used such that a comparison can be made between the various stages (primary and secondary) and hardware (tendon and standing) utilised for roof support and can allow for an assessment of mine layouts so as to optimise development rates and/or costs or to maximise resource recovery.

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