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The Abutment Angle Model and Its Appropriate Use for Longwall Tailgate Design

Mark Cowell
Colwell Geotechnical Services

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Mark Colwell[1]

ABSTRACT: In Australia and the United States the longwall gateroad design methodologies ALTS (Analysis of Longwall Tailgate Serviceability) and ALPS (Analysis of Longwall Pillar Stability) were developed to assist in the design of chain pillar systems to satisfy gateroad serviceability requirements. Important to the application of both methods is a reasonably accurate determination of the vertical load carried by the chain pillars at the various stages of the longwall extraction cycle. To calculate the load, use is made of Tributary Area concepts and the Abutment Angle Model. While Tributary Area Theory and the Abutment Angle Model generally assist in providing a reasonable approximation to a complex issue; chain pillar monitoring studies conducted in Australia over approximately the last 30 years strongly indicate that without the application of prudent engineering judgment significant errors in the calculation of the abutment loads carried by the chain pillar system can be made. This paper explores the appropriate use of the Abutment Angle Model for longwall tailgate design and details a number of case studies to highlight the issue.

INTRODUCTION

Where total extraction methods such as longwall mining are employed, failure of the rock mass above the extraction horizon occurs and a goaf is formed. The goaf is of reduced stiffness compared to the original rock mass resulting in a portion of the overburden load above the extracted panel being distributed to adjacent solid coal (i.e. unmined area or in pillars) away from the goaf edge. The distributed load is referred to as the abutment load. With respect to longwall mining it is the side abutment load (A, MN/m) which is typically calculated and then utilised in conjunction with Tributary Area concepts to determine the vertical load carried by the chain pillars at the various stages of the longwall extraction cycle.

Various methods have been used to estimate both the magnitude and distribution of the side abutment load about the longwall panel, including stress balance approaches (e.g. Wilson, 1973 and 1981) as well as the use of surface subsidence profiles (e.g. King and Whittaker, 1971, Choi and McCain, 1980 and Mills, 2001) to assist in the evaluation. In developing the ALTS (Analysis of Longwall Tailgate Serviceability - Colwell, 1998) and ALPS (Analysis of Longwall Pillar Stability - Mark, 1990) design methodologies, the abutment angle and load distribution functions were assessed based on industry wide underground investigations (e.g. vertical stress change monitoring of chain pillars).

However, irrespective of which method is used to calculate the side abutment load; chain pillar monitoring studies conducted in Australia over approximately the last 30 years strongly indicate that without the application of prudent engineering judgment significant errors in the calculation of the abutment loads carried by the chain pillar system can be made (particularly at the tailgate corner of the longwall face). This paper explores the appropriate use of the Abutment Angle Model for longwall tailgate design and details a number of case studies to highlight the issue.

THE CHAIN PILLAR LOADING CYCLE

The chain pillars that will experience the greatest vertical loading at any particular stage of the extraction process will be situated between two longwall panels. This obviously accounts for the bulk of chain pillars in a longwall extraction area (i.e. series of longwall panels).

To assist with subsequent discussion and the terminology used, reference is made to Figure 1, which is a plan schematic of a typical Australian longwall mining layout utilising a two-

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[1] *Mark Colwell, Principal, Colwell Geotechnical Services. Email: markcolwell@bigpond.com Tel: +61 7 5499 7233*

heading gateroad system. Figure 1 depicts a fully extracted longwall panel, one currently being extracted and a third where the gateroads (Maingate 3 or MG 3 – 'A' and 'B' Headings) are still to be completed to fully delineate the longwall panel and chain pillars. 'A' Heading is generally referred to as the travel road along which men, materials and machinery will travel, while 'B' Heading is called the belt road where the conveyor belt is installed to transport coal from the longwall extraction face.
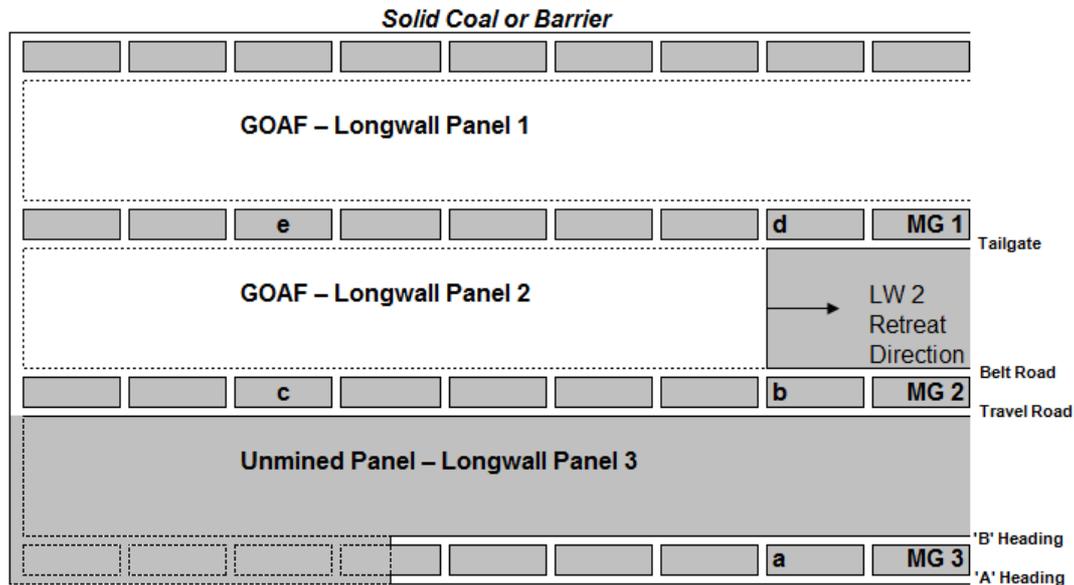
Figure 1: Typical Australian longwall layout (using a 2-heading system)

In a series of longwall panels, 'A' Heading typically serves two roles, firstly as the travel road of the current longwall panel and secondly as the tailgate of the next. For example, the travel road of Longwall Panel 2 (LW 2, refer Figure 1) will become the tailgate of LW 3. Therefore this travel road/tailgate is subjected to a series of changing geotechnical environments, moving from development (Position a) to the passage of the 1st adjacent longwall face (Positions b and c respectively) and finally being subject to the approach of the 2nd adjacent longwall face up to the tailgate intersection (Position d) with the *travelling* longwall face.

With reference to Figure 1 it can be seen that the chain pillars are also subject to a series of changing loading environments with the following terminology being used to describe each stage of the chain pillar loading cycle:

- Position a – Development Loading
- Position b – Maingate Belt Road (MGB or Front Abutment) Loading
- Position c – Maingate (MG) Loading
- Position d – Tailgate (TG) Loading
- Position e – Double Goaf (DG) Loading

It is during tailgate loading that the chain pillar (or cross-section thereof adjacent to the tailgate intersection) will experience the greatest vertical loading throughout its *active life*. Where the *active life* is the period of time during which the chain pillar is playing its role in helping to maintain satisfactory roadway conditions. ALTS and ALPS focus on tailgate performance (at the T-junction, refer Position d - Figure 1) as the design condition. Within ALTS the chain pillar index in relation to the TG Loading Condition is designated as the Tailgate Stability Factor or TG SF and with respect to ALPS it is referred to as the ALPS Stability Factor or ALPS SF

Both the TG SF and ALPS SF are calculated in a similar manner to a pillar's Factor of Safety (i.e. Pillar Strength divided by Average Pillar Stress). In developing ALTS, Colwell (1998) suggests the chain pillar TG Load is generally equal to Tributary Area Load (T) plus 1.5 A,

while the Pillar Strength (where w/h is the chain pillar minimum width to height ratio) is calculated using the Bieniawski (1984) equation where:

Pillar strength = 6.2 (0.64 + 0.36 w/h) MPa

In reality there can be significant variations to the general TG Load = T + 1.5 A (MN/m) between coalfields, collieries and along an individual gateroad due to several factors; in particular variations in the panel/pillar geometry and natural strata variations. Also in utilising the TG SF it is vitally important to note that the TG SF is not a Factor of Safety. To undertake the empirical analyses associated with the ALTS research, numerical values (or indices) needed to be assigned to the various parameters that affect gateroad performance. The TG SF Rating allows for an assessment of the impact (or contribution) that chain pillar size has on tailgate performance.

ABUTMENT ANGLE MODEL

To calculate the load carried by a chain pillar at the various stages of its loading cycle use is made of Tributary Area concepts and the Abutment Angle Model. The Abutment Angle Model utilises the panel and pillar geometry and the abutment loading parameters to calculate the abutment load associated with a longwall panel and thereby allows the chain pillar load to be calculated for the various stages of the chain pillar loading cycle associated with longwall operations (refer Figure 1).

In terms of the calculations, the required panel and pillar geometry are the solid (i.e. rib to rib) chain pillar width (w), roadway or entry width (w_e), cover depth (H) and longwall panel width (W, being the maingate belt road to tailgate centre to centre distance i.e. W = face width + w_e).

The abutment loading parameters are essentially 1) the vertical pressure gradient (γ) which in ALTS is generally taken to be 0.025 MPa/m, 2) the abutment angle (ϕ) and 3) the ratio between TG and MG Loading Conditions (i.e. ΔTG:ΔMG), where this ratio is calculated solely in terms of the additional measured abutment load subsequent to development.

It is important to note that; the abutment angle should not be considered as a physical reality (e.g. such as the angle of draw associated with surface subsidence measurements). The abutment angle and ΔTG:ΔMG are generally obtained (or back-calculated) based on field investigations with the abutment angle then used as a part of the Abutment Angle Model (i.e. a mathematical process) to estimate the portion of the overburden load not supported by the goaf (i.e. the side abutment load). The following discussion in combination with Figures 2 and 3 provides a more detailed explanation of the abutment loading parameters and how they are utilised in calculating the chain pillar load at the various stages of its loading cycle.

As LW 1 (refer Figure 2) laterally approaches and retreats past a chain pillar, the pillar goes through a dynamic loading cycle. This incorporates the development load (T, calculated using tributary area concepts) plus the onset of a front abutment load as the longwall face approaches the pillar. The portion of abutment load carried by the chain pillar increases (up to a limit) as the longwall faceline continues to retreat outbye. Once the face retreats to a distance sufficiently removed from the chain pillar, static (i.e. side abutment or MG) loading conditions apply (refer Position c – Figure 1).
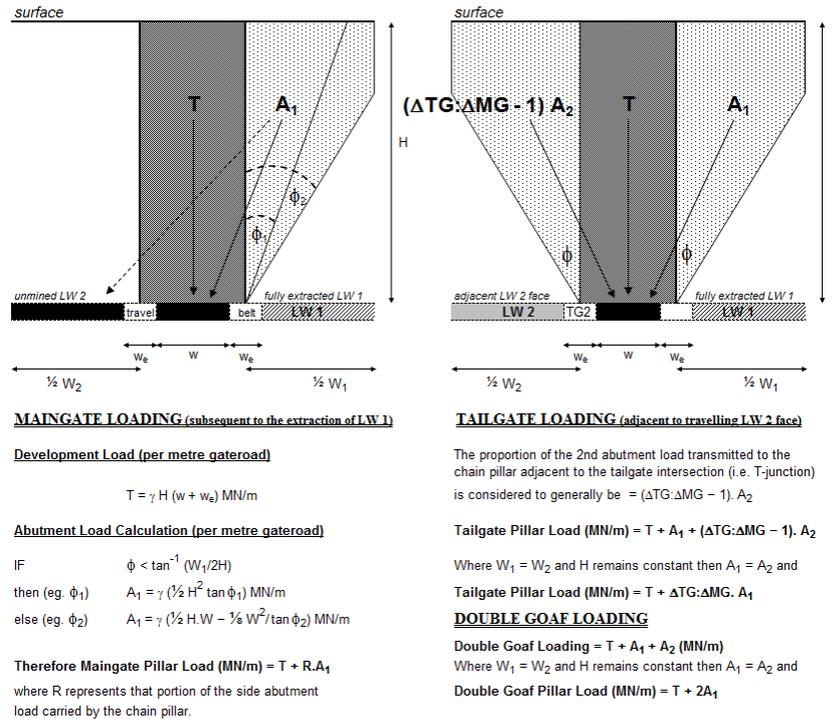
Figure 2: Abutment angle loading model

Subsequent to the full extraction of a longwall panel, the total abutment load is considered (as a reasonable approximation) to be evenly distributed on either side of the longwall panel centre line. Therefore the side abutment load (A, MN/m) is defined as that portion of the redistributed load associated with half the longwall panel width (½W) per metre of gateroad (as illustrated in Figure 2).

Dependent on the longwall panel width to cover depth ratio (W/H) and the size of the abutment angle (ϕ), the abutment area may first intersect ½ longwall panel width or extend to the surface (refer Figure 2), which determines the equation utilised to calculate the side abutment load (A) as detailed on Figure 2.

At the MG Loading stage of the longwall extraction cycle, the side abutment load (A_1) associated with LW 1 is distributed between the chain pillar and the solid coal within the unmined LW 2 (refer Figure 2). To estimate the portion of the side abutment load carried by the chain pillar (at MG Loading) use is made of the stress decay curve employed within ALPS, which is illustrated by Figure 3.
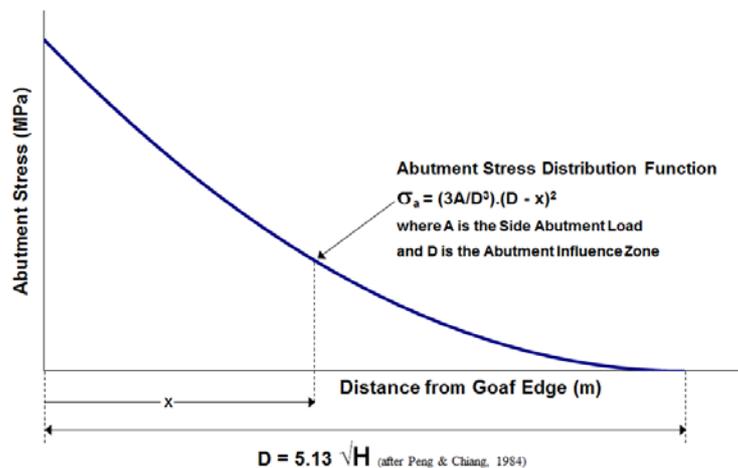

Figure 3: Abutment stress distribution function

In relation to Figure 3, D is referred to as the Abutment Influence Zone, which is based on field measurements analysed by Peng and Chiang (1984). They defined this zone as the distance from the panel edge that abutment stress increases could be detected. Field measurements associated with Australian studies (i.e. Colwell, 1998 and Colwell, 2006) are in general agreement, albeit with some notable exceptions.

Utilising the Abutment Angle Model, Abutment Stress Distribution Function as well as longwall panel and roadway centre to centre distances, the load carried by the chain pillar under MG Loading is estimated to be T + RA (MN/m), where R is referred to as the Stress Reduction Factor and is calculated as follows:

$R = 1 - [(D - w - w_e) / D]^3$

As LW 2 retreats (refer Figure 2), the chain pillars located between LW's 1 and 2 go through a 2nd dynamic loading cycle. This incorporates the development load and the first side abutment load plus the onset (and therefore a portion) of a second front abutment load. Where the longwall panels are of equal width (i.e. $W_1 = W_2$) and the cover depth remains reasonably constant (therefore $A_1 = A_2$) then the ratio between Tailgate and Maingate Loading Conditions (ΔTG: ΔMG) can be used to estimate the TG Load such that:

TG Load (MN/m) = T + ΔTG:ΔMG . A_1

Once the second longwall face retreats to a distance sufficiently removed from the pillar then Double Goaf Loading Conditions apply and in theory this results in the chain pillars being subjected to the development load plus twice the side abutment load (i.e. L = T + 2 A). Therefore in theory ΔTG:ΔMG must li3e between 1 and 2, however field investigations undertaken in Australia challenge the *theory* and therefore challenge how to best use the Abutment Angle Model as a part of an industry wide geotechnical design tool.

SUMMARY OF FIELD INVESTIGATIONS

To provide commentary on the appropriate use of the Abutment Angle Model for longwall tailgate design it is worth summarising the chain pillar monitoring studies reviewed by the author, which also provides some historical basis associated with the development, understanding and use of the Abutment Angle Model. There are essentially four sources of information:

- The research/field investigations associated with the ALPS research.
- The six chain pillar monitoring studies associated with Australian Coal Association Research Program (ACARP) Project C6036 entitled, "Chain Pillar Design – Calibration of ALPS" (Colwell, 1998).
- Thirteen chain pillar monitoring studies conducted in Australia prior to 1998, which were reviewed as a part of ACARP Project C6036.
- Subsequent to 1998, mine sites have provided the author with six chain pillar monitoring studies conducted by Strata Engineering Australia Pty Ltd (SEA) and three such studies undertaken by SCT Operations Pty Ltd (SCT).

The initial research in developing ALPS was undertaken by Mark and Bieniawski (1986) and further refined (Mark, 1990, 1992 and Mark et al, 1994) under the auspice of the United States Bureau of Mines (USBM). The initial research was carried out over five years with field measurements conducted at five separate mines (incorporating 16 longwall panels) to correlate an abutment angle (ϕ) with measured abutment loadings.

The full side abutment load was successfully measured at six of the sites where the cover depths ranged from approximately 140 m to 230 m. It is understood that all stress cells were installed within the chain pillars with none located within adjacent longwall panels or solid blocks. The full side abutment load was estimated using the Stress Reduction Factor (R), while calculated abutment angles were 10.7°, 17.3°, 18.5°, 20.3°, 21.8° and 25.2°. The six sites analysed by Mark (1990) have W/H ratios ranging from approximately 1 to 1.9 with no apparent correlation between the abutment angle and cover depth, panel width or W/H.

Unfortunately TG Loading could only be measured at one site and it was found that the *tailgate front abutment factor* (F_t, being the fraction of the tailgate side abutment reporting to the chain pillar at the T-junction) was 0.7. Therefore in terms of ALTS, this would equate to $\Delta TG: \Delta MG$ of 1.7, where $W_1 = W_2$. Based on the field investigations, Mark (1990) recommended generic values of $\phi = 21°$ and F_t, = 0.7 (i.e. $\Delta TG:\Delta MG = 1.7$) in assessing the abutment loads as a part of utilising ALPS for geotechnical design purposes.

By the mid-1990's there was recognition in Australia of the need to develop a chain pillar design technique specifically related to roadway serviceability. In 1997 with ACARP 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 and therefore the chain pillar monitoring sites associated with the ALTS research were set up in a similar manner to that used in the development of ALPS. For example the goal of the ALPS field investigations (and therefore for ALTS) was to measure the abutment loads rather than the total loads carried by the chain pillars. Therefore it was only necessary to utilise stress cells that measured the change in vertical load during adjacent longwall extraction.

The chain pillar widths associated with the six instrumentation sites associated with ACARP Project C6036 varied from approximately 25 m to 40 m (rib to rib), while Figure 4 illustrates a proposed instrumentation layout for a 30 m wide pillar.
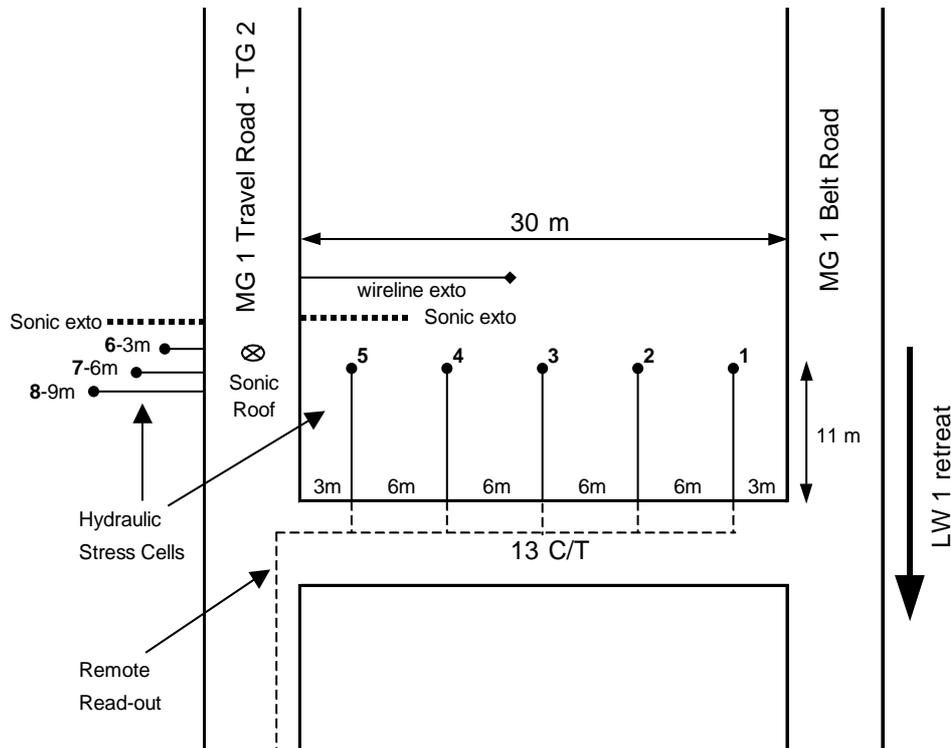

Figure 4: Typical instrumentation layout (30 wide pillar)

The stress cells were installed across the pillar from the cut-through at around mid-seam height and at a distance of approximately 10 m to 11 m from the cut-through ribline. In addition the cells were installed on the inbye side of the cut-through. Therefore if for any reason the wiring associated with the remote read-out was compromised, this allowed for the cells' pressure gauges (at the *mouth* of hole) to be read up to and including Tailgate Loading (i.e. where the longwall face is *in line* with the stress cells).

As well as the stress cells within the pillar, three cells were also installed within the 2nd adjacent longwall panel with a view to better defining the load distribution between the chain pillar and unmined panel at the MG Loading stage of the longwall extraction cycle and also to assess the correctness of the Stress Reduction Factor (R).

In addition to the array of stress cells; rib and roof extensometers were also utilised to assess the degree of movement and depth of softening within the pillar and roof. The stress cells immediately adjacent to the gateroad riblines often lost load as the longwall face approached and passed a site and in these instances the rib extensometers were particularly useful in providing corroborating evidence that the coal within the section of the pillar where the stress cell was located had in fact yielded under increased vertical load as opposed to a failure of the cell.

With respect to the six instrumentation sites, three were located in the Bowen Basin Coalfield (i.e. Central, Crinum and Kenmare), two collieries within the Newcastle Coalfield (i.e. Newstan and West Wallsend) and West Cliff Colliery in the Southern Coalfield. Table 1 summarises the panel and pillar geometry

Table 1: Summary of panel and pillar geometry

Monitoring Site	H(m)	W1 (m)	W2 (m)	W1/H	h (m)	w (m)	we (m)
Central	265	200	230	0.75	2.5	39.9	5.1
Crinum	125	275	275	2.20	3.6	30.2	4.8
Kenmare	130	200	200	1.54	3.1	24.8	5.2
Newstan	180	130	130	0.72	3.2	26.0	5.0
West Cliff	475	200	200	0.42	2.5	37.2	4.8
West Wallsend	240	145	145	0.60	3.2	30.1	4.9

Although not published, the author became aware during the original ALTS research that in the United States some concern had been expressed that *'ALPS does not work very well'* at deep cover with particularly strong ground conditions. The chain pillar monitoring studies (undertaken and reviewed as a part of ACARP Project C6036) associated with the deep cover South Coast (Illawarra) and Ellalong collieries identified the probable reason for that concern. Simply the TG Load is overestimated by using a generic abutment angle of 21°. The empirical analyses confirmed that to be the case.

However it was recognised that in most instances ALPS provided sound recommendations in relation to chain pillar sizing and was a proven chain pillar design tool such that prudent engineering judgment (based on compelling evidence) needed to be exercised before varying any of the loading parameters associated with the ALPS methodology. In the development of ALTS, the following criteria were applied to the calibration/adaptation process for Australian conditions:

- The ALPS abutment loading parameters utilised to estimate the TG Load (i.e. the design condition) should be maintained unless there is substantial evidence to the contrary.
- If changes to the abutment loading parameters are required, then to maintain the broad approach of the design methodology it is desirable to retain generic loading parameters.
- However where site specific corroborative information (both measured and anecdotal) is available, which indicates a significant departure from the ALPS abutment loading parameters then such changes will be made.

The tailgate loading data clearly indicated a generic ∆TG:∆MG of 1.5 (rather 1.7) would be more suitable for most Australian collieries, while it was assessed that there was no benefit to be gained in altering the generic abutment angle of 21° except for some notable exceptions as previously alluded to. Subsequent to the original ALTS project direct industry support was given to complete the ALTS II project (refer Colwell et al, 2003), which significantly increased the database. The combined database (i.e. information collected in 1997/98 and 2000) represented 31 collieries involving some 140 data sets.

Based on the above research and an SEA chain pillar monitoring investigation in 2000 associated with Southern Colliery in the Bowen Basin Coalfield (confirming previous Central Colliery investigations both conducted and reviewed as a part of ACARP Project C6036), the

following abutment loading recommendations were provided to the Australian industry in the use of ALTS for tailgate design:

An Abutment Angle of 21° and ∆TG:∆MG of 1.5 (i.e. default values) should be used; with the only variance to these default values being advised for the following specific instances:

- South Coast (Illawarra) Collieries operating in the Bulli Seam where H > 350 m and Southland (formerly Ellalong) Colliery - the recommended values for ϕ and ∆TG:∆MG are 10°and 1.5. (note: this recommendation has also applied to Austar Mine)
- Central and Southern Collieries, Bowen Basin Coalfield - the recommended values for ϕ and ∆TG:∆MG are 26° and 1.6 (note: for future workings these values are applicable to lithology that is similar to that being experienced at each colliery).

The subsequent chain pillar monitoring studies conducted by SEA and SCT, which have been reviewed have since confirmed that the above recommendations are still the most practical way of estimating the chain pillar load associated with the TG Loading Condition (refer Position d - Figure 1) for all current Australian longwall operations and therefore the TG SF for chain pillars subject to double pass longwall extraction. These recommendations are still embedded in the current version of ALTS i.e. ALTS 2009 (refer Colwell and Frith, 2009).

CASE STUDIES OF PARTICULAR NOTE

Figure 5 plots ∆TG:∆MG against the Relative Face Position of the 2nd Adjacent Longwall face for the six chain pillar monitoring studies associated with ACARP C6036.

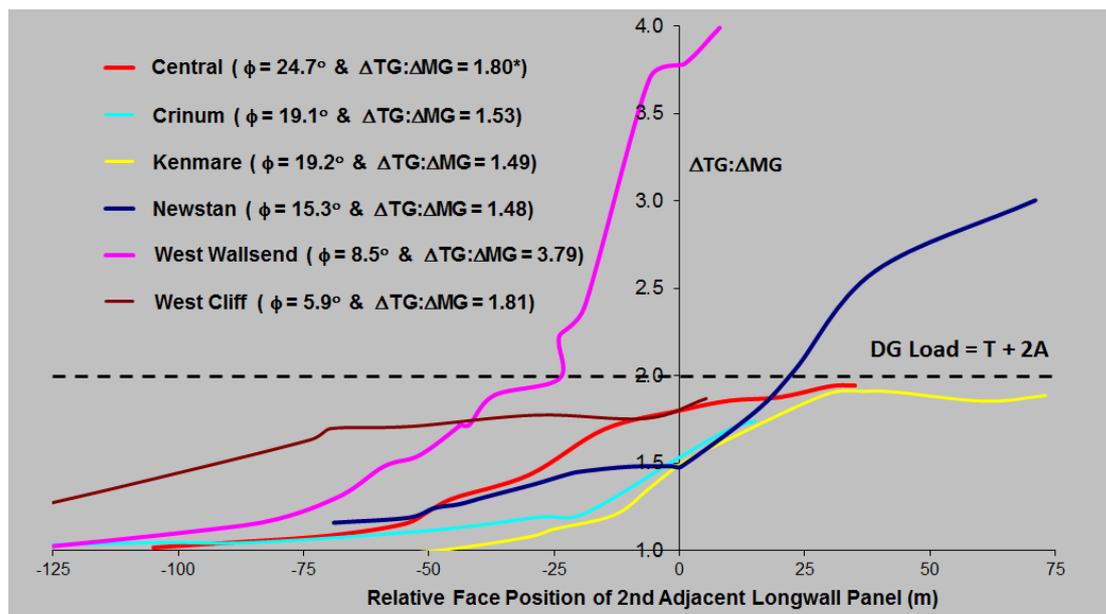**Figure 5: ∆TG:∆MG versus 2nd LW face position**

As Figure 5 illustrates, both Maingate (i.e. the full side abutment load) and Tailgate Loading were successfully measured at all six sites. At three of the six sites Double Goaf (or at least close to Double Goaf) Loading was also measured prior to the cabling for remote read-out being destroyed. They were Central, Kenmare and Newstan collieries. Please note in relation to Central Colliery W_2 of 230 m is greater than W_1 of 200 m and therefore it is likely that the measured ∆TG:∆MG of 1.8 is slightly greater than had W_2 equaled W_1 as was the case for all other sites.

While the three Bowen Basin collieries (and for that matter even Newstan Colliery up to TG Loading) reasonably approximate the Abutment Angle Model utilising the generic ALTS abutment loading parameters, clearly West Wallsend and West Cliff Collieries do not. Also based on the Abutment Angle Model, in theory, the maximum measured change in vertical

load associated with double pass longwall extraction should not be greater than 2A and clearly West Wallsend and Newstan collieries significantly exceed the *theoretical cut-off*.

Figures 6 and 7 respectively display the measured stress profiles in relation to the extraction of Longwall Panels 16 and 17 associated with the West Wallsend Colliery chain pillar monitoring site. Figure 6 also displays the theoretical stress distribution associated with MG Loading based on an abutment angle of 21° and the stress distribution function displayed on Figure 3.

Subsequent to MG Loading there was significant concern that Cells 3 to 7 inclusive were malfunctioning with the measured/back-calculated abutment angle was only equal to 8.5°, which is based on the calculated MG Load being the integral under the stress profile with the LW 16 face position 242 m outbye of the site. However during the retreat of LW 17 (i.e. the tailgate loading phase – refer Figure 7) it became clear that such concern was not warranted and that an interesting loading phenomenon had occurred.
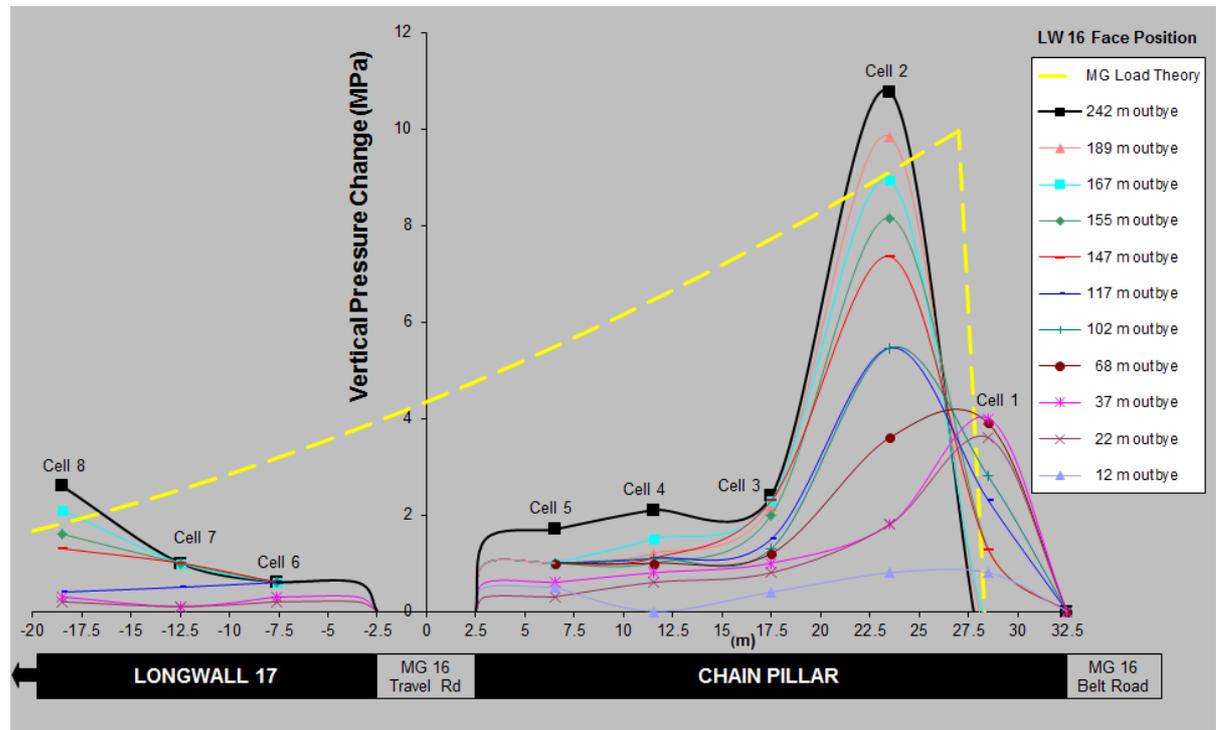

Figure 6: Maingate loading phase stress profiles – West Wallsend Colliery
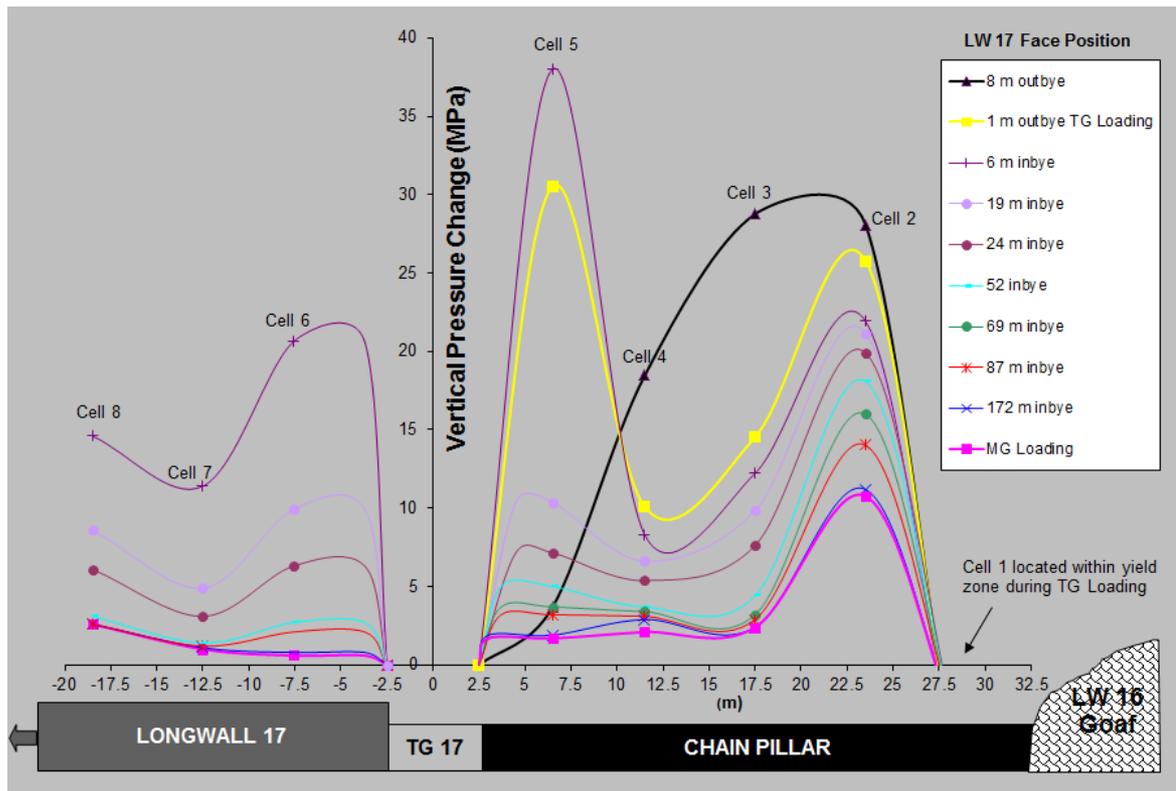
Figure 7: Tailgate loading phase stress profiles – West Wallsend Colliery

As illustrated by Figure 7, the abutment load that had not reported to the chain pillar as part of MG Loading came into *full force* during tailgate loading. The integral of the stress curve associated with the LW 17 faceline 1m outbye of the cells (which closely approximates the TG Loading Condition) results in a ΔTG:ΔMG = 3.79. Based on ϕ and ΔTG:ΔMG of 8.5° and 3.79 and the panel/pillar geometry (refer Table 1) the average chain pillar stress is 20.53 MPa resulting in a TG SF = 1.22. If the recommended generic ALTS abutment loading parameters of ϕ and ΔTG:ΔMG of 21° and 1.5 had been used the calculated average chain pillar stress would be 20.12 MPa resulting in a TG SF = 1.24 i.e. a minor to negligible difference.

Colwell (1998) suggested that the nature of the overlying strata (i.e. a number of relatively thick sandstone and/or sandstone/conglomerate units within the overburden) in combination with the sub-critical nature of the panel width i.e. W/H = 145 m/240 m = 0.6), may result in the distribution of the side abutment load over a wider area rather than concentrating the side abutment load on the chain pillar and immediate rib line of the adjacent longwall panel during MG Loading as per the Abutment Angle Model. The stress cells within the adjacent longwall panel do indicate there is a gradual stress increase moving away from the solid rib (refer Figure 6).

Wold and Pala (1986) had made similar observations in relation to chain pillar monitoring studies conducted by CSIRO at Ellalong Colliery where they state, *"The visual evidence of heavy abutment loads being distributed about the longwall block more broadly than might have been expected on theoretical grounds tended to be supported by the field measurements"*.

As illustrated in Figure 5, the last successful stress cell measurements associated with Newstan Colliery (prior to the cabling being destroyed) occurred with the 2nd adjacent longwall face (LW 11) being approximately 71 m outbye of the line of stress cells. Given the shape of the curve and the panel width/cover depth ratio it is unlikely that full double goaf loading had been established at this point, however if one were to assume this to be double goaf loading then based on the measured change in load being equal to a theoretical 2A, then a back-calculated abutment angle of 22.8° results.

All chain pillar monitoring sites simply represent one *2D slice* of loading information associated with an entire tailgate and due to the costs involved, this means they are not routinely employed. However there are certain monitoring programs that have been successfully implemented to record the performance of various outcomes and strata behaviour associated with the entire longwall retreat. These are generally in relation to subsidence (i.e. survey lines), longwall face weighting (chock monitors) and roof extensometry devices regularly installed along the gateroad.

What all these types of regular monitoring exercises have clearly shown is that standard deviation (i.e. variance about the mean result) is *'alive and well-developed'* in regards to underground coal mining strata mechanics. Therefore there is no reason to assume that the variance in chain pillar loading would be any different, if the monitoring of chain pillars along the full length of a panel were to be undertaken.

It was noted by Colwell (1998) that the tailgate performance at Newstan Colliery was quite variable and it was considered highly likely that a significant factor contributing to that variability was a changing TG Loading Condition probably similar to that, which had occurred at the neighboring West Wallsend Colliery. Both collieries carried out extraction in the West Borehole Seam with similar overburden lithologies and reduced panel widths as part of controlling periodic weighting associated with near-seam, thick massive conglomerate units.

Finally in relation to chain pillar monitoring studies; it is worth noting the results associated with the study conducted by SEA at Angus Place Colliery (within the Western Coalfield) in 2009/10 in the context of the findings associated with ACARP Project C6036. The chain pillar monitoring site was located adjacent to 20 c/t Maingate Panel 950 at a cover depth (H) of approximately 360 m, chain pillar width (w) of 43 m and adjacent longwall panel widths (W) of 287 m.

With respect to the Western Coalfield Colwell (1998) states, *"It is assessed that given the wide range of mining environments there is insufficient (reliable) monitoring data in relation to the Western Coalfield collieries contained within the database (i.e. Angus Place, Clarence, Springvale and Ulan Collieries) so as to significantly modify the tailgate loading behaviour proposed by ALPS".* Therefore the recommended abutment loading parameters for the Western Coalfield collieries became ϕ and ΔTG:ΔMG of 21° and 1.5 <u>specifically</u> to assess the TG Loading Condition in undertaking tailgate design using ALTS.

Over the years it was put to the author that the above recommendations overestimated the TG Loading Condition in relation to Angus Place and Springvale collieries, which would result in chain pillar widths greater than what certain industry personnel considered necessary based on other proposed abutment loading concepts.

The SEA chain pillar monitoring study conducted at Angus Place Colliery finally *'put to bed the debate'* concerning ALTS' suitable application in relation to the Western coalfield collieries. The resultant measured/back-calculated abutment loading parameters associated with the SEA investigations were ϕ and ΔTG:ΔMG of 13.5° and 2.4, which would result in a TG Load of approximately 933.4 MN/m resulting in a TG SF = 1.07. If the ALTS recommended values of ϕ = 21°and ΔTG:ΔMG = 1.5 are used then the calculated TG Load is 932.8 MN/m resulting in a TG SF = 1.07 i.e. no difference to the 2nd decimal place.

As previously discussed with respect to the quite variable Newstan Colliery tailgate performance; it is highly likely that individual chain pillars (or various *2D slices* of a chain pillar) along the full length of the Angus Place 950 Panel would be subject to a wide range of MG Loading abutment angles and associated ΔTG:ΔMG, while it is likely that the resultant TG Load in most cases would have closely approximated the use of the Abutment Angle Model utilising the generic abutment loading parameters ϕ and ΔTG:ΔMG of 21° and 1.5, that had been recommended by Colwell (1998).

More recently Hill et al (2015) provided a predictive formula to estimate the abutment angle based on cover depth, the chain pillar width and longwall panel width to cover depth ratio. However it is important to note that the formula predicts the MG Loading abutment angle and no guidance or formula is provided with respect to ΔTG:ΔMG. In fact in relation to ΔTG:ΔMG

Hill et al (2015) state, *"This factor was also found to be highly mine specific and not to relate strongly to the geometrical factors influencing the abutment angle."* Without a credible predictive capability for $\Delta TG:\Delta MG$, which relates directly to the measured MG Loading abutment angle, then having only a predictive capability for the MG Loading abutment angle is not even '*half the story*' with respect to a credible estimate for the TG Load.

CONCLUSIONS

Given that the chain pillar minimum width/height (w/h) ratio associated with the vast bulk of Australian longwall operations is > 8 and the effective w/h (based on the UNSW Rectangular Pillar Strength Equation, refer Galvin et al, 1999) is > 15 this negates the possibility of inner core pillar failure. Therefore the principal use of the Abutment Angle Model for practical purposes is for the design of chain pillars as a part of an overall tailgate design strategy/methodology such as ALTS.

While the Abutment Angle Model also finds application as part of the Analysis and Design of Rib Support (ADRS) Design Methodology (Colwell, 2006) and assessing induced horizontal stress increases in adjacent roadways due to Poisson's Effect, nonetheless its principal purpose is to estimate the chain pillar TG Load adjacent to the *travelling* tailgate intersection with the 2nd adjacent longwall face (refer Position d, Figure 1) being the design condition associated with ALTS.

Based on the field investigations, the variability with respect to the abutment loading parameters is clearly more pronounced for collieries associated with the NSW coalfields as opposed to those located in the Bowen Basin, which tend to more closely and consistently approximate the Abutment Angle Model. The findings associated with ACARP Project C6036 and subsequent ALTS research clearly recognised and effectively accounted for this in terms of the recommendations provided.

The ALTS recommended abutment loading parameters, which have been clearly explained in all publications associated with ALTS and during the numerous training courses provided by the author to industry personnel over the years, provide the most effective means of estimating the TG Load associated with current Australian longwall operations and therefore the need for any further chain pillar monitoring investigations is extremely limited and in most cases would be only of an *academic* interest.

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