Limitation of Sonic Logs in Delineation of Weak Floor at Southern Colliery, German Creek Mines

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Abstract: Rock strength from boreholes at Southern Colliery (German Creek Mines) has traditionally been estimated from downhole sonic velocity with confidence until the development of the last 4 to 5 pillars of 701 longwall panel and the installation road. In these areas the immediate floor strength appeared to be weaker than the predicted unconfined compressive strength (UCS) derived from the downhole sonic velocity logs.

Consequently a series of geotechnical investigations were carried out to delineate the nature and extent of the weak floor. Both surface and underground boreholes were drilled and a considerable number of samples were taken. The retrieved samples were tested for a variety of tests in order to find out the most effective way of delineating weak floor area prior to mining, and to determine the floor degradation mechanism.

The drilling investigation successfully enabled the weak floor zone with a UCS value of less than 7MPa to be delineated over an area of approximately 120,1000 square metres. The geotechnical test results indicated that the sonic UCS values derived from the traditional German Creek Coal Measures relationship over-estimated the in-situ strength by about 10MPa for sonic values below 45MPa. It was also found that the weak floor occurs in area where the German Creek and German Creek Lower seam interburden is less than 2.5m. The moisture content and slake durability values also served as a good indication for identification of weak floor in this particular site.

Key Words: German Creek Formation, geotechnical investigation, sonic logs, weak floor, UCS.

Introduction

Southern Colliery lies in the Bowen basin situated inland between Rockhampton and Mackay, Queensland, as shown on Figure 1. It is one of the two underground mines operated by Capricorn Coal Management Pty Ltd (Capcoal) mining the German Creek seam of the Permian German Creek Formation.

Southern colliery is currently mining the 700’s block which is the continuation of the successful mined 600’s block.
In the area of concern the thickness of the German Creek seam ranges from 2.9m to 3.1m. It is mined to full height in both development and extraction. The seam dips at around 3.1° towards the east south-east.

The immediate floor is determined by the German Creek Lower Seam splitting away from the base of the German Creek Seam. The German Creek Lower seam is nominally 0.6m thick and underlies the German Creek seam by 1.0m to 3.0m. The interburden between the seams generally comprises siltstone up to 0.5m thick, grading through 0.5m to 1.0m of fine grained sandstone interbedded with siltstone, into fine grained sandstone. On the eastern side of the 700's block the German Creek Lower seam interburden is in excess of 9.0m thick (Ward & Ko Ko, 1997).

However not only is there a reduction in thickness from east to west across the panels but there is also a marked change in strength. Over the eastern half the rock is strong (50MPa to 100MPa), ranging from 70MPa at the eastern extremity, down to 50MPa or so by mid panel. From mid panel the interburden strength continues to reduce reaching values of the order of 7MPa at the western limit of mining.

The interburden thickness in the soft floor area ranges from 1.0m in the northwest corner to over 2.5m in the northeast, comprising siltstone in the immediate floor and grading to coarser interbedded siltstone/sandstone and fine to medium grained sandstone overlying the German Creek Lower seam.

The determination of rock strength from the geophysical sonic velocity logs has indicated that floor with a rock strength not less than 15MPa to 20MPa occurs in the northwestern part of the 700's block where the interburden thickness decreases to less than 2.0m. An intact strength of 20MPa would not normally give rise to concern in regard to floor performance in either development or extraction, providing it was not subject to ponding and trafficking. However considerable difficulties were experienced in maintaining horizon during development of 701 in both tailgate and maingate inbye of 21ct, and in particular along the faceline to 27ct which was subject to more concentrated trafficking by the shuttlecars. Horizon control and reduced bearing capacity of the floor also had a severe impact on the longwall face.

A geotechnical investigation was accordingly carried out to find out the following:

1. The actual or true ground condition and its behaviour and breaking mechanism upon mining.
2. The applicability of sonic derived UCS.
3. The effective method to identify and delineate weak floor.

Geotechnical Drilling Investigations

Core drilling was carried out in several stages during 1996 and 1997 comprising surface exploration drilling and floor coring from underground roadways as they were developed. In all a total of 58 boreholes were drilled in the area of concern, the locations of which are shown in Figure 2.
Floor core drilling was carried out in two stages, under the supervision of Capcoal. The holes were drilled using a Pro-Ram rig with a single tube core barrel, giving 45mm nominal diameter core.

The first stage of drilling involving 30 holes in total was carried out between 28th May and 2nd August 1996. Boreholes were drilled in each cut-through from 10ct to 25ct in 701MG and from 14ct to 27ct in 701TG (except 20ct, 22ct and 24ct in the tailgate). Along the longwall face 4 holes were drilled at 40m to 60m intervals (Huddleston-Holmes & Ko Ko, 1997).

In general the holes were cored to a depth of 1.0m to 1.5m below the floor and then open hole drilled down to the German Creek Lower seam to confirm the interburden thickness. The holes on the faceline and at 25ct in the maingate, however, were cored to the German Creek Lower seam.

The second stage of drilling, comprising 11 boreholes was carried out from 25th to 28th February 1997. Holes were drilled in 18 to 22, and 24 cut throughs in the 702 maingate, and along the face line at 50m interval. Coring depths of these holes ranged from 1.05m to 1.9m, with openhole drilling down to German Creek seam lower to obtain the interburden thickness (Huddleston-Holmes, 1997).

**Surface Drilling Investigation**

Surface drilling was carried out in two stages. The first was a pre-planned 12 hole exploration drilling program carried out in March 1996 of which 7 boreholes (DD217A, DD320, DD321, DD323, DD324, DD326 and DD327), were located in the area concerned. The second stage comprised 8 boreholes in the panels (DD329 to 336) and 3 bore holes along 701 faceline (DD337 to 339) and was carried out in July and August 1996 (Ward, 1997).

The boreholes for the most part, were cored from 6m to 11m above the top of German Creek seam to between 3.5m and 5m below the German Creek Lower seam. All the boreholes except those on the faceline were cored using a triple tube barrel and diamond bit, giving HQ core of nominal 61mm diameter.

The 3 faceline boreholes were drilled approximately 15m to 20m ahead of the longwall face at a spacing of 55m to 65m, the aim being to observe the contrast between the mined and unmined areas, by comparing the results to the floor cored holes along the faceline. These holes were cored from the top of the German Creek seam to around 0.90m below the German Creek Lower seam. They were drilled using a triple tube, tungsten bit and airlflush as diamond drilling could not be carried out due to loss of water flush into fractures in the coal seam. Core was HMLC with a nominal diameter of 63mm.
Sampling

A total of 101 samples (67 from floor coring and 34 from surface drilling) were collected for the geotechnical testing.

Representative samples of the immediate floor of the German Creek seam were taken at each of the underground boreholes. Additional samples were collected from different rock types in 701 tailgate and along the face line.

In the case of the surface exploration boreholes 2 representative samples were selected in each hole from immediate floor of the German Creek seam and the German Creek Lower seam floor (except DD326, only 1 sample from German Creek seam floor and DD338 where an immediate floor sample was unobtainable).

The samples were wrapped in cling wrap and aluminium foil as soon as possible to preserve their moisture content. Prior to transshipment for testing the samples were sealed in core trays with paraffin wax to protect them against breakage.

Geomechanical Testing

The principle objectives of the testing program were to establish the use of relatively simple index tests for delineating weak floor and hence use them for that purpose in the unmined parts of the 700's, and to attempt to determine the mechanism of strength reduction during longwall mining that was affecting the performance of the longwall face equipment.

UCS, moisture content and slake durability were considered to be likely index parameters and values were accordingly determined for all samples. Sodium sulphate soundness determinations were made on 28 samples (21 from 701 tailgate and faceline, and 7 from 702 maingate and faceline) to assess the usefulness of this test as a durability indicator.

Five samples were selected from 701 tailgate for more detailed analysis. These covered the strength range of the floor samples from weak (1.25MPa - 5MPa) to moderately strong (12.5MPa - 50MPa). The tests made on these samples were X-ray diffraction, sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP) and the modified Emerson crumb test.

Test Results

Unconfined Compressive Strength

A total of 100 UCS determinations were made on German Creek Seam floor (83 tests) and German Creek Lower Seam (17 tests) floor samples. Results ranged from
1.6MPa to 61.3MPa. Contours of UCS are shown in Figure 3; these show a systematic reduction in floor strength from over 30MPa outbye of 15ct in 701 maingate to values less than 7MPa inbye of 25ct.

The general trend of the strength reduction is from east to west so that successively less of each panel is affected going from 701 to 704. In particular, the zone of weak to moderately weak floor (5MPa - 12.5MPa), does not impinge on 704 panel.

**Moisture Content**

Moisture content determinations were made on all UCS samples. As it was suspected that the decrease in strength of the German Creek seam floor in the 700’s block could be associated with an increasing clay content in the matrix of the siltstones and sandstones, there was a possibility that moisture content could be a cheap diagnostic indicator of strength.

These show a consistent trend of increasing moisture content from east to west, with values less than 3.0% outbye of 16ct in 701 maingate and over 5.5% inbye of 23ct. The range of results was from a minimum value of 1.9% to a maximum of 7.7%.

The trend of increasing moisture content reflects the trend of reduction in strength. In general terms, the zone of moderately weak floor (UCS less than 10MPa) corresponds to a moisture content greater than 4.0%. As shown on Figure 4 correlation of UCS values with moisture content values suggests a statistically reliable logarithmic relationship for moisture contents between 1.5% and 5.0%. In terms of delineating potential weak floor it would appear that moisture contents of 4.4% (equivalent to a UCS of 10MPa) or over would give a reliable first approximation.

![Figure 4 UCSh versus moisture content.](image-url)
Slake Durability Index

Slake durability tests were made on all UCS samples. The results ranged from 61.1% to 98.9%, with the majority being over 85%. This would indicate that the rocks should not be particularly susceptible to slaking, which was not the case in terms of in-situ performance. However the data revealed that there was a systematic variation, even though the range of variation was low.

The slake durability indices also show the east to west reduction from inbye of 21ct in 701 maingate, and the zone of moderately weak floor corresponds to a slake durability index less than 90%.

Correlation of slake durability index with UCS values is shown on Figure 5; it indicates a constant slake durability index of 97.5% for rock strengths greater than 18MPa, with an exponential decrease in slake durability below 18MPa. A value of 92.5% is equivalent to approximately 10MPa.

As a means of delineating potential weak floor it would appear that slake durability indices of less than 92.5% would give a reliable indication.

![Figure 5 UCS versus slake durability.](image)

Sodium Sulphate Soundness

Sodium sulphate soundness is a standard civil engineering test for giving a measure of the resistance of rock to weathering, particularly with regard to freeze-thaw cycles.

As shown in Figure 6 the results indicate a linear trend for strengths greater than 18MPa however for weaker rocks the rate of increase in % loss is too steep to be of
use and in any case reaches its terminal point of 100% before entering the range of weaker rocks with strengths less than 11MPa except for one value.

Although a value of 100% loss could be taken as an indicator of potentially weak floor, the above limitation plus the cost of the test itself, suggest that sodium sulphate soundness does not have much scope as a single diagnostic test.

![Graph showing UCS versus sodium sulphate soundness test.](image)

**Figure 6** UCS versus sodium sulphate soundness test.

**X-Ray Powder Diffraction Analysis**

X-ray diffraction analysis was carried out on five samples from 701 tailgate covering the strength range from 48MPa down to 4.1MPa. The samples were mostly siltstone from the immediate floor and the underlying fine-grained sandstone with interbedded siltstone.

The results are largely inconclusive, with little difference in mineral composition of the samples across the strength spectrum. In all cases the amount of mixed layer, illite-smectite, clay, which expands in the presence of water, was low, from 5% to 20%. Similarly, there is no systematic variation in the mineral composition of the clay fraction. The general composition of the samples and in particular the small amount of mixed layer swelling clay does not suggest particularly reactive material.

The results do not indicate any reason for the change in performance from outbye to inbye, except for the mica/illite content, which shows a trend of increasing proportion inbye. The increasing micaceousness of the floor was also noted in the geological records. Illite is known as a moderately dispersive mineral and muscovite mica has a tendency to swell (Fell, MacGregor & Stapeldon 1992).
Modified Emerson Crumb Test

The modified Emerson crumb test is used to give a prediction of the behavior of rock due to the uptake of water by clay minerals. Tests were carried out on the same five samples as the X-ray diffraction. The results were all Class 3M with no variation along 701 tailgate. Class 3M material does not disperse in its natural condition but shows a moderate to strong dispersion after remolding.

In mining terms this would suggest that undisturbed floor would remain intact, even in the presence of water, but could rapidly soften when subject to trafficking or possibly cyclic loading.

SAR/ESP Values

SAR (sodium adsorption ratio) and ESP (exchangeable sodium percentage) tests are used to determine the dispersivity of a soil sample by means of chemical analysis of the soil pore water. Both tests give the proportion of sodium cations in the total exchangeable cation content of clays in the sample. Since SAR generally has a linear relationship with ESP in soil, and being a relatively a cheaper test, it is typically used as a preliminary indicator for ESP values. However, this relationship does not necessarily hold with rock samples.

This was the case with the samples tested, where ESP ranged from 25.6% to 60.2%, whereas SAR varied non systematically from 2.99 to 32.65. Soils with ESP values greater than 10% are considered to be highly dispersive. All the samples tested had ESP values over 25%, which would suggest that the rock matrix would have the potential for high dispersivity, once presumably there had been some degree of physical comminution.

Sonic Derived UCS

The empirical relationships for estimating rock strength from sonic velocity logs at German Creek has been established by McNally (1987). There has been no cause to doubt this relationship in the past.

Figure 3 shows the sonic derived UCS and laboratory UCS contours of the German Creek seam floor over the area under investigation. It clearly shows a reduction in strength over the western half of the panels, the indication being that floor strength would drop to between 15MPa and 25MPa inbye of 25ct in 701 maingate. Figure 3 is based on all the drilling to date, most of which was done during the previous two years. Nevertheless the general trend of floor strength was apparent from the limited number of geophysically logged boreholes drilled prior to longwall development in the 700's.
It was clear that either the sonic velocity was giving an over-estimate of the in-situ strength or that the floor had an intrinsic lack of competence when disturbed. There was an initial concern that the latter effect was introducing a bias into samples taken from underground drilling. That is samples could be de-stressed in-situ as a result of forming the underground opening, permitting an uptake of moisture, physical relaxation and consequent reduction in strength. However this can be largely discounted since samples taken by surface drilling exhibit similar strength values.

Figure 7 shows the comparison of laboratory measured UCS values with the traditional sonic strength relationship. It can be seen that in general terms, for sonic strength values less than 45MPa, the use of the traditional relationship systematically over-estimates the measured strength by 10MPa. A reasonable estimate can be gained, however if the estimated sonic strength is discounted by 10MPa over the range 15MPa to 45MPa.

![Sonic Velocity vs Rock Strength](image)

Figure 7  Measured UCS - sonic strength comparison

Discussion

The floor coring and surface drilling investigation has successfully delineated the weak floor area of the 700’s block. It has detected the occurrence of an incompetent floor which was significantly weaker than predicted and thus questions the applicability of established sonic strength relationship.

The traditional German Creek Coal Measures sonic velocity relationship is not reliable in providing an accurate measure of the absolute strength of weaker rock in the 700’s area. Figure 7 reveals that the current sonic derived UCS curve does not represent the true strength of the weak floor. It was thought that the samples representing the weak
floor may have belong to a separate population or geological regime originating from a different geological process or nature.

X-ray diffraction analysis does not reveal any significant difference in mineral composition to support the above statement apart from mica/illite content increasing inbye. The variety of geotechnical tests would mainly describe the mechanical properties of the material, but would not explain the differential characteristics of the floor across the 700's, nor indicate the existence of a different geological environment. It is believed that there is an overriding sedimentological control which is probably related to the thinning of the interburden between the German Creek and German Creek Lower seams as they coalesce.

The results of the testing program show that the in-situ strength of the weak floor area ranges from in excess of 30MPa down to around 5MPa to 8MPa, with one exceptionally low value of 1.6MPa. Slake durability indices generally range between 85% and 95%. Floor rock of this nature would be expected to degrade and rut when subject to ponding and heavy trafficking but would not be expected to be of any concern with regard to chock bearing pressure.

Comparison of the interburden thickness with the UCS contours shows that there is no systematic relationship (See Figure 2 & 3). The trend of the thinning is towards the WSW whereas the strength reduces towards the WNW. However comparison of the interburden thickness with the sonic strength does indicate a superficial relationship between strength and thickness. In general terms the floor strength starts to weaken significantly where the interburden is less than 2.5m thick (Equivalent to about 30MPa sonic strength).

This would suggest that for this geological environment a preliminary indicator for weak floor conditions would be interburden less than 2.5m thick and sonic strength less than 30MPa.

Once any such areas have been identified it is necessary to carry out laboratory testing of floor samples to provide a detailed definition since, as described earlier, the sonic strength relationship ceases to be reliable at low values and can over-estimate the actual UCS strength by 1.5 to 2.8 times. This factor indicates that even considering the fact that UCS results themselves commonly vary by 10 - 20% from the mean even in very uniform rock due to minor sample variations (McNally, 1987) there would still appear to be a significant difference between sonic UCS and measured UCS.

The UCS and slake durability tests, and the X-ray diffraction analysis, give no indication of high degradability. The ESP values, the modified Emerson crumb test and the sodium sulphate soundness tests, however, suggest the material has a high potential to disintegrate completely in the presence of water if coupled to a high level of physical disturbance. However they did not offer any means of differentiation across the block and hence are non-predictive. The sodium sulphate soundness test was too severe to resolve variation within the strength range of interest. It should be noted that only a small number (5 samples) were tested for ESP values, Emerson crumb test and X-ray diffraction.
Based on the results of this evaluation potentially weak floor, that is, floor susceptible to degradation under mining conditions can be defined by any one of the following, whichever provides the most widespread extent:

UCS < 10 MPa
slake durability index < 92.5%
Moisture content > 4.4%

As the mechanism of material breakdown has not been established the above criteria for defining weak floor must be considered site specific (Ward & Ko Ko, 1997).

Conclusions

1. The geotechnical investigation exercise reveals that true ground conditions to be significantly weaker than the predicted sonic UCS values. There is no difference between samples taken from surface drilling or from underground headings, and the detailed analysis of the material characteristics and observation of floor performance under operating conditions indicates that extensive physical disturbance in the presence of water is the main factor in causing degradation.

2. The propensity for degradation is an intrinsic characteristic of the floor material in the western corner of the 700’s but the reason for this is not clear. X-ray diffraction, exchangeable sodium percentage and Emerson crumb test did not show any differentiation between weak and competent rock.

3. Sonic UCS values derived from the traditional German Creek Coal Measures relationship over-estimate the in-situ strength by about 10MPa for sonic strength values below 45MPa. At this stage it is conjectured that a second population exists which does not correspond to the established curve. The actual cause of this deviation is not known.

4. An initial indication of weak floor can be given by areas where the interburden is less than 2.5m thick and the sonic strength is less than 30MPa. Although thinning of the interburden may be significant, it does not provide a reliable indicator of weak floor.

5. The UCS, slake durability and moisture content can all provide a reliable means of identifying and delineating potentially weak floor. For this site weak floor can be defined by any one of:

UCS < 10 MPa
Slake durability index < 92.5%
Moisture Content > 4.4%

The presence of all the above indicators may suggest a higher degree of weakness in the immediate floor.
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