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THE IMPACTS OF MINE SUBSIDENCE ON CREEKS, RIVER VALLEYS AND GORGES DUE TO UNDERGROUND COAL MINING OPERATIONS

Arthur Waddington [1] and Don Kay [1]

ABSTRACT: Measured subsidence profiles above coal mining operations regularly show less than expected subsidence at creeks, river valleys and gorges. Horizontal measurements across such surface notches indicate that they reduce in width as mining occurs. The reduction in subsidence is referred to as 'upsidence' and the reduction in width is referred to as valley closure. The upsidence and closure movements tend to increase in amplitude as the size of the valley increases, and as the magnitude of subsidence increases. The movements are greatest when the insitu horizontal stresses are high and when the valleys are fully undermined. The upsidence is a combination of anticlinal valley bulging and buckling or shearing of the surface and near-surface strata.

As Longwalls 8 and 10, at Tower Colliery, in the Southern Coalfield of New South Wales, were mined beneath the Cataract River Gorge, the incremental upsidence in the base of the gorge, due to mining each longwall, was approximately 360 mm, resulting in the base of the gorge being uplifted as much as 250 mm above its original level. At the same time, the width of the gorge was reduced by approximately 280 mm. Cracking and buckling of the strata, within the base of the gorge, resulted in a loss of water from some of the natural ponds in the bed of the river, with consequential criticism from local landholders and regulatory authorities.

A comprehensive research study supported by an ACARP grant and assisted by CSIRO and The University of New South Wales has provided some additional insight into the valley bulging phenomenon. The major findings arising from the research project provide new methods for the prediction of mining-induced ground movements in creeks, river valleys and gorges.

INTRODUCTION

The major findings of a research project, funded by ACARP research grants, which was carried out between March 1999 and September 2002 have been summarised. The research work was funded in two halves, as ACARP Research Projects C8005 and C9067. Detailed research reports on these projects, (Waddington and Kay 2001d, 2002), are available on CD and copies can be obtained from the offices of Australian Research Administration Pty Ltd (ARA) in Brisbane (Tel: 07 3229 7661). The research reports form the basis of the 'Management Information Handbook on the Undermining of Cliffs, Gorges and River Systems', for the mining industry, which is also available from ARA.

ANALYSIS OF MEASURED GROUND DISPLACEMENTS

When longwalls are extracted beneath steeply incised terrain, the ground movements that occur around the longwalls are very complex, particularly within a high horizontal in situ stress regime, and these complex movements result from a number of distinct mechanisms. The measured movements can be a combination of some or all of the following components:

- Normal mining-induced horizontal movements of points on the surface around an extracted panel, as subsidence occurs, which are generally directed towards the centre of the extracted goaf area.
- Upsidence and closure of creeks, gullies, river valleys and gorges due to valley bulging, which is caused by redistribution of pre-existing in situ stresses in the base and walls of the valley, as mine subsidence occurs.
- Predominantly horizontal displacements of surface strata due to release and redistribution of pre-existing regional, or far-field, in situ stresses, as the extracted goaf areas increase in size within a local mining area.

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- En masse slippage movements in a downhill direction due to topographic factors.
- Differential movements of the strata on opposite sides of a fault line.
- Continental drift, which is known to change the positions of points on the Australian Plate by approximately 70 mm each year towards the northeast.

In order to develop methods for the prediction of each of the above components of movement, the measured data, ideally, have to be broken down into the various components prior to analysis. This is not, however, an easy task, because in most cases the measured survey movements are relative movements rather than absolute movements. When analysing the closures that have been measured in creeks and river valleys due to valley bulging, however, it appears that many of the other components have little or no effect on the closure measurements.

En masse slippage down steep slopes, due to mining is a relatively rare occurrence and is due to the instability of surface soils in particular locations. Where steep slopes exist and could be affected by mining it would be prudent to study the geology of the site and the nature of the surface soils so that any unstable areas can be identified.

It is possible that some of the data which formed the basis of the research projects discussed in this paper could have been affected by this mechanism, but if so it will have led to overstatement of closure movements.

Differential movements on opposite sides of a fault line are equally rare occurrences and there were only a few known major faults within the areas of study. There was no evidence to indicate that any of the measured data gathered during the research work were affected by differential movements at faults.

In analysing the valley closure data, no allowance was made for differential movements caused by regional horizontal stress redistribution or continental drift, because the differential movements in the two sides of a valley, as a result of these mechanisms, would be relatively small and in many cases negligible.

In the steep-sided Cataract and Nepean River Gorges it was found that the closures in the sides of the gorges were almost mass movements with little differential shear displacement between different horizons in the strata. Almost all of the closure, therefore, occurred in or just below the base of the gorge. Because the gorge bases were relatively narrow, the differential mining-induced horizontal movements, due to differential tilting in the sides of the gorges, were relatively small in comparison with the closure movements.

In the vee-shaped valleys, a large proportion of the closure occurred in the bottoms of the valleys, coupled with localised concentrations of compressive strain, but some of the closure was noted to occur at horizons above the bottom of the valley. This observation from measured data is supported by numerical modelling results, which indicate that in vee-shaped valleys some of the shearing occurs along weaker horizons in the valley sides. The closure movements are, therefore, spread over a greater width than those measured in the gorges. It is, therefore, possible that some of the measured closure data in the vee-shaped valleys could have been affected by differential mining-induced horizontal movements in the valley sides.

In some cases these differential movements could have caused the sides of the valley to open and the measured closure, being the sum of the two movements, could, therefore, be less than the actual closure caused by valley bulging.

The extent to which the data might have been affected in this way is difficult to determine, because many of the surveys that were carried out in the past did not measure the absolute movements of the ground in three dimensions and the closures, in those cases, have been calculated from the strains.

The method that has been developed for the prediction of closure is, therefore, based upon the overall closure of the valley recognising that, in the case of vee-shaped valleys, some of the movement will occur in the valley sides.

When predicting closures in vee-shaped valleys it would be prudent to ignore the impacts of differential mining-induced horizontal movements in the valley sides, if those movements cause a reduction in the predicted closures.

NORMAL MINING INDUCED HORIZONTAL GROUND MOVEMENTS

In flat or gently sloping terrain, i.e. where steep slopes or surface incisions do not influence ground movement patterns, the subsidence induced horizontal displacements are generally directed towards the centre of the mined longwall panel. The 'normal' horizontal component of subsidence, also referred to as horizontal displacement, can be determined at a point, approximately, by multiplying the tilt at that point by an appropriate strain-curvature factor. Predicted subsidence profiles can be obtained using the Incremental Profile Method, (Waddington and Kay 1995, 1998a, 198b, 2001b), or other methods calibrated to local data. Predicted tilt profiles can be determined as the first differentials of the predicted subsidence profiles.

The appropriate strain-curvature factor for the Southern Coalfield is 15 and if, for example, the predicted tilt at a point is 2 mm/m, then, the predicted horizontal ground displacement will be approximately 30 mm towards the centre of the mined goaf. The appropriate strain-curvature factor for the Newcastle Coalfield is 10 and if, for example, the predicted tilt at a point is 2 mm/m, then, the predicted horizontal ground displacement will be approximately 20 mm towards the centre of the mined goaf.

Whilst this method is only approximate, it tends to be conservative where the tilts are high and tends to understate the horizontal movements where the tilts are low. Where the tilt is low, the 'normal' horizontal displacement is generally very small, even though it could be many times greater than the vertical subsidence at the same point.

The tilts reduce with increasing distance from the goaf edge of the longwall. At the edge of the subsidence trough, where the tilts approach zero, any small horizontal displacement at that point could be infinitely greater than the tilt.

When large horizontal displacements are measured outside the goaf area, they are more likely to be caused by regional movements, as discussed in later.

VALLEY BULGING EFFECTS DUE TO MINING BENEATH GORGES, RIVER VALLEYS AND CREEKS

When creeks and river valleys are affected by mine subsidence, the observed subsidence in the base of the creek or river is, generally, less than the level that would normally be expected in flat terrain. This reduced subsidence is due to the floor of the valley bulging and buckling upwards. This phenomenon is referred to as valley bulging and is caused by the redistribution of, and increase in, the horizontal stresses in the strata immediately below the base of the valley as mining occurs. Valley bulging is a natural phenomenon, resulting from the formation and ongoing development of the valley, but the process is accelerated by mine subsidence. The phenomenon appears to be triggered, to varying degrees, whenever escarpments, gorges, river valleys, creeks or other surface incisions are undermined.

The graph in Figure 1 shows a series of typical subsidence profiles along a survey line that crosses a tributary of Brennans Creek and an upsidence spike is clearly visible, coincident with the base of the valley. The upsidence was accompanied by closure as indicated by the bay length differences shown in the graph.

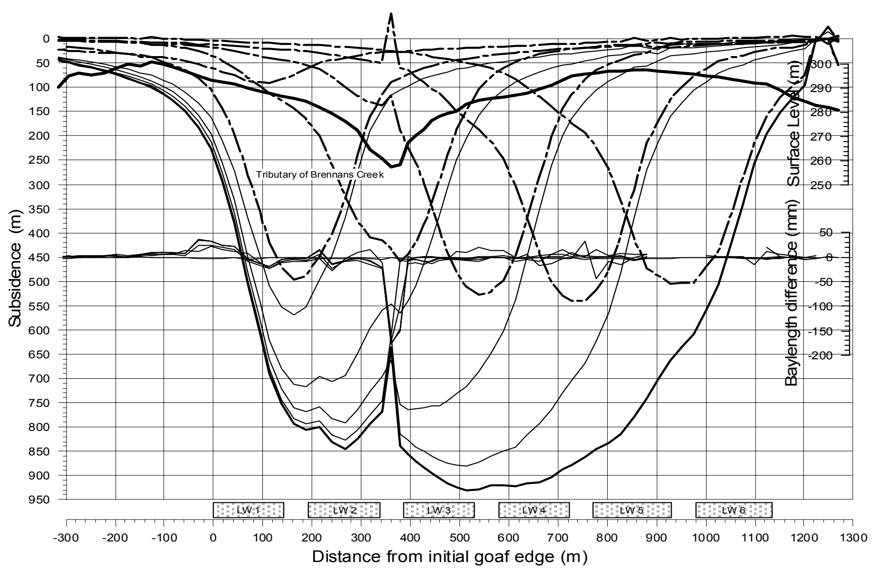

FIG. 1 - Typical Subsidence Profiles across a Valley showing an Upsidence Spike

The local reduction in subsidence, which is referred to as 'upsidence', is generally accompanied by localised changes in tilt and curvature leading to high compressive strain in the centre of the valley and horizontal closure of the valley sides. In the case of escarpments and wide river gorges the movements may be limited to the cliffs that are closest to the extracted area.

In most cases studied, the upsidence effects extend outside the valley and include the immediate cliff lines and the ground beyond them. For example, monitoring within the Cataract Gorge, at Tower Colliery, as Longwalls 8 and 10 were mined, revealed that the upsidence extended up to 300 metres from the centre of the Gorge, on both sides of the Gorge. In that case, the magnitude of the upsidence movements was greater than the subsidence leading to an overall uplift in the base of the Gorge, consequently leaving it above its original pre-mining level.

In other cases, within creek alignments, upsidence has been observed well outside an extracted panel, apparently due to a beam within the near-surface strata rotating and pivoting as a seesaw, as one end of it rises and the other subsides. However, in these cases, the measured upsidence and strains have been less than would be expected to arise from the compressive buckling mechanism described above.

During the first stage of the research project, many cases of valley bulging were analysed and it was concluded that the magnitude and lateral extent of the upsidence and the extent of the closure appeared to be dependent on many factors including;

- the depth of the valley,
- the width of the valley,
- the shape of the valley,
- the direction and magnitude of in-situ horizontal stresses,
- the rock strengths and fracture characteristics,
- the local stratigraphy and joint spacing and
- the magnitude of the mining induced stresses, which are dependent on;
  - the cover depth,
  - the seam thickness,
  - the panel and pillar widths and
  - the location of the valley, or escarpment, relative to the goaf edges.

Based upon the empirical evidence, upsidence and closure movements can be expected in cliffs and in the sides of valleys, whenever longwalls are mined beneath them. Such movements, however, tend to be smaller outside the goaf areas and tend to reduce as the distance outside the goaf edge increases. The movements are incremental and increase as each longwall is mined in sequence and the movements caused by the mining of one longwall can be spread over several longwalls.

During the second stage of the research project additional cases of closure and upsidence were studied and this led to the conclusion that the major parameters affecting the closure and upsidence were:

- The lateral distance from the base of the valley to the side of the current longwall.
- The longitudinal distance from the base of the valley to the end of the current longwall.
- The depth of the valley.
- The maximum incremental subsidence over the current longwall.
- The direction and magnitude of the in-situ horizontal stress.

Based upon this finding, methods of prediction have been developed for closure and upsidence, as discussed below.

THE PREDICTION OF CLOSURE IN CREEKS AND RIVER VALLEYS

A method for the prediction of closure in creeks and river valleys is based upon measured data over a wide range of cases, with valley depths varying from 27 metres to 74 metres. The data was mainly collected from collieries in the Southern Coalfield where the valleys are incised into flat lying sedimentary deposits and where the in situ horizontal stresses are high. The method of prediction would be expected to give best results in areas with similar geology and similar stress regimes. The method is based upon upper-bound measured values and it is anticipated that it will overpredict in areas of lower stress. Further research is required to determine how pre-existing in situ horizontal stress influences the closure movements.

The method for the prediction of closure is based upon a series of graphs that show the interrelationships between closure and a number of contributory factors. The interrelationships between the factors are illustrated in Figures. 2 to 5.

- Figure 2 shows the graph of closure plotted against the transverse distance from a point in the bottom of the valley to the advancing goaf edge of the longwall divided by the width of the panel plus the width of the pillar.

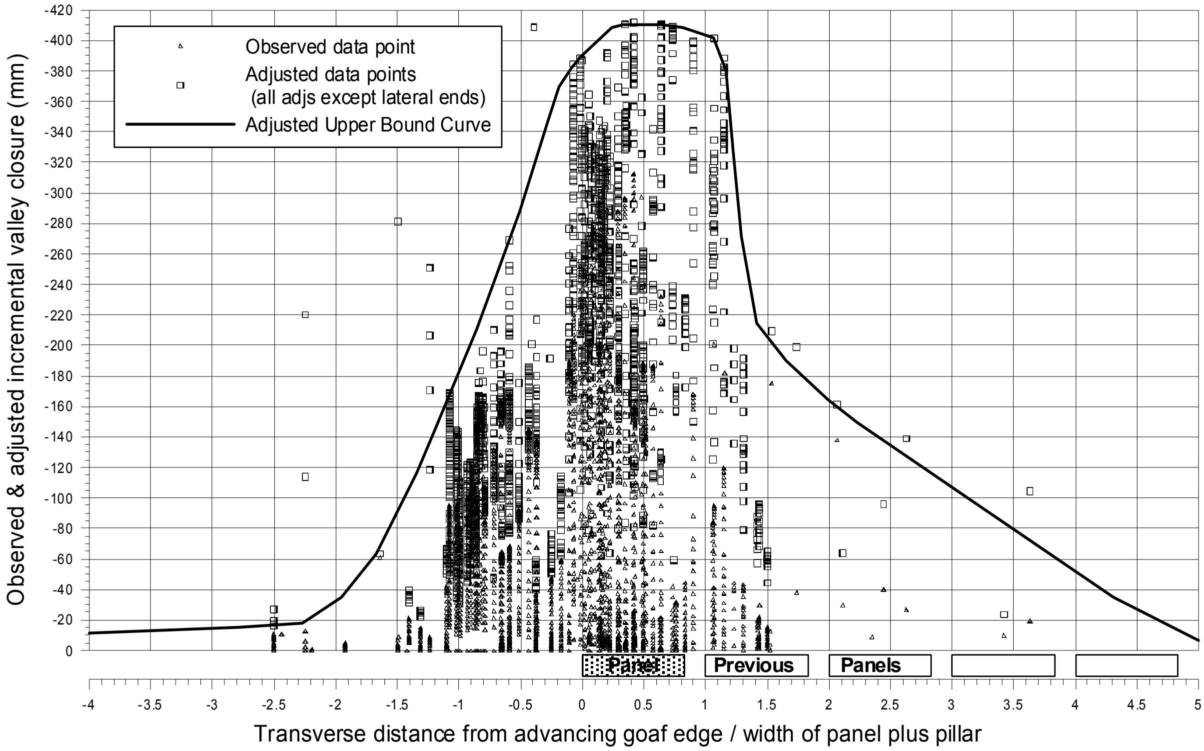

FIG. 2 - Graph of Valley Closure versus Transverse Distance from the Advancing Goaf Edge

- Figure 3 shows a longitudinal distance adjustment factor plotted against the longitudinal distance from a point in the bottom of the valley to the nearest end of the longwall in metres.
- Figure 4 shows a valley depth adjustment factor plotted against valley depth.
- Figure 5 shows an incremental subsidence adjustment factor plotted against the maximum incremental subsidence of the panel.

The graphs indicate the upper bound values, which are mainly based upon closure data from the Cataract and Nepean Gorges, where the maximum incremental subsidence was approximately 410 mm and the depth of gorge was approximately 68 metres.

The closure is initially predicted from the upper-bound line of the graph shown in Figure 2 and the value so obtained is multiplied by the factors obtained from the graphs shown in Figures. 3, 4 and 5, depending on the position of the bottom of the valley relative to the end of the longwall, the valley depth and the maximum incremental subsidence of the longwall.

The valley depth is determined by calculating the average level of the opposite sides of a valley and then deducting the level in the bottom of the valley.

The depth is easy to define in the case of a valley or gorge that is incised into an otherwise flat plain, but it is not so easy to define where the surface is undulating. In this situation, the valley depth has to be calculated relative to the average surface level.

In wide vee-shaped valleys, the sides of the valley have been defined as points on each side of the valley that are located at a horizontal distance of half the depth of cover from the lowest point in the bottom of the valley.

In all cases, the closure is measured at right angles to the general alignment of the valley.

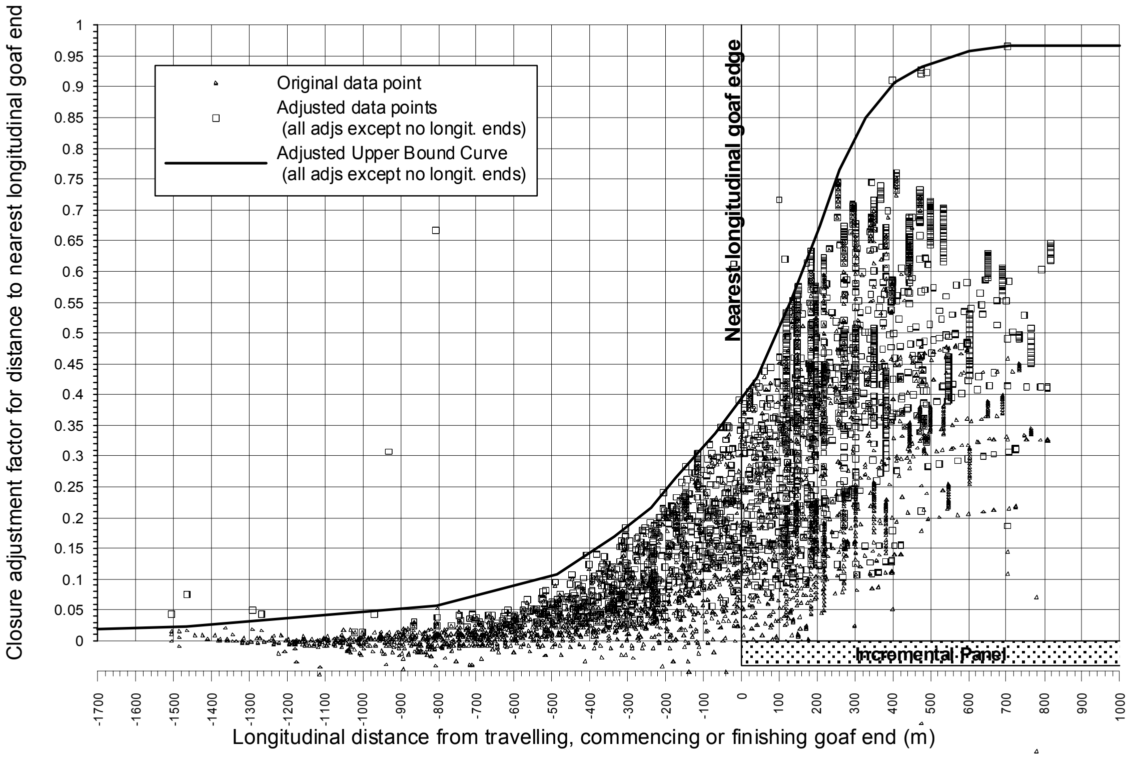

FIG.3- Valley Closure Adjustment Factor versus longitudinal Distance

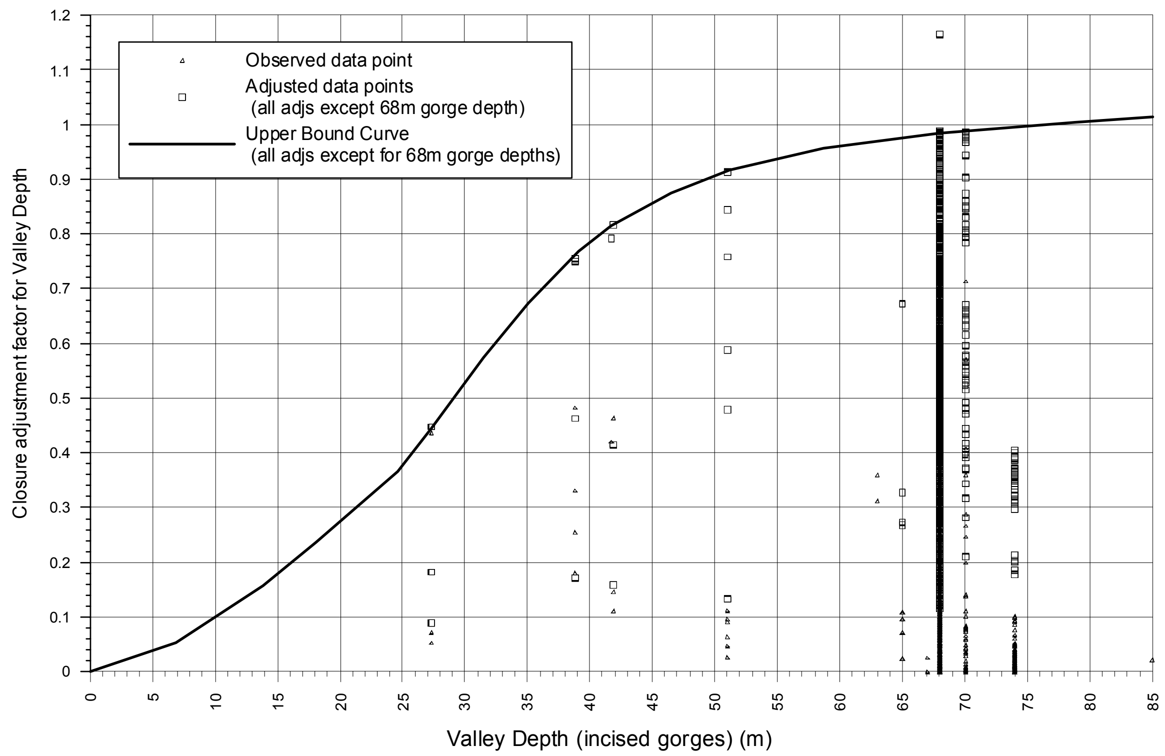

FIG. 4 - Valley Closure Adjustment Factor versus Valley Depth

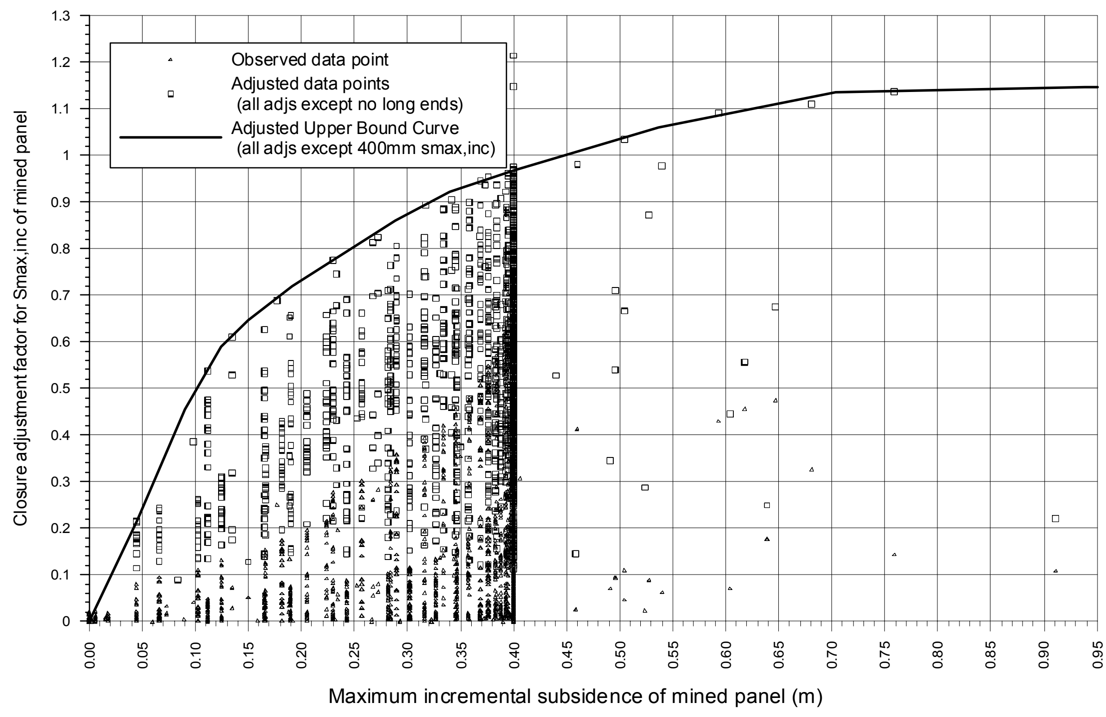

FIG. 5- Valley Closure Adjustment Factor versus Maximum Incremental Subsidence

Figure 6 shows the distance measurement convention used to define the location of the point for which closure and upsidence predictions are required.

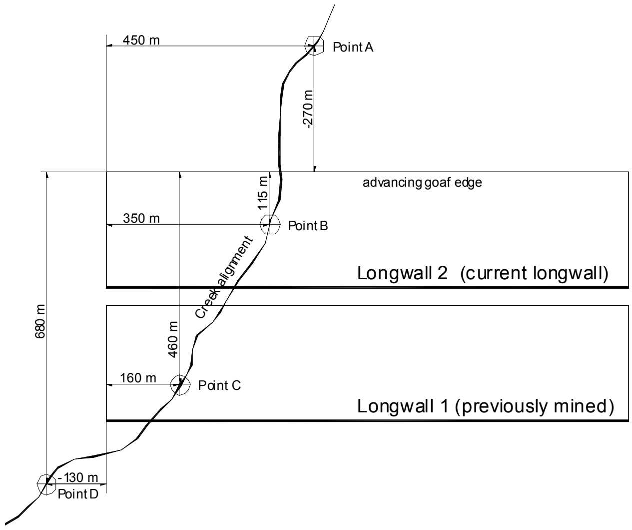

FIG. 6 - Distance measurement convention for closure and upsidence predictions

The transverse distances plotted in Figure 2 are the distances measured at right angles to the advancing goaf edge of the longwall expressed as a proportion of the width of the panel plus the width of the pillar.

For example, the transverse distances for points A, B, C and D in Figure 6 are -270 metres, 115 metres, 460 metres and 680 metres, respectively, distances outside the goaf being negative.

The longitudinal distances plotted in Figure 3 are the distances from the nearest end of the longwall, measured parallel to the longitudinal centreline of the longwall.

For example, the distances for points A, B, C and D in Figure 6 are 450 metres, 350 metres, 160 metres and -130 metres, respectively, distances outside the goaf again being negative.

THE PREDICTION OF UPSIDENCE IN CREEKS AND RIVER VALLEYS

A method based upon measured data over a wide range of cases, with valley depths varying from 8 metres to 87 metres can be used for the prediction of upsidence. The data was collected mainly from collieries in the Southern Coalfield where the valleys are incised into flat lying sedimentary deposits and where the in situ horizontal stresses are high. The method of prediction would therefore give better results in areas with similar geology and similar stress regimes. The method is based upon upper-bound measured values and it is anticipated that the method will overpredict in areas of lower stress. Further research is required to determine how pre-existing in situ horizontal stress influences the upsidence movements.

The method for the prediction of upsidence is the same as the method for the prediction of closure and is based upon a series of graphs that show the interrelationships between upsidence and a number of contributory factors. The interrelationships between the factors are illustrated in Figures. 7 to 10.

- Figure 7 shows the graph of upsidence plotted against the transverse distance from a point in the bottom of the valley to the advancing goaf edge of the longwall divided by the width of the panel plus the width of the pillar.
- Figure 8 shows a longitudinal distance adjustment factor plotted against the longitudinal distance from a point in the bottom of the valley to the nearest end of the longwall in metres.
- Figure 9 shows a valley depth adjustment factor plotted against valley depth.
- Figure 10 shows an incremental subsidence adjustment factor plotted against the maximum incremental subsidence of the panel.

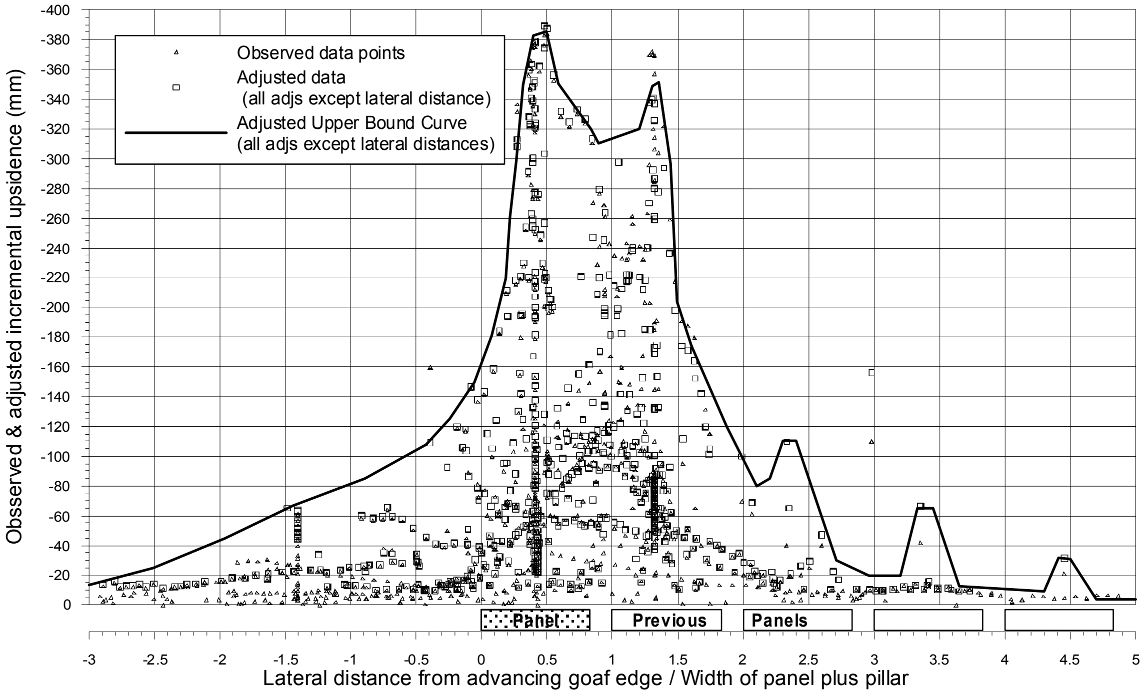

FIG. 7 - Graph of Upsidence versus Distance from the Advancing Goaf Edge of the Longwall relative to the Width of the Panel plus the Width of the Pillar

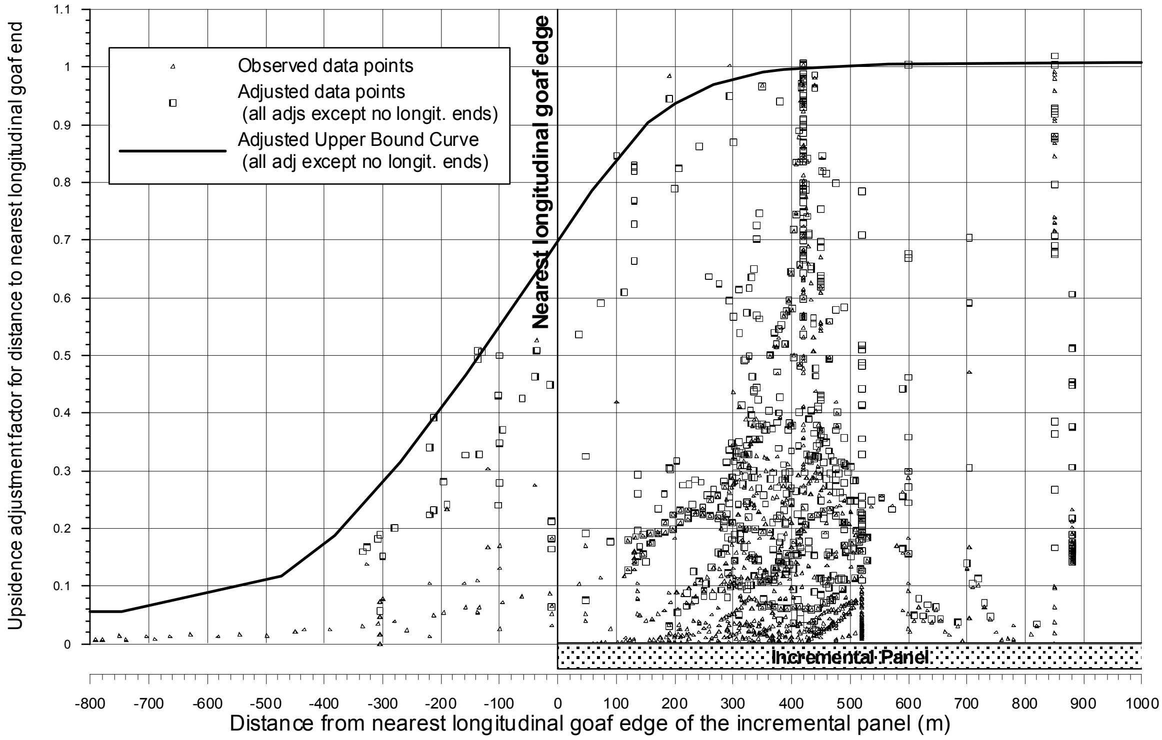

FIG. 8 - Graph of Upsidence Adjustment Factor versus Longitudinal Distance

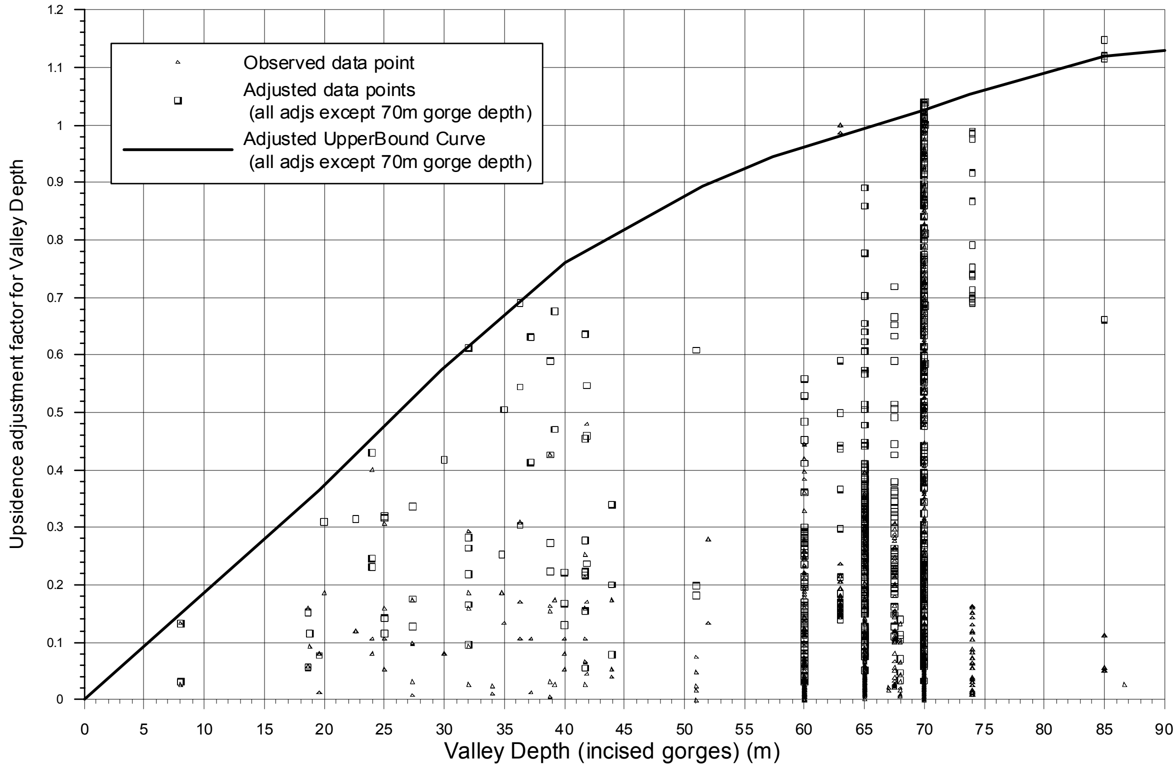

FIG. 9 - Graph of Upsidence Adjustment Factor versus Valley Depth

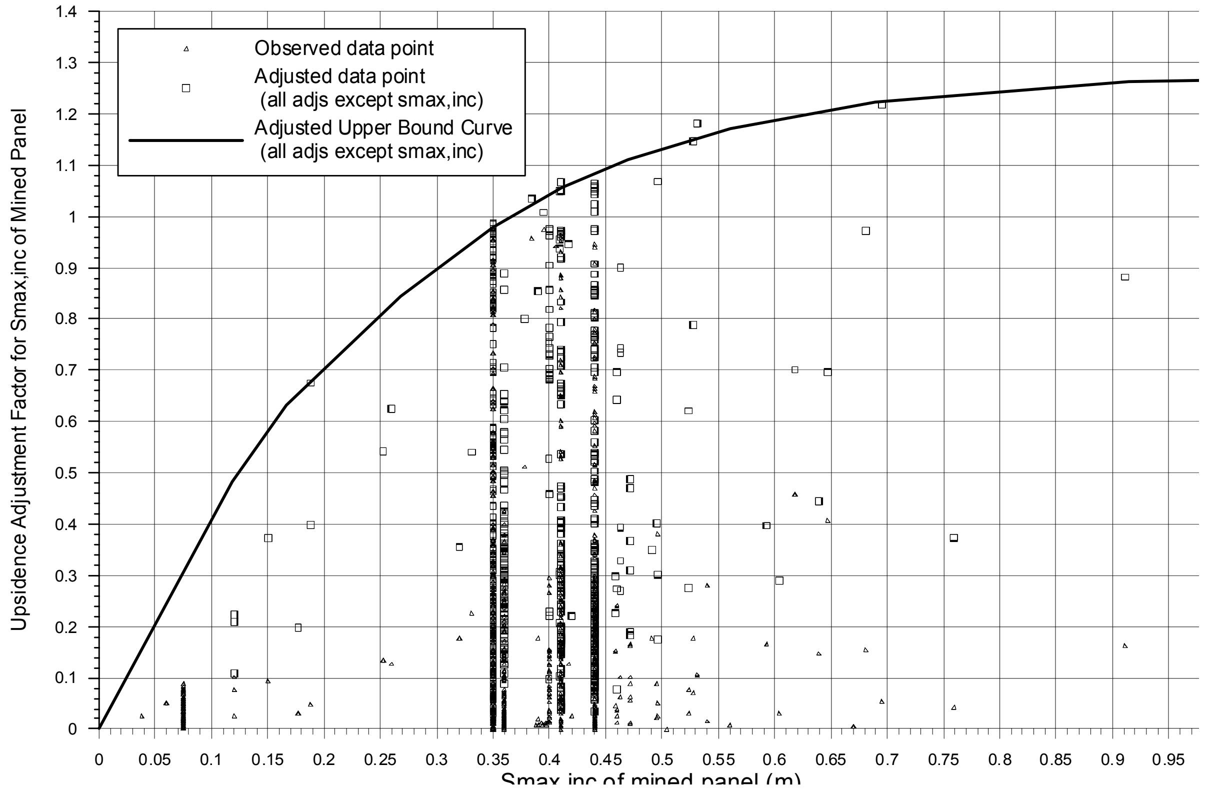

FIG. 10 - Graph of Upsidence Adjustment Factor versus Maximum Incremental Subsidence

The graphs indicate the upper bound values, which are mainly based upon upsidence data from the Cataract Gorge, where the maximum incremental subsidence was approximately 350 mm and the depth of gorge was approximately 70 metres.

The upsidence is initially predicted from the upper-bound line of the graph shown in Figure 7 and the value so obtained is multiplied by the factors obtained from the graphs shown in Figures. 8, 9 and 10, depending on the position of the bottom of the valley relative to the end of the longwall, the valley depth and the maximum incremental subsidence of the longwall.

The transverse distances plotted in Figure 7 are the distances measured at right angles to the advancing goaf edge of the longwall expressed as a proportion of the width of the panel plus the width of the pillar. Figure 6 shows the distance measurement convention used to define the location of the point in the creek for which closure and upsidence predictions are required.

The longitudinal distances plotted in Figure 8 are the distances from the nearest end of the longwall, measured parallel to the longitudinal centreline of the longwall.

THE LATERAL DISTRIBUTION OF UPSIDENCE

Upsidence in a valley is the result of two separate mechanisms, namely an anticlinal valley bulging coupled with buckling or shearing of the strata in the base of the valley. The maximum upsidence occurs in the bottom of the valley, where the buckling or shearing effect occurs, but the valley bulging effect spreads outwards from the bottom of the valley under both sides of the valley for a considerable distance. For example, in the Cataract Gorge above Longwall 8 at Tower Colliery, whilst the upsidence in the base of the gorge was 360 mm, the upsidence in the clifflines was around 100 mm and the upsidence effect extended for a distance of 300 metres on each side of the gorge.

The upsidence profile is dependent upon the way in which the rocks in the bottom of the valley buckle upwards and, since this is controlled by local geology, any method for predicting the profile can only be expected to provide approximate answers.

Figure 11 shows idealised profiles of upsidence across the Cataract Gorge, both along the goaf edge and along the centreline of the longwall.

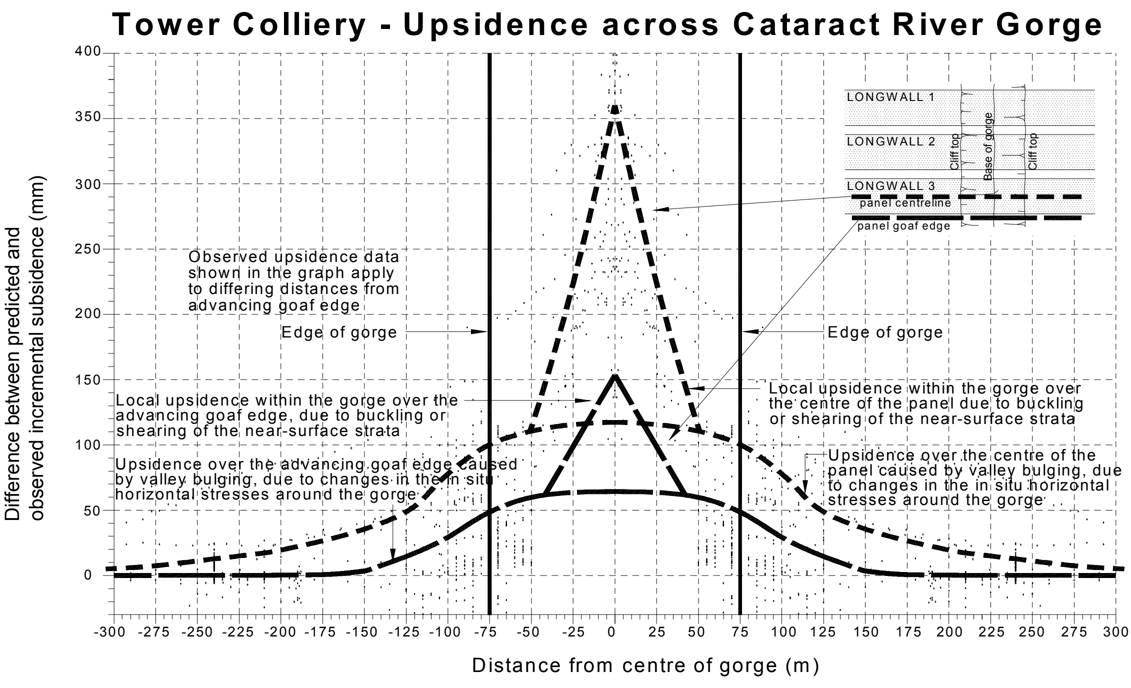

FIG. 11 - Idealised Upsidence Profiles across the Cataract Gorge

It can be seen that the lateral spread of the upsidence was greater where the amplitude of the upsidence was greater. Further research is required in order to develop a more definitive method for the prediction of upsidence profiles, but in the meantime it seems reasonable to model the profiles on the upper measured profile shown in Figure 11. An approximate profile can be obtained by scaling both the width and amplitude of the profile in proportion to the predicted upsidence value. It should be noted, however, that the predicted profile can only be approximated since the actual buckling will depend upon local geology and might not be centrally positioned in the bottom of the valley or gorge.

THE ANALYSIS OF COMPRESSIVE STRAINS IN CREEKS AND RIVER VALLEYS

The relationship between the closure in the sides of a valley and the maximum measured horizontal compressive strain in the base of a valley is complex, because it is very much dependent upon local geology. It seems reasonable to assume, however, that as the closure increases, the level of strain should increase and this appears to be borne out when measured data is studied.

Figure 12 shows a graph of closure, across the steep section of a valley, versus maximum compressive strain, based upon data that was observed over longwalls at Tower, Appin, West Cliff and Baal Bone Collieries. The trend for strains to increase as closures increase is clearly seen.

The data includes measured strains from surveys with different bay lengths, which is the cause of some of the scatter in the data points shown in the graph. The curved line drawn on the graph indicates the upper-bound limit of the data for bay lengths of 20 metres. The straight lines show what the relationship between strain and closure would be for bay lengths of 10 metres and 20 metres, if the closure all occurred in one bay.

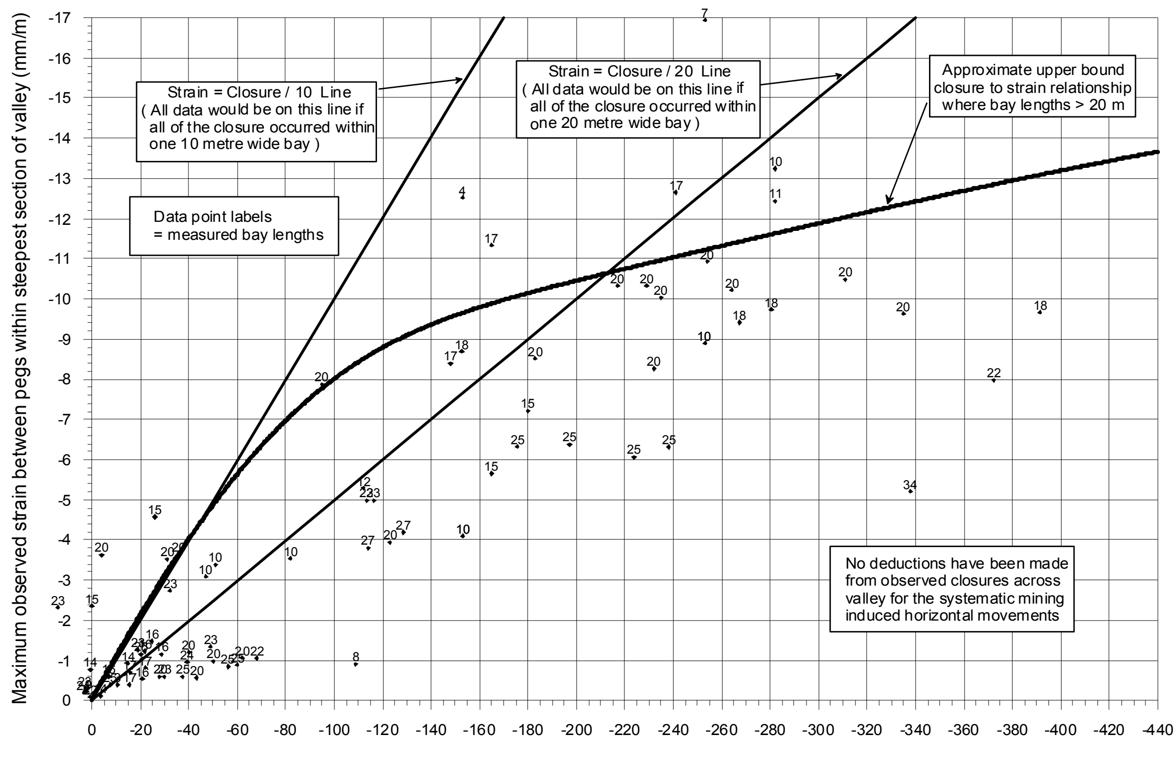

FIG. 12 - Graph of Strain versus Closure in the Steepest Part of the Valley

The upper bound graph can be used to predict the likely maximum level of compressive strain in the base of the valley, over a bay length of 20 metres, once the predicted overall closure of the valley has been determined. The strain values obtained from the upper bound graph are generally expected to be conservative and are unlikely to be exceeded in practice.

The likely range of strains can also be determined from the graph for particular values of closure and it can be seen that the range can vary considerably. This is due to variations in the nature of the topography and the levels of insitu horizontal stress in the base of the valley.

It might at first seem paradoxical that, in some cases, the predicted overall valley closure is less than the closure in the base of the valley, over a 20 metre bay length, based on the predicted strain. This is because the predicted closure is the overall closure of the steepest part of the valley and as the closure occurs in the base of the valley, due to compressive failure of the bedrock, the sides of the valley expand due to stress relief.

This situation is illustrated in Figure 13, where the overall valley closure is shown as 100 mm, whilst the closure in the base of the valley is 160 mm. The closure in the base of the valley should thus be calculated from the predicted strain over a survey bay length of 20 metres.

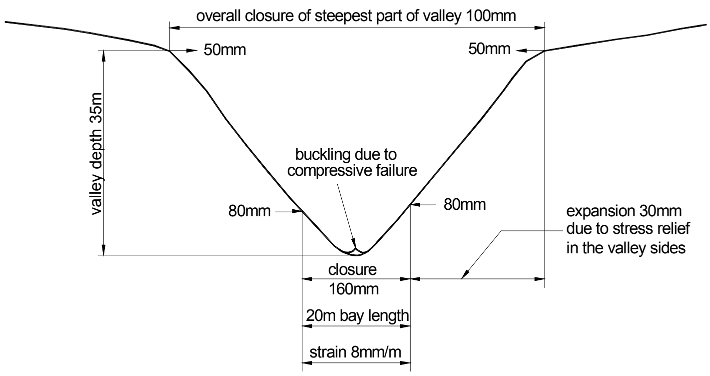

FIG. 13- Typical Closure Movements in a Vee-Shaped Valley

Similarly, the overall closure in the base of a gorge can be greater than that measured over a 20 metre survey bay length and greater than that measured overall between survey marks behind the clifflines on the plateau. This is illustrated in Figure 14, where the overall closure is 100 mm, whilst the closure in the base of the gorge is 350 mm. The maximum strain of 12 mm/m occurs over a 20 metre survey bay length in the base of the gorge.

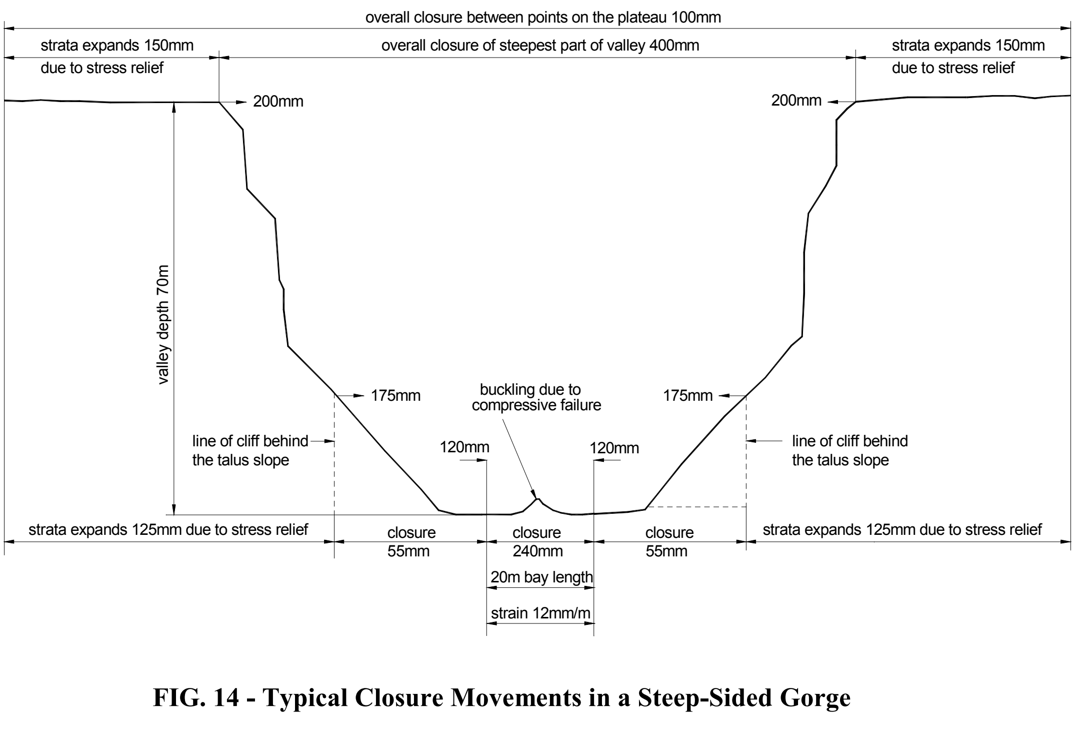

FIG. 14 - Typical Closure Movements in a Steep-Sided Gorge

MINING INDUCED REGIONAL OR FAR-FIELD HORIZONTAL GROUND MOVEMENTS

In addition to the 'normal' and valley related movements, far-field regional movements have also been recorded in a number of cases, at considerable distances from the mined goaf areas. Such movements have often been several times higher than the vertical subsidence movements measured at the same points.

It has been conjectured that these regional movements are caused by redistribution of the stresses in the strata between the seam and the surface due to the regional mining activity. The direction of such movements would tend to be towards the currently active mining area, but the direction of movement could also be dependent upon the scale and proximity of previous mining in adjacent areas.

It has been suggested by some authors that the regional movements are generally aligned with the principal horizontal in situ stress direction and initially this appeared to be the case in the Cataract Gorge over Longwalls 8 to 17 at Tower Colliery. It seems, however, more reasonable to suggest that the movements will be directed towards areas where the confining stresses have been reduced by mining activity, thus allowing expansion of the strata to occur.

The stresses generally within the strata are compressive in all directions and until mining occurs the stresses are in equilibrium, the balance being controlled by the shear resistance within and between strata units. As mining occurs, the equilibrium is disturbed and the stresses have to achieve a new balance by shearing through the weaker strata units and by expanding into areas of greatest dilation, i.e. towards the goaf areas, where the confining stresses have been relieved.

THE PREDICTION OF REGIONAL HORIZONTAL MOVEMENT

A method for the prediction of regional horizontal movements has been developed. The method is based upon measured data over a wide range of cases, with measured horizontal displacements up to 125 mm and distances from the mined goaf up to 6.2 times the depth of cover. The measured displacements were found to be greater where the in situ horizontal stress at seam level was greater. The measured displacements increased incrementally as each longwall was mined and the greatest displacements occurred as the total width of extraction became critical.

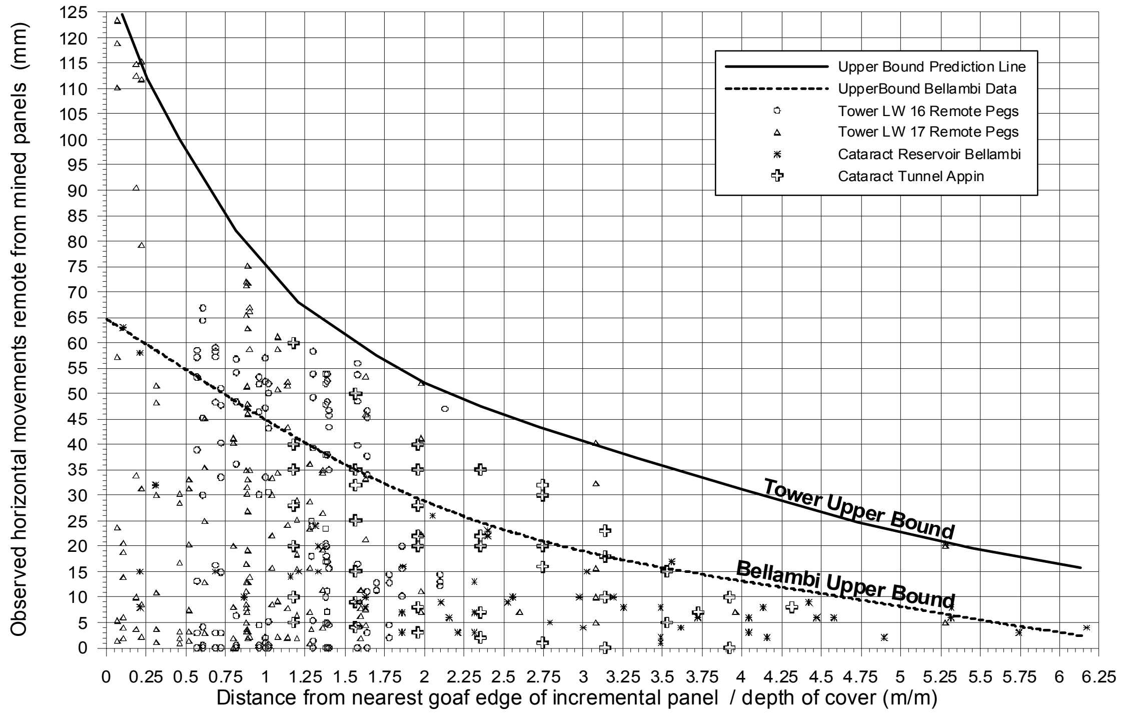

FIG. 15 - Graph showing Incremental Regional Horizontal Movements plotted against Horizontal Distances from Goaf Edge divided by Depth of Cover

It can be seen from the data in Figure 15 that the regional movement is greatest at the goaf edge and decreases with increasing distance from the goaf edge. The maximum recorded movement was almost 125 mm and movements were recorded as far away as 6.2 times the depth of cover from goaf edge, i.e. at a distance in excess of 3 kilometres. The movements are maximum incremental movements caused by the mining of one longwall and the upper-bound data relates to the second longwall in each series, which caused the highest movements.

The top curve in the graph is the upper-bound curve for the data from Tower Colliery, where principal in situ horizontal stresses as high as 44 MPa have been measured, at seam level. The bottom curve is the upper-bound curve for the data from South Bulli Colliery where the maximum principal horizontal in situ stress measured at seam level was approximately 26 MPa. It therefore appears that the regional horizontal movements are almost proportional to the in situ horizontal stress at seam level.

The curves can be used with care to predict the regional movements that are likely to occur, due to mining longwalls at collieries in the Southern Coalfield, once the in situ stresses at seam level have been determined. The maximum movements tend to occur when the second and third longwalls are mined in a series and to decline as subsequent longwalls are mined. This is possibly due to the fact that once the strata has been stress relieved by the first few longwalls, the potential for further movement is reduced.

Research in this area is continuing and it is hoped that a greater understanding will be gained by further study.

CONCLUSIONS

The research carried out by the authors during the last three years has provided considerable insight into mining-induced movements in the vicinity of creeks, river valleys and gorges. Useful methods have been developed to enable the prediction of valley closure, valley upsidence, compressive strain and regional horizontal movement.

It should be noted that the predictive methods are based upon data measured in the Coalfields of New South Wales, where the in situ horizontal stresses are generally high and, since they use upper-bound values, are expected to overpredict at collieries where the in situ stresses are lower than at Tower Colliery.
Further research is required to investigate the actual influence of in situ horizontal stress on the mining-induced movements. It seems reasonable to assume that the movements, which are caused by the in situ horizontal stresses in the strata, would be proportional to the pre-mining levels of in situ stress. At this stage, however, this can only be conjectured, since baseline data is not available to support this assumption.

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- South Bulli/ Bellambi Colliery

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