Influence of Geology on Valley Upsidence and Closure

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Summary

The current valley upsidence and closure prediction methods were first published in 2002, following completion of ACARP Research Projects C8005 and C9067. These methods use conservative empirical prediction curves, which were drawn above all of the observed upsidence and closure data. The data was extracted from subsidence surveys that had been carried out in valleys at most of the collieries in the Southern Coalfield. Little site-specific surface geological data was available at that time for the monitored valley sites and the considerable scatter that existed under the prediction curves indicated that many factors probably influenced the extent of the upsidence and closure movements.

Extensive monitoring has been carried out in valleys since 2002 and the observed upsidence and closure movements have shown that the current methods for predicting upsidence and closure movements are predominantly conservative. Reviews of the few exceedance cases have indicated that various local geology and landform factors at these monitored sites may have also influenced the magnitude of the observed upsidence or closure movements.

ACARP Research Project C18015, which commenced in 2009, seeks to improve the accuracy of upsidence and closure predictions and impact assessments, by collecting and studying additional upsidence and closure data and gathering geological and topographical data at all previously monitored valley sites. This additional information is being used to develop a more comprehensive database of valley-related ground movements. Studies based on the increased quantity and quality of data are progressing well, with a view to developing a revised prediction method, based on multi-variant statistical analyses, with the assistance of the Centre of Excellence for Mathematics and Statistics of Complex Systems (MASCOS) at the University of New South Wales. This research project is to be completed later this year and this paper presents the background to the project and some of the preliminary findings.

1. Introduction

When mining occurs near or beneath a creek or river valley, the observed vertical subsidence in the base of the valley is less than would normally be expected, and the observed compressive ground strain in the base of the valley is much higher than would normally be expected, in flat terrain. The reduced subsidence is due to the floor of the valley bulging and, in some cases, buckling or shearing upwards and this phenomenon is referred to as *upsidence*. The observed higher compressive strain is accompanied by inward movements of the sides of valley which are referred to as valley *closure*.

Upsidence is defined as the "difference between observed subsidence profiles within valleys and conventional subsidence profiles that would have otherwise been expected in flat terrain". Upsidence profiles are observed along monitored survey lines that cross valleys and the length of the observed upsidence profiles often extend from top of valley to top of valley. The point of *maximum upsidence* is usually associated with the maximum dilation of the near-surface strata in the base of the valley.

Closure is defined as "the reduced distance between two points across a valley." Most of the closure occurs in the base of the valley, although additional compressive strain may be observed on the valley sides. Hence, the observed closure profile may extend across both sides of the valley. *Maximum closure* is defined as "the maximum reduction in distance between any two points across a valley" and, hence, it has no fixed baylength, but it is almost always centred near the base of the valley.

These upsidence and closure movements are observed whenever mining occurs near or beneath a valley and are, in essence, an acceleration of the natural mechanism of valley formation and valley bulging.

The current methods for the prediction of upsidence and closure movements in valleys were developed between 1999 and 2002 during ACARP Research Projects C8005 and C9067.

It has been conjectured that the observed upsidence and closure movements within a valley could result from a number of mechanisms, including; an increase in the horizontal compressive stresses in the strata in the base of a valley caused by a redistribution of these stresses due to the goafing process, increased horizontal movements caused by the release of in situ horizontal compressive stress (far field movements), downslope movements, blocky strata or cube effects, dilation, "headland" movements, the conventional mining-induced movements, and various other possible strata mechanisms.

Although it was recognised that several mechanisms and factors could possibly influence the magnitude of the observed upsidence and closure, the current methods for the prediction of upsidence and closure movements are based on only four quantifiable parameters. These parameters are;

- distance between the longitudinal end of the longwall and the valley,
- distance between the maingate edge of the longwall and the valley,
- depth of the valley, and
- maximum predicted incremental subsidence over the longwall.

The current prediction method uses four empirical curves to predict closure and four empirical curves to predict upsidence based on the above parameters. The prediction curves were drawn conservatively above all of the available raw upsidence and closure data. The raw data was then adjusted for each of the four parameters by normalising the data based on the other three parameters. The four empirical prediction curves for upsidence and closure were then modified, through an iterative process, so that they remained above all of the raw data and the majority of the adjusted data.

Figures 1 & 2 illustrate two of these prediction curves, which show the raw and adjusted closure data plotted against the distances between the valley and the edges and ends of the longwalls.

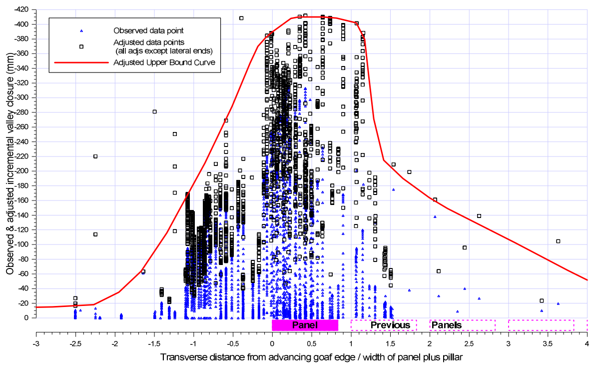

Figure 1 Incremental Closure versus Distance from the Longwall Advancing Goaf Edges relative to Panel plus Pillar Widths

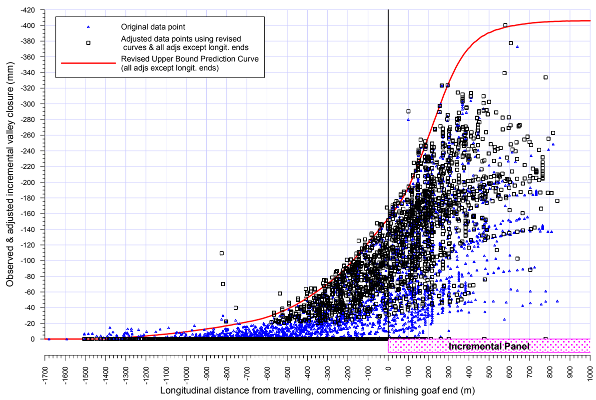

Figure 2 Incremental Closure versus Distance from the Ends of the Longwalls

Considerable scatter was noted in the raw and adjusted data under all of the conservative prediction curves. This scatter in the plotted data indicated that other factors or mechanisms must also influence the extent of the upsidence and closure movements. In order to develop methods to predict the movement due to any of the possible mechanisms, the measured data, ideally, should be broken down into its various components. However, it was recognised that it would be almost impossible to separate the components accurately and this was not attempted. It should also be noted that neither the time nor the resources were available during those previous studies to include detailed analyses of all of the potential factors. In particular, it was recognised that little information was available on the surface geology and local in situ stresses at each of the monitored valley sites, both of which could influence the upsidence and closure movements.

2. Review of Observed Valley Movements

The current valley related movement prediction methods have been used to predict upsidence and closure movements at many locations within valleys since it was developed and published in 2002 and, as anticipated, the predicted valley upsidence and closure movements were found to be predominantly conservative.

Comparisons between the predicted and observed upsidence and closure movements in the database of valley related movements are shown in the graphs presented in Figures 3 and 4. In these graphs, the average measured upsidence was 30% of the predicted upsidence and the average measured closure was 50% of the predicted closure. The extent of scatter, i.e. the differences between the observed and predicted values, seen in the upsidence graph is greater than the extent of the scatter seen in the closure graph.

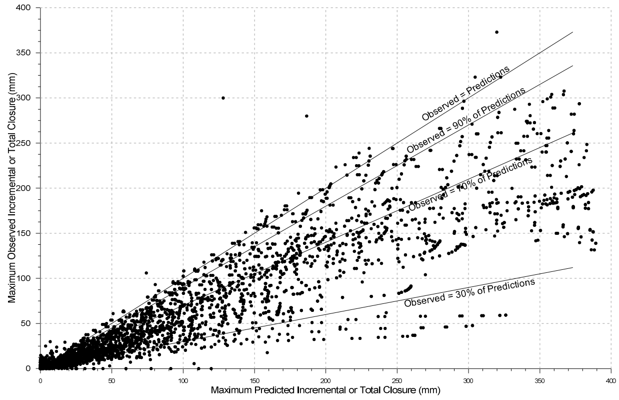

Figure 3 Comparisons of Predicted and Observed Upsidence Movements in Database

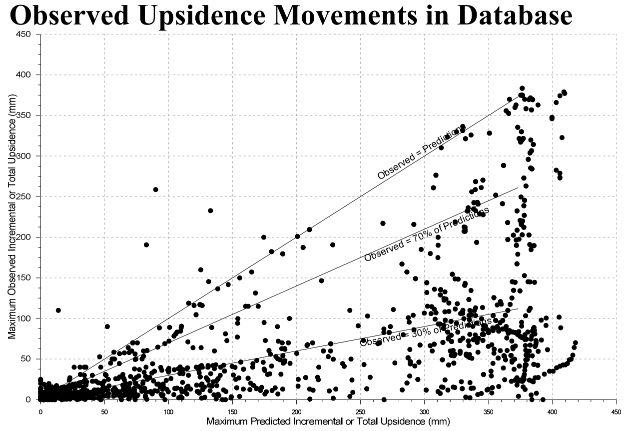

Figure 4 Comparisons of Predicted and Observed Closure Movements in Database

Whilst, the current method over-predicted both upsidence and closure for more than 95% of the valley movements studied, the method was found to under-predict upsidence and closure movements in some isolated valley cases. A review of all of these cases indicated that various local geology and landform factors may have influenced the magnitude of the observed upsidence or closure movements, such as where;

- the valley bedrock was found to be seated within the Wianamatta Shale, or
- the valley bedrock consisted of thin, highly jointed, or cross bedded, strata layers, or
- downhill slumping was observed in the sides of the valleys, or
- 3D surveys indicated that some 'headland' movements contributed to the measured valley closures, or where
- there could have been high conventional horizontal displacements.

It was concluded from this review of observed data that closure is a more reliable parameter than upsidence to indicate the extents of valley movements and to assess valley impacts, for the following reasons:-

- The observed upsidence movements are seen to be very dependent on the placement of survey pegs, which can miss the point of maximum upsidence within the cross-section.
- The observed upsidence can also be underestimated where the length of a survey line across a valley is too short.
- Closure is now seen as a measure of macro valley movements with less variation in the observed movements between adjacent cross-sections within a valley.
- Upsidence is seen as a measure of micro valley movements in the base of the valley, which can differ greatly between adjacent cross-sections depending on variations in near-surface geology, whether or not failure of the bedrock occurs and the nature of the failure.

For these reasons, there is much greater scatter in the observed upsidence data when compared to that observed in the closure data. It is then reasoned, that an upsidence value only provides an indication of the localised movements in the position of measurement, whereas a closure value provides a better indication of overall valley movements.

Even though fracturing and dilation of the strata in a creek bed, and the potential for surface water flow diversions, principally results from upsidence movements, the predicted closure movement is considered to be a more reliable parameter than the predicted upsidence movement for assessing impacts in valleys.

Fortunately, a good correlation exists between observed closure and upsidence effects, and this allows us to use the predicted closure movements to assess the potential impacts on creek beds.

It was also found from the review, that it was much easier to assess the shapes of the upsidence profiles using the incremental subsidence profiles rather than from total subsidence profiles, since the incremental profiles follow regular standard shapes, whilst the total profiles are far more irregular. (Incremental subsidence is the additional subsidence at a point resulting solely from the extraction of one panel.) However, even when working off the incremental subsidence profiles, the main difficulty in determining the shape of the upsidence profile is still in deciding on what level of conventional subsidence would have occurred if the valley was not there. Hence, the determination of the upsidence profiles and the maximum upsidence is viewed as a subjective assessment for which there is no simple formula.

3. Effects of Geology on Upsidence and Closure Movements

Many collieries are extracting, or are proposing to extract longwall panels close to valleys, where sensitive infrastructure is located or where sensitive environments exist. Various infrastructure owners and government authorities are therefore seeking not only conservative predictions, but they are also seeking advice on the expected (i.e. most likely) movements and the range of potential movements (i.e. probabilities of exceedance).

ACARP Research Project C18015 was commenced in 2009 with the aim of improving the accuracy of upsidence and closure predictions and impact assessments and to indicate the likelihood of different levels of upsidence and closure occurring. This ACARP research project is to be completed later this year and this paper presents some of the preliminary findings from these studies.

The available funding being provided by ACARP for this project, was considered to be sufficient to;

- collect field data, at as many of the previously monitored upsidence and closure sites as possible, including a number of basic landform and geological factors that are believed to influence upsidence, closure and strain in valleys,
- develop new or revised methods for the prediction of upsidence, closure and strain in valleys to include the effects of these new factors, and to
- write a study report that supplements previous studies and provides an up to date "state of the art" on the coal industry's knowledge of upsidence, closure and strain in valleys.

Approximately half of these funds have been spent gathering the geological data, and the remaining funds are being spent analysing the data, developing the new prediction models and writing the report.

The collection of geological data for this study was designed to only include field geological mapping in the valleys that have already been monitored for upsidence and closure and to review all the available landform and geological data that can be supplied by each colliery for these previously monitored valleys.

When applying for funds for this new project, it was emphasised, that this study could not and was not intended to provide data on the pre-mining in situ stresses within the various valley strata layers, or the changes in these stresses as mining occurred. This is an area that will require further study since the influence of mining on in situ stresses can only be determined as mining occurs.

As a result of this new study, it is anticipated that new or revised methods for the prediction of upsidence, closure and compressive strain will be developed, and it is anticipated that these methods will reduce scatter when compared to the current conservative prediction methods. But because in situ stress, and other factors identified during various reviews, will not be addressed, and since it is difficult to separate out the movement components from each of the possible mechanisms, then, some scatter is still to be expected under the proposed new closure prediction lines.

The work programme for this study is detailed below and comments are provided on the progress to date;

- Gather observed upsidence and closure data from all mines in the Southern Coalfield, *[In 2002 there were 4,000 observed valley upsidence or closure cases in the database from many of the mines in the Southern Coalfield.*
  New data has now been added from more recent observations from existing mines and from additional mines so that the database now includes more than 9,000 observed upsidence and closure cases from all of the mines in the Southern Coalfield.
  For the previous study a database of the maximum upsidence and closure movements was developed. For the new research project, it was decided to expedite the completion of a new raw subsidence database. The database now includes, in a standardised digital format, all the original survey data from all of the monitoring lines in the Southern Coalfield where valleys were monitored. Far more detailed analyses concerning the observed valley movements can now be performed, having ready access to the movements of each peg in the valley rather than just the maximum upsidence and closure values. This new raw survey database now includes more than 500,000 subsidence, strain and horizontal movement measurements from almost 500 survey lines.]
- Gather site-specific surface geological data for all previously monitored valleys, *[Geologists have visited all previously monitored valley sites and have gathered a range of geological and landform field data for each site.]*

- Gather site-specific topographic and mining data (subsets) for all of the previously monitored valleys, *[Completed]*
- Incorporate the maximum observed valley strain data into the database, *[Observed valley strain measurements were not included in the previous database, because of the influence of differing bay lengths, and hence preference was given to only reporting valley closure measurements. Now all maximum observed valley strains are included in the new database.]*
- Incorporate "total" subsidence, upsidence, closure and strain data and distances from the edge of the total series of longwall panels in addition to the current "incremental" per panel values, *[At present all valley predictions at a point are based on the addition of "incremental" movements from each of the longwalls in the vicinity of that point. Since each incremental prediction is conservative, the "total' prediction from a series of longwalls is even more conservative. Where there were many longwall panels adjacent to a creek or valley, it was found that the accumulation of incremental movement predictions added up to an overly conservative total prediction. A new database and a new prediction method based on "total" movements is being developed to provide more reasonable or more appropriate "total" valley predictions.]*
- Study the influence of local surface geology and landform on previously observed upsidence and closure movements, *[This is being carried out now and it is hoped that a relationship can be established to reflect the influence of each of the geological and landform factors identified during the Steering Committee Meetings. The predicted initial upsidence, closure and strain values would then incorporate these "landform and geological" factors to determine the final predicted upsidence, closure and strain at a point.]*
- Review alternative methods for determining the depth of the valley. *[Most of the upsidence and closure data that was included in the previous upsidence and closure research project was measured within the "U" shaped Cataract Gorge, which is deeply incised into the surrounding plateau. Alternative ways of defining the valley depth, based on the shape and overall dimensions of a valley, are currently being reviewed.]*
- Prepare a revised upsidence and closure prediction method that incorporates the effects of geology and topography, *[Being developed now.]*
- Provide a probabilistic approach for a range of upsidence and closure predictions rather than just using conservative prediction curves, *[Being carried out now with the assistance of the Centre of Excellence for Mathematics and Statistics of Complex Systems (MASCOS) at the University of New South Wales. The probability of particular levels of incremental and total closure occurring are being analysed using multi-variant statistical methods using the expanded database.]*
- Document the available observed data on measured impacts of upsidence and closure on surface features and infrastructure, including aquifers, pools, waterfalls, pipelines, roads, bridges, etc, and add into the database, and
- Publish a detailed study report and update upsidence and closure guidelines.

4. Comments on Research Approach and Methods

The methods used to predict the valley-related mining-induced ground movements have been based entirely on empirical monitored data. Mathematical models have been used to replicate the observed upsidence and closure ground movements, but these mathematical models have not been used with confidence to predict upsidence or closure movements.

To provide a prediction of possible ground movements at a point within a valley, firstly the conventional mining induced subsidence, tilts and ground strain movements are predicted and secondly the valley-related ground movements are predicted. These two predictions are then combined or added to determine the total predicted ground movements.

It is important to recognise that predictions of valley related movements are based on the observed valley movements from past mining cases with no adjustments to separate out any individual components of the observed movements.

Attempts could have been made to separate out mining-induced conventional horizontal movements and far-field movements, however no such adjustments of the raw data were attempted, as it was considered to be better to base the prediction methods solely on the observed data. It should also be noted that the current methods for the prediction of conventional horizontal movements and far-field movements are only approximate and could lead to erroneous results.

The conventional horizontal movements and far-field movements can represent a significant component of valley related closure movements above extracted longwalls, especially for small valleys.

Using the conservative valley-related prediction lines that are drawn above the observed valley–related data, without adding or deducting the conventional horizontal movements and far-field movements, a degree of conservatism is added for those valleys that are located in the centre of the panel, where the predicted conventional ground shortening adds to the predicted valley-related closure.

Caution must be used, however, for those valley cases that are located around the edges of a panel where the predicted conventional mining-induced opening movements would reduce the predicted closure movements in the valley.

Rather than attempting to separate the components of movement due to various mechanisms, it is believed that the influence of these components can be better addressed by incorporating additional mining and geometry factors into the new statistical model, including longwall width-to-depth ratio, orientation relative to the longwall, maximum bay length and position relative to the longwall extraction face. In this way, these statistical models can provide more reliable predictions of the overall movement, i.e. valley plus conventional movements.

Additionally, and especially for small valley cases within the tensional zones of the conventional ground movements, the predicted movements can be determined using the expanding detailed database of raw survey data and a subset of the available empirical data where the mining geometry, longwall position, topography and geology are similar to the valley case being studied. The subset of available empirical data can then be statistically analysed to provide a probability distribution for the predicted total combined movements based on the most relevant or appropriate empirical data.

For both of these methods, recognition should be given to the bay lengths and the bay directions over which the predictions are required. The current prediction method (2002) provides a maximum upsidence and maximum closure prediction within the valley and it provides a maximum closure strain based on a 20 metre bay length. In the future it is proposed to provide valley-related predictions for specific bay lengths or for a range of bay lengths, and provide predictions specific to the orientation relative to mining. In this way, the predictions will be more appropriate for use in impact assessments for infrastructure located within a valley.

The fact that extensive monitoring in many valleys since 2002 has only revealed a few exceedances of the current prediction method highlights that the current method is conservative. For all the exceedance cases, there were understandable geological or landform factors that could have caused the exceedances. The current research is analysing the influence of these geological and topographical factors in an attempt to develop relationships with the observed valley related movements. Geological and topographical factors will be incorporated into the new prediction model based on the established relationships. Alternatively, or additionally, predictions could be made based on subsets of the empirical data based on specific topographical and geological settings.

Whilst it is intended that the new model will provide predictions of total movements, it is important to understand and recognise the influence of the conventional mining induced movement component and the far field movement component and whether such movements are increasing or decreasing the overall closure movements.

It is also important to appreciate the magnitude of the conventional and far field movements which could develop within a valley. An estimate of the conventional or systematic component of ground movement within valleys has been made by analysing these movements in areas of flat terrain in the Southern Coalfield. It was found that observed total ground shortenings of 50 mm to 200 mm can be measured across long bay lengths, within the centre of longwall panels, and that total ground openings of 50 mm to 100 mm can be measured around the edges of panels over long bay lengths.

For this reason, the new research report will analyse and provide discussions on conventional and far-field movements in flat terrain. It is noted, however that further research is required to develop methods that can be confidently used for the prediction of such movements.

5. Preliminary Observations from Current Research

All field work associated with this study has been completed by the geologists. This geological and landform data and the new observed ground movement data have been entered into an expanded database of upsidence and closure movements and this database is now is being analysed to develop new upsidence and closure prediction models.

Work is concentrating on developing a new closure prediction method because, as previously indicated, closure is considered to be a more reliable parameter than upsidence to indicate the extents of valley movements and to assess valley impacts.

Preliminary plots of the new data have confirmed all of the trends that were shown in the previously published closure data, i.e.;

- The observed closure is greater directly above the mined panel than it is over surrounding areas,
- The observed closure is greater within deeper valleys than it is in shallow valleys, and
- The observed closure is greater where the observed subsidence above the mined panel is greater.

The field geological and landform data has confirmed that in the few cases where the previous method under predicted the closure movements, various geological and landform factors can account for most of those exceedances.

Preliminary reviews of this new geological and landform data have shown other trends, indicating that, more closure is observed;

- where the surface strata layers in the base of a valley comprised weaker shale layers rather than strong sandstone layers,
- where the surface strata layers in the base of a valley were highly jointed,
- where the surface strata layers in the base of a valley were cross bedded,

- where the surface strata layers in the base of a valley were thin,
- where the angle between the strike angle of the natural joints within the bedrock strata and the orientation of the valley floor was between 30 and 60 degrees,
- above claystone or shale layers
- where the stream bed meandered with tight corners, or, at the conjunction of streams as these landforms result in “headlands” being created that can move more freely towards the valley,
- where the valley floors were wide,
- where the currently mined panel, or any previously mined panel, extracted coal from beneath the monitored point, or
- where the currently mined panel, or any previously mined panel, extracted coal within a depth of cover of the monitored point.

When the original predictive models were developed in 2002, it was recognised that it would not be possible to develop an acceptable method for the prediction of upsidence and closure movements, for different mining scenarios and different valley depths, using the limited amount of observed raw data available at that time and binning that data into separate small groups.

The current prediction method uses four empirical curves to predict closure and four empirical curves to predict upsidence based on four quantifiable parameters.

In preparing the upper-bound prediction curves, the raw data was adjusted for each of the four parameters by normalising the data based on the other three parameters. This process was rather subjective, but it did result in predictive methods that have been shown to be conservative.

As well as repeating this adjustment approach, the new closure prediction method will be based on standard statistical multi-variant methods analyses with up to 12 variables that are currently being worked on with the assistance of MASCOS at the University of New South Wales. The probability of particular levels of incremental and total closure occurring are also being analysed using these multi-variant statistical methods.

The current ACARP funded research project is due to be completed at the end of September this year and a Final Report will be published at that time, including the data, the analyses and the findings of the study.

6. Acknowledgement

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