

CASE STUDIES IN THE APPLICATION OF INFLUENCE FUNCTIONS TO VISUALISING SURFACE SUBSIDENCE

Roger Byrnes ¹

ABSTRACT: The influence function method assumes that a subsidence surface can be represented as a mathematical function. In the case studies presented a gaussian function is used. Examples are given of how the influence function is calibrated to local mine performance, and also in greenfields applications. In the latter cases, geotechnical analysis of likely performance of pillars and roof and floor strata were incorporated into the analysis.

The major application of the influence function method is in visualising subsidence – as the method models surfaces and surface deformations. Detailed post mining topography and deformation histories can be produced.

INTRODUCTION

There is a range of methods used for predicting subsidence. These include:

- the prediction of two or three points on a cross line (for example Holla (1985) where S_{max} , inflection point and angle of draw are predicted)
- profile functions that predict the full shape of cross lines (for example the incremental profile method of Waddington and Kay (1998))
- influence functions that predict the shape of the subsidence surface, for example the Surface Deformation Prediction System (SDPS)

There is still no way to accurately predict subsidence solely from the application of geotechnical engineering to a knowledge of the rock mass, so all three methods require calibration to local experience when available. Holla (1988) and Waddington and Kay (2001) have discussed the validity of predictions and these authors suggest that predictions of vertical subsidence are within 10%. No study of the reliability of the predictions of tilt or strains have been conducted. The impact of unrecognised changes in geology are usually used to explain mis-predictions. Influence functions have not been extensively used to date so that there has been no study of the accuracy. However, since the method is calibrated in the same way as for the point and profile methods, a similar accuracy is likely.

Influence functions can be incorporated into integrated subsidence studies. Prediction is done separately using a combination of back-analysis of subsidence history and also the application of geotechnical engineering to determine panel sag, pillar compression, and roof /floor compression. This allows an assessment of the geology and hopefully improves the accuracy of the resulting predictions. Influence functions are then used to visualise the surface deformation that follows from the calibration.

FUNDAMENTALS

The shape of the subsidence profile across a panel or group of panels can be approximately described by mathematical functions. A number of different functions have been published. One of these, the bell-shaped Gaussian function is incorporated in the SDPS program, which Seedsman Geotechnics Pty Ltd (SGPL) have used with success to visualise subsidence over various mine layouts.

Karmis et al (1990) describe the Gaussian function for the 2-dimensional case:

$$g(x, s) = ((S_0(x))/r) * \exp(-\pi * ((x-s)^2)/r^2)$$

¹ Seedsman Geotechnics Pty Ltd

where:

r	=	the radius of the principal influence = h/tan(beta)
h	=	the overburden depth
beta	=	the angle of principal influence
s	=	coordinate of point P, where subsidence is considered
x	=	coordinate of the infinitesimal excavated element; and
S ₀ (x)	=	convergence of the roof of the infinitesimal excavated element

Subsidence at any point can be expressed by the following equation:

$$S(x, s) = 1/r * \int_{-x}^{+x} S_0(x) \exp(-\pi((x-s)^2)/r^2) dx$$

where:

S ₀ (x)	=	m(x)a(x)
m(x)	=	extraction thickness; and
a(x)	=	roof convergence (subsidence factor)

The process of calibration requires fitting subsidence profiles calculated in SDPS to the profiles measured across the project. The subsidence basin calculated in SDPS, and hence the profiles across the panels in question are adjusted by changing the input parameters. Experience over a number of projects shows that the above functions usually produce acceptable results.

The calibration of the function to a specific project requires the following parameters:

- Subsidence factor (S_{max} / T ratio) as a percentage
- Location of inflection point (compensation width)
- ratio of strain to curvature
- Angle of influence (angle to zero subsidence)
- Panel layouts
- Seam thickness
- Depth of cover

Influence functions are based on predicting surfaces and not profiles. Once a subsidence surface has been calculated, subsidence at specific points or along any line across the surface can be illustrated, by taking a slice through the gridded surface. To use the influence function, the locus of the inflexion points need to be supplied. For longwalls, this can mean that, at its simplest, four points need to be supplied to fully describe a panel.

Outputs possible from the influence function include:

- vertical subsidence,
- tilts (in east direction, north direction, and maximum),
- curvatures (in east direction, north direction, and maximum),
- strains (in east direction, north direction, and maximum),
- horizontal movement (in east direction, north direction, and maximum)

Gridded surfaces of each of these parameters are obtained.

Run times for the program are very quick. Large projects with closed spaced prediction points will run in the space of minutes on a Pentium 3 or 4 computer with say 1.5GHz processing speed. For example a project with say 15 panels and prediction points at grid nodes of 10m (200,000 points) will run in the space of around 10-15 minutes. This quick run time allows fine tuning of calibrations against known data by allowing input parameters to be repeatedly changed until the closest possible calibration has been obtained.

Various case studies and the calibration results that have been gained for different projects are discussed.

SHALLOW LONGWALLS WITH NON-YIELDING CHAIN PILLARS

For shallow longwalls, where the chain pillar design is such that pillar deformation is low, each longwall panel can be considered independent from adjacent ones. The subsidence of the surface over a series of longwalls can be considered to be the result of the addition of the subsidence of each individual panel.

Figures 1 and 2 show the subsidence and strain measured across a line that traverses an extracted panel at a mine in the Hunter/Newcastle coalfield. The actual data is shown with the solid line and the calibration of the predicted surface is shown in the dashed line. The subsidence plot shows a good agreement between the actual and predicted. The profile has been well described by adjusting the location of the inflection point, the angle of influence and S_{max}/T . In this case subsidence over the pillar is represented well.

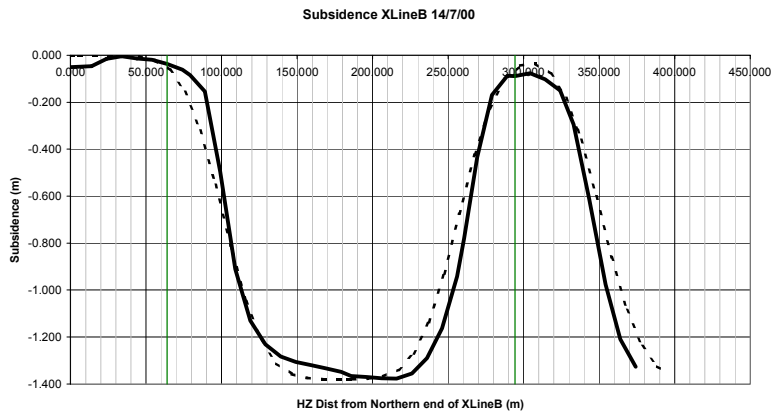


FIG. 1 - Comparison of measured versus predicted subsidence at Mine A - Hunter/Newcastle coalfield

Figure 2 shows the comparison of strains between measured and predicted. The actual measured data shows that maximum tensile and compressive strains are not well predicted in this case. This area shows localisation of strains, which is probably due to thin soil cover and widely spaced joints in the near surface rocks. There is a reasonable fit to tilts and curvatures for the data.

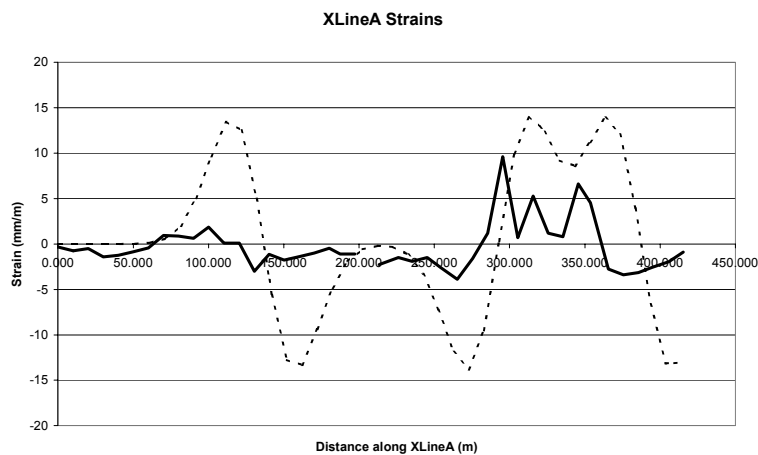


FIG. 2 - Comparison of measured versus predicted strains at Mine A - Hunter/Newcastle coalfield

VISUALISING THE SUBSIDENCE

Surface contours

Figure 3 shows a subsided topographic surface for Mine A in the Newcastle/Hunter Coalfield. Influence function methods were used to derive a grid of subsidence over the area. This subsidence grid was added to the grid of original topographic surface. The addition of the grid of existing R.L.'s of the original surface, plus the grid of negative subsidence values at each point results in the grid of predicted subsided topography. Once this grid has been calculated, it can be represented in a number of ways, including contour plan, coloured solid contour plan, and shaded relief plan. Slices of the gridded surface can be taken to show the profile in section. These sections can be straight lines between two points or can be more complex route lines. Examples include along surface infrastructure such as pipelines or along a creek that traverse the panels.

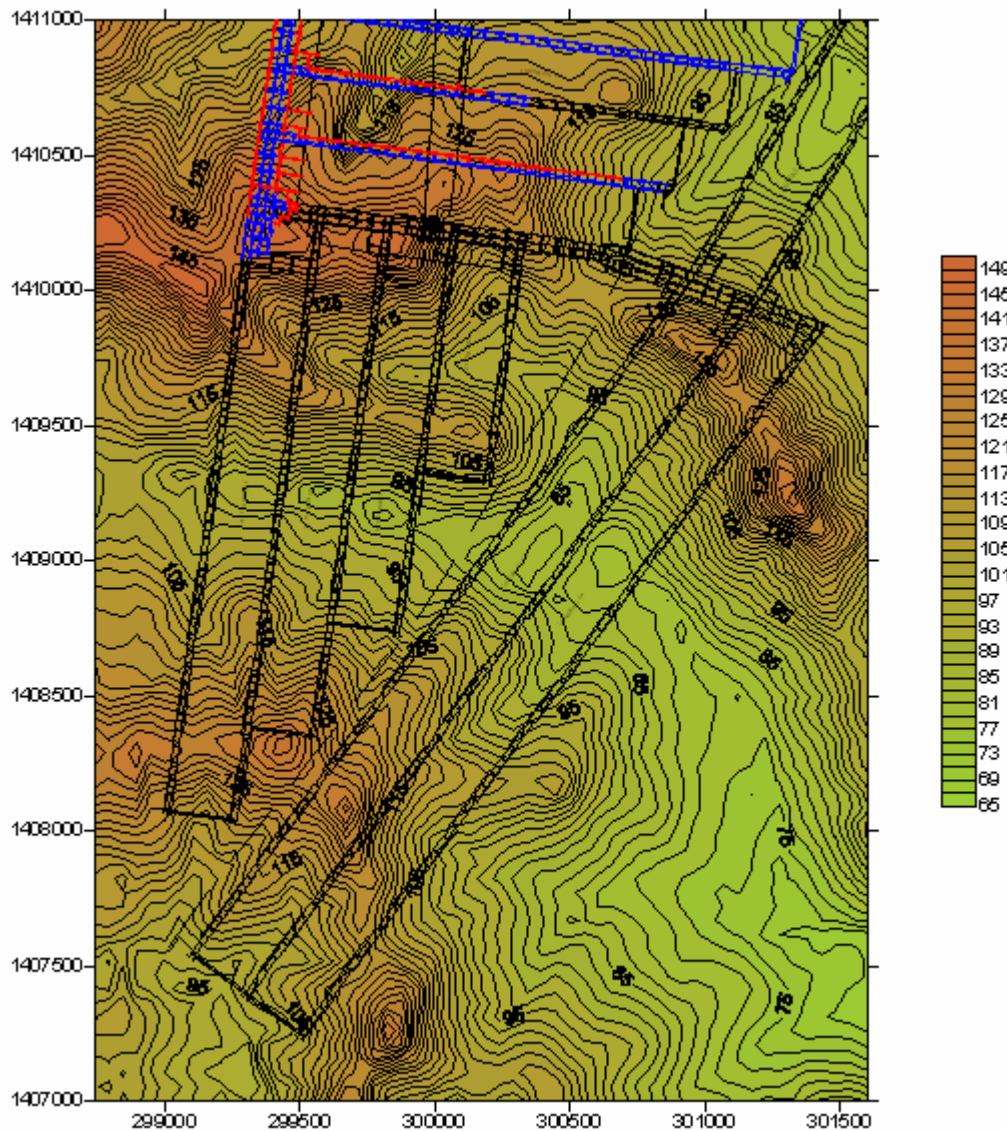


FIG. 3 - Predicted subsided topographic surface over Mine A – Hunter/Newcastle coalfield

Full movement of a transmission tower

Grids of subsidence, horizontal movement, strain and tilt, that had been calculated for Mine A were used to calculate the movement at the base of power transmission towers positioned above longwall panels. The change in movement at the surface at a point can be represented as curves showing movements as the panel retreats

underneath it. Tower A is located approximately 37m from the centreline of a 229m wide panel. The panel is aligned at approximately 97°.

Figure 4 shows how tilt and subsidence change with the retreating panel. The curves show the subsidence and tilt when the longwall is approximately beneath the transmission tower. The panel start line is at approximately E300610m. Therefore the subsidence profile approaches zero at the Eastern end of the line, while the tilt profile mirrors the situation beneath the transmission tower.

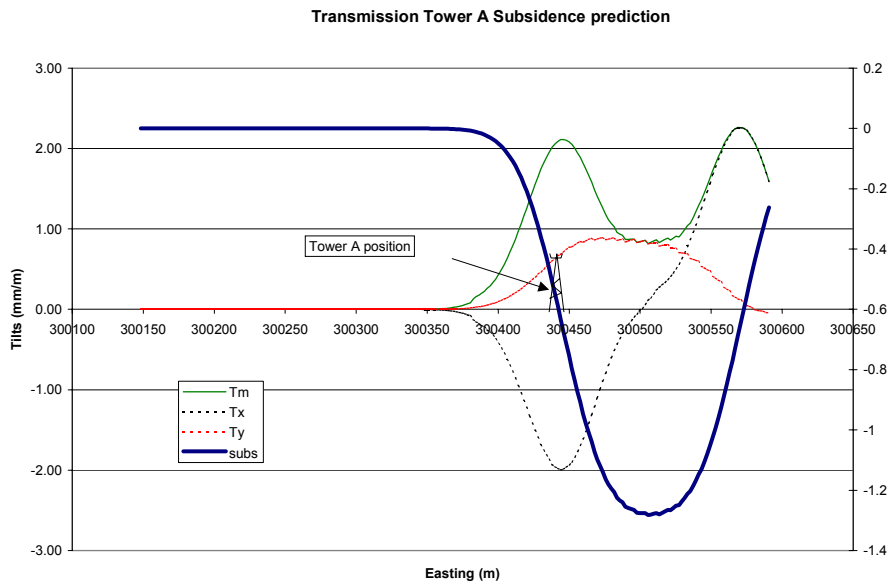


FIG. 4 - Tilt and subsidence at the location of a transmission tower, with changing longwall position

Figure 5 shows the horizontal movement as the longwall retreats underneath the same tower. Up to 0.3m of horizontal movement is predicted.

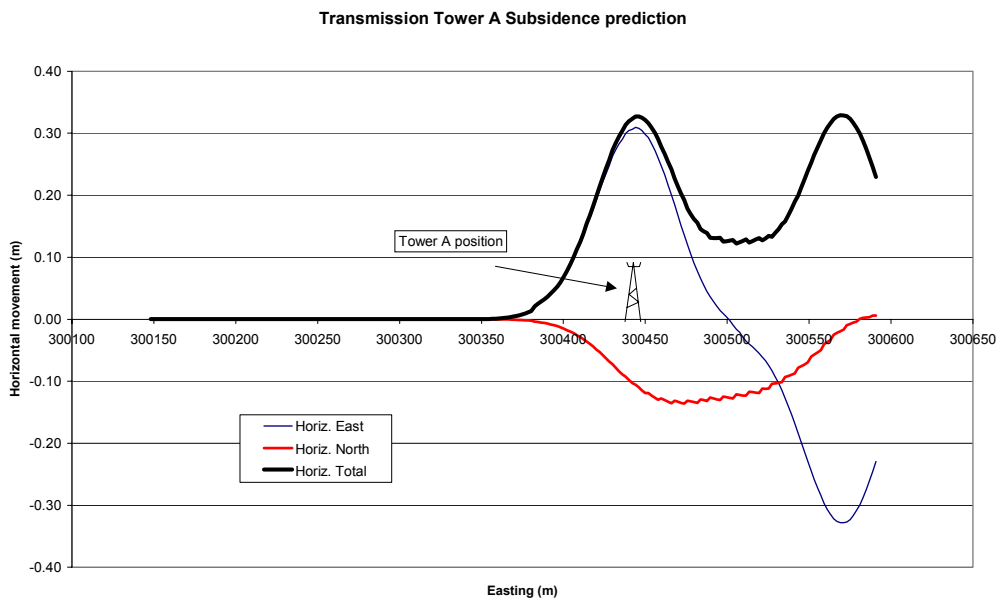


FIG. 5 - Horizontal movement above retreating longwall

DEEP LONGWALLS WITH YIELDING CHAIN PILLARS.

At depths greater than about 250m, longwall chain pillars are typically designed to yield into the goaf. This allows increased reserve recovery and also reduces the amount of roadway driveage. Pillars may compress by up to 40% of their original height. The result is that eventually surface subsidence is dominated by the compression of the chain pillars and adjacent roof and floor strata and not the sag of the strata above the extraction panels.

As an example, Figure 6 gives an indication of the maximum vertical subsidence associated with 250m wide longwall panels and 30m pillars in a 3m seam as the depth is increased. Note that this would be an appropriate mine layout if there was a competent sandstone in the immediate roof, that allowed tailgate serviceability to be maintained. It is important to note that the chain pillars would be yielding under double goaf loading at a depth of around 250m. The figure shows that as depth increases, the proportion of subsidence contributed by pillar and roof and floor compression increases, while the proportion contributed by panel sag decreases.

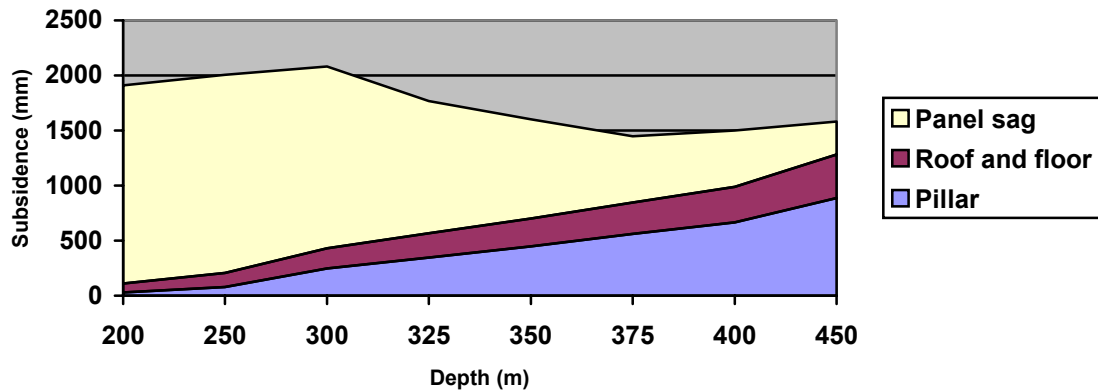


FIG. 6 - Contribution of various modes of subsidence with increasing depth

In this model, the panel sag is taken from Holla curves (Holla, 1985), and roof and floor compression is based on rigid footing calculations (Poulos and Davis, 1974) with a Young's modulus of 10 GPa. The pillar deformation is based on data from the Southern Coalfields(Figure 7) and an interpretation of laboratory data on model coal pillars (Figure 8) based on work by DAS (1986).

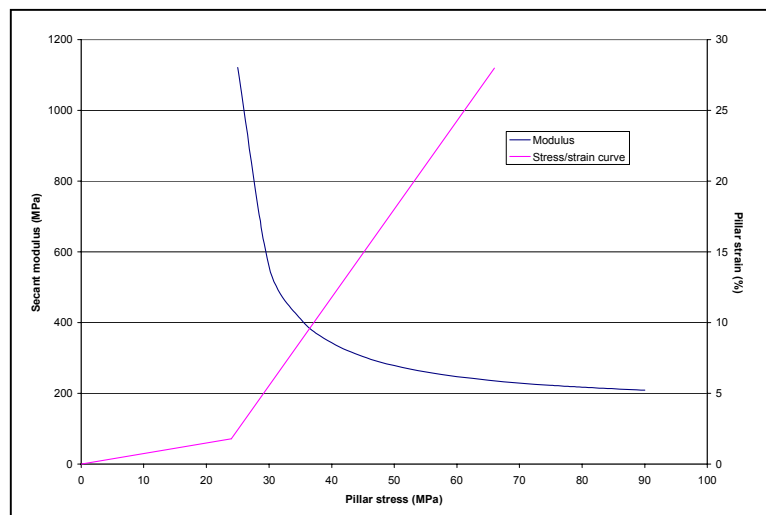


FIG. 7- Deformation data of Southern Coalfields coal pillars

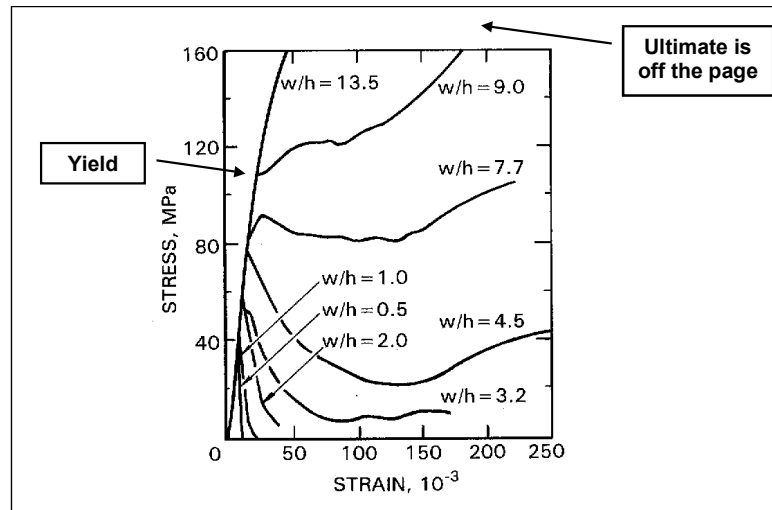


FIG. 8 - Testing of model pillars of different width/height ratios (Das, 1986)

For the case of multiple panels and pillars where the depth of cover increases significantly such that the chain pillars yield when loaded, a different approach to subsidence prediction using SDPS is required. SDPS provides the ability to model each series of panels as one super panel. Contained in the boundaries of the super panels are chain pillars that act to reduce the subsidence. In this mode, SDPS models the negative subsidence (upsidence) of the pillars instead of the subsidence of the panels. This is depicted in Figure 9 where the super panel boundaries are shown in dotted line and the chain pillars in solid line.

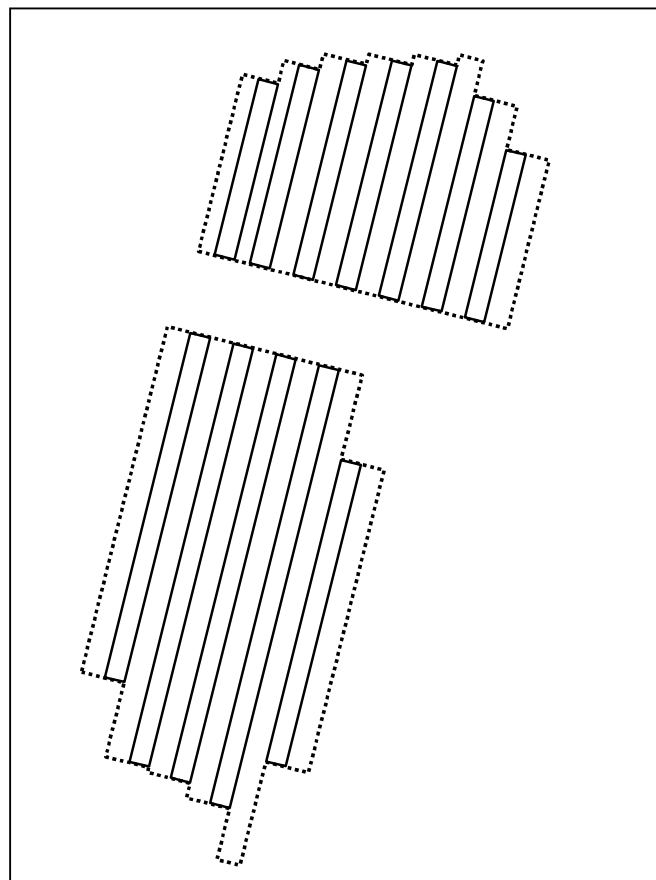


FIG. 9 - Super panels (dotted line) and active pillars (solid line) with compensated geometries

The width of these active chain pillars is equal to the distance between the compensated panel boundaries. The feature of this method is that the pillars can be given their own negative subsidence factor, allowing greater control over subsidence prediction due to pillar compression. This can be observed in Figure 10 where the difference between the two series '-65% Pillar Subsidence Factor' and '-55% Pillar Subsidence Factor' – can be readily seen.

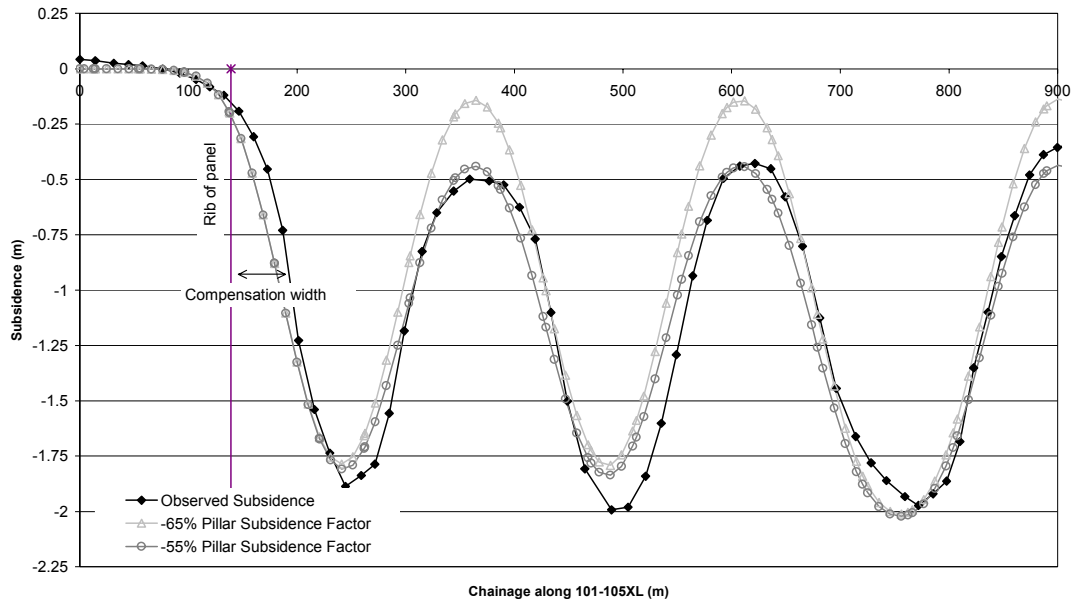


FIG. 10 - Comparison of 55% and 65% negative pillar subsidence factors - Mine B

Calibration

Mine B is in Central Queensland and has a thick weathering profile. Figure 10 shows the subsidence calibration and Figure 11 shows the strain calibration. A good calibration to S_{max} has been achieved. In addition, the shape of the strain curve shows a very good fit to the actual data. This may be due to the thick weathering profile and highly fractured bedrock, which reduces the likelihood of fracture localisation and hence strain peaks occurring.

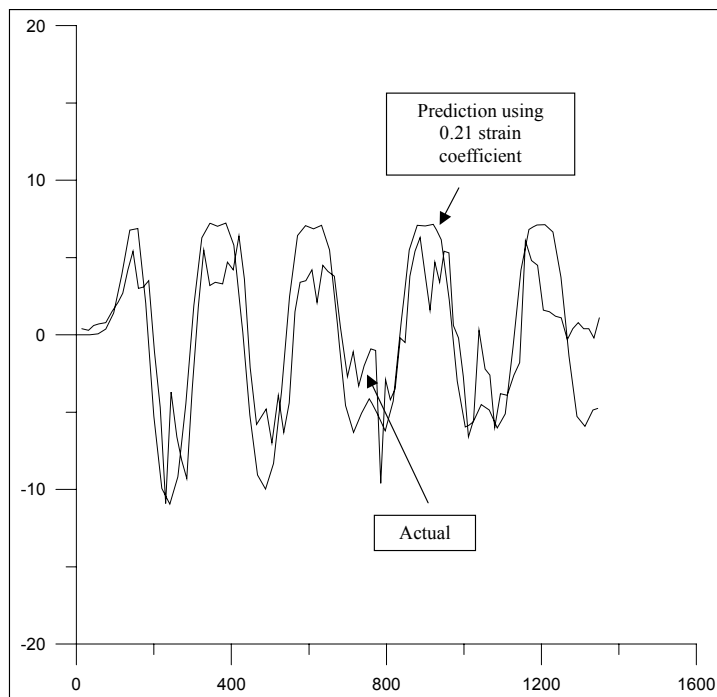


FIG.11 - Calibration of strain at Mine B

Visualisation of surface

The SDPS program allows large grids of subsidence predictions to be calculated quickly, in the order of minutes to seconds. This means that high data density grids are readily achievable. This density in turn allows the ability to display in high resolution graphics. Figure 12 shows the predicted subsidence over Mine C in Central Queensland, displayed as a line contour plan.

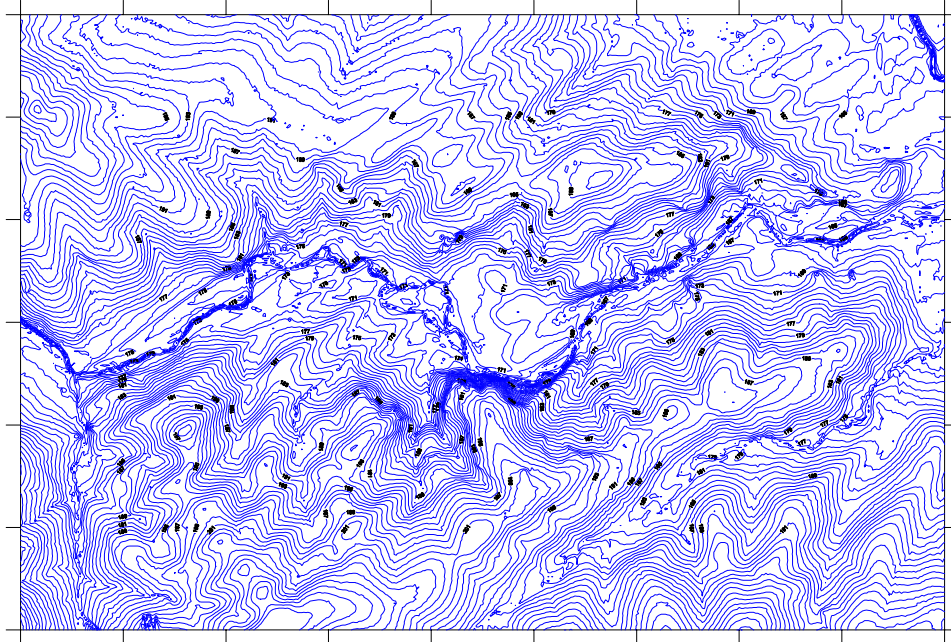


FIG. 12 - Subsided topography prediction for Mine C in Central Queensland

Queries can be run along a line through the subsided topographic surface. This allows the subsidence strain to be illustrated along infrastructure routes, for example a cable line, or along creek lines. Figure 13 shows the existing levels and subsided levels along a creek for Mine D.

Subsided vs Original Topography along the Main River Feature

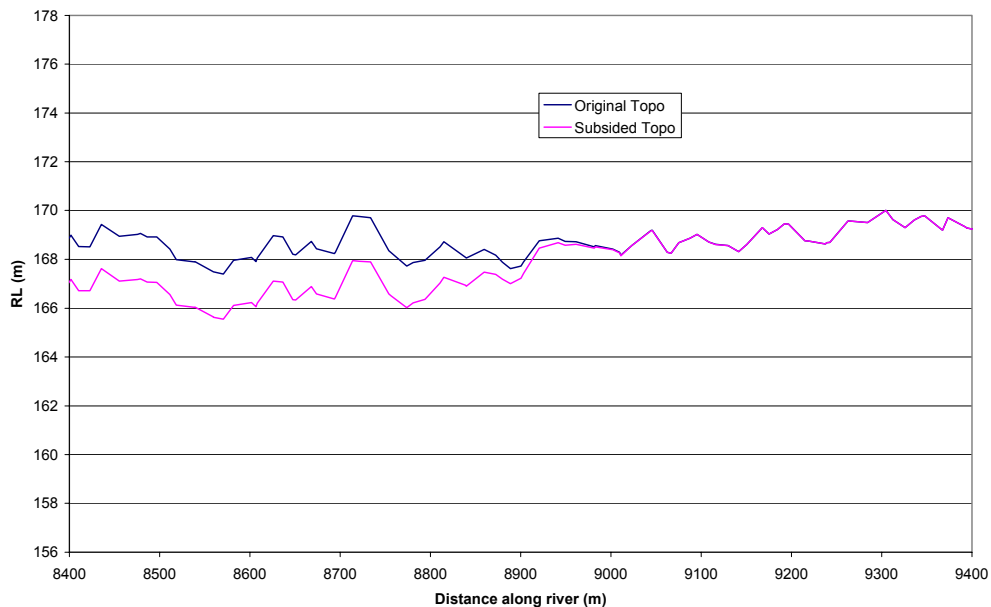


FIG. 13 - Comparison of existing topography and predicted subsided Topography along the route of a creek

Figure 14 shows a shaded profile surface of the subsided topography over Mine C. The subsidence troughs and humps are clearly visible in the surface (angled panels in the SE part of the figure). This is a useful way of presenting data to non-technical persons, with the important note that the surface has been exaggerated to show the subsidence basins. Different amounts of exaggeration can be applied.

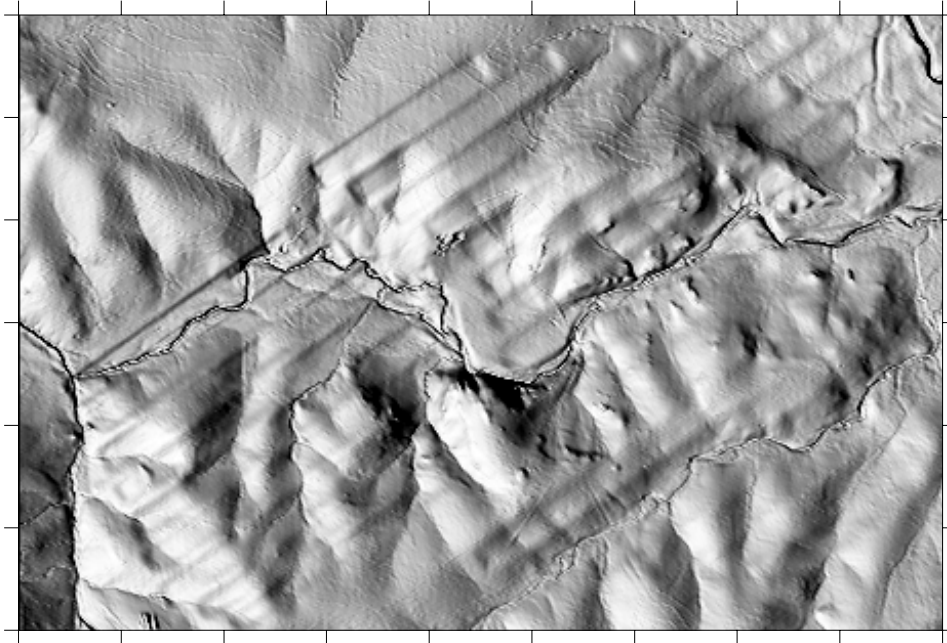


FIG. 14- Shaded relief surface of subsided topography

CONCLUSIONS

The use of influence functions is an efficient and flexible method for generating subsidence parameters over surfaces. Calibration of the function against measured subsidence is essential, and allows a measure of reliability of the predictions. Subsidence prediction is undertaken by using geomechanical and empirical methods to determine the behaviour of pillars and strata. These methods generate the input parameters to the influence function program. The program generates surfaces very quickly allowing repeated calculation runs to fine tune calibrations against measured data.

Once confidence in the input parameters has been gained from the calibration, then the program can be used to visualise the surface deformations. The program generates a surface rather than just a point or line profile across the surface. This allows a detailed view of the subsidence basin. Sections across the area, routes along the surface and specific points can be queried from the generated deformation grids. Surface gridding programs can be used to produce a variety of graphical outputs. This flexibility in graphical output makes the program very useful for a range of end users, from technical analysis through to non-technical viewing of the predicted subsided surface.

The SDPS influence function program was developed in the US, and has been successfully used in a number of projects in the Eastern US coalfields since the late 1980's. Over the past few years, the combination of geotechnical analysis to predict subsidence, plus the use of SDPS for visualisation of the deformed surface has been used successfully on a number of Australian coal projects. The method has great potential to help meet the increasing demands that are currently being placed on subsidence prediction.

REFERENCES

- Waddington AA and Kay DR 1998. Development of Incremental Profile Method of Prediction of Subsidence and its Application in the Newcastle Coalfield. Buildings and Structures Subject to Ground Movement, Mine Subsidence Technological Society, 4th Triennial Conference, Newcastle, July 1998.
- Waddington AA and Kay DR 2001. Comparisons of Predicted and Observed Mine Subsidence Profiles. Coal Mine Subsidence 2001 Current Practice and Issues. Mine Subsidence Technological Society, 5th Triennial Conference Proceedings, Maitland – August 2001
- Karmis M, Agioutantis,Z and Jarosz, A 1990 Recent developments in the application of the influence function method for ground movement predictions in the US. Mining Science and Technology, 10, 233-245.
- Holla L 1985 Mining Subsidence in New South Wales, 1.Surface Subsidence Prediction in the Southern Coalfield, NSW. Department of Mineral Resources, Sydney
- Holla L 1988 Effects of Underground Mining on Domestic Structures – Predictions versus Performance. Fifth Australia-New Zealand Conference on Geomechanics, Sydney 22-23 August.
- Poulos HG and Davis EH 1974 Elastic solutions for soil and rock mechanics. New York: Wiley.
- Das, M. N. 1986. Influence of width/height ratio on the post failure behaviour of coal. Int J of Mining and Geological Engineering, 4, 79-87.