

## **A Method of Determining Longwall Abutment Load Distributions for Roadway and Pillar Design**

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This paper describes a method to determine abutment loads on longwall chain pillars and adjacent roadways. The method is based on: observation of subsidence behaviour, field measurements of abutment load distributions, and considerations of total overburden load about one or more longwall panels.

Surface subsidence data is used to deduce how far the overburden strata can transfer overburden weight and the total abutment load required to be distributed for any particular depth and longwall geometry. To be of practical use in roadway and pillar design, the shape of the abutment load distribution is also required as a function of distance from the goaf edge. Direct field measurement using high quality, three dimensional stress monitoring instruments is considered to provide the most reliable method of determining the magnitude and shape of the abutment load distribution at various stages of longwall mining.

The abutment load distribution determined at any one site by field measurement can be scaled horizontally to account for changes in overburden depth and vertically to account for changes in total abutment load. Thus, within the limitations of extrapolating data from one site to another, the abutment load distribution can be estimated for different depths and longwall geometries. Pillar loading and the vertical stress acting on adjacent roadways can then be determined from the measured load distributions, or scaled versions thereof, for any particular stage of mining, longwall geometry or depth of overburden.

### **INTRODUCTION**

This paper describes a method that has been successfully used to determine the vertical loading on longwall chain pillars and adjacent roadways. Vertical loading is useful as a general indication of roadway and rib performance, as well as input for more detailed numerical modelling studies of roadway performance at various stages of mining. The approach described is based on observation of subsidence behaviour, field measurements of abutment load distributions and considerations of total overburden load about one or more longwall panels.

Field measurement allows this method to be as site specific as circumstances allow. However, the strength of the approach is that, when access is not possible, loading conditions can be estimated from measurements elsewhere and applied to new sites through consideration of subsidence observations, overburden depth and general overburden behaviour. The estimated distribution can subsequently be confirmed when mining commences.

The general concept of using subsidence information to estimate abutment loading has been recognised for some time (Wilson 1972). The potential to refine this relationship even further has now become available through recent detailed measurements of

surface subsidence and of sub-surface overburden behaviour.

Stress monitoring instrumentation has also improved in recent years to overcome some of the limitations of earlier systems. Now it is possible to measure changes in the full three dimensional stressfield with a high degree of confidence. Best results are obtained by making the measurements in the stronger roof strata typically found immediately above the coal seam. Equilibrium considerations require that the vertical stress in the immediate roof is equal to that in the pillar, but in the stronger strata above a coal pillar, instruments can survive at vertical loads beyond those at which boreholes in coal become overloaded. When borehole breakout occurs in boreholes that become overloaded, the results of uniaxial stress monitoring systems required to be located within the pillar may be compromised. For example, such instruments typically do not register increased vertical load beyond the load at which breakout occurs. With improved instrumentation systems in stronger strata it is possible to follow the loading to higher stress levels. Furthermore, confirmation through independent checks on the correct function and integrity of the instruments at any stage of the monitoring boost confidence in the quality of the results. The recent elimination of time related creep that has been an issue with some types of instrument has also boosted confidence in the results

obtained.

The full benefit of improved prediction of vertical loading is realised through numerical modelling. Numerical modelling not only provides a method to predict roadway and pillar performance for various scenarios before mining commences, but also provides a framework in which to interpret observations made during actual mining.

## BACKGROUND

The principal source of vertical load in underground coal mining environments is the weight of overlying strata. Mining removes coal from one area causing the load it previously supported to be transferred to another area. The ability of the strata to transfer weight and the distance that weight can be transferred are characteristics of the overburden strata. These characteristics are of interest to understanding the vertical stresses that act on chain pillars and gateroad developments.

In typical Australian coal mining environments, the coal seams are flat and more or less horizontal so the average pre-mining vertical load can be estimated with reasonable confidence from the weight of overburden strata. For each 40m of overburden depth, the average vertical stress increases by approximately 1MPa. Although geological structures such as faults and dykes, and rapid variations in surface topography are recognised to locally modify this pre-existing vertical stress environment, equilibrium requires that, overall, the average is maintained.

On development, and in other non-caving geometries, the tributary area method of load redistribution is an effective method of estimating pillar load. The method is well used and works by redistributing all the original weight onto the remaining pillars on a pro-rata areal basis.

With the onset of caving, pillar load estimation is complicated by the uncertainty as to how much load is carried by the fallen goaf. Through a process of deduction from observations of surface subsidence, it becomes possible to separate the weight carried on the abutments from the weight supported on the goaf, and that process is the beginning of a method of determining pillar loading about longwall goafs.

## IMPLICATIONS OF SUBSIDENCE MEASUREMENTS

Surface subsidence measurements provide a basis to separate the proportion of overburden load supported on the solid abutments around a total extraction mining area, from the load supported on the goaf. This section describes the deductive process that leads to a practical method of separating these two components.

In the centre of a longwall panel of supercritical width, the subsidence profile measured over a solid

goaf edge is of the form shown in Figure 1(a). Over the solid, far away from the panel edge, there is zero subsidence and the full weight of overburden strata is clearly supported on the unmined coal. Likewise, far away from the panel edge over the goaf, there is full subsidence (as implied by supercritical width) and all the weight of overburden strata in this area is now fully supported on the goaf. In between, there is a transition zone and the size of this zone provides a direct measure of the distance that the overburden strata can transfer load.

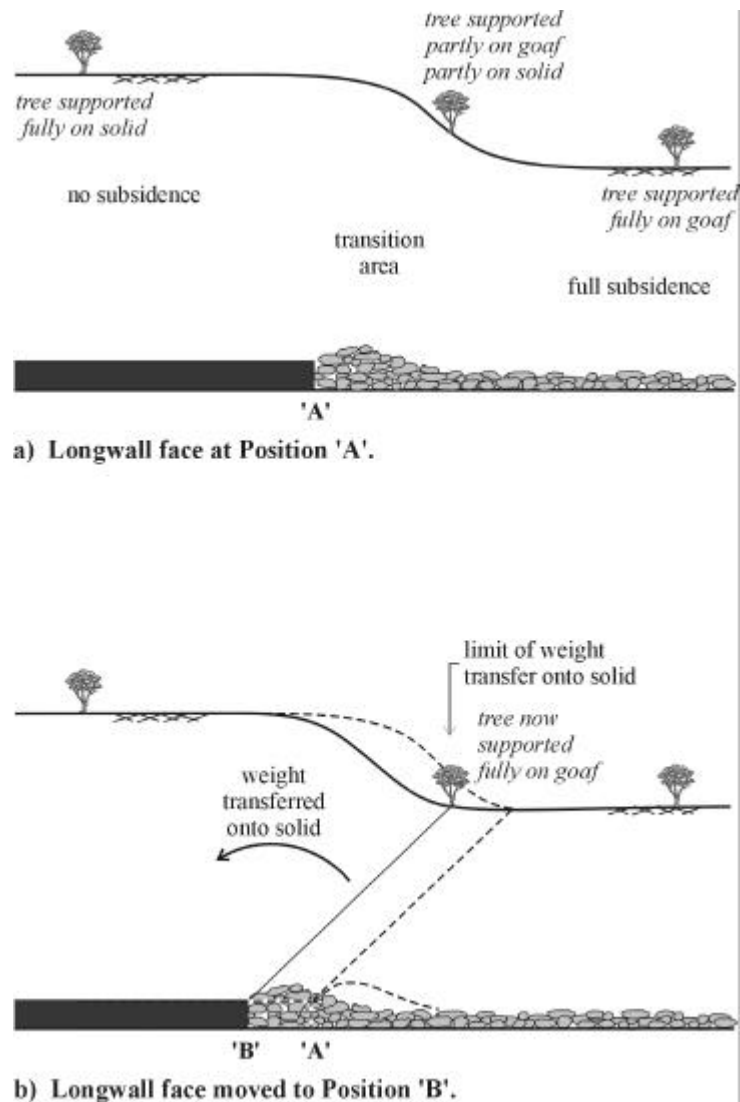
The relationship between load and subsidence can be illustrated by considering the surface at three locations indicated in Figure 1 by trees. The weight of the tree on the left is fully supported on the solid coal. There has been no downward movement, so there can be no transfer of weight. Similarly, the tree on the right is fully supported on the goaf. This tree has undergone the full amount of subsidence and further mining does not cause it to move downward any further, so by implication, its full weight must be supported on the goaf.

The middle tree is located in the transition zone. While the face is in position A, the tree is not fully subsided. When the face has moved to position B, the tree has fully subsided and its weight is therefore supported fully on the goaf. The key question is, what was holding it up when the face was in position A? The only thing that has changed is that the face has moved from position A to position B. Therefore the coal that was between positions A and B had to be contributing to the support of the middle tree. Since the tree was being supported, at least in part, by the coal on the face, the tree must have been contributing to the load on the face when the face was in position A.

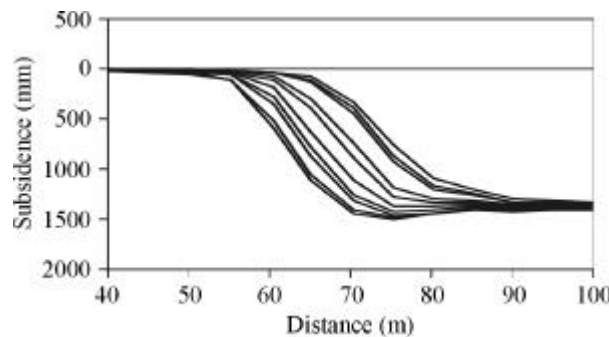
By the time the longwall face has moved to position B, as shown in Figure 1(b), the tree is fully supported on the goaf. Therefore the weight of the tree is not supported on the longwall face. The point at which load ceases to be transferred onto the longwall face is that point out from the goaf edge at which full subsidence is first reached.

Figure 2 shows an example of surface subsidence profiles measured at frequent intervals during longwall retreat. The profiles show that for each metre of longwall coal mined, there is a corresponding shift in the subsidence profile. The surface lies down incrementally behind the longwall face. The distance from the longwall face to the point of maximum subsidence, the "maximum load transfer distance", remains essentially constant. This distance is the maximum distance that this overburden strata can transfer weight at this overburden depth.

Figure 3 shows subsidence data for a range of overburden depths in essentially the same overburden strata. The horizontal distance is normalised with respect to distance from the goaf edge and subsidence is normalised with respect to seam thickness mined.



**Figure 1** Implications of the subsidence profile behind a retreating longwall face, of supercritical width, for determining the maximum lateral distance that overburden strata can transfer weight.



**Figure 2** Close spaced subsidence monitoring, showing surface subsidence profiles behind a retreating longwall face and the constant "maximum load transfer distance".

The distance to the point of maximum subsidence is more or less constant and falls within the range 0.5-0.7 times depth, even though the overburden range captured in this data set ranges from 25m to 230m.

Figure 3(a) shows subsidence data from over the longwall face. Figure 3(b) shows data from over solid edges on the sides of the panel. The range of distances that the overburden strata can transfer load from the goaf to the solid is essentially the same in both cases. This result suggests that the distance that horizontal load is transferred is not a characteristic of the caving process, which would be different behind the longwall face compared to off the sides of the panel, but rather a characteristic of the overburden strata itself.

When subsidence results from different overburden strata are plotted in the same way as Figure 3, it is found in most cases that the variation from one overburden strata type to another is surprisingly small. Some strata types are able to bridge more effectively, but once full subsidence is generated, the profiles seem to be generally similar.

A key aspect of the subsidence profiles shown in Figure 3 is that the distance from the goaf edge to the point at which maximum subsidence is first reached is a linear function of overburden depth (as implied by normalisation with respect to depth). For any overburden depth, the distance to full subsidence divided by overburden depth remains a constant in the range 0.5-0.7 times depth.

Given this linear relationship and the inference that the point at which maximum subsidence is first observed is the maximum distance that the overburden can transfer load, the load distribution through the overburden strata is constrained to be a triangular distribution as illustrated in Figure 4. The volume of material above the line 'AB' represents material that is supported on the solid abutment. The volume of material below the line represents material that is supported on the goaf.

This triangular load distribution should not be confused with the development of fractures within the overburden strata or caving behaviour. It is simply a way of dividing up the overburden load between the goaf and the solid abutment that is consistent with subsidence observations.

Sub-surface extensometer monitoring (Mills & O'Grady 1998) demonstrates that the weight distribution is located inside the zone of large downward movement identified as defining the edge of the caving zone as illustrated in Figure 5. This is consistent with the expectation that subsiding strata on the fringes of the caving zone are supported partly on the goaf and partly on the solid abutment.

The delineation of the various zones is illustrated by physical modelling of longwall caving behaviour (Hall 1982). In these physical models, the strata on the fringes of the caving zone deform as a series of beams. For beams of this type, the load is supported more or less equally at both ends. Figure 6 shows a composite diagram that illustrates the effect. The edge of the zone of large downward movement and the edge of the zone

where strata is clearly resting fully on the goaf are shown. The line that delineates the load carried on the goaf from the load carried on the abutment is within the zone defining the edge of large downward movement, but outside the fully subsided zone. This line should not be regarded as the fringe of the caving zone or as representative of any fracture surfaces, it is purely a division between load carried on the goaf and load carried on the solid abutment.

So far, only panels of supercritical width have been considered. However, sub-surface monitoring (Mills & O'Grady 1998) and computer modelling (Gale 2001) indicates that essentially similar processes occur within the overburden strata even when the surface has not fully subsided.

## TOTAL ABUTMENT LOAD

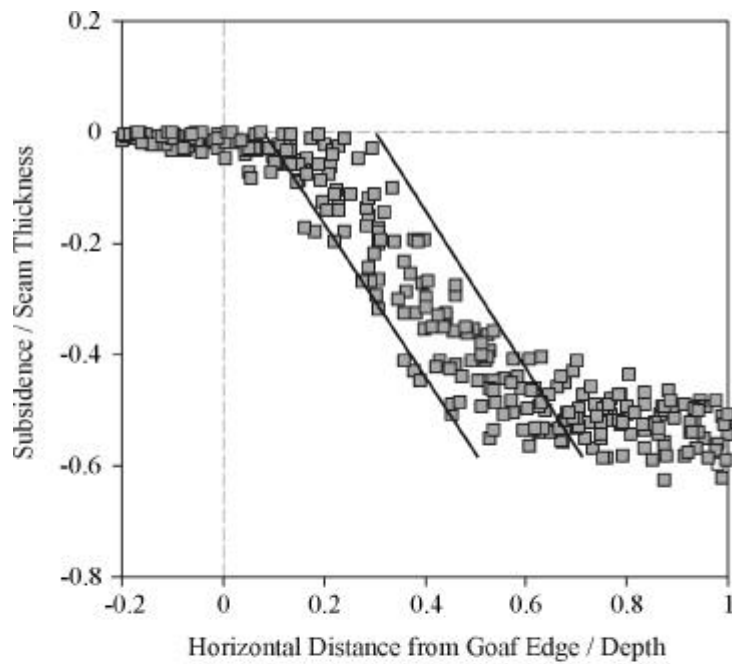
The implications of subsidence data discussed above provide a basis to estimate total load on chain pillars fully isolated in the goaf. Figure 7 the load distribution that is inferred for different overburden depths. At shallow depths, the weight is low and derived from the weight of overburden strata near the panel edges. At moderate depths, the abutment load on each side of the panel remains independent of the load supported on the other side of the panel. At great depths, the overburden load supported on the goaf is only a small proportion of the total overburden load. The bulk of the load is shared between the abutments on each side of the panel.

In some geological settings (and stress environments), strong units within the overburden strata are able to bridge more effectively and can change the way that load is redistributed. For instance in the Southern Lake Macquarie area, massive conglomerate strata are able to bridge across 100m wide longwall panels so that almost the full overburden load has to be supported on the chain pillars, more or less as defined by tributary area.

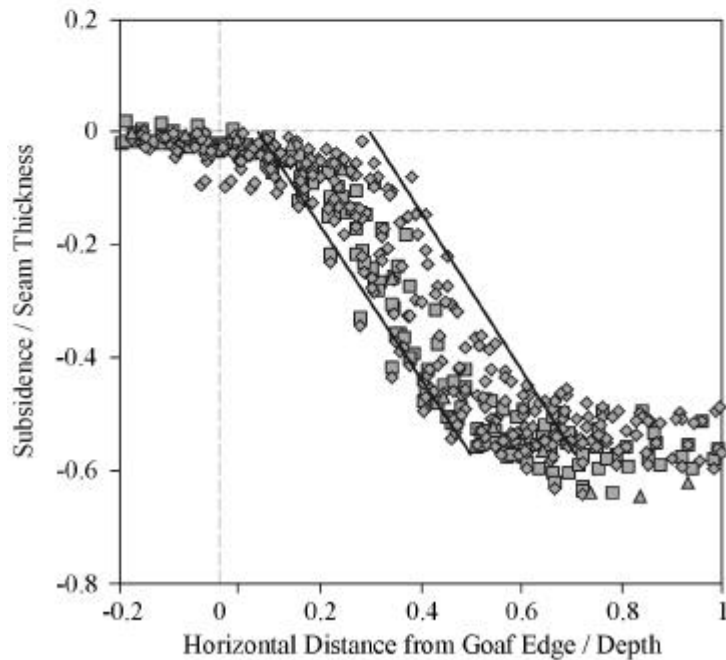
## ABUTMENT LOAD DISTRIBUTIONS

Subsidence behaviour provides a method to estimate the magnitude of the total abutment load as, described above. However for this information to be useful for estimating loads on pillars and roadways there are two further issues that need to be addressed. The first is the three dimensional distribution around the corners of the longwall panel and under full side abutment loading, and the second is the shape of the load distribution as a function of distance from the goaf edge.

The three dimensional distribution around the corners of the longwall panel can be addressed by considering, in three dimensions, the overburden weight transfer from over the goaf shown in Figure 4.

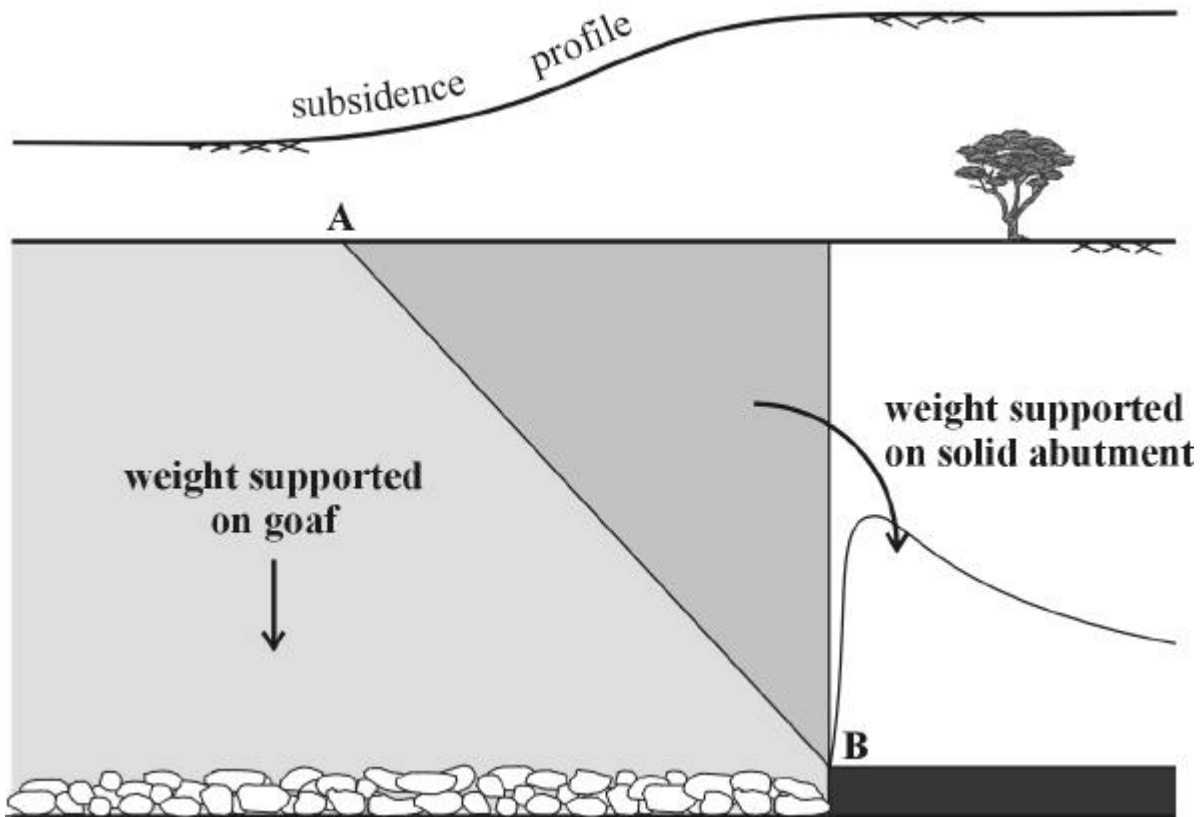


a) Subsidence measurements over longwall face at one mine site for a range of overburden depths up to 240m.



b) Subsidence measured over panel sides at same mine site for a range of overburden depths up to 240m.

**Figure 3** Subsidence measurements from a single mine site with essentially constant overburden geology, but variable overburden depth for: a) longitudinal profiles behind the longwall face, and b) cross-panel profiles over the sides of longwall panels.



**Figure 4** Results of extensometer monitoring at Clarence Colliery showing the edge of the zone of large downward movement and the extent of load transfer indicated by subsidence monitoring.

Subsidence data shown in Figure 3 indicates that the triangular load distribution inferred to exist ahead of the face is also valid over the sides of the panel. In the corners of the panel, the overburden load can be distributed to the face and to the panel sides. The magnitude of the abutment load in these corner areas is therefore less than the full side abutment loading where the entire load is distributed onto the chain pillar.

Figure 8 shows how the triangular load distributions ahead of, and to the side of, the panel interact to form a tent shaped division of overburden load. The load inside the tent shaped surface is supported on the goaf.

The load above the tent shaped surface has to be supported on the solid abutments and chain pillars.

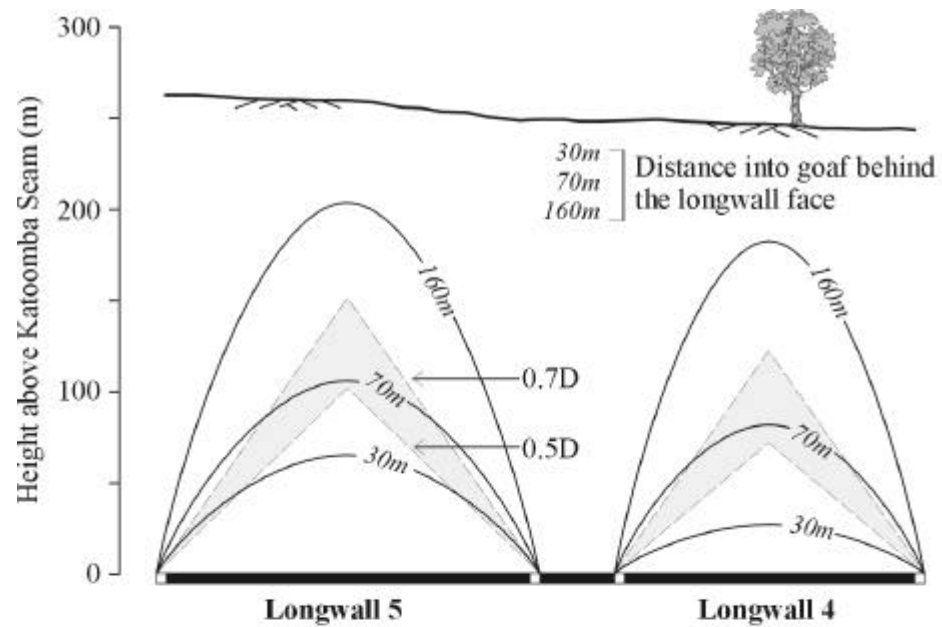
The actual magnitude of the loading in the panel corners and the distribution of the load away from the goaf edge is determined directly and most effectively by; field monitoring of stress changes during longwall retreat, or direct field measurement in the case of an existing goaf. The geometry of longwall panels and the relatively rapid retreat rate of most longwall operations make it relatively straightforward to monitor the abutment loading using only a small number of instruments.

There are two basic monitoring strategies that have been found to be effective. These are illustrated in Figure 9. Both involve arrays of three dimensional stress monitoring instruments installed well ahead of the longwall face in areas where the pre-existing three

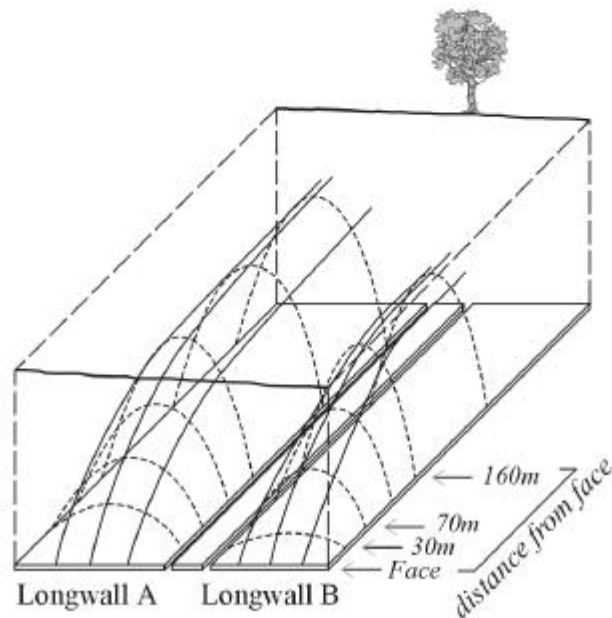
dimensional stressfield has been measured (or is adequately known).

The first strategy involves installing instruments in a linear array across the chain pillar and out above the block of the next longwall panel as shown in Figure 9(a). These instruments are monitored as the longwall retreats past the site. The position of the instrument array changes relative to the goaf as the longwall panel retreats. By plotting the measured stresses relative to the goaf (as if the longwall was actually stationary and the instruments were moving), the array of instruments effectively sweeps down the edge of the panel determining the stress distribution at each stage of mining as it does so. The completeness of the distribution of three dimensional stress changes at each stage of mining is simply a function of how often the instruments are read during retreat and their lateral distribution from the goaf edge.

The second strategy is similar, but instead of deploying the stress change instruments to the side of the longwall face, the instruments are installed in the block ahead of the approaching longwall face. To reduce the drilling distances involved the instruments are located near the outbye end of the panel. Two groups are best, one near the centre of the block and a second near the maingate corner. This arrangement is shown in Figure 9(b).



a) Cross section through Longwalls 4 and 5 at Clarence Colliery showing zones of large downward movement and load division for overhang distances of 0.5 and 0.7D (Mills and O'Grady, 1998).



b) Schematic isometric of completed longwalls showing zones of large downward movement over each panel.

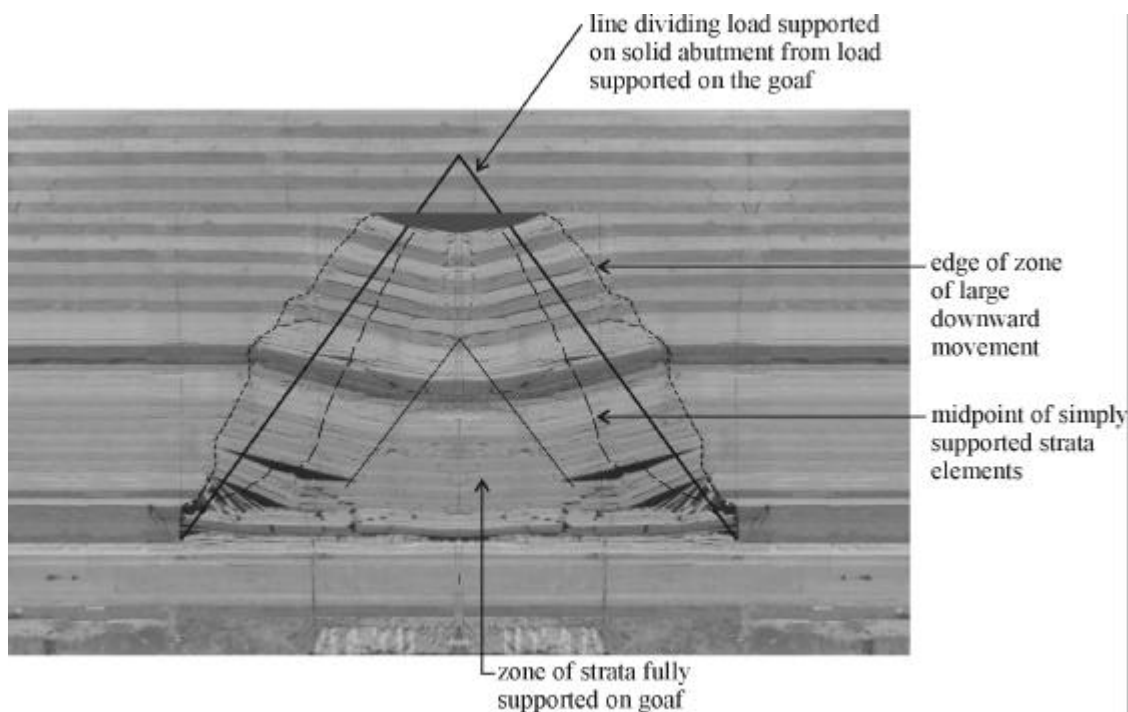
**Figure 5** Results of extensometer monitoring at Clarence Colliery showing the edge of the zone of large downward movement and the extent of load transfer indicated by subsidence monitoring.

The instruments are again monitored during longwall retreat. With this approach, each group of instruments is able to detect the full load distribution about the retreating longwall face providing a measurement of the load distribution curve that is free from the local effects of the chain pillars, roadways and cut-throughs.

The first strategy is more useful for directly measuring the effects of the side abutment load on the chain pillars and adjacent roadway. However, it is typically more difficult to place the instruments sufficiently far away from the goaf edge to get a full measure of the extent of the load distribution. The second strategy provides a better indication of the full extent and form of the load distribution free from the influence of roadways and pillar concentration effects but is most suited to panels of supercritical width. A combination of both strategies provides the most comprehensive measure of load distribution about a longwall panel.

long way to drill, but also because it is difficult to differentiate between random measurement variability and the small changes in load that occur at large distance from the goaf edge.

Figure 10 shows some examples of the load distribution measured for full side abutment loading at overburden depths from 100m to 250m. While all of similar form, peaking near the goaf edge and exponentially decreasing with distance from the goaf edge, there is a significant range in the magnitudes of the peak loads and the area under each curve. Mills & Doyle (2000) present the results of monitoring load distribution ahead of the longwall face and its application to estimating load on other chain pillar geometries and at great depth.



**Figure 6** Results of extensometer monitoring at Clarence Colliery showing the edge of the zone of large downward movement and the extent of load transfer indicated by subsidence monitoring.

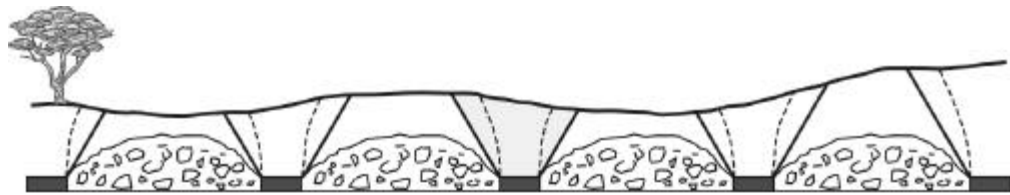
Of course direct measurement of the in situ stresses at various distances from the edge of an existing goaf is also possible. This strategy typically provides high quality data of the side abutment distribution close to the goaf edge, but there are several significant disadvantages:

- measurement costs are typically higher,
- three dimensional effects about the corner of the panel cannot be measured with the same instruments that measure the side abutment loading, and
- it is also difficult to determine the lateral extent of the load distribution, not only because it can be a

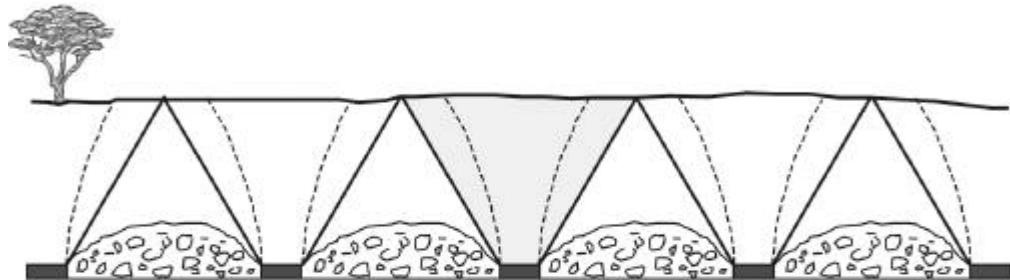
#### **PILLAR LOADS AT VARIOUS STAGES OF LONGWALL RETREAT**

Once the loading distribution has been determined for any particular site and overburden conditions, it is helpful to be able to extrapolate this distribution to other depths and longwall geometries. This can be achieved, at least as an approximation, by scaling the measured distributions to account for variation in the overburden depth, load magnitude and stage of mining, thus allowing the one set of field measurement to be applied to other areas of the mine.

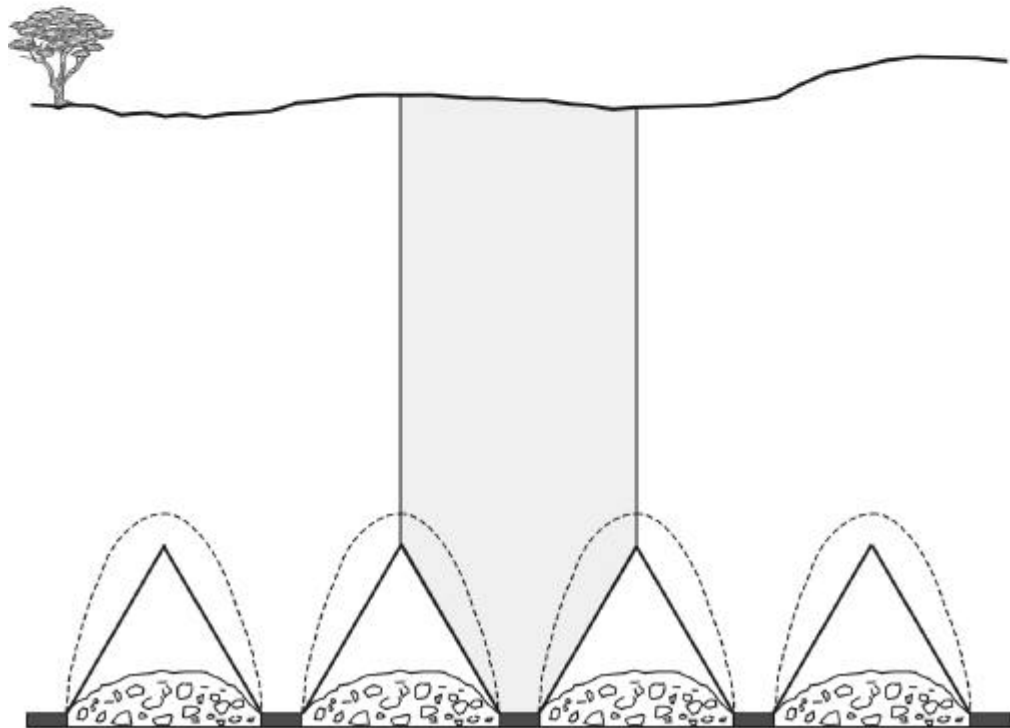




**a) Shallow longwalls.**



**b) Critical width longwalls.**



**c) Deep longwalls.**

**Figure 7** Total pillar loading determined from subsidence information for pillar fully isolated in the goaf at various overburden depths.

As illustrated in Figure 11, the load distribution can be scaled horizontally to take account of changes in overburden depth, if the lateral extent of the abutment load is assumed to be linearly proportional to overburden depth. Field measurements consistently show that the vertical abutment loading first becomes perceptible to stress change monitoring instruments when the goaf edge approaches within a distance from the instruments of half the overburden depth. This observation suggests that the assumption of proportionality with depth is reasonable.

The area under the abutment stress curve is equal to the total overburden load. As the total abutment load changes with changes to longwall geometry or increasing overburden depth, the vertical stress values can be scaled so that the total load equals the total abutment load calculated from consideration of subsidence data.

For most practical purposes, it is useful to know the vertical loads on pillars and roadways at five stages of longwall mining: on development, at the maingate corner of the longwall panel, under full side abutment loading, at the tailgate corner of the longwall face, and for long term subsidence impacts, when the chain pillars are fully isolated in the goaf.

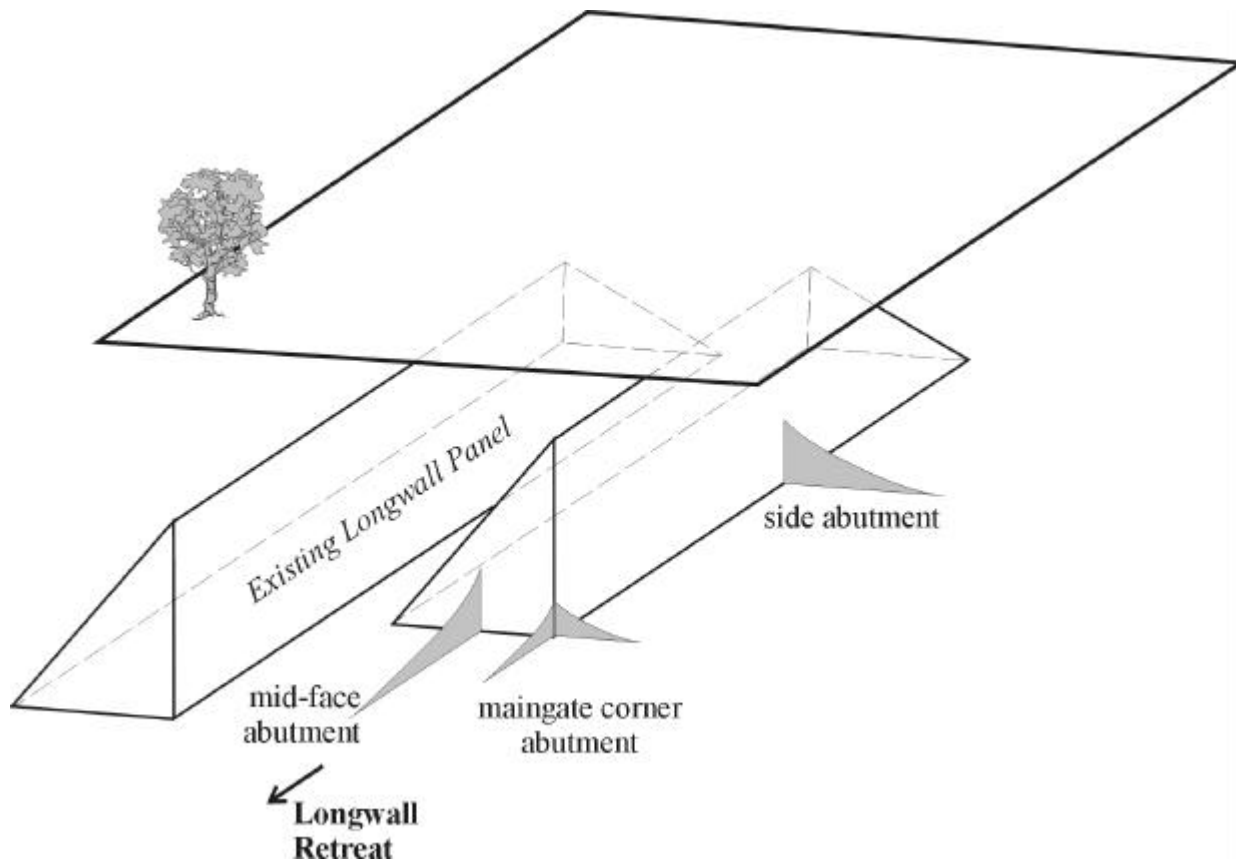
By measuring the load distribution at the corner of the longwall panel and under full side abutment loading, it becomes possible to estimate the load at all these stages of mining.

The load on development is estimated from tributary area considerations. At the maingate corner and under side abutment loading, the abutment load distributions are available directly from field measurements or from appropriate scaling of measured distributions.

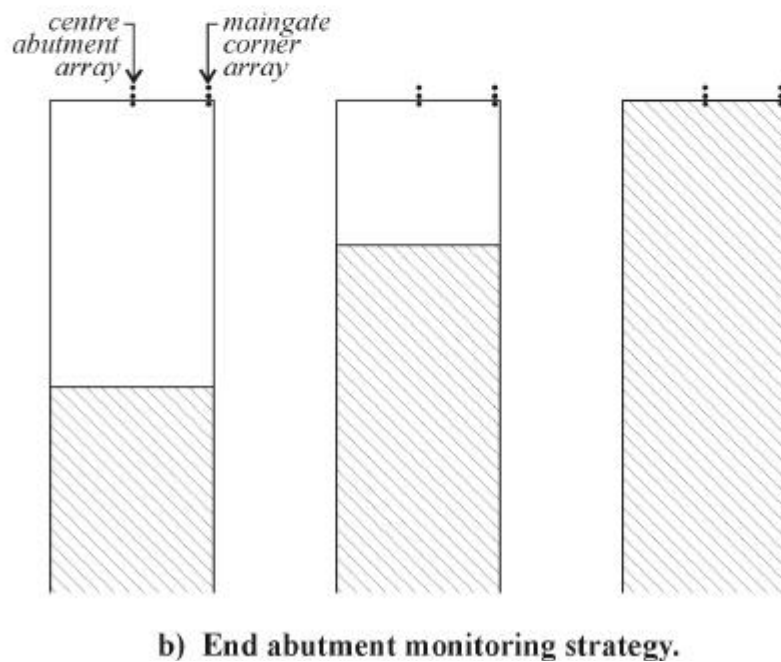
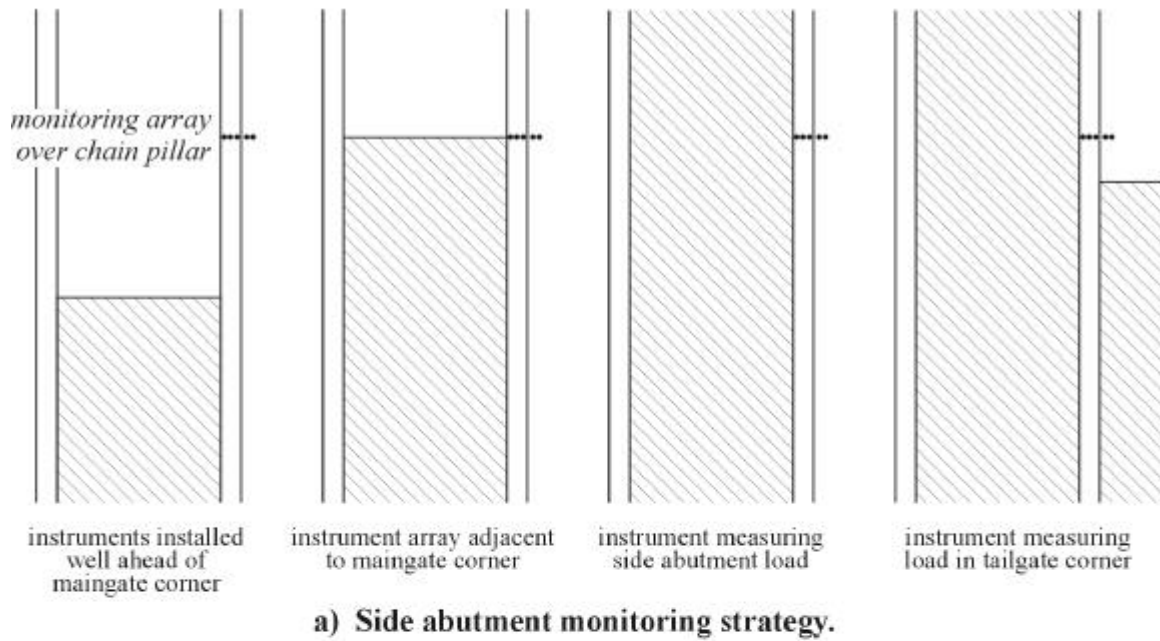
The maximum vertical and horizontal stress increases at the maingate corner of the panel are typically of interest for design of reinforcement suitable to maintain roadway stability at the maingate/longwall face corner. These values are available directly from field measurement and are estimated for other depths and longwall geometries by appropriate scaling for depth and abutment load.

Under side abutment loading conditions, the principal design issues relate to the stress conditions experienced by the travel road inbye of the face (future tailgate roadway) and the stability of the chain pillar. The vertical stress at any given distance from the goaf edge, in this case the width of the chain pillar, is determined directly from the measured stress distribution or from appropriate scaling of the measured distribution for different geometries or overburden depth.

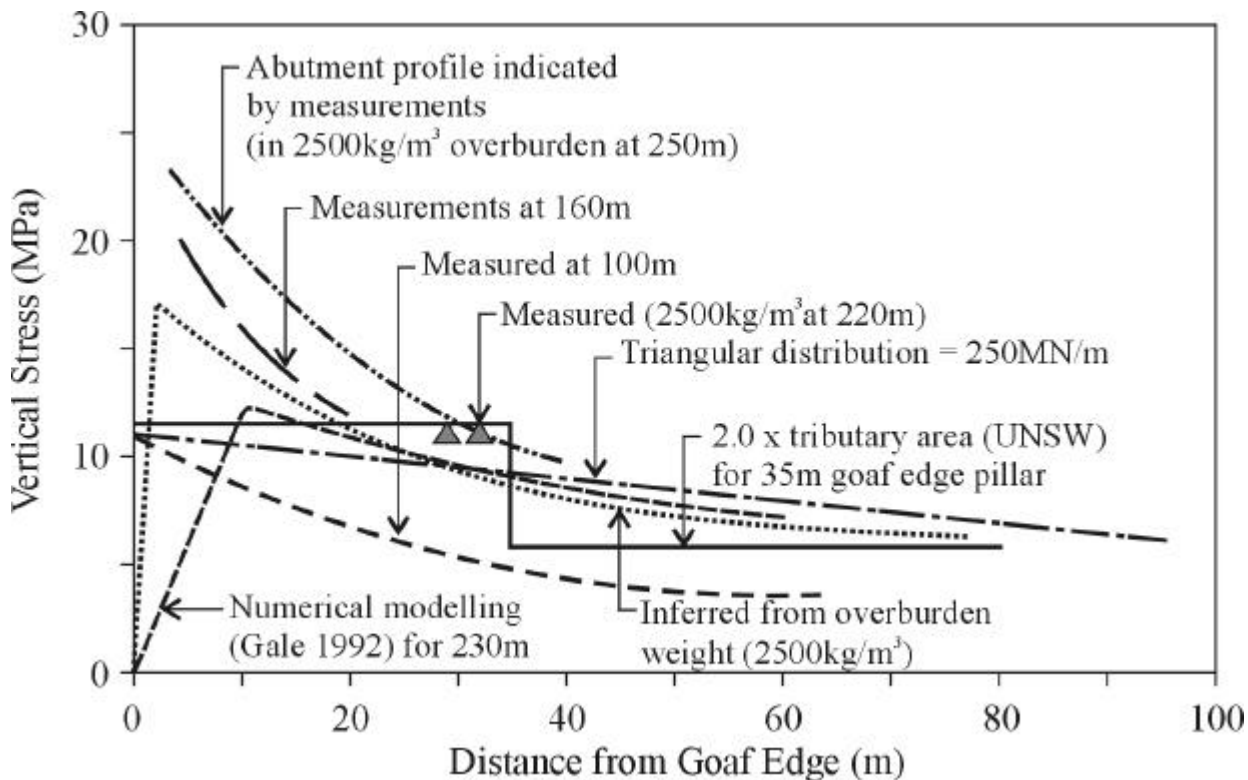
The vertical load on the chain pillar under side abutment loading is estimated by integrating the area under the stress distribution curve above the chain pillar. The load determined by integration over the pillar width is then adjusted to account for the tributary area effect of the cut-throughs to give the total pillar loading.



**Figure 8** Distribution of overburden weight about longwall panels in three dimensions.



**Figure 9** Illustration of strategies to monitor longwall abutment loads using stresscells capable of measuring three dimensional stress changes.



**Figure 10** Examples of full side abutment load distributions measured at overburden depth ranging from 100m to 250m.

This load can then be compared directly with the nominal strength of the chain pillar to assess pillar stability.

In the tailgate corner of the longwall face, the vertical loads experienced by the roadway reach a maximum in terms of roadway support requirements. The magnitude of the pillar stresses, and assuming a uniform distribution, the stresses on the tailgate roadway as well, are estimated by adding the full abutment load about the corner of a longwall panel, to that proportion of the side abutment load supported by the chain pillar. The rest of the side abutment load is assumed to be supported on the solid coal in the block ahead of the longwall face. The average pillar load is calculated as the sum of these two components added to the original vertical stress. The average vertical stress is then concentrated using tributary area theory to take account of the cut-through spacing. The approach assumes that the average load at the tailgate corner is the sum of the various components divided by the area available to support it.

When the chain pillar is completely isolated in the goaf, the total load is no longer important for the assessment of roadway conditions, but the stability or otherwise of the pillar can be important for controlling surface subsidence impacts. The load acting on a chain pillar isolated in the goaf is calculated by adding the original vertical stress to twice the magnitude of side abutment loading and concentrating this total using tributary area theory to take account of the cut-through spacing. Pillar stability is estimated by comparing this

load to the nominal pillar strength.

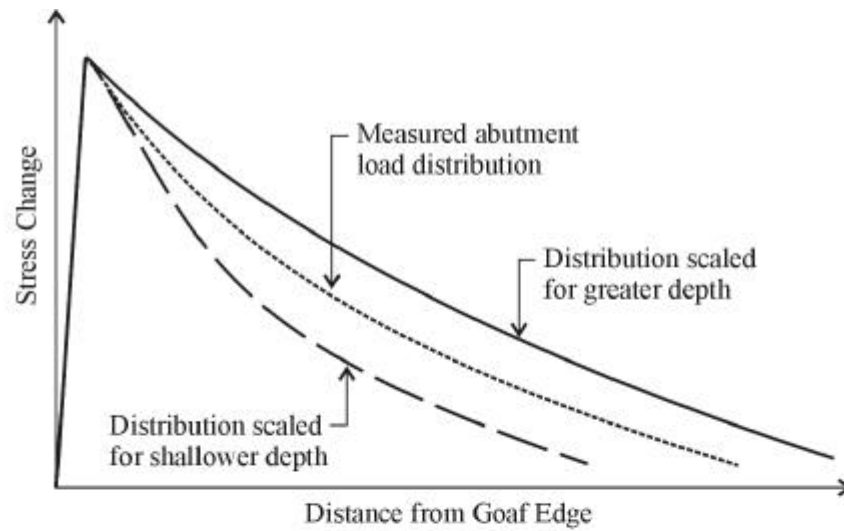
Although the pillar loading can be estimated with reasonable confidence, there is another issue that impacts on the stability assessment of pillars isolated in the goaf. The nominal pillar strength can be difficult to determine with confidence because of the confining effects of the adjacent goafs. The confinement provided by the goaf material is likely to significantly increase the actual strength of the pillars compared to the strength calculated if the pillars were free to deform into an adjacent roadway. At the load levels typically experienced by a chain pillar isolated in the goaf, it is difficult to keep stress monitoring instrumentation alive.

Confirmation of the behaviour of chain pillars isolated in the goaf is likely to require further work.

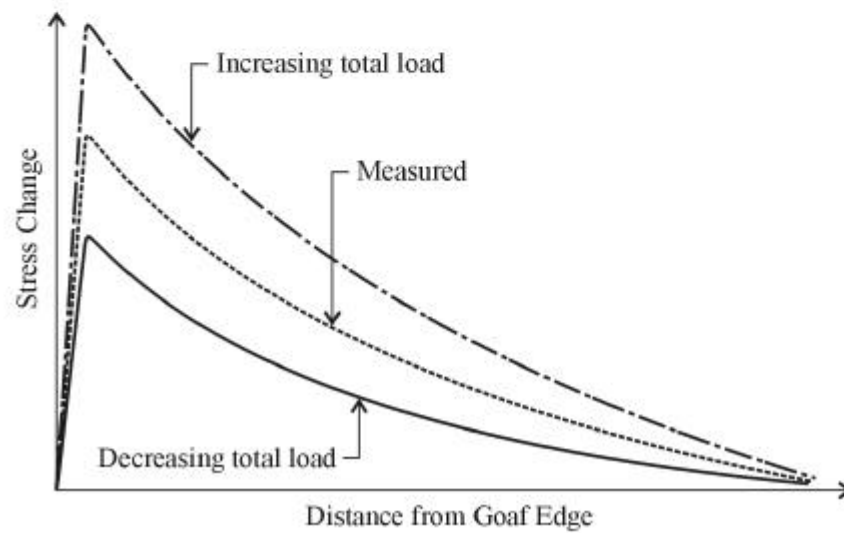
## CONCLUSIONS

A method to determine abutment loads on pillars and roadways has been described. The approach involves using surface subsidence data to establish how far the overburden strata is able to transfer overburden weight. Using this information and applying some deductive reasoning, the total magnitude of abutment load can be estimated for any particular overburden depth and overburden strata conditions.

In order for the abutment load to be used for practical benefit in roadway and pillar design, it is necessary to establish how the abutment load is distributed as a function of distance from the goaf edge.



**a) Horizontal scaling of abutment load distribution to account for changes in overburden depth.**



**b) Vertical scaling of vertical stress to account for changes in stress magnitude.**

**Figure 11** Illustration of the method of scaling abutment load distributions.

Direct field measurement using high quality, three dimensional stress monitoring instruments is considered to provide a sound method of determining the abutment distribution.

The abutment load distribution determined at any one site can be scaled horizontally to account for changes in overburden depth and vertically to account for changes in total abutment load. Thus, within the limitations of extrapolating data from one site to another, the abutment load distribution can be estimated for different depths and longwall geometries.

Pillar loading and vertical stress acting on adjacent roadways are determined by superimposing the measured load distributions, or scaled versions thereof, for each stage of mining.

The method described in this paper is considered to provide a valid method for assessing pillar loading and vertical stress levels at all the various stages of longwall mining.

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