Introduction to Longwall Mining and Subsidence

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CHAPTER 1. INTRODUCTION TO LONGWALL MINING AND SUBSIDENCE

1.1.   The Longwall Mining Process

Fig. 1.1, below, shows a cutaway diagram of a typical longwall mine. The main features of the mine are indicated in the key below the diagram. The longwall face is indicated by the number 8 in the diagram.
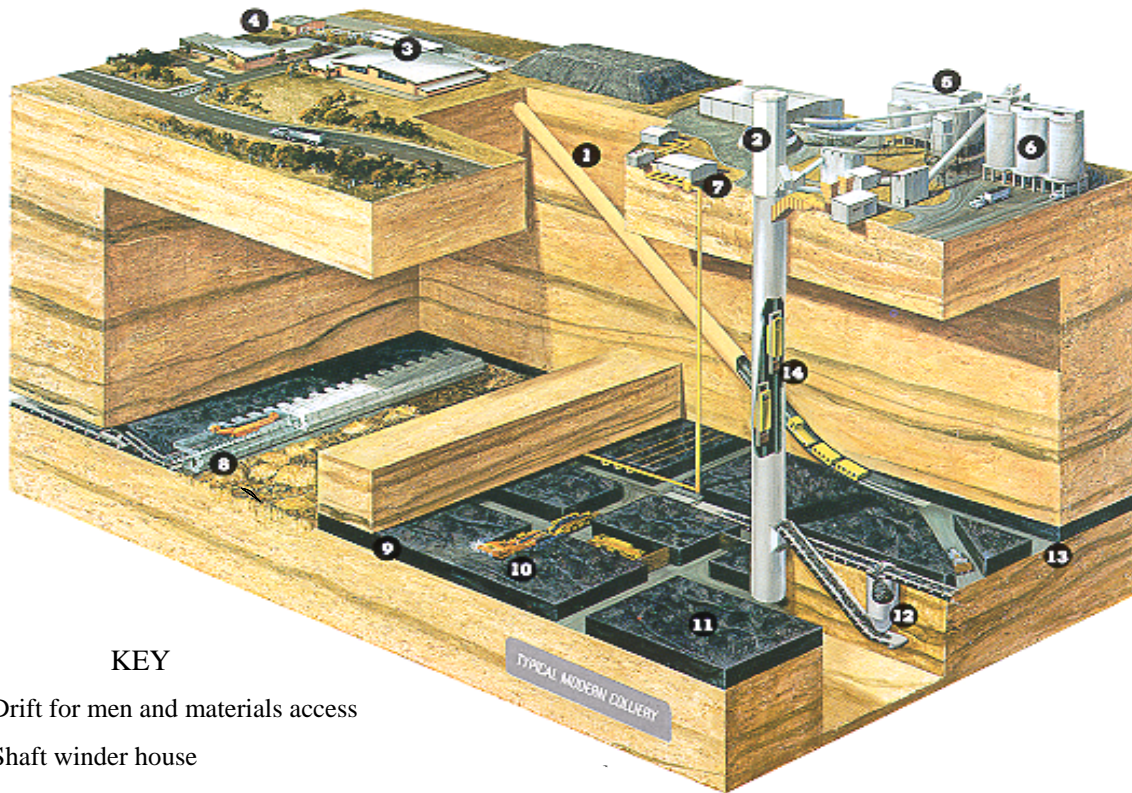

KEY

1. Drift for men and materials access

2. Shaft winder house

3. Bathhouse and administration building

4. Workshops

5. Coal preparation plant

6. Coal storage bins

7. Gas drainage system

8. Longwall face equipment

9. Coal seam

10. Continuous miner unit

11. Coal pillar

12. Underground coal bin

13. Main roadway or heading

14. Coal skips to carry coal to the surface

Fig. 1.1   Cutaway View of a Typical Longwall Mine

In longwall mining, a panel of coal, typically around 150 to 300 metres wide, 1000 to 3500 metres long and 2 to 5 metres thick, is totally removed by longwall shearing machinery, which travels back and forth across the coalface. A typical section through a coal face is shown in Fig. 1.2 and a photograph of typical longwall face equipment is shown in Fig. 1.3. The shearer cuts a slice of coal from the coalface on each pass and a face conveyor, running along the full length of the coalface, carries this away to discharge onto a belt conveyor, which carries the coal out of the mine.
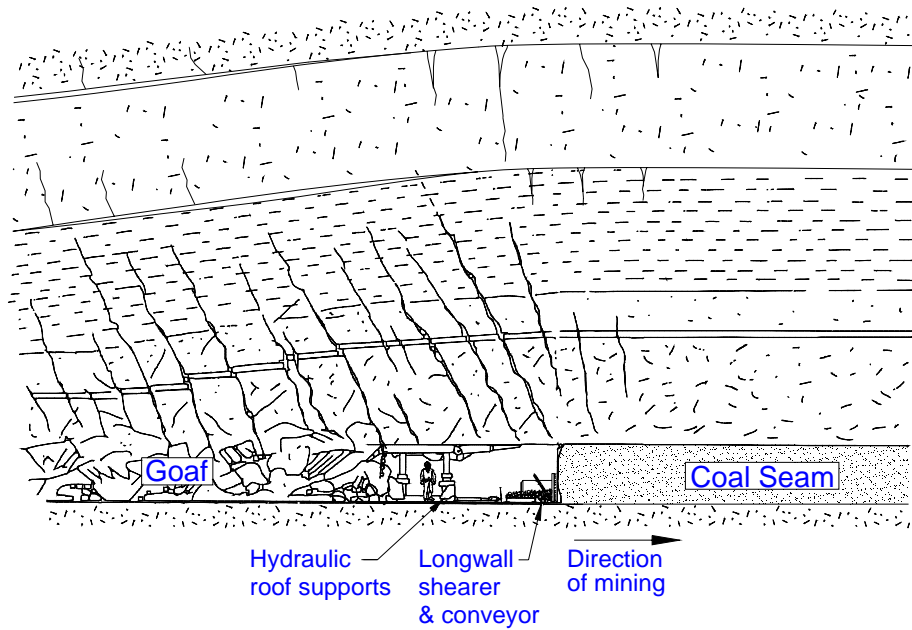
Fig. 1.2   Cross Section of a Typical Longwall Face

The area immediately in front of the coalface is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata and provide a working space for the shearing machinery and face conveyor. After each slice of coal is removed, the hydraulic roof supports, the face conveyor and the shearing machinery are moved forward. Fig. 1.3 shows the arrangement of machinery on a typical longwall face, with the hydraulic roof supports on the left hand side and the coal face on the right hand side of the picture. The drum in the background is the rotating cutting head of the coal shearer and the chain conveyor can be seen in the foreground.

Fig. 1.3   Typical Longwall Face Equipment
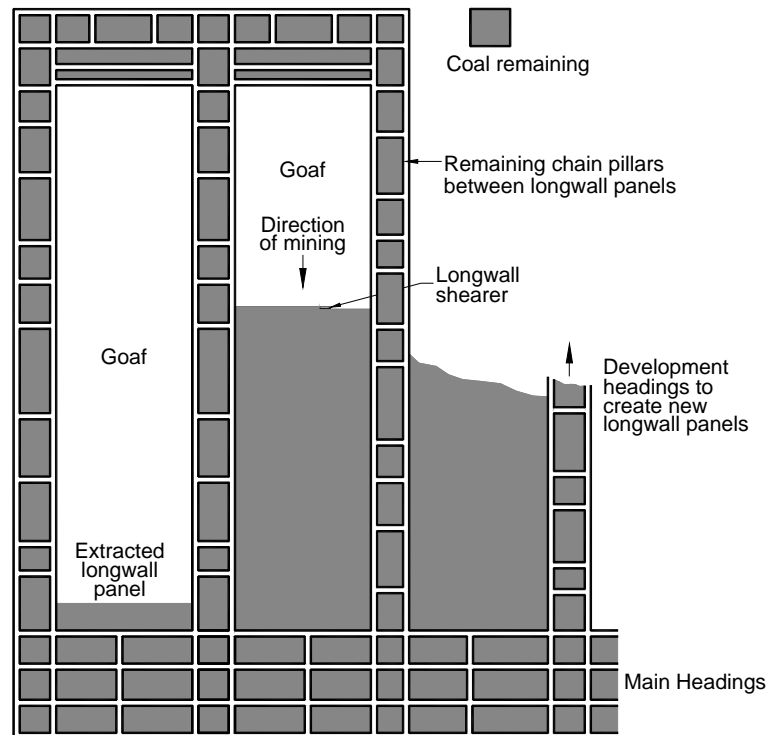
Fig. 1.4   Typical Plan View of a Series of Longwall Panels

Fig. 1.4 shows a typical layout of a group of longwalls. Before the extraction of a longwall panel commences, continuous mining equipment extracts coal to form roadways (known as headings) around the longwall panel. These roadways form the mine ventilation passages and provide access for people, machinery, electrical supply, communication systems, water pump out lines, compressed air lines and gas drainage lines. The roadways, which provide access from the mine entrance to the longwalls, are referred to as the main headings. Once the main headings have been established additional roadways, known as development headings, are driven on both sides of the longwall panel and are connected together across the end of the longwall.

The longwall face equipment is established at the end of the panel that is remote from the main headings and coal is extracted within the panel as the longwall equipment moves towards the main headings. This configuration is known as retreat mining. Typically, a longwall face retreats at a rate of 50 metres to 100 metres per week, depending on the seam thickness and mining conditions. The coal between the development headings and between the main headings is left in place as pillars to protect the roadways as mining proceeds. The pillars between the development headings are referred to as chain pillars.

When coal is extracted using this method, the roof immediately above the seam is allowed to collapse into the void that is left as the face retreats. This void is referred to as the goaf. Miners working along the coalface, operating the machinery, are shielded from the collapsing strata by the canopy of the hydraulic roof supports. As the roof collapses into the goaf behind the roof supports, the fracturing and settlement of the rocks progresses through the overlying strata and results in sagging and bending of the near surface rocks and subsidence of the ground above, as illustrated in Fig. 1.2.

If the width of an extracted panel of coal is small and the rocks above the seam are sufficiently strong, it is possible that the roof will not collapse and hence no appreciable subsidence will occur at the surface. However, to maximise the utilisation of coal resources and for other economic reasons, wide panels of coal are generally extracted and, in most cases, the roof is unable to support itself.

Longwall panel widths between 250 metres and 300 metres are becoming common as collieries strive towards more cost-efficient production and some collieries are now considering longwall widths of 400 metres or more.

1.2. The Development of Subsidence.

1.2.1. Subsidence Mechanisms

As the immediate roof strata, i.e. the rocks immediately above the seam, collapse into the goaf, the rocks above them lose support and sag to fill the void beneath them. The mechanism progresses towards the surface and the affected width increases so that at the surface, an area somewhat larger than the extracted panel of coal undergoes settlement. Fig. 1.5 shows a typical subsidence profile above an extracted longwall panel and it can be seen that the majority of the subsidence occurs over the centre of the longwall and tapers off around the perimeter of the longwall. The subsidence is typically less than the thickness of coal extracted underground.
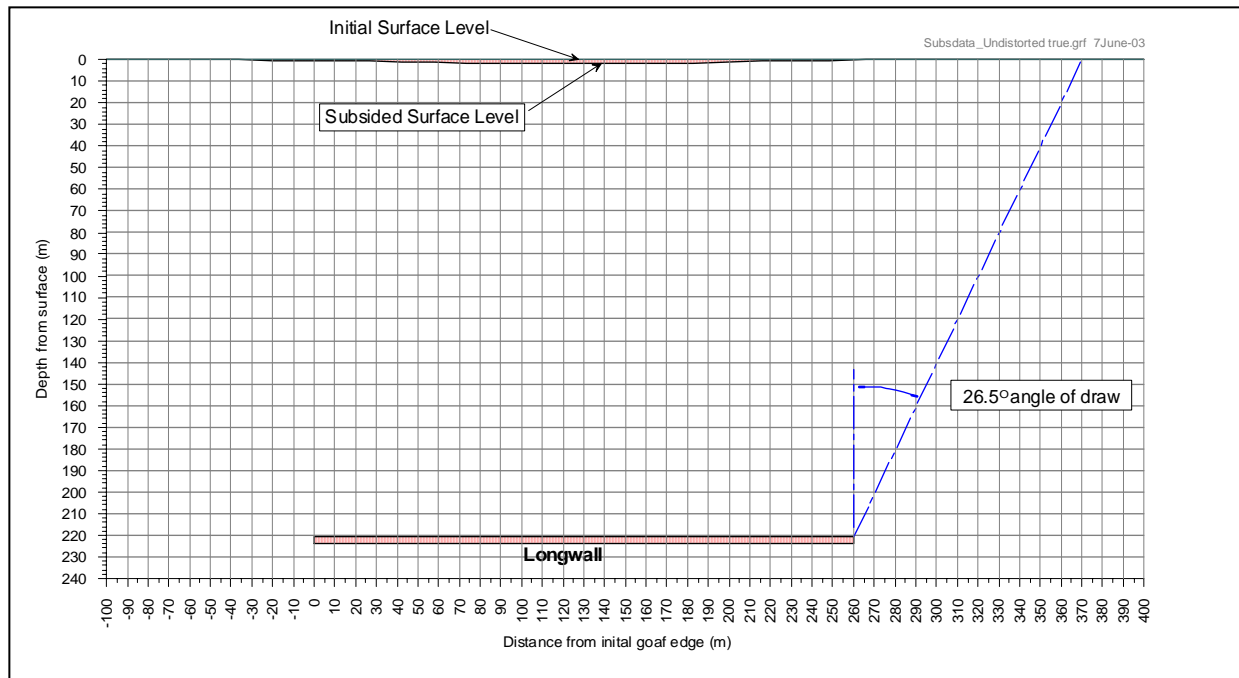
Fig. 1.5   Typical Subsidence Profile Drawn to a True Scale

The angle at which the subsidence spreads out towards the limit of subsidence, at the surface, is referred to as the angle of draw. The angle of draw depends upon the strength of the strata and the depth of cover to the coal seam and typically lies between 10 and 35 degrees from the vertical, depending on how the limit of subsidence is defined.

It is generally accepted that subsidence of less than 20 mm will have negligible effect on surface infrastructure and this is generally adopted as the cut-off point for determination of the angle of draw. In the Coalfields of NSW, if local data is not available, the cut-off-point is taken as a point on the surface defined by an angle of draw of 26.5 degrees from the edge of the extraction, i.e. a point on the surface at a distance of half the depth of cover from the goaf edge. Where local data exists and it can be shown that the angle is generally less than 26.5 degrees, then, the lower angle of draw can be used.

The subsidence of the surface is considerably less than the thickness of coal removed, due to the voids that are left within the collapsed strata. The extent of the settlement at the surface is therefore dependent upon the strength and nature of the rocks overlying the coal seam and is a direct function of their capacity to bridge over the voids.

When a panel has a width that is small, relative to the depth of the seam below the surface, the fractured rocks have a tendency to bridge over the goaf by arching between the solid abutments on each side of the panel, thus reducing the amount of subsidence.

As the panel width is increased, however, the overlying rocks are less able to arch over the goaf and a limiting panel width is reached where no support is available and maximum subsidence occurs. This limiting panel width is referred to as the critical width and is usually taken to be 1.4 times the depth of cover. It does, however, depend upon the nature of the strata.

Where several panels are mined in a series and chain pillars are left between the panels, the maximum subsidence does not occur unless each panel is, at least, of critical width. The chain pillars crush and distort as the coal is removed from both sides of them, but, usually, they do not totally collapse and, hence, the pillars provide a considerable amount of support to the strata above them.

Where large super-critical areas are extracted, the maximum possible subsidence is typically 55% to 65% of the extracted seam thickness, but, because chain pillars are normally left in place, and provide some support, this maximum possible subsidence is rarely reached.

Research has shown that the incremental subsidence of a second or subsequent panel in a series is greater than the subsidence of an individual isolated panel of identical geometry. Because the subsidence effects above a panel extend beyond its goaf edges, these effects can overlap those of neighbouring panels.

Where the width to depth ratios of the panels in a series are sub-critical, which is normally the case in the Southern Coalfield, the amount of subsidence in each panel is determined by the extent of these overlaps, which are further influenced by the widths of the chain pillars. In this situation, the first panel in a series will generally exhibit the least subsidence and the second and subsequent panels will exhibit greater subsidence due to disturbance of the strata caused by mining the preceding panels and consequential redistribution of stresses within the strata.

The subsidence at the surface does not occur suddenly but develops progressively as the coal is extracted within the area of influence of the extracted panel. In many cases, when the cover over the coal seam is deep, a point on the surface will be affected by the extraction of several adjacent panels.

When extraction of coal from a panel is commenced, there is no immediate surface subsidence, but as the coal within the panel is extracted and the resulting void increases in size, subsidence develops gradually above the goaf area. As mining continues, a point is reached within the panel where a maximum value of subsidence occurs and despite further mining beyond this point, within the panel, this level of subsidence is not increased.

As further adjacent panels are extracted, additional subsidence is experienced, above the previously mined panel or panels. However, a point is also reached where a maximum value of subsidence is observed over the series of panels irrespective of whether more panels are later extracted.

The subsidence effect at the surface occurs in the form of a wave, which moves across the ground at approximately the same speed as the longwall face retreats within the longwall panel. The extraction of each panel creates its own wave as the panels are mined in sequence.

The development of subsidence at any point on the surface of the ground can be seen to be a very complex mechanism and the cumulative effect of a number of separate movements.

1.2.2. Subsidence Parameters

Subsidence, tilt, horizontal displacement, curvature and strain are the subsidence parameters normally used to define the extent of the surface movements that will occur as mining proceeds and generally form the basis for the assessment of the impacts of subsidence on surface infrastructure. These parameters are illustrated in Fig. 1.6 which shows a typical subsidence profile drawn to an exaggerated vertical scale.
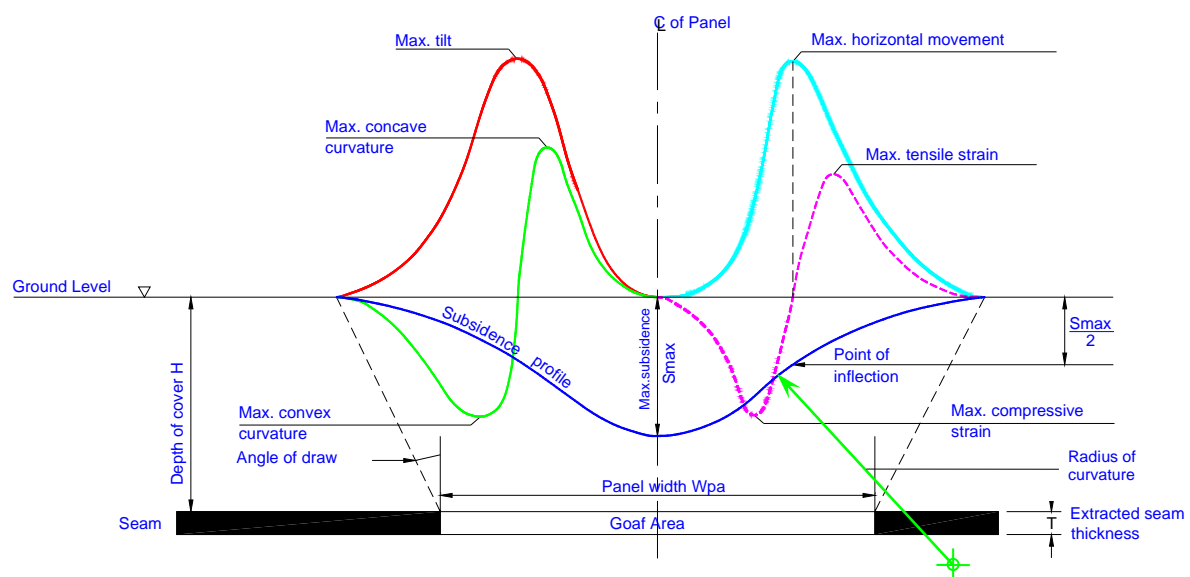
Subsidence

Subsidence usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements can in many cases be greater than the vertical subsidence, where the subsidence is small. The amplitude of subsidence is usually expressed in millimetres.

Tilt

Tilt is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. The sign of tilt is not important, but the convention usually adopted is for a positive tilt to indicate the ground increasing in subsidence in the direction of measurement.

The maximum tilt, or the steepest portion of the subsidence profile, occurs at the point of inflection in the subsidence trough, where the subsidence is roughly equal to one half of the maximum subsidence. Tilt is usually expressed in millimetres per metre.

Fig. 1.6   Subsidence Parameter Profiles above a Single Longwall Panel

Horizontal Displacement

The horizontal component of subsidence, or horizontal displacement, is greatest at the point of maximum tilt and declines to zero at the limit of subsidence and at the point of maximum subsidence. Horizontal displacement is usually expressed in millimetres.

Curvature

Curvature is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the radius of curvature with the units of 1/km, or km^{-1}, but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in kilometres.

Curvature is convex or 'hogging' over the goaf edges and concave or 'sagging' toward the bottom of the subsidence trough. The convention usually adopted is for convex curvature to be positive and concave curvature to be negative.

Strain

Strain is caused by bending and differential horizontal movements in the strata. Measured strain is determined from monitored survey data by calculating the horizontal change in length of a section of a subsidence profile and dividing this by the initial horizontal length of that section.

If the section has been extended, the ground is in tension and the change in length and the resulting strain are positive. If the section has been shortened, the ground is in compression and the change in length and the resulting strain are negative.

The unit of measurement adopted for strain is millimetres per metre. The maximum strains coincide with the maximum curvature and hence the maximum tensile strains occur towards the sides of the panel whilst the maximum compressive strains occur towards the bottom of the subsidence trough.

1.2.3. Subsidence Impacts at the Surface

The most significant impacts on surface infrastructure are experienced during the development of the subsidence trough, when maximum ground movements normally occur.

As the subsidence wave approaches a point on the surface, the ground starts to settle, is displaced horizontally towards the mined void and is subjected to tensile strains, which build from zero to a maximum over the length of convex or hogging curvature, as shown in Fig. 1.7.
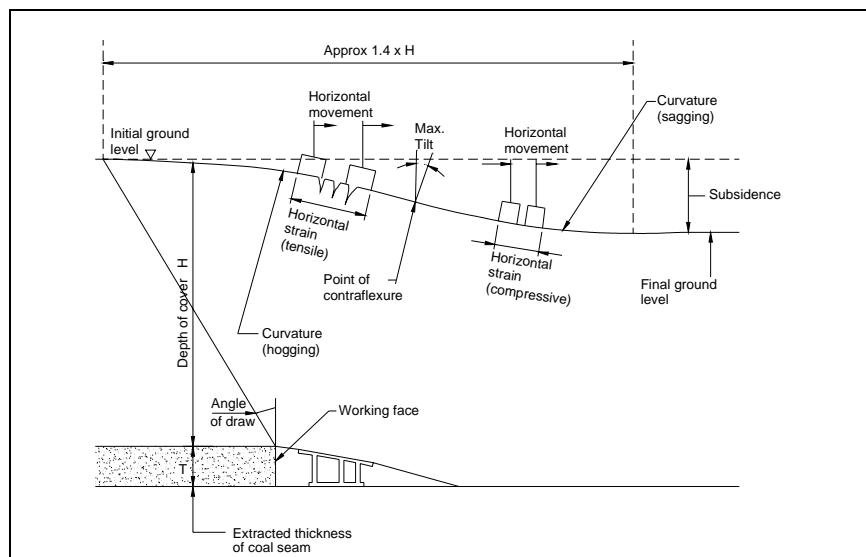
Fig. 1.7   Development of a Subsidence Trough (to an exaggerated vertical scale)

The position of maximum hogging curvature is the position of maximum tensile strain. When vertical subsidence is approximately half of the maximum subsidence, i.e., as the face passes under the surface point, the ground reaches its maximum horizontal displacement and the strain reduces to zero again.

As the longwall face moves further away from the surface point the settlement continues, horizontal displacement reduces and the ground is subjected to compressive strains, which build from zero to a maximum over the length of concave or sagging curvature and then decline to zero as maximum subsidence is reached. The position of maximum sagging curvature is the position of maximum compressive strain. When the subsidence is complete, the ground is commonly left with no horizontal displacement and little residual tilt or strain.

Between the tensile and compressive zones is the point of inflection, which is the point at which maximum tilt and maximum horizontal displacement occurs. For critical extraction conditions, it is also the point at which the subsidence is, approximately, equal to half the maximum subsidence.

As the longitudinal wave passes, the transverse subsidence profile gradually develops and is completed as maximum subsidence is reached. The transverse subsidence profiles over each side of the panel are similar in shape to the longitudinal subsidence profile and have the same distribution of tilts, curvatures and strains. Most of the points on the surface will thus be subjected to three-dimensional movements, with tilt, curvature and strain in both the transverse and longitudinal directions. The impact of subsidence on surface infrastructure is therefore dependent upon its position within the trough.

The above sequence of ground movements, along the length of a panel, only applies to surface structures if they are located at a point where the maximum subsidence is likely to occur. Elsewhere, the impacts, in the both the transverse and longitudinal direction are reduced.

If a structure is located on the perimeter of the subsidence trough, it will only be slightly affected, will suffer little settlement and will have little residual tilt or strain.

A structure or surface feature on the side of the trough between the tension and compression zones will experience some subsidence, and will be left with residual horizontal displacement and tilt, but will be subjected to lower curvatures and strains. Structures or surface features located at the positions of maximum curvature and strain would generally suffer the greatest impact.

As each panel within a series is extracted in turn, an incremental subsidence trough is formed above it. If the width-to-depth ratios of the panels are low, the incremental subsidence troughs overlap at the surface and the resulting subsidence at any point, in these circumstances, is a combination of the effects of a number of panels.

A point on the surface may then be subjected to a series of subsidence waves, which occur as each panel is extracted, and the duration of these impacts will depend upon the position of the point relative to each of the subsidence troughs that are formed.

CHAPTER 2.   REFERENCES