APPENDIX D: Subsidence Effects

D.1 - Subsidence Associated with Underground Bituminous Coal Mining

D.1.A - Room-and-Pillar Mining

Whenever coal is mined by the underground room-and-pillar mining method, an opening in the rock is created. Groundwater moving through overlying strata can find its way into these openings, creating a loss of groundwater and, if the water discharges from the mine, can create acid mine drainage. Also, under-designed pillars can punch into a softer floor rock and potentially produce subsidence on the surface.

D.1.B - Pillar Recovery and Longwall Mining

Both pillar recovery and longwall mining allow the overlying strata to collapse into the mine void, resulting in the formation of a subsidence basin. The strata immediately above the full extraction area caves and the broken rock layers fill the void (Figure D-1). Above the cave zone is the zone of extensive fracturing. It can extend as much as 20 times the extraction zone height in thickness (Figure D-1). Peng (2006) has reported that the zone of extensive fracturing can extend from 111 to over 170-ft above Pennsylvania longwall panels. On occasion, persistent fractures can extend over much greater distances. Above this zone, the stratum gently bends into the subsidence basin to form the zone of continuous deformation (Figure D-1).

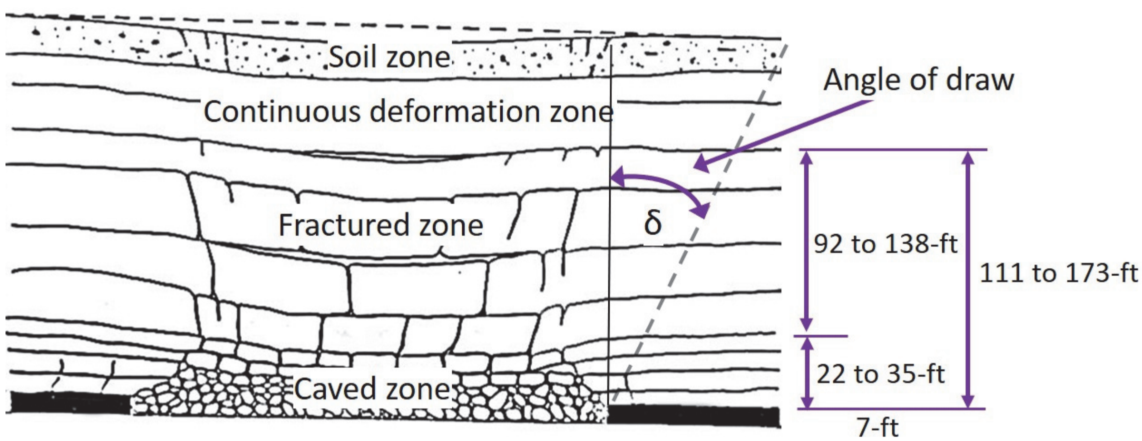

Figure D-1. Idealized subsidence basin overlying a portion of a typical longwall panel showing four zones (from Peng 2006). Values on the right show the ranges for the thickness of the caved and fracture zones as reported by Peng (2006).

The angle of draw (δ) is defined as the angle formed between the edge of the longwall panel and the place on the surface where no measurable subsidence occurs (Figure D-1). The prominent bending promotes separations along bedding as the strata moves inward toward the center of the subsidence basin. These fractures and bedding plane separations can affect the water-bearing strata by altering the groundwater flow path. The zone of groundwater impacts is most commonly found within the basin defined by the angle of draw. It outlines the limits of deformation associated with the subsidence basin formation (Figure D-1).

D.1.C - Formation of Subsidence Basins

A subsidence basin can be initiated when the extraction zone width-to-overburden ratio exceeds 0.25 (Peng 1992). In longwall mining, the extraction zone width (panel width) during the 5th assessment period ranged from 1,000 to 1,600-ft (Table E-1) while overburden averaged 810-ft with a standard deviation of 125-ft (Table 3-11). On average, longwall panels have an extraction zone width-to-overburden ratios ranging from 1.2 to 2.0, so well-formed subsidence basin are common. These ratios will yield supercritical subsidence basins.

In pillar recovery mines, full extraction panels are typically 400 to 800-ft wide with overburdens averaging 492-ft (Table 3-13), yielding extraction zone width-to-overburden ratios ranging from 0.8 to 1.6. These ratios will yield a combination of subcritical and supercritical subsidence basins. Therefore, a subsidence basin, with significant vertical deformations (> 1-ft), will develop with every longwall and pillar recovery panel mined in Pennsylvania. Furthermore, the maximum vertical subsidence is achieved when the extraction zone width-to-overburden ratio exceeds 1.0. The maximum vertical subsidence is dependent on the thickness of the extraction zone multiplied by a subsidence factor for that coalbed. Subsidence factors are dependent on overburden and the characteristics of the overlying strata.

D.2 - Overburden and Panel Width Influence

Because general conditions from the past, present, and future are available, subsidence models can be used to investigate how changing overburden and panel widths have influenced surface impacts. In conducting this work, the University has used several models to investigate Pennsylvania subsidence characteristics. Of these models, the one with the least number of parameters and easiest to apply is the profile function. Here a profile function is used to simulate the formation of a basin from a flat surface. Profile functions (Peng and Cheng, 1981, Karmis et al. 1984, and Peng, 1992) also allow for the indirect evaluation of deformations and strains along the surface subjected to basin formation. For example, a hyperbolic tangent function method is suitable for simulating conditions associated with a supercritical panel, i.e. longwall panels where the width of the panel is greater than the overburden. Currently, the majority of all longwall panels in Pennsylvania are considered supercritical.

For the analysis below, a hyperbolic tangent function (Equation 1) was used:

$$S(x) = Smax/2 * (1 - \tanh((c * x)/h)) \qquad [1\}$$

where, S = vertical movement, ft
Smax = maximum possible vertical movement, ft
c = 8.3 is the coefficient for the Pittsburgh Coalbed,
x = distance (ft) from the inflection point (pointing outwards),
-x = distance (ft) from the inflection point (pointing inwards), and
h = overburden, ft

A key component of the hyperbolic tangent function is the inflection point (Figure D-2). The inflection point on a cross-section of the subsidence basin divides the convex and concave portions of the cross-sectional profile. For supercritical panels, it is typically found when the vertical movement (S) is one-half of the maximum possible vertical movement (Smax). This is the point when the slope of the curve is at its maximum and the curvature is zero. Its location is dependent on size of extraction zone and geology of the strata in the overburden. When extraction zone is small, the inflection point can be located over solid coal. As the extraction zone grows, the inflection point moves inward towards of the center of the basin.

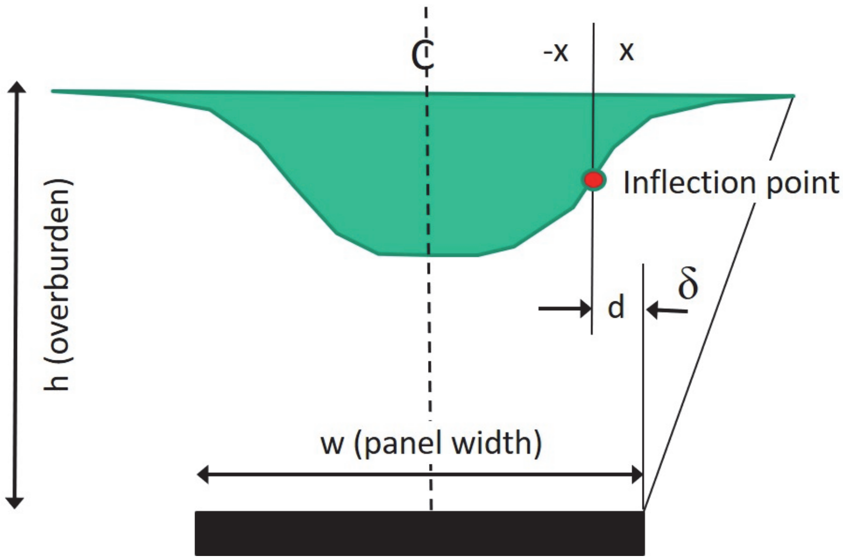

Figure D-2. Parameters important in characterizing a supercritical subsidence basin. Note, the depth of the subsidence basin is exaggerated to allow visualization of the inflection point. Therefore, this figure is not to scale.

Another important parameter is the inflection point offset distance (d) from the edge of the mined longwall panel. Peng (1992) using numerous case histories from Pittsburgh Coalbed longwall panels, derived an empirical relationship (Equation 2) between the offset distance (d) and overburden (h).

$$d = 0.45439*h*e^{(-0.000914*h)} \text{ [Pittsburgh Coalbed]} \qquad [2]$$

Figure D-3 shows the relationship between overburden (h) and the offset distance (d) for the Pittsburgh Coalbed. This relationship has been confirmed with observations and measurements made by the University.

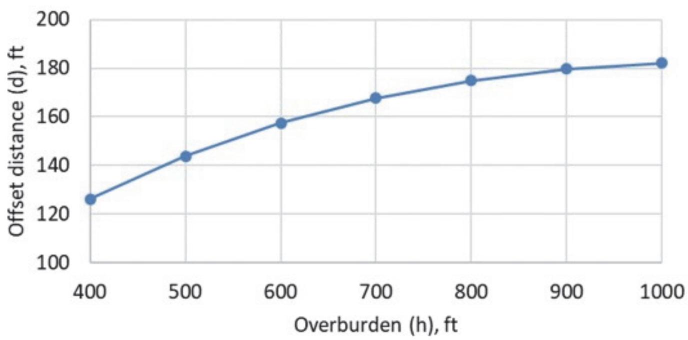

Figure D-3. Relationship between offset distance (d) and overburden (h) for the Pittsburgh Coalbed.

Applying the above conditions for a 7-ft extraction height, yields a generalized shape for the Pittsburgh coalbed subsidence basins. Figure D-4a shows the vertical movement of a half-width subsidence basin for conditions associated with past (low overburden and panel width), current (moderate overburden and panel width), and future (high overburden and panel width) longwall mining in Pennsylvania. Two conditions are obvious. The overburden and panel width increase, the maximum vertical subsidence and the steepness of the subsidence basin sides decrease.

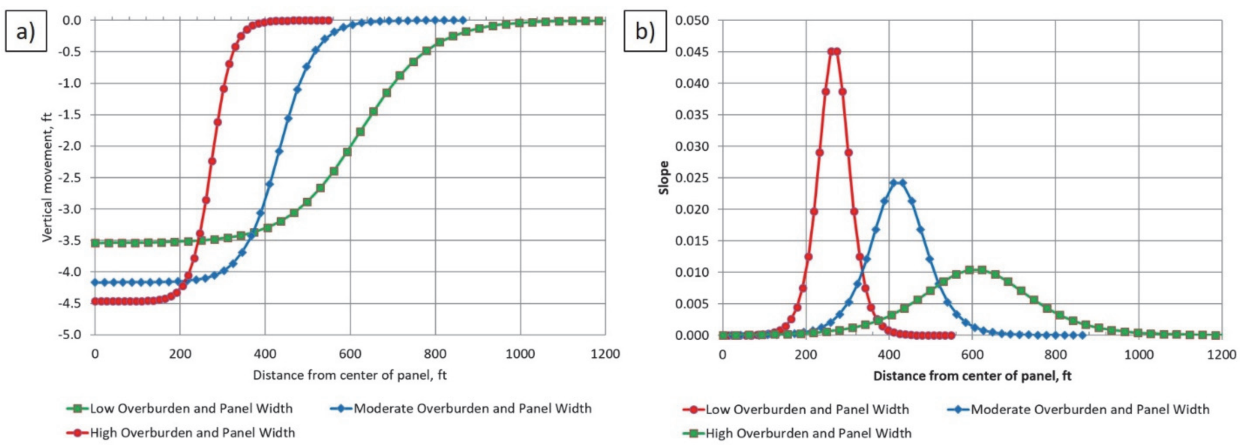

Figure D-4. a) vertical movement associated with three different conditions of overburden and panel width; and b) slopes of subsidence basins associated with different conditions of overburden and panel width.

The more important of these two conditions is the steepness of the subsidence basin. Steeper sides produce higher slopes (Figure D-4b). Areas of maximum slope represent places on the surface where deformations will be the greatest. These data show, when examining the permanent subsidence basin, surface impacts are most likely to occur along the sides of the subsidence basin. It also implies that, in general, the magnitudes of strains and deformation will diminish as overburden and panel width increase.

<u>D.3 - Impacts during Active Longwall Panel Extraction (Dynamic Subsidence)</u>

Most surface impacts will occur during panel extraction. The developing subsidence basin produces a wave of deformation that first extends then compresses points on the surface. As discussed above, the transition from tension to compression occurs at the inflection point. The inflection point occurs in a continuous form around the developing dynamic subsidence basin (Figure D-5). All points on the surface, between the side inflection points, experience both extension then compression. This flexing of the surface has the potential to impact all features overlying this portion of the longwall panel.

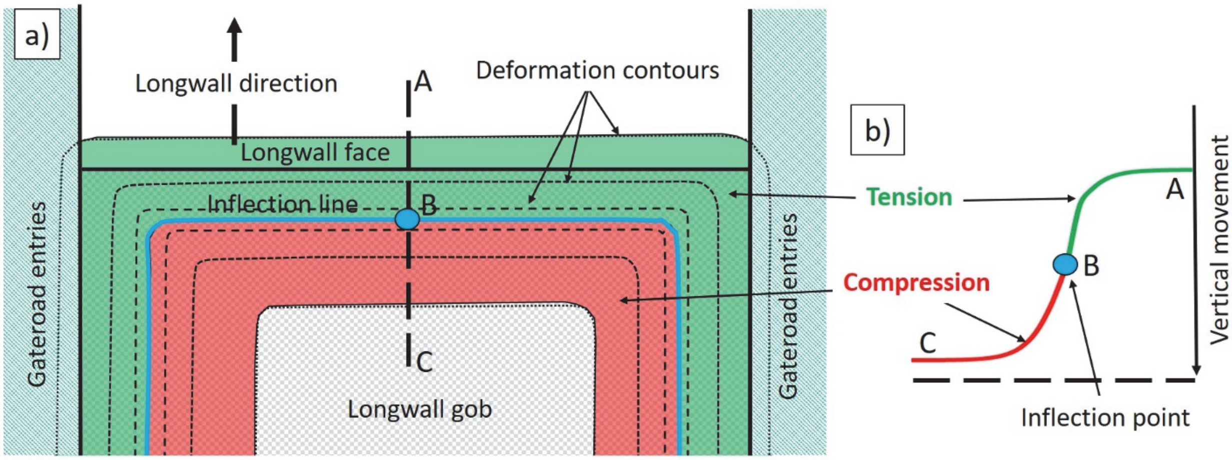

Figure D-5. a) dynamic deformation wave associated with a developing subsidence basin showing the position of the inflection line; b) cross-sectional view of the advancing subsidence basin showing the tension and compression of the surface.

References

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