MINE DESIGN: LONG TERM EFFECTS OF HIGH EXTRACTION MINING[1]

by

Paul W. Jeran[2]

Abstract. A consideration when designing a high extraction coal mine is the effects that mining will have on the ground above the mine. This becomes particularly important when the surface has been improved or is inhabited. Surface owners are concerned about; when the effects will begin?, how large will they be?, and how long they will last?. Each of these should be addressed by the designer.

For more than a decade, the U.S. Bureau of Mines (USBM) has been monitoring subsidence at various sites. Based upon the data gathered, some inferences may be made regarding the above stated questions. Essentially surface movement begins with undermining. The magnitude of the movements are proportional to the thickness extracted and the width of the mined area, and inversely proportional to the depth of the mine below surface. The duration of the subsidence process in the northern Appalachian Basin is approximately one year.

The USBM has developed a computer model which predicts the final subsidence profile across a longwall panel in the northern Appalachian Coal Basin. USBM studies on the dynamic development of subsidence have shown that the magnitude of the deformations developed during the subsidence process never exceed those exhibited in the final subsidence profile. Use of the model will provide engineers with a starting point in the design process.

INTRODUCTION

The mining of a large rectangular block of coal by the longwall method results in the development of a trough-shaped depression of the surface above the extracted area. The process of subsidence is dynamic as surface movement begins with undermining and continues until some maximum displacement has occurred: the magnitude of which is controlled primarily by the extracted thickness, the width of the panel, and the overburden thickness and geology. At the end of the subsidence process, equilibrium is achieved and the resulting surface deformations become static. Any subsequent movement of the surface does not result from subsidence but from the altering of the conditions affecting the rock strata disturbed by subsidence (i.e., injection or removal of fluids, erection of structures).

During any discussion of subsidence with longwall mine operators and particularly surface property owners, several questions always arise: How much subsidence will occur?; What will be affected?; When will subsidence begin?; and How long will the process of subsidence last? The first two questions can be estimated using the geometry of mining as input into the U.S. Bureau of Mines' (USBM) subsidence

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[2]Paul W. Jeran is a Geologist, U.S. Bureau of Mines,Pittsburgh Research Center, Pittsburgh PA 15236.

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prediction model for the northern Appalachian Coal Field (Jeran 1986). The latter two are the subject of this paper.

Subsidence monitoring is typically carried out in two directions: along the centerline of the panel to obtain data which will show the maximum amount of subsidence and the duration of the dynamic phase of movement; and, across the panel (perpendicular to the centerline) to evaluate: the lateral extent of surface deformations, the final cross-section of the developed subsidence trough, and the distribution of final deformations. This is the static result of the subsidence process and any further movement must be attributed to some other cause. Subsidence prediction is typically limited to the final shape of the subsidence trough. Practically all predictive models address this aspect of mining-induced ground movement.

Study of subsidence data gathered along the centerlines of a number of longwall panels in the northern Appalachian Coal Basin, by Adamek and Jeran (1992), has shown that the subsidence process starts with the undermining of a surface point and is 90 percent completed by the time the longwall face has been advanced the thickness of the overburden beyond that point. In this study, it was determined that: the speed with which the face is advanced has no effect on the magnitude of surface deformations; the final movement is usually achieved with mining of the adjacent panel; and, the magnitude of surface deformations that occur during dynamic subsidence are always less than the static case (Adamek 1992)

Examination of manmade features on the surface has shown that they are affected by the forces applied to them throughout the subsidence process. Therefore, the final static shape of the subsidence trough cannot be used to fully explain their degradation or how they came to their final condition. It has also been observed that the degree of degradation is dependent upon location within the subsidence trough (Walker 1990).

Field Studies

As has been noted above, the description of dynamic subsidence has been limited to movement along the centerline. However, does this behavior occur equally across the developing subsidence trough? In an effort to obtain some insight to this question, long term subsidence data were needed. At one site, in northern West Virginia, the USBM monitored a series of longwall panels, in the Pittsburgh Coalbed, remote from previous high extraction mining. Monitoring was conducted for over two years during which time four adjacent longwall panels were mined. Surface monuments were installed over the first three panels (figure 1) and monitoring was conducted over the portions of the array that were actively moving due to undermining. Periodic measurements were also made of the previously undermined portions of the array to determine final movement. Above the first two panels there was no further vertical movement detected after the subsequent adjacent panel was mined (Jeran 1988).

To simplify the analysis, four monuments across the first panel, as shown in figure 1, were selected: (A) above the centerline, (B) 30.5 m (100 ft) from the centerline, (C) 30.5 m (100 ft) inside the rib abutting the barrier pillar, and (D) above the rib abutting the barrier pillar. Figure 2 shows a plot of the subsidence of these four monuments verses time. Also included are the face positions showing the progress of mining for the studied panels. The last measurement was made after mining of the fourth panel was completed. Each face position line is marked to indicate the location of the face when the four monuments were either undermined or when the longwall face passed by them. From this, we can see that each monument experienced the majority of its movement with the mining of Panel 1 and had completed movement with the mining of Panel 2. Figure 3 shows the first 60 days of the study. From this, it can be observed that the monuments were undermined on the 25th day and some minor movement had been detected as much as 10 days earlier. Furthermore, most movement had occurred within 30 days after undermining.

Since each monument subsided a different amount, the percentage of final movement for each measurement was computed to provide some basis of comparison. Please note that negative values of time and face position, where they occur on graphs, indicate data acquired prior to undermining of the monuments. When the percentages of final subsidence are plotted against face position (figure 4) it can be seen that the three interior monuments (A, B, and C) subsided more than 85 percent of the final movement by the time the face was 245.4 m (800 ft) past the monument line. Movement of the monument over the rib (D) was only 70 percent complete at this time. Plotting the percentage of final subsidence against time (figure 5) shows that all of the monuments behaved similarly for the first 10 days after undermining. After that period, the two central monuments (A and B) behaved similarly and the monument 30.5 m (100 ft) inside the rib (C) lagged slightly behind. The rib monument (D) behaved differently.

From the above, it can be concluded that subsidence of the monuments within the panel limits is governed by face position and time. While subsidence of the monument over the rib, after its initial movement, is more governed by time.

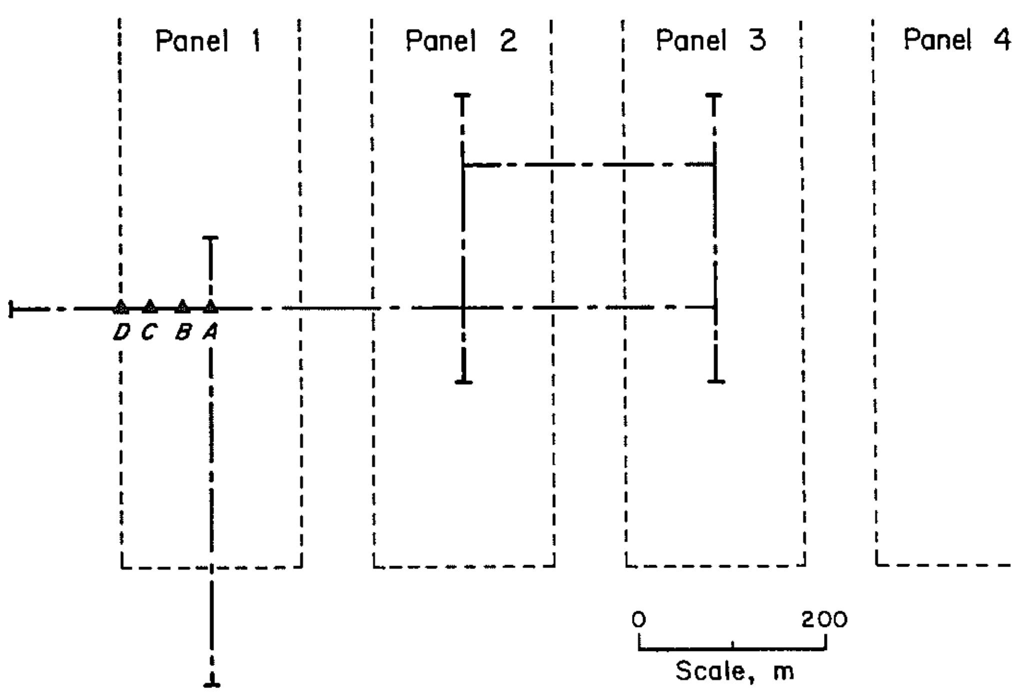

Figure 1. Monitoring Array

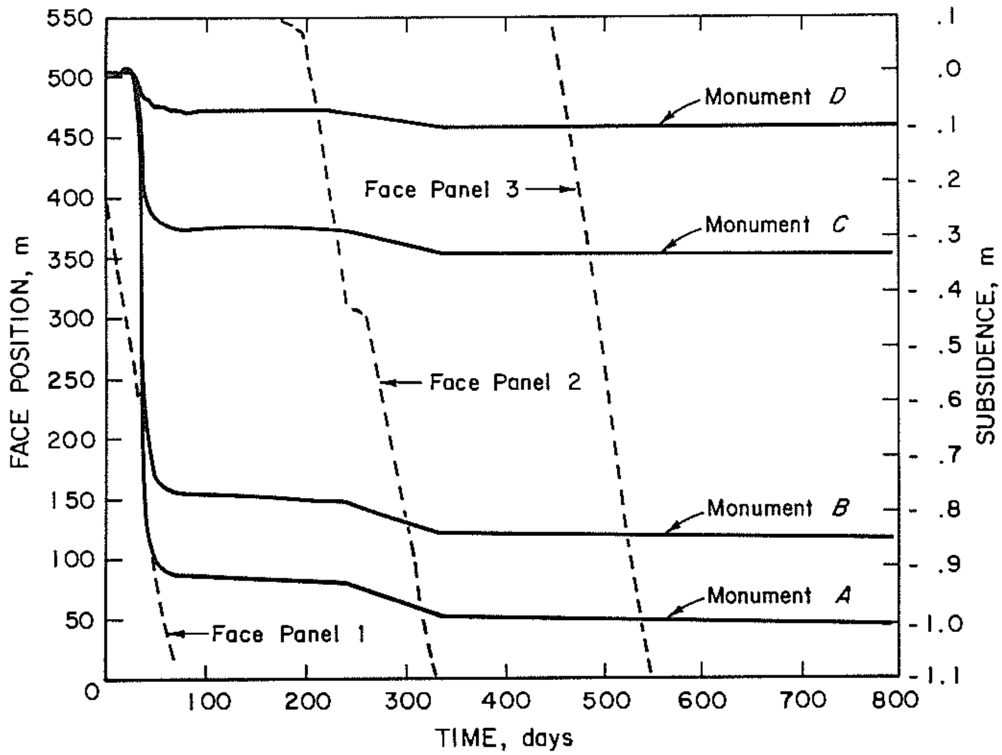

Figure 2. Subsidence during the study versus time

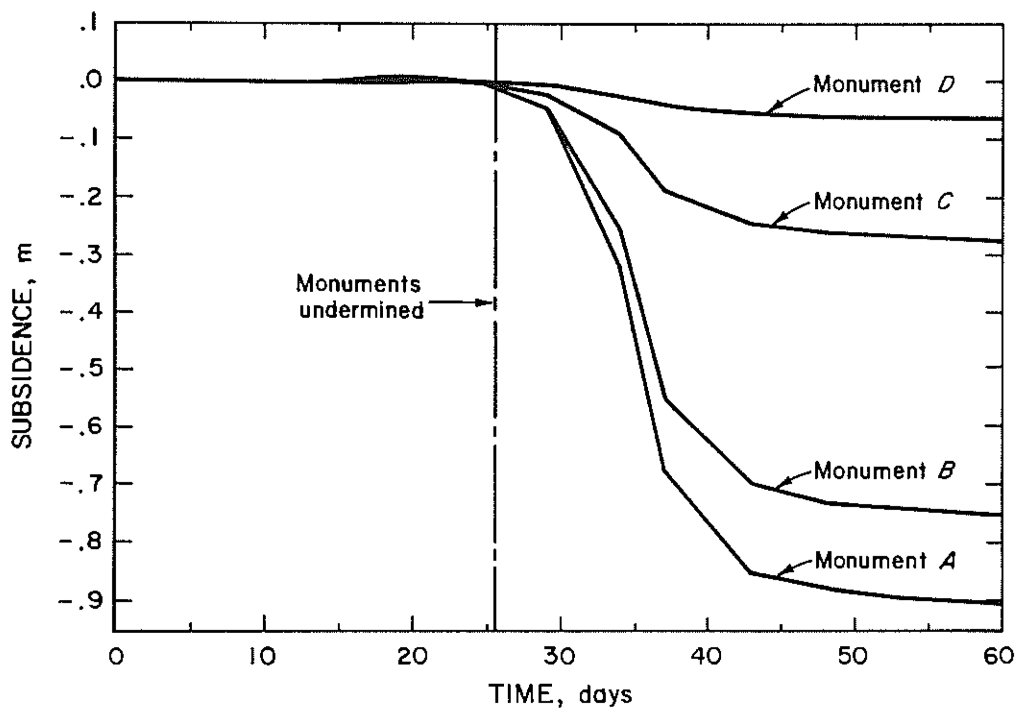

Figure 3. Subsidence during first 60 days

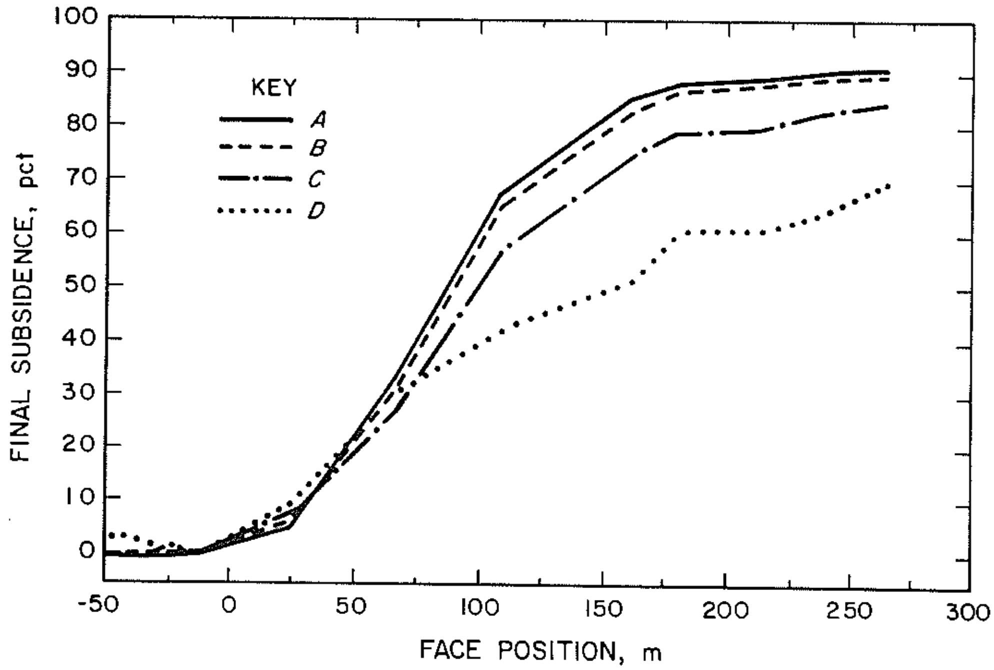

Figure 4. Percent final subsidence versus face position

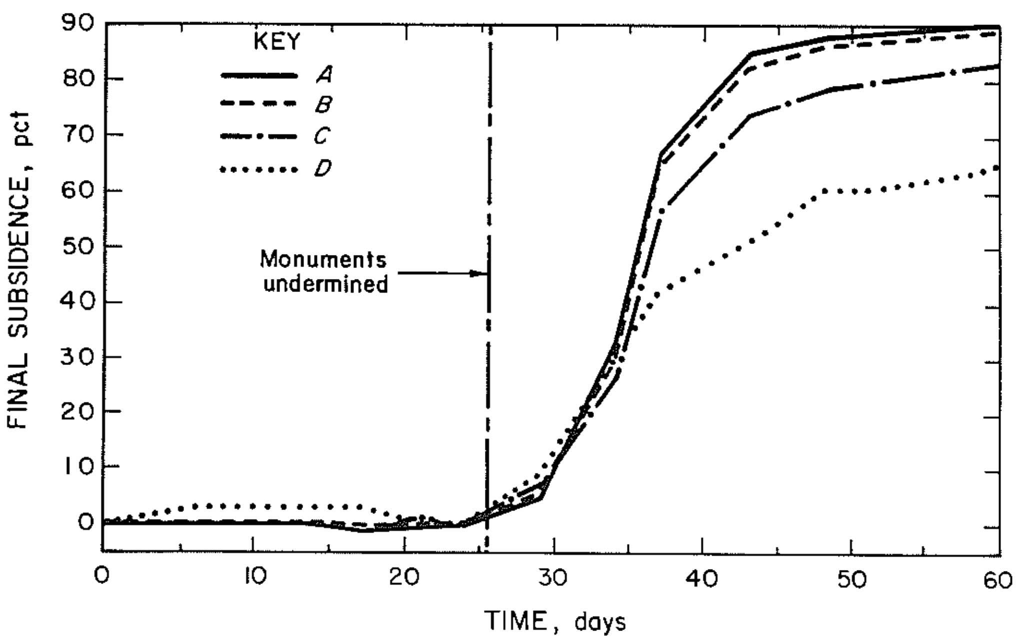

Figure 5. Percent final subsidence versus time

Since these conclusions only represent information from one site, other sites, with shorter duration of study, were investigated to substantiate our observations. Mine sites were selected, one in each of three different coal beds: Pittsburgh, Lower Kittanning, and Freeport. Figure 6 shows the locations of these sites.

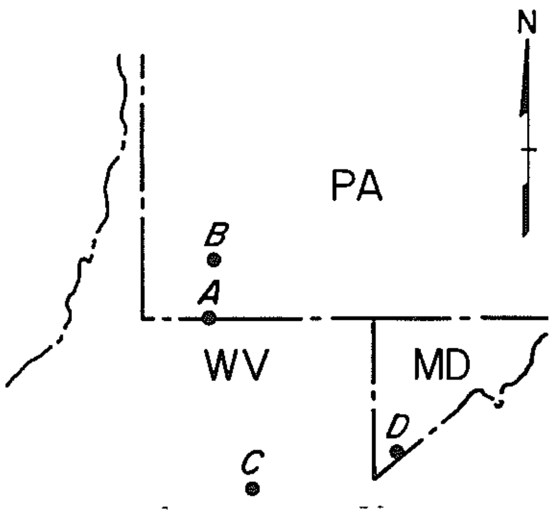

Figure 6. Location of Mines

Mine A is the original site. The Pittsburgh Coalbed site was chosen to determine if the observations were limited to operations in this coalbed (the original site was in the Pittsburgh Coalbed). Overburdens, extracted thicknesses, rates of face advance and geometries varied among the sites. Figure 7 is a plot of face advance for each of the sites. The average rates of mining ranged from 3.1 m/day (10.0 ft/day) at Mine B to 11.8 m/day (38.8 ft/day) at Mine D. Table 1 contains data describing overburden thickness, panel width, average rates of face advance, and coalbed for the sites.

In all cases, the monuments chosen were from the profile line extending from the centerline outward away from subsequently mined panels. Since the extracted thicknesses were different and resulted in differing magnitudes of subsidence, the percentage of the final movement of each monument was calculated and used in the comparisons. It should be noted that the process of subsidence at all sites was completed within one year of undermining.

Data from the centerline monuments at each of the 4 sites plotted against time (figure 8) show that subsidence at mines C and D generally agreed with that at Mine A, while Mine B was much slower. Mine B had the slowest face advance and greatest overburden thickness. Considering that dynamic subsidence is proportional to face advance and inversely proportional to overburden thickness (Adamek 1992) this could be the expected result. When the percentage of final subsidence was plotted against face position, (figure 9) Mines A and B (Pittsburgh Coalbed) are in agreement with Mines C and D differing. It should be noted however, that Mines C and D had lesser overburden thicknesses. When plotted against face position in terms of overburden thickness (figure 10) all sites are in closer agreement. Note, in figure 10, for the centerline monuments, subsidence at all sites was about 90 percent complete when the face had advanced the thickness of the overburden beyond the monument location. These observations agree with the findings of the earlier mentioned study by Adamek and Jeran (1992).

The same plots were made for the monuments 30.5 m (100 ft) from the centerline for the 4 sites under study (figures 11-13). Again, as for the centerline points, the plot versus face position in terms of overburden thickness shows the closest agreement and again, over 90% of the final subsidence was completed when the face

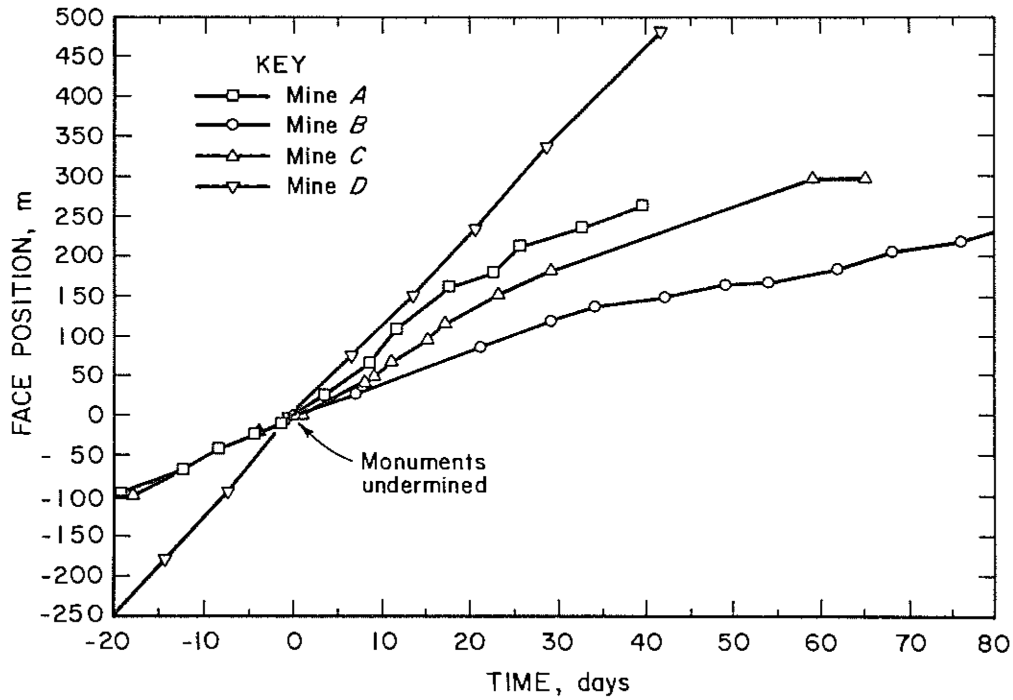

Figure 7. Face advance for each site

Table 1. Study Sites Information

Mine	Panel width, m(ft)	Overburden, m (ft)	Average face advance m/day (ft/day)	Coalbed
A	190.5 (625)	210.3-213.4 (690-700)	6.55 (21.5)	Pittsburgh
B	182.9 (600)	277.4-298.7 (910-980)	3.05 (10.0)	Pittsburgh
C	289.6 (950)	118.9-126.5 (390-415)	4.94 (16.2)	Kittanning
D	182.9 (600)	143.3-155.4 (470-510)	11.83 (38.8)	Freeport

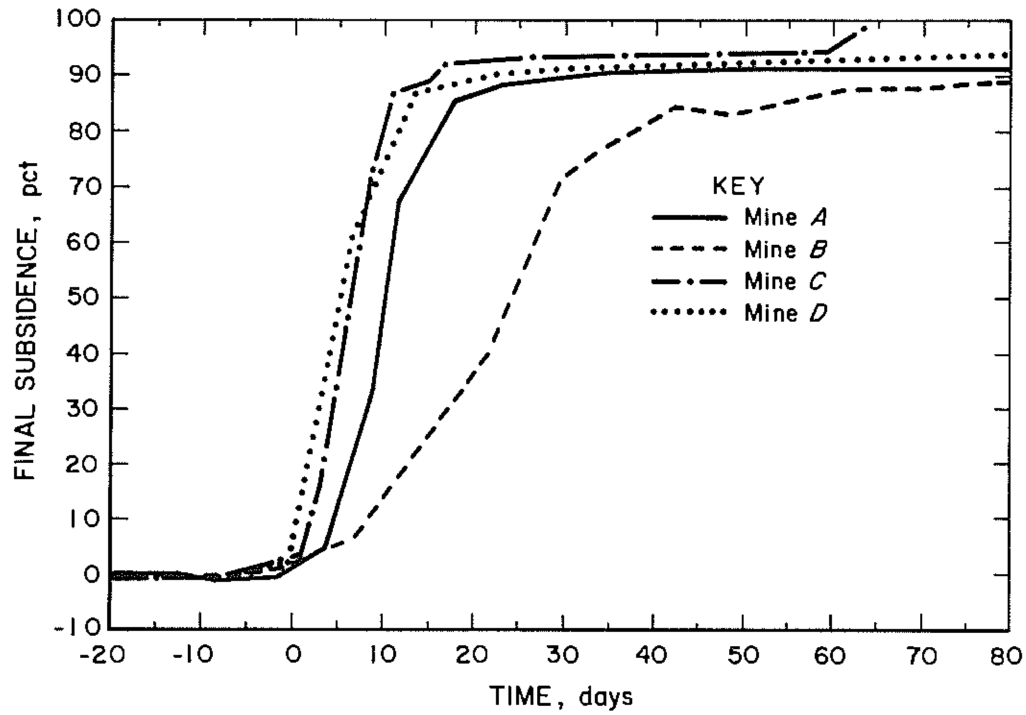

Figure 8. Centerline poinst versus time

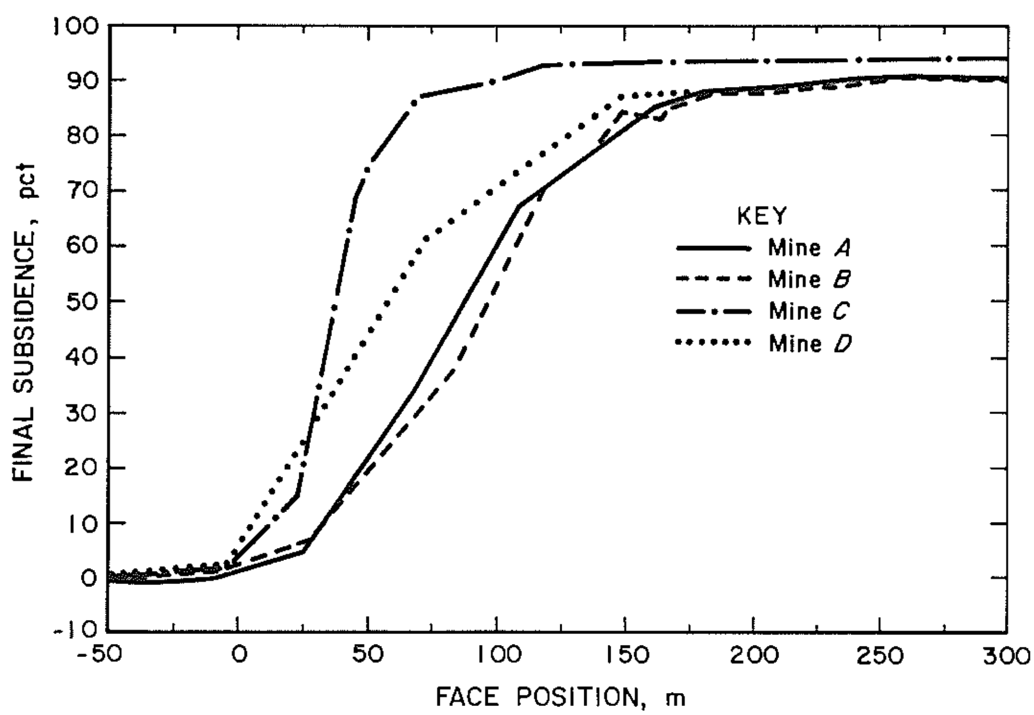

Figure 9. Centerline points versus face position

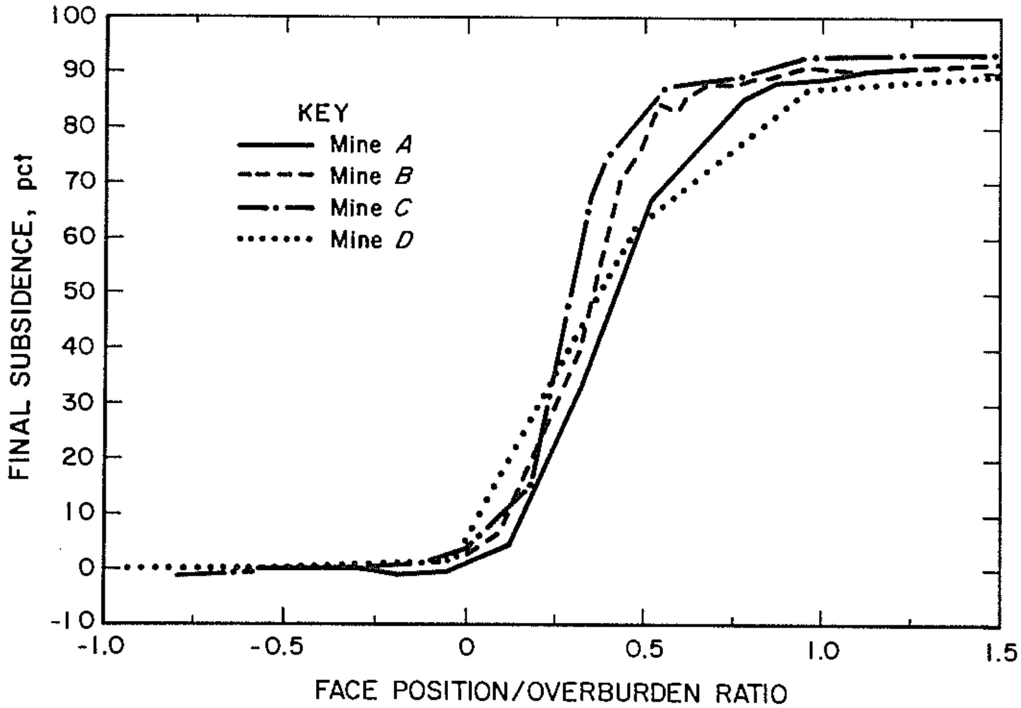

Figure 10. Centerline points versus face position/overburden

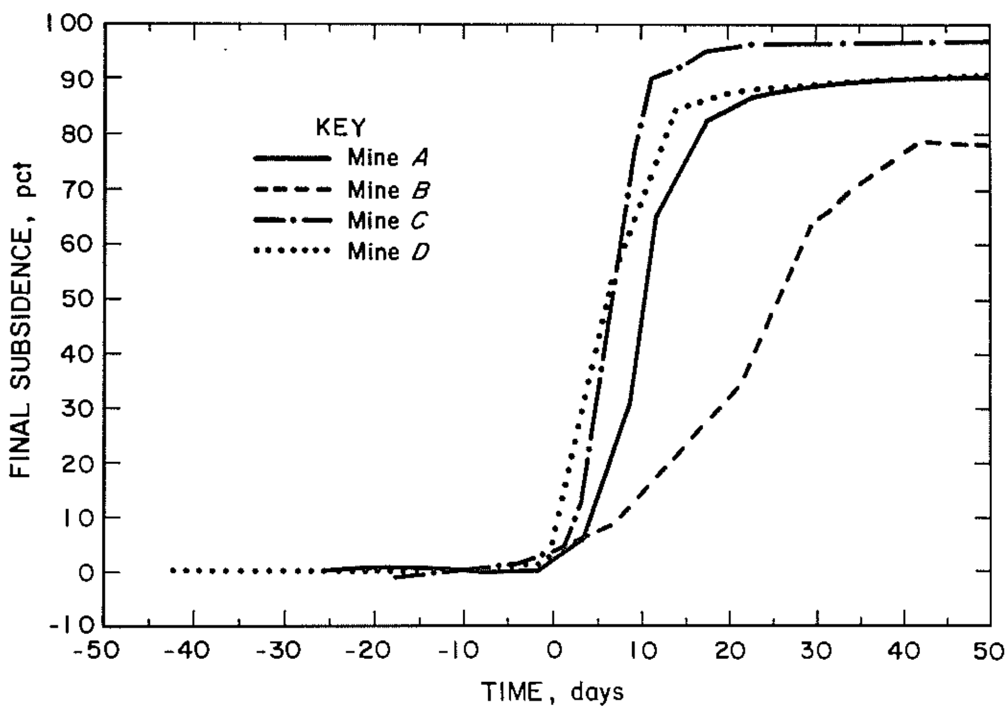

Figure 11. Centerline +100 points versus time

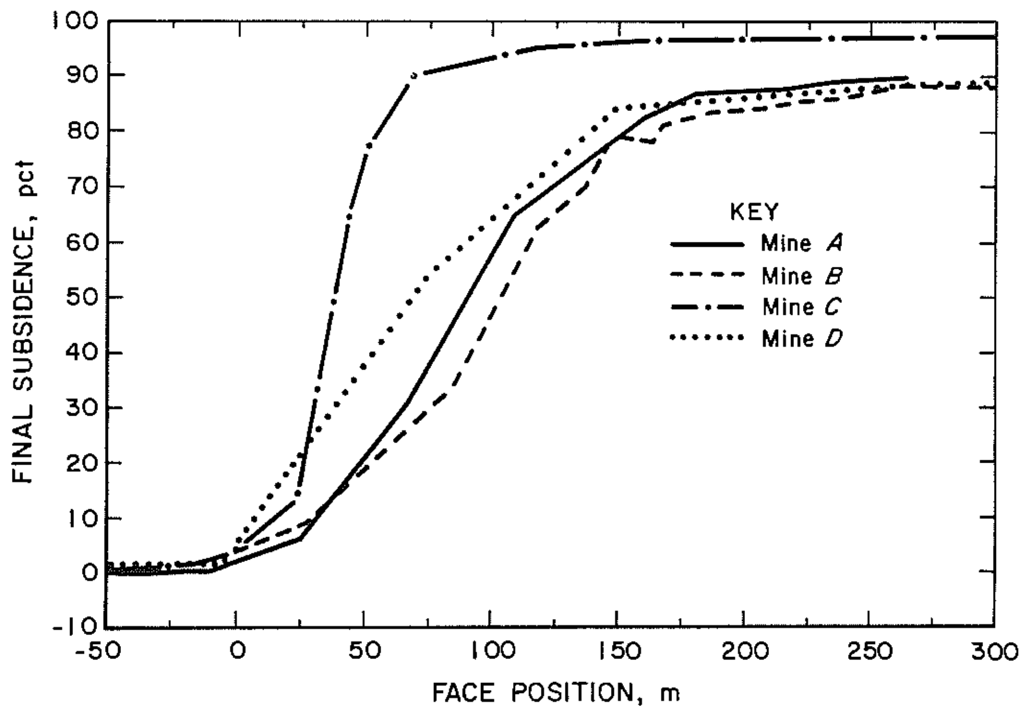

Figure 12. Centerline +100 points versus face position

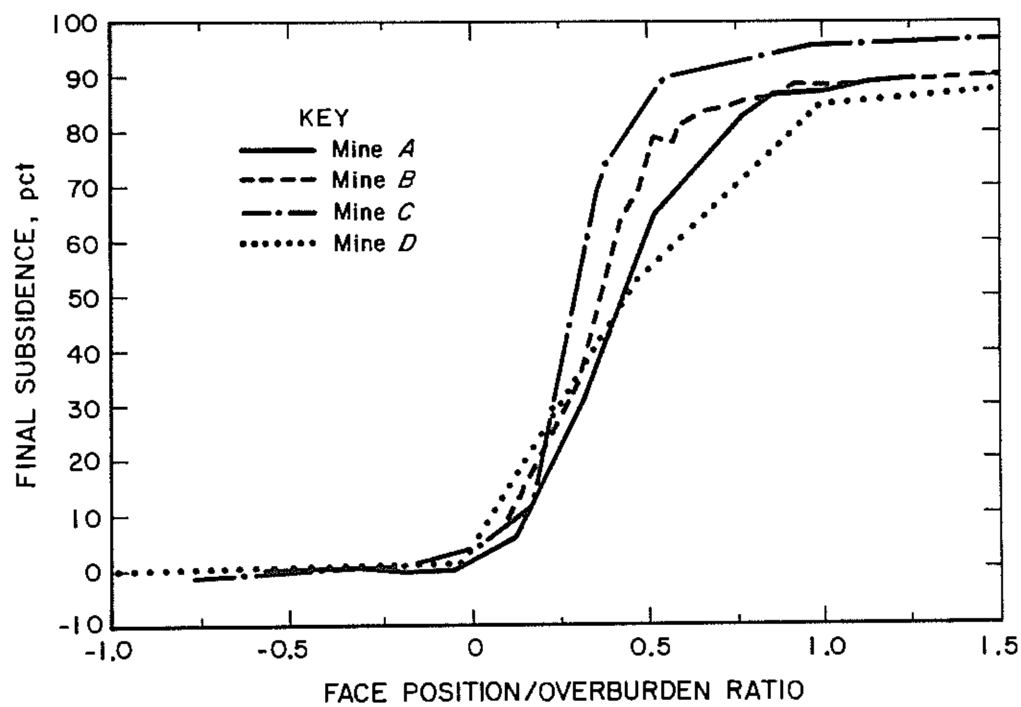

Figure 13. Centerline +100 points versus face position/overburden

had advanced the thickness of the overburden past each point.

Plots for the monuments 30.5 m (100 ft) inside the rib versus time and face position (figures 14 and 15) are similar to those for the more centrally located monuments. However, the plot the percentage of final subsidence versus face position/ overburden ratio (figure 16) shows that this location at Mine D lagged behind the same location at the other 3 mines indicating retardation of the subsidence process. The overburden at this site contains significantly more and thicker sandstone units. These stiffer members bridge further over the gob than the less resistant strata at the other sites. Additional time is needed for the stiffer units to bend into the gob area.

The similar plots for the rib monuments (figures 17-19) show a different characteristic. Plots of the percentage of final subsidence versus face position (figure 18) and face position in terms of overburden thickness (figure 19) do not show the same trends as observed for the other points. The plot of percentage of final subsidence versus time (figure 17), however, shows that within a month of undermining these monuments had completed from 40 to 70 percent of their final subsidence. This indicates that the process of subsidence over the rib is very much site dependent and time appears to play a very significant role.

Deformations

Underlying all discussions of subsidence resulting from longwall mining is the concern for damage. From the above discussion it can be seen that except for the area above the rib most of the surface movement is accomplished by the time that the longwall face has mined past the thickness of the local overburden. It is therefore logical to assume that most of the deformations of the surface are also completed by this time.

The study of dynamic subsidence showed that the magnitude of dynamic deformations (inclination, curvature, and horizontal strain) are always less than the static values (Adamek 1992). Therefore, if the difference between the values of final static deformations and those developed at the time the longwall face has mined one overburden thickness past the profile are small, then the additional deformations from a dynamic point of view should also be small.

The distribution of static inclinations were calculated for each of the profiles used in this study at the point where the longwall face had mined 1 overburden thickness past and again when subsidence had been completed. These are shown in figures 20 - 23. They show that static inclinations increased by less than 3 mm/m. Therefore, dynamic inclinations should be smaller than these values. From these we must conclude that, for these sites, the surface deformations occurred primarily during the mining of the longwall face one overburden thickness past the profile. Additional deformations were small. Since there are no criteria established in this country correlating magnitude of deformation with structural damage it is impossible to state that no additional damages would result from the additional deformation. If criteria developed in Europe (Adamek 1982) are any indication, then these additional deformations should not significantly contribute to surface damages.

Summary

Subsidence data from four sites in the northern Appalachian Coal Basin were studied. These data show that for locations in the central portion of the

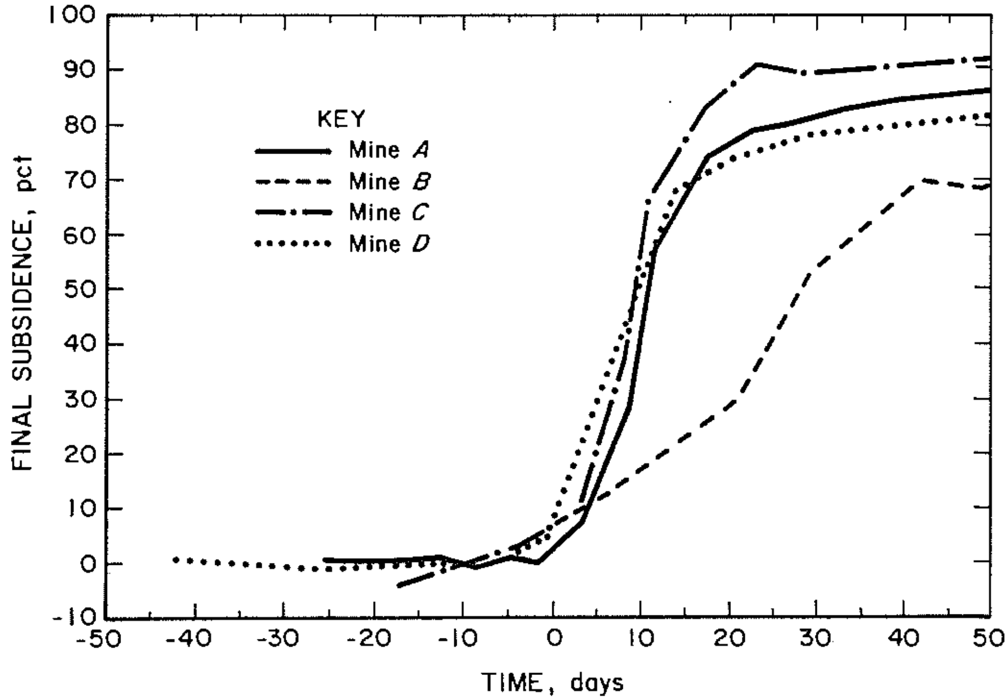

Figure 14. Rib -100 points versus time

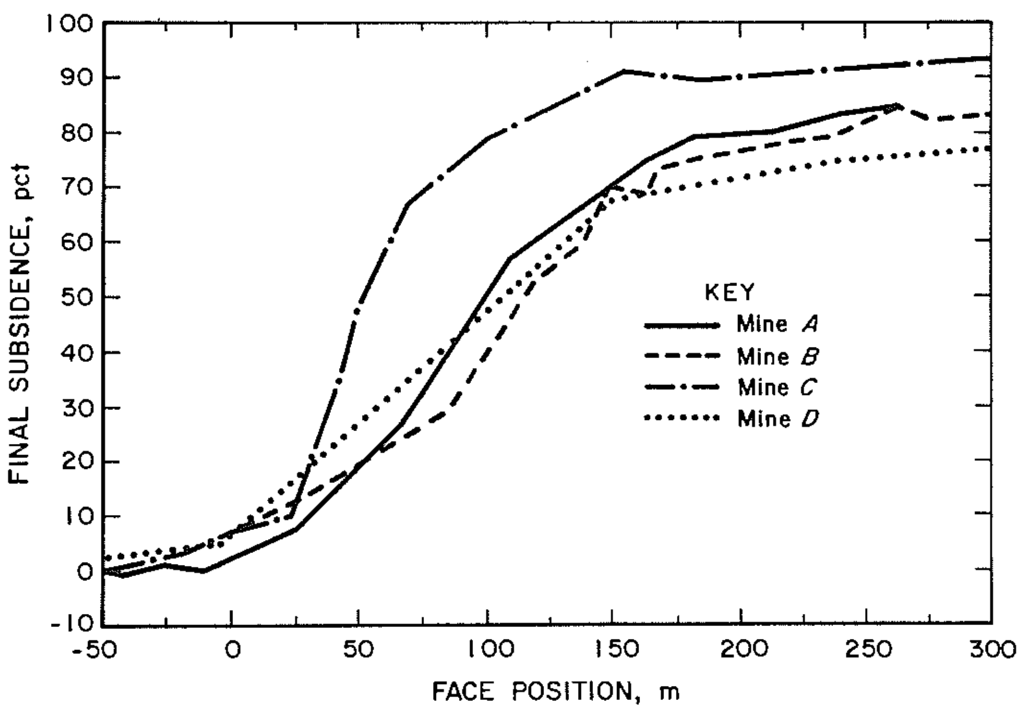

Figure 15. Rib -100 points versus face position

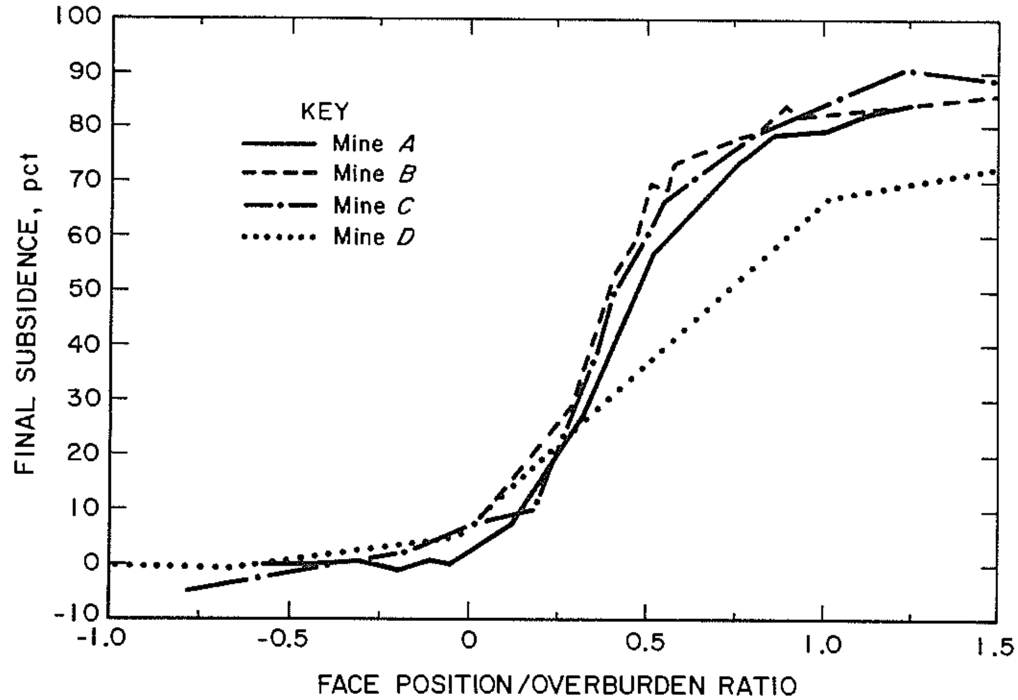

Figure 16. Rib -100 points versus face position/overburden

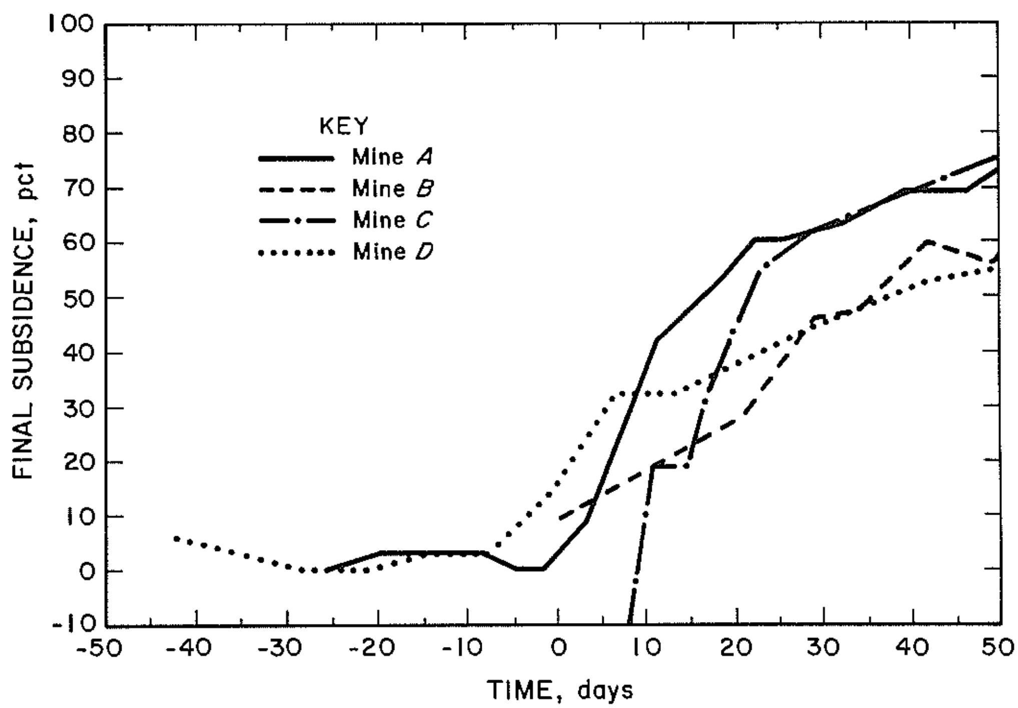

Figure 17. Rib points versus time

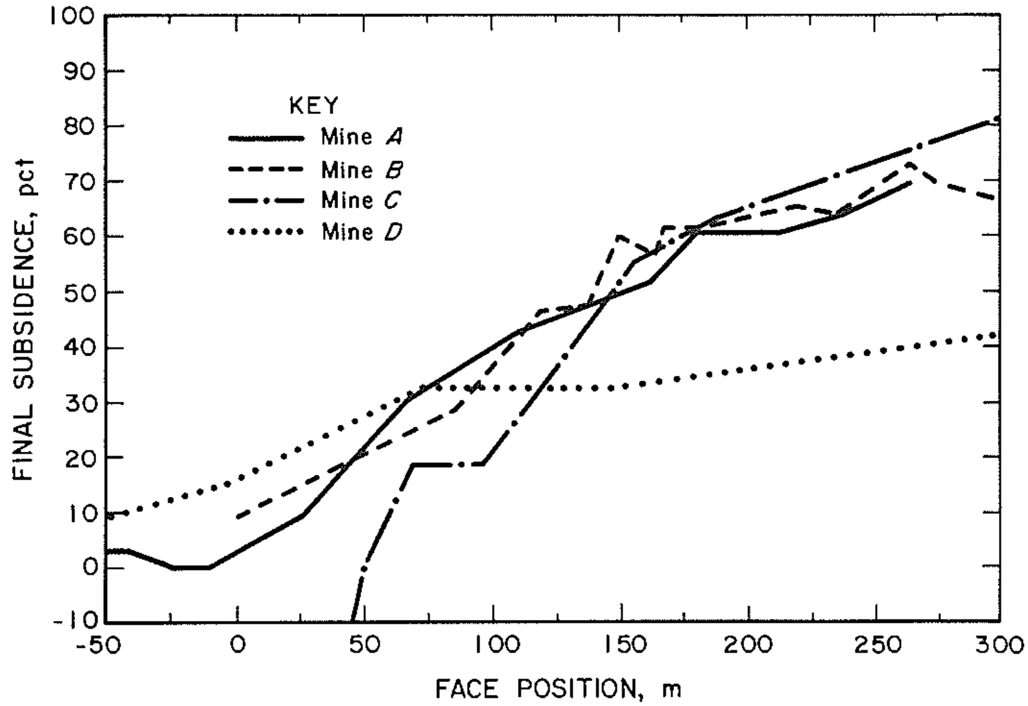

Figure 18. Rib Points versus face position

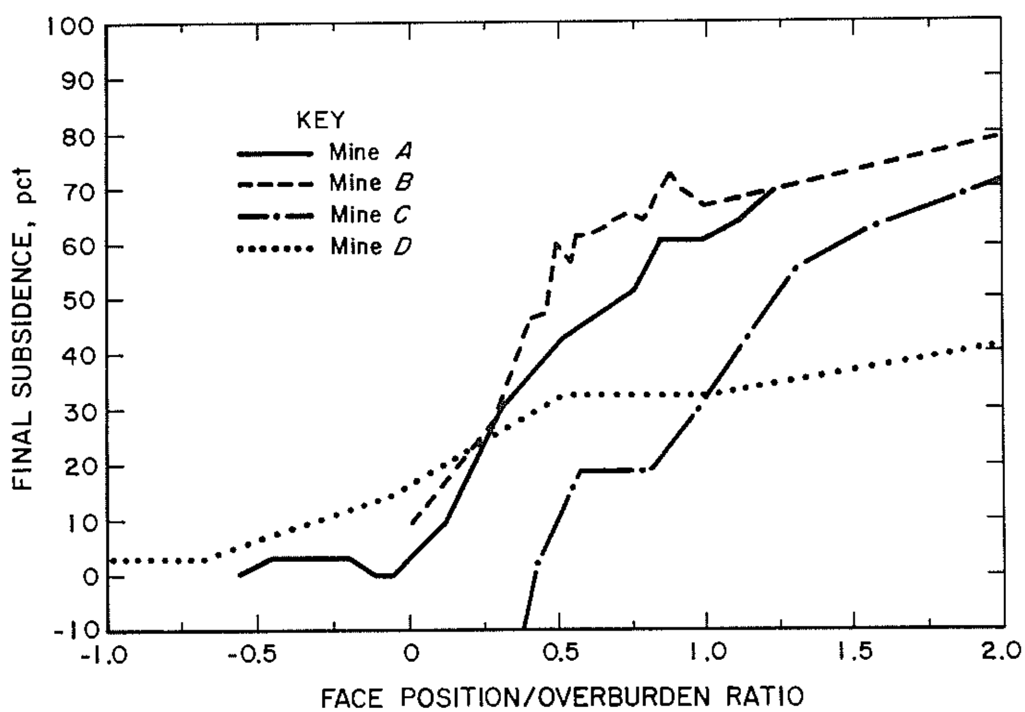

Figure 19. Rib Points versus face position/overburden

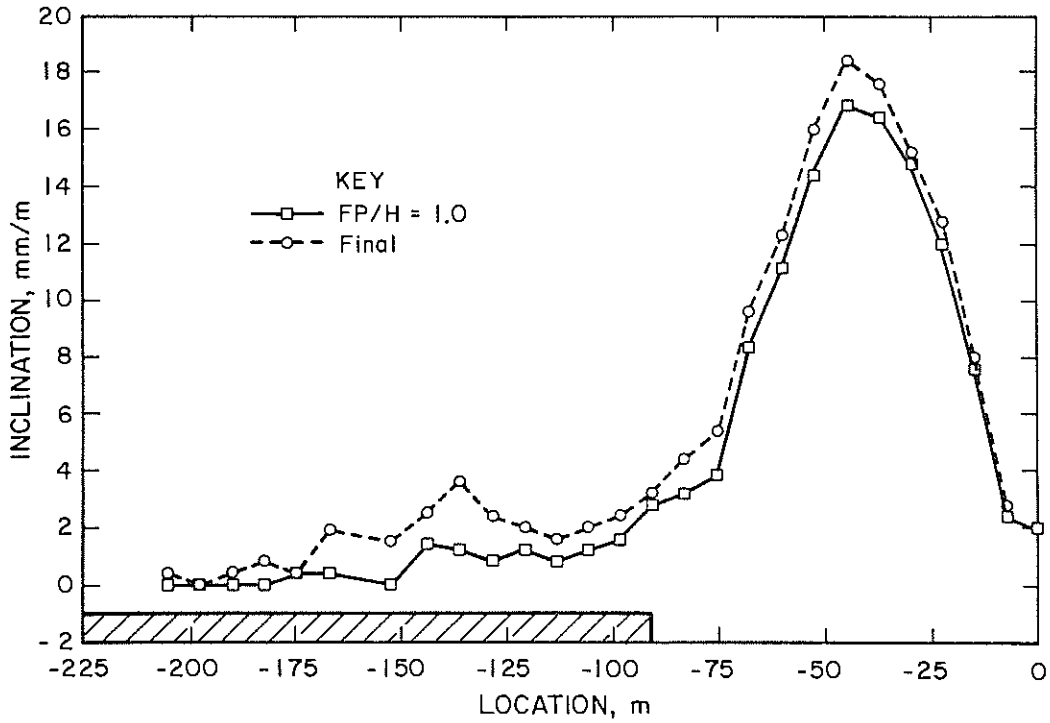

Figure 20. Inclination difference at Mine A

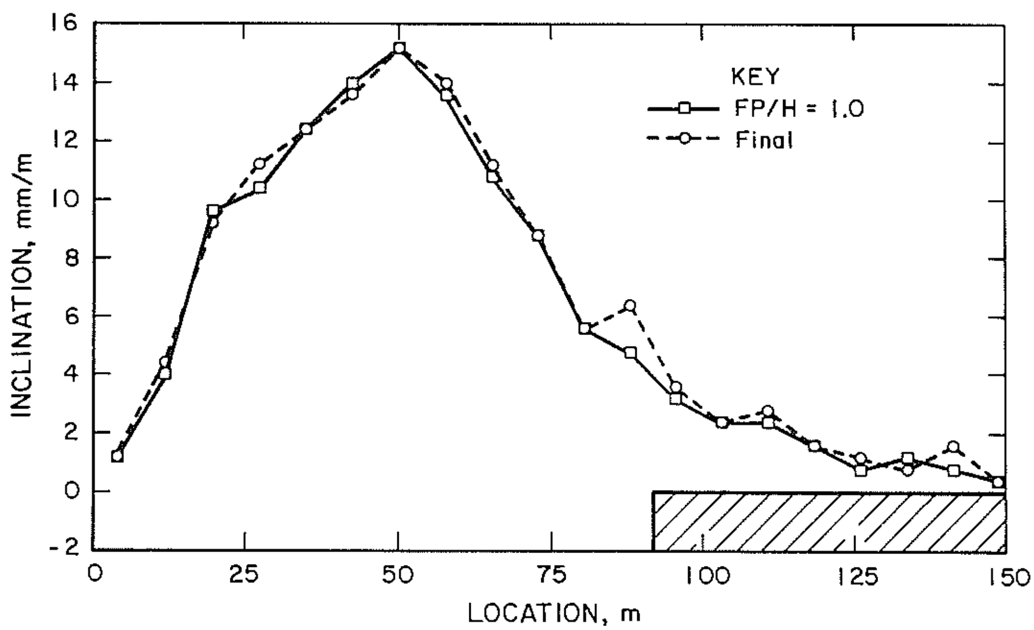

Figure 21. Inclination difference at Mine B

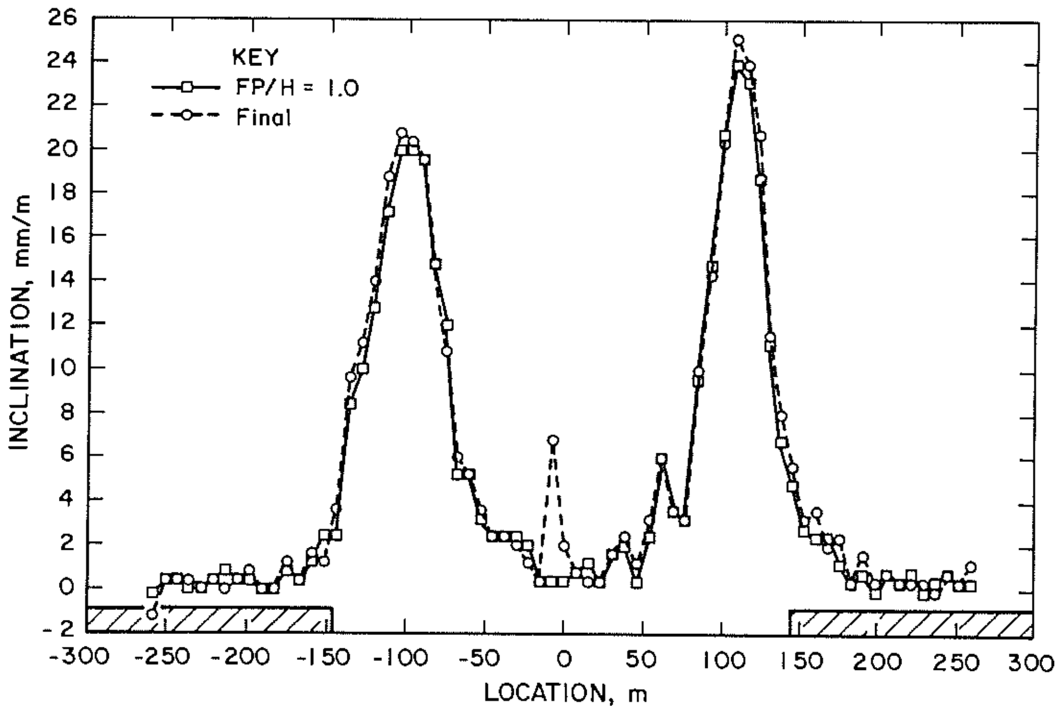

Figure 22. Inclination difference at Mine C

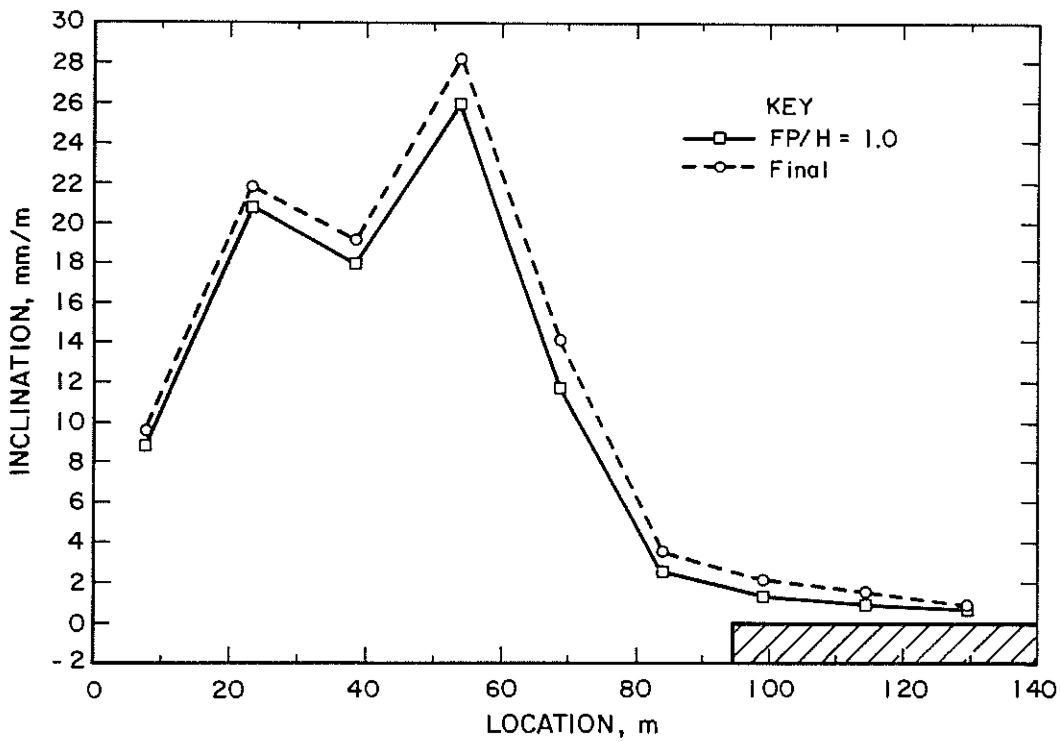

Figure 23. Inclination difference at Mine D

developing subsidence trough (within 30.5 m (100 ft) of the centerline) subsidence develops relative to face position and overburden thickness and is about 90 percent complete when the face has advanced the thickness of the overburden beyond the point in question. Above the rib of the panel the process of subsidence is very much site dependent and time appears to play a significant role, in that, when the face has advanced the thickness of the overburden past a monument only 40 to 70 percent of the movement has taken place. The remainder of the surface movement, irrespective of location above the longwall panel, takes up to a year to complete.

The monuments 30.5 m (100 ft) inside the rib exhibited movements that were characteristically between that of the centerlines and rib areas. With slow to moderate face advance (3.1 to 6.6 m/d), the subsidence process is similar to that over the central portion of the panel with over 80 percent of the final movement completed when the face has advanced the thickness of the overburden past a monument. However, with fast face advance (11.8 m/d) there appears to be some retardation or lag in the subsidence process.

At the sites studied, the preponderance of the surface deformations had occurred by the time that the longwall face had mined one overburden thickness past each profile. The additional deformations were small. All of these factors should be taken into account when designing a high extraction mine to evaluate the potential for damage resulting from mining-induced subsidence.

References

A Subsidence Prediction Model for Longwall Mine Design. P. W. Jeran, V. Adamek and M. A. Trevits, Proceedings of the Longwall USA Conference, Pittsburgh, PA, June 1986, pp. 101-112.

Static and Dynamic Subsidence Prediction in the Northern Appalachian Coal Region Based on the Use of a Variable Subsidence Coefficient. V. Adamek, P. W. Jeran, and M. A. Trevits. Procs. 3rd Workshop on Subsidence Due to Underground Mining, West Virginia University, Morgantown, WV, June 1-5, 1992.

Effects of Longwall Mining on Surface Sructures. J. S. Walker and M. A. Trevits. Procs. Mine Subsidence: Prediction and Control, 33rd Annual Meeting of Association of Engineering Geologists, Pittsburgh PA, October 1990, pp.141-143.

Subsidence Due to Undermining of Sloping Terrain: A Case Study. P. W. Jeran and V. Adamek. USBM RI 9205, 1988. 10 p.

Evaluation of Surface Deformation Characteristics Over Longwall Panels in the Northern Appalachian Coalfield. V. Adamek and P. W. Jeran. Proceedings Soc. Min. Eng. AIME 1 st Conf. on State-of-the-Art of Ground Control in Longwall Mining and Mining Subsidence. Honolulu HI, Sept 5-9, 1982, pp.183-198.