OVERBURDEN DEFORMATION DUE TO LONGWALL MINING; ITS DEVELOPMENT AND FINAL DISTRIBUTION[1]

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Abstract: The objective of this U.S. Bureau of Mines investigation was to characterize overburden response due to longwall mining. Subsurface strata and surface deformations were monitored during the mining of two adjacent longwall panels in southeastern Ohio. Multipoint borehole extensometers (MPBX) with eight anchors were installed in six boreholes across both panels to measure subsurface displacements. Survey monuments were installed along the center lines and profile lines over both panels to measure surface deformations. During the mining of the first panel, subsurface displacements occurred in a radiating pattern beginning just above the extracted area in the center of the panel and extending upward and outward towards the surface and margins of the panel. Overburden deformation did not project over the gate road entries. During the mining of the second panel, the MPBX's showed almost simultaneous displacement, indicating that the overburden moved as a unit. Again, overburden deformation was confined to the immediate panel area. At both panels, overburden movement began when the longwall face was approximately 25% of the overburden thickness beyond the line of MPBX boreholes.

Additional Key Words: subsidence, coal mine subsidence, coal mining, overburden deformation, longwall mining.

Introduction

Mine operators are mandated by law to predict and reduce the effects of subsidence. Previous subsidence research has mainly focused on surface deformations and correlating mining data with ground movement data. Geologic conditions are usually generalized or overlooked. The goal of this Bureau research effort was to identify and characterize the dynamic response of the overburden rock mass due to longwall mining.

Site Description

The study area was situated over two adjacent longwall panels in southeastern Ohio. Each panel measured approximately 270.0 m by 2,700.0 m. The panels were separated by a five-entry, four-pillar system (about 105 m wide). The extraction thickness ranged from 1.7 to 1.8 m. Overburden ranged from 64.2 to 84.0 m. The strata have a regional dip of about 1° toward the southeast. There are no major geologic structures, and the topography is mainly of rolling hills with a maximum relief of approximately 26.0 m.

The overburden consists of approximately 30% sandstone, 30% shale, 30% claystone, and 10% coal (fig. 1). For the most part, all of the lithologic units are laterally continuous. Individual units are generally thin, ranging in thickness from less than 1 m to about 6.0 m. Exception to this is a sandstone unit, approximately 15 m thick 33 m above the coalbed.

Monitoring Program

This project was designed to measure, identify, and characterize overburden strata deformations.

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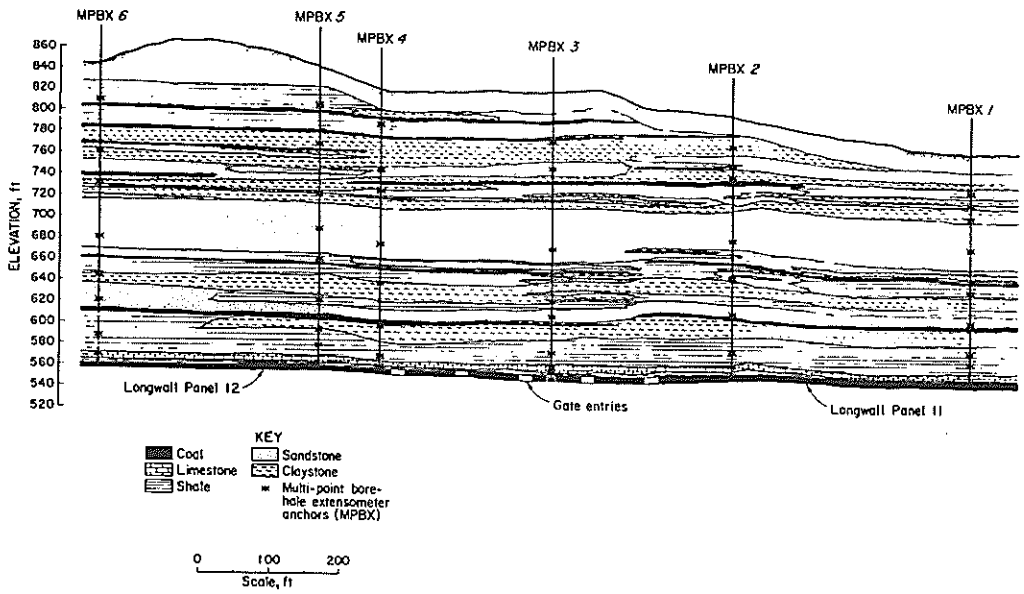

Figure 1. Cross section of the lithology with MPBX borehole and anchor location.

Overburden Failure

Six 219.1-mm boreholes were drilled along a profile line extending across the two longwall panels. Each borehole was outfitted with an eight-anchor multipoint borehole extensometer (MPBX). During this study, MPBX anchor displacements at each borehole were recorded every hour.

The MPBX anchor locations were selected to verify the theoretical zones of overburden deformation. Two of the eight anchors in borehole 3 were installed inside a coal pillar to monitor any pillar yielding. They are numbered one through eight downward from the surface.

All of the MPBX boreholes were located at strategic locations as dictated by surface subsidence theory (Peng and Chaing 1984). Boreholes 1 and 6 were located in the center of each panel, where the maximum amount of subsidence was expected to occur. Boreholes 2 and 5 were located 30.0 m from the ribline inside each panel at positions where the inflection point was expected to occur. Borehole 4 was situated 3.0 m from the ribline inside panel 12. This location was in the expected zone of maximum horizontal tension. Borehole 3 was located in a pillar in the gate entries between the panels to observe the lateral extent of overburden deformation.

Surface Subsidence Monitoring

Survey monuments were installed over the study area to monitor the surface deformation during longwall mining. Surface monitoring was necessary to identify the dynamic subsidence and, the final subsidence profile, and to reference the MPBX head assemblies. Survey measurements were scheduled before, during, and, after mining. Frequency of the surveys was increased to twice a week while the study area was being undermined.

Field Data Results

MPBX Boreholes

Typically, the first strata to collapse and have the greatest displacement are located immediately above the void created by the extraction. The magnitude of deformation is progressively reduced, moving upward and outward through the overburden from the center of the panel toward the surface. Provided the anchors remain intact during the entire event, the deepest anchor (anchor 8) should displace first and show the largest movement, while the overlying anchors progressively show less and less displacement. Inevitably some of the anchors become loose or fail.

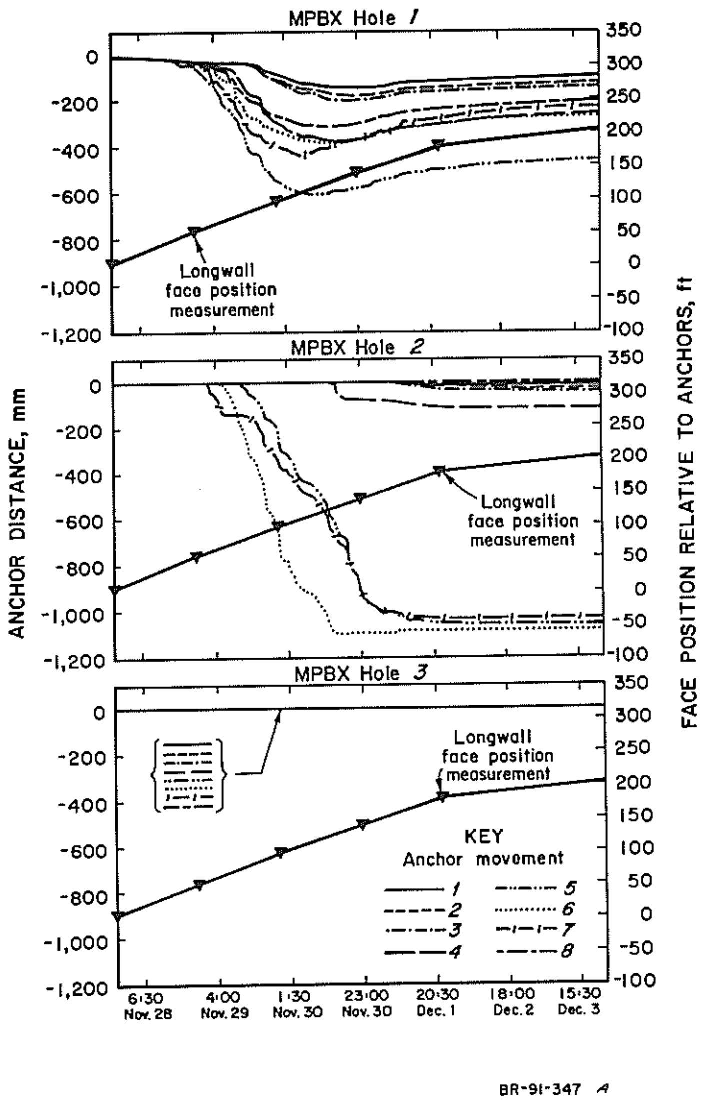

Figure 2. Anchor displacement for MPBX boreholes 1, 2, and 3.

All measurements are relative to differential movement between the MPBX anchors and the surface. No adjustments have been made for surface ground movement except with respect to final displacement. The following observations were made from the MPBX data.

MPBX Borehole 1. The total surface subsidence was 1,036 mm. The final order of anchor displacement (in decreasing order of magnitude) was 5 - 6 - 4 - 7 - 8 - 3 - 2 - 1 (fig. 2, borehole 1). Anchor 5 had the largest displacement of 467 mm. Anchors 6, 7, and 8 failed.

MPBX Borehole 2. Total surface subsidence at this borehole was 548.6 mm. The final order of anchor displacement (in decreasing order of magnitude) was 6 - 5 - 7 - 4 - 3 - 2 - 1 - 8 (fig. 2, borehole 2). Anchors 6, 7, and 8 failed. Anchor 5 is the deepest reliable anchor with the largest displacement of 1,056 mm.

MPBX Borehole 3. The maximum surface subsidence was 27 mm. There was no significant movement of any of the anchors in this borehole (figs. 2 and 3, borehole 3). During the mining of panel 11, the maximum movement of any anchor was less than 2 mm. During the mining of panel 12, the maximum displacement of the anchors was less than 1 mm.

MPBX Borehole 4. Total surface subsidence was measured at 152 mm. The final sequence of anchor displacement (in decreasing order of magnitude) was 6 - 4 - 3 - 8 - 2 - 5 - 1 - 7 (fig. 3, borehole 4). Anchor 6 showed the largest displacement of 15 mm. Anchors 8, 7, and 5 failed.

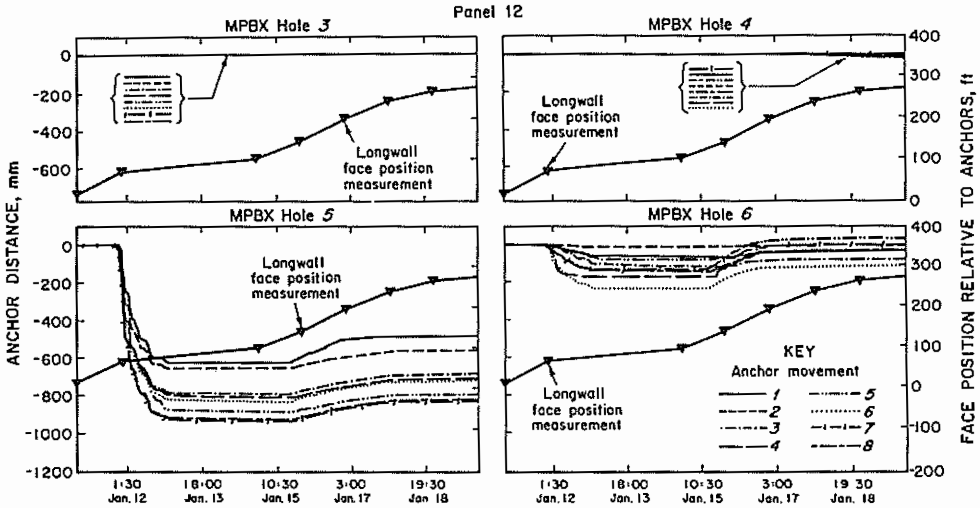

Figure 3. Anchor displacement for MPBX boreholes 3, 4, 5, and 6.

MPBX Borehole 5. Final surface subsidence was 701 mm. The final sequence of the anchor displacement (in decreasing order of magnitude) was 7 - 8 - 5 - 6 - 4 - 3 - 2 - 1 (fig. 3, borehole 5). Anchor 7 had the largest displacement of 830 mm. Anchors 8 and 6 failed.

MPBX Borehole 6. Final surface subsidence was 1,036 mm. The final sequence of anchor displacement (in decreasing order of magnitude) was 6 - 3 - 1 - 8 - 4 - 2 - 7 - 5, (fig. 3, borehole 6). Anchor 6 showed the greatest amount of displacement of 109 mm. Anchors 8, 7, 5, 4, and 2 failed.

Surface Subsidence

Thirty five surveys were conducted of the surface monument array during the study. The maximum subsidence for both panels ranged from 0.9 to 1.1 m, or from 55% to 62% of the average extraction thickness. Figure 4 shows the percentage of the final subsidence plotted against the face position in terms of overburden thickness for both baseline surveys and boreholes 1 and 6. Movement of the surface generally began with undermining. Subsidence was over 90% complete when the mining was the thickness of the overburden past any surface point.

Figure 5 displays the final subsidence profile between the two baselines. The profile of the subsidence between the ribline and baseline varies somewhat between the two panels. At panel 11, the inflection point occurs about 33.9 m from the ribline, while at panel 12 it is at 30.0 m. The most pronounced difference between the two panels is the distance between the first point of the maximum subsidence and the ribline. At panel 11, it is approximately 129 m from the ribline, while at panel 12 it occurs at 89.1 m.

Discussion and Interpretation of Overburden Response Panel 11

When panel 11 was mined, only boreholes 1 and 2 were affected. Deformation was first observed in the strata located immediately above the mined coalbed in the center of the panel. The deformation then radiated outward and upward toward the surface and panel margins. The overburden began to respond when the longwall face was approximately 16.2 m beyond the line of the boreholes. The overburden appeared to reach stability when the longwall face was 54.0 m beyond the line of boreholes.

The lowest three anchors (8, 7, and 6) in boreholes 1 and 2 failed. The deepest reliable anchor in both boreholes was anchor 5, positioned below the 15.0-m-thick sandstone unit. Anchor 4, in both boreholes, was situated in the lower portion of the same sandstone unit. Anchor 5, positioned 25.5 m above the void area in borehole 1, displaced a total (including surface subsidence) of 1,504 mm, or 84% of the extraction thickness (table 1). For the remaining intact anchors in borehole 1, total anchor displacement uniformly decreased, progressing toward the surface. In borehole 2, anchor 5, located 27.3 m above the mine void area, displaced a total of 1,631 mm, or 92% of the extraction thickness (table 1). Unlike borehole 1, borehole 2 (fig. 2, borehole 2), showed a large difference between the total displacement of anchor 5 and the overlying anchors.

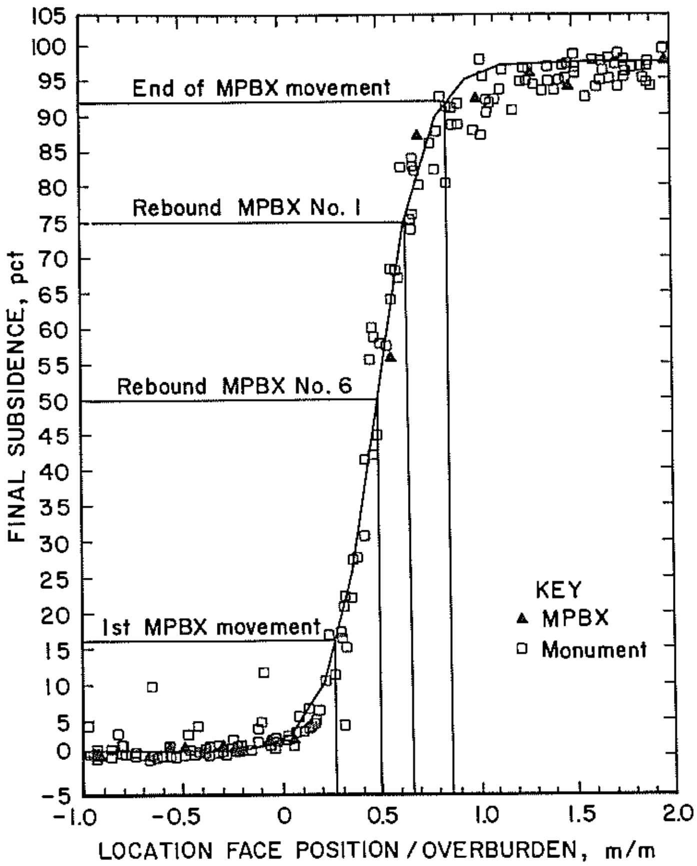

Figure 4. Final surface subsidence baseline data.

This indicates that the sandstone partially supported by the gate road pillars bridged over the collapsed zone at the margin of the mined panel.

Based on all the available data, it is thought that the overburden responded as two zones, a lower caved zone, and an upper zone more representative of a combined fractured and bending zone (fig. 6). It is believed that the lower zone extends from the top of the mined coalbed to the base of the 15.0-m-thick sandstone unit (or a maximum of 18.8 times the extracted coalbed height). The upper zone is interpreted to extend from the bottom of the sandstone unit to the surface.

The lower zone appears to have collapsed into the void area as a unit. The upper zone appears to be influenced by the thick sandstone unit, which is sagging and bending towards the center of the mined area. The lack of movement in borehole 3 indicates that these two zones are confined laterally to the area of the panel.

Panel 12

When panel 12 was mined, boreholes 4, 5, and 6 were affected. Initial response occurred in the overburden areas along the margin of the panel. This may have occurred because the tail gate side of the longwall face (located close to borehole 5) was approximately 3.0 m ahead of the head gate side. Next, overburden movement progressed rapidly toward the center of the panel. In either case, the overburden appeared to collapse, at least initially, as a unit. Finally, movement was detected along the ribline of the panel (borehole 4). Anchor movement began when the longwall face was 17.1 m beyond the line of boreholes and continued until the face was about 72.0 m beyond the boreholes.

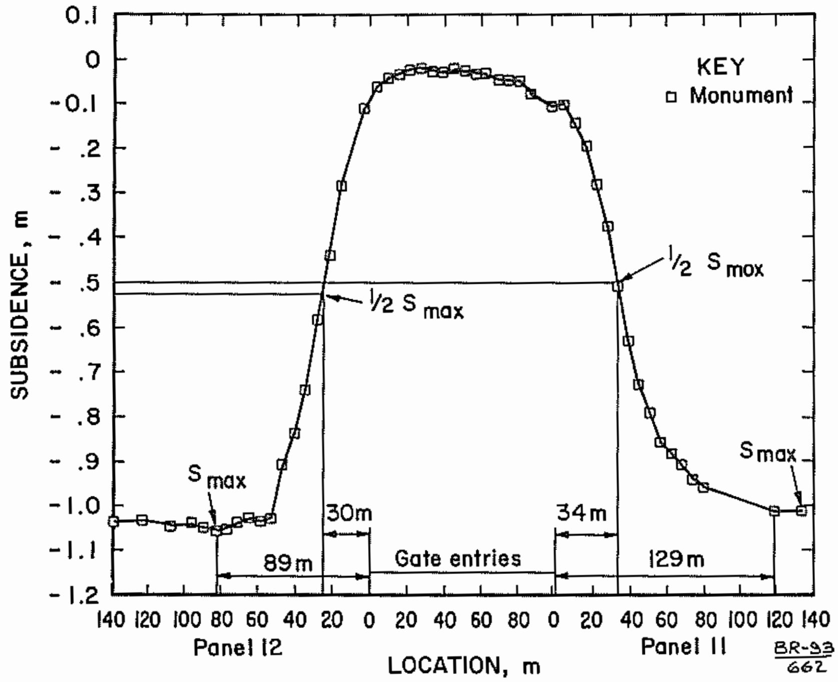

Figure 5. Final surface subsidence profile.

Table 1. MPBX anchor location (height (H)[1] and displacement (D).[2]

	Borehole No.											
	1		2		3		4		5		6	
	H[1]	D[2]	H	D	H	D	H	D[3]	H	D	H	D
Ground surface	64	58	74	31	78	0	81	0	82	41	84	58
Anchor 1	54	64	64	32	69	0	70	0	73	68	74	61
Anchor 2	50	65	57	32	50	0	58	0	63	72	62	F
Anchor 3	46	66	54	34	36	0	52	0	50	80	50	62
Anchor 4	38	73	38	39	17	0	36	0	39	81	38	F
Anchor 5	26	84	27	92	7	0	25	0	31	86	27	F
Anchor 6	16	F[4]	18	F[5]	2	0	13	0	19	F	19	64
Anchor 7	8	F	9	F	1	0	4	0	10	88	9	F
Anchor 8	6	F	5	F[5]	0	0	2	0	6	F	4	F

[1]Height expressed in meters extraction area.
[2]Total displacement expressed as a percentage of extracted thickness.
[3]Total displacement percentages less than 1% are expressed as 0.
[4]Anchor failed.
[5]Anchor failure, displaced beyond range of counterweight movement.

Final overburden failure characteristics for panel 12 are not well defined because the only anchors that remained reliable in borehole 6 were Nos. 1, 3, and 6. The displacement data from these anchors show that the strata in the center of the panel moved as expected. Anchors 7 and 8 failed as soon as movement began. Anchor 6 (positioned 19.2 m above the coalbed) had a total displacement of 1,168 mm or 64% of the extraction thickness (table 1). The magnitude of displacement for anchors 3 and 1 uniformly decreased progressing toward the surface.

At borehole 5, anchors 8 and 6 failed. Anchor 7 was the deepest reliable anchor and was positioned 10.2 m above the coalbed. The total displacement was 1,565 mm, or 88% of the extraction thickness (table 1). The displacement of the overlying anchors decreased uniformly towards the surface.

Based on the MPBX data, it is thought that response of the overburden in the center of the panel was different than along the margin of the panel (fig. 6). In the center of the panel, it is believed that the caved zone exists below anchor 6. The strata from anchor 6 and above uniformly responded as a combined fractured and bending zone. Along the margin of the panel, it is believed that the entire column of overburden collapsed as a unit into the void area with no other distinguishable zones of deformation. Finally, based on the lack of movement in boreholes 3 and 4, strata deformation is confined within the panel margins.

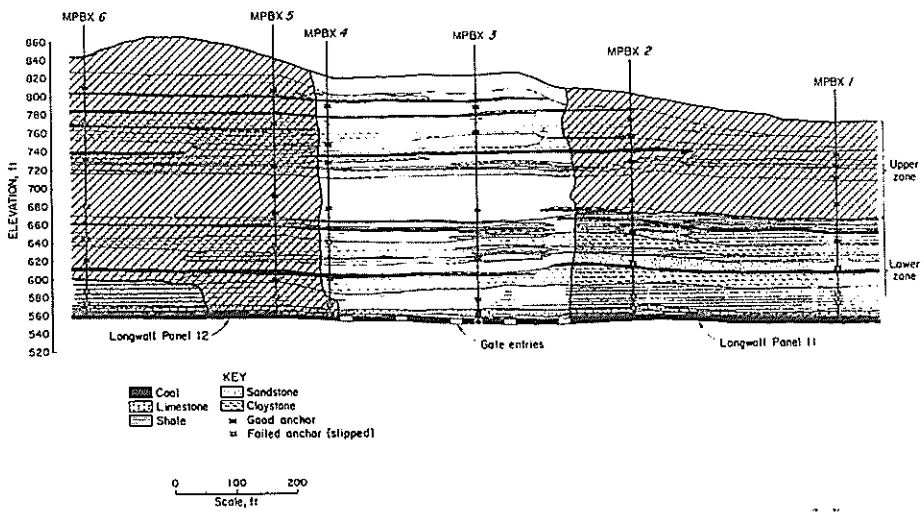

Figure 6. Interpretation of overburden strata collapse bases on MPBX information.

Surface Subsidence

Several observations can be made when the final surface subsidence from the baseline array is compared with the displacements of the surface assemblages at boreholes 1 and 6. Figure 4 illustrates the combined surface subsidence data from both baseline arrays. By combining the two data sets, a reasonable dynamic subsidence curve is obtained. Plotting surface subsidence from MPBX boreholes 1 and 6 on this curve (indicated by triangles) shows the validity of using the composite curve to describe the dynamic movement for the borehole 1 and 6 surface locations.

When differential movement between the anchors and the surface began in both boreholes (i.e., anchors started to displace), the longwall face was about 25% of the overburden thickness beyond the boreholes. Surface surveys indicate that the surface had already subsided 15% of the total final subsidence at this time. When the surface at borehole 1 began converging on the anchors, the face was approximately 60% of the overburden thickness past the borehole. At that time, the surface had already subsided approximately 75% of the final subsidence. For borehole 6, convergence began when the face was approximately 50% of the overburden thickness beyond the borehole. At that point, the surface at borehole

6 had subsided about 50%. Finally, when the anchors stabilized, or the differential movement between the anchors and the surface ceased in both boreholes, the longwall face was about 85% of the overburden thickness past the boreholes. At this point, less than 10% of subsidence remained to occur.

Additional observations can be made with respect to the final surface profile (fig. 5). The maximum surface subsidence is not at the center of panel 12. This correlates with the interpretation that the strata surrounding MPBX borehole 5 collapsed as a unit rather than as two distinct zones as interpreted in MPBX borehole 6. This is to say that the unit collapse caused greater surface subsidence around borehole 5 by the absence of a caved zone that would have caused more strata bulking and less surface subsidence.

Summary and Conclusions

Overall, there were significant similarities and differences in the development and final characteristics of the overburden response over two adjacent longwall panels. Both areas had similar mining geometries and geologic characteristics. Other major similarities observed from this investigation include –

1. Initial differential movement between the MPBX's and the surface began when the longwall face advanced 25% of the overburden thickness beyond the MPBX boreholes.

2. Differential movement between the MPBX's and the surface stabilized when the longwall face advanced approximately 85% of the overburden thickness beyond the MPBX boreholes.

3. Approximately 15% of the total subsidence occurred before, and less than 10% of the total subsidence occurred after, differential movement between the MPBX's and the surface.

4. There was no significant movement in the overburden over the gate entries during the mining of either panel.

Major differences that were observed during this investigation include –

1. Initial ground movement occurred in the center of panel 11 and along the margin of panel 12.

2. The development of overburden response to undermining occurred in stages over panel 11 and as a unit over panel 12.

3. Final overburden failure characteristics were different for the two panels. Two zones of deformation occurred uniformly over panel 11. Over panel 12, the failure characteristics in the center of the panel were identified as two zones of deformation and one zone of deformation along the margin of the panel.

While the mining geometries and geology of the two adjacent panels were nearly identical, the response to the subsidence process was not.

References

Peng, S. S. and H. S. Chaing. 1984. Longwall mining. Ch 2, Strata mechanics. Wiley, New York. p. 17-72.