Appendix 3-C

Prediction of Mining-induced Surface Movements and Ground Deformations Associated with the Proposed Mining Plan for the Murray Coal Project

REPORT

PART 2 - PREDICTION OF MINING-INDUCED SURFACE MOVEMENTS AND GROUND DEFORMATIONS ASSOCIATED WITH THE PROPOSED MINING PLAN FOR THE MURRAY COAL PROJECT

PREPARED FOR HD MINING INTERNATIONAL LTD

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Introduction

HD Mining International, Ltd commissioned Xtraction Science and Technology Inc. (XS&T) to perform a subsidence study as part of their Environmental Assessment package for the multiple seam mining operation known as the Murray River Coal Project. This report constitutes the second part of the study. HD Mining International, Ltd has proposed to conduct an underground longwall mining operation, using regular and top caving methods, in a number of coal seams within the Murray River Property. The project site is located about 12.5 km southwest of the district municipality known as Tumbler Ridge in northeastern British Columbia, Canada.

The coal units to be mined are buried at considerable depths (up to 1,250 m or 4,100 ft). The thicknesses of the coal seams vary considerably too. There are a number of geological features (i.e., faults and folds) that traverse the property. Due to these geological conditions, only a portion of the mineable coal seams within the property boundary will be mined by longwall mining methods. The design of the longwall panels in each coal seam are laid out in a pattern similar to that practiced in China. According to the proposed mining plan, the single-slice longwall mining method will be conducted for thinner upper coal units and the top coal caving method will be used for thicker subjacent coal units.

Traditionally, mining operations have occurred remotely from population centers. Because of the remote locations, few were exposed to subsidence effects, and there was little concern for the alteration of the local environment. Today, the juxtaposition of mining, population, farming and industry has made it necessary that each control its effects on the others. For underground mining, this means that a general lack of concern for the local environment is no longer tolerable or acceptable. The subsidence processes associated with the planned longwall mining operations in the Murray River Mine may be impact the ground surface, various buildings (if any are located in the area) and man-made structures (roads, pipelines and power lines), water bodies, and other resources overlying their workings (Adamek 1987).

Upon the direction of HD Mining, XS&T has conducted an extensive subsidence study according to the proposed mining plan to assess the possible subsidence impacts. In this study, the final surface subsidence effects that will be created in the first three years of mining operations are predicted. For the duration of the mine, subsidence predictions are made along three major cross-sections where largest impact will be observed. Based on the subsidence predictions, areas that could be impacted by the subsidence processes will be identified.

Subsidence Prediction Model

The modeling work contained in this report was conducted by Dr. Yi Luo, Associate Professor, Department of Mining Engineering at West Virginia University. Dr. Luo specializes in prediction and control of mine subsidence. Dr. Luo developed Comprehensive and

Integrated Subsidence Prediction Model (CISPM-W). CISPM is a computer program package for predicting surface subsidence induced by underground mining operations. Dr. Luo has conducted numerous projects on assessing and mitigating subsidence influences on various residential, industrial and public structures and water bodies. He has conducted various investigations on abandoned mine subsidence. He has served as expert witness for many subsidence related issues.

The art of subsidence prediction is believed to have begun in Europe in the early 1800's. In a general sense, subsidence prediction models can be broadly classified into three groups: 1) theoretical models based on elastic, plastic and viscoelastic methods which are widely used in the engineering fields; 2) numerical solutions, most widely used as solutions to complex situations; and 3) empirical or semi-empirical methods, such as profile functions and influence functions and the zone area method. (Karmis et al., 1986) The models based on theoretical and numerical methods usually require extensive information about the properties of the overburden to be properly calibrated for a particular field site. On the other hand, models based on the empirical or semi-empirical methods require an extensive set of discrete measurements (Ingram et al., 1989).

The subsidence predictions presented in this study were generated by the program CISPM-W (Luo and Peng, 1989; Peng and Luo, 1992, Luo et al., 2008). The prediction package is based on the influence function method that is widely adopted by the major mining countries including US coal mining industry. More than 100 longwall subsidence cases collected in the US have been used in the program development and validation. The program has been successfully used by various mining and consulting companies for numerous and various subsidence projects (Luo et al., 1992, Luo, 2008). Moreover, the program has been successfully employed in numerous cases of assessing the subsidence influences on as well as designing and implementing mitigation measures for various surface structures.

Generally, a subsidence prediction model consists of mathematical models and the derived empirical formulae for final and dynamic subsidence parameters. The mathematical models also include the mathematical functions to represent the subsidence process and its outcomes and the computational procedures to value these functions accurately and efficiently. It should be notes that a large number of mathematical functions were developed to form the backbone of CISPM.

CISPM is capable of predicting final surface subsidence troughs induced by longwall mining and room and pillar mining operations as well as predicting dynamic (time dependent) subsidence induced by longwall operation. For longwall mining operations, it predicts final and dynamic subsidence troughs over a longwall district which may consist of one or several longwall panels (the plane-view shape of each panel is rectangular). The program is capable of predicting final surface subsidence (S), horizontal displacement (U), slope (i), strain (ε) and curvature (k) for up to 3,000 surface points of interest. The points can be distributed evenly along a straight line or randomly in an area in the subsidence trough. For those direction-dependent indices (i.e., U, i, ε and k), their magnitudes can be determined along any specified directions and/or along their principal directions. Mathematically, slope and curvature are the first and second derivatives of the subsidence, respectively while strain is the first derivative of horizontal displacement.

Effects of Mining-Induced Subsidence

Note, determination of the effects of mining-induced subsidence have not been included in this study, but may be studied at some time in the future based on information derived from this work. It is a well known fact that mining-induced subsidence can cause various influences to the ground surface and man-made surface structures. However, due to its immediate occurrence and predictable nature, the effects of this type of subsidence can be accurately assessed and effectively mitigated if actions are planned in advance of mining.

Subsidence Predictions

In order to assess potential subsidence influences, a good understanding of the surface movements and deformations should be gained first through subsidence predictions. In this section, the subsidence predictions are made in two stages. In the first stage, detailed subsidence predictions are made for the longwall panels mined in the first three years. In this stage, the subsidence troughs formed over the mined panels and the area distributions of final surface movements and deformations are presented. In the second stage, the profiles of the final surface movements and deformations along three selected cross-sections after all planned panels in the mine have been predicted. The cross-sections are selected to ensure the most sever surface movements and deformations in each of the mining blocks are predicted.

Subsidence Predictions for Mining in D-Seam

According to the proposed mining sequence, the company will mine five longwall panels in the Block 1 in the D-Seam – the upper most mineable coal seam in the property during the first three years of operation. The average overburden depth and mining height used in the subsidence prediction for Block 1 are 1,640 ft (500 m) and 8 ft (2.5 m), respectively. Two longwall panels will also be mined in the Block 2 area in the D-Seam later. The overburden depth in Block 2 is about 950 ft (290 m) and the mining height of 9.0 ft (2.7 m) is assumed there. The planned longwall panels in the D-seam are shown in Fig. 1. These panels vary in length while all except for one (Panel D1105) are 754 ft (230 m) wide. A solid coal pillars of 33 to 36 ft (10 to 11 m) will be left to separate the adjacent panels.

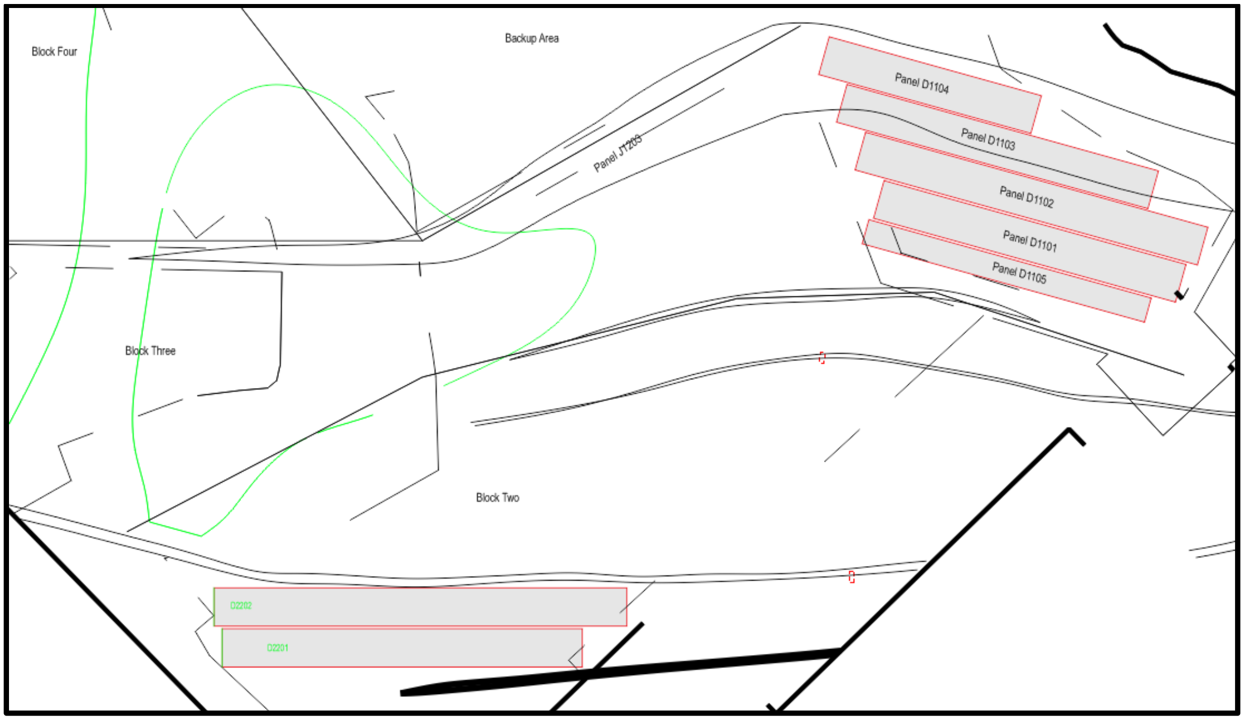

Figure 1 Longwall Panels in D-Seam

Final Subsidence Prediction in D-Seam Block 1

For subsidence predictions in Block 1, the panels have been rotated to make the panel longitudinal direction parallel to the x-direction as shown in Fig. 2. The predictions are separated in the following three steps: panel D1101 mined, panels 1101 and 1102 mined, and all five panels are mined.

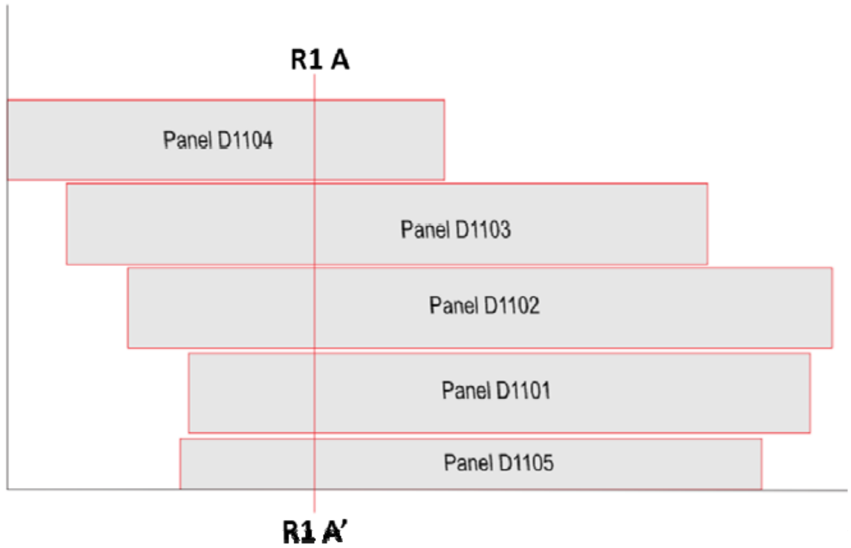

Figure 2 Rotated Five Panels in Block 1 of D-Seam and the Cross-Section for Profiles (Note the profile line is shown in red).

When the panel D1101 has been mined, the predicted surface subsidence, horizontal displacement and strain are presented in Figs. 3 - 5, respectively. Due to the relatively large depth and small mining height, only surface strain in this area is able to cause some problems to some structures. The slope and curvature are too insignificant and they are not presented in this report. For the direction-dependent subsidence indices (i.e., horizontal displacement and strain), their respective components along the panel transverse direction are presented. A high compression zone is formed over the central part of the panel.

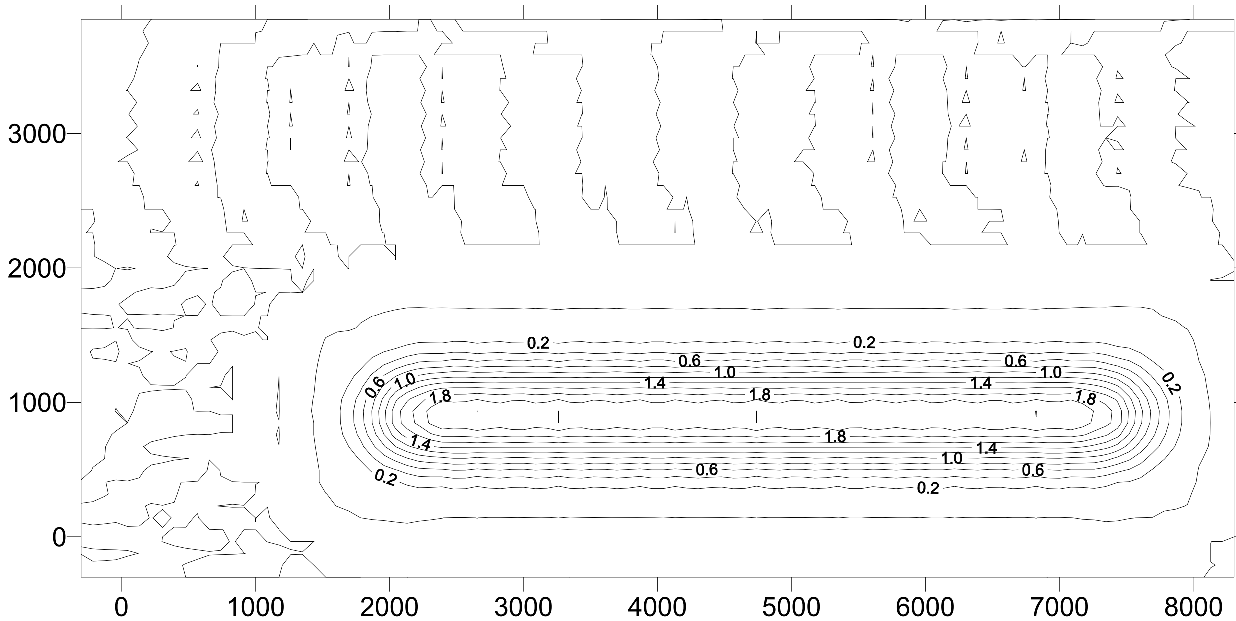

Figure 3 Predicted Final Surface Subsidence Trough after Mining Panel D1101

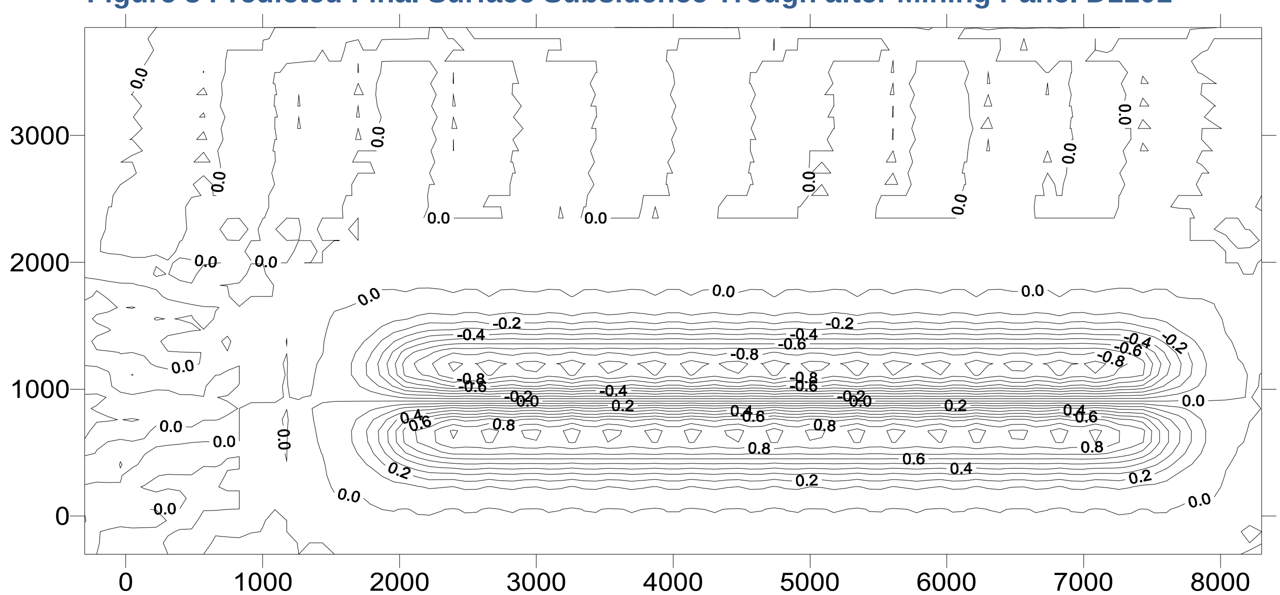

Figure 4 Predicted Final Surface Horizontal Displacement (Transverse Component) after Mining Panel D1101

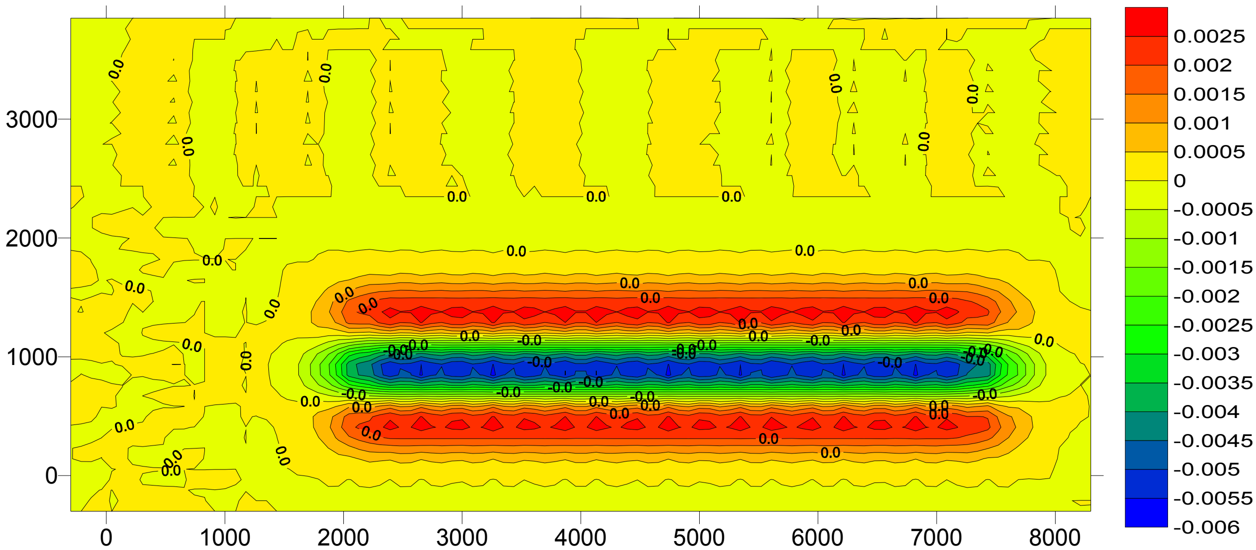

Figure 5 Predicted Final Surface Strain (Transverse Component) after Mining Panel D1101

After the first two panels (D1101 and 1102) are mined, the predicted subsidence, horizontal displacement and strain are shown in Figs. 6 - 8, respectively. In the prediction, the narrow pillar (10 m or 33 ft wide) between the adjacent panels will be completely crushed under the heavy overburden and abutment load.

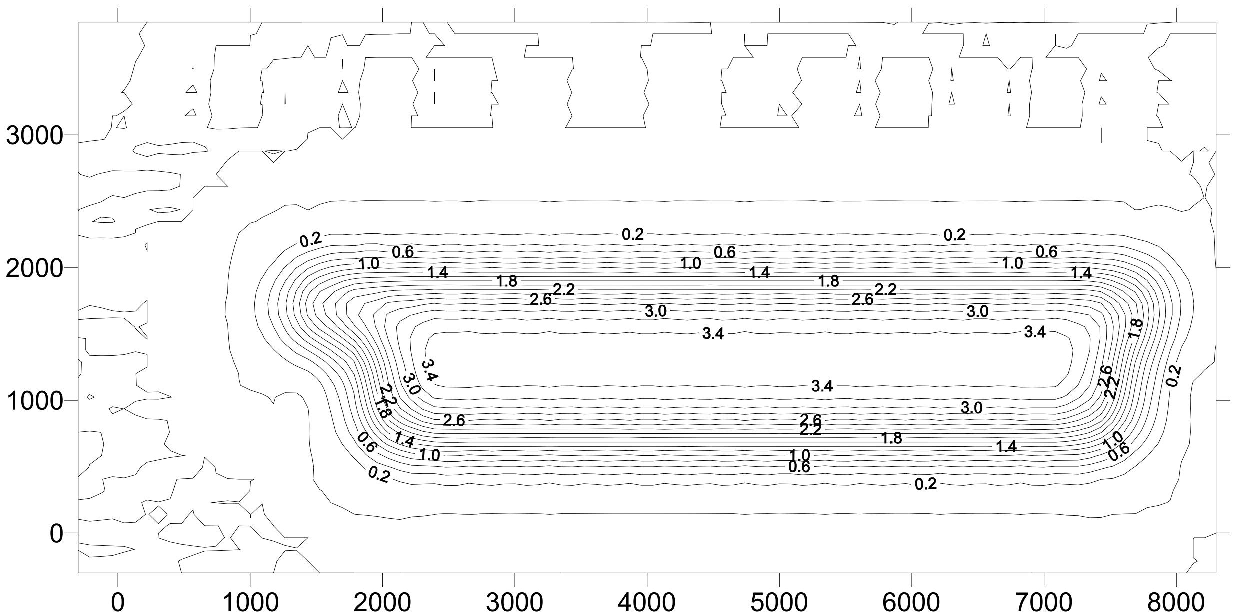

Figure 6 Predicted Final Surface Subsidence Trough after Mining Panels D1101 and D1102

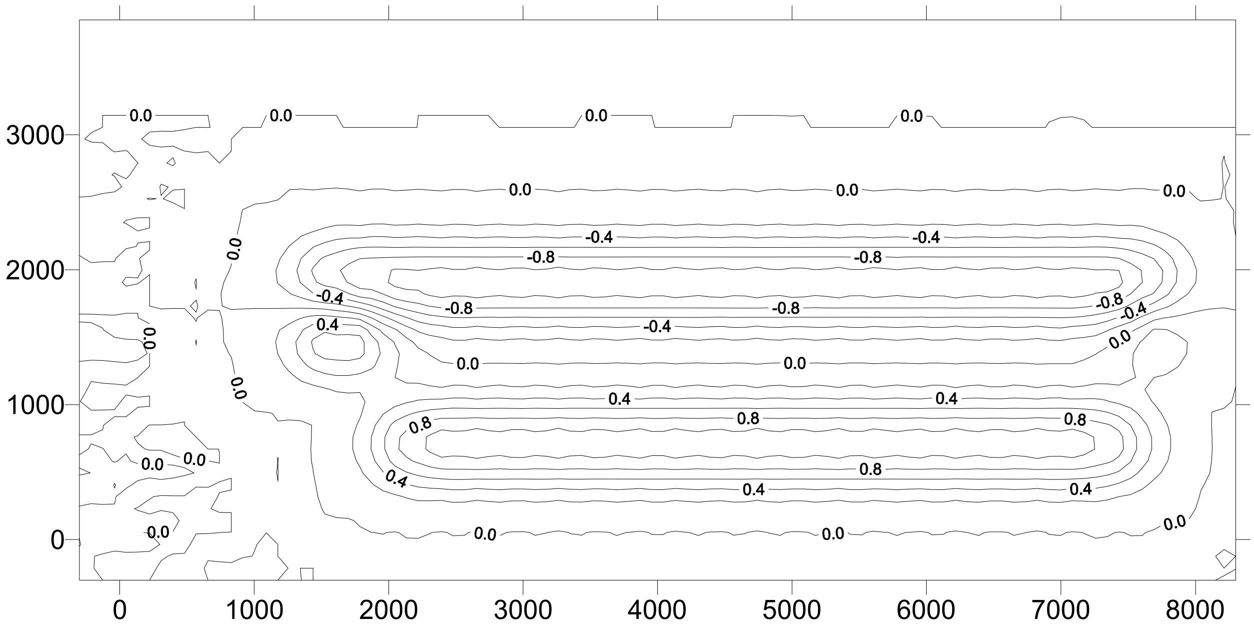

Figure 7 Predicted Final Surface Horizontal Displacement (Transverse Component) after Mining Panels D1101 and D1102

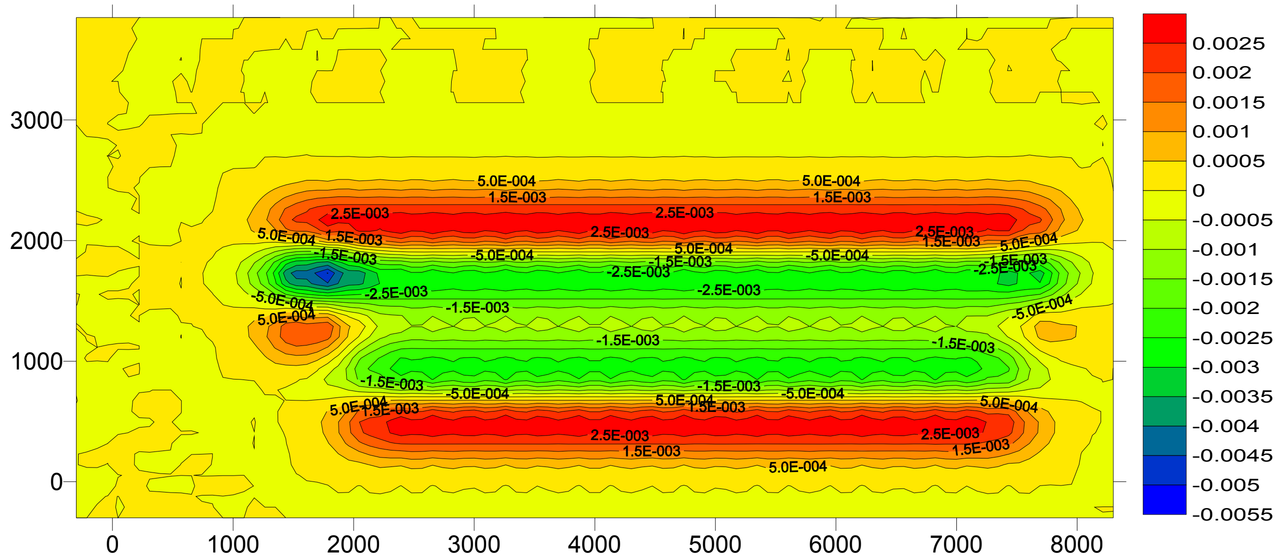

Figure 8 Predicted Final Surface Strain (Transverse Component) after Mining Panels D1101 and D1102

Figures 9 - 11 show the predicted subsidence, horizontal displacement and strain after all five panels in Block 1 in D-Seam have been mined, respectively.

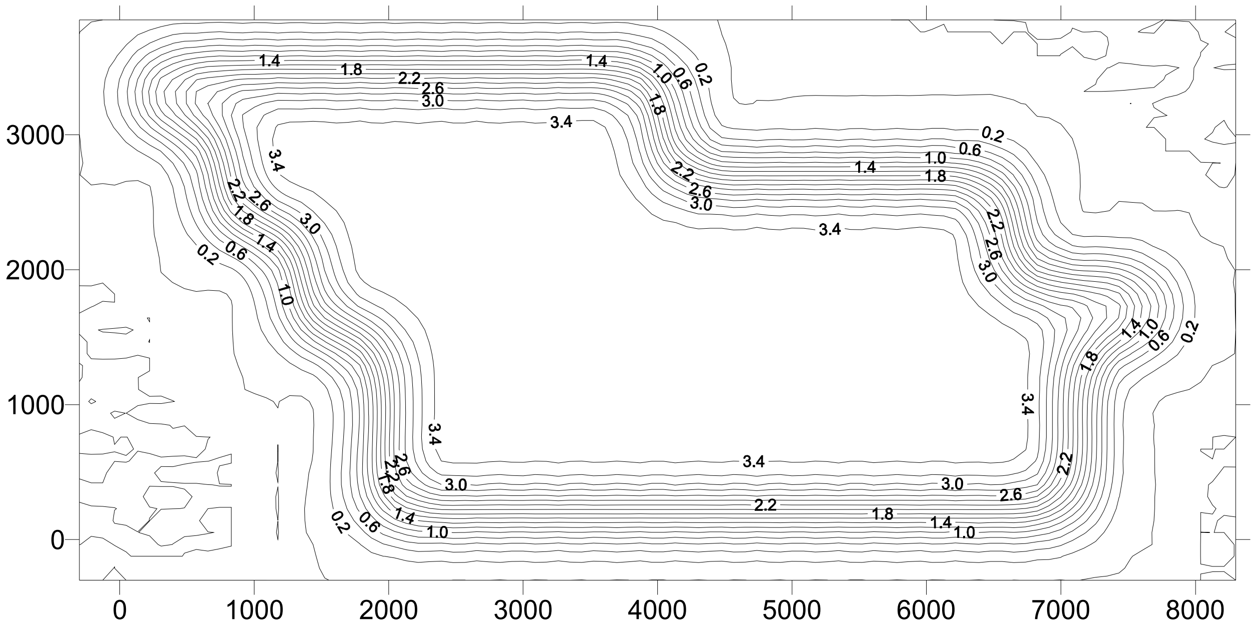

Figure 9 Predicted Final Surface Subsidence after Mining All Five Panels in Block 1 D-Seam

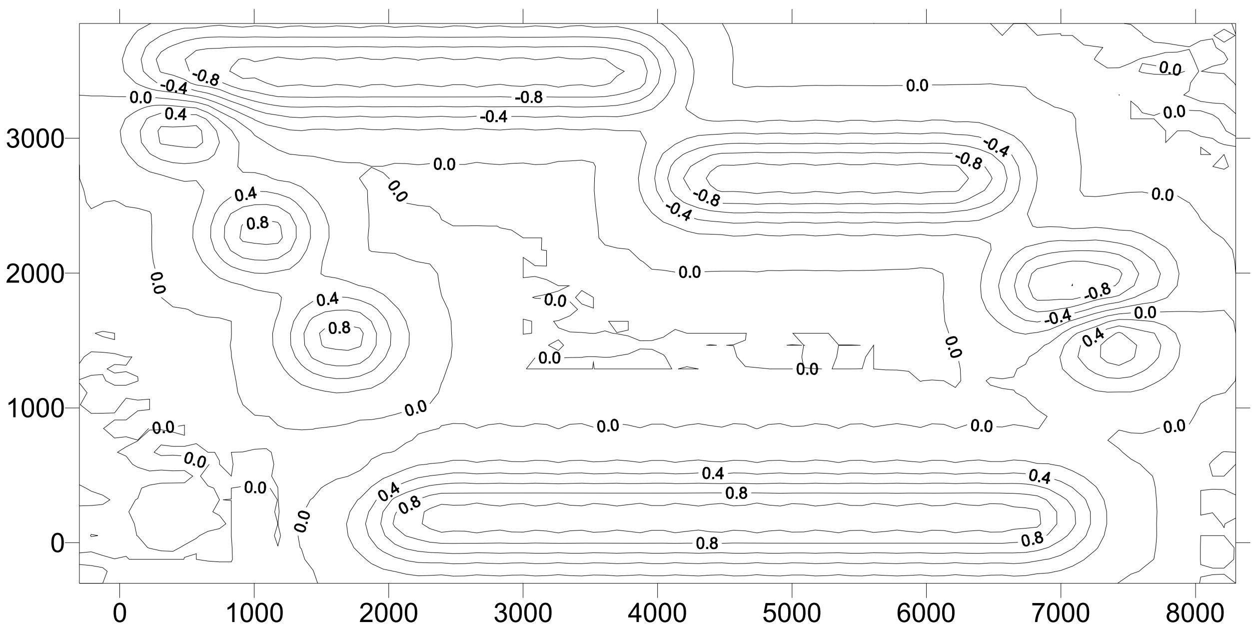

Figure 10 Predicted Final Surface Horizontal Displacement (Transverse Component) after Mining All Five Panels in Block 1 D-Seam

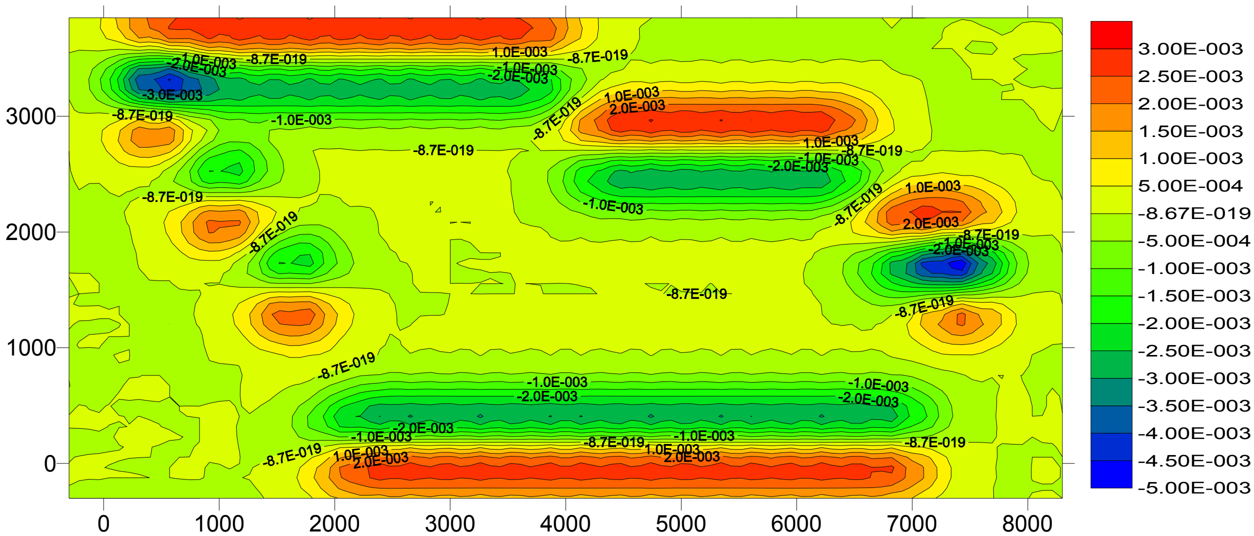

Figure 11 Predicted Final Surface Strain (Transverse Component) after Mining All Five Panels in Block 1 D-Seam

The magnitude of the final surface movements and deformations was predicted for three mining stages (mining of Panel D1101, Panels D1101-02 and Panels D1101-05) along the specified cross-section shown in Fig. 2. The results are shown in Figs. 12 - 16. Based on an intensive subsidence monitoring program conducted at the West Virginia University, the derived **critical slope, tensile strain, compressive strain and curvature to cause problems to common structures are 1.0%, 2.0x10^{-3} ft/ft, -4.0x10^{-3} ft/ft and 6.0x10^{-5} 1/ft**, respectively. Among these predicted surface deformations, only strain is over the limits.

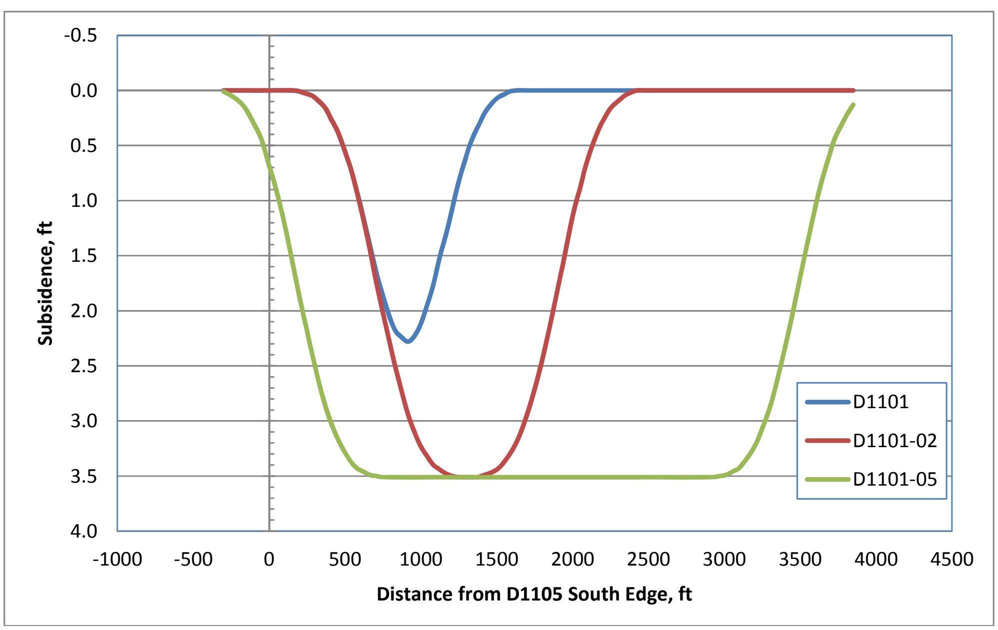

Figure 12 Predicted Final Subsidence Profiles along the Specified Cross-Section in D-Seam Block 1 Line R1A-A'

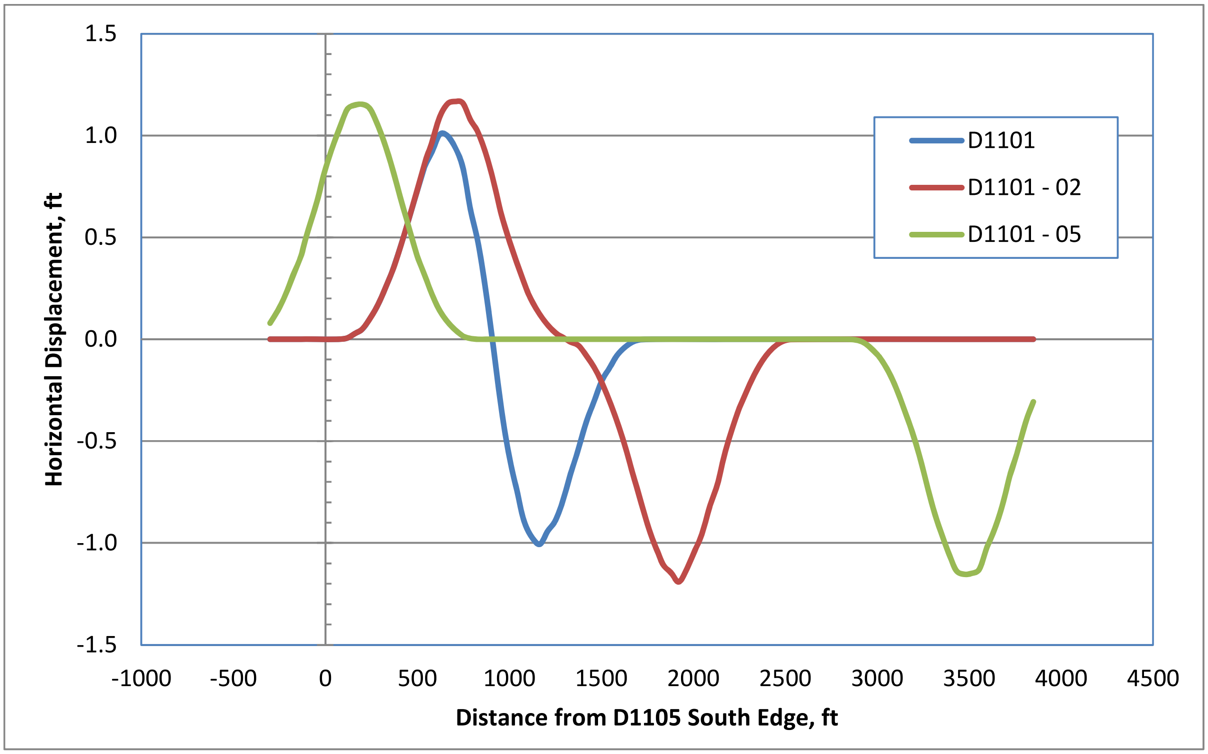

Figure 13 Predicted Final Horizontal Displacement (Transverse Component) Profiles along the Specified Cross-Section in D-Seam Block 1 Line R1A-A'

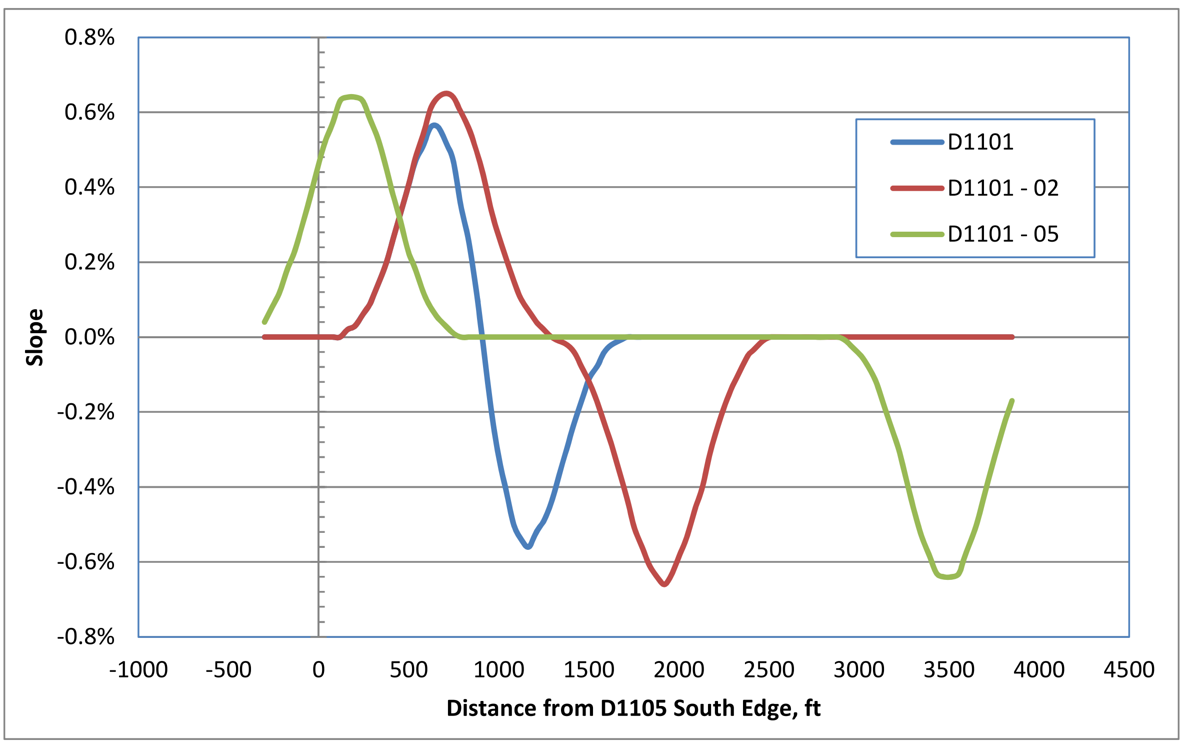

Figure 14 Predicted Final Slope (Transverse Component) Profiles along the Specified Cross-Section in D-Seam Block 1 Line R1A-A'

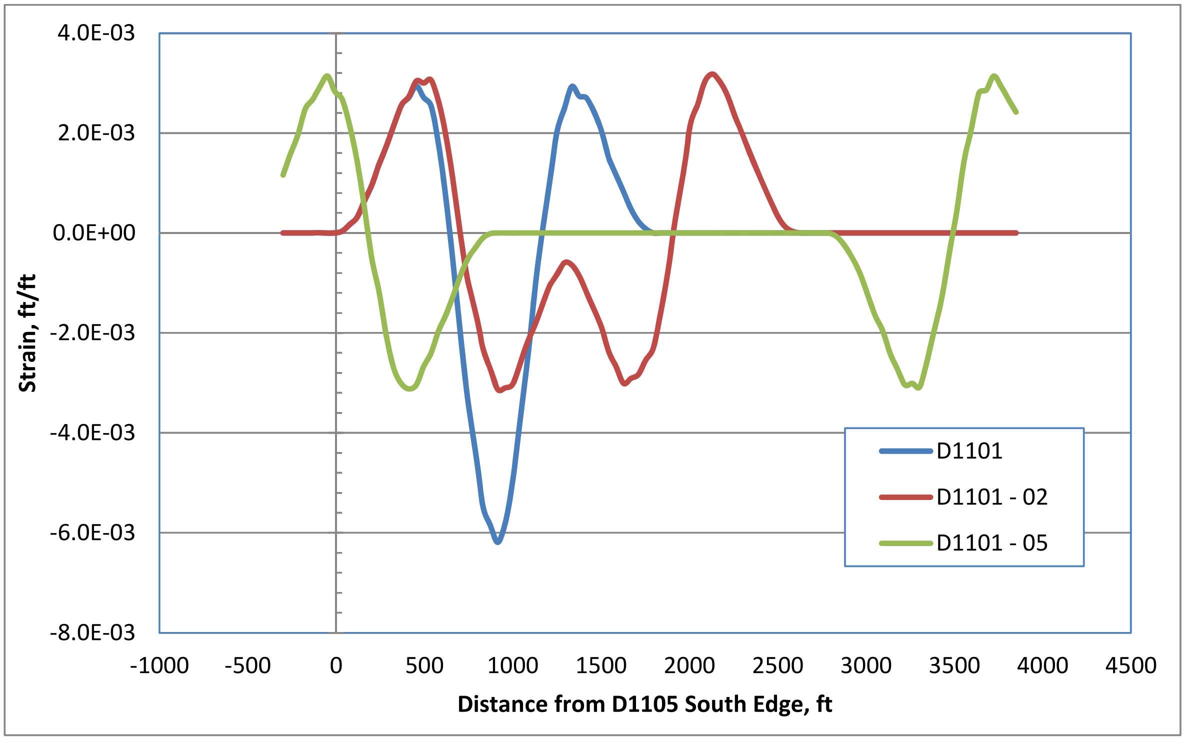

Figure 15 Predicted Final Strain (Transverse Component) Profiles along the Specified Cross-Section in D-Seam Block 1 Line R1A-A'

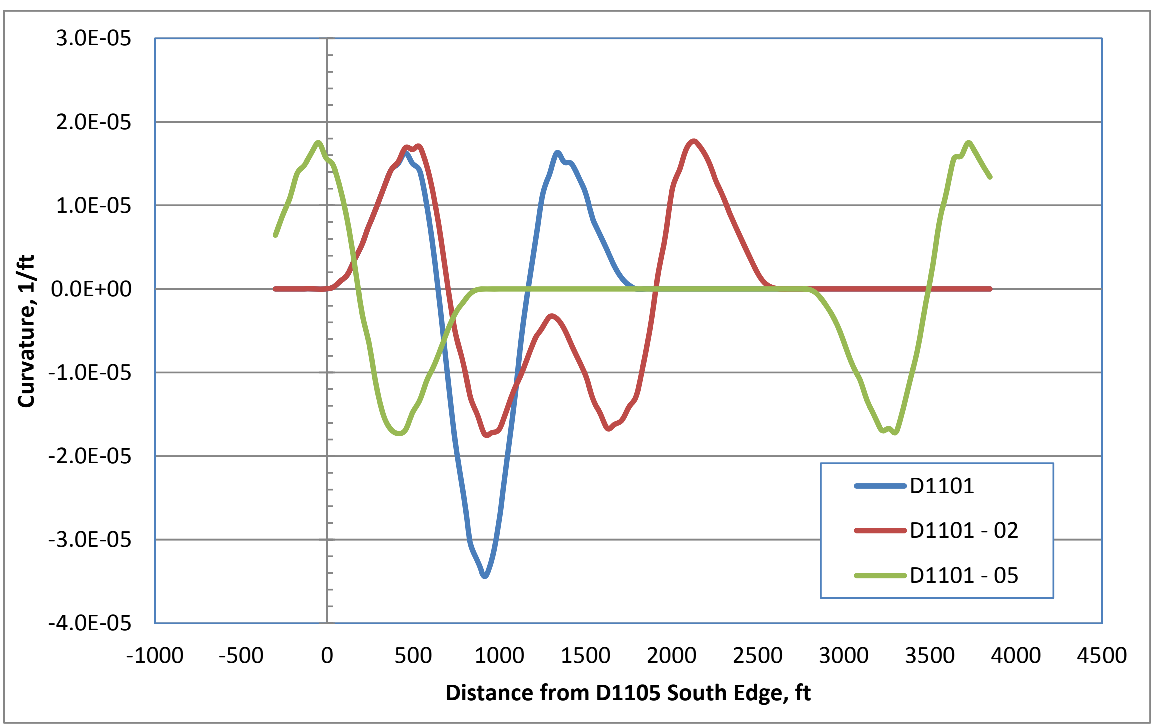

Figure 16 Predicted Final Strain (Transverse Component) Profiles along the Specified Cross-Section in D-Seam Block 1 Line R1A-A'

Final Subsidence Prediction in D-Seam Block 2

This block has a relatively shallow overburden depth (950 ft) and the mining height is expected to be larger than that in Block 1. The subsidence prediction process was conducted in two steps: mining panel D2201, and mining both panels D2201 and D2202. The predicted final surface subsidence, horizontal displacement, slope, strain and curvature after mining panel D2201 are shown in Figs. 17 - 21, respectively. It should be noted all the maximum deformations are significantly higher than their respective critical values.

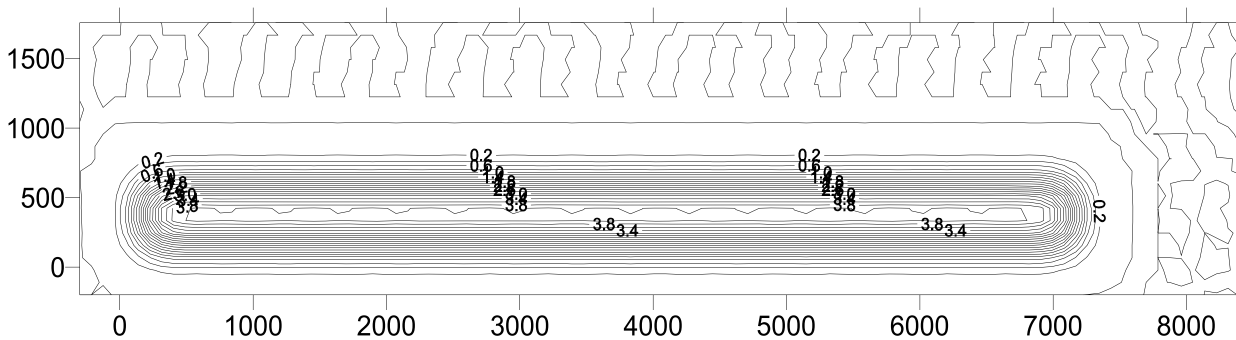

Figure 17 Predicted Final Surface Subsidence after Mining Panel D2201

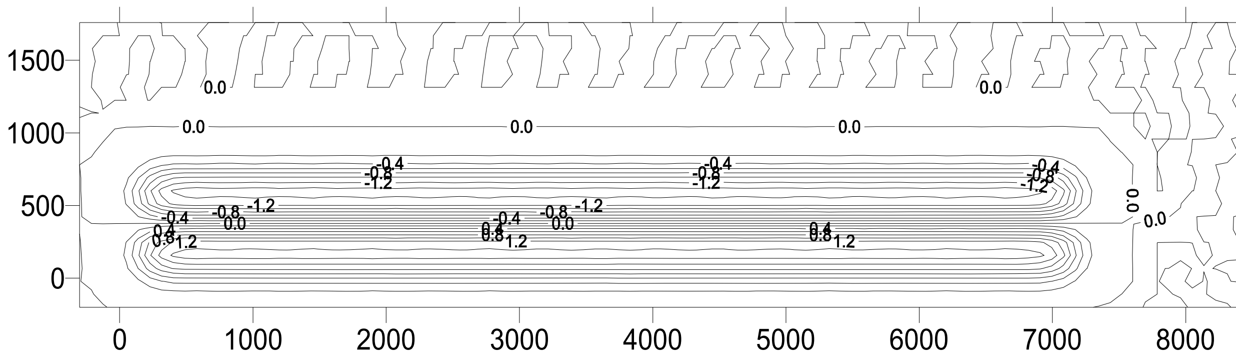

Figure 18 Predicted Final Surface Horizontal Displacement (Transverse Component) after Mining Panel D2201

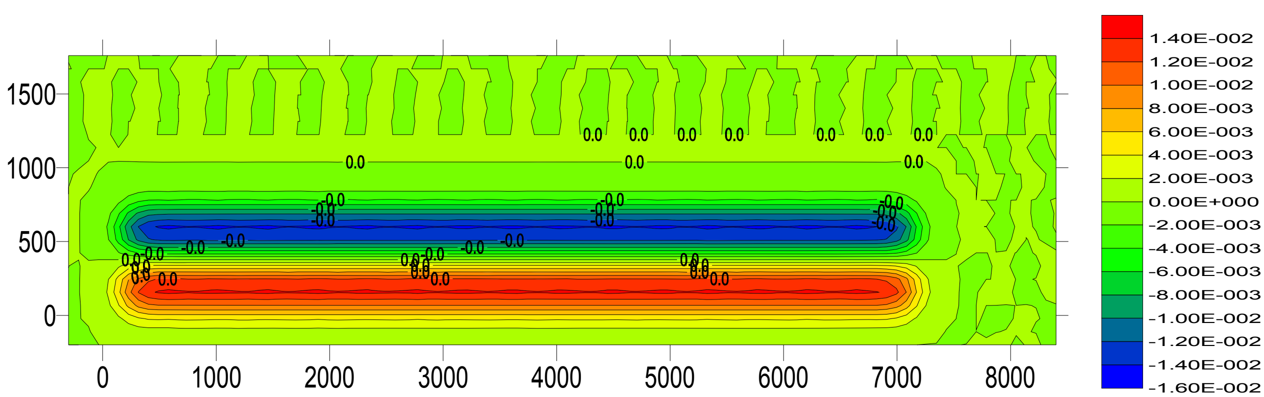

Figure 19 Predicted Final Surface Slope (Transverse Component) after Mining Panel D2201

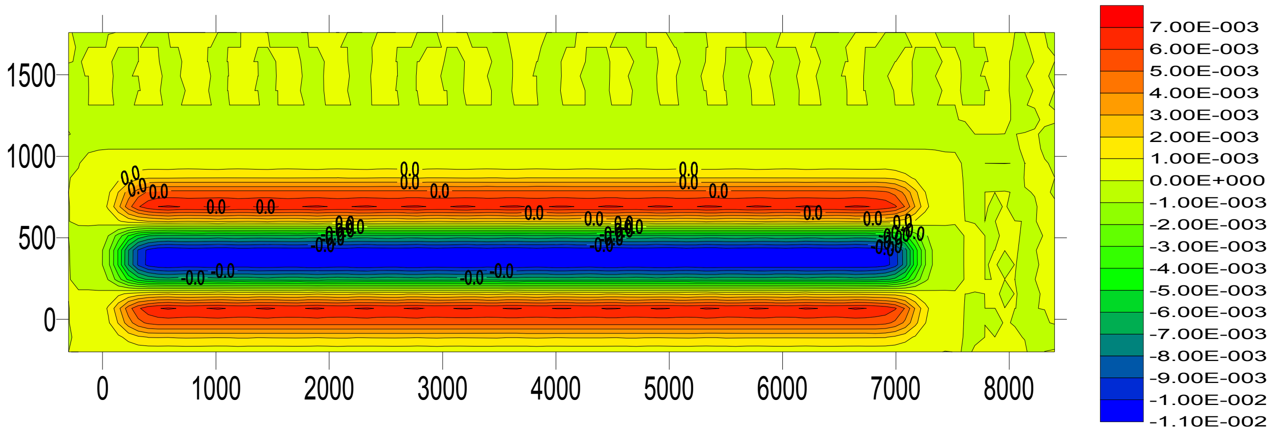

Figure 20 Predicted Final Surface Strain (Transverse Component) after Mining Panel D2201

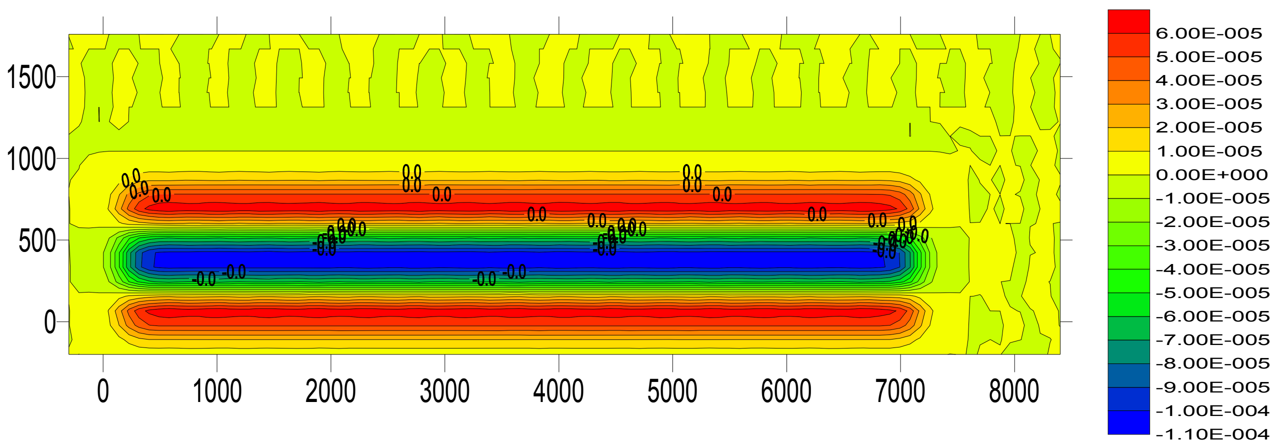

Figure 21 Predicted Final Surface Curvature (Transverse Component) after Mining Panel D2201

Mining of panels D2201 and D2202 will expand the subsidence trough. The results are shown in Figs. 22- 26, respectively.

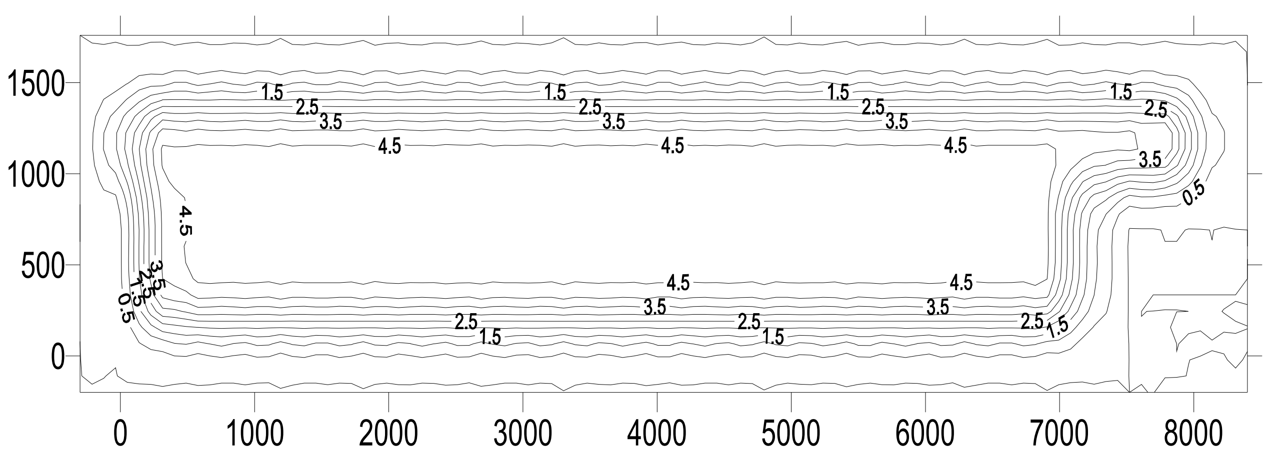

Figure 22 Predicted Final Surface Subsidence after Mining D2201 and D2202

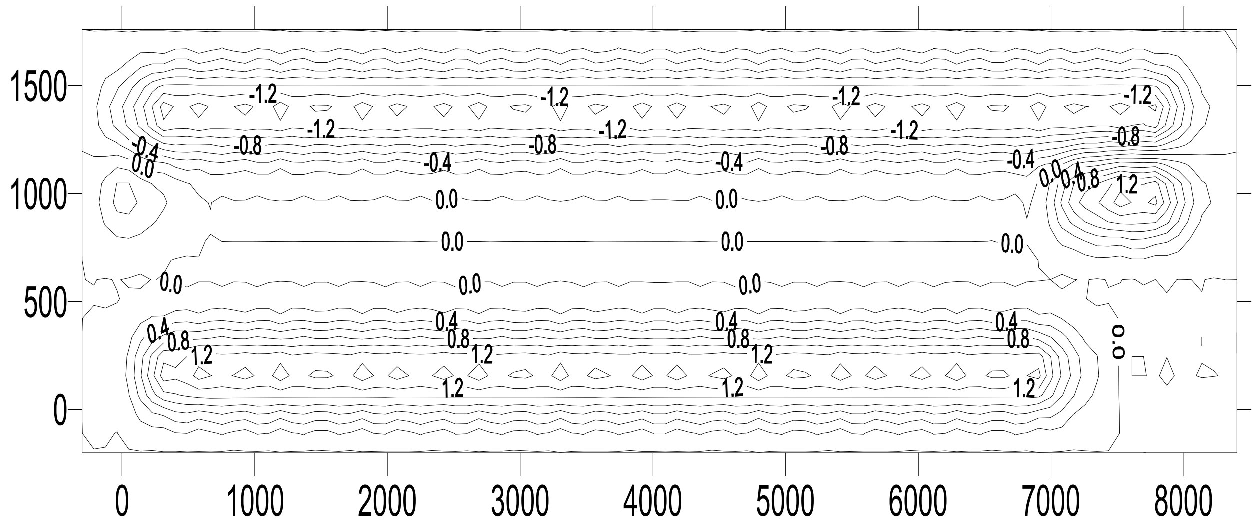

Figure 23 Predicted Final Surface Horizontal Displacement (Transverse Component) after Mining D2201 and D2202

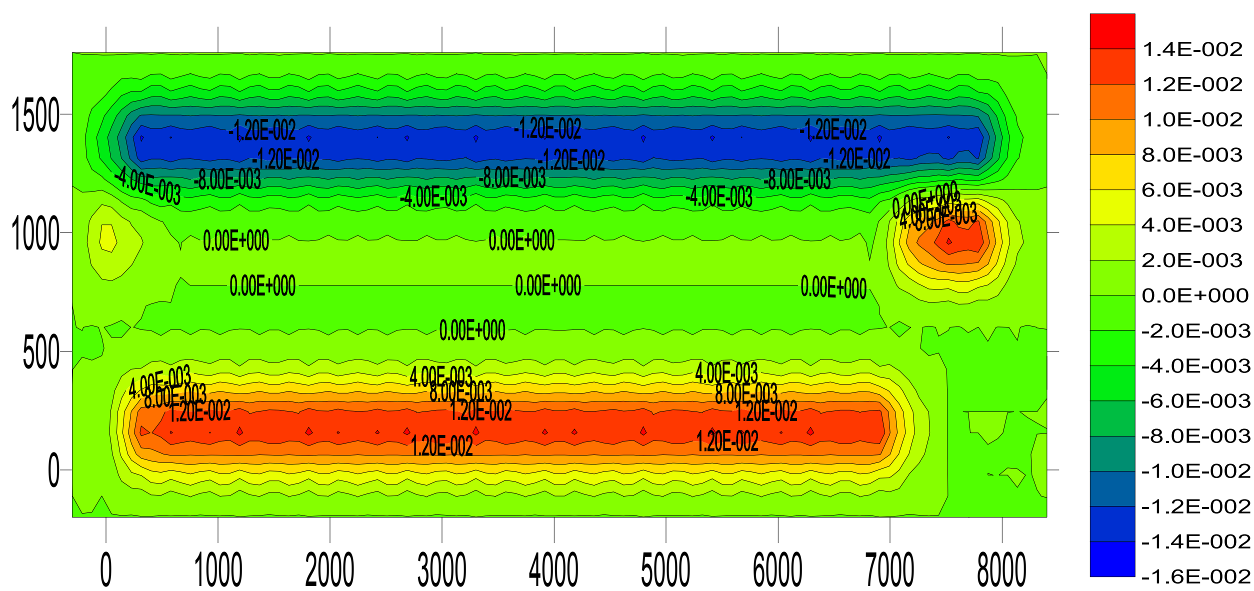

Figure 24 Predicted Final Surface Slope (Transverse Component) after Mining D2201 and D2202

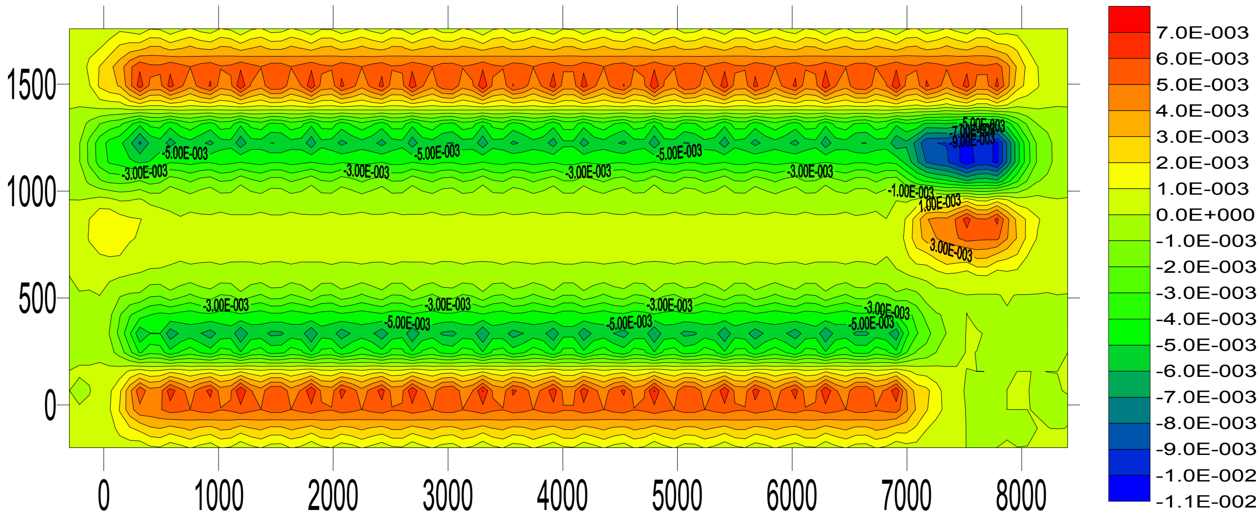

Figure 25 Predicted Final Surface Strain (Transverse Component) after Mining D2201 and D2202

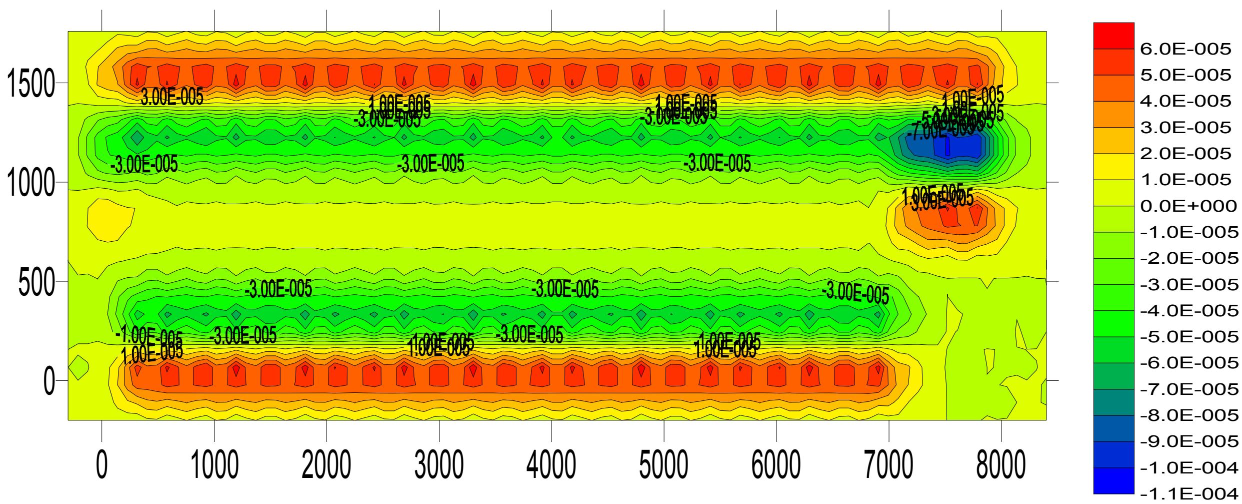

Figure 26 Predicted Final Surface Curvature (Transverse Component) after Mining D2201 and D2202

Subsidence Predictions for Mining in J-Seam

In the first three years, four longwall panels (J1201, J1202, J1204 and J1205) in the backup block of J-Seam will be mined using top-caving method as shown in Fig. 29. The area is about 3,000 ft (915 m) in depth and an approximate mining height of 14.8 ft (4.5 m). Due to the large depth, mining the first panel J1201 only is unlikely to cause surface subsidence. The predictions are conducted in the following two mining stages: panels J1201 and J1202 are mined, and then all five panels are mined (including panel J1203 which will be mined at a later time). Due to insignificant slope, and curvature, only the final surface subsidence, horizontal displacement and strain for mining these panels are shown in Figs. 28 - 31 respectively.

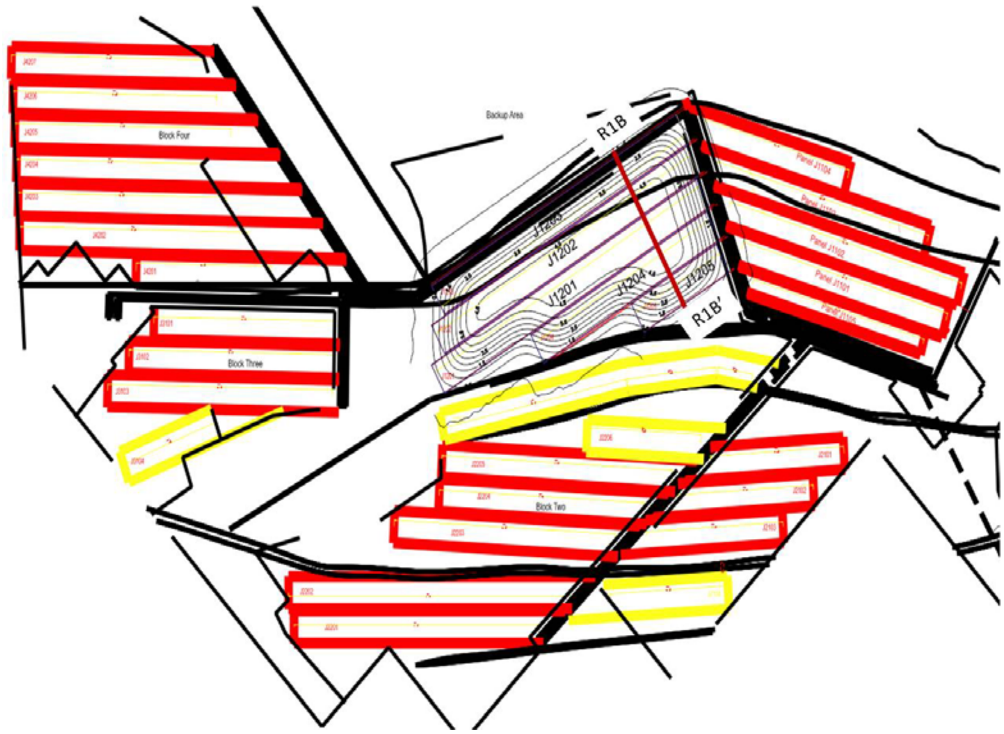

Figure 27 Longwall Panels to be Mined in the First Three Years in J- Seam

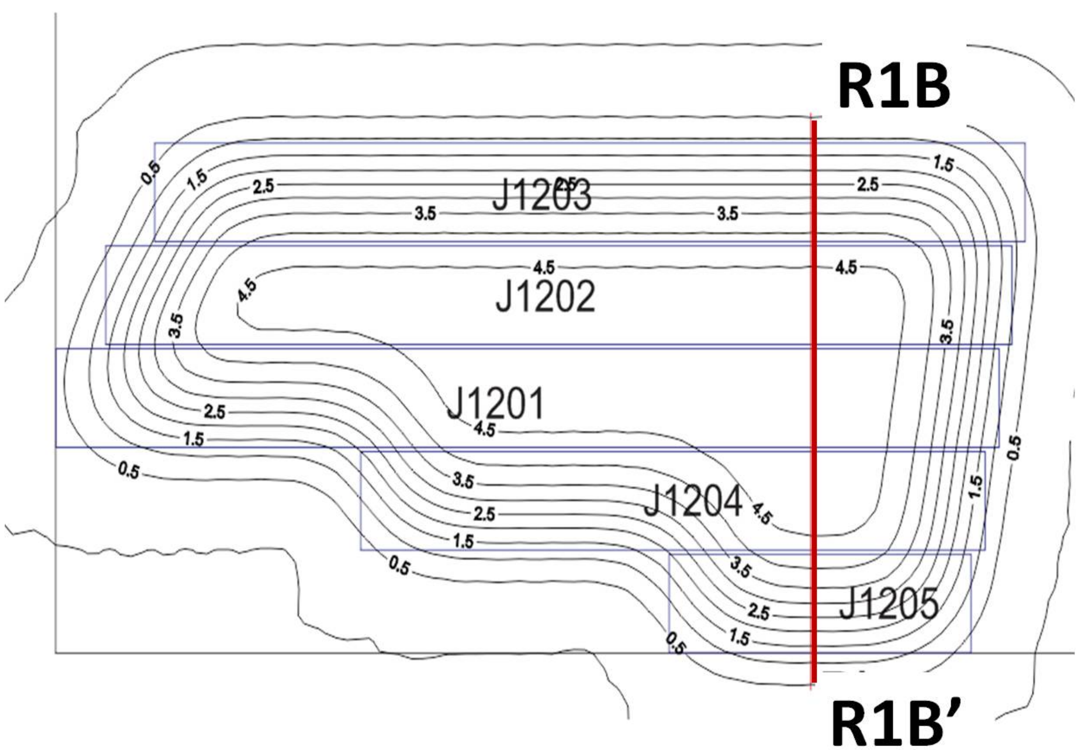

Figure 28 Rotated Panels and Final Subsidence Trough

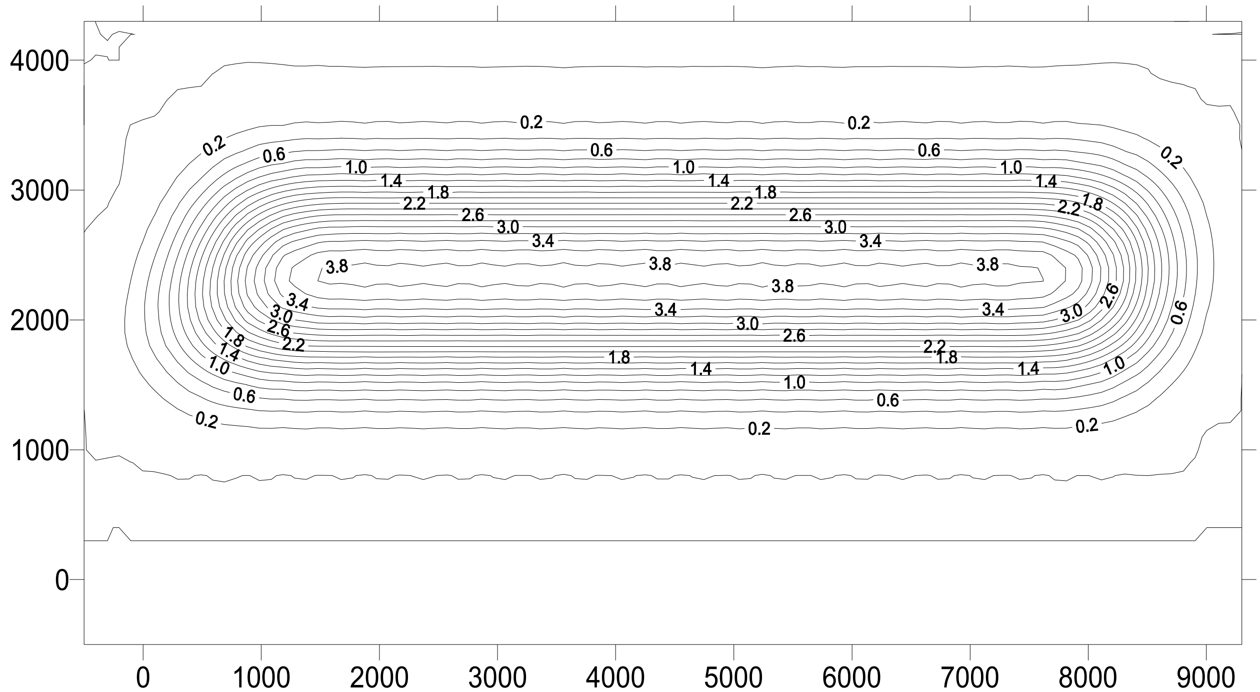

Figure 29 Predicted Final Surface Subsidence after Mining J1201 and J1202

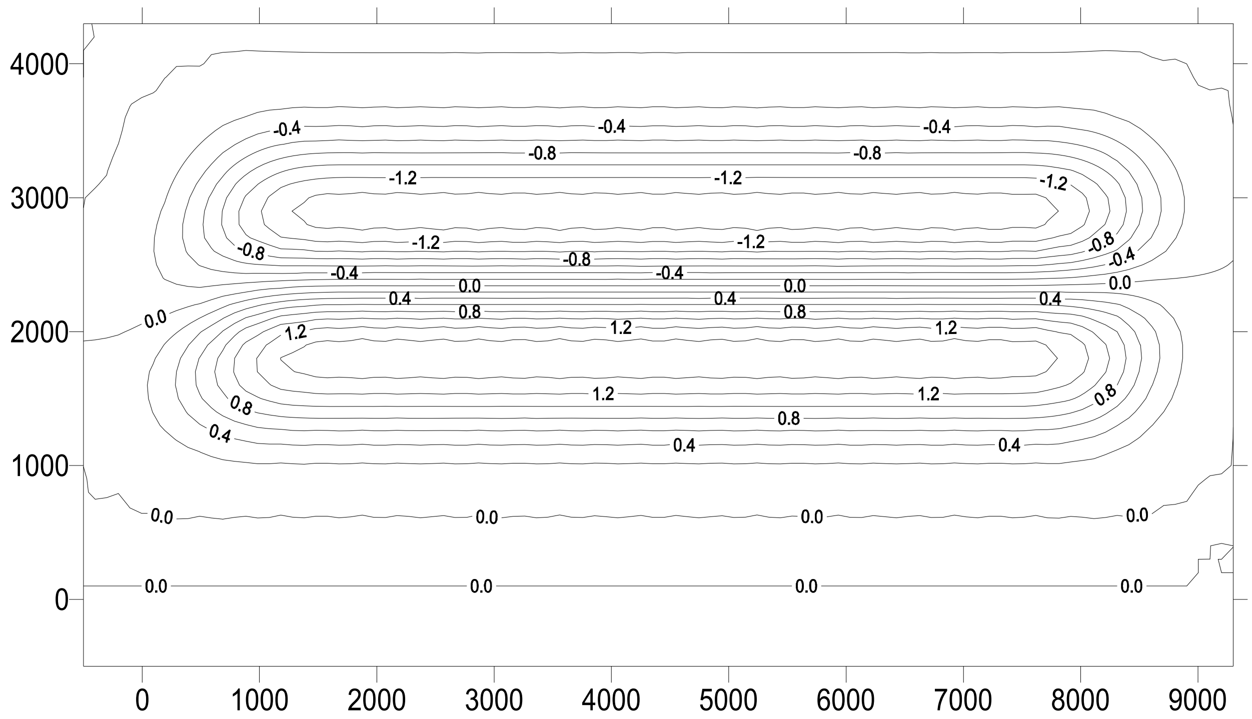

Figure 30 Predicted Final Surface Horizontal Displacement (Transverse Component) after Mining J1201 and J1202

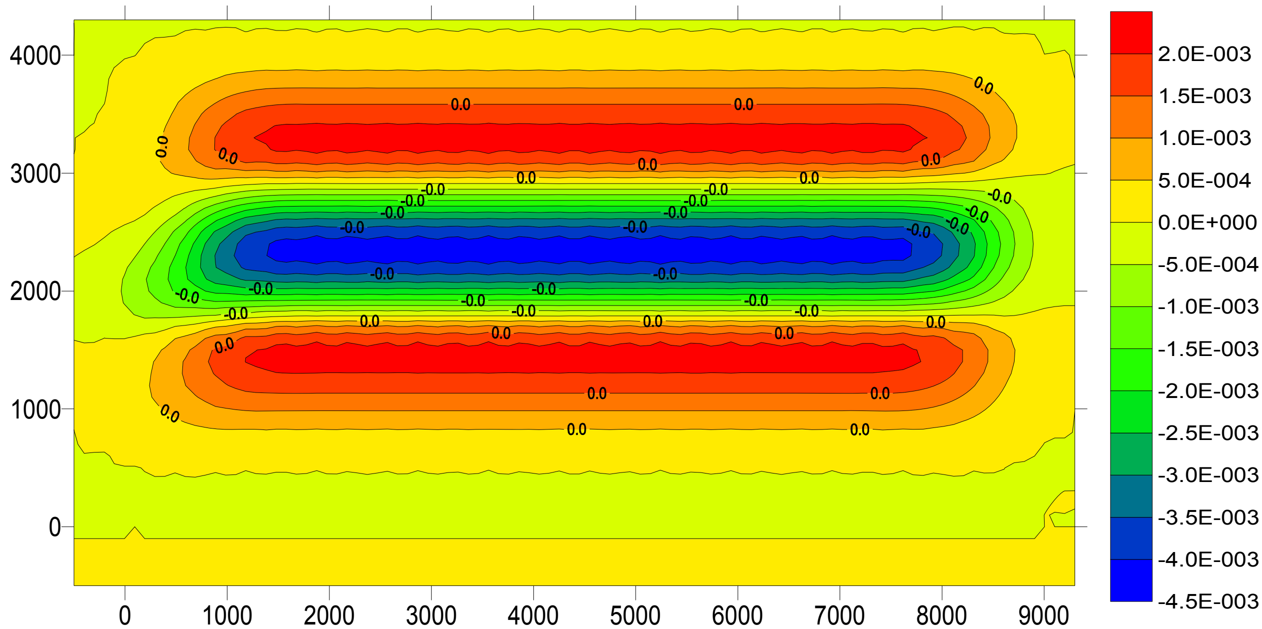

Figure 31 Predicted Final Surface Strain (Transverse Component) after Mining J1201 and J1202

After mining all the five longwall panels in block 2 area in J-Seam, the prediction results are presented in Figs. 32 - 34.

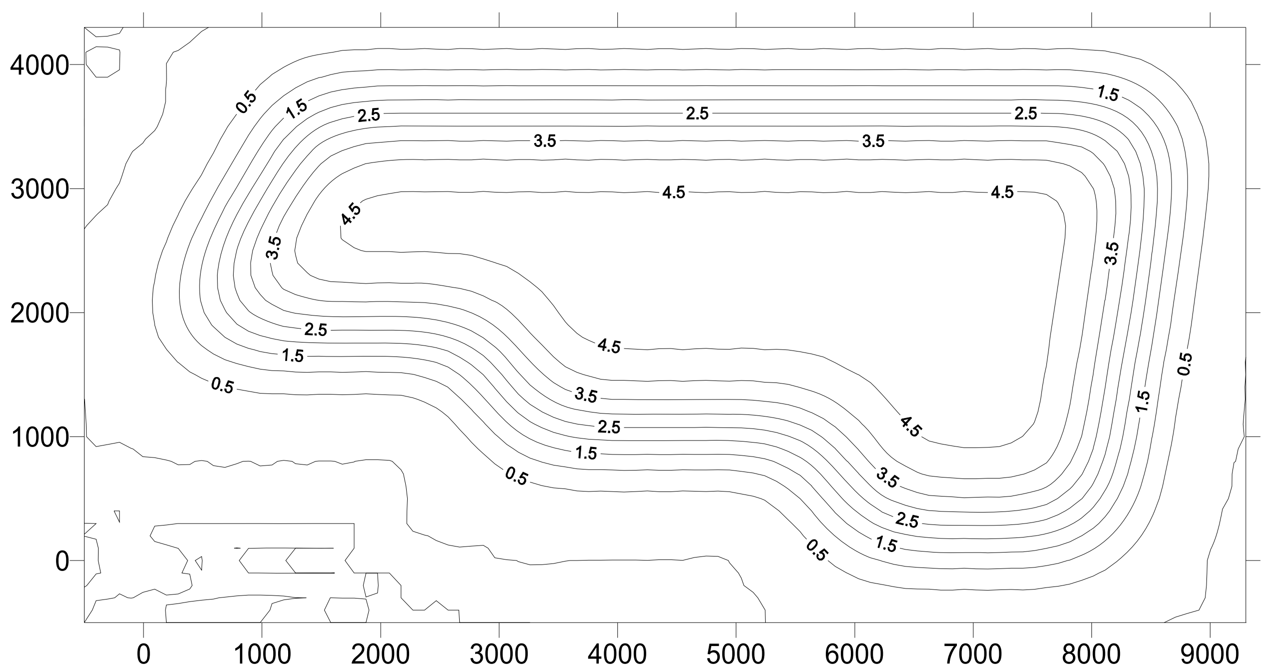

Figure 32 Predicted Final Surface Subsidence after Mining all Five Panels in Block 2, J-Seam

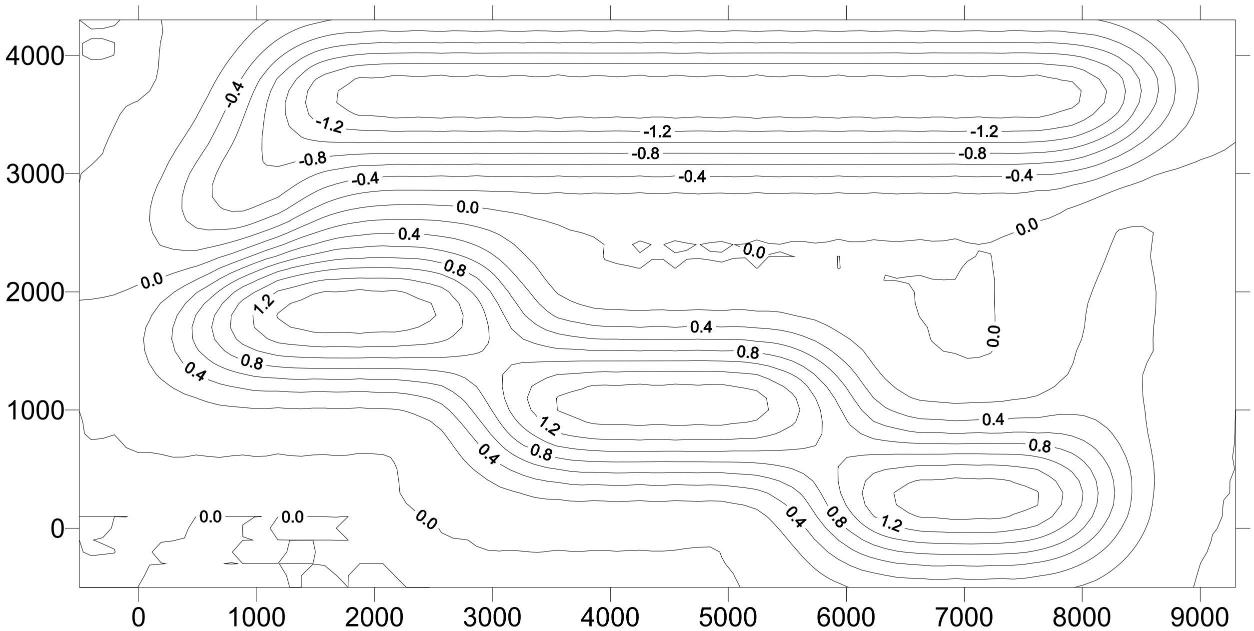

Figure 33 Predicted Final Surface Horizontal Displacement (Transverse Component) after Mining all Five Panels in Block 2, J-Seam

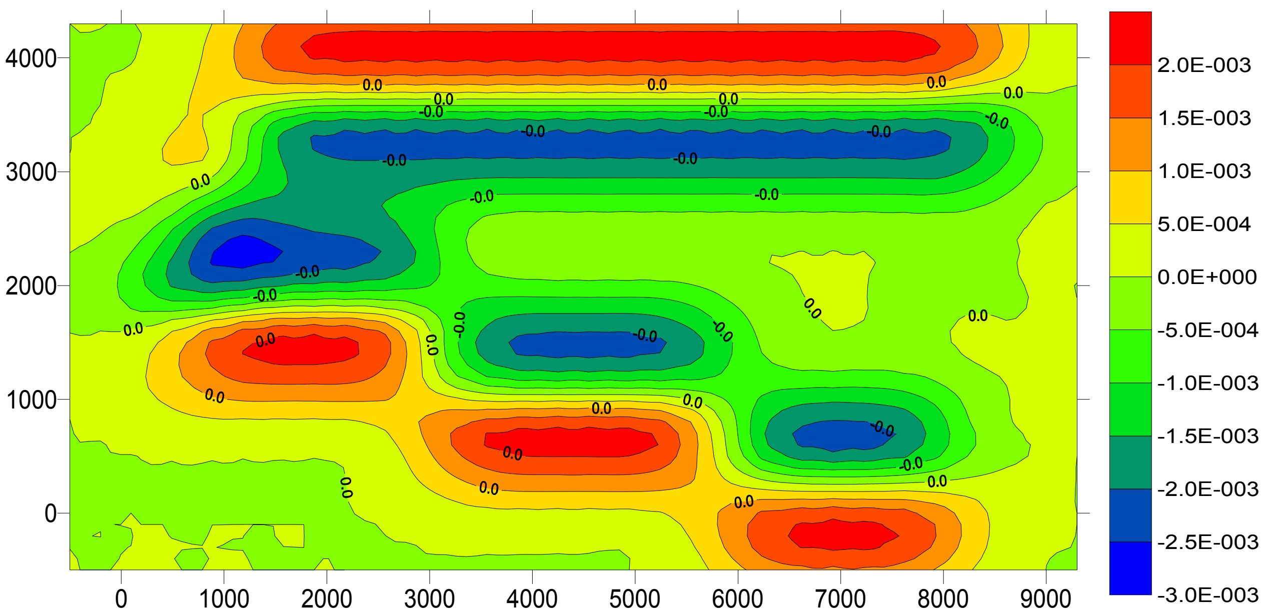

Figure 34 Predicted Final Surface Strain (Transverse Component) after Mining all Five Panels in Block 2, J-Seam

The predicted final surface movements and deformations along the specified cross-section over these panels (Fig. 28) are presented in Figs. 35 - 39.

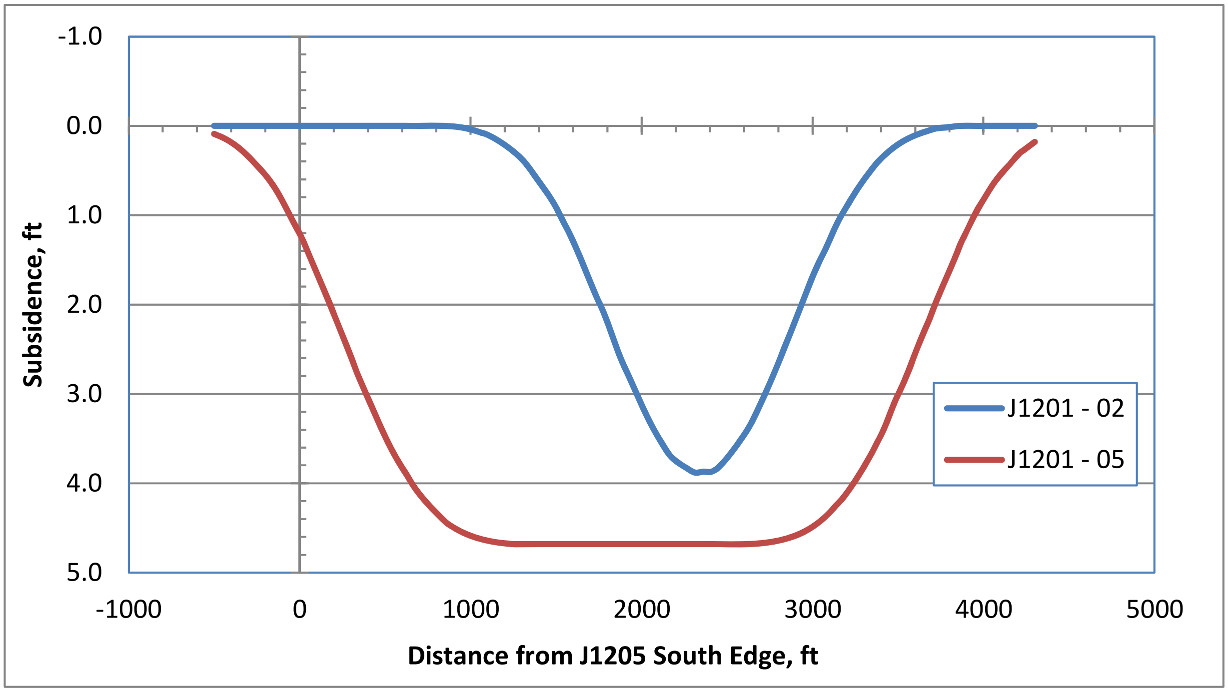

Figure 35 Final Subsidence Profiles for the Two Mining Stages Along Profile Line R1B-B'

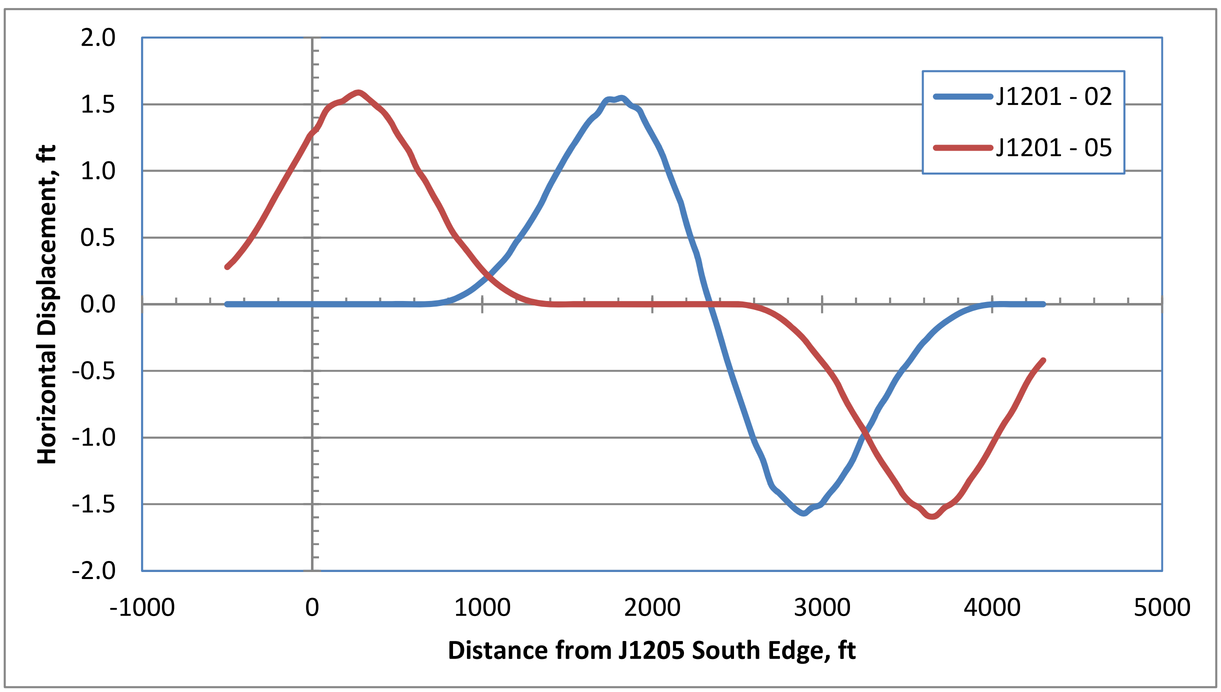

Figure 36 Final Horizontal Displacement (Transverse Component) Profiles for the Two Mining Stages Along Profile Line R1B-B'

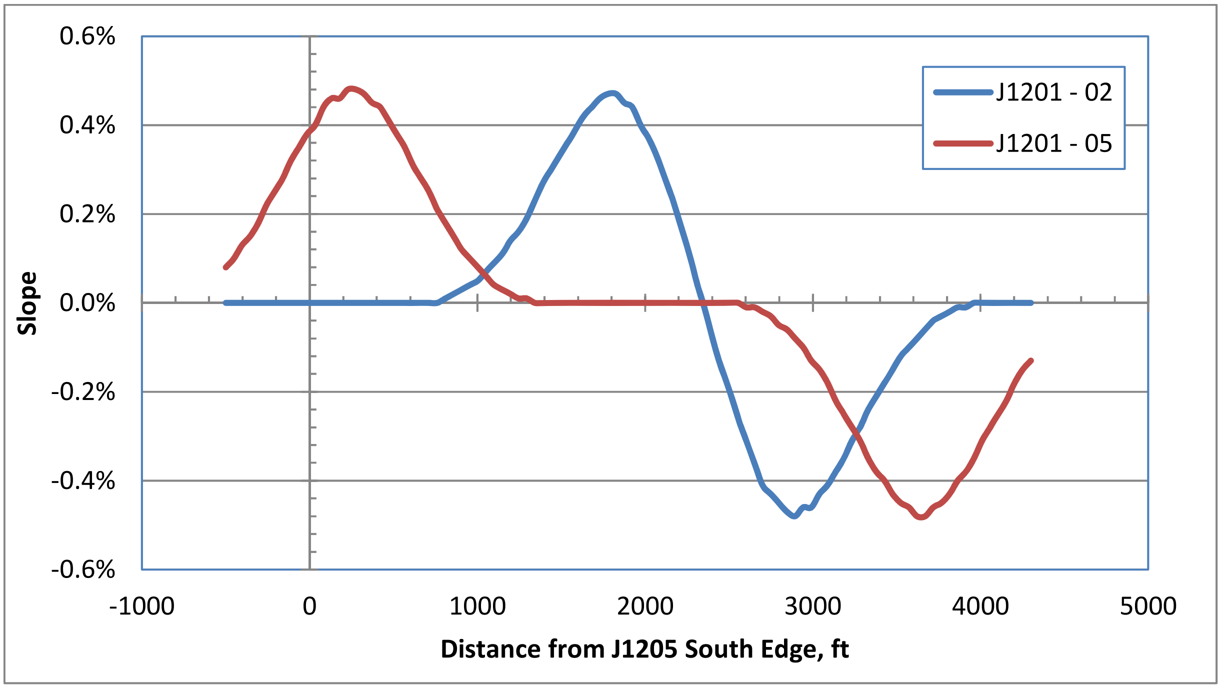

Figure 37 Final Slope (Transverse Component) Profiles for the Two Mining Stages Along Profile Line R1B-B'

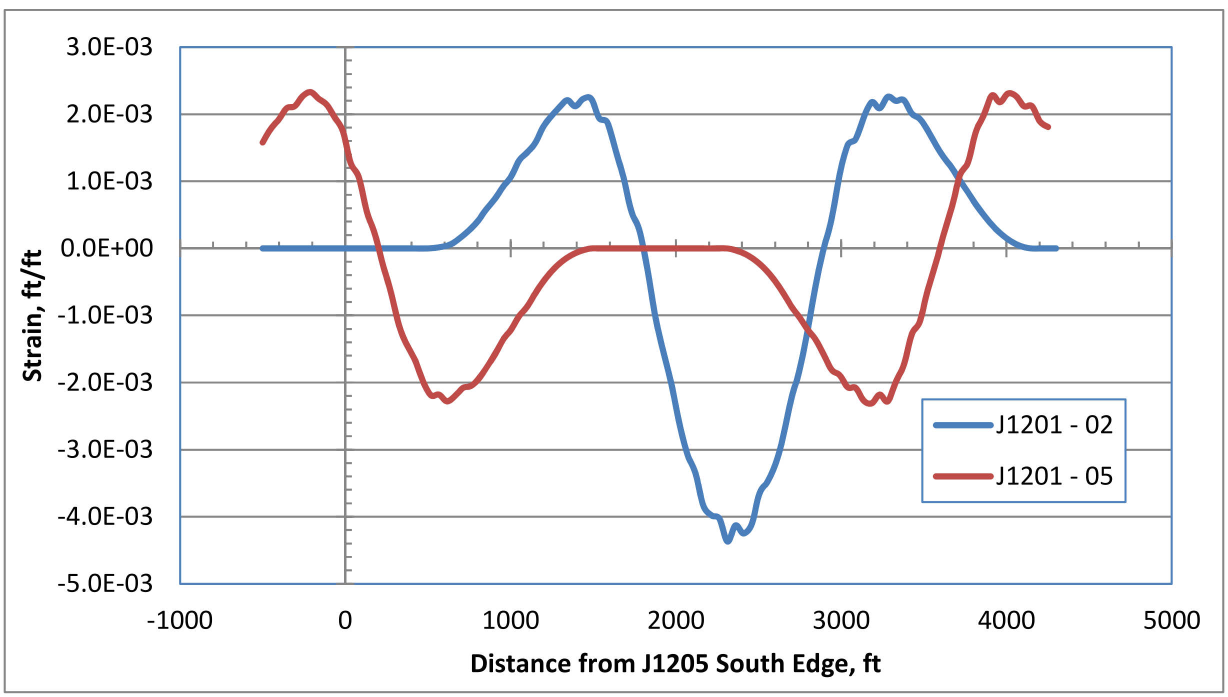

Figure 38 Final Strain (Transverse Component) Profiles for the Two Mining Stages Along Profile Line R1B-B'

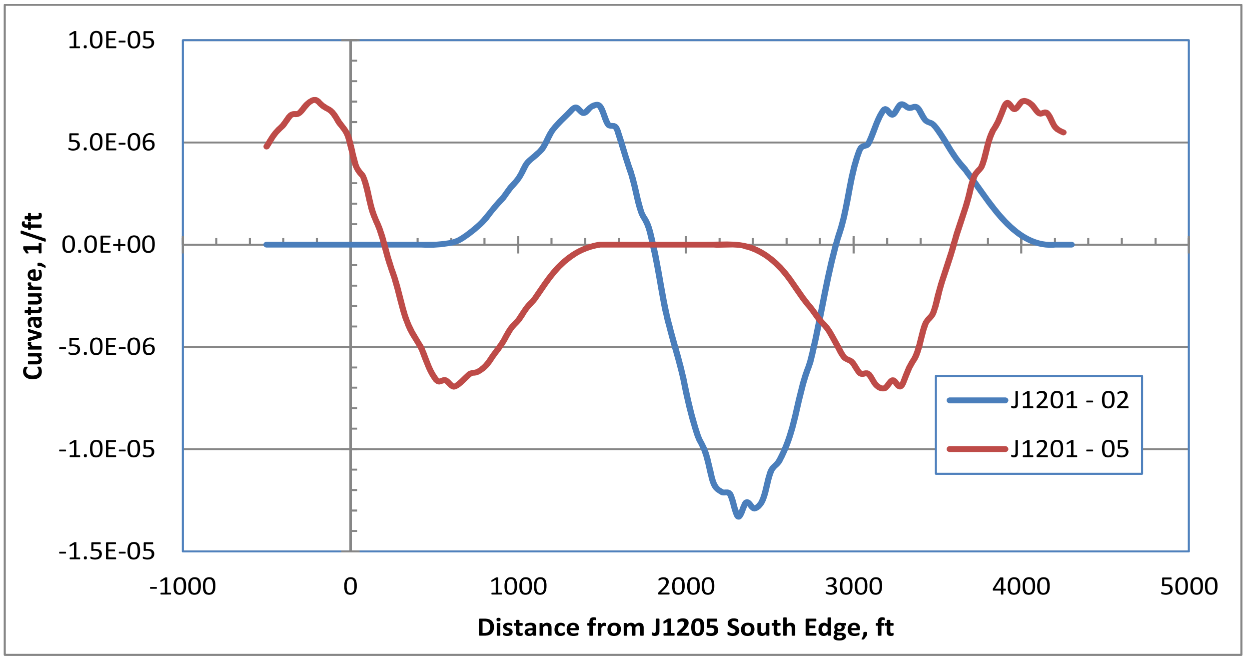

Figure 39 Final Curvature (Transverse Component) Profiles for the Two Mining Stages Along Profile Line R1B-B'

Areas of Intensive Mining

Three cross-sections (A-A', B-B' and C-C') over three different mining blocks (Blocks I, II and IV) have been selected for final subsidence predictions as shown in Fig. 40. The cross-sections are chosen because these areas will be the most intensively mined and the final surface movements and deformations along each of the cross-sections represent the largest expected ground movement and deformations for each mining block.

Subsidence Prediction along A-A' Cross-Section

In Block I, mining will be conducted in coal seams D, E, F and J. In each of the four mineable seams except for seam E, five longwall panels will be mined. In the case of the E seam, only two panels will be mined. These panels will be superimposed (vertically stacked). The subsidence predictions were made after the panels in each of the four coal seams are completely mined out. Figures 41- 45 show the predicted profiles of final surface subsidence, horizontal displacement, slope, strain and curvature along cross-section A-A', respectively.

When all the seams are mined, the maximum subsidence is about 18.7 ft (5.7 m). The maximum horizontal displacement is about 6.4 ft (1.95 m). The maximum sinal surface slope, tensile strain, compressive strain convex curvature and concave curvature are 2.8%, 1.35×10^{-2} ft/ft, -1.51×10^{-2} ft/ft, 6.0×10^{-5} 1/ft and -6.62×10^{-5} 1/ft, respectively. Among these deformations, the slope, tensile and compressive strain and concave curvature could cause problems to common surface structures (If any are located in the mining area). The maximum tensile strain could create surface cracks.

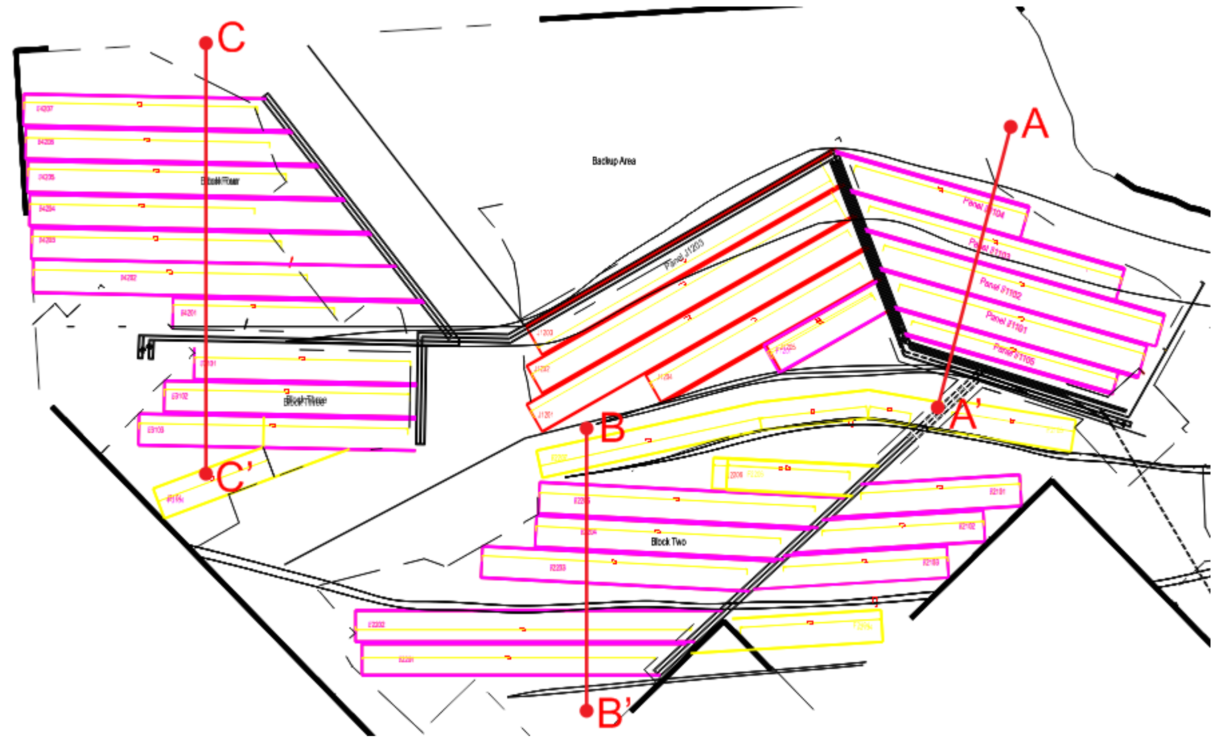

Figure 40 Location of Three Cross-Sections with Respect to Panels in J-Seam

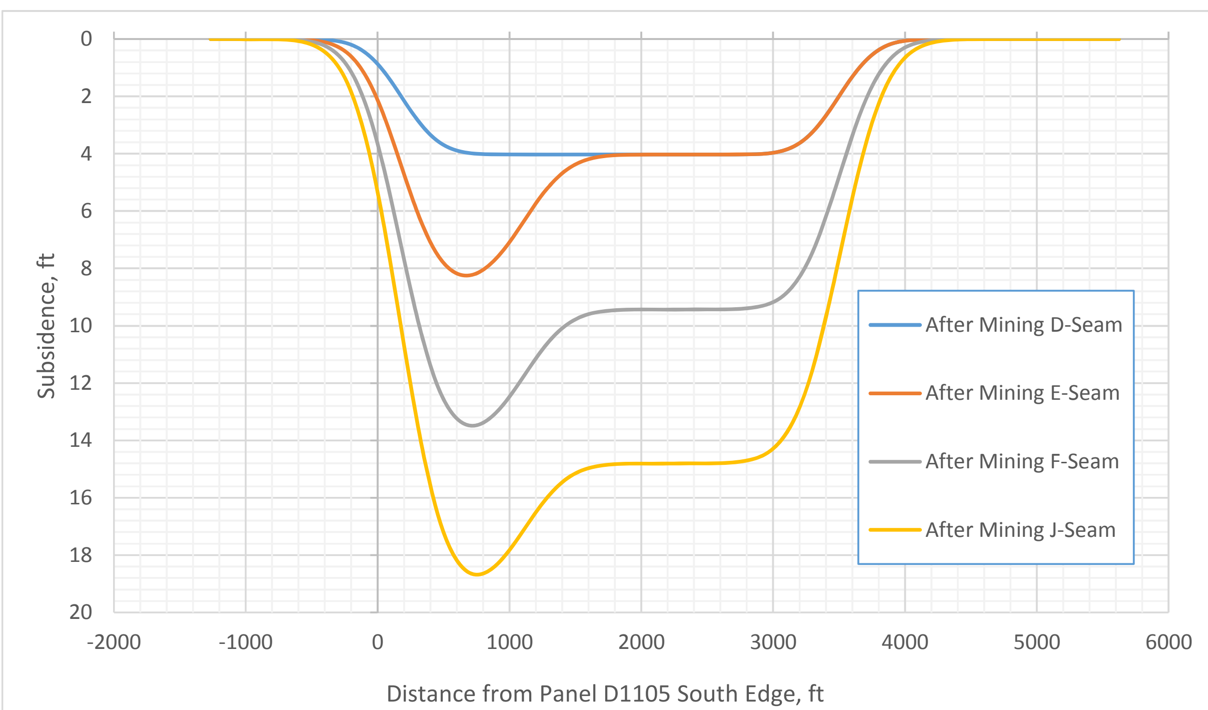

Figure 41 Predicted Final Subsidence Profiles along Cross-Section A-A'

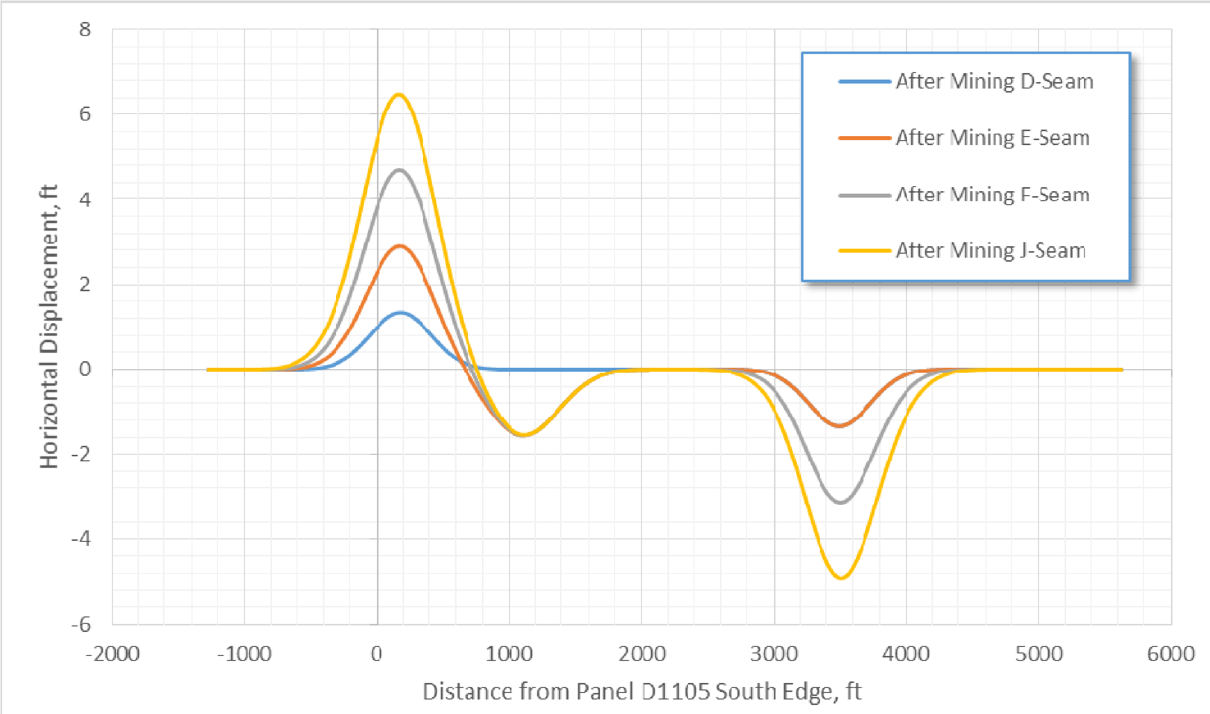

Figure 42 Predicted Final Horizontal Displacement (Transverse Component) Profiles along Cross-Section A-A'

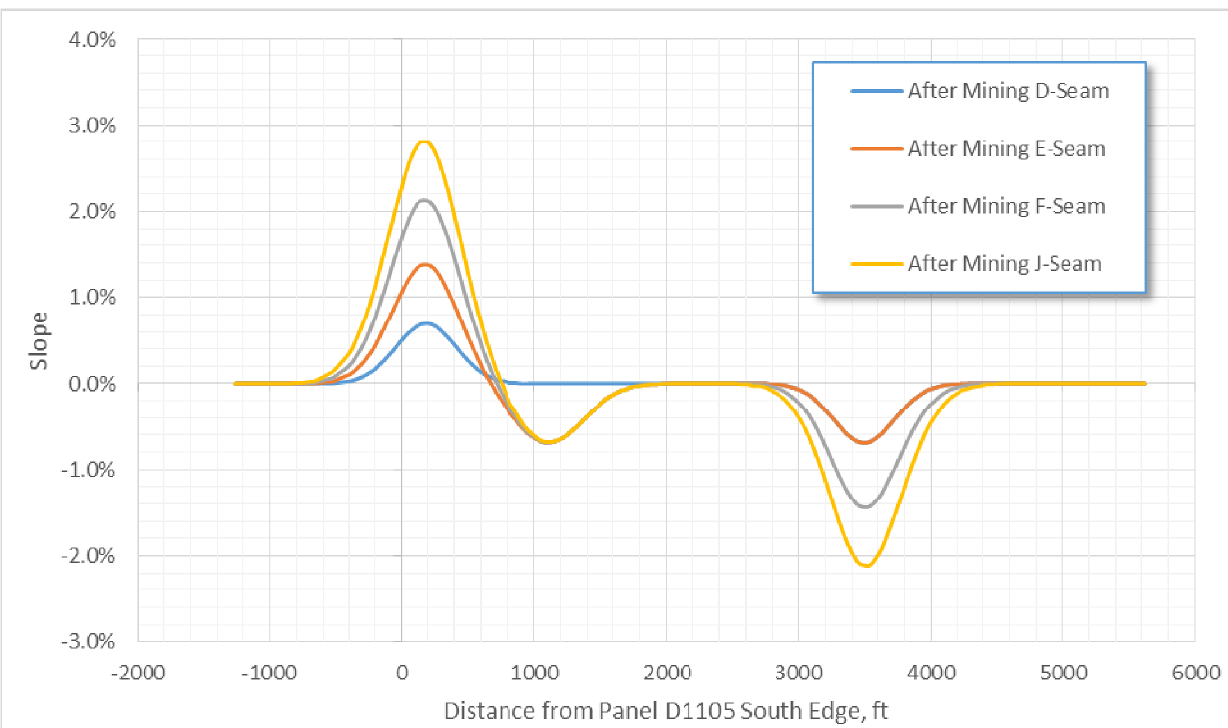

Figure 43 Predicted Final Slope (Transverse Component) Profiles along Cross-Section A-A'

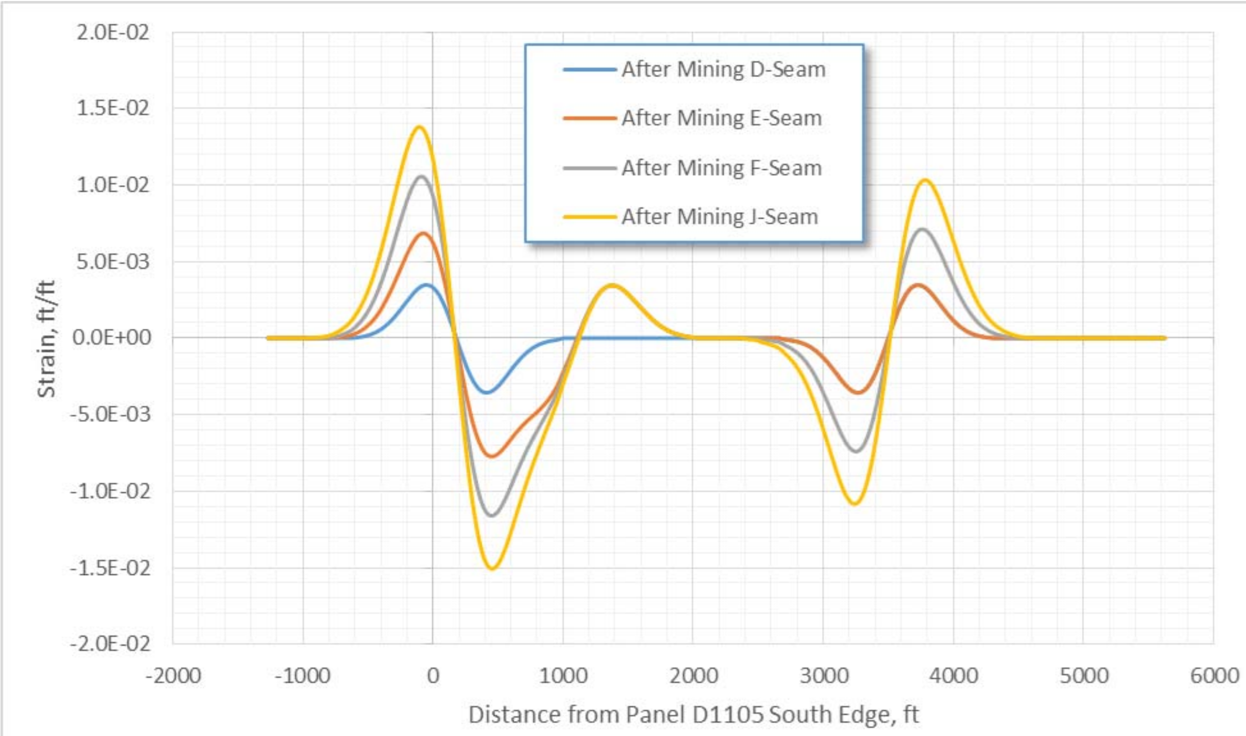

Figure 44 Predicted Final Strain (Transverse Component) Profiles along Cross-Section A-A'

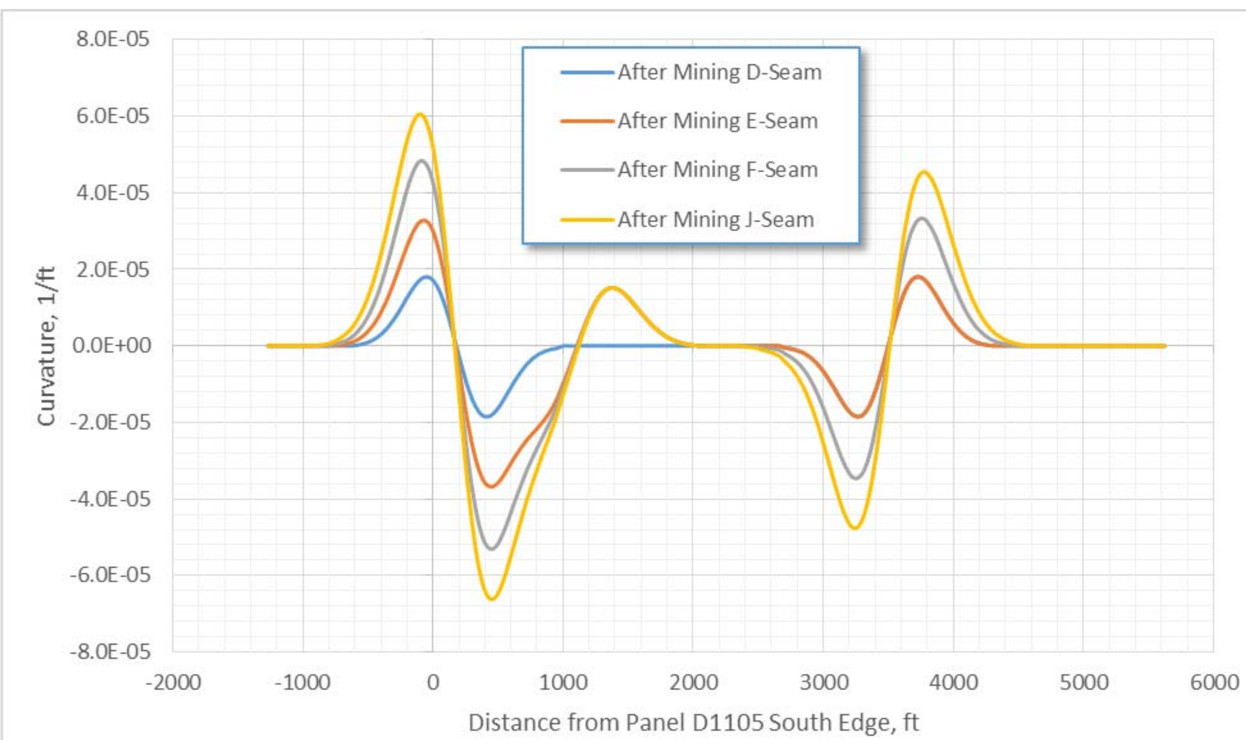

Figure 45 Predicted Final Curvature (Transverse Component) Profiles along Cross-Section A-A'

Subsidence Prediction along B-B' Cross-Section

It should be noted that mining all the coal seams in Block II area will cause the highest surface movements and deformations within the mine property. In this area, the overburden depth over each of the coal seams is smallest, the possible mining heights are largest and mining will be conducted in all of the five coal seams. In this section, the subsidence prediction was made along a cross-section B-B' covering the panels mined in the area (Fig. 40). It should be noted all the panels in different coal seams are superpositioned (vertically stacked up) based on the current design. The prediction profiles of surface final movements and deformations at each of the five mining stages are shown in Figs. 46 - 50.

The maximum final surface subsidence, horizontal displacement, slope, strain and curvature over the two panels in the south edge are 29.1 ft, 9.6 ft, 7.1%, 3.76×10^{-2} ft/ft, 2.64 $\times 10^{-4}$ 1/ft, respectively. These high deformations will be unlikely be tolerated by any structures in the area (if any) without significant damage. The high tensile strain is likely to create large cracks to the ground surface that could potentially drain surface water bodies. However, since the mining in the different coal seams will be conducted over a significant time period, the ground surface may self-heal some of the disturbance between the mining stages.

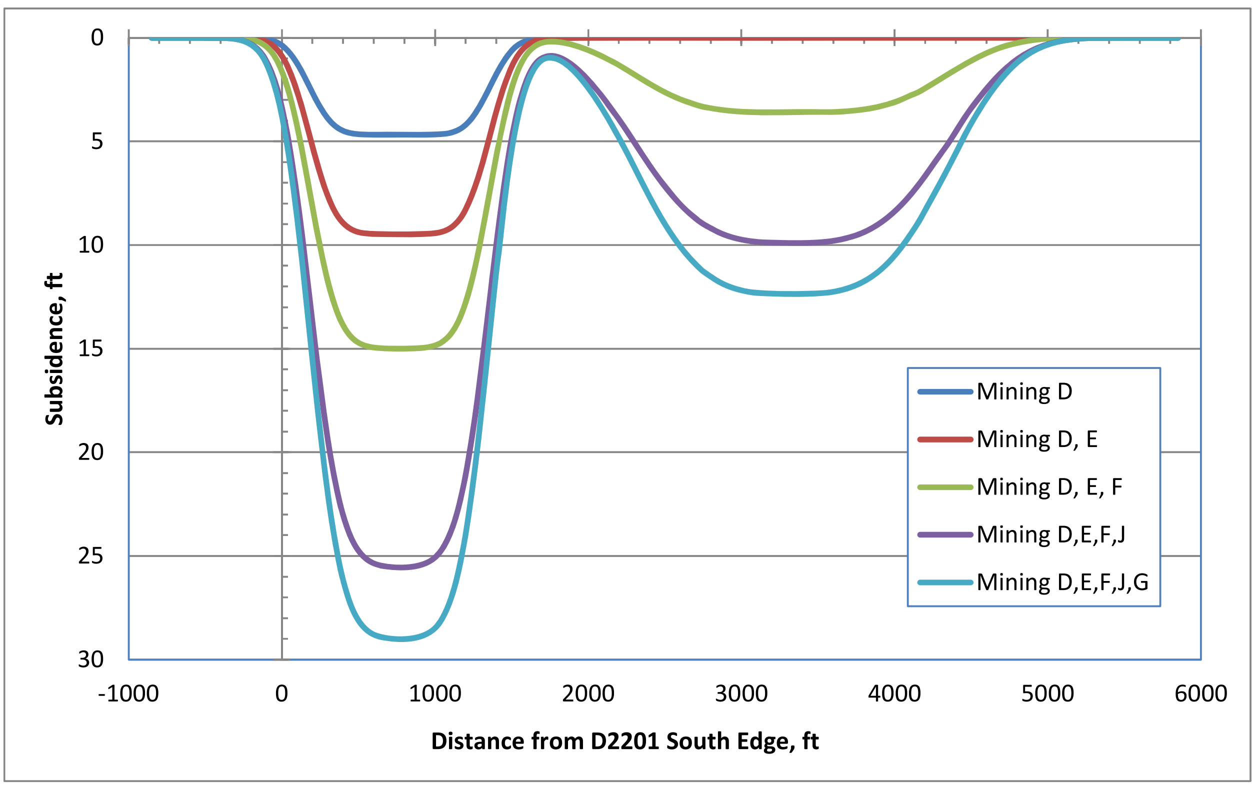

Figure 46 Predicted Final Subsidence Profiles along B-B's at Each Mining Stage

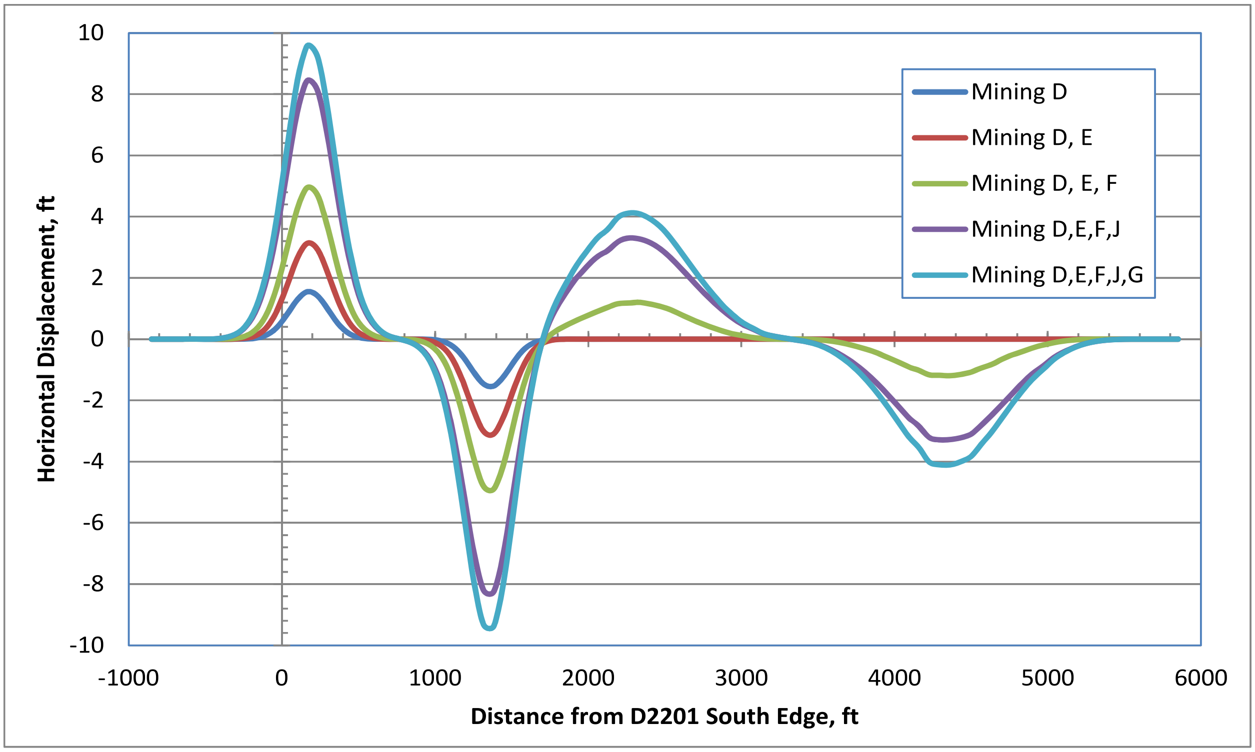

Figure 47 Predicted Final Horizontal Displacement Profiles along B-B at Each Mining Stage

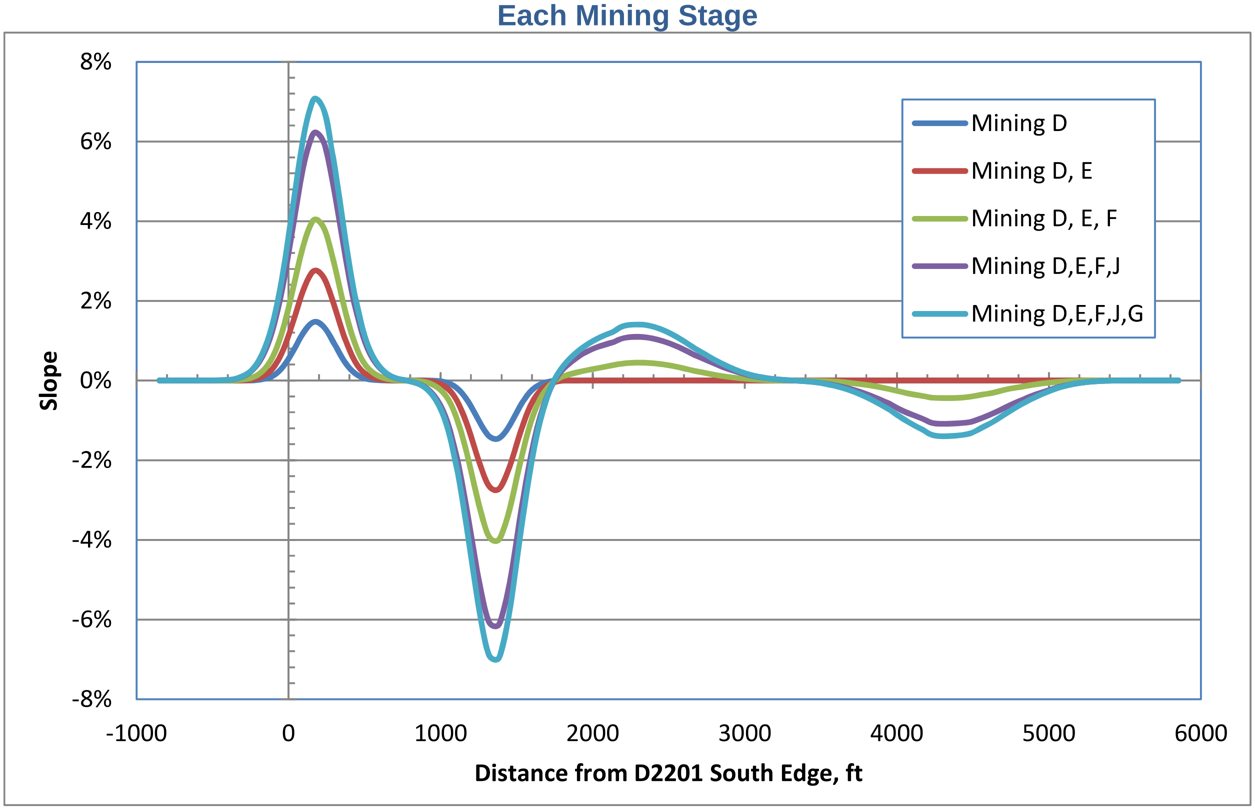

Figure 48 Predicted Final Slope Profiles along B-B's at Each Mining Stage

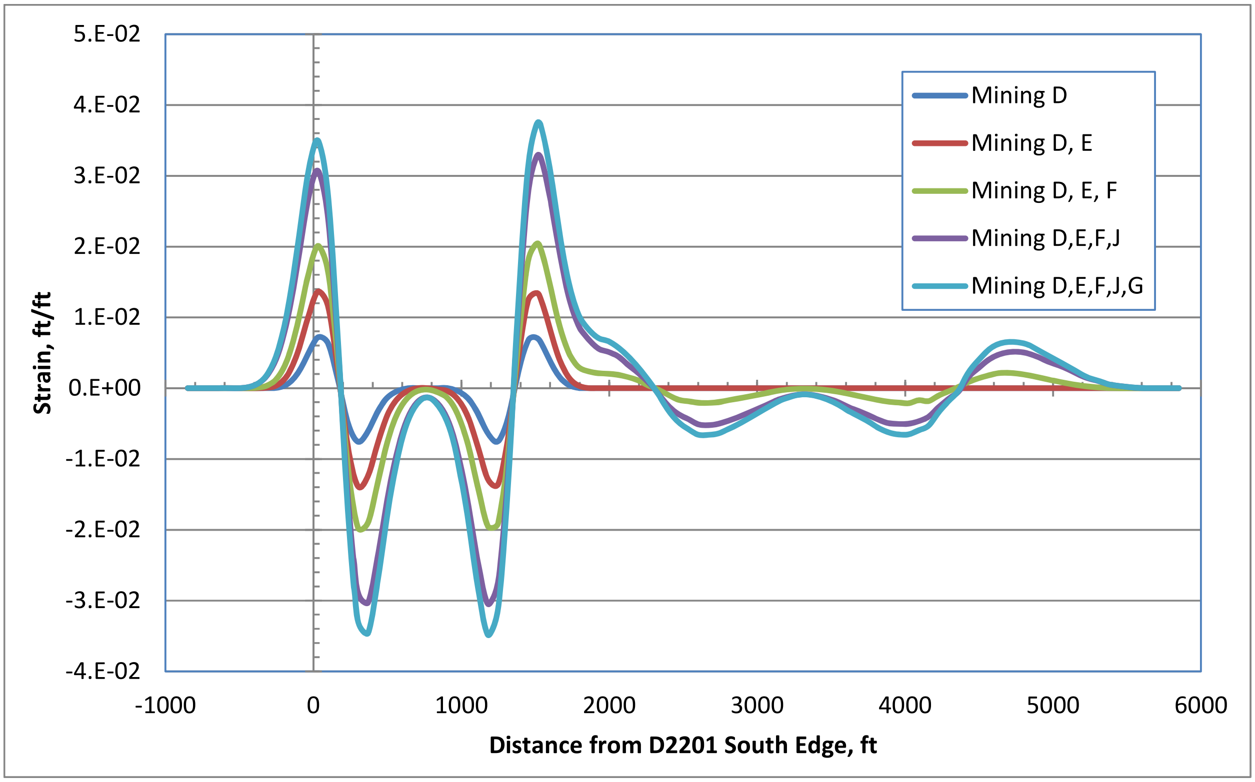

Figure 49 Predicted Final Strain Profiles along B-B's at Each Mining Stage

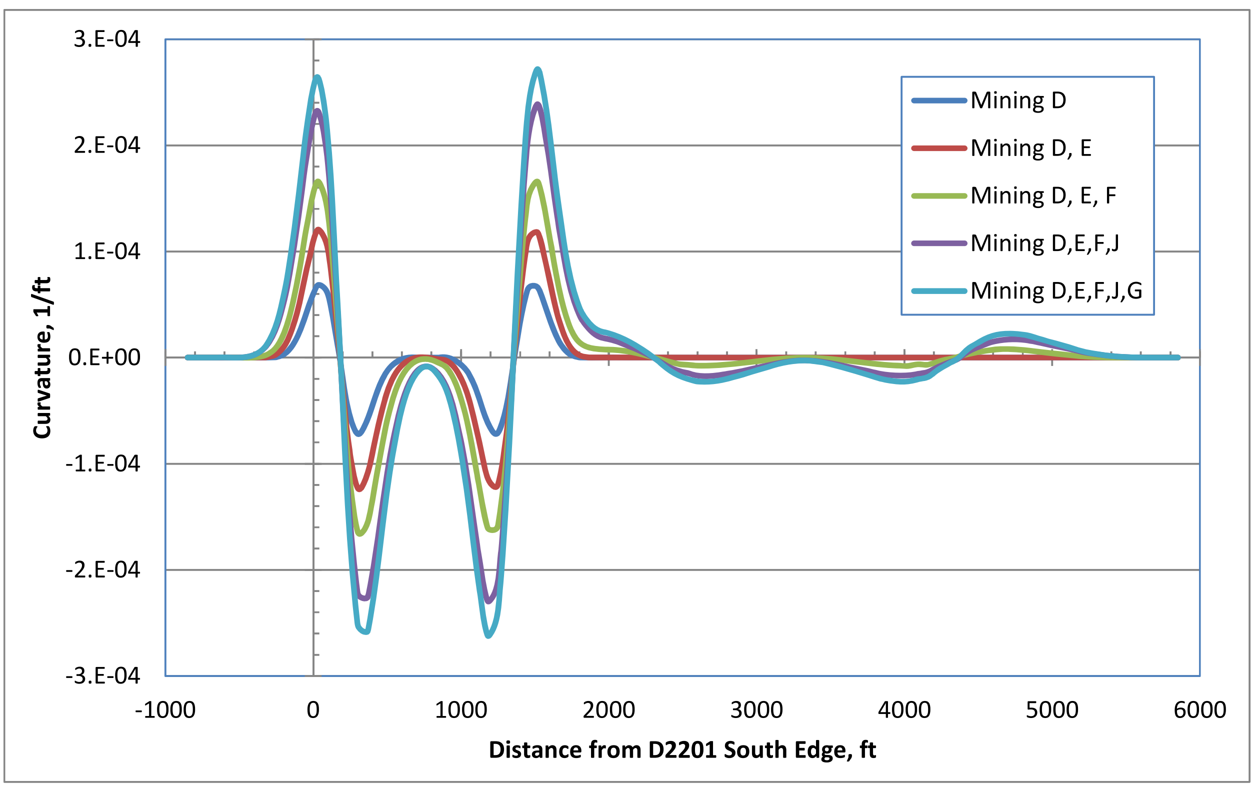

Figure 50 Predicted Final Curvature Profiles along B-B's at Each Mining Stage

Subsidence Prediction along C-C' Cross-Section

Cross-section C-C' is located in mining Block IV. The overburden depths in this block are largest, up to 1,250 m (4,100 ft). Only three coal seams (E, F and J) will be mined in the block. In E- seam, seven longwall panels are planned north of the mains. In F and J seams, three additional panels are planned south of the mains. The predicted final surface subsidence, horizontal displacement, slope, strain, curvature along C-C' are plotted in Figs. 51 – 55, respectively.

Because of the large mining depths and only three seams will be mined in this block, the predicted maximum deformations along C-C' are also smaller than those along the other two cross-sections. The predicted maximum final surface subsidence, horizontal displacement, slope, strain and curvature are 9.1 ft, 3.1 ft, 0.71%, 5.84×10^{-3} ft/ft and 1.62×10^{-5} 1/ft, respectively. Among the final surface deformations, the tensile strain is the only one that could disturb surface structures (if any are located in this area) to a significant degree.

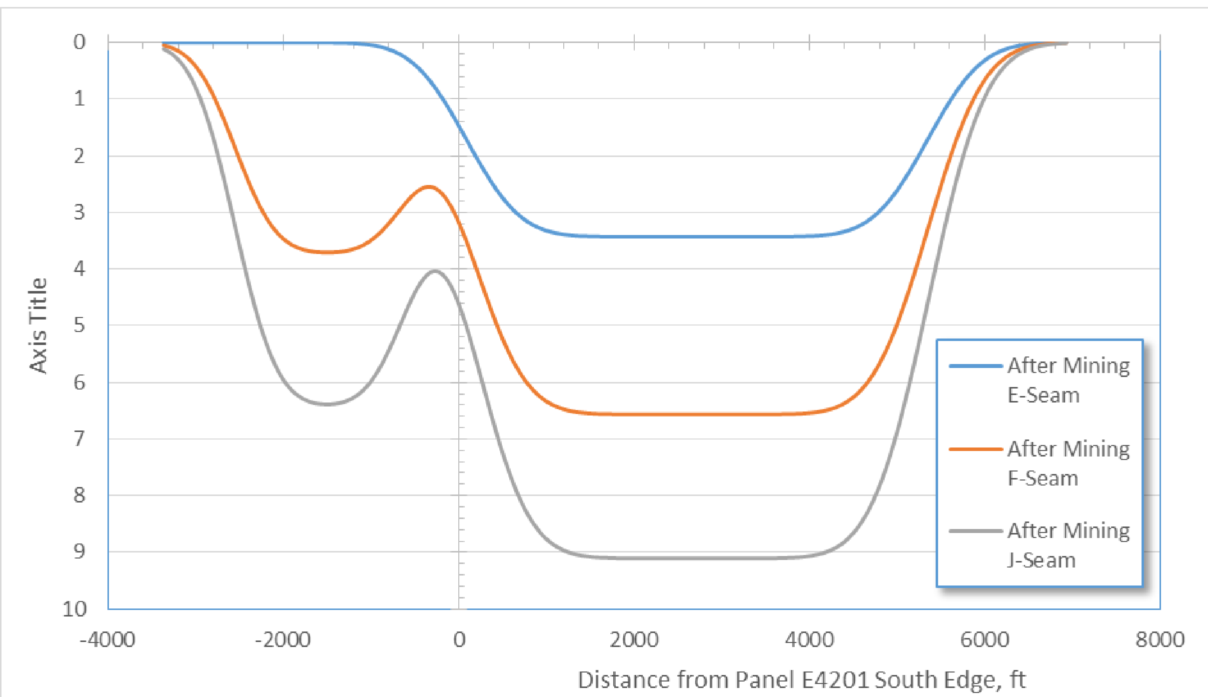

Figure 51 Predicted Final Subsidence Profiles along C-C's at Each Mining Stage

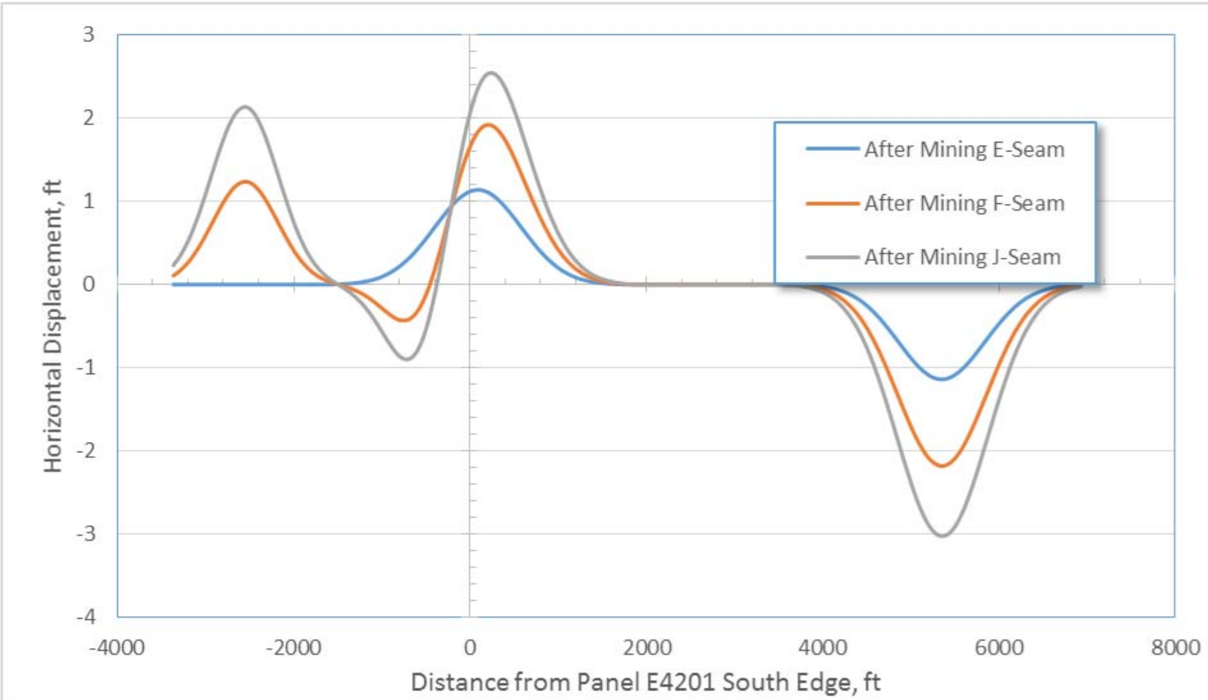

Figure 52 Predicted Final Horizontal Displacement Profiles along C-C' at Each Mining Stage

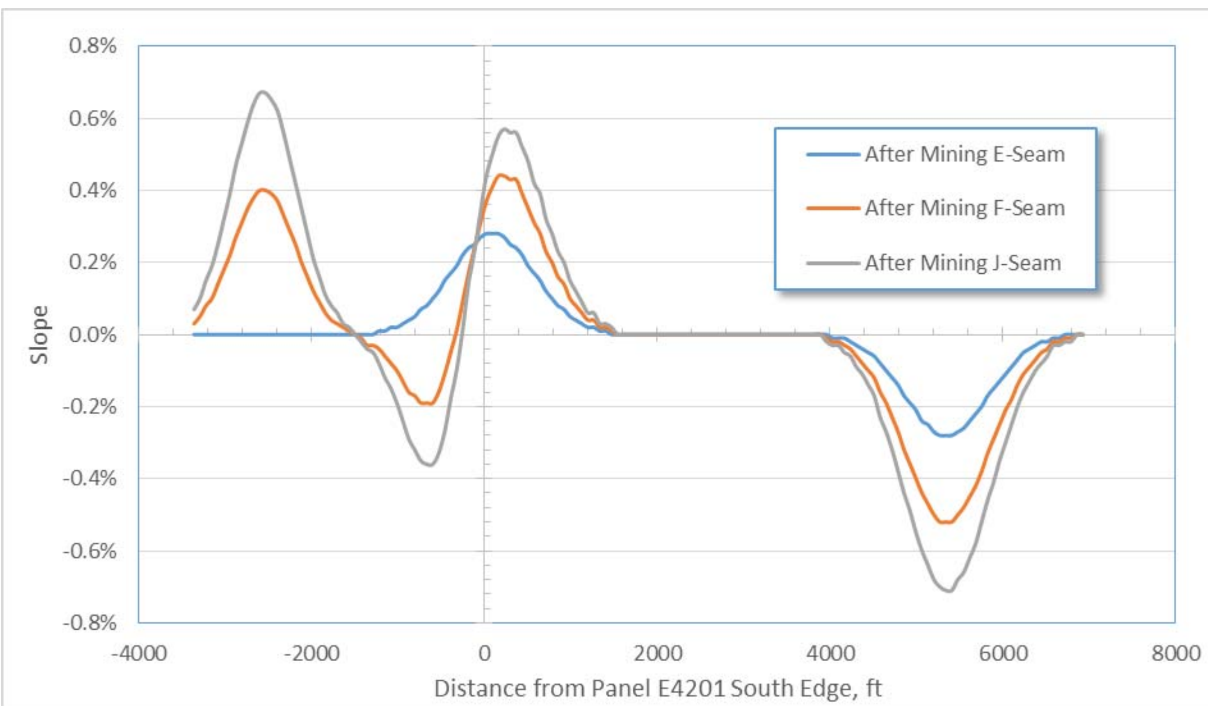

Figure 53 Predicted Final Slope Profiles along C-C' at Each Mining Stage

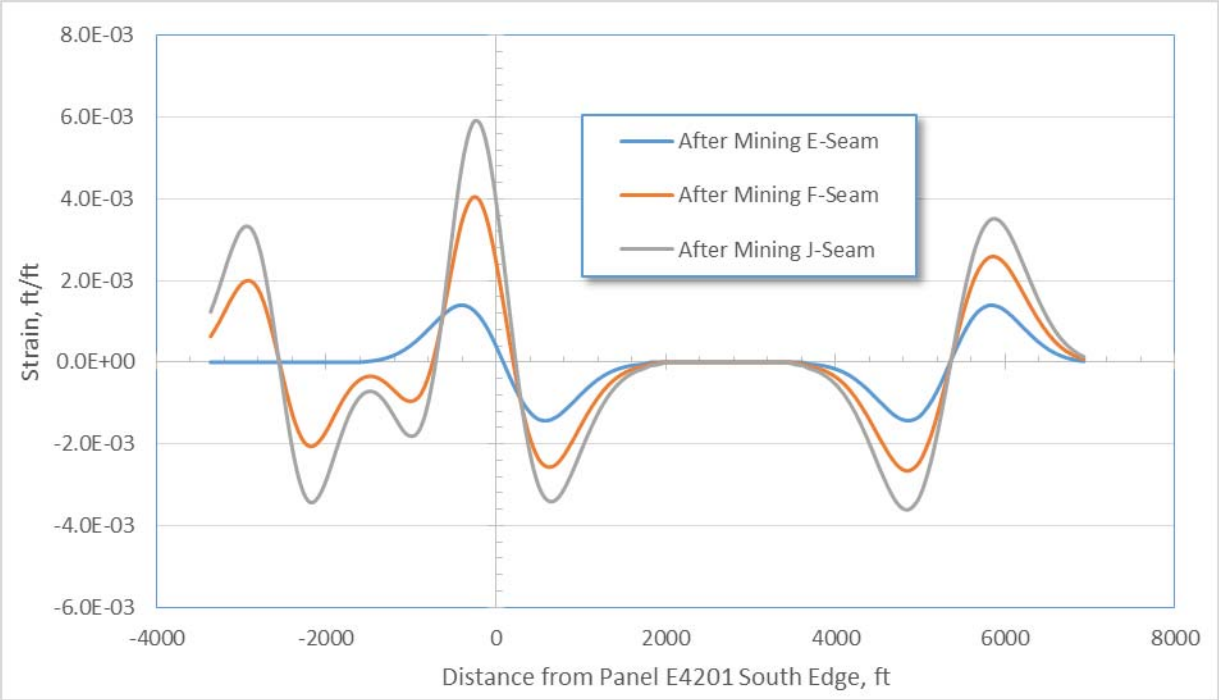

Figure 54 Predicted Final Strain Profiles along C-C' at Each Mining Stage

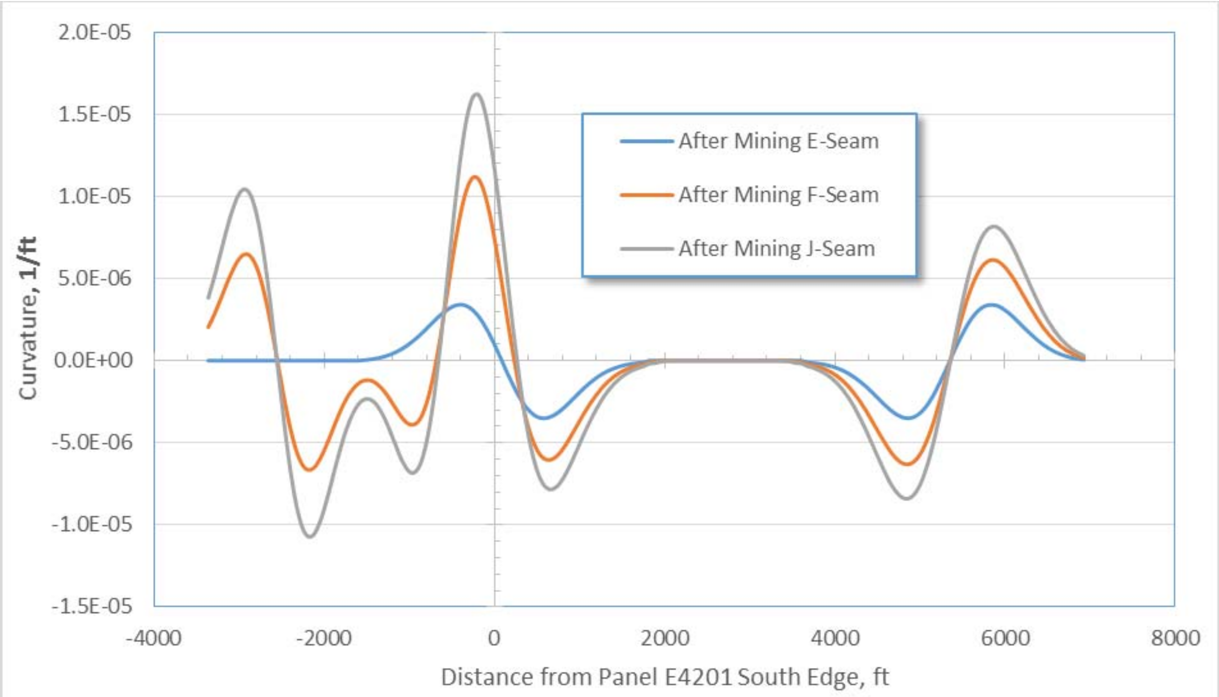

Figure 55 Predicted Final Curvature Profiles along C-C' at Each Mining Stage

Subsidence Influences and Potential Mitigation Measures

Potential Subsidence Issues

Based on the subsidence predictions performed in the previous section, it is found that:

- In the first three years of mining, only the tensile strains induced by mining the D and J seams could cause minor problems to common surface structures if any are located in the area. The tensile strains are too small to disturb surface water bodies. However, if buried pipelines, railroad tracks, power lines roads and bridges are located in the impacted area, it is recommended that additional detailed subsidence studies be performed to determine the potential influence on these structures. If necessary, certain mitigation measures could easily be designed and implemented to reduce the impact of the predicted ground movement.
- Mining of the multiple coal seams in Block I according to the current plan is may also cause problems to surface structures (if any are located in the area) and some minor problems to surface water bodies. However, most of the problems can be mitigated using proven measures. For buried pipelines, railroad tracks, power lines roads and bridges it is suggested that detailed studies be performed to assess the subsidence influence of the predicted ground movement.
- Mining in Block II according to the current plan could cause the most sever disturbances to ground surface. All the final maximum surface deformations are significantly over the critical values for most of the common structures (structures if any are located in the area). The impact to buried pipelines, railroad tracks, power lines roads and bridges could be significant. The most adverse effects will be that the maximum tensile strains over the panel edges are fully able to create very large ground cracks that could lead to significant loss of surface water bodies.
- When the multiple coal seams are mined in Block IV, the tensile strain near the panel edges is able to cause some minor problems to common surface structures if any are located in the area.

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