Investigation Of Surface Effects From Mine Subsidence In Mountainous Terrain.

By Clyde DeRossett

Abstract: This paper discusses an investigation of surface effects of mine subsidence in mountainous terrain. The investigation examines a regional database of surface fracture occurrences in the eastern Kentucky coal field, and compares the surface impacts to predicted impacts in current literature based on the effects of mine void height and topography. A case study of mine subsidence impacts to a communications tower is examined. Surface features and other information concerning movement of the tower was used to determine the impact potential of three different mines. The subsidence database and software (SDPS) developed by Virginia Polytechnic Institute (VPI) was used to assess the potential of each of the three mines to impact the site. The investigation has resulted in a number of observations regarding validity of applying the database and subsidence prediction software to mountainous terrain, as well as recommendations for mine planning and layout and suggestions for site investigations of subsidence impacts in mountainous terrain.

Additional Key Words: mine subsidence modeling, surface fractures

Introduction

It is important in any investigation of mine subsidence to have a clear conceptual model of how the strata and surface have deformed. To validate this model it is necessary to collect data of the surface features present and to compare these features to past case studies. Use of regional databases and surface subsidence software provide a helpful tool in these investigations.

A database of surface fractures resulting from mine subsidence is presented. This data is compared to work done in West Virginia to see what similarities can be observed involving mine subsidence in mountainous terrain. Additionally, another subsidence database and software, as well as the surface fracture database are used in an investigation of a subsidence site involving a communications tower in eastern Kentucky.

Surface Fracture Formation

A feature commonly encountered in eastern Kentucky is surface fractures ("mountain breaks") as a result of mine subsidence. Surface fractures can sometimes be several feet wide and tens-of-feet deep, making the features a public safety concern.

A database of surface fractures in eastern Kentucky is shown in Figure 1. The data set consists of 21 cases located throughout the eastern Kentucky coal region. This is an enlargement of a database done several years earlier and this trend is supported by additional data collected. Study of the database revealed several factors that illustrate some of the differences between mine subsidence in the mountainous terrain of eastern Kentucky as compared to more level land. The clearest trend in the data set is the tendency of surface fractures to occur on the uphill side of the retreat mining area (the "pillared area"). Only one of the cases has a fracture located on the downhill side of the retreat mining area. Two of the cases have fractures inside of large areas of retreat mining. This trend was also noted by subsidence research done in eastern Kentucky (Minns 1996). It is also interesting to compare the seam height to occurrence of the surface fractures. The mean height of the seams is 65 inches with all of the data being in the range of 48 to 90. To put this data in perspective it should be noted that 47 percent of all the mines in eastern Kentucky reported a seam height below 40 inches (1998 Kentucky Department for Mines and Mineral data).

Lou et al (1996) studied the increased horizontal displacement on sloping terrain. Comparison of predicted flat land horizontal displacement values to measured values in sloping terrain was done. As he explained, total horizontal displacement can be related to the sum of subsidence, horizontal displacement as calculated for flat terrain and an incremental increase due to the surface slope (see Figure 2). Regression analysis of the data compared movement to the angle of the slope and a combination of the angle of the slope and magnitude of the subsidence. Horizontal displacement was best predicted when both slope angle

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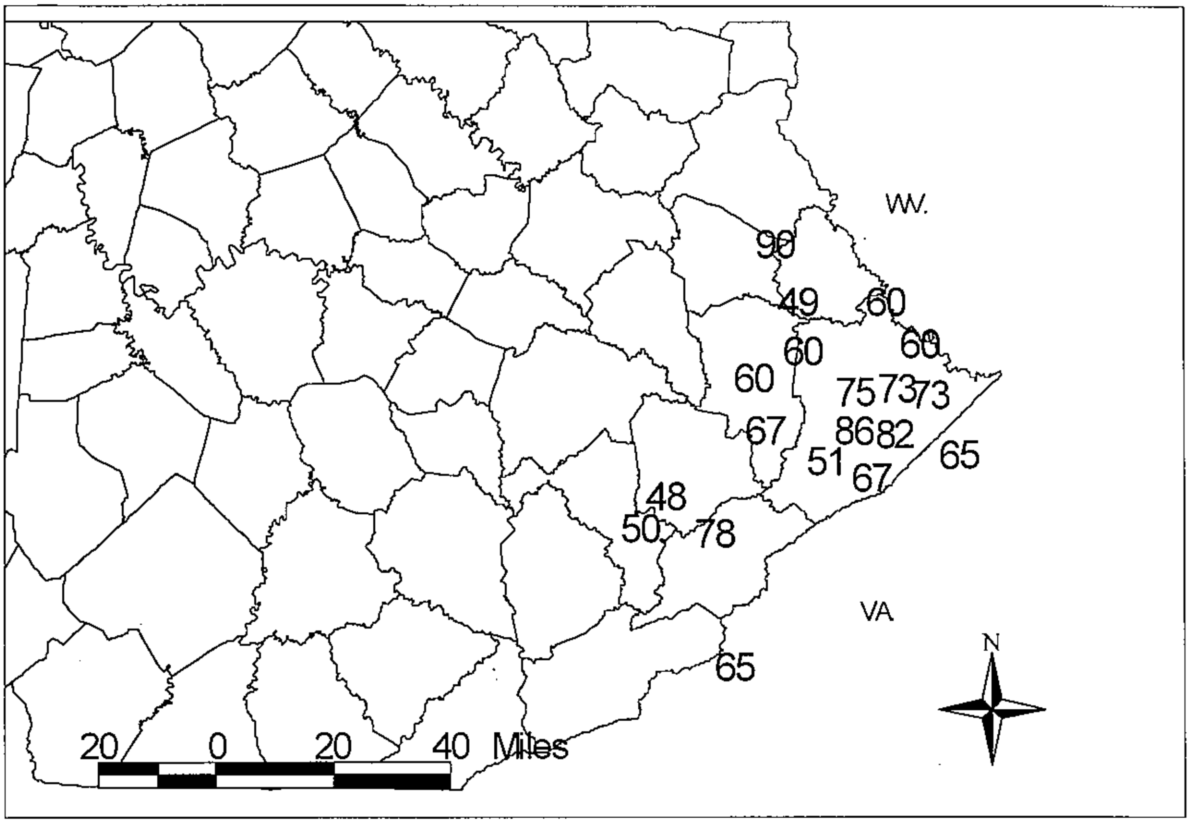

Figure No. 1. Location and Seam Height (in inches) for Surface Fractures in database.

and amount of subsidence were used to predict the value. The surface fracture database seems to correlate with this data especially given the fact than so much of the mining in eastern Kentucky coalfields is done in thin seam mines. The dataset indicates that fractures tend to occur in coal mines with a greater mine void height which provide the greater surface subsidence (Figure No. 3). Higher than predicated horizontal displacement and large fractures located on the uphill side of pillared areas also indicate another phenomenon that needs to be considered. Downslope movement of the mountain will result in a compressional stress at the base. This compressive stress can impact structures located on the surface. This phenomena has been documented by others (Lin et al 1987, Khair and Molesky 1988) and has been observed in several cases investigated by the author. The trend of the fractures occurring on the uphill side, with fewer fractures found on the downhill side of the mountain indicates that compressional stresses are likely. It also is good practice when investigating subsidence damage claims to check the location of the uphill side of retreat mining area for evidence of surface subsidence. Absence of any surface fractures however, cannot be taken as proof of no mine subsidence in the area. One of the case studies revealed a water well borehole offset, almost cutting off the well, approximately 40 feet below the surface (well below the colluvium / rock interface). The uphill side of the retreat mining area was searched and the fractures in the area were initially, quite hard to distinguish. These fractures occurred in a sandstone outcrop and on an abandoned contour mine cut. Finding these features in undisturbed forestland would have been very difficult. The location of the fractures were plotted on the mine map and fell at the edge of the pillared area (or, in one case inside of a larger pillared area.) The mine void was given as 6.5 feet and the coal seam was located above the valley

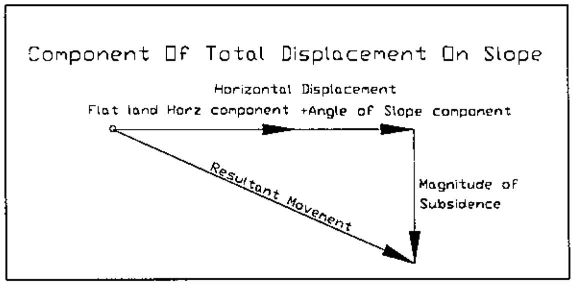

Figure No. 2. (After Lou et al 1996)

floor with approximately 250-400 feet of overburden (on the uphill side of the high extraction areas). In similar situations we have seen many severe surface fractures develop. However, at this site, some fractures were hard to find on the ground. This would suggest that other factors besides mine void height and steep terrain play a role in the formation of surface fractures. Two factors that may be an influence are the orientation and sequence of the removal of the pillars. It has been noted in longwall panels that surface horizontal movements were greater when the longwall panel was progressing in an uphill manner. (Khair and Molesky 1988).

Its has been noted that using the predicated radius of influence determined by depth of the mine works below the surface would not accurately give a range in which to estimate the extent of possible strata movement. A well borehole offset was discovered approximately 180 feet from the mine works with approximately 40 feet of depth between the coal seam and the surface. (Giving a radius of influence greater than a calculated radius using a 27 degrees angle of draw.) In situations involving compressive stress at the foot of the mountain calculating the radius of influence, as traditionally done, would result in underestimation of the range of influence by mining.

Case Study of Mine Subsidence Damage in Mountainous Terrain.

Investigation of subsidence damage in eastern Kentucky is complicated because of mountainous terrain and sometimes multiple mines may have a potential to impact the area. This case study involved damage to a communications tower (1000 ft high) located near three mines, one active mine and two abandoned mines (see Figure No. 5). The scope of the investigation was to determine if the structure had been impacted by subsidence and to identify the responsible operation.

One of the most important parts of many of our investigations is the collection of surface features and mine information for the area. The tower is situated in relation to the mine works as sbown in Figures No. 4a and 4b. Several surface fractures were present, with the closest 90 feet from the base of the tower. Several others were reported at the site and reconnaissance showed evidence of more subsidence. Four surface fractures were initially reported to be present at the site. Three of tbe surface fractures were mapped as shown in Figure No. 4a. One of the alleged fractures was eliminated as a mine surface fracture. That feature was determined to be a natural joint uncovered at the time when the northeast anchor was installed. After doing the initial reconnaissance of the site, surface features were plotted on a composite of the two mine maps of the 3 different mine works. After the determination of the northern most fracture to be a natural joint the ground features were all located on the southeast side of the tower. The other three surface fractures all plotted over sections of the old Hindman seam mineworks which were shown as still having sizeable pillars. Additionally, three fractures were dated as to the time of occurrence because of the routine maintenance of the tower and transmitting equipment. This information was compared to the mine map dates of the active mining and the occurrence of the fractures proved contemporaneous to the pillaring operation of that mine. A fourth surface fracture was located. This feature was identified by a faint linear depression in the woods and one spot where the fracture was exposed had a depth of several feet.

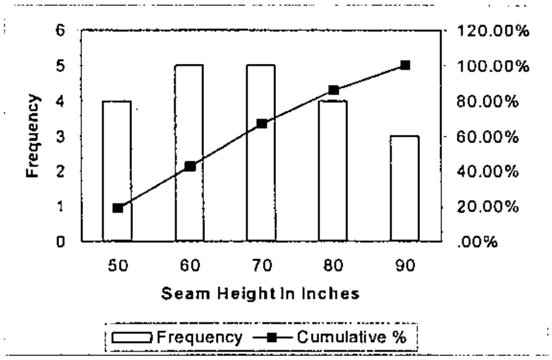

Figure No. 3. Histogram/cumulative percent chart.

The abandoned Hazard no. 4 seam mine was examined to determine to what extent its expected influence was near the tower. This was done by looking at the radius of influence of expected subsidence from the mine works. Both 15 and 27-degree angles were used to construct the extent of the influence at the site. These two angles were chosen because the 15-degree angle is often used in designing a subsidence protection plan and VPI database of subsidence cases would support the peak tensile strain to occur within that range. The 27-degree angle was used, as this was the projected angle-of-draw given for super critical conditions given by the VPI database (Agioutantis et al. 1987). As discussed above, the extent of the radius of influence normally accepted in level terrain may not

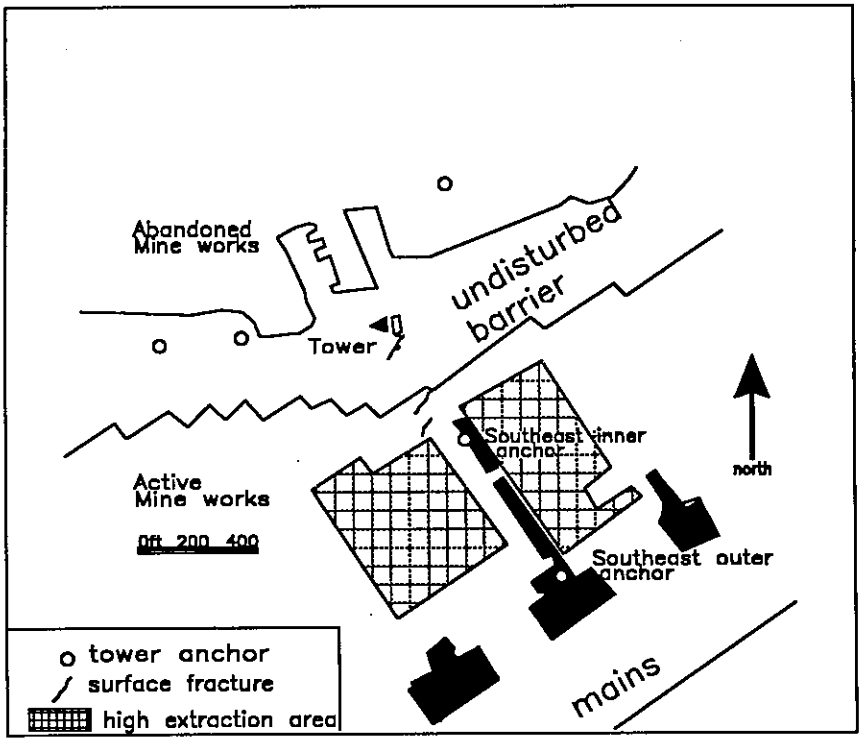

Figure No. 4a Hazard no. 4 Mine works.

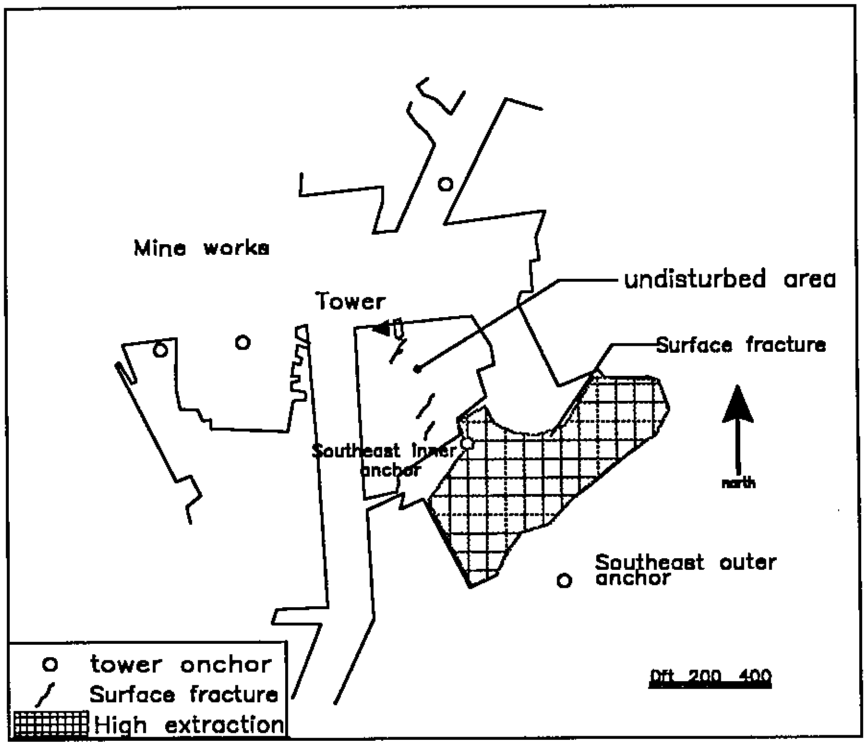

Figure no. 4b Abandon mine works in the Hindman seam.

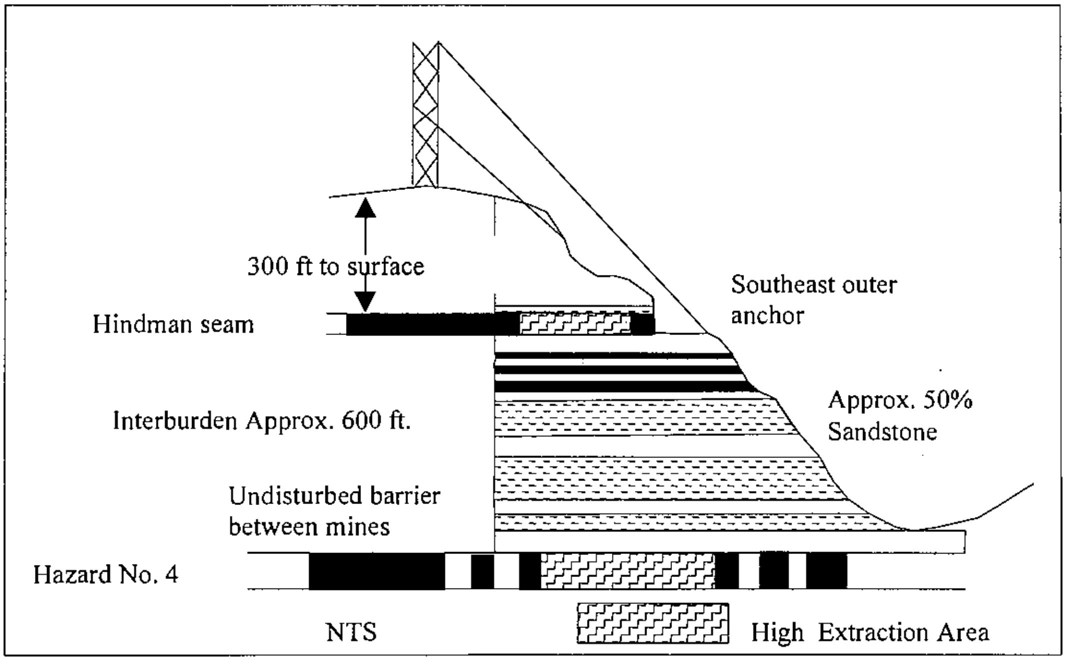

Figure No. 5. Generalized cross section.

be valid for all situations in mountainous terrain. The use of the above mentioned angles seems appropriate in looking at the radius of influence on the uphill side of the high extraction panel. That side of the panel should be experiencing tensile stresses. The presence of any joints in the strata would only tend to reduce the actual extent of strata movement to less than predicted by the above angles. Result of the investigation showed all the surface fractures except the natural joint at the northeast inner anchor, were outside of the expected radius of influence of the mineworks. This information, supported by the information concerning the tower displacement (explained later), allowed a conclusion that this mine had no impact on the tower.

The third mine was located approximately 600 feet above the active Hazard no. 4 mine (about 300 feet below the tower) and had mine works over the area of the tower and the surface fractures (see Figure No. 4b). These mine works were shown to have the mine pillars intact and the pillars were substantial enough to have supported the overburden. Review of the mine map showed pillaring operations only in small areas. The radius of influence for this area would not extend to the fracture closest to the tower. The fourth fracture found in the woods away from the tower plotted at the edge of the pillared area. This would be at a location that we typically locate these fractures. This would give some validation to the mine map accuracy.

The active mineworks were examined to determine the possibility of surface subsidence affecting the tower. Location of the mine works to the tower was close enough to have affected the tower and high extraction mining was done in the area. It was also noted that mining in the area occurred in July to September, this matches the occurrence of the surface fractures that first appeared in September of the same year. The location of the inner anchor (the anchor closest to the tower) was located over or near a barrier pillar shown on the mine map.

At the end of the initial investigation the information obtained from mine maps and surface features enabled us to eliminate one of the mines from consideration as source of the surface subsidence. However, we were unable to eliminate the active Harzard no. 4 mine and the overlying Hindman seam mine works. One of the questions we were unable to answer was, did we in fact, have the final configuration of the mine works in the Hindman seam. Large pillars in the mains could have been mined at a later date and the mine map may not have reflected the final configuration of the mineworks. Additionally, thick sandstone strata provide some possibility of bridging the pillared area; raising the possibility of the Hindman seam causing surface subsidence despite the coincidence of the timing of the pillaring operation occurring concurrently with the surface fracture formation. At this stage we then proceeded to do further field reconnaissance and analysis of the site. It was decided to try to find surface subsidence in the immediate area that could only be contributed to the active mining. Because of our previous experience with surface fracture occurrence, the uphill side of the pillared panels of the active mine, were searched. However, the search revealed no other surface fractures.

Some of the most valuable information available was the report of deformation of the tower during and after mining. The anchor supports cover a large area. Some of the anchors are approximately 1000 feet from the tower. As this tower was routinely serviced, it was noticed that excessive tensional stresses were present in the guy wires. How the tower deformed explained much about the surface subsidence in the area. Some guylines were overstressed and the adjustment of the cables could not be completed in the southeastern direction. The southeast inner anchor cables were lengthened to the maximum extent possible, while the southeast outer cables were shorten to the maximum extent possible. (The other anchors, after adjustments, were within acceptable limits.) The tower maintenance company estimated the approximately 12 inches of guy wire was lengthened at one of the inner anchors in order to reduce the tension in the cable. Deformation of the structure is the greatest in the middle of the tower. The inner anchor contained the cables extending up to level no. 4 (the middle of the tower). It should also be noted the general tendency of most guy wires is to stretch over time, requiring the guy wire to be shortened, in order to increase the tension. From this information we could see that movement of the surface was greater in the southeast area of the surface. The distance from the inner southeast anchor to the tower was increasing. However, the distance from the tower and the outer southeast anchor was decreasing. The tower was providing excellent indication of movement of the ground surrounding the structure. The need to keep the tower plumb required that adjustments to the tower be done in order to maintain the stability of the structure. From this information we now know the subsidence trough exists in the area of the southeast anchor of the tower. The inner southeast anchor is probably near the center of the trough and the tower and outer southeast anchor is near the edge of the trough. A rough measurement of 12 inches of increased length in the cable at level 4 also gives an approximate subsidence of 8 inches. The tower and anchors made a very good indicator of surface movement on that hillside and provided some of the best information as to the nature of the ground movement in the area. The large height of the tower and with the inner and outer anchors situated in such a way that subsidence coming from the pillared area of the active Hazard no. 4 mine would be very noticeable in the differential movement of the three locations.

A subsidence model SDPS (developed by VPI for the OSM tips program) was used to analyze the potential of the active Hazard no. 4 seam mine to create strain values sufficient to create the surface fracture on the surface. Default values of subsidence factor, strain factor, and angle of break were used. The predicted subsidence at the southeastern inner anchor was approximately 7 inches. Maximum strain values given near the tower was 0.0016 about the threshold of where some surface damage would be expected. (Agioutantis et al 1987). As mentioned earlier, this predicted value would be expected to be lower than actual field values due to the location of the anchor on the uphill side of the high extraction areas. Analysis for the area near the outer southeast anchor showed a surface subsidence of 3 inches. The maximum subsidence given by the model was a little greater than 14 inches. Comparing this to the information concerning the adjustment of the anchors supports the model prediction that a greater amount of subsidence is occurring at the inner anchor. Information from the tower adjustments and the model indicate that Figure No. 6 was a valid conceptual model of the surface deformation in the area.

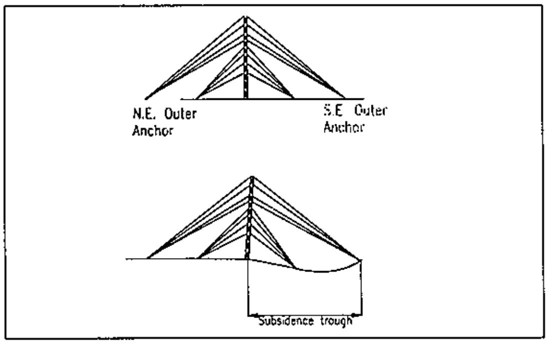

Figure No. 6. Conceptual model of ground movement at tower.

While many of the case studies in the VPI database are in mountainous terrain, when analyzing the results of SDPS it is still necessary to remember how the model will predict the result differently than the strata movement seen in mountainous terrain. One of the best examples is the prediction of strain values and the magnitude. Earlier it was explained how the base of the mountain often experiences a compressive force. However, the influence subsidence model will always predict a tensile strain value pass the inflection point of the subsidence trough. Additionally, Predicated strain values will be higher in the more shallow edge of the high extraction area. In this case, the strain values are much higher at the location of the outer southeast anchor (.0025) than at the areas of the surface fracture. This is due to the fact that the outer southeast anchor is approximately 300 feet lower. No fractures were noted on the downhill side of the retreat mining areas.

The model appears to be giving realistic prediction of subsidence. This would be consistent with earlier work. It has been observed by others that subsidence values were more accurately predicted by the subsidence model than strain values (Khair et al 1988).

Conclusions

- In mountainous terrain, increased height of the mine void tends to increase the chance of surface fractures typically on the uphill side of the high extraction area.
- The case study and database show need for more study of the behavior of overburden movement resulting from subsidence. This would allow better mine layout of future operations to avoid impact on the nearby residences. Better analysis of abandoned mine works could then be done to determine the potential influence to surrounding structures. Abandoned mine land and mine subsidence insurance programs could then be more confident of their decisions.
- The case study shows how both regional subsidence information and current software provide useful tools for the investigation of alleged mine subsidence sites. While this information may not provide strong conclusive information on their own, they are very useful tools for anyone investigating a site. This information can also provide guidance to direct investigations in a way that provides more information in an efficient manner. The case study also illustrates the shortcomings of such information. The use of regional databases to predict strata movement is only that. Examination in the field is necessary to obtain conclusive findings.
- The case study also shows the need for current mine planning keeping track with often rapid changing features on the surface. Often small changes in the high extraction mine layout can dramatically reduce the chance and severity of the impact of mine subsidence on any surface structure.

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