INVESTIGATION OF A SUBSIDENCE EVENT NEAR FLUSHING OHIO[1]

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Abstract: An investigation was undertaken to determine the cause and extent of events which caused problems to a number of residences along State Route 149 near Flushing, Belmont County, Ohio. The events began in 1988 and continued through 1991 and affected nine homes. The type of problems occurring, as well as surface effects, compared to available mine maps of the area, indicated the problems were caused by subsidence from coal mining. The mining occurred in the Pittsburgh seam at a depth of between 180 and 220 feet. The mining beneath the site took place between 1975 and 1977 and was of the room and pillar type. A subsurface investigation was performed, along with "down the hole" video camera inspections to provide necessary subsurface information for analysis of the subsidence event. Factors of safety were calculated for pillars throughout the mine. Based on this analysis, it was determined that pillar failure caused the subsidence event. Once a determination was made as to the likely cause of the subsidence, the data was re-examined to determine the possible location of pillar failure, as well as the type and extent of subsidence. This analysis involved the use of RQD versus depth plots and the compilation of isopach maps of the mine overburden and the Sewickley Sandstone. The trend of the two maps suggested that a relationship existed between the sandstone thickness, the overburden and the surface expression of the subsidence. In order to determine this relationship, the two maps were combined into a second order map showing the mine overburden - Sewickley Sandstone thickness ratios. The combination was accomplished by computer matrix operations using the grid values of the two previous maps that were generated by kriging. It was concluded that the ratio of the Sewickley Sandstone thickness to the mine overburden had a tremendous effect on the amount of damage that occurred to specific residences.

Introduction

Underground mining for the removal of coal has taken place in the eastern portion of the United States since the early part of this century. Millions of acres of abandoned room and pillar mines exist, many of these below existing structures. As the coal pillars, mine floor and roof strata of these mines degrade with age, subsidence of these abandoned mines continues to occur.

Many factors contribute to the cause, extent and effects of the subsidence. These factors include overburden thickness and composition, seam thickness, pillar configuration, condition and strength, groundwater levels, mine floor conditions, location and composition of structures above the mine, etc. The number and variability of these factors has precluded the development of methods to predict the likelihood and extent of room and pillar mine subsidence with any degree of accuracy. Because of this, it is necessary to examine each subsidence event with a broad based approach, paying particular attention to trends in the data that may give an indication of cause and extent.

This paper presents a case history of a subsidence event near Flushing, Ohio. In cooperation with the Office of Surface Mining (OSM), this investigation was undertaken to determine the cause and extent of subsidence occurring at this site. Using standard investigation techniques in conjunction with some unique analysis of the data, a relationship between the surface expression of the subsidence and the thickness of a sandstone bed and the overburden stress was developed. While this relationship is site specific, it provides insight into the means and methods necessary to investigate room and pillar subsidence.

Site Description and Mining History

The study area is situated along State Route 149 beginning approximately 518 m. north of its intersection with S.R. 331 and extending north approximately 549 m. in Belmont County, Ohio. The site encompasses eleven (11) single family dwellings as well as three (3) mobile homes.

The area is underlain by room and pillar mine workings in the Pittsburgh or No. 8 seam with the depth to the top of the seam varying between 54.9 m. and 67.1 m. The mine began operation in the late 1960's and according to MSHA records closed in November, 1990. Dates on the mine map indicated that mining under the study area took place between 1975 and 1977.

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According to former employees of the mine, this particular section was mined with conventional mining techniques, with retreat mining performed by a continuous miner. The shape of many of the pillars on the mine map indicate that slabbing and/or splitting of pillars was conducted. The extraction rate was 61%. The mine map indicates that the overlying No. 9 (Meigs Creek Coal) was mined approximately 1.2 km. west of the site. However, the map does not show any deep mining in this seam within the study area, although it has been surfaced mined adjacent to the site.

Geology

Strata underlying the study area belong to the Pennsylvania Age Monongahela Group. This group averages 76 m. thick, and is composed of alternating beds of limestone, claystone, shale, sandstone, and coal (see Figure 1).

Known as the Upper "Productive Coal Measures", the Monongahela Group contains three regionally economic coal seams, as well as several non-persistent, locally minable coal seams. Within the study area, the top 9 m. of Monongahela strata has been eroded. The remaining strata of this group contain the other two economic coal seams - the No. 9 and the stratigraphically lower No. 8. The No. 9 coal lies from 34 m. to 37 m. below ground surface and averages 1.2 m. thick. The No. 8 coal lies from 55 m. to 67 m. below ground surface and averages 2 m. thick and has been extensively mined beneath the study area.

Limestones comprise nearly 50% of the overburden. There are five limestone units within the Monongahela Group in the study area. They are in ascending order: the Redstone, the Fishpot, the Benwood, the Arnoldsburg and the Uniontown.

The Redstone Limestone lies from 1 m. to 2.7 m. above the No. 8 coal. The limestone consists of light gray limestone at the bottom grading into a shaley limestone at the top. The interval between the coal and the limestone consists of an incompetent slickensided claystone.

Approximately 1.5 m. above the Redstone Limestone is the Fishpot Limestone. The interval between the limestones is composed of claystone, and the thin discontinuous Redstone coal horizon which denotes the division between the two limestone units. The Fishpot is composed predominantly of light gray fine-grained limestone. There are also several beds of claystone 0.6 m. to 2.1 m. thick within this unit.

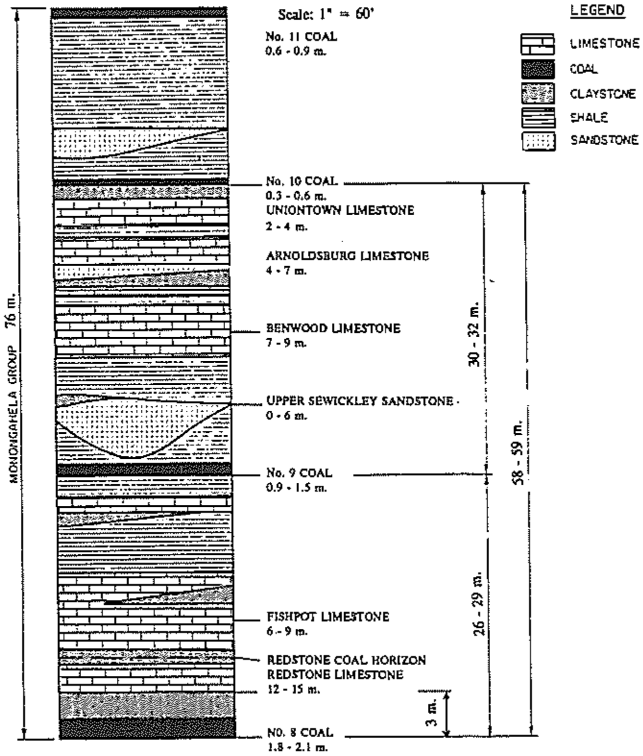

Figure 1. Generalized stratigraphic column of project area.

Another limestone lies from 0.3 m. to 3.7 m. below the No. 9 coal. This limestone, although persistent within the study area, may not be aerially extensive. It is very thin, averaging only 1.4 m. thick.

The Benwood Limestone lies approximately 10.7 m. above the base of the No. 9 coal and like the Fishpot is composed predominantly of light gray fine-grained limestone. It ranges in thickness from 7.0 m. to 8.5 m. thick and contains beds of shale and clayshale.

The Arnoldsburg Limestone lies from 0.6 m. to 2.7 m. above the Benwood Limestone, separated from it, by a thin sandstone. The Arnoldsburg is shalier than the Benwood or Fishpot, although some fine-grained limestone beds are present along with the beds of shale and claystone.

The Uniontown Limestone occurs within a meter of the base of the Uniontown coal. It is separated from the underlying Arnoldsburg by 1.5 m. to 3.0 m. of shale and claystone. Several on-site drill holes show a thin sandstone layer at the base of this limestone. In the study area, the Uniontown is predominately a medium gray shaley limestone.

The Upper Sewickley Sandstone is the only prominent sandstone occurring within the study area. It is a cross-bedded channel sand ranging from 3.0 m. to 7.0 m. thick. It lies from 2.7 m. to 6.7 m. above the top of the No. 9 coal.

Site History and Structural Damage

The event or events causing the problems to the homes began in 1988. The Office of Surface Mining conducted an investigation at an adjacent property in early 1988, which appears to coincide with the beginning of these events. Subsidence monitoring indicated that movement was still taking place as of 1990. Also, sudden and severe structural failures at an adjacent property during September 1990 are further evidence that the movement is ongoing.

The subsidence has caused damage to most of the residences in this area. The following is a summary of problems which were found in the Marinucci, Doty, Taylor and Robert Hyest residences:

1. Tension cracking in floor slab.
2. Floor slabs separating from basement walls.
3. Cracks in the masonry block basement walls.
4. Cracking and/or separation of concrete sidewalks.
5. Staircase style cracks between and through exterior brickwork.

In addition, all homes other than the Robert Hyest residence experienced waterline breaks.

The Britton residence experienced the following unique problems which were:

1. Septic system failure.
2. Apparent uplift of the furnace into the first floor joists.
3. Main floor support beam lifted off pilasters.
4. Basement walls bulging inward.

The tension cracking in the three perimeter homes examined indicate an oblong type subsidence feature bounded by the Marinucci, Doty and Robert Hyest residences. It should be noted that these are only arbitrary boundaries, due to a lack of surface expression of subsidence beyond these homes, (i.e. except for a ground crack that developed behind the Doty residence in September 1990.

The problems at the Britton residence is indicative of compressional forces. The damage at the remaining residences is indicative of tensional forces.

Methods of Investigation

Field Reconnaissance

The field reconnaissance for the project consisted of three site visits. The initial site visit was performed on May 1, 1990 to examine conditions at the site. A second site visit was conducted prior to the drilling investigation, to more thoroughly examine the structures involved and the proposed boring locations. A third site visit was made upon completion of drilling to re-examine the structures and any new subsidence features as well as to examine a new and recent event that had damaged an adjacent residence.

Subsurface Investigations

A drilling program was begun on July 18, 1990. A total of 12 drill holes were completed to aid in determining subsurface conditions. Split spoon samples of soils were taken and drill holes were advanced through bedrock with an HQ core barrel. The HQ core size was chosen to allow the use of OSM's borehole camera and distant viewing light source. Due to fracturing in the overburden and numerous clay seams, drilling was difficult and extended through September 10, 1990.

Upon completion of the drilling, all holes were examined and videotaped with OSM's borehole camera. Each hole was first videotaped using the axial lens, followed by the close-viewing right angle lens. It was anticipated that any mine voids encountered would then be viewed using the distant-viewing right angle lens and light source; however, due to the collapsed condition of the mine, this was only possible in one borehole.

Subsurface Conditions

Based on the drilling and examination of rock core as well as examination of the borehole video the following subsurface conditions were found to exist.

Overburden

A thin to moderately thick mantle of soil was encountered above the rock overburden at the site. The soil thickness ranges from approximately 2.1 m. to 5.5 m. The soils were generally fine to medium grained residual soils, consisting of silty to sandy clays with varying amounts of rock fragments. The soils were soft to stiff in consistency and moist.

The rock overburden encountered during drilling generally consisted of alternating layers of limestone, shale, claystone, sandstone and coal. The rock quality designation or RQD of the rock core varied extensively ranging from very poor to excellent. Core recovery during drilling was generally excellent. However, some areas of poor recovery and poor RQD were encountered within the first 12.2 or 15.2 m. above the mine. This is attributed to small voids and broken rock strata.

Fractures

The rock core shows that the overburden of the No. 8 coal is fractured. High angled fractures are common. The fracture surfaces are rough to jagged, with some forming a "criss-cross" pattern while others consist of 2 high angle parallel fractures, generally less than 3 cm. apart. These irregular fractures are indicative of subsidence of the overburden and are most commonly found in the zone of caving and/or zone of breaking as shown in Figure 2.

Both naturally occurring and irregular fractures were observed in the core; however, the irregular fractures are more common. Both fracture types are iron stained, at depths less than 15.2 m. At greater depths, generally only the naturally occurring joints are iron stained, indicating that the irregular fractures are relatively recent. Iron-stain development (iron hydroxide) is dependent on the presence of oxygen. Fractures at greater depths, where oxygen is not as readily available as near the surface, would need a longer exposure time to develop a coating of iron hydroxide. Subsidence fractures, being a recent development, may be slightly iron-stained at the surface where oxygen is abundant, but, not at greater depths.

The irregular fractures occur primarily in the light gray fine-grained limestone of the Fishpot, Benwood and Arnoldsburg limestones. These limestones are extremely hard and brittle. In DDH-7, the top part of the Fishpot limestone core was shattered. The fragments consist of small angular, sharp-edged pieces along with some "cork screw" shaped pieces.

The borehole camera showed, in addition to numerous high angle fractures, low angle and horizontal fractures. The horizontal fractures generally occur along bedding planes in shaley layers or at changes in rock type. Low angle fractures occurring within limestone, sandstone, shale, and claystone beds are thought to be subsidence related. Most horizontal and low angle fractures occur in the rock strata lying above the Upper Sewickley Sandstone, while high angle fractures predominate below the sandstone. The horizontal separation ranges from 2.5 cm. to 5.1 cm. in width. This separation is indicative of the zone of downwarping of strata as shown on Figure 2.

Analysis

To analyze the mode of subsidence we looked at three possible causes:

1. Roof failure.
2. Pillar punching.
3. Pillar crushing or failure.

Any individual or combination of the above causes could have been responsible for the mine subsidence. The following is a description of each.

Pillar Punching

The potential for a bearing capacity or pillar punching failure depends on the engineering properties of the mine floor. Pillar punching occurs when weak floor strata exist in the mine and bearing pressures of the pillar exceed bearing capacity of the floor. When this occurs the pillar either settles or, in the worst case, the pillar punches through the floor strata. This generally occurs when the mine floor consists of underclay. However, the floor in this mine is a fairly competent limestone and/or siltstone unit. One boring, encountered a 1.2 m. thick seam of underclay. However, due to the low recovery in this particular section of the boring and the nature of the core, it is unclear whether this is truly an underclay or possibly mine gob. The RQD of core samples in most borings that penetrated the floor are good to excellent indicating that the floor material is competent. This indicates that pillar punching most likely did not cause or contribute to the subsidence.

Roof Failure

Roof failure occurs when the strata comprising the roof of the mine are not strong enough to span the distance between pillars. Degradation of roof strata can be accelerated by weathering and/or of groundwater levels in the mine.

Plots of elevation vs. RQD show that the rock quality of the roof strata is poorest within the first 12.2 m. above the mine. This is particularly evident in borings that were drilled through the rooms of the mine. However, even drill holes, which penetrated pillars, show this trend, though to a lesser degree than the borings into mine voids. It should be noted that this is likely due to both poor roof

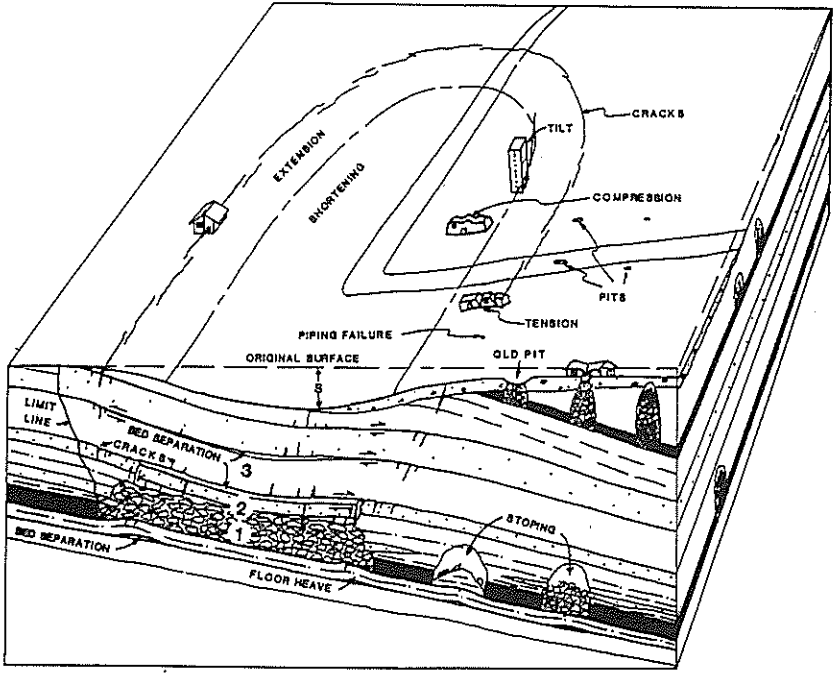

Figure 2. Conceptual diagram showing coal mine subsidence processes and deformation above extraction areas and mine openings. In downwarped zone: 1) zone of caving, rotation of caved fragments, and permanent bulking; 2) zone of breaking with little rotation of caved fragments, much cracking and bed separation, some permanent bulking; 3) zone of downwarping of strata as laterally constrained plates with local separation along planes of stratification, little or no permanent bulking. (AEG, 1987)

and pillar failure. This concentration of fracturing indicates that roof collapse has taken place, and that quite possibly this has contributed to subsidence at the site.

In the portion of the study area north of State Road 149, 10 holes were drilled through the No. 8 mine; 3 encountered coal pillars and 7 encountered mine passageways. The 7 holes that encountered passageways all show that the mine roof has fallen and that the mine is inundated. The height of the failure ranges from 0.37 to 0.82 m. above the top of the coal. The 2 holes drilled on the Watson property both encountered pillars at mine level.

The cause of the immediate roof failure is attributed to the nature of the claystone that forms the roof. This claystone is soft and slickensided, which makes it difficult to support. The height of the roof collapse observed during drilling, however, exceeds the claystone thickness; this indicates that either the strata overlying the claystone are also incompetent and cannot span the support pillars or that the pillar spacing is inadequate to support the resultant span. As noted in the geology section, the Redstone Limestone (the first limestone above the mine) is split by shale and claystone partings. These abrupt lithologic changes form natural planes of weakness in the strata. The thinner beds of limestones in the base of the Redstone are probably not strong enough to support the overburden and the roof spalls upward to the more competent limestone beds above.

Pillar Crushing or Failure

The strength of the coal pillars depends on the size, shape and compressive strength of the coal. Pillar failure occurs when the overburden stress on the pillar exceeds the strength of the pillar. This can occur when pillars are too small or when the strength of the pillar is reduced by weathering effects or other factors (additional surface loading, redistribution of stresses due to other pillar failures, etc.)

Based on the mine map, the topographic mapping, and the drilling results, factors of safety were calculated for the pillars. Average stress was calculated based on the following formula:

$$S_{AVG} = \frac{D \times 25.9 \text{ kg/cm}^3\text{/m.}}{1\text{-\% Extraction}} \quad \text{(Given, 1973)}$$

Where:

S_{AVG} = Average stress
D = Depth to top of seam = approx. 64 m.
% extraction = 61%
25.9 kg/cm^3/m = Overburden stress/m.

Based on this, the average overburden stress is approximately 41.6 kg/cm^2

To determine pillar strength the Holland-Gaddy formula was used:

$$S = \frac{K\sqrt{L}}{T}$$

Where:

S = Pillar strength kg/cm^2
L = Least lateral dimension of pillar (cm)
T = Thickness of seam or pillar height (cm)
$K = Sp\sqrt{D}$

Where:

Sp = compressive strength of cubical sample of coal in question.
D = Edge dimension of cube

Based on testing of samples obtained during drilling, as well as data from previous testing of samples from the Pittsburgh seam, a value of 5400 was calculated for K. The smallest pillars under the site had a least lateral dimension of approximately three meters. A value of 53.3 kg/cm^2 was then calculated for the pillar strength based on a least lateral dimension of three meters. Because of degradation of the pillars with age, as well as pillar fracturing induced by conventional mining techniques, 0.6 m. were subtracted from the least lateral dimension when calculating allowable pillar strength. This resulted in a pillar strength value of 47.7 kg/cm^2 for 3.0 m. wide pillars.

The resultant factor of safety is 1.15, a figure considerably less than the recommended factor of 2.0 using this formula [SME Handbook (1973)]. Because of this, we felt that any pillars equal to or less than 3.0 m. wide were of very questionable stability. We then back calculated and found that pillars equal to or less than 8.2 m. would be of questionable stability, and pillars greater than 8.2 m. should be stable. (It should be noted that because of pillar failure and redistribution of stresses to other pillars, pillars greater than 8.2 m. wide may also fail.) These pillars were highlighted on the mine map showing their distribution across the site. From this map it can be seen that many of the pillars with the lowest factor of safety lie on the west side of the main heading below S.R. 149 and parallel it throughout the site. The pillars with factors of safety between 1 and 2 make up the majority of the rooms below the site.

The drilling revealed evidence that some of the support pillars have been "robbed" or split, and are not as shown on the mine map. Two boreholes that should have bottomed in pillars; however, both encountered passageways. Another borehole, which encountered a pillar, shows only 1.25 m. of coal while adjacent drilling shows the coal to be approximately 1.83 m. thick. This may be due to a local roll in the coal seam, but the fractured nature of the coal more likely indicates that the pillar has failed and "crushed out".

Discussion

Once a determination was made as to the likely cause of the subsidence, the data was re-examined to determine the possible location of initial pillar failure, as well as type and extent of the subsidence.

Main Area

As mentioned previously, structural damage at the site varied. The Britton residence experienced compressional damage while the remaining structural damage in nearby residences was tensional in nature. This suggests that the Britton residence is near the center of the event within the compressional zone (see figure 2).

The possibility of the subsidence event beginning near the Britton residence was then investigated. An examination of the geologic sections reveals that the Sewickley Sandstone is the prominent competent unit underlying the study area. Numerous limestone units exist, but are interbedded with shales and claystones. Examination of the rock core and the borehole videos show the limestones to be fractured and brittle in nature. Graphic plots of RQD vs. depth show a consistent spike (increase in rock quality) in the Sewickley Sandstone with RQDs generally above 80%. This indicates that the sandstone is competent and has largely withstood the stresses produced by the mine subsidence. The same plots show varying RQDs in the limestones and shales, indicating that these units are not as consistently competent as the sandstone and that they have not withstood the subsidence-induced stresses as well.

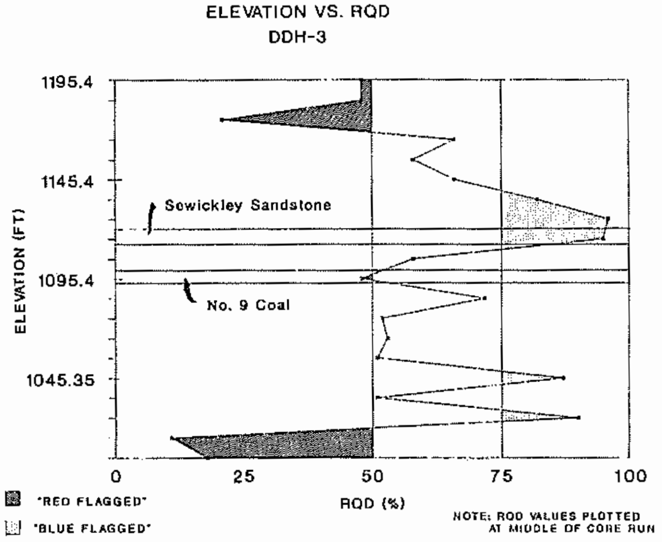

Figure 4. Example of graph depicting RQD values obtained from drill core versus elevation.

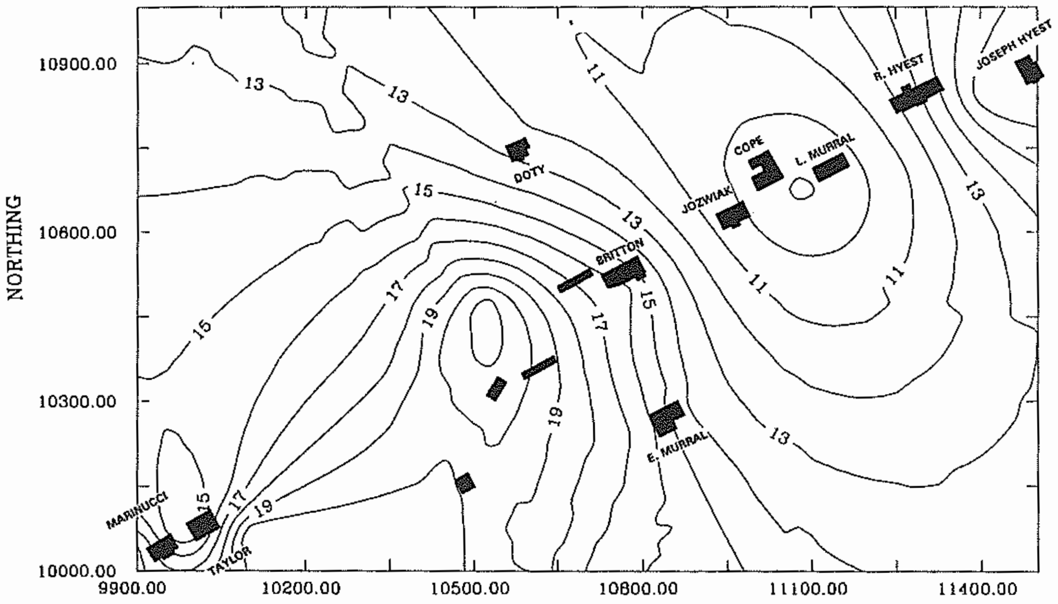

Figure 3. Map showing ratio of mine overburden thickness to Sewickley Sandstone thickness.

The ability of the Sewickley Sandstone to withstand stress is primarily dependent on its thickness as well as its location within the overburden. The Sewickley Sandstone is located within the zone of breaking or zone of downwarping, as shown in Figure 2. Because of this location, the sandstone is not subject to the higher degree of stresses that many of the stratigraphically lower limestones are. To determine the variations in thickness of the Sewickley Sandstone, we produced an isopach map of the unit. Values were obtained from the drill holes based upon sandstone thicknesses and the laterally equivalent siltstone. These values were input into the Surfer computer program and grid values were calculated using a kriging algorithm. Based on these grid values, the computer produced contour lines representing areas of equal sandstone thickness. The resulting map shows a thickening of the unit in the area surrounding the Jozwiak, Cope and Murral residences, while showing the sandstone to be thinnest in the region between the Britton and Taylor residences.

Because many of the pillars had factors of safety near unity it was determined that slight increases in overburden stress may cause pillar failure. Therefore, a second map was produced using the Surfer program. This map represents the thickness of the overburden between the top of the mine and the ground surface. Values for this map were obtained from drill holes as well as from the topographic map and elevations on the mine map. Again a kriging algorithm was used to calculate grid points; subsequently, contour lines representing areas of equal overburden thickness were derived. As expected, the map showed that the overburden was a somewhat subdued reflection of surface topography with greatest thickness near the Everett Murral residence.

The trends of the two maps suggested that a relationship exists between this sandstone thickness, the overburden and the surface expression of the subsidence. In order to determine this relationship, the two maps were combined into a second order map called the Overburden/Sewickley Thickness Ratio Map (see Figure 3). To combine the two maps, we again used the Surfer computer program. In this procedure, a matrix operation was performed in which the grid values from the overburden grid were divided by the grid values from the sandstone thickness grid. The resulting grid was then contoured. Contour lines on this map represent lines of equal overburden/sandstone thickness ratios. The areas with the larger values represent areas where the sandstone is the thinnest, and overburden is the greatest. Areas with the lower values represent areas where the sandstone is thicker and overburden is less. The mapping shows that the area slightly west of the Britton residence has a ratio of 21:1; that is 21 m. of overburden for every meter of sandstone. This indicates that while the overburden stress on the pillars is greater in this region, the competent sandstone unit is thinner and less able to provide ground support. The area with the largest ratios (18 to 21) corresponds with the area in which we believe the initial subsidence event occurred.

To further investigate the location of the initial event, plots of RQD vs. elevation for DDH-1 through DDH-10 were examined. The RQD values are indicative of fracturing in the strata, with low RQD values being representative of areas with the greatest fracturing. A "flagging" technique was used on the individual RQD vs. elevation plots. The flagging technique involved drawing vertical lines at 50% and 75% RQD on the individual plots. Areas less than 50% on the plots were "red flagged" and areas above 75% were "blue flagged" (see Figure 4). The 50% value was chosen as it represents the cut-off below which rock is considered poor. The 75% was chosen as it represents values above which rock is considered good. All pre-mining factors being equal at the site, the RQD values at the site should be fairly consistent and furthermore, below the zone of weathering, the rock quality should generally be good at this site. The latter is true due to the generally competent lithologies present and general lack of premining structural deformation in the units above the mine (both of which could affect the RQD).

RQD values in the uppermost portions were low, representing the weathered zone; most borings demonstrated higher values in the Sewickley Sandstone and markedly lower values in the No. 9 coal. The trends in RQD below the No. 9 coal then began to vary until most borings disclosed a dramatic drop above and continuing to the No. 8 coal horizon.

In addition, the flagging revealed some anomalous trends within individual drillholes. As expected, the borings above pillars exhibited the least "red flagging" and the most "blue flagging". The inference here is that the strata in these areas withstood the subsidence best and/or experienced the least stress. DDH-5 and DDH-10 have the most "red flagging", while DDH-3 has the least "blue flagging". This is indicative of areas where strata have endured the most fracturing. A closer examination of DDH-3 also reveals that the RQDs in this boring are considerably lower than any other boring at the site. An examination of the borehole videotapes confirms the RQD data.

Based on the RQD plots, borehole videotapes, Sandstone - Overburden Thickness Ratio, mine map analysis and surface damage, it is evident that the subsidence event at the site began in the room just south of the Britton residence and propagated radially outward.

Conclusions

Based on our analysis, the following conclusions are presented:

1. Structural distress at the site is related to subsidence from the collapse of mine workings in the No. 8 coal seam.

2. Poor roof conditions exist in the mine. The shales, claystones and thin limestones are incompetent and spall with time. This collapse may be a contributing factor to the subsidence; however, due to the presence of the competent Upper Sewickley Sandstone member and the overburden thickness, roof collapse does not appear to have been the primary cause of subsidence.

3. The floor of the No. 8 seam is a fairly competent limestone unit and therefore pillar punching most likely is not a contributing factor to the subsidence.

4. Based on our calculations, the majority of the pillars at the site have a factor of safety of 2.0 or less. In addition, degradation of pillars with time likely further decreases pillar strength.

   Therefore it appears that pillar crushing has occurred and is the major cause of the mine subsidence.

5. Based on our superposition of the topographic map on the mine map (using state plane coordinates as the common control), the location of the structures on the mine map are not accurate. Structures as shown on the mine map may be mislocated by as much as 12.2 m. In addition, drill holes DDH-3 and DDH-7 should have penetrated mine pillars but encountered passageways. This indicates that actual pillar configuration appears to be different from that shown on the mine map.

6. Initial subsidence most likely began in the section just south of the Britton residence and propagated elliptically with a northeast-southwest trend.

7. Subsidence is generally of the "sag" type (Craft, 1990) with some individual room subsidence contributing to the overall damage.

8. Subsidence propagation at the site is likely related to the overburden - Sewickley Sandstone thickness. Areas where the overburden sandstone ratios are below 12 seem to have the least, if any, damage, while areas with ratios above 12 have the most.

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