STRUCTURES AND GROUND DAMAGES OVER ABANDONED MINE LANDS[1]

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Abstract.--Damages to surface structures and ground surface above abandoned mine lands have been found in many regions of Pennsylvania and West Virginia. Many cases of damage can be attributed to abandoned mine failures or some other known causes. However, in cases the causes cannot be easily identified. Twenty cases of subsidence damage to dwellings have been investigated. Among them fourteen cases were determined to be abandoned mine failures based on the identification criterion developed in this research; three cases were due to differential settlement; two cases were due to soil piping or drainage problems; and one case was due to active mine subsidence.

In this paper, the procedures of investigation and instrumentation applied to the case studies are described. The damage patterns, the location of subsidence epicenter and the severity of damage derived from the information collected are illustrated. The results obtained from the instrumentation such as the inclinometer and Sondex measurements are discussed. Based on those intensive case studies some general findings and trends are obtained. For instance, the basements of the dwellings likely are subject to more severe damage than the upper structures. These features are also discussed in detail in this paper.

INTRODUCTION

Damages to the ground surface and surface structures above abandoned coal mine lands have affected about 2 million acres in 30 states (Johnston and Miller, 1979). This problem appears to be the most severe in Pennsylvania, Illinois, and West Virginia (HRB - Singer, Inc. 1977). Approximately 57% of the total subsidence prone areas in the U.S. are located in Pennsylvania and West Virginia (Johnston and Miller, 1979). These damages can be attributed to mining-related or nonmining-related causes. Federal abandoned mine subsidence remedial program and private insurance companies subsidence insurance policies only take care of mining-related subsidence. For purposes of damage compensation and underground stabilization, it is essential to identify the real causes of the damages. In order to identify the real causes of the damages, the damaged features associated with each possible cause and the mechanism of each damage feature should be well understood.

Twenty cases of subsidence damage to dwellings were investigated. Among them fourteen cases were due to abandoned mine failures; three cases were due to differential settlement of backfilled materials; two cases were due to soil piping or drainage problems and one case was due to active mine subsidence (Peng and Hsiung, 1986 and 1987). Based on the subsidence features five of

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the twenty cases were pothole subsidence and the remainder were sag or trough subsidence.

In this paper the approach and procedures of the investigation will be briefly discussed. The instrumentation will be reviewed. The data from some of the cases will be briefly discussed. The damage to the ground surface and structure, the links between the ground movement, ground damage and structure damage will be discussed and analyzed.

APPROACH AND PROCEDURES

The approach and procedures for the study of subsidence over abandoned mine lands have been established by the AML subsidence research group in WVU, Mining Engineering Department. Time is essential because the damaged conditions may be disturbed and the exposed features may disappear. Therefore, a site investigation is always the first step for AML subsidence research because most of the information must be collected from the subsidence site, especially during the first time reconnaissance. For most cases the causes, damage pattern, and the status of ground movement can be determined by the obtained information. The information mainly consist of six categories such as: (1) general information, (2) structure information, (3) surface condition, (4) geological information, (5) geometry and characteristics of the subsidence, and (6) mining activity. Each category will consist of several sub-categories. In order to make sure that a complete set of information can be collected a site investigation checklist has been developed by this research group. Table 1 is a site investigation checklist (Peng and Hsiung, 1987) which provides a guideline for inspectors to collect a complete set of information during the site reconnaissance.

With the data collected from a site investigation, a hypothesis should be established to clear up the logic and narrow down the number of possible causes. In order to determine the cause of the damage, the cause identification system with an identification list (Table 2) (Lin et al., 1987; Peng and Hsiung, 1987) have also been developed by this group to evaluate the most possible cause. If the cause cannot be determined due to insufficient data, an in-depth exploration should be adopted.

An in-depth exploration mainly consists of surface and subsurface measurements and instrumentations including surface survey, borehole TV camera examination, crackmeter, inclinometer and Sondex settlement measurements. The results can be used to determine the cause(s) of the damage, the direction and magnitude of movements, and help to design a better remedial program.

GROUND SURFACE DAMAGES DUE TO SUBSIDENCE

When subsidence occurs several types of ground damages will be induced. The most common damages are depressions, cave-in pits, ground cracks, and compression ridges. The ground depression is associated with trough or sag subsidence. Its mining-related causes are pillar and floor failures; non-mining-related causes are differential settlement on the backfilled area, fluid withdrawal and organic soil drainage. A ground depression is a gentle settlement over a broad area which may range from a few tens of feet to hundreds of feet in diameter while the depth of depression ranges from 2 to 4 feet for mine subsidence. The depth of the depressions due to non-mining-related causes is relatively unknown but a 30-feet depression has been reported due to fluid withdrawal (Christian and Hirschfeld, 1974).

The cave-in pits are most likely associated with potholes, sinkholes or chimney subsidences. Their mining-related cause is roof failure while the non-mining-related causes are limestone solution and soil piping. The newly developed cave-in pits are likely to be steep-sided with straight or bell-shaped walls depending on soil type. The diameter of cave-in pits ranges from 2 to 40 feet but most of them are less than 16 feet in mine subsidence (DuMontelle and Bauer, 1983). The depth of cave-in pits is about 6 to 8 feet for mining-related cases and the coal seams are less than 165 feet deep (Bauer and Hunt, 1981). For the non-mining-related cave-in pits, the diameter ranges from a few feet to 10 thousand feet and the depth ranges from a few feet to 90 feet (Newton, 1984). All the pothole subsidence cases investigated in this research showed that the diameter of the holes ranged from 2 to 19 feet; the depth was about 2 to 17 feet; and the coal seam was about 20 to 60 feet deep (Peng and Hsiung, 1986).

The ground cracks which occur at the margin of the depression and cave-in pits are the result of convex bending and are associated with the stretching of the ground surface. Generally, the ground cracks at the margin of the depression and cave-in pits indicate the location of the maximum tensile strain (peng, 1987). Beyond this maximum tensile strain zone, structures and ground damages are usually minor or nonexistent. Therefore, a subsidence damaged area can be determined by locating the ground cracks. In general, ground cracks are wider, more abundant and extensive near cliffs and steep terrain than they are in flat or gently rolling topography. Moreover, ground cracks are more often located at the asphaltic pavement than that at soil zone since asphat is more brittle than soil and can take less stress. Figure 1 shows that a ground crack was about 2 inches wide across through the width of the asphaltic road but the crack did not develop at the soil.

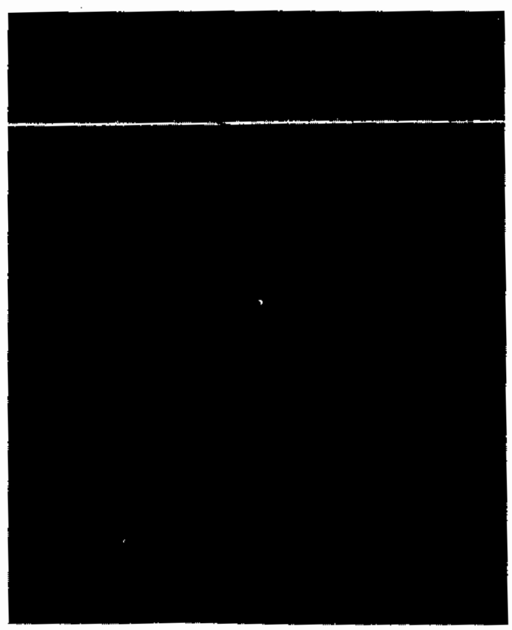


Fig. 1 Crack developed on the asphaltic road but did not develop on the shoulder (soil zone)

Table 1.--Subsidence Investigation Checklist.

1. General Information
   A. Name(s):____
   B. Address(es):____
   C. Location: (See Fig.)____
   D. Date of initial occurrence____
   E. Date of investigation____
2. Structure Information
   A. Background and history of the problems
      (a) History of damage____
      (b) History of similar events in the vicinity____
      (c) Age of structure____
   B. Type of construction and material
      (a) Type of house: with slab____ with crawl space____ with full basement____or partial basement____
      (b) Type of construction and material: frame____ brick____ brick veneer____ concrete block____ stone veneer____
   C. Damage description (with drawings or photographs)
      (a) 1st Floor: ceiling____floor____ utility____internal wall____ external wall____
      (b) 2nd Floor: ceiling____floor____ utility____internal wall____ external wall____
      (c) Basement: ceiling____ floor____ utility____internal wall____ external wall____
   D. Drainage system (with drawing)
      (a) Downspout discharging points and conditions
      (b) Location and condition of sewage/water lines
3. Surface Conditions
   A. Topographic features (with tophographic map)
      (a) Landform: flat____ slope____ dip____% direction____ natural ground____backfill____
      (b) Special features (e.g. highwall, road cut, creek, pond, etc.)____
   B. Soil
      (a) Type of soil____
      (b) Conditions of top soil: dry____damp____ saturated____coarse-grained____ medium-grained____fine-grained____
      (c) Specific characteristics____
   C. Local drainage, springs, and any water problems____
4. Geological Information
   A. Surfacail geology
      (a) Geological map: yes(included)____no____source____
      (b) Major rock type____
      (c) Structure patterns: faults____strike____dip____ joints____strike____dip____steps____
      (d) Hydrological information: elevation of watertable ____status of aquifer____
   B. Borehole information
      (a) Borehole(s): yes____no____source____
      (b). Core logging: yes____no____source____
5. Geometry and Characteristics of the Subsidence
   A. Geometry of the subsidence
      (a). Type: sinkhole____trough____heave____ step____crack____
      (b). Size: diameter (or width)____length____ depth____inclination____
   B. Location of the ground damage and the damaged Structure (with description, drawings and photographs____
   C. Date of occurrence and its current status
      (a). Date of occurrence:____
      (b). Status: stable____unstable____unknown____
6. Mining Activity
   A. Mining status and mining method
      (a). Status: active____abandoned____unknown____ date of mining ceased____
      (b). Method: room and pillar____Longwall____

Table 1 Subsidence Investigation Checklist (Cont'd)

Strip____
      (c). Company name:____
   B. Mine map and layout
      (a). Map: available (attachedd)____not available____ Unknown____
      (b). Mine layout: length____width____
      (c). Seam: name____thickness____ depth____
   C. Location of mine workings vs surface subsidence and damaged structures (with drawing)

Recorded by____

Date____

Table 2 Subsidence Identification List

Specific Characteristics & Features	C	L	LS	FA	ES	OS	SP	FW	DS
Mined out coal seam	C								
Pothole on the surface (coal seam < 165 ft. deep)	C								
Depression on the surface (small to medium area)	C								
Fluid withdrawal in the area								FW	
Polygonal crack pattern								FW	
Large scale of depression, earth fissure or fault								FW	
Active ground movement all the time						OS		FW	DS
Hill or slope area		L							
Newly formed hummocky, scarp, steplike ground		L							
Moved blocks of rock, or displaced posts or poles		L							
Tilted trees and utility poles		L							
Transverse and radial cracks on the hill		L							
Wavy appearance in the driveways or sidewalks					ES				
Puffy or "popcorn" texture					ES				
Soil is sticky when wet but is hard when dry					ES				
Floor heaves when soil is wet, but settles when dry					ES				
Ground moves seasonally or periodically				FA	ES				
Floor heaves in cold weather and settles in warm weather				FA					
Stone nets, garlands and stripes on surface				FA					
Sheets- and lobes-shaped unconsolidated sediments				FA					
Thick frozen ground				FA					
Carbonate rock formations located near ground surface			LS						
Karst topography			LS						
Circular cracks on the surface	C		LS				SP		
Areas of vegetable stress caused by lowering of water table			LS						
Backfilled area									DS
Settlement starts right after structure is built									DS
Settlement rate is the highest in the beginning and is time dependent									DS
Outlets available							SP		
Potholes on the surface			LS				SP		
Loess, silt, uncemented sandstone and sand bed area							SP		
Damages develop quickly	C		LS				SP		
Organic soil exists						OS			
Artificial drainage in the area						OS			
Large area of surface depression						OS		FW	
On the coast area or lake shore						OS			
Reference rating	5	5	6	5	5	5	5	6	5
Observation rating									
Subsidence index									

C = Coal mine failure
L = Landslide
LS = Limestone solution
FA = Frost action
ES = Expansive soil
OS = Organic soil drainage
SP = Soil piping
FW = Fluid withdrawal
DS = Differential settlement

Compression ridges occur in the depression where the ground surface is subjected to concave bending and associated with shortening of the ground surface. Generally, compression ridges will be located in the central part of the depression. The ground cracks and compression ridges sometimes are not visible when they are located in the soil zone, especially when the surface is covered by vegetation. Figure 2 shows a ground crack that can be seen in the barren ground surface but can not be seen in the grassy surface. Figure 3 shows the direction of the ground crack change near the contact point of barren and grassy surfaces. Figure 4 shows a ground crack developed at the bottom and sidewall of a dug hole. The crack did not reach the surface. As the results of these three cases demonstrated that the stress at the tip of the crack in propagation was less than the soil cohesion and roots binding forces. Crack propagation was either stopped or changes its direction to the weaker part of the soil. In addition, a ground crack may have been developed in the subsurface and cannot reach the ground surface. Therefore, if the ground crack cannot be seen in the area it does not necessarily mean that a ground crack has not developed.

STRUCTURAL DAMAGE DUE TO SUBSIDENCE

Structural damages due to subsidence range from slight to very severe. Some structures may have a few hair-line cracks while others may have cracks a few inches wide. The damage severity is dependent upon (1) the types of ground surface deformation, (2) the type of stresses, (3) the type and size of structures, (4) the location of the structure with reference to the mine openings, (5) the material of the structures, and (6) the type of foundation or structure attached to the ground. For instance, structures attached firmly into the ground are likely affected more by the ground movements.

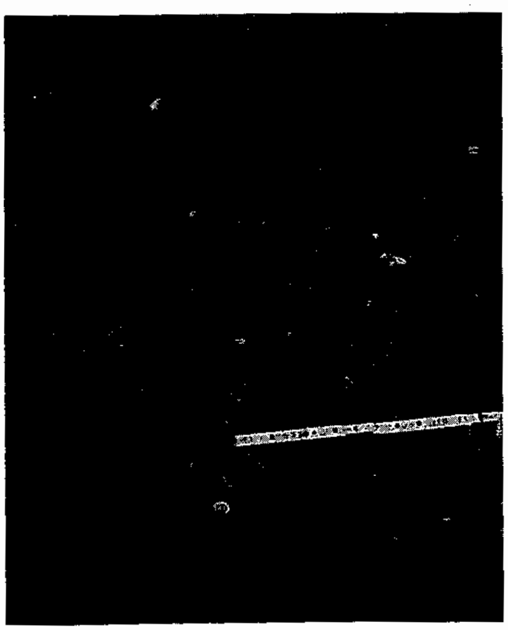


Fig. 2 Ground crack is stopped at the interface between barren and grassy surface shown by the arrow head. (Blacksville Case)

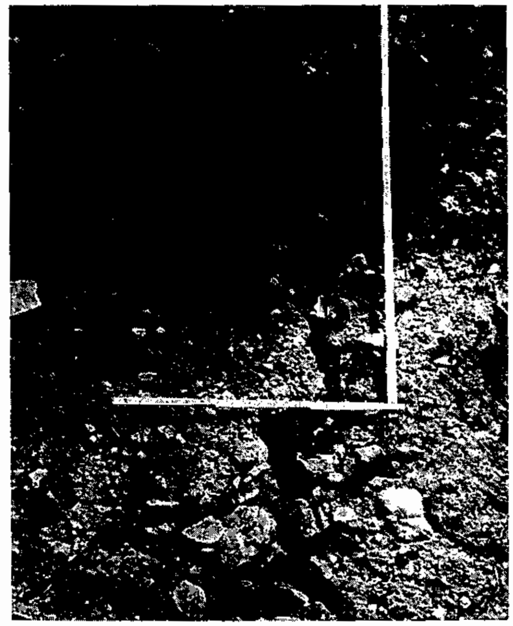
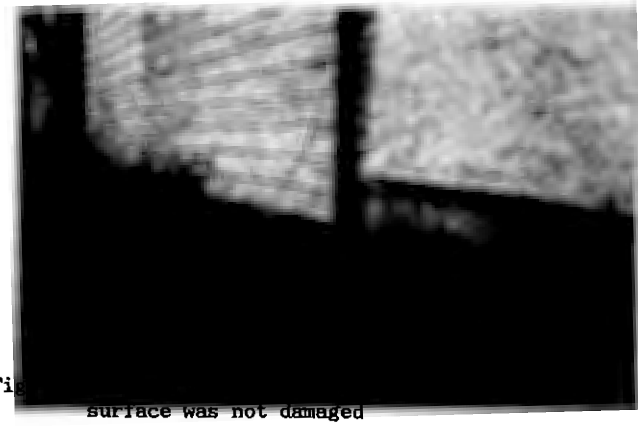


Fig. 3 The direction of ground crack changes near the intersection of barren and grassy surface shown by the arrow heads. (Blacksville Case)

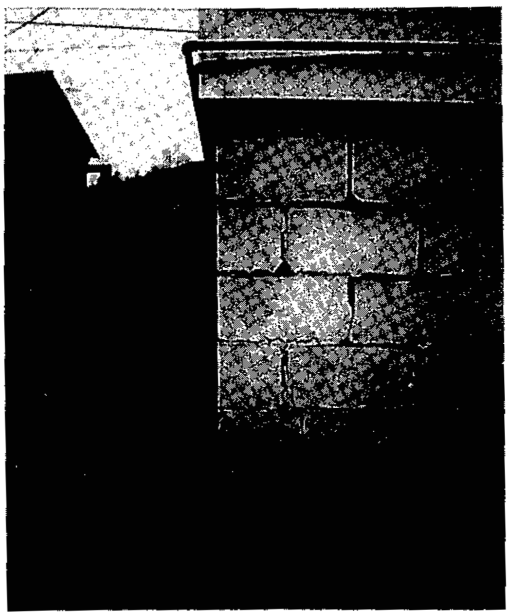
Fig. 4 Ground cracks developed at the bottom and sidewalls of a dug hole but do not reach the surface. (Blacksville Case)

Figure 5 shows that the two-story wood frame house was laid on the ground surface and was not subjected to subsidence damage even when the surface subsided for 4 feet. This house was located almost in the center of a longwall panel and was laid on the ground surface without having basement or foundation attached into the ground. However, at the same panel another wood frame house with partial brick basement was subjected to damages (fig. 6), although the house was located close to the edge of panel and the surface subsided for only 1 foot.



Fi... surface was not damaged

Fig. 6 A wood frame house with concrete block basement subjected to damage



Damages to buildings can be divided into functional (structural) and cosmetic (achitecture) damages. The major functional damages are misalignment of windows, doors and walls, slanting floor, leakage in the roof, and breakage of utility lines. This type of damages may impair the function and usage of the structure. The major cosmetic damages are cracks along the mortar lines on the exterior and interior walls, cracks on the stone facing and plaster, separation of siding and frames, and cracks on the floor. This type of damages are more annoying than dangerous. Both the functional and cosmetic damages can occur separately or simultaneously based on the level of the damage source. For instance, a low level of vibration due to traffic or industry may cause cosmetic damage. But a high level of vibration due to blasting or earthquick will cause not only cosmetic damage but also functional damage and some times even cause the collapse of the structure. If a building have a basement, the deformation of the building due to subsidence most likely will be initiated from the foundation or basement and propagate upward to the upper structure. The foundation or the basement is likely to suffer more severe damage than the rest of the building because the basement is directly subjected to the stresses. The damage are referred to the degree of the structure deformation not the repair cost.

RELATIONSHIP BETWEEN GROUND DAMAGES AND STRUCTURAL DAMAGES

Generally, the structural damages are associated with ground movements and the structures are assumed to move with the ground. However, there exists a resistance or friction, which is due to the weight of the strcture, between the structure and ground. Therefore, the ground movement cannot be entirely transmitted to the surface structures. Accordingly, several types of stresses such as axial, shear, and bending will be induced against the foundation of the structures or the structures directly. The axial stresses, either extension or compression, are caused by the horizontal movement. This type of stress will induce tensile and compressive damages to the structures. The shear stresses are caused by the friction between structure and ground. The bending stresses are caused by the vertical movement of the ground and will induce tilt and curvature damages to the structures.

As discussed earlier linear deformation is mainly due to nonuniform horizontal movement which will induce tensile and compressive damages to the structures. If a structure is subjected to tension the structure will be lengthened and open cracks will be induced along the joints and weak points such as the contact line between the windows, door frames and the walls. Figure 7 shows a typical example of tensile damage to concrete block walls.

Fig. 7 ... developed ... block wall.(Peng and Hsiung, 1986; Jenkins Case)

All the tensile cracks are uniformly developed along the brick faces and mortar lines because the brick faces and mortar lines are the weakest places on the brick wall. If a structure is subjected to compression the foundation walls will be buckled inward and induce horizontal cracks perpendicular to the direction of the compression along the mortar on the brick faces. Tensile cracks and buckled structures are the specific characteristics of tensile and compressive damages, respectively. Those characteristics can be used to identify the types of stresses which cause the damage to the structure.

When the ground slope changes, tilting will be induced on the structures. Tall structures with a small base, e.g., towers and chimneys are most sensitive to tilting. Natural ground slope will also affect the stability of the ground surface and structures when subsidence occurs. If the dip of a slope is consistent with the ground movement direction, the ground movement will be enhanced. On the other hand, when the dip of a slope is opposite from the ground movement direction, the ground movement will be reduced. In addition, a slope area may be an area prone to instability or landslide. Figure 8 shows the differential movement between the top of the soil and the top of the bedrock on a slope area after subsidence. The movement rate of the soil was about 0.07 in/month and was about 0.007 in/month for the bedrock during the study period. The movement of the soil was much faster than that of the bedrock. By the time the soil movement reaches its tertiary stage it may have caused additional damages to the structures located downslope.

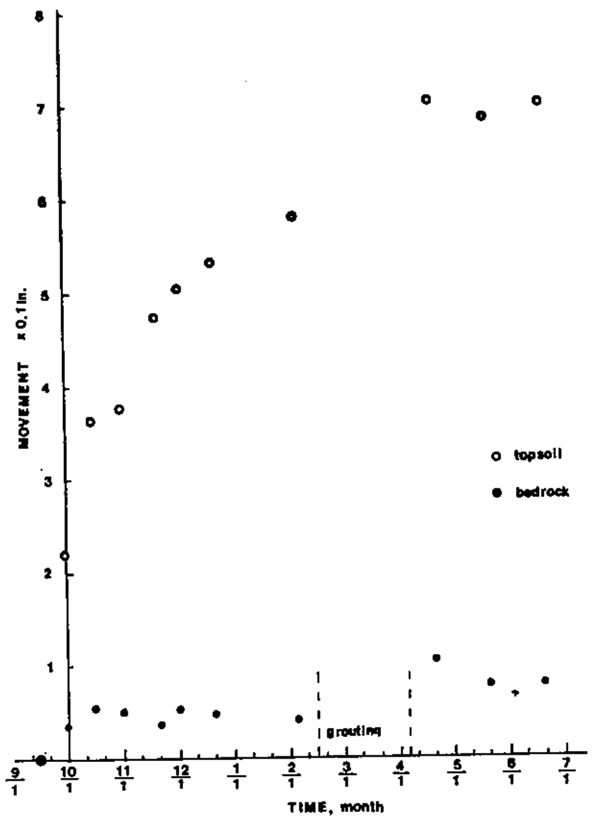


Fig. 8 Differential movement between top soil and top of the hedrock. (Peng and Hsiung, 1987; Johnston Case)

Depending on the location of the structure in the depression, the structure may be subjected to sagging or hogging damage. Sagging and hogging are two different types of ground curvatures which are caused by the differential settlement. Sagging is a negative or concave curvature. For structures located on the concave area, the lower portions of the structures are subjected to tension and the upper portions are subjected to compression. As a result, vertical cracks with wider gaps at the bottom occur at the window and door frames, on the walls, and at the wall joints. Figure 9 shows that the cracks on the wall in the bedrooms have wider gaps at the lower portion, i.e., an inversed v-shaped crack. This crack pattern indicates that the structure has been subjected to sagging. Generally, structures which are located at or near the central part of the depression will be subjected to sagging damage. Figure 10 shows the relative locations of the damaged houses which were subjected to sagging and the estimated subsidence depression. The most specific damage characteristics on the structure due to sagging are the concave bending and an inversed v-shaped crack.

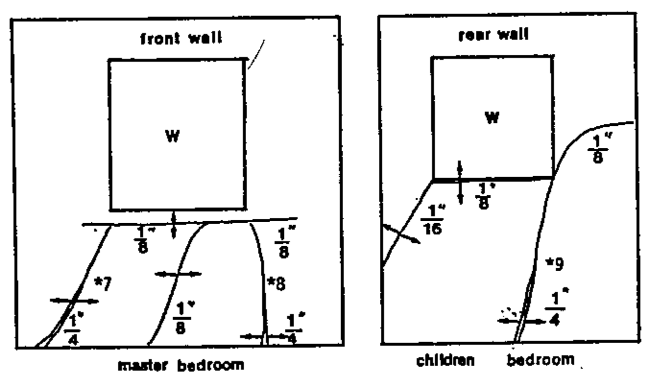
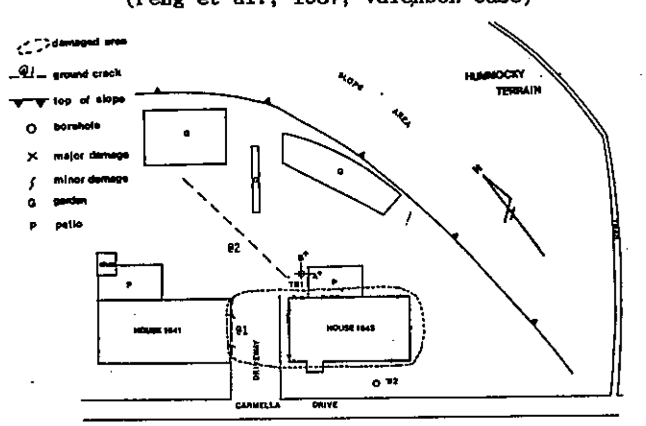


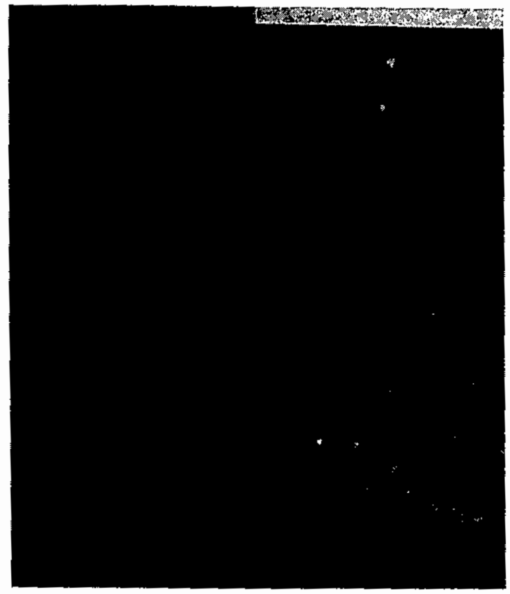
Fig. 9 Tensile cracks in the bedrooms due to sagging. (Peng et al, 1987; Valenson Case)

Fig. 10 Location of the damaged houses subjected to sagging and subsidence depression. (Peng et al., 1987; Valenson Case)



Hogging is a positive or convex curvature. For structures located in the convex area, the upper portions of structures are subjected to more severe stretching than the lower portions. As a result, vertical cracks with wider gaps are found at the top of the window and door frame, on the wall and at the wall joints. Figure 11 shows a crack with a wider gap at the upper portion, i.e. a v-shaped crack. This crack pattern indicates that the structure has been subjected to hogging. In general, structures located at the edges or the inflection point of the depression will be subjected to hogging damage. Figure 12 shows the relative location of the house which was subjected to hogging damage with respect to the estimated subsidence damage zone. The most specific damage characteristics on the structure due to hogging are the convex bending and v-shaped crack.

Fig. 11 Wall separation along window frame subjected to hogging damage. (Peng and Hsiung, 1987; Fleming Case)



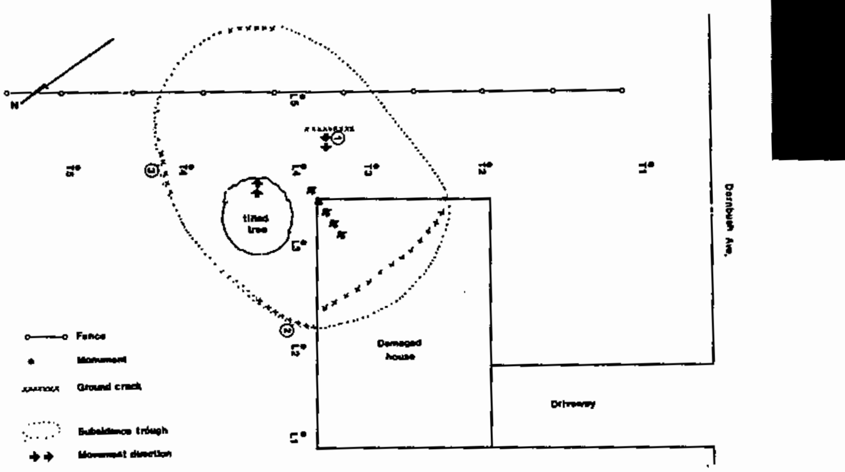


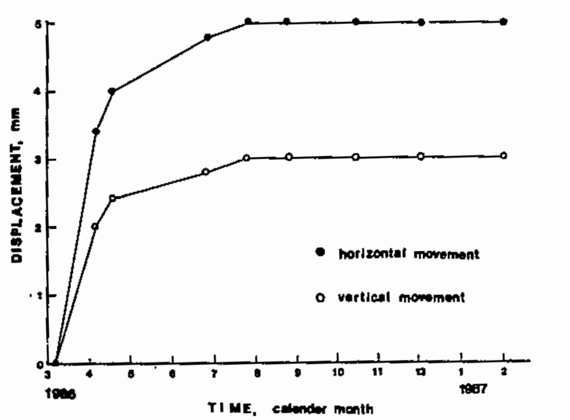
Fig. 12 Location of the damaged house which was subjected to hogging and the estimated subsidence depression. (Peng and Hsiung, 1987; Fleming Case)

INSTRUMENTATION AND RESULT

In order to have a better understanding of the underground conditions and the real cause of the damages, some instrumentation such as borehole TV camera, crackmeter, inclinometer and Sondex measurements should be conducted.

The 2-D tell-tale crackmeter and 3-D crackmeter can be installed at the strategic points on the exterior or interior walls to measure the changes of the crack width. The 2-D crackmeter is preferred because it can be installed and removed easily without leaving any trace on the walls. The measurement results from the crackmeter can be used to determine the movement direction and rate of movement. For instance, Figure 13 shows the horizontal and vertical measurement results using a 2-D crackmeter installed at the Valenson subsidence site (Peng, et al, 1987). It demonstrates that both the horizontal and vertical movements were significant in the early stages and that total movements were 5 mm and 3 mm, respectively, by July 23, 1987. After that date no movements were detected. The average horizontal movement was 0.036 mm/day and the average vertical movement was 0.022 mm/day.

Fig. 13 Results of the crackmeter measurement. (Peng et al., 1987; Valenson Case)



The borehole TV camera can be used to examine subsurface conditions such as fracturing of the strate, the condition of voids and underground openings. In order to get a complete picture of the strata fracturing and voids conditions in the boreholes, three types of viewing attachments to the camera head, e.g., downhole, radial close-up, and spotlight right angle can be employed. If the area is subjected to subsidence problems, the horizontal, vertical and diagonal fractures can be observed in the borehole in the strata above the mined out coal seam. In addition, cave-in and roof fall features and mine voids can also be observed by the borehole TV camera.

The inclinometer can be used to measure the horizontal ground movement by measuring the angle of inclination along its vertical axis of a grooved casing. The measurements are conducted along two axial directions perpendicular to each other. The measurement results can be used to determine the principal direction and magnitude of the ground movement. The principal movement direction is expected to point toward the epicenter or center of the subsidence basin in the mining-related cases. Figures 14 and 15 show the inclinometer data from the Valenson case (Peng, et al, 1987). They indicate that the history and magnitude of the ground movements can be used to determine the prinicipal direction of movement. For instance, before grouting operation started (October 16, 1987) the movements along A and B axes were continuously toward 180^{o} i.e. negative direction. The principal ground movement direction was toward the epicenter. After November 19, 1987 (i.e., completion of the grouting) the movement along A axis almost stopped, especially the zone below the backfilled zone which was about 25 feet below surface. However, the movement along B axis did not stop and changed it direction to 0^{o} or positive which was opposite to its original direction of movement. In addition, the backfilled zone had shown a significant amount of movement after the grouting. These phenomena indicate a potential problem of soil instability .

Fig. 14 Total displacement in A axis. (Peng et al., 1987; Valenson Case)

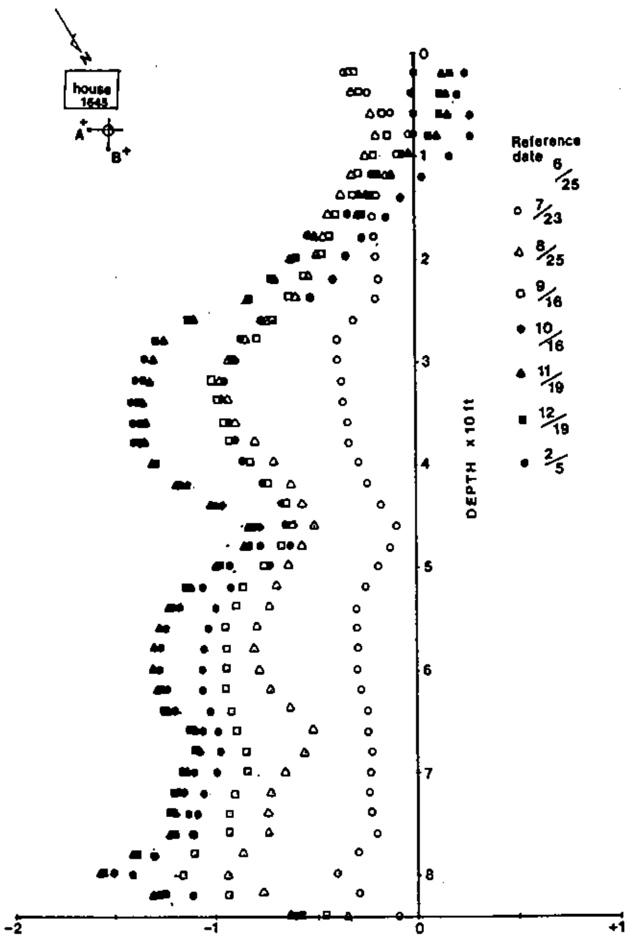
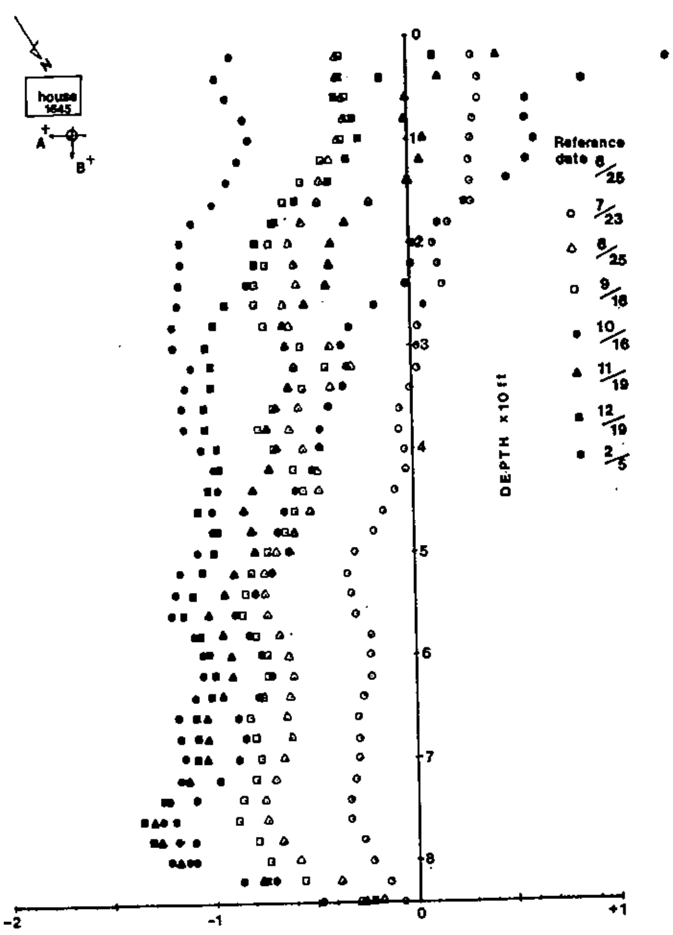
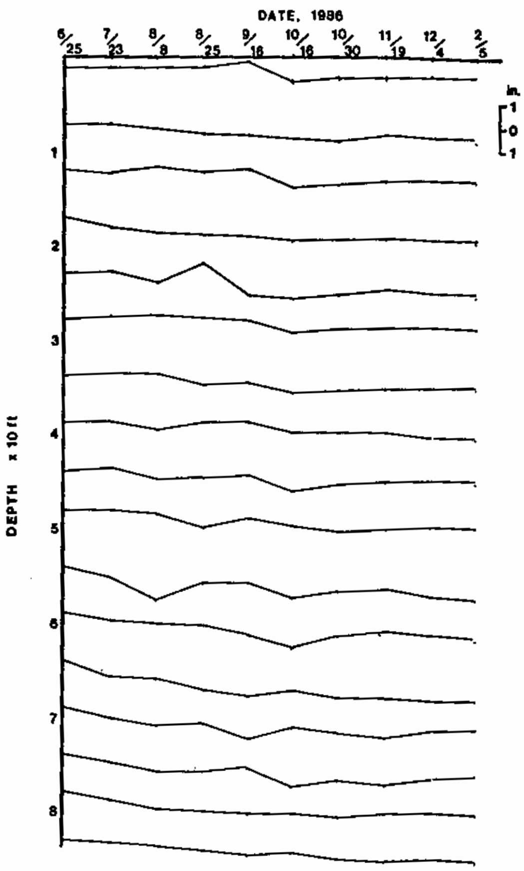


Fig. 15 Total displacement in B axis. (Peng et al., 1987, Valenson Case)



The Sondex settlement system is designed to measure subsurface vertical ground movements such as settlement or heave. A probe consists of a radio frequency oscillator and detector circuit will be lowered into the casing to locate the position of each sensing ring. The sensing rings is permanently mounted on the casing which is installed in the borehole. The vertical movement can be determined by the change in distance between rings which move with the subsurface strata. By interpreting the Sondex data, the rate of subsurface strata movement can be determined and the active formation can be located. Both items can be used to determine the causes of subsidence. For instance, if an area is subjected to subsidence all sensing rings will be subjected to movement. If an area is subjected to expansive soil problems, only those rings located in the soil zone will be affected. Figure 16 shows the measurement results from the Valenson site in which movement was about 1/2 to 1 inch for most of the rings. The movement for the top ring was about 1/2 inch and about 1 inch for the bottom ring. Since all the rings moved and bottom ones which were closer to the mined out coal seam moved more than the upper ones, it is most likely that the movement was induced by the abandoned mine failure.

Fig. 16 Vertical movement of the Sondex rings. (Peng et al., 1987; Valenson Case)



SUMMARY AND CONCLUSION

In this paper the approach and the procedures for abandoned mine lands subsidence research are described. The mechanisms of the possible causes, the damages to the ground surface and structures, and the relationship between the ground movement and structures has been explored. The methods and purposes of the instrumentations are discussed.

The most common damage to the ground surface are depressions, cave-in pits, ground cracks and compression ridges. There is no positive correlation between the dimension of the depression and its cause.

Due to different degree of stress concentration at the tip or at the end of the ground cracks, the direction of the cracks may be changed and the propagation of the ground cracks may be stopped. Therefore one may not be able to observe the ground cracks at the places where they are expected to be observed.

Structural damages can be divided into functional and cosmetic. Generally, functional damages are more severe than the cosmetic ones. Cosmetic damage can occur alone or may occur simultaneously with functional damage. Generally, the foundation or basement will be damaged more severely than its upperstructure. Structure damage is associated with the ground movement. Different types of ground movement will induce different types of damages to the ground surface and structures. Different locations of the structures in the depression or subsidence basin will be subjected to different types of deformation.

Sagging and hogging damages are due to the combination of linear and bending deformation. Most of the structural damages above abandoned mine lands are due to sagging or hogging but pure linear deformation is not common. The most specific damage characteristics on the structure due to sagging are the concave bending and reversed v-shaped crack. The convex bending and v-shaped crack are the specific damage characteristics due to hogging. By examining the damage pattern, the type of stresses and the damaged area can be located. Thses information can help people to identify the damage causes.

LITERATURE CITED

Aughenbaugh, N. B. and Elifrits, C. D., 1983, Subsidence and Time, 1983, SME-AIME Fall Meeting, Salt Lake City, UT, Preprint No. 83-388, 4 pp.

Bauer, R. A. and Hunt, S., 1981, Profile, Strain, and Time: Characteristics of Subsidence from Coal Mining in Illinois, Chapter 16 in Workshop on Surface Subsidence Due to Underground Mining, ed. S. S. Peng and M. Harthill, pp. 207-217.

Christian, J. T and Hirschfeld, R. C., 1974, Subsidence of Venice: Predictive difficulties: Science, V. 185, p. 1185.

DuMontelle, P. B. and Bauer, R. A., 1983, The Midcontinent Field: General Characteristics of Surface Subsidence in Surface Mining Environmental Monitoring and Reclamation Handbook, Elsevier, pp. 671-680.

Dunrud, C. R., 1976, Some Engineering Geologic Factors Controlling Coal Mine Subsidence in Utah and Colorado, U.S.G.S. Professional Paper 969, 39 pp.

Gray, R. E., Bruhn, R. W., and Turka, R. J., 1978, Study and Analysis of Surface Subsidence over the Mined Pittsburgh Coalbed, USBM OFR 25-78, 145 pp.

HRB - Singer, Inc., 1977, Nature and Distribution of Subsidence Problems Affecting HUD and Urban Areas, U. S. Department of Housing and Urban Development, 113 pp.

Johnston, W. and Miller, G. C, 1979, Abandoned Coal-Mined Lands; Nature, Extent, and Cost of Reclamation, U.S.B.M. Special Publication 6-79, 29 pp.

Lin, P. M., Peng, S. S., and Hsiung, S. M., 1987(A), Investigation of Subsidence Over AML: A Case Study, Proceedings Fourth Coal Mine Ground Control Conference, pp. 249-252.

Lin, P. M., Peng, S. S., and Hsiung, S. M., 1987(B), Identification of the Causes of Surface Subsidence over Abandoned Mined Land, Paper presented at the 1987 National Abandoned Mined Land Conference, Little Rock, Arkansas, Oct. 18-22.

Newton, J. G., 1984, Sinkholes Resulting from Groundwater Withdrawals in Carbonate Terrains - An Overview, Reviews in Engineering Geology, V. VI, pp. 195-201. http://dx.doi.org/10.1130/REG6-p195

Peng, S. S., and Hsiung, S. M., 1986, Guidelines for Subsidence Abatement over AML, First Annual Report, Submitted to West Virginia DOE, Purchase Order No. 52 (1985), 139 pp.

Peng, S. S. and Hsiung, S. M., 1987, Guidelines for Subsidence Abatement Over AML, Second Annual Report, Submitted to West Virginia DOE, Purchase Order No. 52 (1985), 212 pp.

Peng, S. S., 1987, Surface Subsidence Engineering, A. A. Balkema Publishers. (in press)

Peng, S. S., Lin, P. M. and Hsiung, S. M., 1987, Subsidence over AML and Its Causes - A Case Study, Proceedings, ASCE Spring Convention, May 1988. (in press)