CLASSIFICATION OF MINE-RELATED SUBSIDENCE
EAST OF THE MISSISSIPPI RIVER, U.S.A.

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ABSTRACT

Field investigation of surface subsidence events associated with both active and abandoned underground coal mines in the United States has established criteria that enable the prediction and classification of mine-related subsidence. The key was establishing the role of geology in all types of subsidence and the recognition of beam subsidence in specific geologic settings. The classification is based on overburden thickness, variations in stratigraphy, topography and mine plan. Types of subsidence are Pit, Room, Sag, and Beam.

Pit subsidence is associated with three geologic settings: shale overburden, seasonally wet unconsolidated overburden, and perched water table in unconsolidated overburden.

Room subsidence occurs where the roof across the width of the room fails to the surface and a shallow depression develops.

Sag subsidence develops where the pillars are failing in conjunction with roof failure. Overburden thickness is generally greater than 100 feet.

Beam subsidence can occur in all terrains. It is associated with retreat mining and room and pillar mining where pillar crushing or pillar compression has taken place and barriers are left in place. They occur as beam arch or one-sided beam subsidence.

Beam arch failure occurs where mining has taken place on both sides of a coal barrier. One-sided beam failure is associated with retreat mining moving from a barrier towards the entry in hilly topography. This type of subsidence occurs where a hard, thick, rock unit is acting as a bridge supporting the overburden and outcrops on the hillside.

INTRODUCTION

Mine-related subsidence investigations associated with both active and abandoned underground coal mines over the last 10 years have enabled the author to correlate subsidence types with overburden geology, topography, and mine configuration. Table I summarizes these relationships.

PIT SUBSIDENCE

The term "pit subsidence" refers to the development of a small diameter depression at the surface that extends in varying depths towards the mine. Pit subsidence occurs where fractures in the overburden are created by the mining operation, or where the mining operation intercepts existing fractures. If the overburden is shale, the mine void will extend up the broken zone to the surface by caving.
rock and unconsolidated material, the fractures will stop at the unconsolidated contact.

Unconsolidated sediments can be transported into the mine void by piping. In either case, a steep sided pit develops at the surface. The depressions created range from a few feet to many tens of feet deep and across. The shape and configuration of the depression depends on composition and thickness of the overburden and the presence or absence of a perched water table. Pit subsidence has been observed in areas where the overburden thickness ranges from a few feet to 285 feet (Craft et al., 1982). Pit subsidence occurs in three geologic settings: areas of seasonal water table; areas of thin-bedded shale overburden; and areas of unconsolidated overburden with a perched water table.

Areas of Seasonal Water Table

(Figure 1). If the unconsolidated overburden becomes water saturated, sediment can move through the natural joint or mine-induced fracture systems into the mine void. This movement will create a pit depression at

![Figure 1 - Piping of unconsolidated sediments into a mine void associated with a seasonal water table.](image)

Figure 1. - Piping of unconsolidated sediments into a mine void associated with a seasonal water table.

Figure 2 is a photograph that shows silt piped into a mine void through an open jointing system that extends into the overlying, unconsolidated sediments of an old river terrace. This piping was occurring during the mining operation as small barriers were built to hold the material out of the working area. The movement of sediment has been continuous. Approximately 10 inches of silt and clay were covering the mine floor at the time of the investigation. This piping was causing depressions to develop around a house directly over the mine.
Figure 2. - Silt piped into the mine void from the overlying unconsolidated terrace deposits.

Figure 3. - Pit subsidence associated with partial room collapse of overburden into the mine void.

Figure 4. - Pit depression developed in shale overburden.

Figure 5. - Looking down into the pit developed in the shale overburden.

Areas of Thin-Banded Shale Overburden

Figure 3 shows how small areas of the mine roof collapse and the caving area slowly works its way upward. Small areas of the mine roof will collapse and this caving area slowly works its way upward. Figure 4 is the surface hole in a pit formed in a shale overburden in North Dakota. Figure 5 is a view directly into the pit. The character of the overburden is clearly shown. In many cases the pit will continue to enlarge to the approximate size of the room in the mine (see room subsidence discussion).

Areas of Unconsolidated Overburden with a Volcanic Water Table

Figure 6 and 7. In areas where the volcanic water table lies within the unconsolidated overburden and the mine-induced fractures extend to the base of the unconsolidated overburden, extensive piping can occur. The surface expression of the subsidence is much wider (Figure 6). The water table in the vicinity of the fracture system and within the unconsolidated overburden will be lowered by draining into...
Room subsidence occurs when the overburden across the width of the room fails and a shallow depression develops on the surface (Figure 8). The angle of break tends to converge towards the surface and the area of depression of the surface is equal to or less than the area of failure in the mine. The best examples of this type of subsidence have been recorded in North Dakota and Montana (Figure 9). However, many examples have been observed in western Pennsylvania and northern West Virginia. Overburden is generally less than 100 feet thick and predominantly shale. The surface area disturbed is generally small. The vertical displacement in the center of the subsided area is less than one-half the thickness of the original mine void (Figure 10 and 11). Initial room failure occurs rapidly. There will be minor movement at the edges of the depression after the initial failure.
Sag subsidence develops where the pillars are failing in conjunction with roof failure (Figure 12). Sag depressions develop in areas where the overburden thickness is greater than 150 feet. The overburden consists of alternating thin interbedded limestones, shales, and siltstones, with only minor sandstone units present. Pillar crushing is generally accompanied by release of large amounts of methane gas (Kelley and Craft, 1984). Surface crack development is minor, generally less than a few inches wide and deep. The angle of draw tends to diverge towards the surface. The area affected can be large. Substantial damage to structures is common, especially when the structure is at the edge of the subsiding area. The subsidence event usually starts rapidly and the depression continues to develop over a long period of time.

Beam subsidence was first recognized by Dunrud (1975) in Utah. Field investigation in Alabama and Kentucky has established that the concept of beam-controlled subsidence is applicable in these areas as well. Beam failures are of two types: cantilever beam failure and arch beam failure.
CANTILEVER BEAM FAILURE

This type of subsidence occurs where retreat mining is moving from a barrier, toward the entry, in extremely hilly topography (Figure 13).

Figure 13. - Cantilever beam subsidence associated with retreat mining, steep topography, and thick sandstone members in the overburden.

Cantilever beam subsidence occurs where a thick, hard, rock unit is in the stratigraphic section above the coal. This stratigraphic unit is initially acting as a continuous beam or bridge, supporting the overburden as the coal is being removed. If the bridging member outcrops on the hill side and the pillars are removed under the outcrop zone, the supported bridge becomes a cantilever beam. When the pillars will no longer support the beam they will crush, dropping the beam on one end. Since the beam is failing as a single unit it will create a large crack over the support structure on the opposite end of the beam (Figure 13).

Figure 14 is the mine map for site where cantilever beam subsidence occurred, showing the sequence of mine retreat and surface crack development. Site "D" is the most recent crack development. Area "E" is the approximate location where the next crack will develop. Figure 15A is an aerial view of the ridgeline crack development above this mine. Figure 15B is a closeup of the crack. Figure 15C is an aerial view of the newest crack to develop.

Figure 14. - Mine map showing period of mine retreat and subsidence crack development in Eastern Kentucky.

11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W. July 1962.
Figure 15A. - Aerial view of crack area 'C' on mine map.

Figure 15B. - Ground view of crack shown in Figure 15A.

ARCH BEAM FAILURE

Arch beam failure occurs where a large block of coal remains and room and pillar mining takes place on both sides of the block (Harrison and Craft, 1988). Figure 15C. Over a period of time the pillars will compress or, in some cases, crush, allowing the overlying stratigraphic units to settle. The beam bends, creating a tension arch over the barrier. When enough settlement has taken place to exceed the tensile strength of the beam, tension cracks will develop in the center of the arch. If the bending tension is great enough, graben block faulting can occur. The graben faults develop in areas where pillars are left in place between two solid coal barriers. Horizontal friction in the overburden approaches zero, and direct overburden load exceeds pillar strength in the center of the tension arch (Figures 16, 17 and

Figure 18. - Gravity faulting associated with pillar compression of small pillars within a large panel and a larger support area at the edge of the panel.
181. This type of subsidence can occur in all types of terrain. In some cases pillar crushing has occurred; in other cases only pillar compression. Arch beam type of failure is always associated with coal barriers left in place under thick overburden. The area will continue to move over a long period of time.

CONCLUSIONS

The importance of understanding the role of geology, topography and underground mine plan cannot be over-emphasized. It provides the background knowledge to be applied in subsidence investigations, subsidence prediction, development of subsidence plans for permits, and new mine plan development.

IMPORTANT IN ABANDONED UNDERGROUND MINES
1. Defines area of subsidence.
2. Defines potential for continuation of a subsidence event.
3. Determines scope and type of remedial measures.

IMPORTANT IN ACTIVE UNDERGROUND MINES AND MINE DESIGN
1. Enables mine operators to evaluate

Figure 17. - Beam arch subsidence affecting a shopping center. Small graben faults in foreground. Building has settled 24 inches from middle to right side of picture.

Figure 18. - Tension arch subsidence development associated with the Mary Lee Coal Seam in Graysville, Alabama.
subidence potential and predict areas of possible surface impacts.
2. Enables mines to be designed to reduce or eliminate subsidence impacts on the surface.
3. Improves the information in the mine permits pertaining to subsidence potential, remedial measures applicable, and the definition of potential areas of subsidence damage to the environment.
4. Establishes the basic framework of information to be included in the development of computer models to predict subsidence impacts.

REFERENCES:


