Lecture-13

Mining Subsidence due to Alteration of Fluid Levels and

Methods of Avoiding Mine Collapses

Ground Subsidence

- Subsidence is the mainly vertical downward displacement of the Earth’s surface generally due to insufficient support from beneath, a superimposed load, or a combination of both. It can arise from natural causes, human activities, or, often, by human activities destabilizing natural systems. Collapse is sudden, and sometimes catastrophic, land subsidence.

Mining Subsidence due to Alteration of Fluid Levels

- Subsidence induced by underground extraction is a class of human-induced (anthropogenic) land subsidence that principally is caused by the withdrawal of subsurface fluids (groundwater, oil, and gas) or by the underground mining of coal and other minerals.
- Extraction of materials such as coal, salt, sulfur, and gypsum from soft rocks often results in ground subsidence during the mining operation or, at times, many years after operations have ceased. Subsidence can also occur during hard rock mining and tunneling operations.
- Subsidence caused by withdrawal of ground water, oil, and gas has been observed and studied for more than 100 years. Some of the earliest best-known examples of subsidence due to ground water withdrawal are Osaka, Japan (first noted in 1885), London, England (first noted in 1865) and Mexico City, Mexico (first noted in 1929). Subsidence often occurs due to man's need for fresh water, oil, and gas to satisfy domestic, industrial, and agricultural demands.

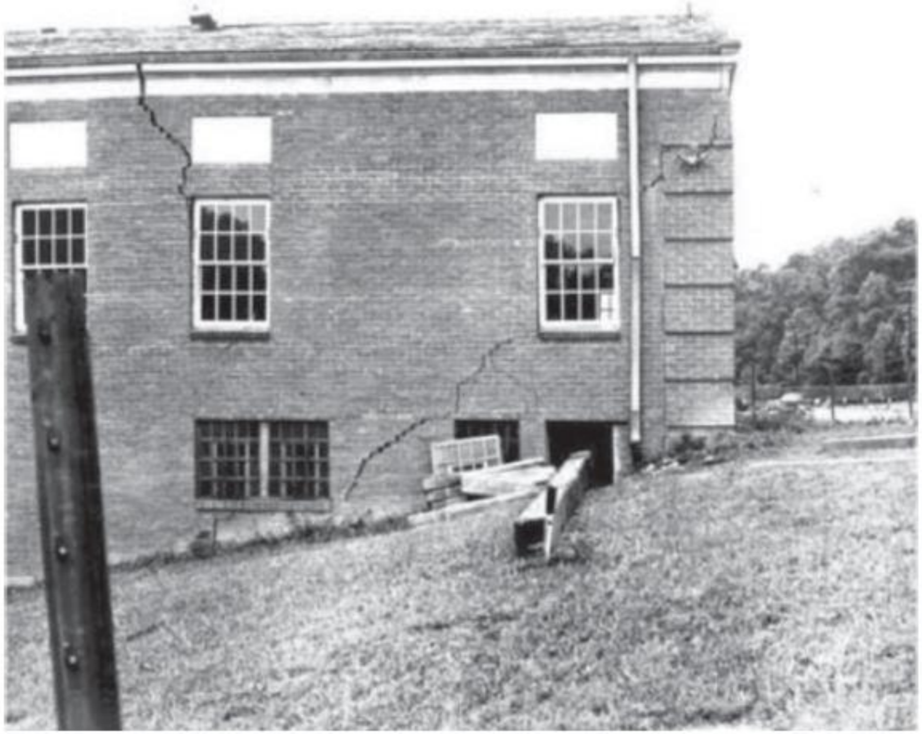


FIGURE 2.6
Building damaged by mine subsidence in Pittsburgh. (Photo courtesy of Richard E. Gray.)

Groundwater Withdrawal

Aquifer Compaction

Lowering the groundwater level reduces the buoyant effect of water, thereby increasing the effective weight of the soil within the depth through which the groundwater has been lowered. For example, for a fully saturated soil, the buoyant force of water is 62.4 pcf (1 t/m3) and if the water table is lowered 100 ft (30 m), the increase in effective stress on the underlying soils will be 3.0 tsf (30 t/m3), a significant amount. If the existing stress in the soils is exceeded, compression occurs and the surface subsides. In an evaluation of the effect on layered strata of sands and clays, the change in piezometric level in each compressible stratum is assessed to permit a determination of the change in effective stress in the stratum. Compression in sands is essentially immediate; cohesive soils exhibit a time delay as they drain slowly during consolidation. Settlements are computed for the change in effective stress in each clay stratum from laboratory consolidation test data. The amount of subsidence, therefore, is a function of the decrease in the piezometric level, which determines the increase in overburden pressures and the compressibility of the strata. For clay soils the subsidence is a function of time.

Construction Dewatering

Lowering the groundwater for construction projects has the same effect as “aquifer compaction,” that is, it compresses soil strata because of an increase in effective overburden stress.

Ground Subsidence due to Groundwater Withdrawal

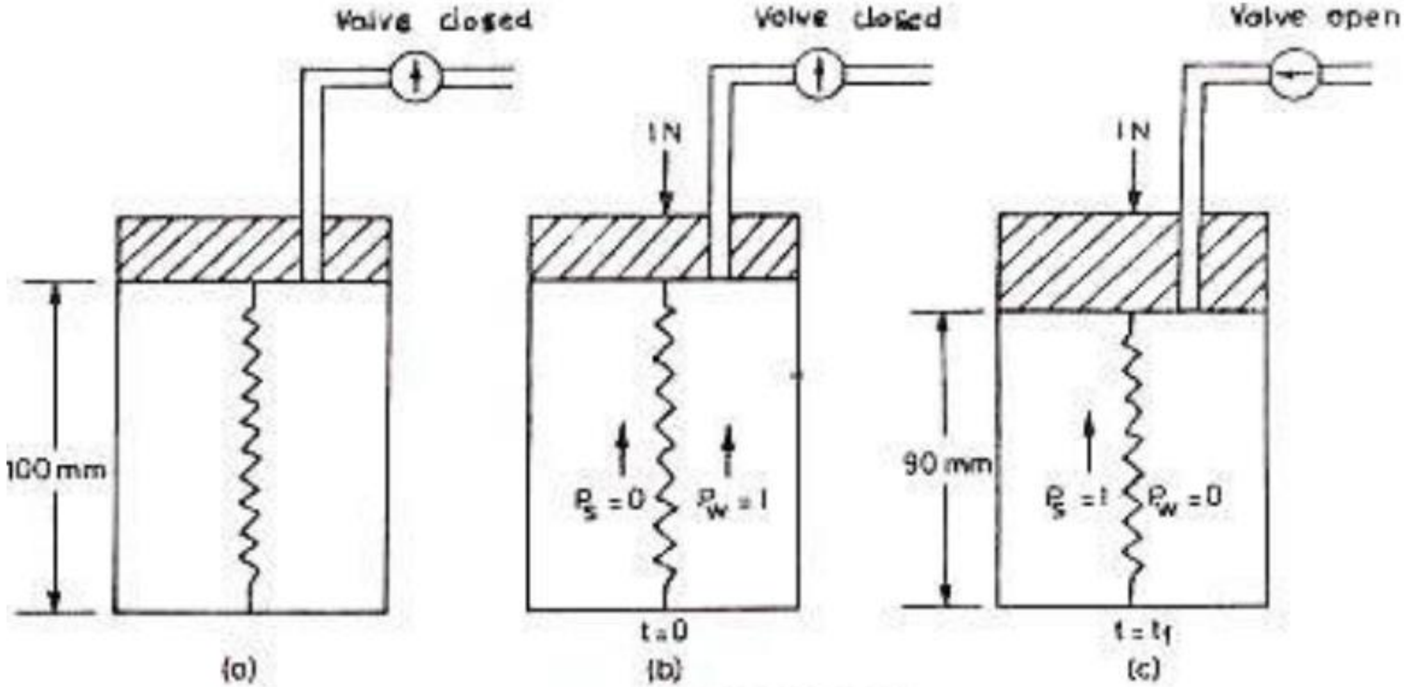
- Ground subsidence also occurs when groundwater is withdrawn from a basin aquifer or subsurface reservoir faster than natural or artificial recharge can replace it. In the case of shallow groundwater aquifers, rapid withdrawal of groundwater causes regional groundwater levels in a basin to decline. Accompanying groundwater level decline is a decrease in pore pressure. A decrease in pore pressure causes an increase in effective stress, which causes the sediment to compress. Sediment compression eventually results in surface subsidence.
- The removal of fluids from reservoirs can cause sinking of the land surface. The decrease in hydrostatic pressure due to the removal of fluid increases the load on the sediments, which then compact and the land (surface) subsides.
- Both vertical and horizontal displacements of the land surface occur, resulting in many forms of damage: structural failure of buildings, pipelines, and railroads; flooding of tidal areas; changes in the gradient and capacity of waterways, sewers, drains, and streams; failure of well casings. A less obvious effect is the permanent reduction in reservoir capacity by irreversible compaction of sediments.

Oil Extraction

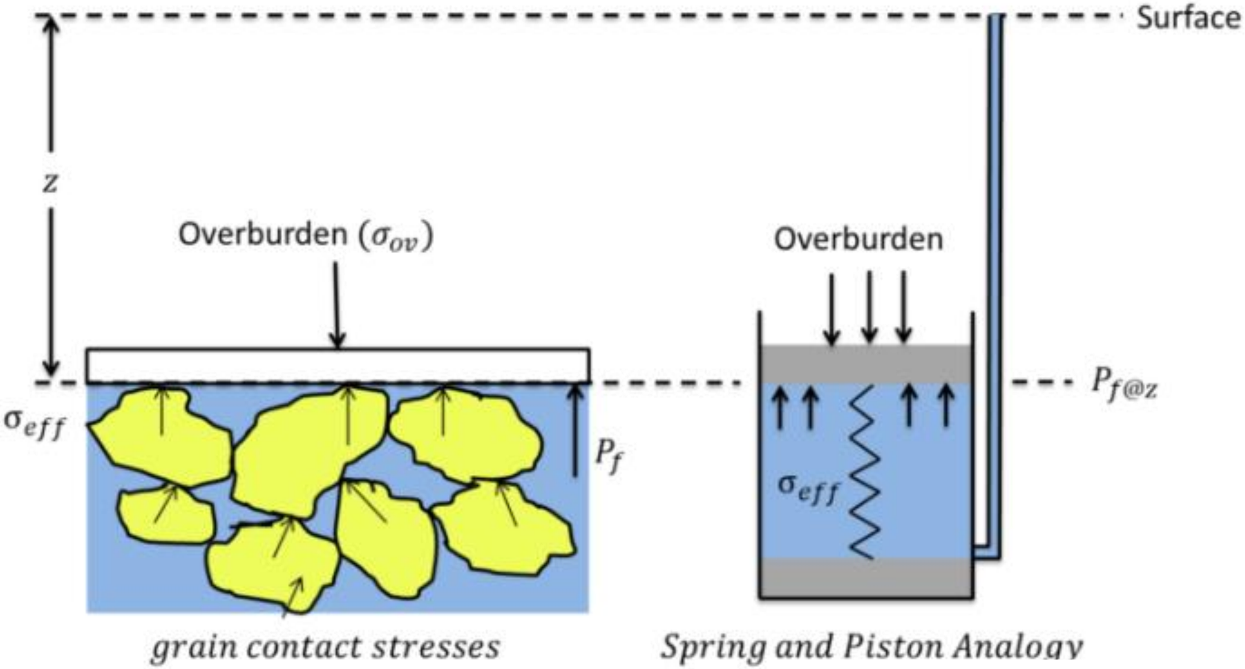
Oil extraction differs from groundwater extraction mainly because much greater depths are involved, and therefore much greater pressures. Oil (or gas) extraction results in a reduction of pore-fluid pressures, which permits a transfer of overburden pressures to the intergranular skeleton of the strata. Compaction takes place by sand grain arrangement, plastic flow of soft materials such as micas and clays, breaking and sharding of grains at stressed points etc.

Local Subsidence from Construction Dewatering

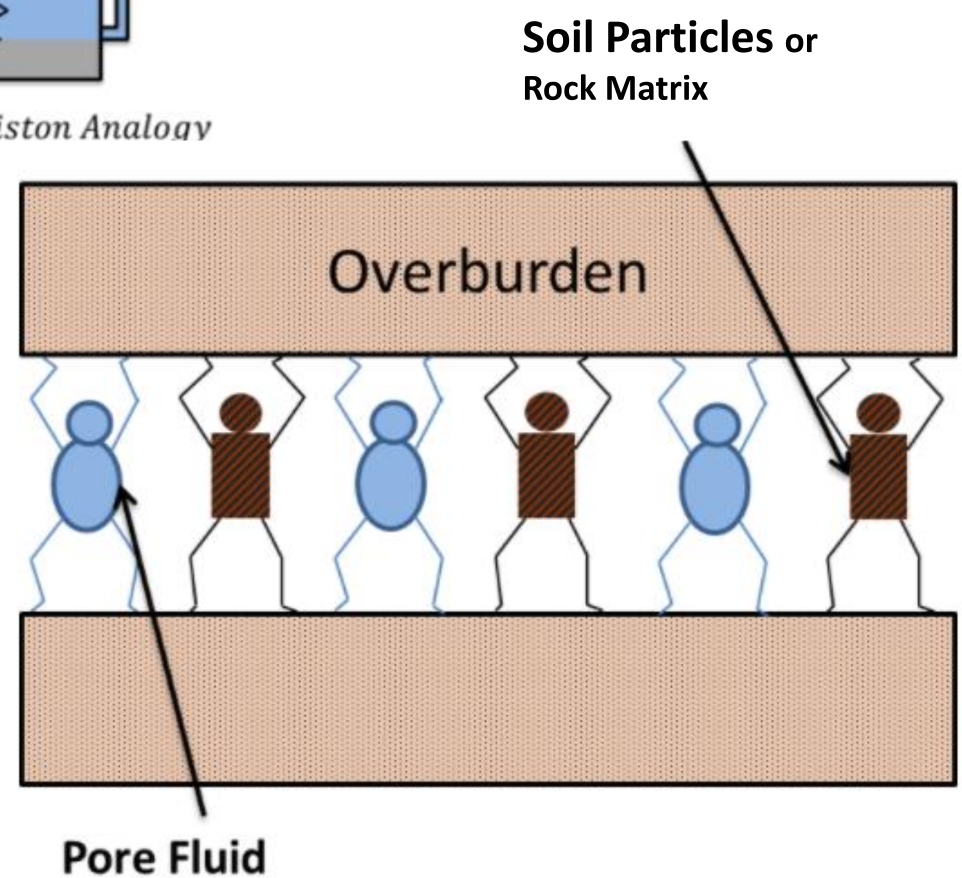
Drawdown of the water table during construction can also cause **surface** subsidence for some distance from the dewatering system. Differential settlements reflect the cone of depression. The differential settlements can be quite large, especially when highly compressible peat or other organic soils are present, and the effect on adjacent structures can be damaging.



Spring Analogy.



Surface
z
Overburden (σ_{ov})
Overburden
σ_{eff}
P_f
$P_{f@z}$
σ_{eff}
grain contact stresses
Spring and Piston Analogy



Soil Particles or
Rock Matrix
Overburden
Pore Fluid

Prevention & Control

- <u>Groundwater drawdown:</u> Only control of over-extraction prevents subsidence. Approximate predictions as to when the water table will drop to the danger level can be based on withdrawal, precipitation, and recharge data. By this time, the municipality must have provisions for an alternate water supply to avoid the consequences of overdraft. Where subsidence from withdrawal is already troublesome, the obvious solution is to stop withdrawal. Artificial recharging will aid the water balance ratio.
- <u>Oil and Gas Extraction:</u> Prediction of subsidence from oil and gas extraction is difficult with respect to both magnitude and time. Therefore, it is prudent to monitor surface movements and to have contingency plans for the time when subsidence approaches troublesome amounts. Control by deep-well recharging appears to be the most practical solution for oil and gas fields. Water injection into the oil reservoirs may halt the subsidence and even some area may rebound.

Prevention & Control

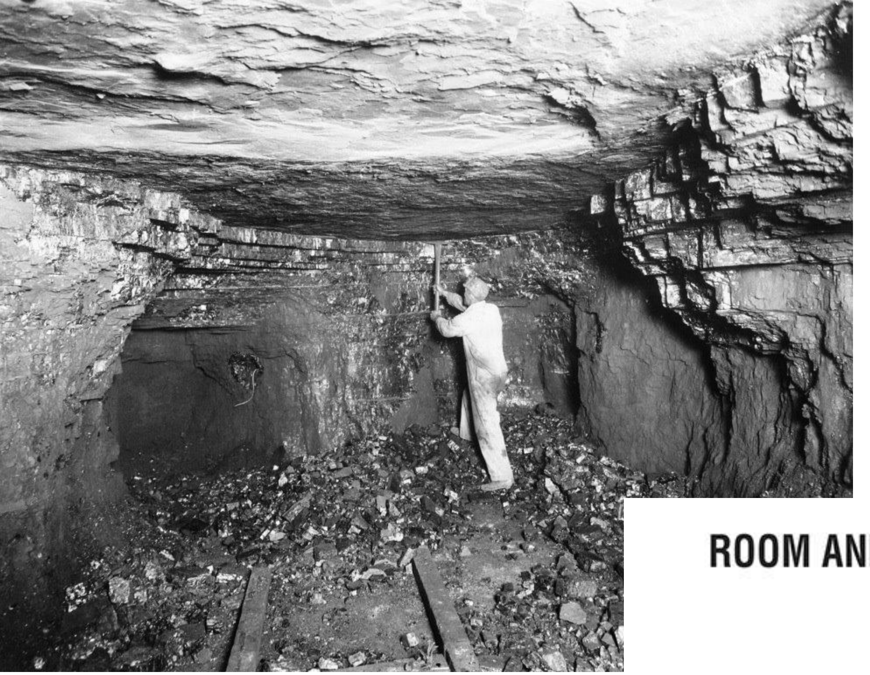
- Construction Dewatering: Only control of over-extraction prevents subsidence. Approximate predictions as to when the water table will drop to the danger level can be based on withdrawal, precipitation, and recharge data. By this time, the municipality must have provisions for an alternate water supply to avoid the consequences of overdraft. Where subsidence from withdrawal is already troublesome, the obvious solution is to stop withdrawal. Artificial recharging will aid the water balance ratio.

Methods to avoid Mine Collapse

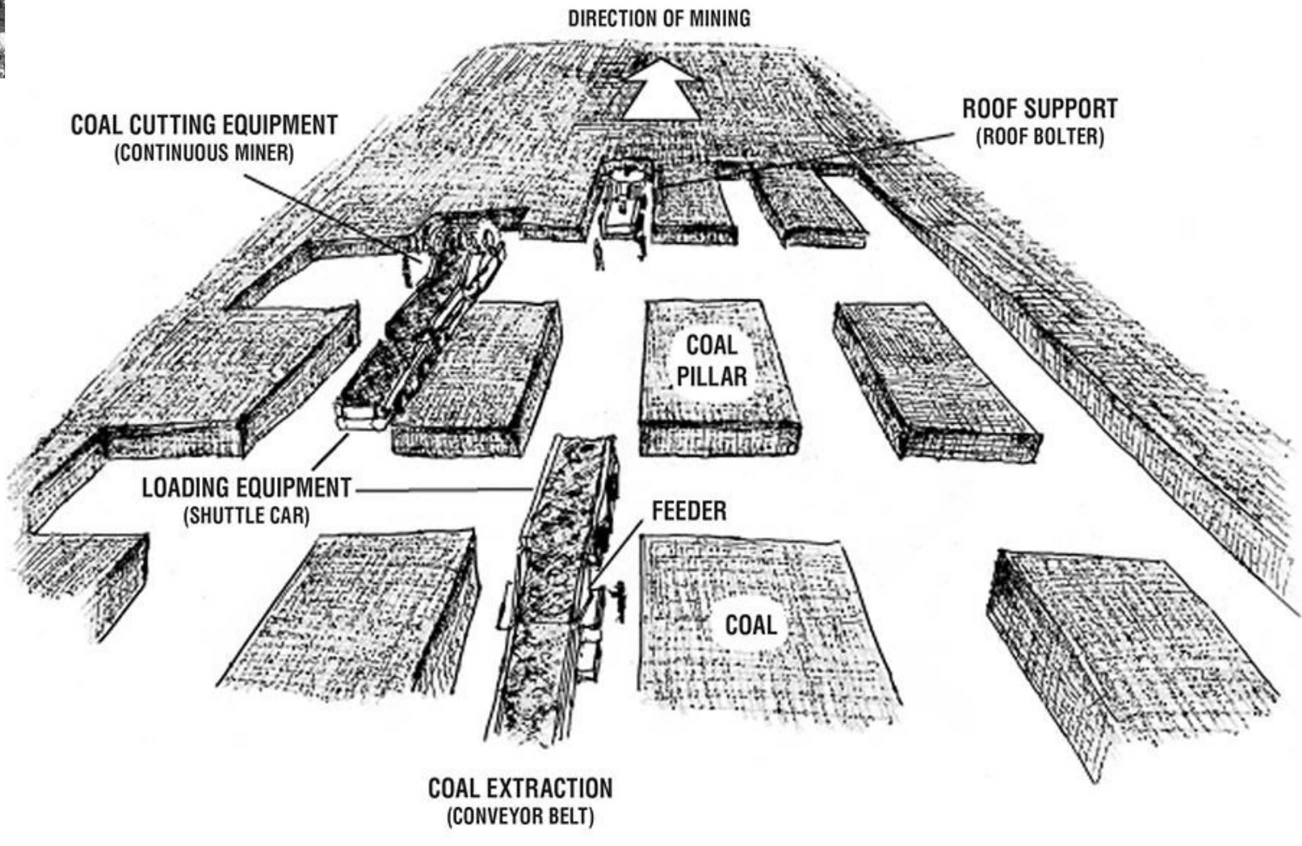
- In a commonly used coal mining technique, workers created rooms in a checkerboard or grid pattern, leaving pillars of un-mined coal to support the mine roof and the surface. Over time, there is sinking or shifting of the ground surface resulting from collapse in the underground mine.
- Mine Subsidence is caused by a failure initiated at the mine level, of man made underground mines.
- In simpler terms, when the roof of a subsurface mine collapses, it causes the ground above to sink or subside.
- Most experts agree that room and pillar mines will eventually experience some degree of collapse, but currently there is no way to know when or exactly where mine subsidence will occur.

Subsidence over Abandoned Mines

Two types of subsidence occurring above abandoned mines have been classified; **sinkholes** (pits) which is a depression on the ground surface resulting from the collapse of overburden into a limited mine opening, such as a room or entry and **troughs** (sags) which form where a pillar or pillars fail by crushing or punching into the mine roof



ROOM AND PILLAR MINING



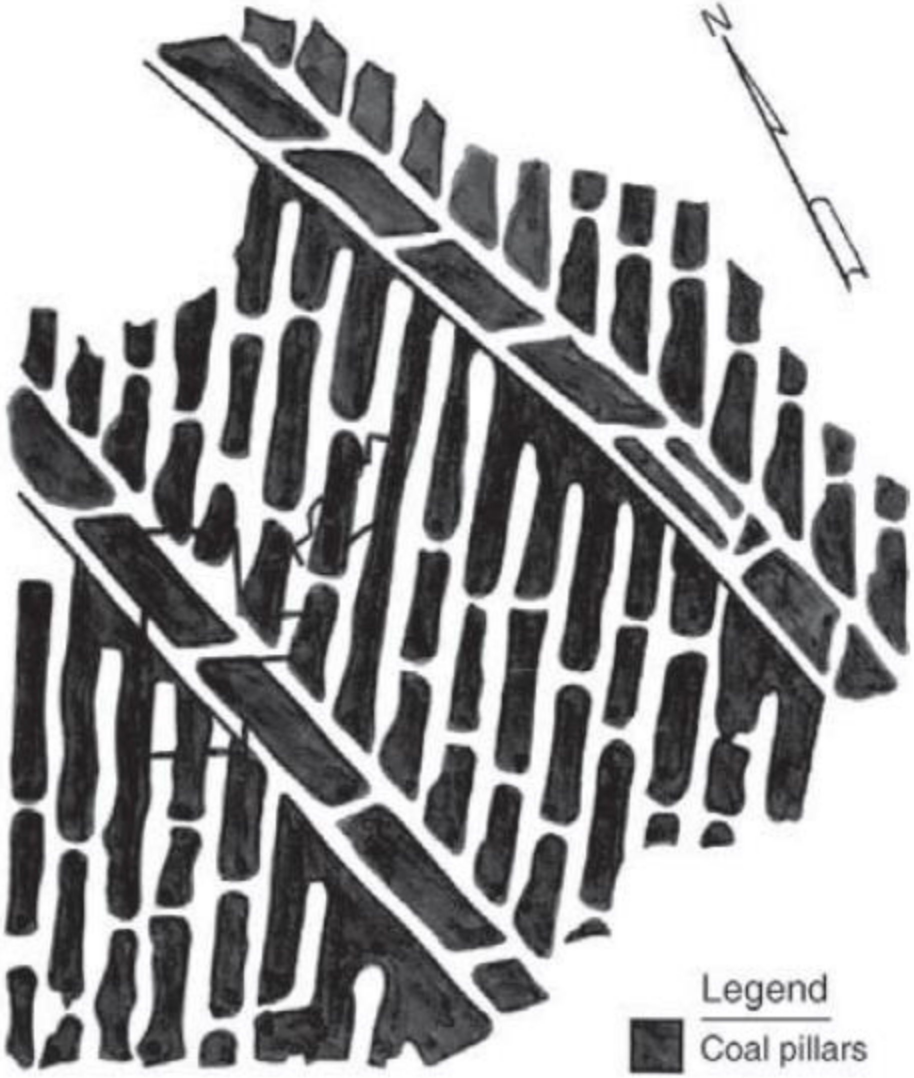


FIGURE 2.9
Plan of coal mine room and pillar layout, Westmoreland County, Pennsylvania. (From Gray, R. E. and Meyers, J. F., *Proc. ASCE J. Soil Mech. Found. Eng. Div.*, 96, 1970. With permission.)

Mine Collapse

Mine Collapse Mechanisms
Three possible mechanisms which cause mine collapse are roof failure, pillar failure, or pillar foundation failure.

Roof Failure: Roof stability depends upon the development of an arch in the roof stratum, which in turn depends on the competency of the rock in relation to span width. In weak, fractured sedimentary rocks, this is often a very difficult problem to assess, since a detailed knowledge of the engineering properties and structural defects of the rock is required, and complete information on these conditions is difficult and costly to obtain. If the roof does have defects affecting its capability, it is likely that it will fail during mining operations and not at some later date, as is the case with pillars.

Pillar Failure: The capability of a pillar to support the roof is a function of the compressive strength of the coal, the cross-sectional area of the pillar, the roof load, and the strength of the floor and roof. The cross-sectional area of the pillar may be reduced in time by weathering and spalling of its walls, as shown in Figure (next slide), to a point where it cannot support the roof and failure occurs.

FIGURE 2.10
Spalling of a coal pillar in a mine room (Pittsburgh). (Photo courtesy of Richard E. Gray.)

Mine Collapse

Pillar Punching: A common cause of mine collapse appears to be the punching of the pillar into either the roof or the floor stratum. Associated with coal beds, clay shale strata are often left exposed in the mine roof or floor. Under conditions of high humidity or a flooded floor in a closed mine, the clay shales soften and lose their supporting capacity. The pillar fails by punching into the weakened shales, and the roof load is transferred to adjacent pillars, which in turn fail, resulting in a lateral progression of failures. If the progression involves a sufficiently large area, surface subsidence can result, depending upon the type and thickness of the overlying materials.

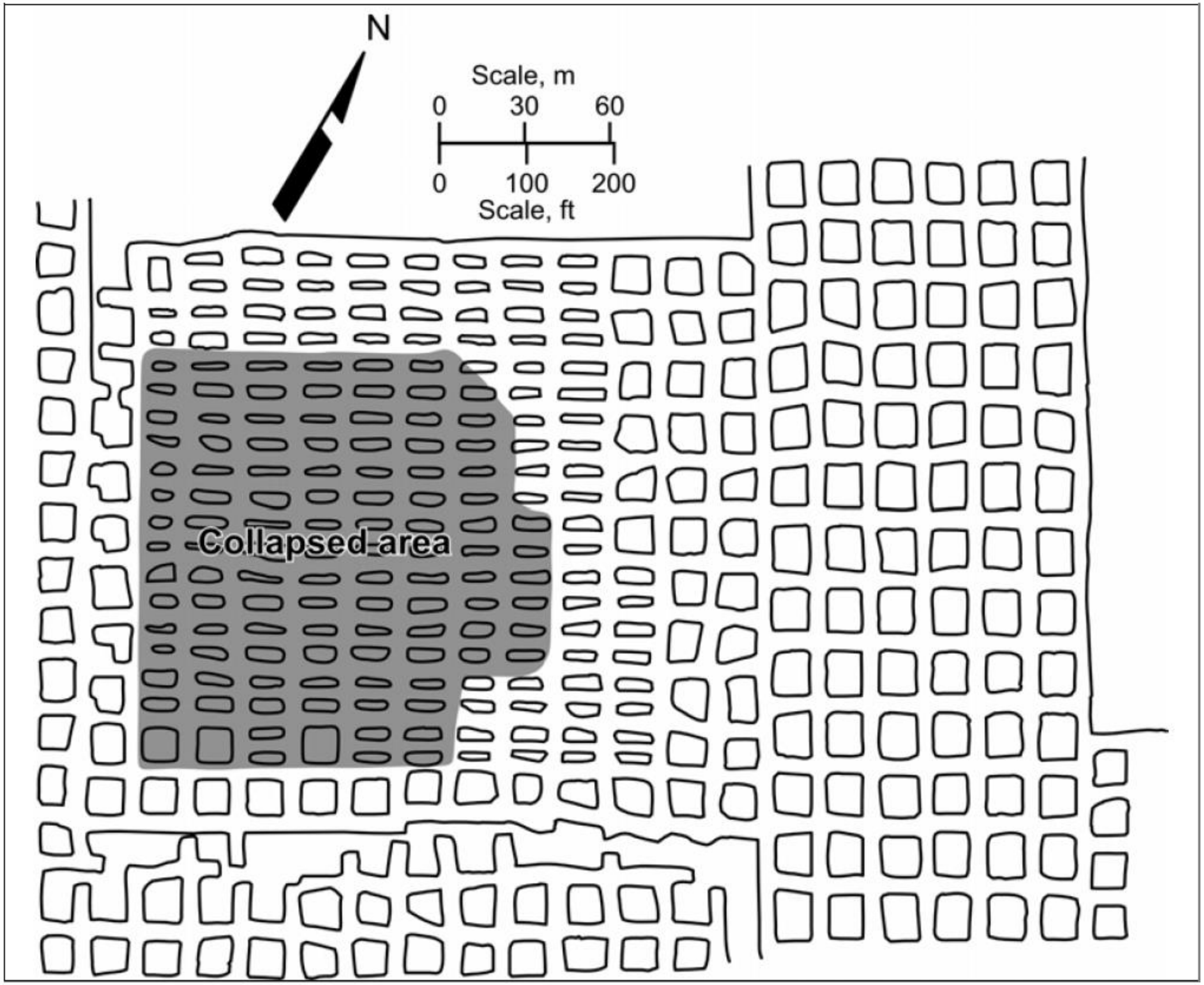
Earthquake Forces: In January 1966, during the construction of a large single-story building settlements began to occur under a section of the building, causing cracking. It was determined that the settlements may have started in late October or early November 1965. An earthquake was reported in Belleville on October 20, 1965. The site was located over an old mine which was closed initially in about 1935, then reworked from 1940 to 1943. It was considered that building settlements were the result of pillar collapse and mine closure initiated by the earthquake.

Methods to avoid Mine Collapse

- For finding methods to avoid mine collapse and to build projects over mines, investigations are done in which data is collected like information on local geology, local subsidence history, and mining operations beneath the site etc., and site explorations are also carried out (extent of exploration will vary depending upon the comprehensiveness of the existing data and the accessibility of the mine for examination. Actual inspection of mine conditions is extremely important, but often not possible in old mines.
- The information thus obtained is then analyzed through various methods.

Methods to avoid Mine Collapse

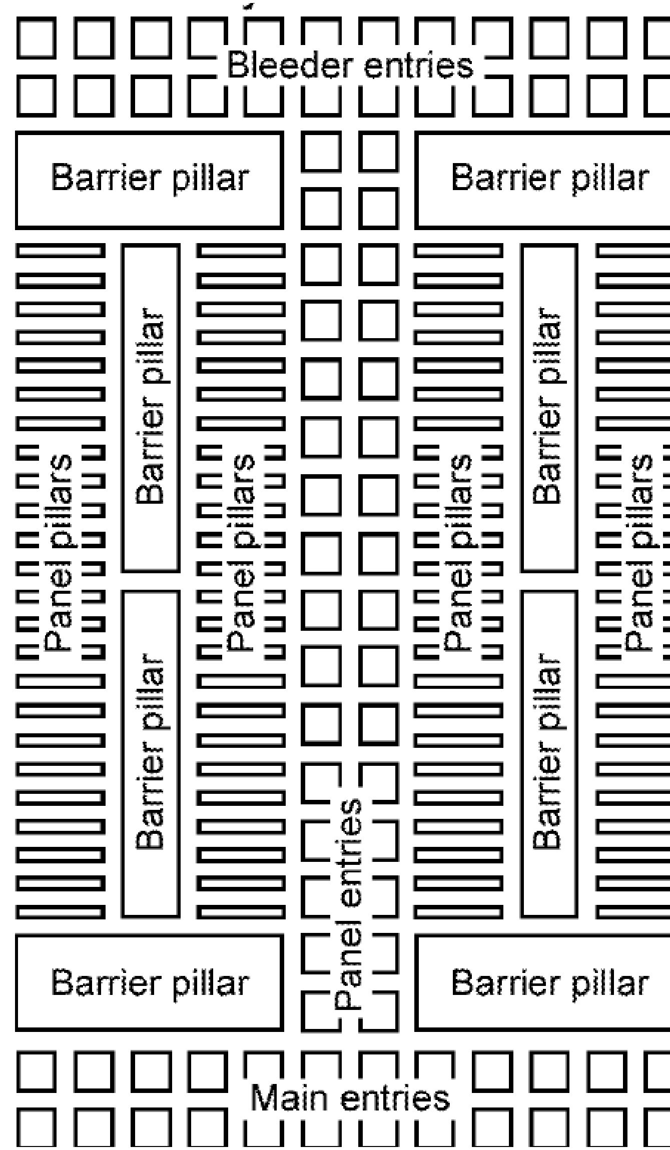
- **New Mines**
- If the strength of a pillar in a room-and-pillar mine is exceeded, it will fail, and the load that it carried will be transferred to neighboring pillars. The additional load on these pillars may lead to *their* failure. This mechanism of pillar failure, load transfer, and continuing pillar failure can lead to the rapid collapse of very large areas of a mine. In some cases, only a few tens of pillars might fail; however, in extreme cases, hundreds, even thousands, of pillars can fail. This kind of failure has many names—progressive pillar failure, massive pillar collapse, domino-type failure, or pillar run or cascading pillar failure (CPF). To avoid it, both the factors of safety (strength criterion) and stability are to be more than 1.
- Three alternative design approaches to decreasing the risk of large-scale catastrophic collapses are: i) the containment approach, ii) the prevention approach, and iii) the full-extraction approach. Until good data on the post-failure behavior of pillars become available, the containment and full-extraction options are the safest.


N
Scale, m
0
30
60
0
100
200
Scale, ft
Collapsed area

Methods to avoid Mine Collapse

- **New Mines**

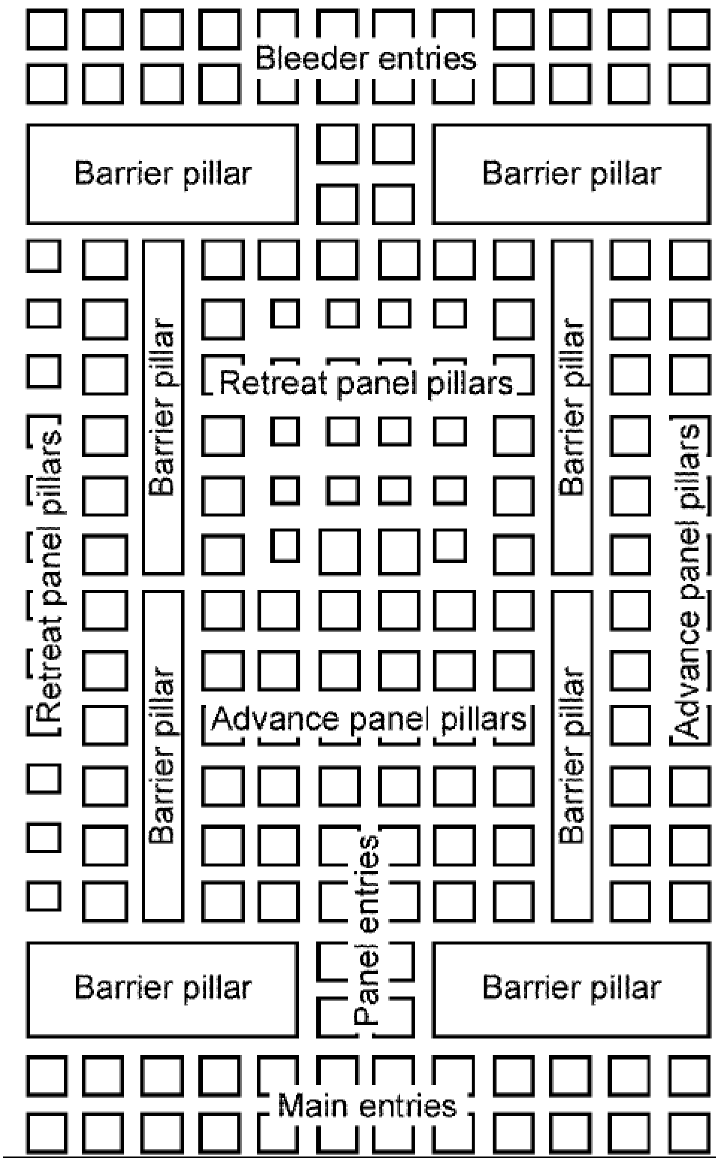
In the **containment** approach, an array of panel pillars that can fail in an unstable, violent manner if their strength criterion is exceeded are surrounded or “contained” by barrier pillars. The primary function of barrier pillars is to limit potential failure to just one panel.



Methods to avoid Mine Collapse

- **New Mines**

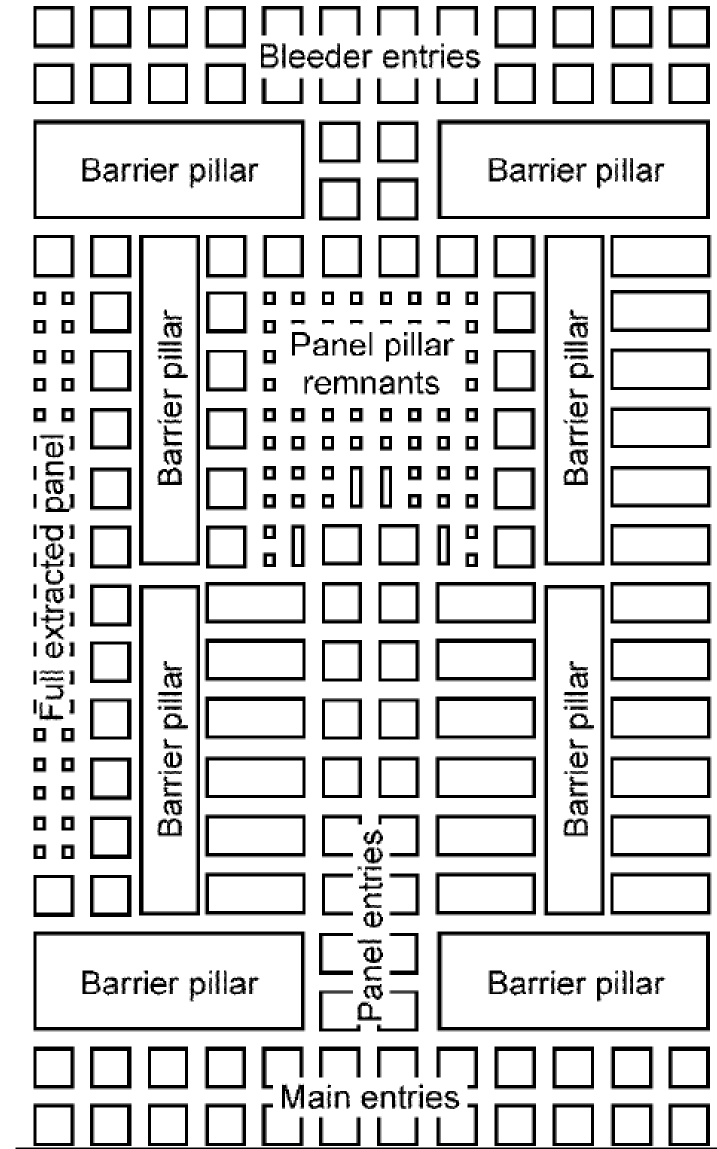
In contrast to the containment approach, the **prevention** approach “prevents” CPF from ever occurring by using panel pillars that satisfy both the stability and strength criterion. The factor of safety and the factor of stability for the panel pillars are both greater than 1. Therefore, panel pillars cannot fail violently, and CPF is a physical impossibility. Strictly speaking, this approach may not need barrier pillars to ensure overall stability against CPF; however, their use is still advisable.



Methods to avoid Mine Collapse

- **New Mines**

The **full-extraction** approach avoids the possibility of CPF altogether by ensuring total closure of the opening and full surface subsidence. This approach does not require barrier pillars for overall panel stability; however, they are needed to isolate extraction areas and overall protection. The factor of safety for the panel pillar remnants is much less than 1 to force them to fail immediately after retreat mining.



Methods to avoid Mine Collapse

- **New Mines**

In general, new mines are excavated on the basis of either total extraction, permitting collapse to occur during mining operations (if not detrimental to existing overlying structures), or partial extraction, leaving sufficient pillar sections to prevent collapse and resulting subsidence at some future date. Legget (1972) cites the case where the harbor area of the city of Duisburg, West Germany, was purposely lowered 1.75 m by careful, progressive longwall mining of coal seams beneath the city, without damage to overlying structures.

Methods to avoid Mine Collapse

- **Old Mines**

Solutions are based on predicted distortions and their probability of occurrence.

- *Case 1*

No or small surface distortions are anticipated when conditions include adequate pillar support, or complete collapse has occurred, or the mined coal seam is at substantial depth overlain by competent rock. Foundations may include mats, doubly reinforced continuous footings, or flexible design to allow compensation for some differential movements of structures.

- *Case 2*

Large distortions are anticipated or small distortions cannot be tolerated, when pillar support is questionable, collapse has not occurred, and the mine is at relatively shallow depths. Solutions may include:

  – Relocate project to a trouble-free area.
  – Provide mine roof support with construction of piers in the mine or installation of grout columns, or completely grout all mine openings from the surface within the confines of a grout curtain installed around the site periphery.
  – Install drilled piers from the surface to beneath the mine floor.