Loss Control TIPS
Technical Information Paper Series
*Innovative Safety and Health Solutions*SM

Understanding Subsidence

Subsidence of the land, which is defined as the loss of surface elevation due to the removal of subsurface support, occurs in every state in the United States. Subsidence is one of the most diverse forms of ground failure, ranging from small or local collapses to broad lowering of entire regions of the earth's surface. The causes of subsidence, which are mostly due to human activities, are as diverse as the forms of the failures themselves. Causes include:

- dewatering of peat or organic soils
- dissolution of limestone aquifers
- first-time wetting of moisture-deficient soils
- subterranean mining
- withdrawal of fluids
- natural compaction
- liquefaction
- crystal deformation.

Although land subsidence has had many negative impacts on human civil works for centuries, especially in the highly developed areas of Europe, the relationship between the removal of subsurface support and subsidence was not understood or recognized for many years. Recognition began in the 1920s, when the United States Geological Survey realized that water aquifers were compressible. At about the same time, Harvard University released a theory that stated that: "compression of soils results from the slow release of pore water and that the water removal transfers the load from the stressed soil materials to the granular structure of the soil".

Why Is Subsidence Hazardous?

Subsidence is essentially downward movement of land surface material, with little or no horizontal movement. It can be a serious hazard that can have adverse, long-term effects on structures constructed in the zone of subsidence, if the structures were not designed and constructed to mitigate the hazard. Subsidence has become more of a problem in recent years as land development expands into areas that are prone to subsidence.

Subsidence in the United States is caused mostly from human activity. For years, people have exploited underground resources, usually with little regard of the consequences to the area. This exploitation has taken the form of removal of groundwater, oil, coal, and ores.

© 2002 The Hartford Loss Control Department

Subsidence may occur if:

- fluids are removed and the pores where it resided are empty
- solids are removed and large voids remain

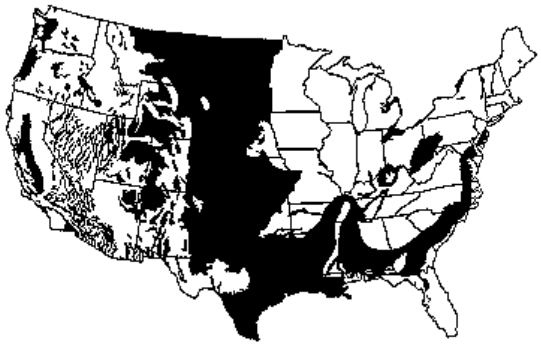
When solids or liquids are removed from below ground, what happens on the surface depends on the nature of the void and the strength of remaining material. Under the pull of gravity, unsupported surface material may subside or collapse.

Subsidence Near the Surface

Three types of subsidence may occur in soils at or near the surface. These forms of subsidence may occur from either human or naturally induced fluctuations of water content of the soil. Soil shrinkage may occur in certain types of soils as they are depleted of water. Removal of water or moisture from the soil can cause:

- Subsidence that occurs above compressible fine grain sediments or organic layers.
- Subsidence where clays shrink and swell with changes in water content.
- Subsidence where draining promotes subsequent decomposition of organic rich deposits under the surface.

Unstable Soils in the United States
Photo courtesy of USGS



Subsidence Above Compressible Deposits

Land development pressures are forcing the building of structures on top of fine grained water saturated sediments. Unfortunately, the weight of the structures presses the water out of the soils. To mitigate the problem, piles are installed from the footings of the heavy structures to a subsurface zone that will support the structural footing loads. Then, utilities, travel ways, and smaller buildings will be constructed to rest on the soil surface. As surface loading causes subsidence, the footings and pile support systems of the heavy structures will be exposed. In extreme situations, it may be necessary build up the area to gain access into the pile supported structures as the area subsides. Structures that are not supported on piles will have a high probability of damage as the area subsides.

Subsidence in Areas Above Expandable Clays

Clays rich rock and soils, like Bentonite, can absorb large quantities of water, swelling to many times their original volumes. These soils are called *shrink-swell clays*. Shrink-swell clays cause damage in the following way: When water enters the ground, the clay layers swell and exert great pressure on overlying building foundations. The upward pressure can exceed the gravitational pull force on structures that have low footing loading.

© 2002 The Hartford Loss Control Department

As water is removed, the clays dry out and shrink and the structures settle. Structures are repeatedly lifted and lowered as the swelling and shrinking takes place at different rates. Foundations can crack and structural damage can occur. Large surface cracks may form. These cracks can seriously damage overlying structures, utility lines, and surface transportation systems. The problem is especially severe in concrete and asphalt paved areas with folding, buckling, and elevation changes; extensive repairs are frequently required.

Subsidence in Areas Having Organic Soils

Organic rich soils occur in a wide range of climates. Many areas underlaid by organic rich soils have been drained for agriculture and land development. A typical method of drainage is the use of canals to promote gravity drainage. The water flows from the soil to the canal, causing the water table to drop. Water loss results in aeration, oxidation, shrinkage, and compaction of the soils. As biological action breaks down the organic soil, further subsidence occurs.

- The Sacramento River Delta in California has experienced subsidence of an average of 8 centimeters a year since canals were dug there for agricultural purposes.

- Areas surrounding the Everglades in Florida contain organic soils. When the areas were cleared for agriculture in the 1920s, drainage canals were excavated in the peat soils. Since that time, subsidence rates have been in the order of 2.5 centimeters per year. Some homes in the area, built on piles, have required the construction of additional steps at their entrances.

- Organic rich soils cannot be drained without some subsidence resulting. However, subsidence can be minimized by managing the rate of loss of the ground water and by recharging the ground water table in areas where subsidence must be minimized.

Subsidence Caused by Pumping Oil or Water

As development increases, so does the demand for groundwater; this increased pumping is lowering the water table in many areas of the country. The resulting reduction in artesian pressure can cause major soil shrinkage and volume reduction in certain soils. Economic demand for liquid petroleum products is also high, contributing to increased pumping of below-ground oils and corresponding effects on soils.

In the pore space of buried sediments or rock, oil or ground water fluids are under pressure from the overburden. The fluids contribute to the support of the overlying material. Removal of these fluids reduces the internal pore pressure within the material. If enough fluid is removed over an extended period of time, the overlying material will gradually subside. On a large scale, a subsidence basin will form.

As fluids are withdrawn, tensional forces develop in the soil. As the soil dries and shrinks, it may be pulled apart, creating subsidence fissures on the ground surface. In agricultural areas, the fissures can be filled as the ground is worked (such as by plowing). In urban areas, surface treatments (like asphalt or concrete) or structural foundations may crack and fail.

In other situations, the soil may not only crack, but portions may subside at a different rates than adjacent areas. Fissures and subsidence faults can form across the surface of the soil. Where subsidence faults pass under foundations and transportation systems, serious structural alignment and damage can occur.

© 2002 The Hartford Loss Control Department

- Las Vegas, Nevada is a desert basin bordered by mountains. Aquifers in the basin are recharged by mountain runoff. Development and removal of groundwater has lowered the water table by as much as 55 meters in the basin. Areas of down town Las Vegas have experienced 1.5 meters of subsidence.

- Santa Clara Basin, California is a great agricultural area. Groundwater removal for irrigation has caused downtown areas of San Jose to subside 4 meters; the surrounding basin areas have greater subsidence rates.

- Long Beach, California (specifically the Terminal Island area) has experienced 10 meters of subsidence due to petroleum pumping.

- Houston-Galveston, Texas yields both groundwater and petroleum. Removal of these fluids has resulted in 2.5 meters of subsidence, subsidence fissures 6 centimeters wide, and subsidence faults with 30 centimeters of displacement. Storm surge flooding is a major concern for communities near Galveston Bay. Johnson Space Center and Ellington Air Force Base are both in this zone of subsidence; both have experienced structural damage.

Subsidence Caused by Underground Mine Collapse

Underground mines are prone to subsidence because the removal of materials creates voids below the surface.

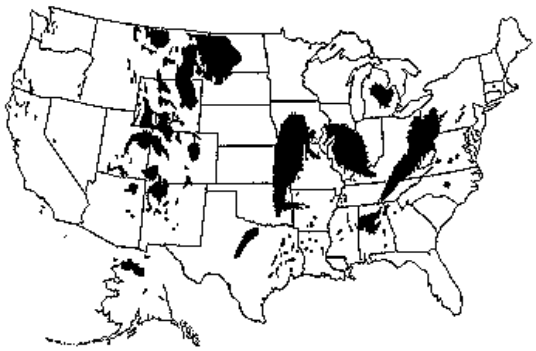
Mine Collapse Pits (Photo courtesy of US Bureau of Mines)

The depth of the mine and overburden material will determine the type of subsidence the area will experience. Shallow mines may experience surface collapse as well as basin type subsidence If the void is very close to the surface, roughly down to 60 meters (varying greatly on rock strength), surface material may break free and tumble into the void. Collapse pits may develop on the surface from the failure of overlying rock into the void.

Deep mines may experience slow downward movement of the overlying rock. The collapse occurs at a greater depth and in the form of slow rock deformation. The deformation downward of the overlying materials may cause the surface over the voids to deform and subside.

© 2002 The Hartford Loss Control Department

Coal Fields of the United States (Map courtesy of USGS)



The surface area affected by subsidence is somewhat predictable, based on past historical occurrences. The area of subsidence is usually broader than the mined area. Called the *angle of draw*, the area affected by the subsidence beyond the mined area is the base of the vertical angle that is formed from the edge of the mined area out to the edge of the subsidence area. Past experience has shown the vertical angle of draw is about 20 degrees.

Subsidence in mined areas does not progress at an even and uniform rate over the entire area. Since the rate of subsidence varies over the area affected, fissures in the surface are common.

Subsidence Caused by Coal Mine Fires

Coal mine fires can also cause subsidence, caused by the gradual removal of the coal by the fire. The fires usually start in a coal seam that is exposed to the surface. Most fires originate from brush and grass fires or from combustible debris in the mine. When the coal burns in the ground, subsidence and fissures may result. The fissures can perpetuate the fire, since they open the ground surface and allow oxygen to enter the burn area. This oxygen supports further combustion, which causes more subsidence and fissures, which in turn allows more oxygen to enter, and so the process continues. In Carbondale, Pennsylvania, an underground coal mine fire burned for 33 years. The area of combustion had to be excavated so that the fire could be extinguished.

Subsidence Controls For Mining

Both construction and mining methods and techniques can mitigate the magnitude of mine subsidence for an area, or can allow development over mined areas.

- Waste rock can be placed into the mined areas as mining progresses to support the mine roof as the mined product is removed.
- Sand or concrete can be pumped into tight areas that are not easily accessible in the mine to support the mine roof after the mined product is removed.
- Piles may be driven down from the surface through the mine roof into the mine floor to support the structure.
- Bore holes may be drilled down to the mine floor. Then piles are poured in two phases. A low slump concrete is poured down the tube to the mine floor. The concrete spills out to form a foot. The footed portion of the pile is allowed to set before the remaining top portion of the piles is poured in the bore hole.
- A waiting period can be used to allow subsidence to take place before the area is developed. This is a practical technique when long wall mining is used. Hydraulic roof supports hold the mine roof in place until the mining machine has passed. Then the supports are removed and the roof is allowed to settle down behind the miner.

© 2002 The Hartford Loss Control Department

Subsidence and Collapse Caused by Dissolving of Limestone

In areas underlaid by limestone that is near the surface, subsidence and collapse can occur from natural causes without human intervention. Groundwater action can dissolve the limestone and form cavities. The groundwater weakens the overlying rock, allowing the surface to subside or collapse into the cavity. These cavities are called *sink holes*.

Sink Hole (Photo courtesy of NOAA)

Development can also trigger sink hole formation. Rapid pumping of groundwater lowers the groundwater table, thereby reducing the water pressure in the limestone. The drop in aquifer pressure increases seepage from the sand layer above. Sediment and fines from the overlying sand are flushed downward with the water flow into the limestone . If these factors are severe enough, a sink hole may develop in the area from which the fines and sediment were removed.

Limestone Areas of the United States
Photo courtesy of USGS

Florida is the state most prone to sink holes because the state is underlaid by limestone very near the surface, and it has a warm, humid climate. After Florida, Texas, Alabama, and Missouri account for most of the sink hole damage in the United States. Other parts of the country may also develop sink holes.

Resources

Federal, state or local agencies have information on earth movement and water resources. Most helpful are the state Geological Survey offices. The state resident geologists can identify and discuss problem areas in their respective states. In addition to detailed geological state maps, they have documents and very specific studies for specific areas prone to subsidence. The Soil Conservation offices are another good source of information. Many areas of the country have been mapped for soil types and underlying rock formations. Most of the soil maps, which are overlays of the quadrangle maps from USGS, will also have elevations. The Soil Conservation Service and United States Geological Survey are part of the United States Department of the Interior.

For more information, contact your local Hartford agent or your Hartford Loss Control Consultant.
Visit The Hartford's Loss Control web site at http://www.thehartford.com/corporate/losscontrol/

This document is provided for information purposes only. It is not intended to be a substitute for individual legal counsel or advice on issues discussed within. Readers seeking resolution of specific legal issues or business concerns related to the captioned topic should consult their attorneys and/or insurance representatives.

© 2002 The Hartford Loss Control Department