That sinking feeling: geology, people and subsidence

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This talk aimed to highlight the role and importance of subsidence to development since new development raise issues of risk and unexpected ground behaviour. It covered why subsidence matters, what causes it, and subsidence features both natural and induced by human activity with a focus on what the media call sinkholes.

In a technical sense, there are a range of different features and most of the occurrences that hit the media in 2014 were induced rather than natural. The BGS has a publicly accessible sinkhole database which records occurrences. There are also other databases, such as the very extensive one held by Peter Brett Associates, which receives reports from insurance sources, which may not have received media attention. As an illustration, the sinkhole reported in the M2 in Kent in February 2014 probably resulted from the collapse of an old mine, a denehole; it was triggered by heavy rainfall. Other examples include that at Upper Basildon, Berkshire in December 2014, a collapse on Sandown Road, Isle of Wight this week, which was probably caused by a drainage failure under the road, and the collapse of a basement under the road in London a few weeks ago. Sinkholes have also influenced popular culture in that Lewis Carroll may have been inspired to create the hole by which Alice entered Wonderland by seeing a large sinkhole caused by gypsum dissolution on a visit to Ripon, North Yorkshire.

Causes of subsidence

Subsidence results from the loss of soil or rock mass total volume beneath the surface. This can reflect a number of processes including:

- dissolution of soluble material (karst) – limestone or evaporates rocks;
- drainage of groundwater or escape of oil or gas (air) leading to a loss of hydraulic support;
- void collapse such as mines, tunnels, basements;
- desiccation shrinkage;
- thaw of buried ice (thermokarst) in areas of permafrost;
- physical washout of solids (piping);
- decay of organic materials and chemical alteration leading to volume changes;
- compaction and consolidation due to loading by development; and
- earth movement such as landslips or earthquakes.

Effects and consequences of subsidence

The effects of subsidence can be slow or rapid. They include surface lowering, changes in surface and subsurface drainage and changes in soil/rock mass geotechnical properties, which may be adverse or beneficial. Subsidence may affect the bearing capacity, permeability, shear strength and stiffness/elasticity. The result is often damage to infrastructure and there may be a risk to life, as in the recent Florida sinkhole.

Natural subsidence

Natural causes include percolating groundwater dissolving limestone or evaporates, soil piping (washout) of weak soil or rock, burrow collapse, loading, eg by a landslide and climate change, which can lead to a fall in the groundwater table and to warming causing desiccation and decay of organic materials. These can lead to landscape-scale soil changes due to karst pocesses. Void loss, subsurface erosion and subsidence can also be caused by earthquake-induced liquefaction as illustrated at Chuetsa, Japan in 2004.

Types of sinkhole have been classified as solution, collapse, dropout, buried, cap rock and suffusion dolines. It is important to know which one is involved.

Solution dolines were illustrated by solution pipes at Kensworth Quarry near Dunstable in Bedfordshire, where solution pipes are filled with clay-with-flints. Typically the contact between the chalk and clay-with-flints is undulating because it is a solution contact. At the same quarry, clay-with-flints can be seen in a solution feature 50m below the surface. Although many such features are infilled, they are often completely open and the use of borehole cameras has shown voids several cm high.


Clay-with-Flints in solution features at surface and 50m down, Dunstable Chalk quarry

During installation of piles as the foundation for a tower block in Dubai, one pile dropped 15m in a cavity in soluble material. The sinkhole at the Corvette Museum in the USA in 2014 caused tens of millions of dollars damage to the museum and the valuable cars contained therein.

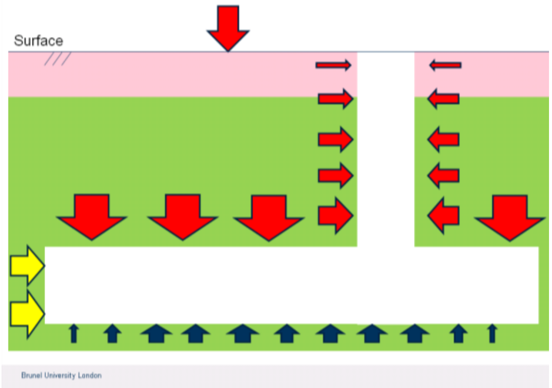
Human-induced subsidence

Human activity can induce or enhance the effects of subsidence through the effects of changes in drainage, which can be positive or negative, vibrations from construction activity, industry or transport, climate change, loading by construction works and mining. The latter is the most hazardous. A bridge in Durham was carefully designed so that HGVs could pass beneath it but after it was built a lorry hit the bridge because the bridge pillars had sunk.

There have been a lot of recent mining events on chalk from 19^{th} to early 20^{th} century mines which had been lost, though in one case at least, examination of the contemporary OS map would have indicated a mine shaft (1880) but no one had noticed it. The local example of the Pinner Chalk Mine was generally a stable structure and the shafts were well built, though there was a collapse of a previously unknown mine beneath the footway of the Uxbridge Road late last century.

Forces acting at cavity boundaries

The load of any building, the ground and the water in it exert a downward force on the roof of the cavity. A point load will also act laterally together with rock pressure on the walls of any shaft. There are also lateral forces on the walls of cavities and a buoyancy effect on the floor. An illustration of the latter was an adit constructed in Yorkshire, which bulged up 30cm over 2 years. Over time, the result of these forces is that cracks open and allow water or air in to cause deterioration in the walls and roof of cavities.



Forces acting at cavity boundaries

The cavity will then grow towards the surface, often with dramatic results as at Field Road, Coley, Reading, or the famous Norwich bus incident in 1988. These incidents caused no injuries but there was a case in St Petersburg, Russia, where about 30 people died.

Salt extraction

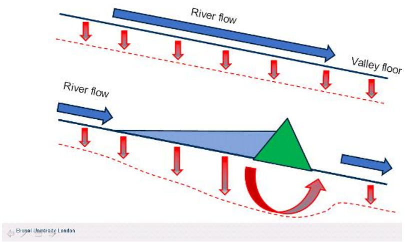
At Bayou Corne, Louisiana, Texas Brine Inc began pumping brine from a salt deposit in 2011. This resulted in subsidence and the appearance of a small lake on the surface within 2 years, which was even bigger in 2014. The salt domes being exploited are linked to hydrocarbons so oil and gas come up from a depth of 4,000ft into the lake. The brine well was on the edge of the salt dome and following salt solution, the wall rock collapsed in, leading fairly rapidly to ground subsidence.

Development of subsidence above brine extraction, Bayou Corne, Louisiana

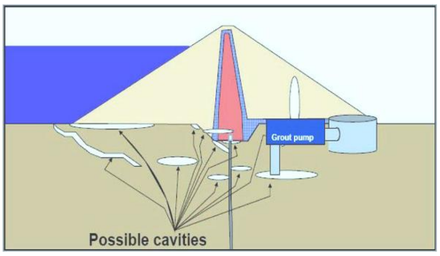
Research

Recent research at Brunel University has focused on gypsum [$CaSO_4$ $2H_2O$], a soft evaporate rock with a solubility of 2.0-2.5g/l at 25^oC, much less than that of salt [NaCl], which is 360g/l at 25^oC. Solution needs continual flow of under-saturated water.

In Iraq, the Mosul dam is an earth dam 3.4km long and 113m high on the River Tigris, which was completed in 1986. It holds back a reservoir with a capacity of 11km^3. There are subsidence hazards under the dam, beneath the reservoir and downstream of the dam. Because of the security situation, it is not possible to obtain samples from Mosul but similar gypsums have been tested. The dam has suffered subsidence since its construction and mitigation has involved grouting 24 hours/day, 6 days/week since the 1980s. Higher water pressure resulting from the filling of the reservoir pushes the water and dissolution deeper and oscillating pressures with water-level changes exacerbate the situation. The dam is founded on gypsum and as the cavities develop, gypsum creeps into the cavities. Long-term tests show the variability between different types of gypsum and 2 samples between 2 types of Iraqi gypsum at different water pressures.



Impact of dam on dissolution potential

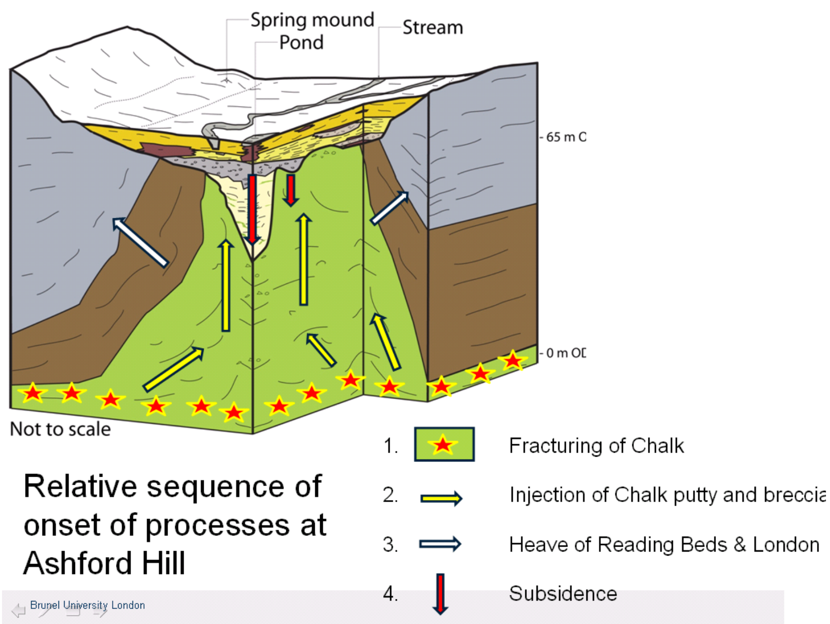


Cavities can collapse by crown failure or creep deformation

Anomalous hollows in London

A number of examples have been found of an unusual drop in the surface of the London Clay to form closed hollows, which are often filled with thick sequences of Quaternary deposits. 80,000 boreholes in London within the M25 are contained in the BGS database and there are lots of commercial boreholes as well but the quality is very variable. Frank Berry (1979) described these hollows as scour holes but it is not clear that they were caused by scour. The question arises as to whether the thickness of the London Clay acts as a control and the importance of their proximity to rivers. The BGS have developed a probability map for their occurrence in central London and the Lee Valley. The output is necessarily biased towards the data used and these are conceptual models and not necessarily the reality. The hollows are possibly linked to faults of normal, reverse, strike-slip and thrust types. Some of these faults are relatively recent, one thrust fault cutting a Roman archaeological layer.

Similar hollows also occur in the Kennet valley at Newbury, Woolhampton, Brimpton, Ashford Hill and Reading. Derek Hill (1985) in his PhD studied the Ashford Hill hollow and noted a sudden drop of superficial deposits in clays sands and silts of the Reading Beds. Hawkins (1953), based on work done in the 1930s, found the hollow is on an upraised section of putty chalk squeezed up to the surface from 0m OD to 60m OD with distorted Reading Beds and London Clay. They are possibly relics of the last ice age. The formation sequence involved fracturing of the chalk, injection of chalk putty and breccia, heave of the Reading Beds and London Clay, subsidence and possibly scour. One of Hawkins' boreholes went through the peat beneath a pond and found a clay pipe of 18th century age at a depth of 7m and covered in peat. Among the many unknowns are the relationship to valley formation, the timing of brecciation, of injection and heave, the exact timing of subsidence and the causes. The sediments have been dated at 12-15,000BP.



In Central London, near Waterloo Station, a 27m-deep hollow and a 20m-deep hollow occur on opposite sides of the River Thames and it is not known whether the two are linked. Nearby structures include Hungerford Bridge, the Ministry of Defence building and the Bakerloo and Northern Lines and between the two hollows is the route of the proposed Thames Tideway tunnel.

Conclusion

The speaker ended his presentation with a view of a 1m-wide hole 40m deep in the floor of a house in Guatemala City in August 2013, probably due to drainage failure. Two blocks away, a hole 30m across and 30m deep occurred.