K

Karst

Tony Waltham
Nottingham, UK

Definition

Terrain, mostly on limestone, distinguished by underground drainage and dissolution cavities. Natural ground cavities and the sinkholes that are formed largely when soil cover is washed down into them constitute the main karst geohazards.

Introduction

Karst terrains provide construction engineers with some of the most variable and unpredictable ground conditions found anywhere. Karst is distinguished by the solubility in water of its bedrock (mainly limestone, but also gypsum and salt) and is defined by its underground drainage through fissures and caves (Jennings 1985; Ford and Williams 2005). Consequently, karst ground can vary, on scales of meters or hectares, between strong, solid limestone, and voids that are either open or filled with soft sediment. Areas of limestone karst occur in all parts of the world, with the karst geohazard of particular importance in southern China, Slovenia, Croatia, and the eastern USA (Doctor et al. 2015), whereas it is of lesser significance within most of Great Britain (Cooper et al. 2011).

The scale of the karst geohazard is greatest in areas with warmer and wetter climates, where dissolution levels are higher in waters enriched with biogenic carbon dioxide. An engineering classification of karst therefore reflects this climatic influence in its recognition of five classes of karst ground conditions (Waltham and Fookes 2003). These classes can only represent generalities in their ground conditions, and the geohazard is normally best assessed by identifying the scale of the three key factors of significance to construction works. These are sinkhole development (mainly in the soil profile), pinnacled rockhead, and ground cavities (Waltham 2016; Waltham et al. 2005; Fig. 1).

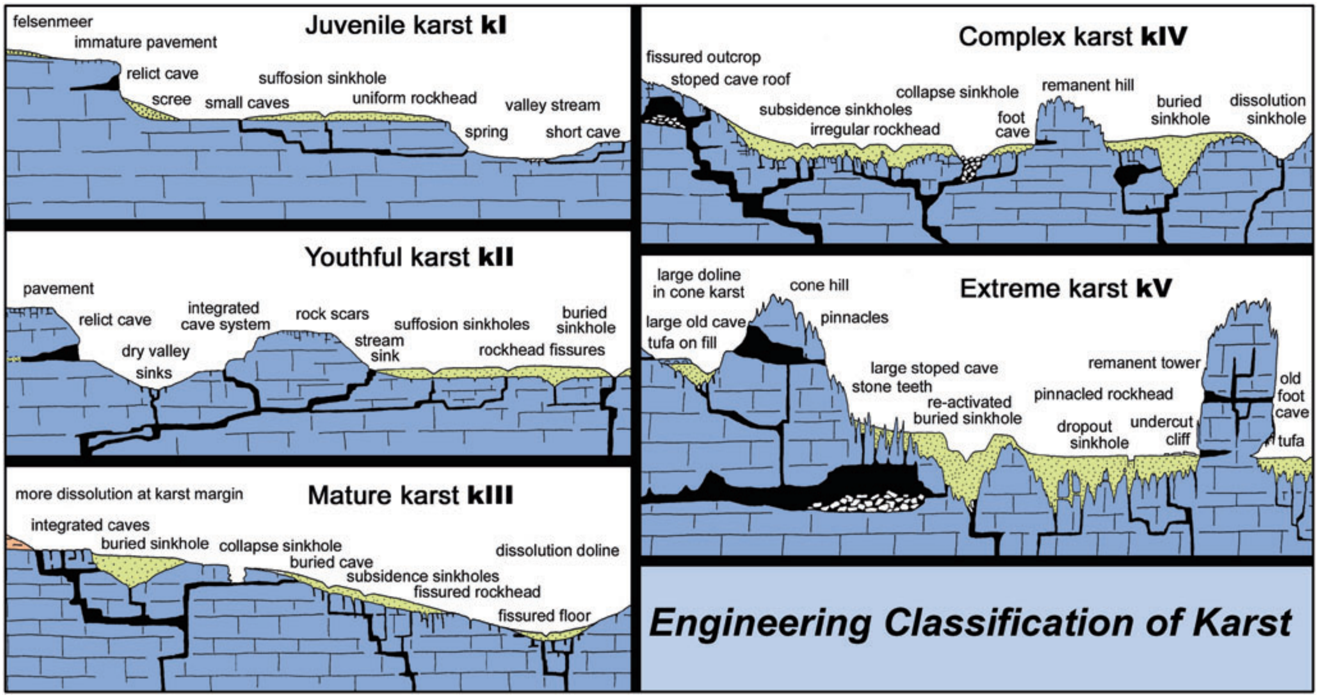
The Sinkhole Hazard, and the Means of Reducing It

Sinkholes (or dolines in most geomorphologists' parlance) are the ubiquitous feature of karst terrains, formed at points where water sinks underground. They can form by dissolution and collapse of the bedrock, but dissolution is extremely slow and collapses are rare. By far the greatest geohazard is presented by the huge numbers of sinkholes developed or developing within soil profiles that overlie fissured limestone. These are known as subsidence sinkholes and are developed where the soil cover is washed downward by any form of drainage flow into the limestone fissures, in a process known as suffosion (Waltham et al. 2005).

Individual subsidence sinkholes are commonly 2–50 m across and 1–15 m deep, typically with a diameter that is less than three times the soil depth. Within the bedrock, the cavity that is the cause of the sinkhole, and is the outlet for the water and soil, could be a fissure just a few centimeters wide or a shaft a meter or more across at a fissure intersection. Of the two types of subsidence sinkhole, a dropout sinkhole develops in a cohesive soil that can bridge over a soil cavity before its sudden collapse, whereas a suffosion sinkhole develops more slowly by continuous slumping. Many sinkholes fit between these extremes and develop in stages lasting hours or weeks that increase depth and diameter.

Though many new subsidence sinkholes occur during major rainfall events, it is well documented that the vast majority of new sinkholes are caused by man's activities (Newton 1987; Waltham et al. 2005; Waltham 2009; Guttiérez et al. 2014). New failures are caused either by increased inputs of water, normally by inadequate, changed, or broken drainage systems, or by water table decline that has

P.T. Bobrowsky, B. Marker (eds.), *Encyclopedia of Engineering Geology*,
DOI 10.1007/978-3-319-12127-7_177-1



Karst, Fig. 1 Variation in karst morphology broadly recognized in an engineering classification that recognizes increasing sizes and numbers of caves, sizes and numbers of sinkholes, frequency of new sinkhole events, topographic relief, and rockhead relief in the increasingly more mature karst terrains (After Waltham and Fookes 2003)

a comparable drawdown effect or can induce failure by the loss of buoyancy support. A fissure large enough to swallow soil takes thousands of years to be formed by rock dissolution, but a new input of water, failure of a soil arch, or washing out of a choke can cause a new sinkhole to develop in the soil profile within hours or days. Prediction of new sinkhole locations is impossible, except to recognize that most will occur where there is a new water input to the soil cover. Short of stripping away the soil cover, open fissures, and potential sinkhole sites cannot be determined by any practicable level of ground investigation.

A stable situation of rainfall filtering through natural ground into myriad fissures in underlying limestone is easily disturbed when a built structure concentrates run-off into a few perimeter points, each of which then becomes a potential site for a new sinkhole. Roads (with their marginal run-off), railways, buried pipelines (with their granular pipe seating along their floors), and any unlined ditches all constitute effective diversions of drainage. The most cost-effective means of minimizing the sinkhole hazard is thorough control of surface water, to ensure that as little of it as possible can ever collect at points where it can sink underground and wash any soil cover into karstic cavities within underlying limestone (Waltham 2016).

Careful design of good drainage is essential in karst terrains. Built drains, as efficient and comprehensive as practicable, should ideally carry run-off water away from the site. Retention ponds that lose water into the soil cover are only appropriate sited away from structures; a guideline minimum distance is double that of the local soil thickness to allow for the flared sides of any new sinkhole and also some lateral flow along rockhead. Soakaway drains are best avoided in karst, or can be cased into bedrock in order to avoid flow through the soil cover.

Inevitably, almost any construction project disturbs soil drainage and accounts for many new sinkholes during or soon after the period of site activity. The hazard can only be reduced by ad hoc drainage control that is site-specific and primarily avoids locally increased infiltration to the soil.

Subsidence sinkholes are commonly induced by any water table decline that increases downward flow of soil drainage. This can induce clusters of new sinkholes across wide areas, especially where the water table declines past the rockhead, so that minimal, lateral groundwater flow is replaced by focused, downward flow at the critical points of soil loss into bedrock fissures. The two main reasons for water table decline are excessive abstraction for water supply and dewatering around mines and quarries (Fig. 2). The only means of reducing new sinkhole occurrences is to allow the water table to recover, and that is normally constrained by wider economic considerations.

Sinkhole remediation is rarely easy. Simple backfilling is invariably followed by reactivation when the fill is itself washed downward. Stability can be achieved by choking the sinkhole with blocks of rock too large to move downward, though this commonly requires exposure of the bedrock fissures to be successful, and is preferably accompanied by diversion of immediate drainage.

Karst, Fig. 2 Failure of a road in Pennsylvania where a subsidence sinkhole developed as soil was washed down into a fissured karst limestone after the local water table had been lowered by pumped drainage of a nearby quarry

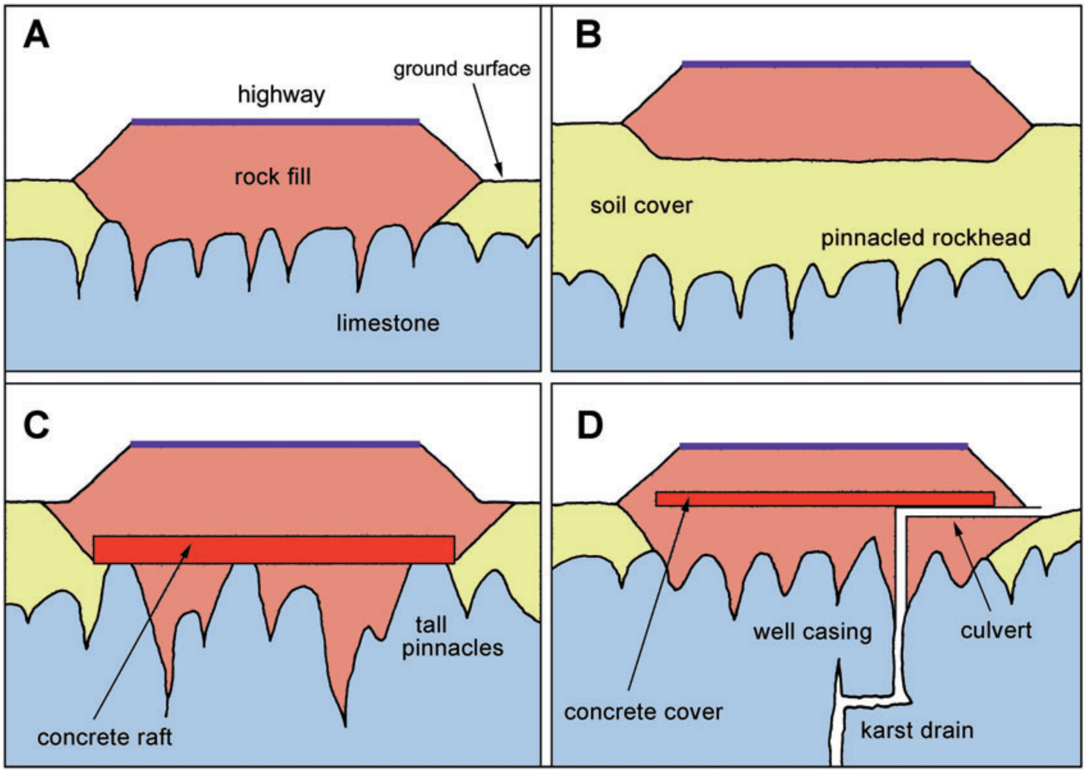
Foundations on Pinnacled Rockhead, and the Means of Ensuring Stability

The surface profile of limestone bedrock within in a karst terrain is typically extremely irregular. A glaciated karst may have only open fissures between flat expanses of limestone pavement, but a tropical karst is normally fretted into columns, gullies, and loose blocks on a spectacular scale (Waltham and Fookes 2003). When buried by a deep soil, rockhead morphology is totally unrecognizable from surface observation alone. In areas of pinnacled rockhead, boreholes only meters apart may reach bedrock at depths varying by tens of meters, where they meet either the crest of a pinnacle or the floor of a dissolutionally widened fissure at its side.

Structures can be founded on buried pinnacles (Sowers 1996; Waltham et al. 2005). The proviso is that pinnacles must be proven to be large enough and stable and are not detached blocks with lateral support only by soft soil. Assessment may require partial exposure, generally accompanied by multiple boreholes. Concrete rafts or beams can bridge between the pinnacles of strong limestone (Fig. 3), and coarse aggregate mats formed over a mixture of soil and rock can achieve stability by distributing loads across multiple pinnacles (Lei and Liang 2005). The use of driven piles requires considerable care in pinnacle karst as they may be bent, deflected, or inadequately seated on steeply inclined rock surfaces on the sides of buried pinnacles.

Unseen Cavities, and the Means of Detecting Them

By definition, karst terrains contain caves, cavities, voids, and fissures. These are filled with air, water, or soft sediment, and have virtually zero bearing capacity. They may represent potential sites for the development of subsidence sinkholes where they can receive debris and sediment that is washed into them from the soil profile. They can also evolve into collapse sinkholes where the rock arches or bridges above them are weathered and eroded to the point of failure. Though collapse sinkholes are a feature of many karst terrains, their natural development is over geological timescales, so that new collapses are extremely rare (Fig. 4). Collapse induced by loss of buoyancy support, due to water table decline, can



Karst, Fig. 3 Design concepts developed for construction of a motorway across limestone karst in southern China. A = coarse rock fill placed on exposed bedrock where soil cover is <3 meters thick. B = mattress of coarse rock fill placed on a thick soil cover. C = concrete raft that spans wide soil-filled fissures and hollows between footings on stable limestone pinnacles. D = culvert installed to maintain drainage into the natural sink within a karst depression (After Lei and Liang 2005)

Karst, Fig. 4 A new sinkhole nearly 50 meters across in central Turkey, which destroyed a road and a house when the ground dropped by more than a meter due to failure of a cave roof at considerable depth

occur (Doğan and Yilmaz 2011), but is very unusual. The main geohazard is created by inadvertent structural loads being imposed on rock that bridges over an unseen cavity.

Natural caves can occur at any depth and to any size within karst terrains, but only the larger caves at smaller depths are relevant to engineering works on the ground surface. The load-bearing capacity of the rock roof over caves varies enormously, as it depends on cave width, cover thickness and the mass strength of the fractured rock (Waltham and Lu 2007). A very rough guideline is that a roof thickness greater than half the cave width is stable for most structural loading in strong limestone, but each situation requires individual assessment.

The only feature predictable about caves is that they are unpredictable, and the only certain means of proving intact rock beneath a built structure in a karst terrain is with boreholes. A guideline is that these should probe to a depth in intact rock equal to the likely cave width, and that dimension

Karst, Fig. 5 Construction on a concrete slab bridging between strong and stable limestone pinnacles without the inconvenience of a soil fill to obscure the ground conditions in deeply dissected limestone karst in the Philippines

can only be roughly assessed through local knowledge of the karst (Waltham 2008).

Geophysics offers some prospect in cavity searches (Waltham et al. 2005). Microgravity surveys are probably the most reliable because a cave creates a clear negative anomaly even if it is filled with water, breakdown or sediment. The disadvantage of microgravity is the high cost, as closely spaced recordings are required for realistic interpretation of the data, so that the method is applicable only at limited numbers of sites. Resistivity surveys can be economically viable over large sites or along transport corridors. However, they suffer from the fact that a cavity filled with clay or water creates a negative anomaly whereas a dry, open cavity creates a positive anomaly. Consequently, ground with both open and filled fissures tends to cancel out its own anomalies, and there have been many cases where the surveys have proved to be unhelpful or even misleading. Resistivity modelling in 3D increases the cost but on a small site can provide results that are more reliably interpreted than 2D surveys. Cross-hole seismic tomography has also produced useful results where a borehole network is available. Depth limitations on ground penetrating radar generally restrict its use in karst.

Any cavity of significant size found with inadequate rock cover beneath a site for load-bearing foundations requires attention. Filling with mass concrete can be the simple remedy, but may be difficult where laterally extensive cavities can swallow huge quantities of injected fill or where a cave's floor of soft sediment cannot adequately support the placed fill. Bridging a cavity with beams that span between solid footings (Fig. 5), or with piles that reach sound rock beneath a cave can be successful in specific cases. In some situations relocation of the structures, to avoid known cavities, can be the best or even the only option.

Summary

The main geohazard in karst is created by the development of new sinkholes within the soil cover, largely when and where the drainage has been disturbed. They are related to ground cavities, which form a second, though smaller, geohazard in their own right. There can be no rigid rules concerning the scale, methods, and detail of ground investigation on karst. Each site on cavernous ground is different and requires individual assessment to a level that provides sufficient confidence that built structures will retain integrity. Construction projects on karst should proceed only when the extremely variable ground conditions are fully appreciated.

Cross-References

▶ Dissolution
▶ Evaporites Geological Hazards
▶ Limestone
▶ Sinkholes
▶ Subsidence
▶ Voids
▶ Weathering

References

Cooper AH, Farrant AR, Price SJ (2011) The use of karst geomorphology for planning, hazard avoidance and development in great Britain. Geomorphology 134:118–131

Doctor DH, Land L, Stephenson JB (eds) (2015) Sinkholes and the engineering and environmental impacts of karst: proceedings of the 14th multidisciplinary conference. National Cave and Karst Research Institute, Carlsbad, 611 pp

Doğan U, Yilmaz M (2011) Natural and induced sinkholes of the Obruk plateau and Karapinar-Hotamiş plain, Turkey. J Asian Earth Sci 40:496–508

Ford DC, Williams PF (2005) Karst hydrogeology and geomorphology. Wiley, New York, 562 pp

Gutiérrez F, Parise M, De Waele J, Jourde H (2014) A review of natural and human-induced geohazards and impacts in karst. Earth-Sci Rev 138:61–88

Jennings JN (1985) Karst geomorphology. Blackwell, Oxford, 293 pp

Lei M, Liang J, (2005). Karst collapse prevention along Shui-Nan Highway, China, pp 293–298 in Waltham et al., op. cit.

Newton, JG (1987) Development of sinkholes resulting from man's activities in the eastern United States. U S Geological Survey Circular 968, 54 pp

Sowers GF (1996) Building on sinkholes. ASCE Press, New York, 202 pp

Waltham T (2008) Sinkhole hazard case histories in karst terrains. Q J Eng Geol Hydrogeol 41:291–300

Waltham T (2009) Sinkhole geohazards. Geol Today 25:112–116

Waltham T (2016) Control the drainage: the gospel accorded to sinkholes. Q J Eng Geol Hydrogeol 49:5–19

Waltham AC, Fookes PG (2003) Engineering classification of karst ground conditions. Q J Eng Geol Hydrogeol 36:101–118

Waltham T, Lu Z (2007) Natural and anthropogenic rock collapse over open caves. Geol Soc Spec Publ 279:13–21

Waltham T, Bell F, Culshaw M (2005) Sinkholes and subsidence. Springer (Praxis), Berlin, 382 pp