

Topic 3. Foundations in karst areas

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ACTIVITIES OF GROUNDWATER SUFFUSION

Soil suffusion (from Latin *suffusio* – dripping) is the process of washing and removal of fine mineral particles from the dispersed soil mass when water percolates through it. The smallest particles can be washed out from non-homogeneous sands and other coarse-grained soils (gravelly soils). Clay fractions less than 0.002 mm in size, silt (0.002–0.05 mm) and even sands (0.05–2 mm) may be washed away by a stream of groundwater and separated or completely removed from the soil mass. Suffusion is often observed in fossil soils, where the movement of water occurs through macropores and moving animals. The process of suffusion is close to the karst process, but the difference is that suffusion is mainly the mechanical removal of soil particles without their physical alteration. Chemical suffusion is less commonly observed, where water dissolves certain salts contained in the soil (NaCl, CaSO₄) and removes the soluble components. Mixed chemical and physical processes may sometimes be observed, mainly in loess soils. These processes cause deformation of the earth surface by formation of smooth settling troughs, funnels and collapse of existing irregular shapes. Suffusion processes are most often observed on steep slopes of river valleys, ravines, on coastal slopes, sides of construction dredges, irrigated territories, that is in places with high hydraulic gradients in moving groundwater.



Fig. 1. Mechanical suffusion of clayey sand when groundwater arrives through the gaps in the sheet pile wall enclosure

Under the influence of man-made factors, natural suffusion processes can increase intensively. Technogenic suffusion may occur with leaks and damages in water supply and sewage systems; in backfills without adequate compaction when laying pipelines and cables; in case of uncontrolled drainage of groundwater into sewer system (Fig.1)

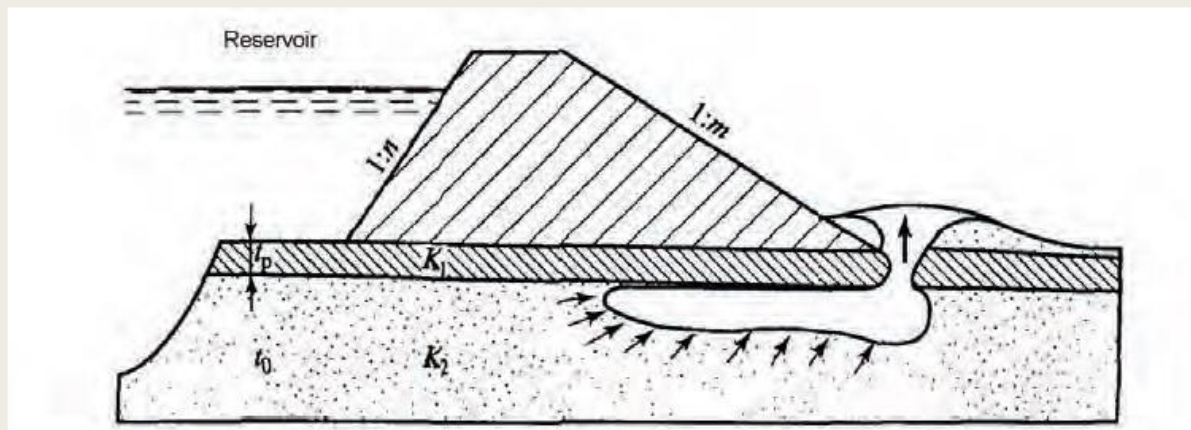


Fig. 2. Scheme of formation of the suffusion cavity under an earth dam

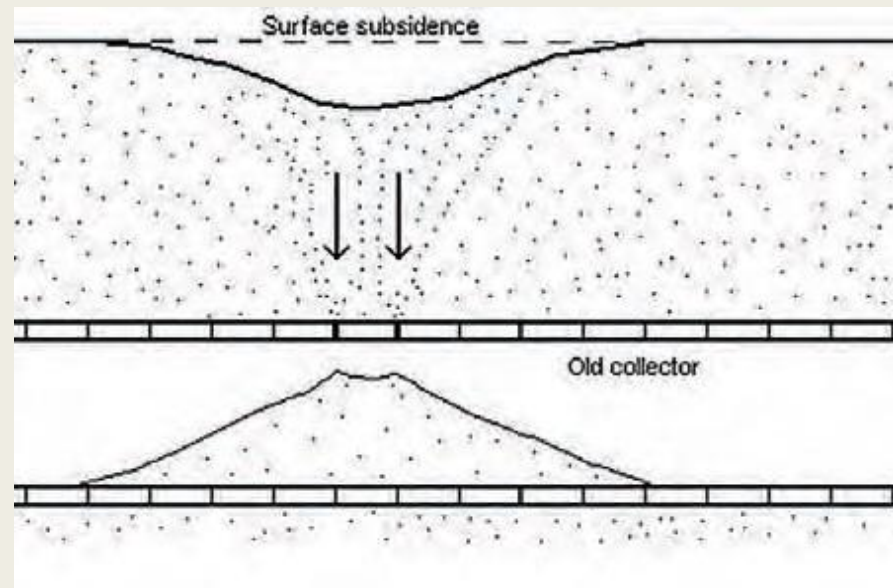
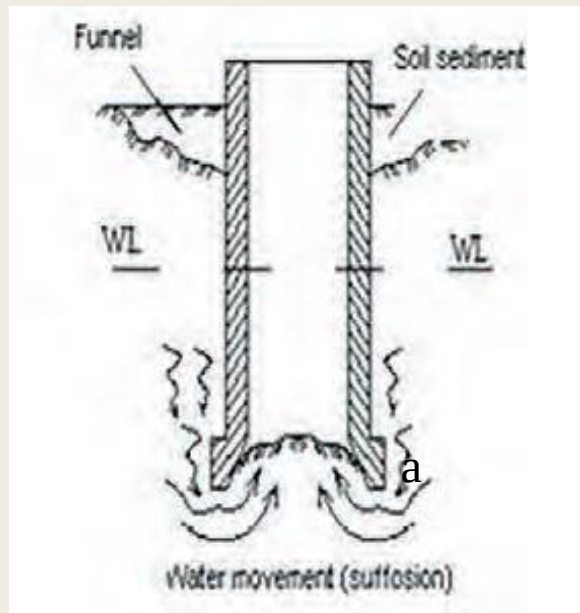


Fig. 3 Suffusion removal of soil particles up through the bottom of the drop well (a) and down through the openings in the manifold (b)

FAVORABLE FACTORS FOR SUFFUSION

High heterogeneity in the particle size distribution of soils, increase of groundwater velocity and filtration transition from laminar to turbulent regime, which occurs at hydraulic gradient $I > 5$ are favorable factors for suffusion. The coefficient of heterogeneity of the particle size distribution, determined by the formula $C_u = d_{60} / d_{10}$, where d_{60} and d_{10} – diameters corresponding to 60 and 10% content of fractions respectively can be used to assess the likelihood of suffusion. Sandy soils are classified in three categories according to C_u value as follows: suffusive – $C_u > 20$, transitional – $C_u = 10-20$ and non- suffusive – $C_u < 10$. Suffusion leads to weakening of soils and settling of the overlying soil thickness with formation on the surface of suffusion funnels, saucers, hollows, dips with diameters from one meter up to 100 meters and more; sometimes even the formation of large underground cavities and caves is possible.

Suffusion near the earth's surface



Fig. 4 Deformation of the pavement surface caused by suffusion and movement of soil into the manhole

Suffusion at the base of roads

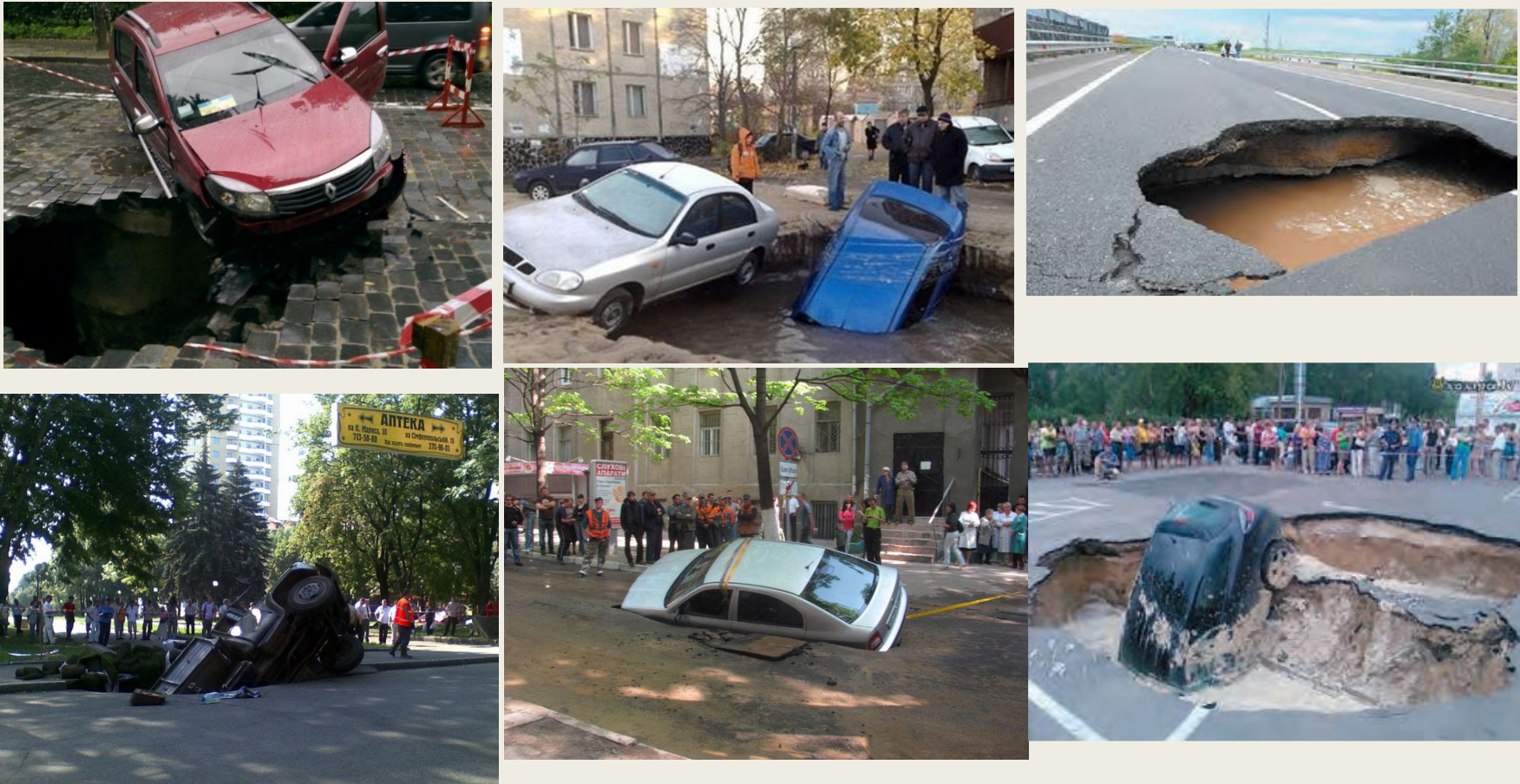


Fig. 5 Suffusion cavities due to groundwater ruptures

Deep in the massifs

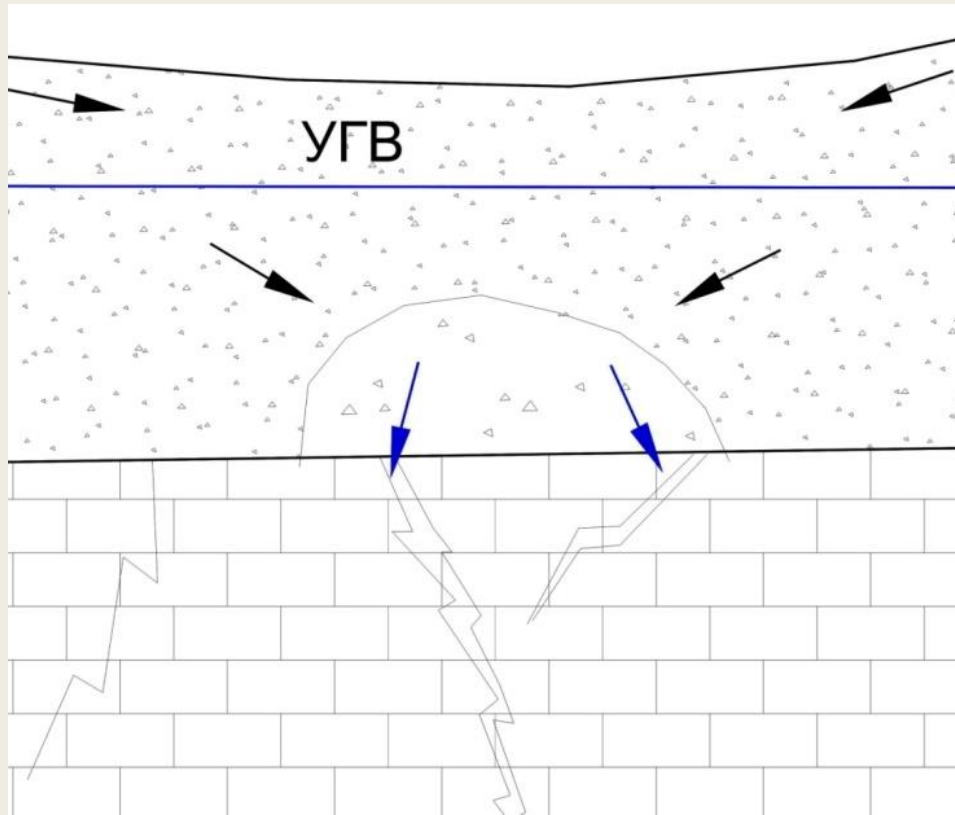
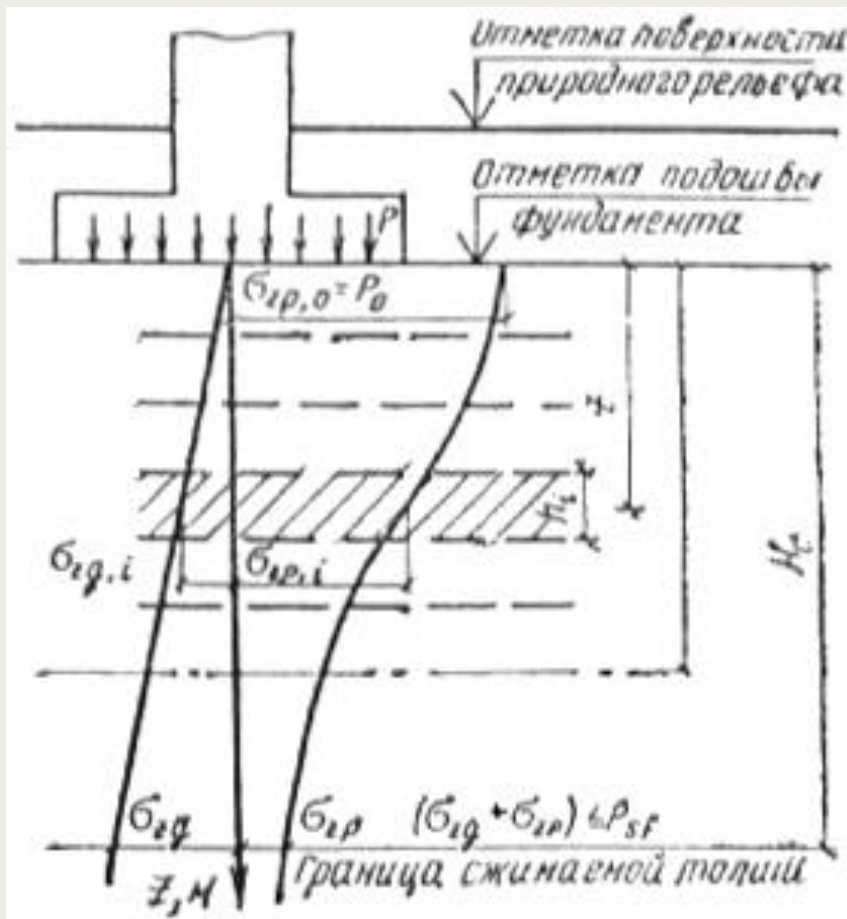


Fig. 6 Scheme of the development of the suffusion process in the depth of the array due to the leaching of particles from the overlying dispersed soil into the cracks of the underlying rock/soil stratum

DETERMINATION OF SUFFUSION SETTLEMENT



The value of the initial pressure of suffusion compression

P_{sf} corresponds to the pressure, at which $\epsilon_{sf} = 0,01$

If at the estimated time $H_i < H_c$

H_i - the length of the zone within which gypsum leaching is possible (leaching zone), the calculation of suffusion settlement should be carried out only within the leaching zone.

If $H_i > H_c$

settlement calculation must be performed within the compressible stratum.

The suffusion settlement of the base composed of saline soils is determined by the formula

$$s_{sf} = \sum_{i=1}^n \varepsilon_{sf,i} h_i,$$

$\varepsilon_{sf,i}$ - relative suffusion compression of the i-th layer soil at pressure p, which is equal to the total vertical stress at a given depth from the external load σ_{zp} and the soil's own weight σ_{zg}

n - the number of layers into which the zone of suffusion settlement of saline soils is divided.

h_i - the thickness of the ith layer of saline soil;

Measures to eliminate the harmful effects of suffusion deformation

Measures	Implementation of measures
Waterproof	Protection of saline soil from erosion; rational planning of the territory; arrangement of drainage ditches; protection of pits and trenches against moisture; use of high-quality pipes for laying water-carrying networks; backfilling of the space between the walls of the trenches and pits and the lateral surfaces of the foundations with compacted unsalted soil; arrangement of drainage
Constructive	The use of monolithic reinforced concrete foundations is compatible with protection against salt corrosion; arrangement of closed reinforced concrete belts; the use of rigid horizontal diaphragms made of prefabricated reinforced concrete floor panels
Partial or full cutting saline soil	Replacing the saline soil with a gravel-pebble mixture using bituminous materials; arrangement of a soil cushion made of unsalted clay soil
Cutting through saline soil	The use of pile foundations made of piles of reinforced construction, which cut through the saline soil, with coating of the side surface with rubber or paint coatings (before driving piles are drilled by leading wells); installation of bored, camouflaged, conical and other piles, as well as piles in drilled wells
Fastening or soil compaction	Arrangement of a soil cushion made of compacted unsalted soil or soil piles
Previous soil salinization by using hydration	Drilling wells from the bottom of a shallow pit on a 5x5 m or 7x7 m pile cap; repeated wetting of the saline soil through wetting the well followed by pumping out the water.

Precautions to avoid suffusion:

1. the cessation of movement of water by waterproofing the surface and drainage of surface runoff water;
2. reduction of groundwater movement speed to value of lower critical filtration rate by means of anti-filtration loops and screens;
3. backfilling of groundwater discharge sites on the surface of the earth (sand is most often used for this purpose);
4. artificial stabilisation of soils, weakened by suffusion using ground improvement techniques (impregnation with cement, lime, fly ash and clay solutions, bituminization, etc.).

Karst

Karst (also spelled *Carst*) is a combination of processes and phenomena associated with the activities of surface and underground waters, expressed in terms of erosion, dissolution of rocks, the formation of voids of various sizes and often negative forms of relief on ground surface. The word *karst* comes from the German word *Karst*, Sloven. *Kras* – the name of the limestone plateau of the north-west of the Balkan Peninsula on the border of Slovenia and Italy.

Karst processes will only develop with the presence a powerful stratum of water-soluble rocks and a low groundwater level. The main *lithological types* of rocks in which such processes develop are the following: 1) limestones; 2) dolomites; 3) marble; 4) chalk and chalky marls; 5) gypsum-anhydrite strata; 6) rock and potassium salts.



Fig. 7 Karst Plateau, Slovenia, giving the name to all karst processes

The surface of the earth in massifs prone to karst is characterized by various specific forms, the main of which are the following: small (deep from a few centimeters to 1-2 meters) furrows and depressions - karras; closed depressions (funnels and saucers), natural wells and mines, fields (valleys with an area of up to several dozen or even hundreds of km², with disappearing watercourses), "blind" ravines and valleys, niches in cliffs.



Karst regions

*Map shows major carbonate rock outcrops that encompass those global scale extents of karst regions

circle of blue

Design by Kathryn Heine for Circle of Blue
Source: Wilford, P.W. and C. Long, 'World Map of Carbonate Rock Outcrops' U.S.
University of Australia School of Environment, www.pw.wilford.com.au/australian/australian.htm
Wilford, P.W. and C. Long, 'Global Distribution of Carbonate Rocks',
www.pw.wilford.com.au/global/global.htm, vol. 142, pp. 1-2

Fig. 8 Map of the distribution of karst in carbonate rocks



Fig. 9. Carras on Karabi-yayla plateau, Crimea



Fig. 10 Cratered landscape in South Canterbury, New Zealand



Fig. 11 Seasonal Lake Slika Cerknisko Jezero, Slovenia



a)



b)

Fig. 12 Karst relief:
a – closed type of karst,
Moravian Karst reserve, Czech
Republic

b – open type of karst – highlands
of Karabi-Yail, Crimea

a)



b)

Fig. 13 Karst forms on the earth's surface:

a - Karras;

b - a stream flowing into a karst funnel;

c - karst terrain;

d - sinkholes with a diameter of up to 300 m;

e - karst lakes;

f - "stone forest".

c)



d)

e)



f)

NATURAL KARST CAVES

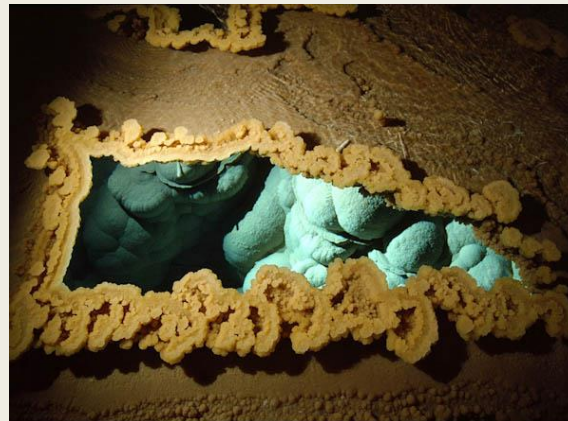
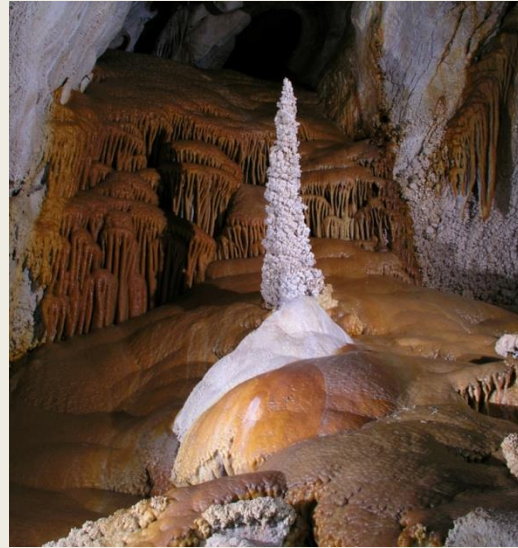
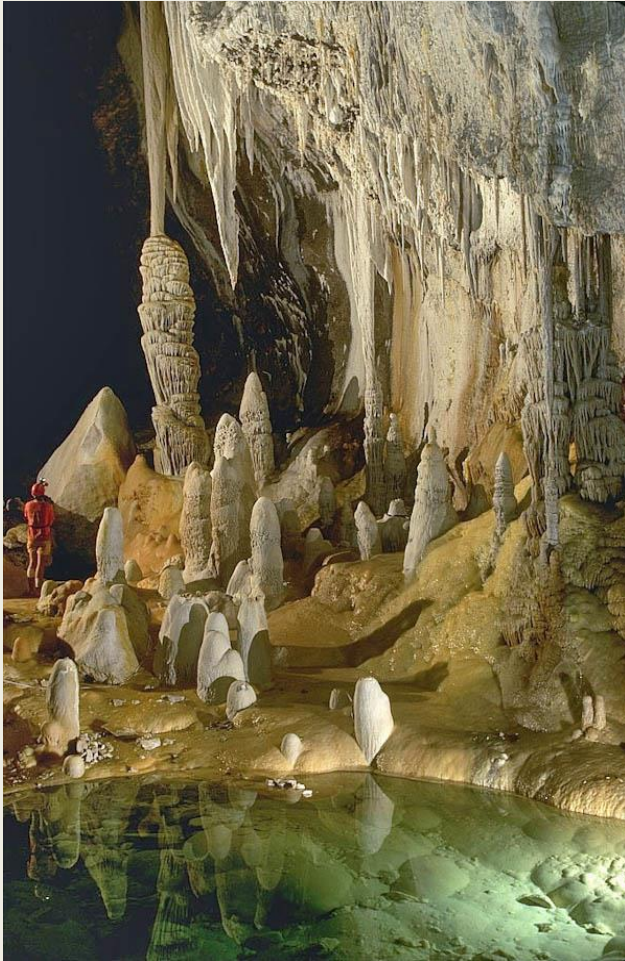


Fig. 14. a, b, c Various karst forms in the cave of Lechugia, USA

There are numerous amazing natural formations in karst caves: huge halls and sinkholes, giant stalactites, stalagmites and crystals, underground waterfalls, lakes and rivers, stone "mushrooms, flowers", etc.



Fig. 15 The cave of the mountain river, Vietnam – the largest in the world in terms of internal volumes:
a – the entrance to the cave;
b – giant stalagmites



Fig. 16. **a, b** Optimistic Cave, Ukraine – the longest gypsum cave on the Eurasian continent

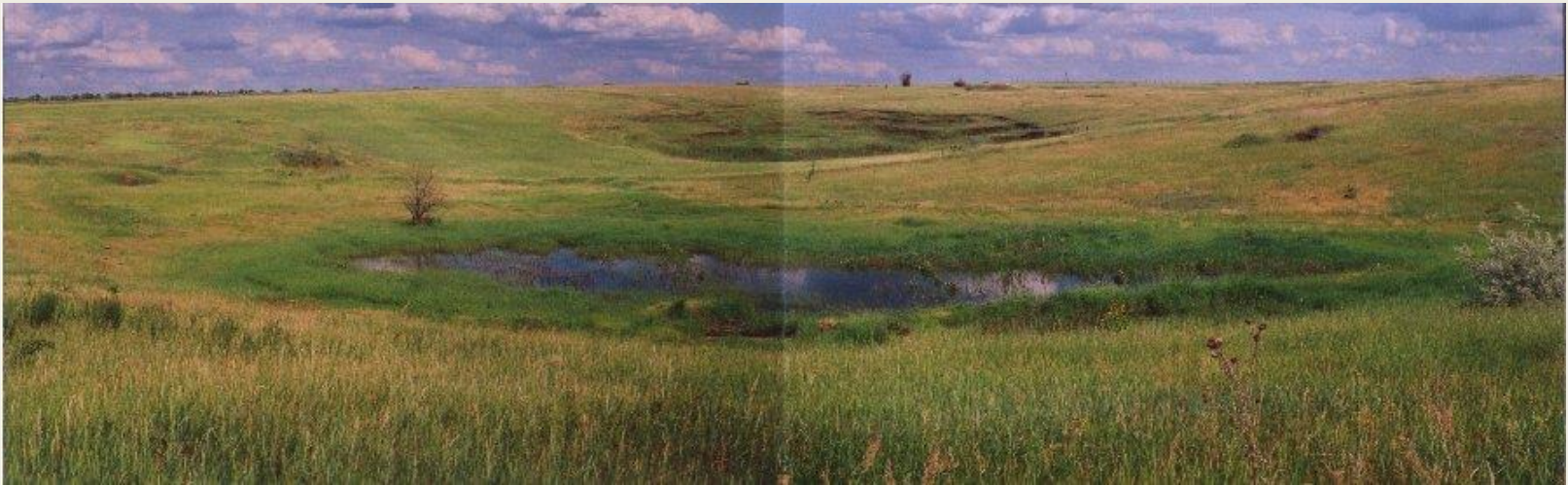


Fig.17 Earth surface subsidence on brine field New Carthage, Donetsk region

A typical example is the New Carthage brine field in the Donetsk region, where rock salt was mined from a depth of about 200 m by underground dissolution with pumping brine through boreholes. Twenty years after the start of operation of the site, gradual smooth subsidence of the earth's surface began and brine solution flowing from wells occasionally occurred.



Fig. 18. Technogenic karst dips in Solotvino village, Transcarpathia: **a** – funnel, which appeared on April 16, 2015; **b, c** – dips threatening buildings





Fig. 19. Karst sinkholes:
 a - failure under the tram track, Nizhny Novgorod Region; b - failure on the territory of summer cottages, Solikamsk; c - part of the hotel collapsed into a large sinkhole in Clermont, Florida, USA



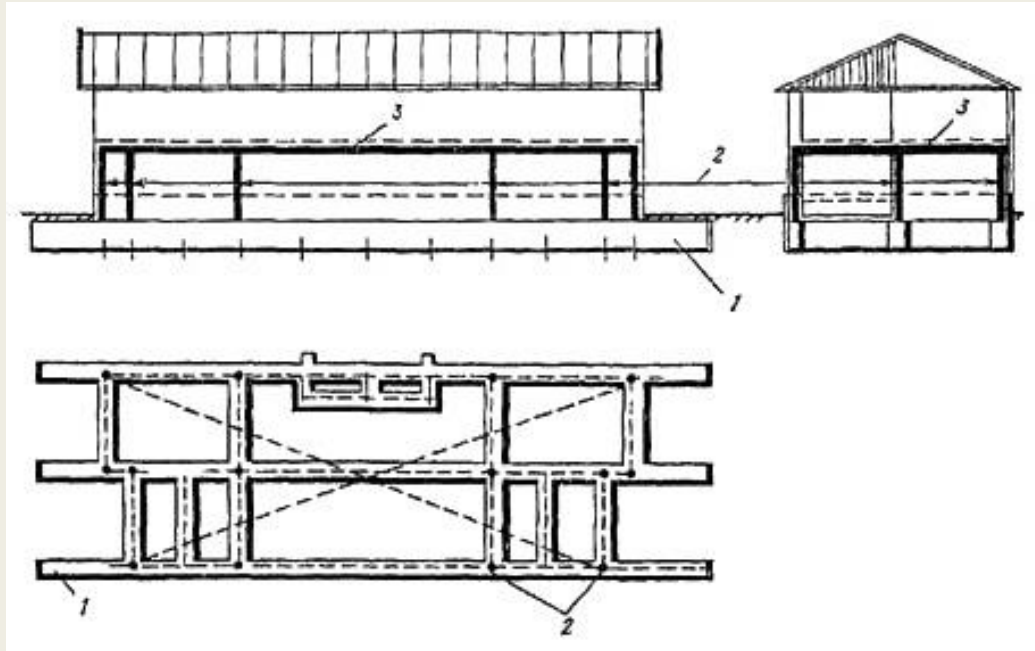


Fig. 20 Karst failure in Bukovyna. September 2021

CONSTRUCTION IN KARST CONDITIONS

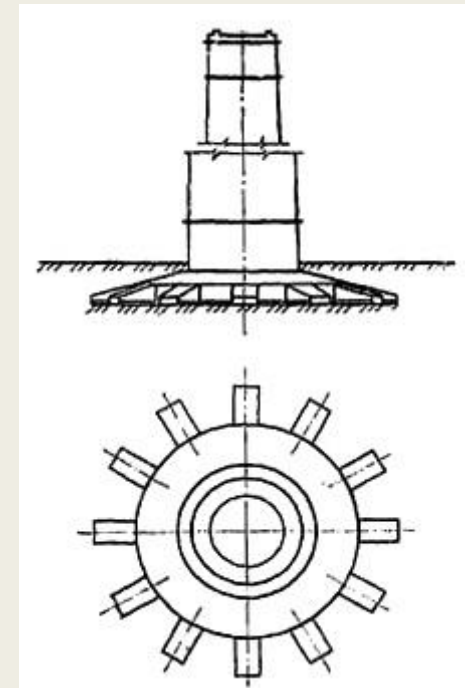
The main precautionary measures may be summarized as follows:

- assessment of the possibility of development in karst-hazardous territories in various environmental conditions;
- protection against storm and surface runoff, household and industrial water from infiltration into karst rocks;
- technical reclamation of rocks subject to karst-suffosion processes, including filling karst cavities with cement, silicate, bitumen filler, taking into account the effect on neighboring areas;
- modeling and design of buildings and structures with consideration of the appropriate foundations and ground structures;
- reliable maintenance of buildings and structures in the event of the formation of karst deformations at base level.



Anti-karst strengthening of a residential building

1 - strip foundation; 2 - reinforced racks; 3 - reinforced horizontal frame at the floor level of the first floor



Anti-karst chimney foundation with cantilever outlets