Design of foundations on karst-prone lands is based on use of two basic principles of anti-karst protection: adaptation of the structures of buildings to the formation of karst deformations (preventative and structural measures), and disallowance of their development in the bed (geotechnical measures).

The most acceptable with respect to the natural surroundings are structural measures that can be designed on the basis of analyses providing sufficient bearing capacity of the foundations for the reception of additional loads that develop during the formation of karst deformations within the bed. This, as a rule, is achieved by analysis of foundations (slab, pile-raft, strip, pile-strip, etc.) jointly with the superstructures when deformations of assigned parameters are formed.

Design parameters of karst-induced deformations are determined as a function of their type. Three alternate schemes are possible for their development based on the following types: collapse — a karst cavity develops in the soils, and ascends to the lower surface of the foundation, and the diameter of the collapse is adopted as a design parameter (the span of the foundation); settlement — the subsidence trough is adopted as a design parameter; and, local settlement — a karst cavity is developing in karsting soils (or in the cover stratum), but does not ascent to the lower surface of the foundation, and the diameter of the cavity for which its dome is stable is adopted as a design parameter.

Selection of an alternate schemes is determined by the soil conditions and structural characteristics of the building. The alternate scheme of highest risk is adopted. For shallow foundation of buildings, it is expedient to perform the analyses for the formation of a collapse beneath the lower surface of the foundation, i.e., when growth of a karst cavity in the soils will result in the formation of a dome in the form of a collapse. For buildings with an underground section, deformations based on a type of local settlement may be of highest risk, since the foundation is situated in the vicinity of karsting soils, and growth of a cavity in them even when the stability of the dome is maintained may give rise to significant additional forces in the bearing structures of the underground section. For the foundations of these buildings, analysis of the formation of a karst cavity of the design diameter is therefore most reliable.

Results of experimental and numerical investigations of the stress-strain state of the bed of a slab foundation over a karst cavity are analyzed. A new method is proposed for analysis of slab foundations of buildings with a developed underground section on karst-prone lands, which are distinguished from standard slabs by the fact that the maximum diameter of the karst cavity, for which the dome above the cavity is stable, is adopted as an analytical criterion.

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The foundations of buildings with development of an underground space are, as a rule, analyzed with respect to analogies of shallow embedment for the formation of a karst-induced collapse, the procedures employed for the determination of which are approximate in connection with the complex nature of the mechanisms responsible for karst formation, and are applicable only within the framework of permissible risks, and do not take into account characteristic features of the underground structures.

A new method of analyzing slab foundations, which can be recommended for buildings with a developed underground space, is distinguished from the standard method by the fact that not the diameter of the collapse under the foundation, but the maximum diameter of the karst-induced cavity for which the dome above it is stable, is adopted as a design criterion. The method has been developed on the basis of experimental and numerical investigations of the stress-strain state of the bed of a slab foundation over a karst cavity, and includes assumptions concerning determination of its design diameter, for which the dome is stable, and the coefficient of subgrade reaction of the bed of a foundation with an underground space developed above the cavity.

**Determination of design diameter of karst cavity.**

A procedure for modeling the growth of a karst cavity by numerical means was developed on the basis of analysis of published materials devoted to the mechanism of karst formation and results of experiments. It includes the following basic positions.

1. Mathematical modeling of step-by-step formation of a cavity and its growth with use of a finite-element model of the soil mass by excluding weakened zones (local losses of stability) around the cavity with continuous monitoring of the equilibrium conditions of the dome.
2. Use of a variable finite-element grid for partitioning into finite elements.
3. Use of contact elements (surfaces) (Fig. 1) in the roof of the cavity, which allows for both shear of the loaded domains of the soil with respect to one another, and also separation.
4. Use of M. M. Protodyakonov's formula to determine the size of the domain of the cover stratum in which the contact surfaces

\[ h = \frac{b}{2f} \]

should be introduced, where \( h \) is the height of the dome above the cavity, \( b \) is the assumed width of the cavity, \( f \) is the strength factor of the clayey soil \((f = \tan \phi + c/(\gamma H))\), \( \phi \) is the angle of internal friction of the clayey cover soil, \( c \) is the specific cohesion, \( \gamma \) is the specific weight, and \( H \) is the thickness (depth of embedment of the roof of the karsting soils).

5. Formation of the maximum diameter of the cavity for which equilibrium of the system is attained in the pre-limiting state of the soil in the cover stratum.

Figure 1 shows isofields of shear deformations of the soil as the width of the cavity in the karsting soils increases from \( b_1 \) to \( b_3 \).

The possibility of mathematical modeling of the karst process using the procedure developed was substantiated by comparing results of physical and numerical modeling.

The distribution of settlements throughout the depth above the center of the cavity as a function of its diameter was investigated in a physical experiment on equivalent materials. The experiment was repeated by the numerical method in the PLAXIS 2D software package [1]. A consolidating soil was employed as a model of the bed.

The numerical experiment is similar to the physical one. Results obtained on the mathematical model were compared with data derived from physical modeling.

It was established that for the numerical modeling, the distribution pattern of the settlements and their magnitude are essentially the same as for the physical modeling on equivalent materials. The results obtained therefore enable us to recommend this procedure for description of processes that occur in soils when a karst cavity is expanding.