INFLUENCE OF DEFORMATION AND STRENGTH PROPERTIES OF COVERING SOIL ON KARST ACTIVITY

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ABSTRACT

In this paper attempted to define general character of karst forms occurrence and its sizes depending on mechanical (deformation and strength) properties of covering soil based on mass statistical analysis of data. As basic technique to defining of relationships between spatial distribution of karst forms, its morphometry and parameters of deformation and strength of soils applied author's methodic.

The analysis completed on the example of 4 key areas, located on the territory of Permskiy kray. These areas are characterized with different conditions of evolution of carbonate and carbonate-sulfate karst. In the result were established lognormal spatial distribution of karst forms relatively to values of modulus of deformation and angel of internal friction. Karst forms have a normal spatial distribution relatively to values of cohesion of soil. Parameters of theoretical distribution laws are also defined.

Determined trend to rise of mean diameters, heights of fractured zones and cavities, allocated in soil massif, with the increasing of deformation modulus and angle of internal friction of covering soil. Backward trend fixed for cohesion of soils and morphometry of karst forms. When cohesion of soil is high, sizes of sinkholes on the ground surface have a tendency to decrease. Based on trend-analysis and with application of special developed technique has been obtained prognostic equations for calculation of average expected sizes of different karst forms from known values of parameters of deformation and strength of covering soil.

Keywords: karst, karst hazard, karst forms, deformation modulus, angle f internal friction, cohesion, intensity of sinkholes occurrence, mean diameter of sinkhole.

INTRODUCTION

Engineering-geological estimation of karst activity of any territory is aimed to coherent studying of development of surface and underground karst forms with considering of geological, hydrogeological, structural, tectonic, geomorphological and some other factors, which influence on occurrence of karst forms. Such estimates at the present time are based on applying different methods and techniques with using of special technologies, which allow investigate rock massif from the surface to the deep.

Today is known about decisive role of geological and hydrogeological conditions, based on structural-tectonical shape, in distribution of karst forms and its morphometric parameters. In general, karst activity is controlled by subsurface geological structure, properties of covering soils and degree of dissolution of karst rocks. Herewith the first factor (subsurface geological structure), in our opinion, is most defining. Especially, when it comes about prognosis of soil collapse in karst areas.

Mutual research of covering soil and its influence on development of karst phenomena and related with them karst forms devoted a sufficient number of works both in Russian and world karst literature. Most of works are aimed to the problems of typization of geological structure [1, 2], influence of thickness of covering soil and interlayers on the activity of karst [3, 4]. Hence, the question of impact of covering soil properties on the evolution of karst still remains without proper attention. Relatively developed in this respect only geomechanical models and design schemes, with which it's possible calculate linear dimensions of karst deformations (diameters of sinkholes, a limit radius of cavities) [5]. In such schemes, as usual, among all of included in calculations parameters are widely used characteristics, which determine strength properties (cohesion, angle of internal friction and some their derivatives) and density of soils. Much less are used parameters of porosity and filtration characteristics of soil layers.

Thus, it can be concluded, that in the considered task still outside the scope of interest are the next directions of research:

– impact of wide specter of physical (moisture, organic content, degree of salinity, grain size distribution etc.) properties and deformation characteristics of subsurface soil cover on the sizes of cavities and sinkholes;

– ability to prognosis of activity and intensity of karst development depending on properties of covering soil;

In this paper attempted to define general character of karst forms occurrence and its sizes depending on mechanical (deformation and strength) properties of covering soil based on mass statistical analysis of data.

PILOT TERRITORIES AND TECHNIQUE OF ANALYSIS

Studying of dependencies of karst development from mechanical properties of soils with using of probabilistic and statistical analysis has been completed on the example of four pilot areas, localized on the territory of Permskiy kray (Russia). This is city of Kungur, Polazna urban village, Oktyabrsky settlement and intensively karstified site of the pipeline route in the Ordinsky administrative region. For many years investigations and works on the collection and analysis of engineering-geological information [6] has been developed the database, which is include data about spatial distribution of karst forms, geological and hydrogeological conditions (borehole data) of above mentioned areas. Data about properties of karst rocks, covering soil and ground water chemistry has also been collected.

It should be said that an attempt to determine of such relationships has been undertaken by us earlier on the example of one from the mentioned above areas – it's a territory of city of Kungur [7]. This investigation has shown that for more suitable and specific dependencies a large specter of data from several sites, localized in various conditions of karst evolution, should be involved in analysis.

Technique of statistical analysis for determine the relations between development of karst forms, their sizes and various factors of natural conditions of karst evolution has been in detail considered in works [8, 9].

In this paper will focus only on list of fundamental features of developed technique, among which it should be noted next:

- analysis of variations of factors values in spatial through construction of digital cartographic models;
- cartographic comparison of constructed digital models of factors of natural conditions and karst forms, represented as a point-layer;
- possibility of joint analyse of different karst forms (sinkholes on the ground surface, cavities and fractured zones in the soil massif) as an single group (entire assembly);
- possibility of defining of average sizes (diameters of sinkholes, heights of cavities and fractured zones) of newly formed karst forms with using of trend analysis, which is based on statistical considering of values of factors of natural conditions and sizes of already existing karst forms.

One of the key moments of the proposed method is a joint study of variability of the sizes of different karst forms with preliminary normalization (bringing to a common denominator) as a result of calculation of special value, which called *index of morphometry I* [8, 9]. That index is defined as a ratio of particular value of study characteristic to its maximum value, peculiar to concrete region. Analogous index is also used in analysis of numerical values of factors of natural conditions of karst development.

As a studied mechanical properties of soils, in statistical analysis have been involved *deformation modulus E*, *angle of internal friction* φ and *coherence c*. Detailed explanation of the reasons of choosing these characteristics is given in works [10].

In analysis used data of laboratory investigations of soil samples, taken in past years from bore pits and boreholes, localized within the studying areas. As the primary method of establishing the mechanical characteristics of soils served the data of compression test and direct shear test [11]. The closest analogues of these tests in International normative documents are ASTM D 3080-98 & D2166/D2166M-13 [12, 13]. True values of deformation modulus from compression results were established with using coefficient m_k that recommended by SP 22.13330.2011 [14]. It's a widely used way in the Russian geological and construction practice in determination real modulus of deformation. In the result of systematization of all soil samples into unified database, formed for the pilot territories, noted about 1500 samples with a fully or partly defined physical-mechanical properties. These soil samples were taken from about 400-500 boreholes.

Taking into account undeveloped and irregular network of soil sampling within the studying territories, in this research besides direct data of laboratory shear test and compression test also used indirect data for mechanical characteristics obtained from laboratory analysis of physical properties and classification of soils according to statistical tables from application B of SP 22.13330.2011 [14]. Values of mechanical properties from tables [14] were determined for each soil sample with full set of physical characteristics. Total amount of such samples is about 3300. Samples were taken from about 1000 boreholes.

Accuracy of evaluation mechanical characteristics of soils with using statistical tables from SP 22.13330.2011 [14] estimated by direct comparison of its values with results of laboratory tests in two ways. First way is in estimation of linear correlation between these values for each sample. Second way is oriented on definition of such correlation between data of laboratory tests and values of mechanical characteristics from the tables in the scope of boreholes in the result of averaging procedure. Results of correlation analysis are shown in table 1. As we can see, between values of mechanical properties, determined in different ways, observed very stable direct correlation. After removing from general dataset the most deviated pairs of test values, the correlation becoming very closely with correlation coefficient exceed 0.7. Such close correlation allows using in karstological research the data from tables [14] for considered mechanical soil properties on a par with the data of laboratory tests.

Table 1. Relations between laboratory tests and data from the tables [14] for considered mechanical properties of disperse covering soils within investigated areas

Mechanical characteristics	Quantity of pairs of values: entire assembly	Quantity of pairs of values: selection	Quantity of pairs of values in selection, %	Correlation coefficient
A. Correlation of values of characteristics for each soil samples				
Deformation modulus *E*	1401	1284	91,6	0,71
Angle of internal friction *φ*	1459	1141	78,2	0,71
Coherence *c*	1430	1219	85,2	0,72
B. Correlation of average values of characteristics in boreholes				
Deformation modulus *E*	396	352	88,9	0,72
Angle of internal friction *φ*	511	405	79,3	0,72
Coherence *c*	510	441	86,5	0,72

RESULTS

In the result of collation of digital maps of considered mechanical characteristics of soils and karst forms within the study areas, was found that normal distribution of karst forms is inherent for all analyzed properties. One of the features of these distributions is the almost full coincidence (in 70% of cases) of distribution curves of different karst forms (Fig. 1). This notice fully repeat the conclusions made earlier in analyze of physical characteristics of covering soil on the territory city of Kungur [8]. Most of the karst forms are toward to mean values of deformation modulus and coherence with minor asymmetry aside greater values. In the case of angle of internal friction asymmetry aside greater values a few bigger. As a whole, accuracy of expression of observed distributions with using normal law sufficiently high. However, it's should be noted that zero and close to zero values of such parameters as deformation modulus and angle of internal friction are not typical for natural soils according to its essence. Final generalized distributions of karst forms for these parameters has been characterized by lognormal laws, which for concrete investigated areas in whole are close to normal distributions.

Established parameters of distributions, shown in table 2, allows to making probabilistic prognosis of karst hazard with using mechanical properties of covering soil.

On Fig. 2 quite clear traced the tendency to rise of mean values of morphometric parameters of karst forms with rising of deformation modulus and angle of internal friction of covering soils. Most demonstrably this tendency appears in analysis of fractured zones. For such zones is typical abrupt rise of thickness when these strength

and deformation parameters has a big values. The inverse type of mentioned above in the text tendency has the angle of internal friction and only in the studying area within Polazna urban village and nearby territories.

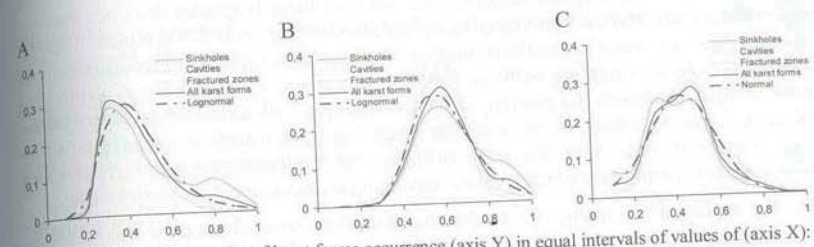

Figure 1. Relative frequencies of karst forms occurrence (axis Y) in equal intervals of values of (axis X): A – deformation modulus; B – angle of internal friction; C – coherence

Also should to note that in case of the surface karst forms (sinkholes) the tendency to rise of the mean diameters with rising of deformation modulus and angle of internal friction in simultaneous data analyzing of the all study areas has not been validated. Apparently, it is due to specificity of technique of analysis, and also with differences in mechanisms of sinkholes formation (classic karst collapse, subsidence of soil, suffosion effect etc.), which is often hard to define in field investigations [4].

Influence of coherence on morphometric parameters of different karst forms, conversely, has inverse type (Fig. 2). Most clear tendency to decrease of mean diameters of sinkholes and heights of underground karst forms with rising of coherence of covering soil observed for site of the pipeline route in the Ordinsky administrative region and Oktyabrsky urban settlement. Unfortunately, any dependencies between these parameters in data analysis within territory of city of Kungur and Polazna urban settlement have not been defined. Generalized curve of variability of morphometric parameters of karst forms in these regions has almost horizontal orientation with no visible trend.

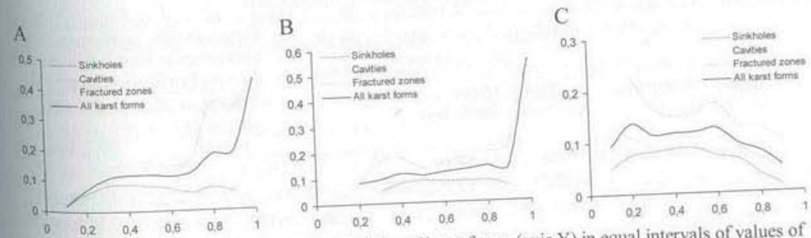

Figure 2. Normalized mean diameters and heights of karst forms (axis Y) in equal intervals of values of (axis X): A – deformation modulus; B – angle of internal friction; C – coherence

Separately, need to pay attention to one feature of characters of all generalized graphics that shows relations between morphometric parameters and mechanical properties of covering soils. It is an existence of zone of the "implicit trend" within mean values of considered soil properties. Such zone can be explained by primordial error in the procedure of analysis. Often estimation of mechanical properties of covering soils has been implemented on the relatively superficial boreholes (before 4-8 m) with sufficiently rare and irregular sampling net. Most of these boreholes does not uncover top of karst rocks and the quantity of sampling are rarely exceeds 2-3 samples. Analysis in such direction was a compulsory measure in the absence of lack of information and regular distributed sampling network for all covering soil as by area so by depth. But even in such conditions the positive result has been reached. Fundamental distributions of karst forms by values of the studying mechanical parameters of disperse covering soils were obtained. Also has been revealed the tendency of variability of mean morphometric parameters of karst forms depending on mechanical properties of soil.

During statistical processing of two-dimensional point cloud, formed by pair of values of mechanical properties and morphometric parameters of karst forms, presented in index (normalized) form, considering of obtained trends and with using of author technique [9, 15], has been calculated prognostic equations, which also represented as graphs (table 2). These equations are also represented as graphs on Fig 3.

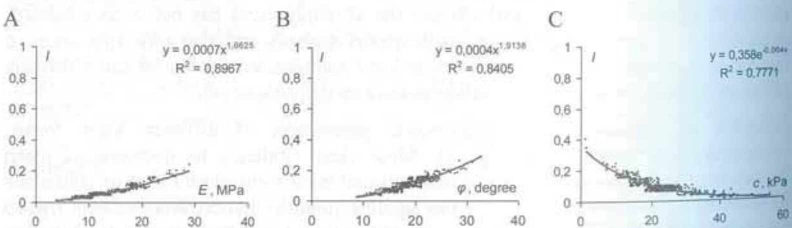

Figure 2. Prognostic curves and equations for estimating morphometric parameters of karst forms using mechanical properties of covering soil: A – deformation modulus; B – angle of internal friction; C – coherence

Table 2. Parameters of distributions and dependencies to prognosis the probability of karst forms occurrence with using deformation and strength properties of covering soil

Mechanical properties of covering soil		Prognosis the probability of karst forms occurrence			Prognosis the morphometric parameters of karst forms in normalized (index) form		
		Parameters of theoretical distribution law		Law of distribution	Coefficients of prognostic equation		Dependence
		mean value x_m	std deviation σ		a	b	
Deformation modulus, MPa	E	2.70	0.37	lognormal	0.0007	1.6625	power
Angle of internal friction, °	φ	3.03	0.26	lognormal	0.0004	1.9138	power
Coherence, kPa	c	22.23	8.76	normal	0.3580	-0.0640	exponent

Transition from index estimations of morphometric parameters of karst forms to real values is implemented as the result of multiplication of index I on the maximum values of morphometry of karst forms, determined within the investigated region (table 3).

Table 3. Maximum values of morphometric parameters of karst forms, localized within the studied areas

Morphometric parameters of karst forms, m		Max
Mean diameter of sinkholes	d	100,0
Height of underground cavities	h_p	18,0
Thickness of fractured zones	h_z	31,5

CONCLUSION

The resulting distributions and prognostic equations can be helpful in estimation of probability and intensity of sinkholes occurrence oт the ground surface and also in calculation their mean expected diameters. These parameters are basic in zoning process of the territory by degree of karst hazard.

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LABORATORY TESTING OF THE PRECISION AND ACCURACY OF THE SHAPEACCELARRAY SENSOR IN HORIZONTAL INSTALLATION

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ABSTRACT

Sensor SAA (ShapeAccelArray) is to certain extent unique device enabling not only the automation of classical inclinometer measurements, but other utilization such as convergence measurements or registering of vibrations. SAA sensor is in basic principle an array of rigid segments and flexible joints. Joints allow movement in any direction except twist and allow the sensor to capture spatial variations of its neighborhood. Rigid segments are equipped with triaxial MEMS (Micro Electro-Mechanical System) accelerometers. These sensors enable high-frequency measurement of segments tilt relative to the direction of gravity. Full range of measurement of MEMS accelerometers allows installation in any position - vertically, horizontally or in combination of both. For inclusion of this sensor to the context of other methods for measuring shifts and deformations should be noted that there are many other geodetic and geotechnical methods used for the deformation size and direction determination. There can be mentioned as an examples 3D (laser) scanning (in [12] or in [13]), classic geodetic methods (in [14]) or GNSS methods (in [15]). Current publications describe functions the SAA sensor, examples of its practical application and comparison with other geotechnical methods. Sensor accuracy in terms of engineering surveying point of view has been solved minimally so far. This paper describes laboratory test of SAA sensor in a horizontal installation. The aim was to determine the accuracy characteristics of the measurement of vertical deformations without affect of the protective PVC casing, where the sensor is installed in field by default. Vertical deformations of the array were performed using special heaver, which allows to realize displacements with high accuracy using rotation of screws. We hope, that this contribution will bring useful information for potential users of this equipment.

Keywords: ShapeAccelArray sensor, test, precision, accuracy, horizontal installation.

INTRODUCTION

At present, it is possible to perform a considerable part of geotechnical measurements automatically using simple sensors. In some cases, it is very difficult on the contrary. Inclinometer measurements in equipped wells are case in point. It is already 50 years