Environ Geol (2007) 51: 787–790
DOI 10.1007/s00254-006-0396-9

ORIGINAL ARTICLE

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Issues of environmental impacts of karst in standards on construction in Russia

Received: 9 October 2005
Accepted: 23 May 2006
Published online: 8 July 2006

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Abstract There are three important ecological aspects to be considered regarding economic development in covered karst terrain: (1) natural karst processes, and karst-suffosion processes in particular, are very responsive to technogenic effects, (2) possibility of intensive and deep pollution of the geological environment and (3) risk of ecological disasters caused by karst collapses on the sites of ecologically dangerous industrial and transport objects. In view of these aspects, a number of Russian standards and normative documents on construction are analysed. Some methodological approaches to practicalapplication of the guidelines stated in the documents are offered.

Keywords Karst · Sinkhole · Environment · Regulation · Russia

Introduction

Carbonate, sulphate and sulphate-carbonate karst types in Russia can be seen on extensive territories. The predominant type is covered karst with overlying water-saturated clay or sand. In case of sand, so-called karst suffosion develops. The major part of covered karst territories is characterized by karstified rock at depths of 20–70 m. Karst and karst-suffosion processes usually manifest on the ground surface in the form of sinkholes or subsidences. At least three aspects of this kind can be specified:

1. Karst processes and karst-suffosion processes in particular are highly responsive to various technogenic impacts on the geological environment.
2. Pollution of the geological environment in karst terrain is characterized by greater intensiveness than in other areas, other things being equal.
3. Industries and constructions which are potentially dangerous for the environment, such as chemical and nuclear plants, oil pipelines, etc., and when located in karstified terrain create a higher risk of ecological disasters caused by accidental collapses in the foundations of constructions.

Consideration of these aspects for the purposes of practical activity to reduce their possible harmful effect creates the need to communicate knowledge of karstology to administrative officials, engineers, economists, lawyers, etc. This communication can be fulfilled by continuous public awareness and educational activities for the involved specialists, which seems rather problematic to accomplish. The geo-ecological aspects mentioned above are rather peculiar, as in many cases they are characterized by a postponed effect, and it may take the effect years or even decades to manifest. Very often this period of time is much longer than the term of office of the executives responsible for the previous decisions. The human aspect is one of the reasons why the local municipal and industrial authorities tend to neglect necessary protection arrangements and do not perform them "on a voluntary basis".

In Russia the system of legal regulation is rather complicated. There are Federal laws (FZ), Constructional norms and rules (SNiP), Codes of regulations (SP), Regional constructional norms (TSN), Departmental instructions, and also Recommendations on certain specific issues of designing. To some extent the system facilitates systematizing of exploration work, designing and maintenance of construction and making use of the most significant results of scientific research through introducing changes into practical activities. Nevertheless, these standards and normative documents very often have uncertainties, inconsistencies and other drawbacks which allow interpreting the same points in different ways. However, in the latest Russian normative documents on construction, environmental protection problems have received much more attention than before. Some of these documents with the reference to the problems of environmental protection at economic development of karstified territories are considered here.

Karst risk

Federal Law No. 184 “On technological regulation” stipulates that any production (including constructions and structures) should meet the requirement of absence of unallowable risk. The risk is understood as a probability of endangering life or health of people, a risk of damage to property and the environment with account for the severity of the potential harm or damage caused. The requirement of assessment of risk related to engineering and geological conditions is also included in SNiP 11-02-96 “Engineering survey for construction. Basic principles”, SP 11-105-97 p. II “Engineering and geological investigation of construction sites”, “Guidelines on engineering, geological and geo-ecological research in Moscow”.

In particular, if there is a probability for sinkhole development, the value P_r of the risk of damage to any part of a construction could be determined with the help of an equation known from previous publications (Tolmachev et al. 1986):

$$P_r = f(\lambda, A, t, d, d_{\max}, r, P_1). \qquad (1)$$

In the equation above,

- λ is a predicted frequency of sinkhole development on a unit area of the territory under consideration;
- A total area of the construction;
- t estimated period of time;
- d, $d_{\max}$ predicted average and mean diameters of sinkholes; and
- P_1 a probabilistic parameter of the system “karst-construction”.

The enterprise “Antikarst and Shore Protection” (Dzerzhinsk, Russia) has widely used the methodology of karst risk assessment in cases of sinkhole development hazard and development of engineering parameters for karst control depending on the risk levels. This usage has become everyday practice and does not present significant difficulties. Still, some particular tasks indicate the need for further improvement of the methods developed so far.

The term “allowable risk” can be understood differently and is a specific challenge. The allowable risk level can be determined by a number of factors, including general economic and social national priorities and strategy. However, with the karstified territories in focus, the allowable risk should be assessed depending on probable damage due to karst collapses. As a first “shot” in this direction, the author Tolmachev (2004) proposed to distinguish between three degrees of economic damage: (a) extreme; (b) significant and (c) insignificant.

Social and ecological damage was also subdivided into three groups: (1) probability of numerous losses of life and/or significant damage to the environment; (2) probability of loss of life and/or local damage to the environment; (3) improbability of loss of life and/or damage to the environment.

For every nine possible combinations of damage types, allowable risk levels R were specified (unit area per unit time). From the engineering perspective, the most suitable unit area is 1 ha, and the most suitable unit time is 100 years, which is commensurable with the service life of economic objects. R values within the classification developed vary from 0.0001 (combination 1a) to 0.1 (combination 3c). The author of the classification does not consider the offered classification of karst induced damage or specified values of allowable risks to be final or perfect and would welcome every opportunity of discussion with the specialists in theory of constructions and environmental protection to improve the current results. In other words, the author looks forward to the next “shots”.

To perform “the risk monitoring” through karst control activities of major and maintenance character, a parameter of “karst risk level” is needed, which can be expressed by the formula:

$$LR = \frac{P_r}{R}. \qquad (2)$$

In numerous practical situations it might be necessary to classify karstified terrain with various existing economic objects and constructions according to the value of LR. For example, the rationale for the karst control activities on the site of a newly built chemical plant in Dzerzhinsk was based on identification of five zones with varying LR values: $LR < 1$; 1–2; 2–5; 5–10; > 10.

Technogenic impacts

The requirement of consideration of technogenic impacts on karst and karst suffosion processes is specified in SNiP “Engineering survey for construction, basic principles” SP 11-105-97; p. II, “Engineering geological site investigations for construction''; as well as TSN 22-308-98 NN, ''Engineering research, design, construction and maintenance of buildings and construction in karstified terrain of Nizhny Novgorod region''. Impact of technogenic changes on each of these processes can be different. That is why it might be reasonable to differentiate between varieties according to direct influence on karst and karst suffosive processes. Thus, for karst terrain in the Dzerzhinsk district, which is predominantly covered karst with pronounced suffosion, the following classification of direct technogenic impacts on karst has been adopted:

(A) Increased rate of karstified rock dissolubility.
(B) Increased rate of subsurface erosion and, in the first place, removal of interior medium out of karst cavities.
(C) Destruction of the roofs of karst cavities.
(D) Intensification of suffosion processes.
(E) Phenomenon of liquation of water-saturated rock.

Technogenic effects can be classified with the different criteria in focus:

1. According to the nature of the impact (transfer of static and dynamic loads, change of hydrogeological situation).
2. According to the type of area involved (within the territory of city, town, residential area or a separate building/construction).
3. According to the period of exposure (continuous, prolonged or eventual).

The degree of predicted potential relative technogenic impact could be assessed by a rating scale with five levels according to the number of identified groups in the classification of direct impacts (A, B, C, D, E). The assessment criteria are the speed of response of karst and karst suffosion processes in a hazardous situation (W) with the following corresponding scores:

$W_A = 1$; $W_B = 2$; $W_C = 5_{[NHG1]}$; $W_D = 3$; $W_E = 4$.

The level of sensitivity S of separate locations within the territory to certain technogenic effects is determined by the engineering and geological situation on these sites. Index S varies in the range of 0–1; $S = 0$ means the territory is not responsive to the technogenic effect; $S = 1$ means that the environment demonstrates no resistance to technogenic effects. Specific values of S could also be determined by experts on the basis of their knowledge of karst nature on the given site under the influence of various technogenic effects. The score of the particular technogenic effect i on karst-suffosion process can be estimated by the formula:

$$B_i = \sum W_j S_i. \tag{3}$$

Here the resulting value depends on the number of considered direct technogenic impacts varying from $j = 1$ to k. For the practical example under consideration, $k \leq 5$. Total realistic impact of all technogenic factors $i = 1, \ldots, n$ on intensity of karst processes on a particular site can be determined in the following way:

$$T = \sum B_i. \tag{4}$$

Regularities of combination of different indications allow evaluation of the rate of influence of existing and predicted technogenic effects on intensification of karst processes. If needed, zoning of the territory under consideration could be performed according to the dependence between technogenic factors and karst risk (such as high, moderate, low, negligible). This will provide a basis for further correction of karst risk predictions and, therefore, will lead to better decisions at the administrative and engineering levels.

Waste disposal

SNiP 2.01.28-85 ''Sites for neutralization and burrying of industrial wastes'' states the norms related to selection of locations for waste disposal and reads: ''waste disposal is prohibited in active karst areas''. However, for everyday practice of waste disposal arrangement this requirement is not explicit enough and often leads to inconsistencies. The main difficulty lies in interpretation of the term ''active karst'' which is not specified and cannot be found in any other national standards on engineering and geologic research or engineering control of the territories exposed to dangerous impacts. The result of the inconsistency of the normative document cited was quite the reverse, because the level of karst activity started to be assessed by people having no expertise in karstology. To solve the problem and change the situation, the notion of ''active karst'' was introduced into the Regional Standard TSN 22-308-98 NN ''Engineering research, design, construction and maintenance of buildings and construction in karstified terrain of Nizhny Novgorod region''. In relation to the waste disposal problems, the term ''active karst'' was defined as including sites with the following indications:

- Sinkhole development intensity index over 0.05 sinkholes on 1 km^2 per year;
- Predicted subsidence rate of over 10 mm per year;
- Multiple sinkholes;
- Karst cavities located by research.

The above indications of karst activity were taken into account in a practical case concerning selection of locations for waste disposal in Dzerzhinsk district. Several separate zones were identified: (1) prohibited for waste disposal; (2) allowed for waste disposal with neutralization to be arranged; (3) allowed for waste disposal without the need for any karst control activities.

It should be mentioned that local authorities, especially in rural districts, generally agree to follow all the above recommendations very unwillingly. Moreover, most officials sincerely believe karst sinkholes to be the best place for waste disposal. And this situation is typical for many countries (Milanović 2003). A good illustration of the problem is a poster which was printed on the book cover of the Proceedings of the fourth multidisciplinary conference on sinkholes and the engineering and environmental impacts of karst (Beck 1993).

A proposal was put forward to connect the criteria for selection of locations for waste disposal on the territories under the risk of karst sinkhole development with the predicted level of contamination V_p penetrating into the rock layer on a unit territory per a specified period of time:

$$V_p = VP_r. \qquad (5)$$

In the equation above, V is an average volume of a karst sinkhole, P_r the probability of karst sinkhole development on a unit territory of 1 ha per a specified period of time (Tolmachev and Mamonova 2005). It allows classification of the karstified terrain according to potential contamination of the geological environment and identification of several categories, e.g. (1) $V_p < 10$ m^3; (2) $V_p = 10$–100 m^3; (3) $V_p = 100$–500 m^3; (4) $V_p = 500$–$1{,}000$ m^3; (5) $V_p > 1{,}000$ m^3.

Conclusion

Standards and normative documentation which regulate economic activities in karstified terrain present the most powerful instrument for improving protection of the environment. However, documentation of this kind needs to be harmonised both at the national and global levels. Russian experience shows that the best result could be expected through application of regionally adopted standards and norms as well as ones for specific spheres, such as railways, pipelines, waste disposal locations, etc. Regional regulations and guidelines can help successfully overcome inconsistencies and uncertainties of the federal standards. This is especially important for countries such as Russia with great variety in climatic zones and economic activities. The challenge is to keep the documentation in line with federal norms in terminology, notions and legal aspects.

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