Studia Geotechnica et Mechanica, Vol. XXXI, No. 1, 2009

TECHNICAL NOTE

GEOLOGICAL AND GEOMECHANICAL ESTIMATION OF KARST DANGER FOR CITY AREA

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Karst is a very contradictory geological phenomenon. There are many beautiful karst origin cavities considered as monuments of the geological history of Earth, on the one hand, and there are numerous catastrophic situations connected with its occurrence, on the other. Two things are necessary for it to develop. These are water and dissolving rocks: salt, gypsum, limestone and dolomite. Such rocks in the upper part of the geological section occupy approximately 20% of the western Urals area.

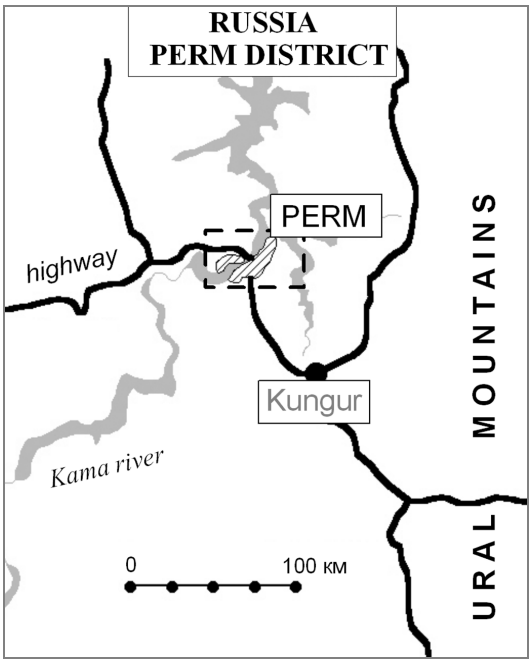

Fig. 1. Location map

It is known that karst is usually responsible for unexpected fast subsiding of the Earth's surface. And it is obviously the karst processes that are most dangerous in the

case where a city and karst phenomenon area coincide. Such a situation takes place in one of the oldest towns in the western Urals – Kungur (figure 1). It was founded in the 17th century. There are many beautiful historical monuments. The famous Ice Cave is located there, too. Besides, Kungur is a big industrial center and many-storeyed houses and buildings are situated there. The artificial influence on the earth is constantly increasing. Only last year, thirteen collapses were registered. So, detection of any karst form at some earlier stage of its development and estimation of possible deformation of the earth's surface connected with it is a very important task.

A geological section of the near surface interval connected with stability of buildings and houses consist of (from the top downwards): loam, gravel, clay with gypsum and limestone pieces, gypsum, dolomite. The depths of the roofs for these layers are: gravel – 7–12 m, clay with gypsum and limestone pieces – 12–24 m, gypsum – 19–30 m, dolomite – 30–60 m. Most of the karst phenomena coincide with areas where gypsum thickness is more than 8 m. Karst collapses happen more often in such places where gypsum roof is closer to the earth's surface.

Complex geological and geophysical research into potential karst origin hazards to houses and buildings in Kungur city was launched last year. The main body of observations was connected with the central part of the city, where many-storeyed houses and buildings are situated. The research included: 1) field CDP seismic reflection survey in areas with visible deformations of buildings and houses; 2) processing and interpretation of the obtained data, construction profile and area's geological models; 3) drilling for checking each kind of interpretation models, 4) geomechanical calculations of possible deformations of the earth's surface for each kind of interpretation models.

These models (figure 2a–c) reflect different stages of the karst form development. First of all, it is a "hole" (a). This kind of the "seismic photo" reflects empty karst cavity. This form is connected with the beginning of the karst process. Next stage in the geological images is shown in (b). In this case, the cavity had been filled in half or some more of its volume by products of gypsum disintegration, but it has a roof made up of unbroken layers of gypsum or limestone. The third stage of karst development is presented in (c). It reflects the final result of the karst process development, including the filling of the cavity by products of gypsum disintegration and upper-lying rocks.

Geomechanical estimation of karst hazard included calculation of its influence on buildings and houses. A comparison among the calculated horizontal deformations of the earth's surface for concrete karst form and maximum limited deformations under concrete building type was made for this aim. Maximum limited deformations under buildings and houses are defined by project documents for each concrete type, which is connected with floor number, form, material and other properties of a building and house.

Unfortunately, there is no engineering methodic for prediction of the karst origin earth's surface deformation. This is due to the difficulties in the mapping and modeling of subsurface karst forms as regards such kind of geological phenomena.

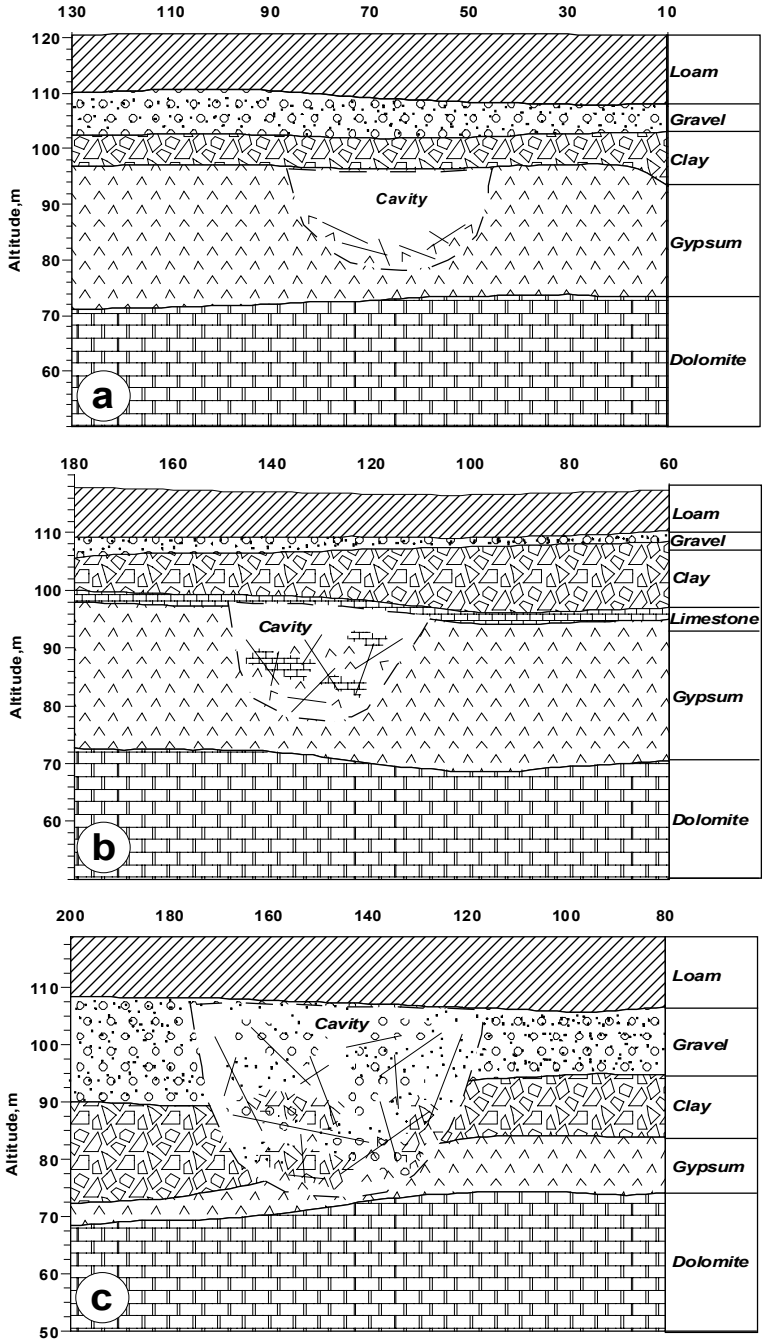

Fig. 2. Seismic interpretation models reflecting
(a) beginning of the karst form, (b) its development, and (c) completion

Mathematical modeling has been used for estimation of deformations. Generation of a 3D calculation scheme was based on accumulation of a variety of information by GIS instruments. Geodatabase included such dataset layers as: geological structure and mechanical properties of the essential beds for the upper part of section, places of the different subsurface karst forms (figure 2), information about buildings and houses, relief and hydrography, lines of communications. A space model of the near surface rock massif for the city area was obtained with this database and used for parametric ensuring of geomechanical calculated scheme forming.

Boundary conditions were defined taking into account the beginning of lithostatic stress-strain state of the massif. Horizontal displacements for the side surface and vertical displacements for the down surface were accepted as equal zero. The upper (earth's) surface was under influence of the weigh of concrete buildings and houses. The calculation area was in conditions of mass loads influence with intensity γ_i (γ_i – density of the geological section elements).

Prediction of the earth's surface deformation was based on the next scheme of concrete karst forms development (figure 2). It was decided that before the beginning of the building in the place of karst form No. 1 (figure 2a) was zone of intensive fractures, in the place of karst form No. 2 (figure 2b) was karst form No. 1, and at last, in the place of karst form No. 3 (figure 2c) was karst form No. 2. So, after the building had ended, each karst form turned into the next one. Realization of such a scheme consists of many variants of calculations for changing parametric ensuring.

Mathematical modelling is based on the finite element method with the use of a 9-node tetrahedron. The result of numerical decision was the field of additional displacements and deformations because of the development of karst form and influence of the loads from building and houses during that period. The data for the different variants of geomechanical calculations were collected in a unified database and this ensured the possibility of selecting different geomechanical parameters for visualization and analysis from among a great volume of information (more than 300000 nodes). Including calculation results in GIS-projects was made with the help of SQL selection and ADO connection.

The influence of karst processes on building and houses was estimated with the help of mathematical environment of spatial join for different dataset layers. Distribution of maximum horizontal deformations (absolute values) of the earth's surface for different karst forms (figure 2) is shown in figure 3. A map of the "coefficient of danger" (a ratio of the calculated and maximum accepted deformation) for the central part of the city of Kungur is shown in figure 4.

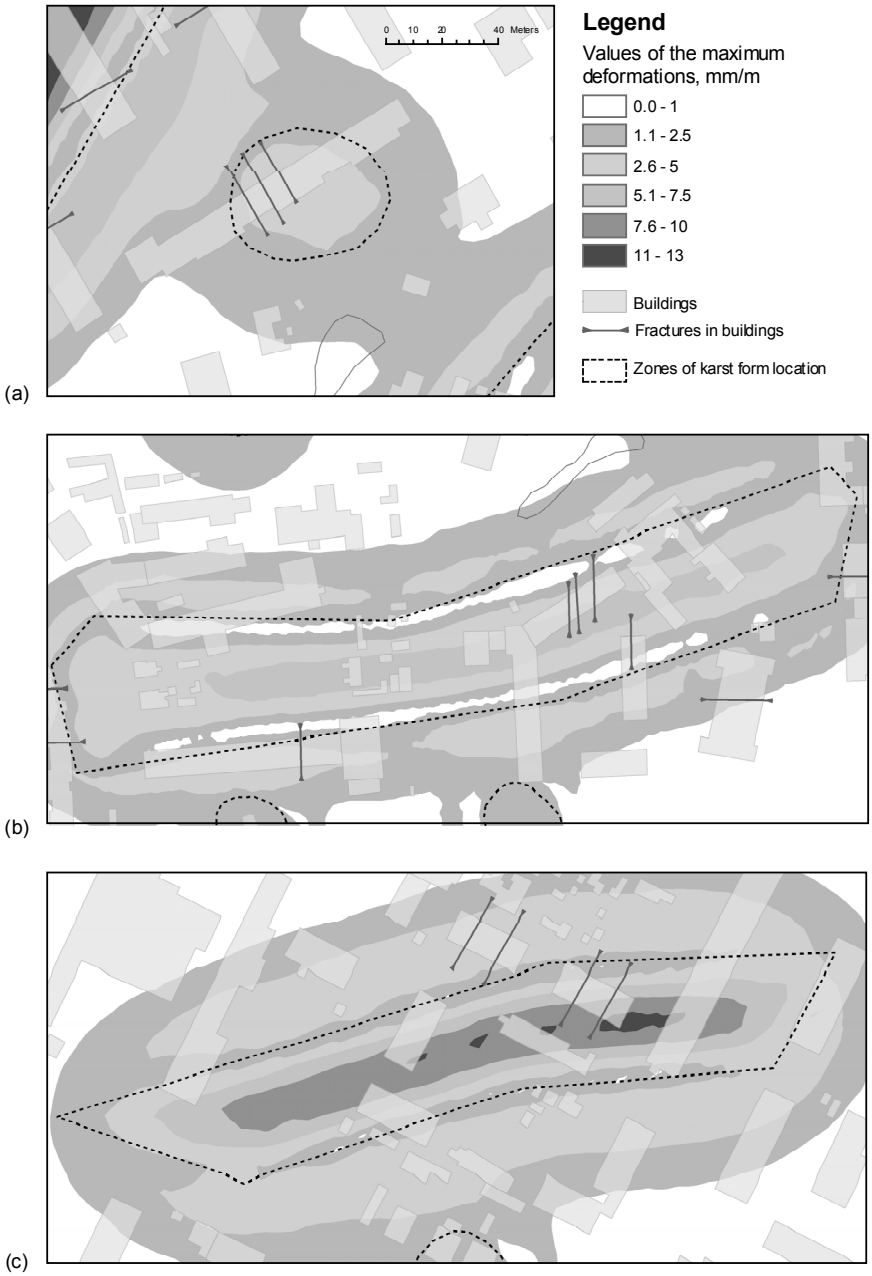

Fig. 3. Distribution of maximum horizontal deformations of the earth's surface for different karst forms:
(a) first type, (b) second type, (c) third type

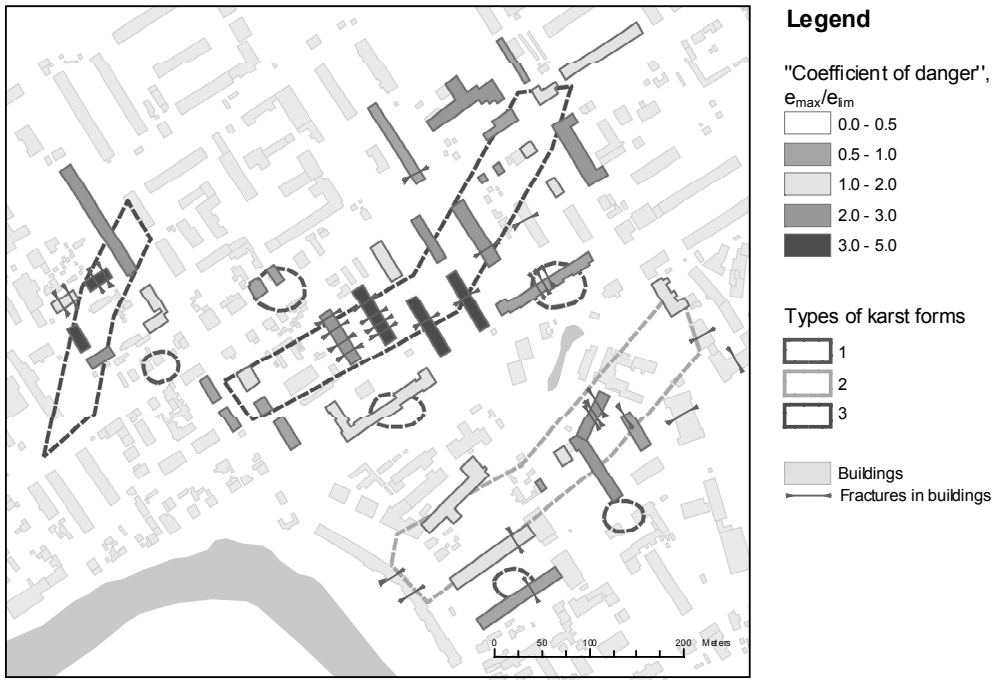

Fig.4. Danger of the karst influence on buildings and houses

So, we can say that common interpretation of the geological results of very shallow micro-seismic investigations and space geomechanical calculations using these results gives the possibility of estimating the influence exerted on buildings and houses by such complex geological phenomena as karst.