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ABSTRACT

The paper describes an approach for qualifying soil-structure systems behavior, using simple numeric models – "geotoys", reflecting the main features of the systems behavior and enabling numeric simulation of various case histories.

Three case histories of major karstic sinkholes are analyzed to show that man-made structures above a karstic cavity prevent formation sinkhole. When plastic zones reach the structure periphery, the soil-structure system becomes unstable. Prior settlements could be negligible to serve as precursors.

Another soil-footing-superstructure (SFSS) model is a 2D geotoy - an exact mathematical solution, used for multiple simulations (about 10,000) of SFSS sensitivity i.e., response to input parameters variations. The sensitivity was rated for each input-output pair [1]. The most interesting findings are the following:

1) SFSS stress state is very sensitive to soil strength parameters *c* and *φ*, which are responsible for formation of soil disruption zones ('plastic zone') under footing edges.
2) If a structure rests on a homogeneous soil base then it is practically insensitive to soil base compressibility i.e., soil modulus *E* variations.
3) 3D FEM analysis confirmed that 2D simulations can be used for qualitative SFSS analysis.
4)

Geotoys can be used for case histories analysis, risk assessment, training practical intuition, education purposes and international exchange and cooperation.

INTRODUCTION

Geotechnical engineers deal with highly uncertain environment: scatter of soil site investigation data and soil test data, different soil deformation theories and analytical methods, etc. In order to make safe decisions a geotechnical engineer applies intuition, based on available case histories and personal experience. One has to spend many years of practical work to develop such experience and intuition, because construction projects are large-size and long-term, and the gained experience could be just conservative. Such experience could be much easier obtained in other areas, where the objects can be manually lifted, touched, bent, stretched and even broken etc., and the result is instantaneous.
Such barriers could be overcome thanks to the evolution of the virtual computer reality. Now numeric solutions can be handled via the keyboard, case histories can be virtually simulated, and hands-on experience has become possible. A computer-smart engineer can manipulate a visualized structure of any size on a computer screen and get the feedback immediately.

But there are yet other problems. Most real projects are linked up with multiple input and output data, various theories and techniques, numerical methods produce numerical errors and noise, because their accuracy is limited. Although graphical visualization is a good help, it is still very difficult to develop the real "gut feeling" and to draw qualitative conclusions on the basis of so multiple data. In order to achieve it this virtual world shall be adjusted so that it would be conceivable.

Children play with their toys and attack adults with zillions of questions. The feedback data is stored in their brains, it updates on-line, until it becomes knowledge.

Simplified solutions (geotoys) could be developed to illustrate physical scenarios. Even exact mathematical solutions, free from numeric noise, can be applied for qualitative analysis.

Simple models are widely used for practical training in various areas. "Geotoys" and their applications in geotechnical engineering are discussed below.

NUMERICAL SIMULATION OF MAJOR KARST SINKHOLES.

Many failures – karstic sinkholes often occur all of a sudden. Their precursors are often to feeble.

Fig. 1. 100 m wide and 30 m deep sinkhole in Winter Park, Florida, USA, 1981.

Fig. 2. 30 m wide and 100 m deep sinkhole in Guatemala, 2007.

Fig. 3. Sinkhole in Dzerzhinsk, Russia, 1991.

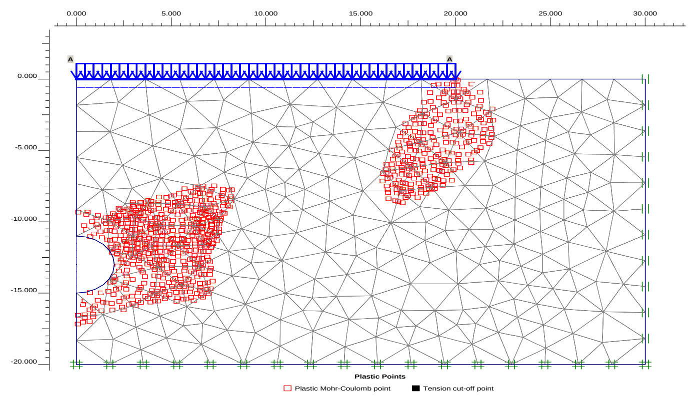

Fig. 4. Appearance of two plastic zones under 40 m dia footing.

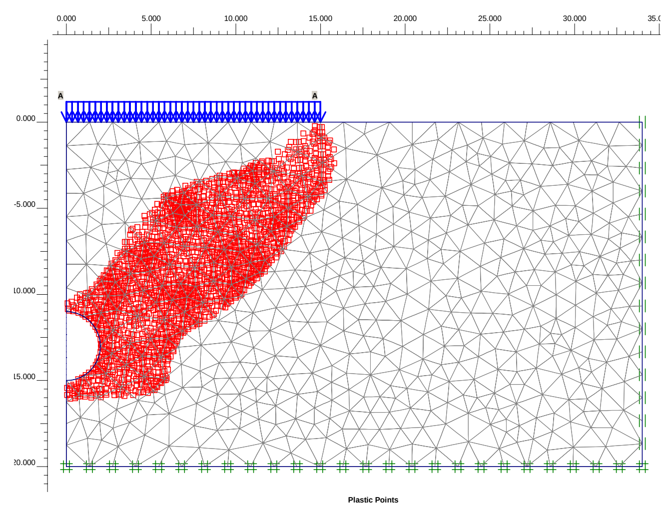

Fig. 5. Merging of two plastic zones under 30 m dia footing (sand loam).

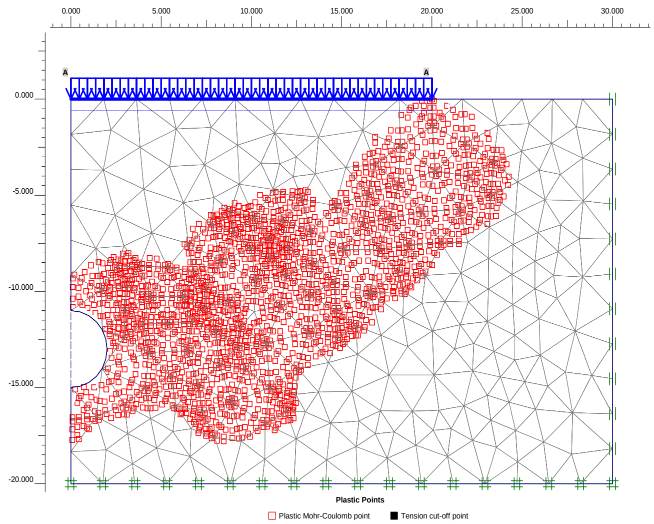

Fig. 6. Merging of two plastic zones (40 m dia footing) – sinkhole formation (clay loam).

An FEM axisymmetric solution was used to investigate the evolution of plastic zones in the soil base with 4 m dia karstic cavity, located 12 m below a uniformly loaded circular structure, resting on a rigid raft footing. The soil had parameters E, c and φ. The plasticity was of Coulomb-Mohr type.

Figs. 4, 5 and 6 show one of the examples of plastic zones and their merging together resulting in instability. A difference of plastic zones shapes was observed between sand and clay loam soils (Figs. 5 and 6).

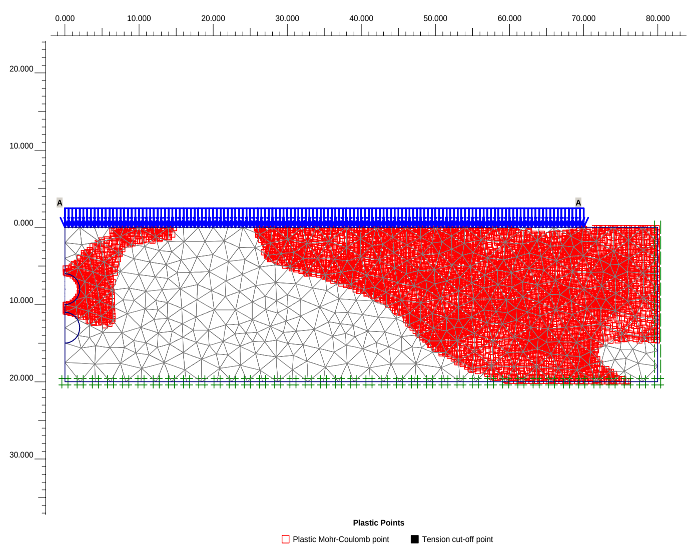

Fig. 7. Local sinkhole above a carstic cavity (140 m dia footing).

No local plastic zones appeared above carstic cavity with the exception of very large footings (Fig. 7), when the central and the side plastic zones are too far from each other to merge together.

Evidently, any structure above a carstic cavity restrains formation of a sinkhole until the above failure (plastic) zones, merge together that makes the whole system unstable. Water that penetrates the ground around the footing makes this event even more probable.

SOIL-FOOTING-STRUCTURE SYSTEM (SFSS)

SFSS FEM converts multiple inputs into multiple outputs. This numerical process produces errors i.e., numerical noise (NN), which gets very "loud" in case of singularities. The numerical computations smooth down these singularities, but the obtained results largely depend on the rate of discretization i.e., they are ambiguous. This is yet another source of NN. Singularities are not realistic, they can only be avoided by applying a more realistic model. The well-known Pasternak model of soil base with two parameters C_1 and C_2 has singularities: point forces under footing edges. The elastic half-space and elastic layer have similar singularities.

The impact of singularities has been evaluated by simulating a SFSS with the help of a 2D geotoy, consisting of Pasternak soilbase and a structure consisting of two beams: one (footing) atop the other (superstructure) with springs (columns) between them (Fig. 1). The exact solution was obtained and coded in MathCad.

One of the computer solutions is displayed on Fig. 1. It shows that the singularities can even damage the symmetry of an exact symmetrical mathematical solution in spite of very high precision of computer calculations.

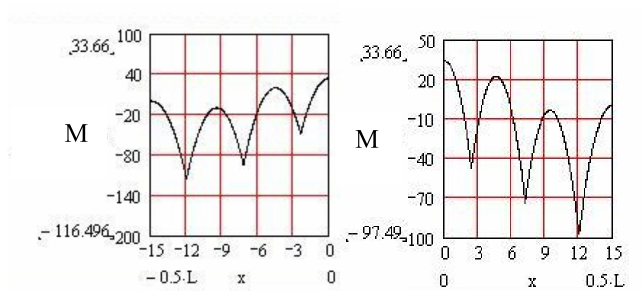

Fig. 8. Bending moments in 30 m long footing of SFSS. Exact 2D axisymmetric solution shows symmetry due to Pasternak model singularities: the maximum bending moment in the left half-footing (at point x= -12 m) is 20% greater than that in the right half-footing (at point x=12 m).

But in reality no such singularities exist, because footing edges cut through the soil, forming local soil disruptions that extend to a certain depth. Therefore, the Pasternak model becomes realistic if it is covered by a Winkler layer, whose depth is equal to the depth of soil disruption. The graphs on

Fig. 2 are symmetrical, because Winkler layer was put on top of the Pasternak model.

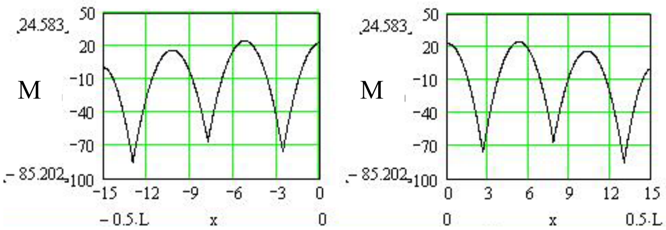

Fig. 9. Perfect symmetry of the exact 2D axisymmetric solution due to 1 m thick Winkler layer.

The depth of the Winkler layer H_0 is equal to the lowermost plastic point depth, which can be determined with the help of the following equation:

$$H_0=\frac{(p-\gamma h)(ctg\phi+\varphi-0.5\cdot\pi)}{\pi\gamma}-\frac{c}{\gamma\cdot tg\phi}-h \qquad (1)$$

The above soil base model (hereinafter referred to as CCC), consisting of Pasternak model covered by Winkler layer is a perfect geotoy for computer simulations of SFSS behavior.

Here follows short description of how the exact mathematical solution of the above problem was obtained. Firstly, solution for settlements $W=W(x)$ of $L=2a$ long beam on uniform soil base subject to $q=q(x)$ load was obtained from the following system of equations:

$$EJW^{IV}=q-p;\ C_3(W-V)=p;\ C_1V-C_2V^{//}=p, \qquad (2)$$

where, EJ is bending stiffness of the beam,

C_1, C_2, C_3 are parameters of CCC model, $C_3=0$ for Pasternak model.

$V=V(x)$ is distribution of settlements below the Winkler layer,

$p=p(x)$ is soil base reactions distribution, $p(x)=0$ if $|x|>a$.

The following boundary conditions were satisfied:

$$V(\pm a\pm 0)=V(\pm a\mp 0)=V^I(\pm a\mp 0)$$

$$W^{II}(\pm a)=W^{III}(\pm a)=0,$$

The Green function (point load solution) $G=G(x,f)$ $(-a<f<a)$ was obtained by satisfying continuity conditions $W^{(n)}(x-0)=W^{(n)}(x+0)$ (n=0,1,2) and discontinuity condition $W^{III}(f-0)-W^{III}(f+0)=1/EJ$. Solutions for any $q=q(x)$ distribution is obtained by integration:

$$W(x)=\int_{-a}^{a}\cdot p(\xi)G(x-\xi)d\xi \qquad (3)$$

In the case of several point forces (columns) applied to the beam the solution is obtained by evident summation

$$W(x)=\sum_i P_i\cdot G(x-\xi_i) \qquad (4)$$

In the case of non-uniform soil base the solution was obtained in terms of integral equation formulation. The integral equation was replaced by respective integral sum, and an approximate solution was obtained using the above Green function. This technique (Zhemochkin method) is widely used in Russia to convert the integral equation into a system of linear equations.

Soil heterogeneity was presented by the non-uniform Winkler model, according to the layer-by-layer summation technique, as per the Russian Construction Code for spread footings.

The above Green function was used to obtain the solution for the whole SFSS system by solving a system of linear equations to calculate unknown forces in columns.

Also the stepwise growth of structure during its erection was simulated. This is a non-linear problem with changing weight, upper structure stiffness and depth of cut under the footing edges. All solutions were programmed in MathCad.

The above geotoy was used to identify qualitative effects by SFSS computer simulations. There were carried out about 10 thousand simulations. All results were presented in visual computer graphics, but it impossible to display all these virtual "history cases" on paper. Therefore, expert evaluation of SFSS *sensitivity* i.e., the impacts of the input data variations on output results was done for each input-output pair. If such influence is negligible it was rated *0*, if this influence shall be taken into account it was rated *1*. If such influence is very high it was rated *2*. All the ratings are presented in Table 1.

Table 1. SFSS sensitivity rating

Input data variations	Output data variations					
	Mean settlements	Deflections	Tilts	M +	M -	Q
Soil modulus E	1	1	1	0	0	0
Soil strength parameters c,ϕ	1	1	1	1	1	1
Depth of footing h	1	1	1	1	1	1
Compressible layer thickness H	1	0	0	0	0	0
Soil heterogeneity	0	1	1	1	1	1
Side column to footing edge distance	0	1	1	2	2	2
Column stiffness	0	0	0	0	0	0
Footing stiffness EJ	0	1	1	0	1	1
Upper structure to footing stiffness ratioтн. жесткость $Ds/EJ < 5$ $5\leq Ds/EJ < 20$ $Ds/EJ \geq 20$	 0 0 0	 1 1 0	 1 1 0	 1 0 0	 1 0 0	 1 0 0
Structure growth during its erection, linear soil base	0	0	0	0	0	0
Structure growth during its erection, non-linear soil base	1	0	0	1	1	0

Impact of a near construction site	0	0	1	1	1	2

CONCLUSIONS

In 1897 an Italian mathematician Vilfredo Paretto formulated his famous principle 20/80: «20% of effort produce 80% of results, only 20% of results are produced by 80% of effort». It means that significant factors are few, while insignificant factors are many.

SFSS behavior involves many insignificant factors, and considerable effort is required to take them all into account in SFSS behavior analysis. In many cases multiple data result in conflicts of judgment and information chaos.

The role of various factors could be analyzed by assessing SFSS sensitivity with the help of the geotoys, described above. The geotoys, free from excessive details, could be a helpful tool for verification of analytical results, standards and regulations, for investigation of history cases, especially in cases of scarce data, in settling theoretical disputes, etc. In this respect they could be even more effective than statistical methods, because the geotoys help quickly build up an intuitive knowledge, which is no less real than statistical data, obtained by, e.g., Monte-Carlo method, which needs multiple calculations to get meaningful results.

Geotoys could be a good tool for qualitative analysis, for risk assessment, for education and international exchange via Internet.

REFERENCES:

Barvashov V.A. *"Sensitivity of Soil-Structure Systems"*. VI International Congress on Mathematical Modeling. Nizhny Novgorod.- Russia, 2003, Book of Abstracts.- P. 315.

Barvashov V.A. "*Chuvstvitelnost sistemy osnovanie-sooruzhenie* (*"Sensitivity of soil-structure system*"). Osnovanya, Fundamenty i Mekhanika Gruntov. Moscow, 2003.

"Design and construction of soil bases and foundations for buildings and structures". (Russian Construction Code. SP 50-101-2004). Gersevanov Research Institute of Foundations and Underground Structures, Moscow, 2004.