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EXAMPLE FOR RISK ESTIMATION OF FAULT APPEARANCE UNDER THE PLACE OF DESIGNED SKYSCRAPER IN SOFIA

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ABSTRACT

There was an interesting discussion during the designing stage of one of the future skyscrapers in Sofia – is the soil basement reliable enough if it is true the hypotheses for a fold under the construction place? The substantial geotechnical report doesn't give answers to this question but the geological profiles suggest to us about an appearance of fold. Topographic and historical specifics of the area are supporting the same unsuitable idea. The additional geophysics investigations clearly establish a lack of fold displacements under the place during the Quaternary period.

The zone has high seism and an individual seismic ratio is calculated and presented. The geophysics and geologic profiles are compared too. According the summary estimation there is not active fold under the construction place in spite of obvious existing conditions. Dynamic soil protection caused by the deep pile foundation is estimated.

PROJECT LOCATION AND PLANED STRUCTURE

The project area is located 3 km away from the historic city of Sofia (Fig.1).

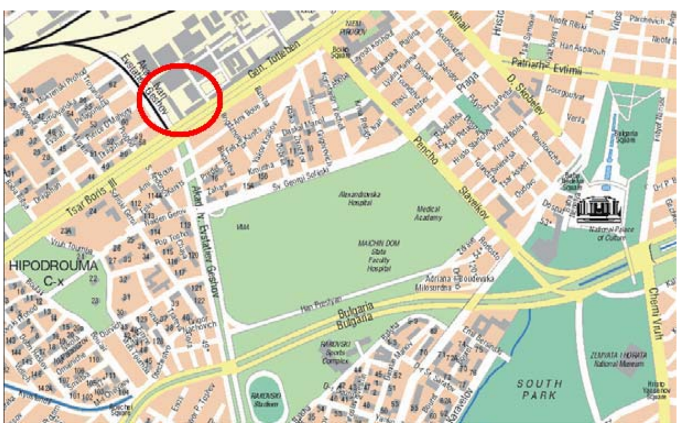

Fig.1. Project location in Sofia

Fig.2. Project view of the Tower acc. to [www.ece.com] , [www.hpp.com]

In plan view the tower will be about 53 m long and 28 m wide. The Europe Tower Sofia ETS will be founded on soil of geotechnical category 3 according Bulgarian Code.

The Tower (Fig. 2) will have 40 over ground storeys and 3 basements (below reference level). The basements are designed to be watertight. The total height of the tall building will be 175m above the reference level. With a thickness of the foundation raft of up to 4.5 m, the bottom of the basement will be 15,75 m below reference level. The total height of the tower above bottom of basement will be about 190,75 m [www.ece.com]. Kowalów M. [2008]
The vertical development of the tower building is restricted to the centrally arranged core zone with dimensions of approx. 12 m x 28 m. Due to the relatively high seismic risk in Sofia the construction has to be resistant against earthquake impacts. The supporting elements and the chosen building materials have to take into account sufficient stiffening as well as a maximum of ductility connected with a high natural absorption of the structure.

SUBSOIL AND GROUND WATER CONDITIONS [Kowalów M. [2008]

The **subsoil** at the project site is comparable to typical local soil conditions at Sofia area and is considered sufficient for the planned project as described there. The ground profile can be subdivided into **two major units**. There is an upper zone of quite heterogeneous composition containing fill, gravel, sand, silt and clay. Underneath this upper zone clay deposit follows about 15 m to 17 m depth from the ground surface, reaching down to about 60 m. At greater depth, there are alternating sand- and clay layers. The dense sand layers dominate in the geotechnical properties below 60m. Altogether, **9 soil types** can be distinguished.
There are two different types of **Pliocene clays**. The upper layer is essentially a clay of medium **CM** to high plasticity **CH**, medium plasticity dominating. At depths below about 15 to 17 m a grey–green to grey–blue clay of high plasticity **CH** which shows transitions **towards** organic clay of high plasticity **OC** was found in all borings. It contains ubiquitous **lenses of shell fragments and organic matter** (lignite). Sand lenses may also occur erratically. Fissures and ancient slip surfaces were encountered at some locations.
In some borings at a depth between 17 m and 19 m, the water content of the clay was very high at w = 60 % to 80 %, the dry density low about $\rho_d = 1{,}0$ g/cm³. **This zone** of the clay deposit with stiff, tending towards soft consistency, deserves special attention.
Water saturated **fine to medium sand** of grey–green colour in a very dense state dominates below 60 m. **Clay layers occur together with the sand between 60 and 90 m**.
The piezometric **ground water** table is encountered at about 6 to 7 m below ground surface. It is assumed that there is only one continuous ground water body reaching from the phreatic surface down to the bottom of exploration at 90 m depth and probably below.
The cohesive soil have low to very low **hydraulic conductivity** ($k = 1*10^{-6}$ to $1*10^{-11}$ m/s). They may be subject to elevated piezometric pressure. The cohesionless soil types are regarded as aquifers with high to medium, partially low hydraulic conductivity ($k = 1*10^{-3}$ to $1*10^{-6}$ m/s).

The results of the analysis exclude **soil liquefaction** risk due by seismic loading for both cohesive layers and cohesionless layers.

PRELIMINARY SEISMIC ANALYSIS OF THE PROJECT PLACE

The studied site is situated in the central part of Sofia City. According to the Geological Map of Bulgaria (Fig. 3) in a scale 1:100 000 this indicated fault **has not been active during the Quaternary.** Because of the high level of urbanization of this area it is not practically possible to investigate properly the probable faults; less possible is to make the evaluation of their activity [Shanov S., A. Mitev [2008]].

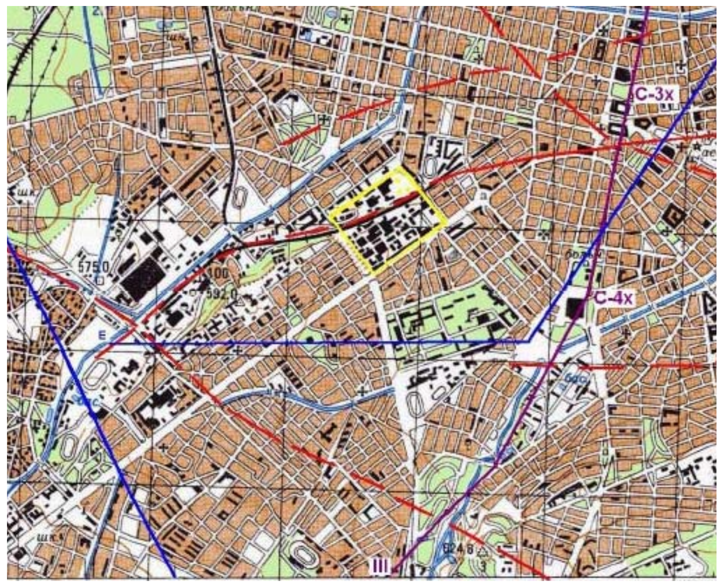

Fig.3. Urban plan of the central part of Sofia City with indicated area of the site (the yellow square). The red lines are the known faults. The blue lines are the profiles of special studies of the seismic properties of the geological grounds

The studied site is closed to a fault. This fault is well expressed also morphologically. The dipping of the fault is North-westwards. Eastwards from the site the fault is plotted as sure known trace, but it can see on the geological profile that the fault is covered by the Quaternary sediments. The morphological expression of the fault can be related to its natural contribution for the formation of the old river terraces of Vladaya River. This fact is difficult to be commented without special geophysical studies, but more of these studies are impossible to be performed properly because of the existing urban structures and noise of permanent traffic on the streets. The information for existing of sliding processes along this fault can be attributed to some natural activity, as well as to human activity [Shanov S., Boykova A. [2007]].
None of the known publications indicates that this fault is an active fault. The future building will be southwards from the fault, on the hanging wall of the fault. This position is better, but in any case it was necessary to find the necessary proves that the fault, even inactive, is not affecting the future building fundamentals. These fundamentals will be totally inside the

sandy-clay sediments of the Lozenets Formation (alternation of clays, sandy-clays, silts, sandstone, and gravels with coal at the basis). This formation is represented by stiff-plastic clays beneath the site. A special design measure can be suggested for increasing of the building safety [Shanov S., A. Mitev [2008]].
EC8 defines the maximum accelerations for rocks and rocky grounds. For the grounds of lower velocities the accelerations are decreased to 40%. For the case of the studied site in Sofia, if the worst ground proprieties are expected (near the slope related to the fault near the border of the site), the Ground Acceleration Coefficient $\mathbf{K_s}$ has to be **0.378 g.**

RESULTS FROM THE ADDITIONAL ELECTRICAL PROFILING [Shanov S., A. Mitev [2008]]

Four additional profiles have been made on the place – three of them across the fault and one along it. In spite of the very hard conditions of measuring of the electrical resistance we finded unknown underground constructions with extremely high electrical resistance. In this manner, especially for the most complicated parts of the section, the possibility to record data of low accuracy was minimized. More, measurements for the first 200m of the Profile 1 were made twice in order to confirm any questionable **results.**

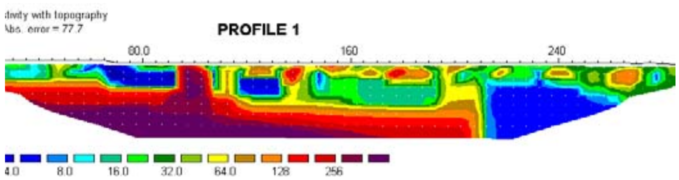

Fig.4. Electrical Profile 1
X-Resistivity [Ohm-m], Z- Deep[m]

Profile 1 (Fig. 5) is situated along the SW border of the site. Its length is 300m. The position of this profile, by pure chance, is oriented over and along unknown underground construction, probably some tunnel or pipe-line facility of unknown diameter. The anomaly is very strong (Fig. 4), in evident contrast to the relatively low electrical resistance of clayed and sandy sediments of the normal cross-section, as represented by the interpretations of the curves from the VES investigations. It is clear, that this construction has some pits towards the surface, and they are well seen at the distance of 95-105 m and 200-210 m from the beginning of the profile. At 210 m the anomaly terminates abruptly and to the end of the profile it is not present more. The upper part of this anomaly of high electrical resistance (underground cavity?) is at the depth of approximately 10 m from the surface. It is not possible to assess the lower part of the anomaly because of the strong screening effect towards the electrical current. The anomaly is probably linear, because none of the boreholes or the VES from its two sides has crossed it. The future excavations at this place have to be done very carefully.
The second electrical profile (300 m length) is representing very different picture from Profile 1 – the picture is without unknown anomaly.
Electrical Profile 3 (200 m length) has been situated at the beginning of profiles 1 and 2 (Fig. 5) with direction SW-NE. The aim of this profile was to confirm or reject the hypothesis for high resistance structure bellow the site, detected by Profile 1. The anomaly was confirmed (Fig. 6) at the depth of 7-10 m and at 65 m from the SW end of the profile. The anomaly is important as dimensions, and it is not possible to evaluate the real geometry at the depth. This anomaly was not detected by Profile 2. The SE end of the profile, due to the method of measurement, doesn't give information deeper than 2-3 m.

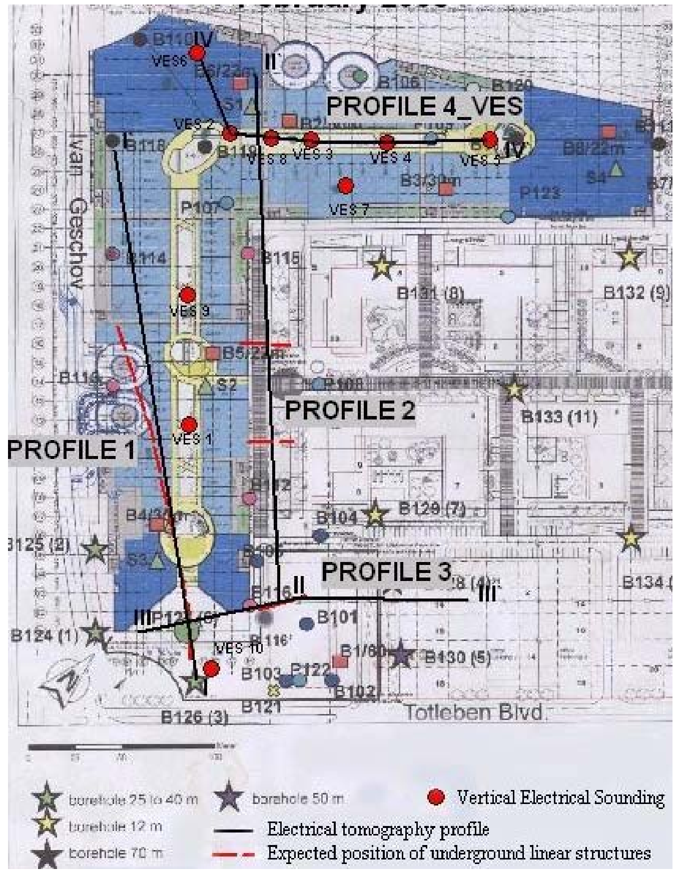

Fig. 5. Situation with the position of the measurement by the method of VES and the profiles of electrical tomography investigation.

The upper part of the cross-section of Profile 3 is represented by embankments and sandy sediments, forming the characteristic lentils of higher electrical resistance. Below are disposed more clayed sediments – from the depth of 5-7 m or less.
Electrical Profile 4 is created on the base of 5 points of VES measurements. This profile represents a cross-section without important anomalous areas of the electrical resistance.

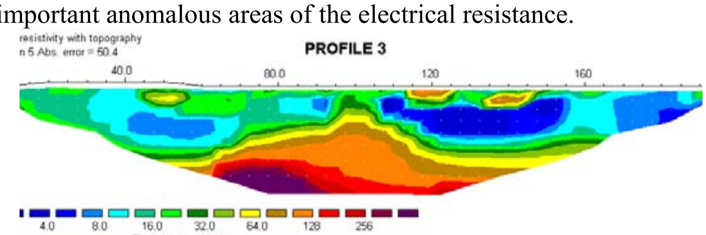

Fig.6. Electrical Profile 3

GEOLOGICAL INTERPRETATION OF THE RESULTS [Shanov S., A. Mitev [2008]]

The anomaly of high electrical resistance below Profile 1 is not permitting to determine if a fault exists. The geologist's opinion [Shanov S., Boykova A. [2007]] is that the lower electrical resistance at the end part of the profile is normal for the clayed materials. The step-like pocket at the end of the profile is probably a reflection of old river terrace. No evidence for fault can be supported. The clear line of separation of the high electrical resistance anomaly and the low electrical resistance cannot be identified as a fault. This is probably the expression of the concrete wall of the unknown underground structure.

Because of this situation, the second Profile 2 was planned to be sub-parallel to the first. This profile is not representing on the cross-section any evidence for existing of fault. Geologically the profile is representing the normal for this area alternation of sandy and clayed sediments.

No evidence for any fault.

PILES FOUNDATION

The new high building will have combined piles – raft foundation [Kowalów M. [2008]]. The piles will have diameters of 1,50m and their length will be 65m. The spires will reach to the compact sand below. Three testing piles prove the design properties and characteristics by bi-directional static load test.

It is well known that the soft soils increase the amplitude of displacement aroused by seismic action. A special micro seismic investigation on the building area is very important, of course, for designing of high multistory buildings. It can be take many structure precautions against increasing of the amplitudes of the shakes. The main ways and means in this case is the Pile Foundations. Threshing out the dynamic soil-structure interaction we see that the piles improve the dynamic properties of the soft soils. Piles compress the soil, expedite the consolidation, restrict the soil and finally they increase the average velocity of the seismic waves through the pile foundations.

CONCLUSIONS

- The necessity of additional profound instrumental analysis of the project place is a hoped-for miracle;

- Eurocode 8 and other National Codes regulate the term of active and inactive fault. If the fault has been active during the latest Quaternary, it is active. In spite of all the situation can create a difficulty and uncertainty about the fault's qualification.

- Piles foundation is an adequate decision for heavy structures on seismic places.

REFERENCES

Kowalów M. [2008a]. "ETS Europe Tower Sofia Bulgaria", Geotechnical Report, ECE.

Kowalów M. [2008b]. "ETS Europe Tower Sofia Bulgaria, Geotechnical Piles-Raft Foundation Design", ECE.

Shanov S., A. Mitev [2008]. "Geological and tectonic structure below the site of Balkan Center, Sofia based on geoelectrical characteristics and electrotomographic cross-sections of the engineering geological layers", ETS Europe Tower Sofia, Bulgaria, ECE.

Shanov S., Boykova A. [2007]. "Evaluation of the seismic characteristics of the site "Balkan Centre" - Sofia City, considering the geological and tectonic structure and the properties of the engineering geological layers", Report of "BulGeoinvest" Ltd.

www.ece.com.

www.hpp.com.