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TECHNICAL NOTE

GEOPHYSICAL SURVEY TECHNIQUES IN CONGESTED URBAN ENVIRONMENT

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The last decade has seen major construction operations in Moscow at large with the most sensitive and important renovation and new construction projects being implemented in the historical downtown. The presence of numerous high-value historical/architectural monuments of unique structural design, diverse soils, high density of urban development and extensive underground infrastructure make the survey difficult, all the more because most of the buildings and structures to be surveyed are currently in service. The last circumstance is essential, as it sets the limits to the application of conventional techniques of structural surveys, site investigations, etc.

Therefore, geophysical survey methods have become very attractive for solving a large spectrum of problems from site surveys for construction/renovation projects, evaluation of soil properties under footings of structures, all the way to survey footings and walls.

Herein we discuss in detail the following applications, based on the know-how, gained by the Laboratory for Survey and Renovation of Buildings and Structures at MGSU.

1. *Seismic reflection method* (SRM) in common depth point (CDP) configuration with polarized shear waves (SH) is applied to survey deep geological structural features (up to 5-m depth) in order to assess site carstic and leaching risk. It is applicable even in the presence of asphalt-concrete cover and frozen ground.

SRM velocity-depth profile data enables deep soil survey from rather small sites to determine lithologic boundaries, the tops and bottoms of soil strata.

In practice, multiple coverage (up to 6) technique is mostly used with end-on shooting. Usually, 12-channel deployment of single horizontal geophones, spaced at 2 m, is applied. The source positions (SP) are also spaced at 2 m distance. The sources are excited by directional blows of a light-weight sledge-hammer (20–40 blows). The pulses of different directivity are added/subtracted. Besides, in order to assess the profile velocity parameters the sounding is performed for opposite SPs with fixed spread.

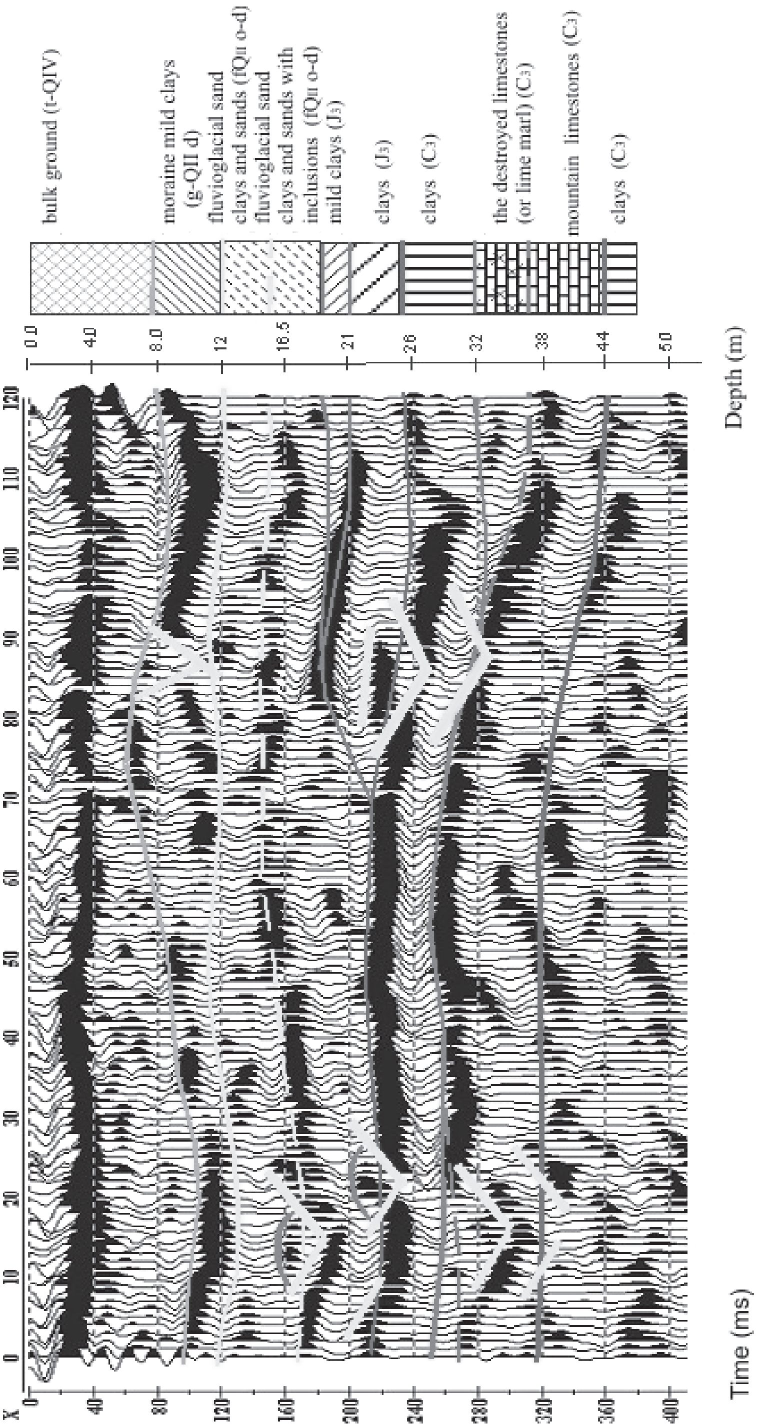


Fig. 1. Example of structural seismic profile

Vibrations are registered by the mobile "Diogen-24" computerized seismic recording system, deployed in a passenger car compartment along with an operator.

The data obtained is processed by PC in interactive mode with the help of special software (Moscow State University).

The objective of data processing was to plot time sections (wave travel time to the reflection point and back) that fix reflections from the surveyed boundaries with maximum precision and reliability.

The procedure is performed by means of the common depth point (CDP) technique with the maximum coverage being equal to 6. Therein are varied: coverage number, offset distances, parameters of digital filtration and bandwidth gain and automatic gain control (AGC). The final positions of lithologic boundaries on time profiles are determined as the pattern of all section versions.

The depth scale (in meters) is determined as per apparent velocities, calculated from sounding time-to-depth curve data and updated to fit test drilling data.

This technique was applied within the Moscow Kremlin area, on the prospective construction site of the "Moscow Kremlin" Museum-Reserve in Borovitskaya Square; on the site of a high-rise building (21 Novy Arbat); for site investigation of buildings at Maly Zlatoustinsky Lane, in Bolshye Kamenschiki Street, Sadovo-Kudrinskaya Street and on other sites.

The example of a structural seismic profile for 8 Bolshye Kamenschiki Street site is given in figure 1. It shows anomalies, suggesting the occurrence of carstic and leaching events. The latter was confirmed by test drilling. Figure 2 demonstrates the procedure of field data acquisition by this method.

Fig. 2. Procedure of field data acquisition by SRM method

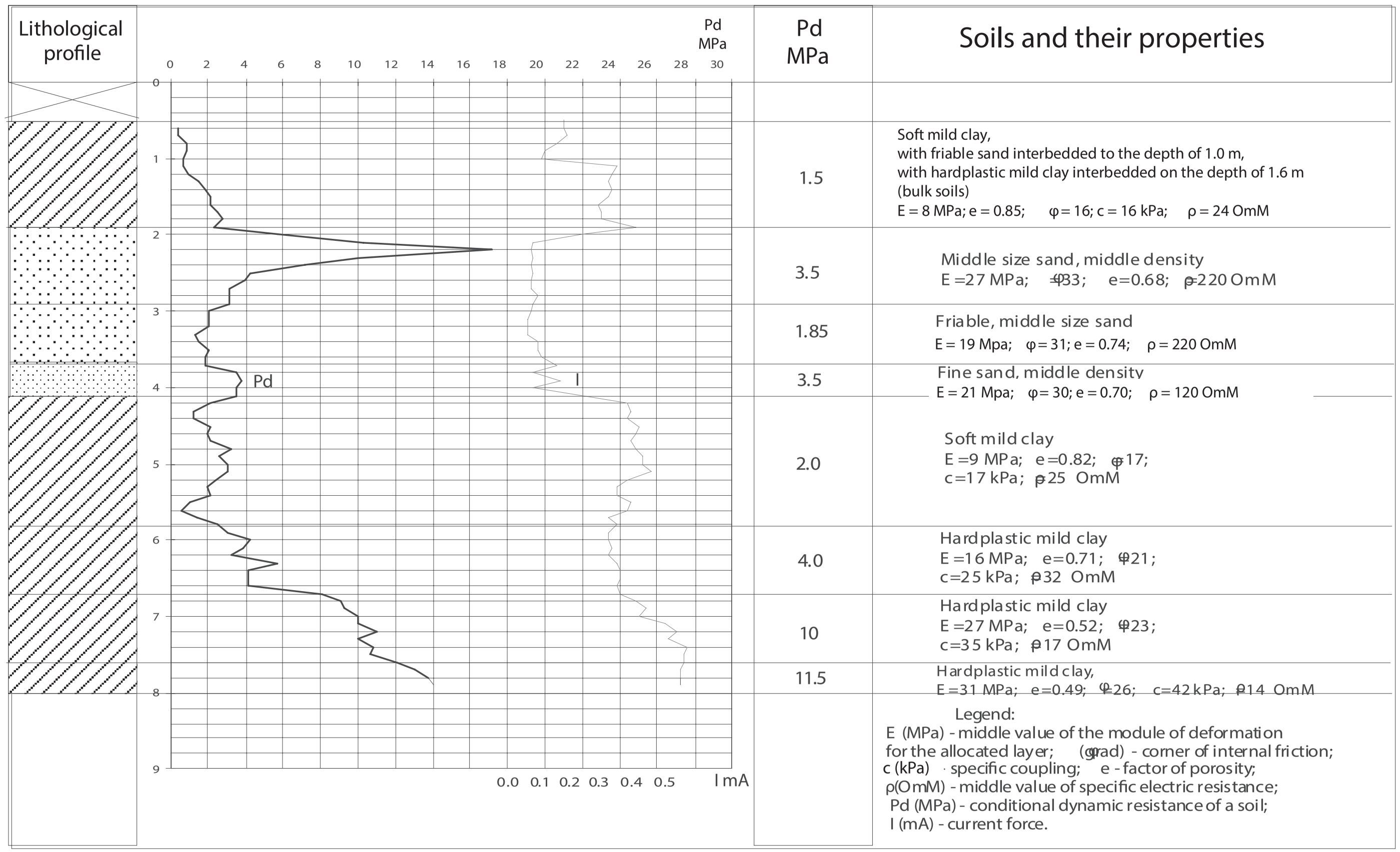


Fig. 3. The results of electric-contact dynamic soil sounding
EDS No. 1. Object: Korolev, 27 Sovetskaya Street. Top point: 0 m. Date: 24.03.2005

2. *Method of electric contact dynamic soil sounding (EDS)*. This method combines dynamic sounding and electric current logging techniques and is used for detailed section survey up to 10–12-m depth and for determining physico-mechanical properties of soils. It is applicable in basements, pits, on embankment slopes and in other places difficult to survey. Its application requires penetration of hard asphalt-concrete revetments by drilling holes and by digging pilot pits.

This method enables investigation of physico-mechanical properties of soils in-situ.

The investigation is performed with a light-weight portable device, developed by the Central Research Institute of Construction (TsNIIS) of the Ministry of Transport-Related Construction (Mintransstroy). The probe penetration measurements are carried out in parallel by dynamic sounding and by electric current logging that enhances the reliability of the data obtained.

In order to perform electric current logging (differentiated), the sounding probe is equipped with two electrodes, installed in the sounding probe.

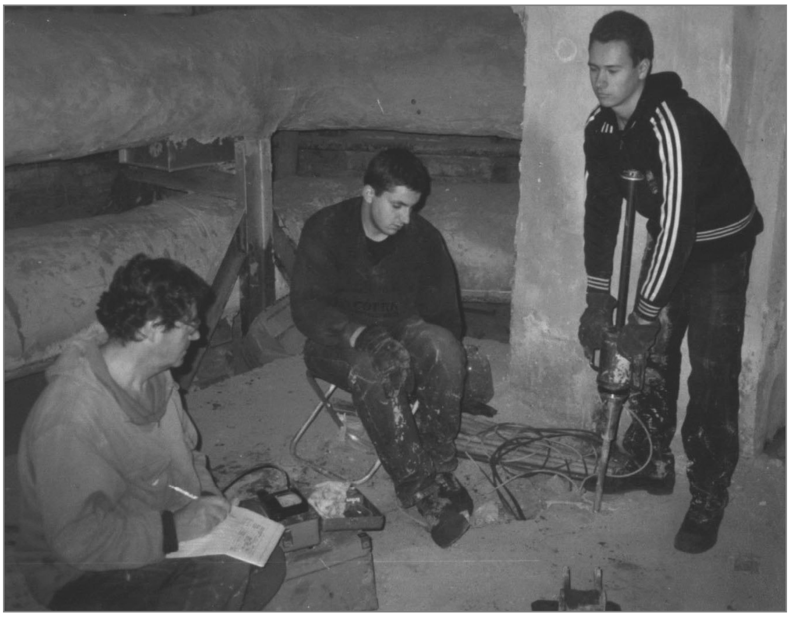


Fig. 4. Respective operations, EDS method

The results of electric current logging yield soil lithologic type, while dynamic probing data analysis provides physico-mechanical characteristics of soil. This procedure makes allowances for rod-soil side friction that enables quantitative assessment of cohesive soil properties.

The shortcoming of this method, applied in urban environment, is the difficulty to separate the lithology of sands and clay sands in a section if they are artificially saline. It stems from sandy soil electric conductivity, which equals that of similar sand clays and clays. Regular, non-saline sandy soils are identified unambiguously by electric current logging data. Saline soils identification error introduces an error in physico-mechanical characteristics due to wrong selection of analytical dependencies. In order to avoid it, the reference geological data shall be available at least in the archive.

The method has been applied at multiple sites, among which the most important are: Moscow Kremlin, Detsky Mir (Children World) trading center in Lubynka Street, Sergiev Posad Monastery, Kalyagin Theater in Arbat Street, a building in unserviceable condition in Myasnitskaya Street, a building in Malya Nikitskaya Street, etc.

EDS data is represented as lithologic columns with descriptions of soils and their characteristics, apparent dynamic resistance *Pd* and electric current logging data (figure 3). The respective operations are shown in figure 4.

3. *Seismo-acoustic P- and SH-wave reflection sounding of piles and footings* for determining footing or pile depth, masonry or pile material condition, for identifying major defects and cracks in masonry or piles. The method is nondestructive, does not require excavations and has been used on a number of sites, including those mentioned above, as well as at the Gostinny Dvor and GUM.

During test operations the vibrations, excited in the superstructure, propagate down the pile length and, having been reflected from the lower pile end or from the footing bottom or from large-size pile heterogeneities, are registered on the surface.

The data processing procedure includes wave noise suppression and amplification of vibrations (direct and reflected waves), achieved through filtration of vibrations and their slant stacking on various spreads. Ambiguity and reliability of results are ensured by records from several excitation sources and by application of different wave types.

The respective conclusion is made after the survey results are compared with the project design requirements. Figure 5 shows seismo-acoustic survey data of seven bored cut-off piles that retain the excavated pit walls of underground parking in 9 Myasnitskaya Street. Figure 6 demonstrates the conditions of field operations.

4. *Seismo-acoustic tomographic sounding of walls and floors*. This technique is applied to investigating internal structure of walls and footings and further detailed mapping of isolines of material properties in the cross sections investigated.

The procedure includes nondestructive measurements along the perimeter (or a part of it) of selected wall cross sections without material integrity violation. It was used for surveying the footings and walls of Gostinnyi Dvor and Kitaigorodskaya (China Town) Wall.

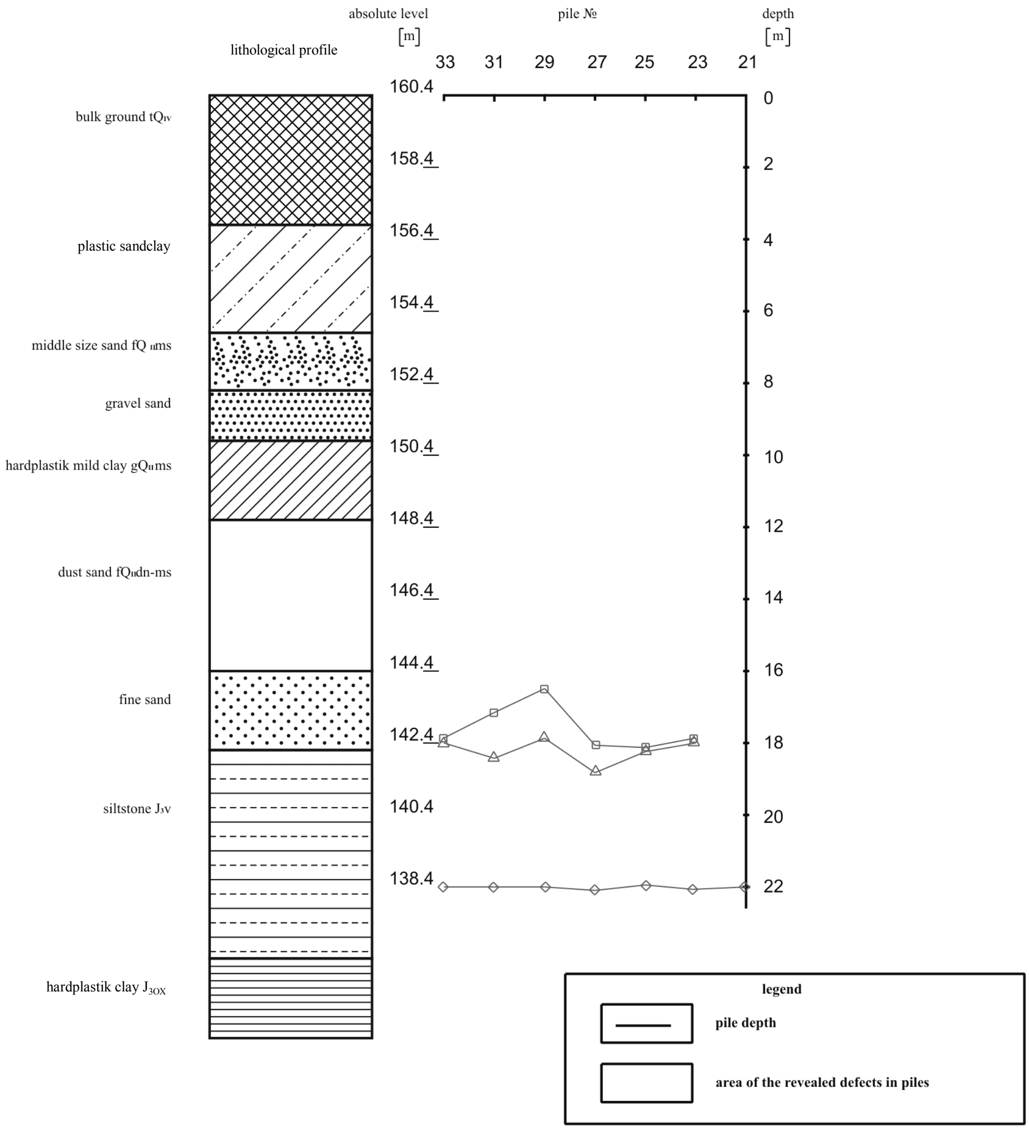


Fig. 5. Seismo-acoustic survey data

Fig. 6. Conditions of field operations by seismo-acoustic sounding piles

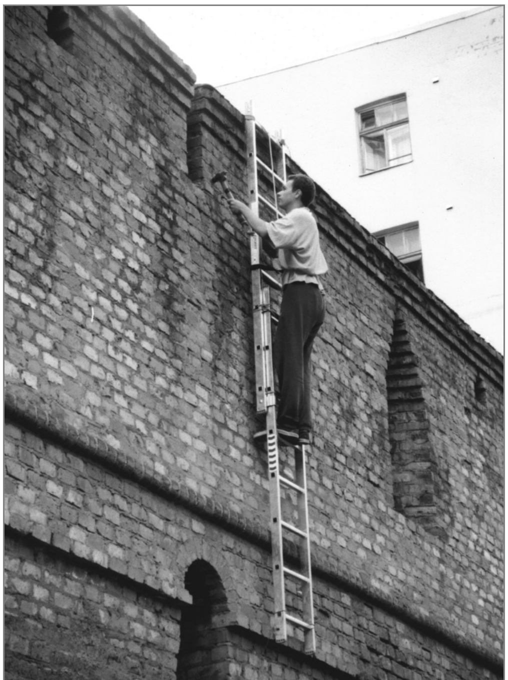
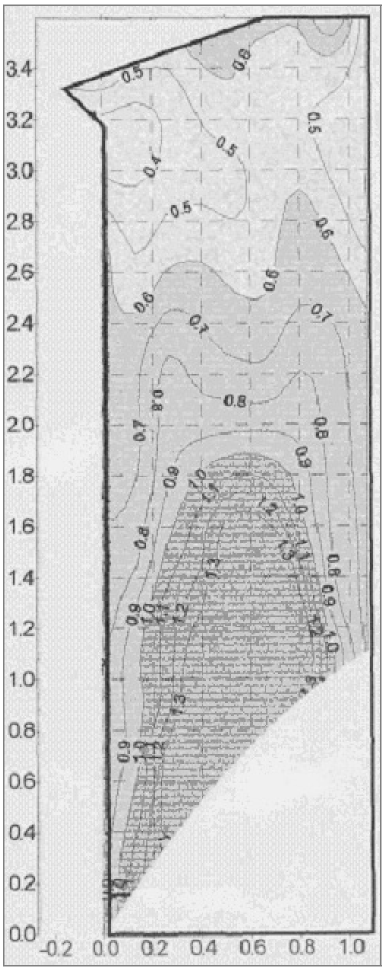
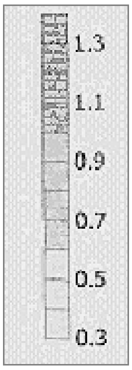


Fig. 7. Segments of Kitaigorodskaya Wall





V_p > 1.0 km/s, zone of safe bricklaying

0.5 km/s < V_p < 1.0 km/s, zone of weakened cement connection and increased jointing in bricklaying

V_p < 0.5 km/s, zone of practical absense of cement connection in bricklaying

Fig. 8. Results of tomographic sounding of Kitaigorodskaya Wall (section 1)
isolines-speed of longitudinal wale V_p (km/s) – M 1:20

The segments of the Kitaigorodskaya Wall, surveyed by MGSU, are shown in figure 7. Figure 8 presents the tomographic sounding data of one of the merlons and demonstrates pronounced strength heterogeneity of the brickwork zone investigated. It features total absence of cementation in some portions as well as the portions with preserved cementation. This information enables optimization of the development of design documents for measurements to be taken to strengthen structural elements.

It should be stressed in conclusion that the above-discussed methods are most effective if combined with direct methods of investigating physico-mechanical properties of soils and structural materials. This statement shall be taken into account while developing survey and monitoring investigation programs.