Assessment of technogenic impacts on the geological environment of big cities

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Abstract: Intensive technogenic impacts on the geological environment, which define particular soils' behaviour within limits of town agglomerations, are the main features of modern megapolis development.

Research has demonstrated that thermal, moisture and chemical fields are widely distributed and have the most significant intensity within cities. They affect soils significantly.

The authors consider technogenic development of the geological environment in the Moscow megacity as an example. They have established thermal and moisture effects caused by underground pipelines which have significant impacts on soil properties. They have developed quantitative techniques allowing the measurement of this technogenic impact using geoinformation methods. Soil behaviour was determined using field and laboratory techniques, while their structure and mineral composition were analysed using SEM, XRD and analytical chemistry methods. The research has shown that there is an area forming around thermal and water underground pipelines, which is characterised by irreversible worsening of geotechnical index properties caused by drastic peak and off-peak fluctuations of moisture characteristics, temperature and structure of soils. The size and degree of change is directly related to the capacity of the pipeline.

The features of technogenic hypergenesis in town area have been discovered and analysed. Migration of iron compounds in dispersed soils and change in cementation features, soil weathering caused by changes in the land surface (asphalting, removing of top-soil) are the main processes of technogenic hypergenesis.

The paper concludes that a high technogenic burden facilitates hypergenesis processes in soils. This conclusion is supported by changes in chemical and mineral composition of soils, and the destruction of old and creation of new structural bonds between mineral particles.

The paper presents the results of computer simulation of the development of thermal, moisture and chemical fields in soils, analyses results obtained with this model and shows diagrams for calculating impact zones of underground pipelines together with recommendations for engineering geological research in zones with a high technogenic burden.

Résumé: La détail importante du développement des mégapolices modernes est l'influence technogenique intensive sur l'environnement géologique qui se determine par la particularité du sol des agglomerations urbaines.

Les auteurs examinent l'environnement géologique de Moscou comme l'exemple de l'influence technogène. Ils ont élucidé les influences thermals et humides des tuyauteries souterraines, qui ont une influence sur les propriétés du sol. Les auteurs ont élaboré la méthode de la mesure quantitative de l'influence technogène à l'aide de technologie géoinformatique. Des propriétés du sol ont été prit par des recherches en les champ et dans les laboratoires. La structure et la composition minérale du sol ont été analysé par SEM, XRD et les méthodes de la chimie analytique. Les recherches ont monté qu'il y a les domaines formées autour les communications souterraines thermales et d'eau, où les propriétés géotechniques du sol s'aggravent à cause des fluctuations violantes des humidité, de la temperature et de la structure du sol. La dimension et la degré de la changement dépendent directement de dimensions de tuyauteries souterraines.

On a découvert et analysé le phénomène de l'hypergenesis technogenique sur le territoire de la ville. Les processus principaux de l'hypergenesis technogenique sont la migration des composés du fer dans le sol dispersé, les changements des caractéristiques cimentés du sol et l'érosion qui se provoque par les changements de la surface (asphaltation, liquidation du terrain supérieur)

Cette article refléte les résultats du fonctionnement du modèle à l'ordinateur imitant les processus thermals, humides et chimiques dans le sol, il y a aussi l'analyse des résultats, les diagrammes pour la découverte des zones de l'influence des communications souterraines et élaborées les recommendations pour les recherches ingénierie-géologiques dans les région avec la charge technogenique augmentée.

Keywords: impact, geographic information systems, geology of cities, numerical models, thermal properties, till.

INTRODUCTION

A succession of Quaternary glacial deposits with preponderant moraine soils (till) is most widely distributed in the Moscow City territory, and these deposits are in most cases the deposit that foundations of buildings and structures in this territory are based.

At the same time, the volumes of soil with anthropogenic changes in their properties are continuously increasing due to the growing technogenic impacts, and these soils form soil masses that are very extensive both throughout the area and down the sequence. The technogenic impacts include: static and dynamic loads from buildings and structures, territory underflooding and exsiccation, soil pollution, groundwater depletion and pollution, as well as physical, chemical, radiation, biological, and other impacts upon the geological environment. It is imperative to outline technogenic impact zones and determine their depth in the process of engineering geological surveys, to construct technogenic burden maps, and to determine the trend and the character of possible alterations in the composition and consistency of the soils under influence of technogenic impacts.

There is so far no unified technique for technogenic impact assessment that, in particular, include influence zones determination. This problem is of a paramount importance in engineering surveys of megapolis areas, since it is impossible to investigate and outline soil masses with anthropogenic alterations without knowledge of the inferred zone and the source of technogenic impact.

STUDY TARGETS AND TASKS

Examination of technogenic alterations in moraine soils and elaboration of a technique for integrated calculation of technogenic impacts within residential areas in Moscow was the principal target of this study. For this purpose, the following problems were solved:

1. Determination of the most typical sources of technogenic impacts within the residential areas and elaboration of parameters for assessing their intensity.
2. Elaboration of a technique for calculating the technogenic effects within a survey site or area.
3. Examination of the chemical and mineral composition of the moraine deposits and of the structure and properties of these soils in their natural state and after anthropogenic alterations.
4. Determination of the principal chemical compounds in the moraine deposits that are most sensitive to technogenic impacts.
5. Examination of the general and specific relationships between technogenic impacts (thermal, underflooding, or changes in moisture content) and the state, composition, structure, and properties of the moraine deposits in Moscow.

This study was based on factual data accumulated by the present authors from over 140 survey sites throughout Moscow as well as those from archived materials and a database of determined physical and mechanical properties in 5500 soil specimens from the Quaternary deposits in Moscow.

SOURCES OF TECHNOGENIC IMPACTS

The coeval moraines in various parts of the Moscow area are little different from each other in their composition, structure, and the principal indices of their physical and mechanical properties. This implies that the dramatic differences between the composition and properties of these soils and the background values are caused by local technogenic impacts.

The following are the principal ones:

1. Soil weathering processes, which are different in various parts of the city.
2. Moisture content in soil successions, which is determined by natural factors (climate, precipitation, percolation, and surface runoff).
3. Build-up character of various areas, which is taken here as the duration of their economic development, the condition of underground pipelines (underflooding, pipeline leakage), and the build-up type.

The main types of technogenic impacts in the residential areas include the following: underground water pipelines, heating pipelines, technogenic disturbance of the soil surface, and its screening by asphalt covers and buildings. The necessary data concerning the condition of a site and the possible technogenic burdens can be obtained from a topographic plan showing underground pipelines. The information was collected and accumulated using digitization and vectorization of topographic plans, geological sections and columns, data of laboratory studies, and thermal field modeling.

The techniques of quantitative evaluation of the technogenic impacts (thermal, hydrodynamic, chemical, and physicochemical) suggested by the present authors (Koshelev, Sokolov, & Korolev 2001) allows the relationships between them and the composition, structure, state, and properties of soils within limits of individual survey sites to be determined.

Heat losses from heating pipelines, the length and cross-section area of the pipelines allows the introduction of a parameter such as the thermal burden on the site ($Q_{thermal}$, W/m^2 hr). This is calculated from the ratio between the total norm heat losses and the site area.

The site saturation with water pipelines is evaluated from a parameter, which the present authors termed as the water pipeline load. It is calculated as the ratio between the volume of water pipelines crossing the site (including the heating pipelines) and the site area Σ_{pipe}, liter/m^2.

Technogenic transformation of the soil surface, i.e., nature of the territory build-up, asphalt covering, and the presence or absence of soil-vegetable cover, considerably affects the soil masses and is evaluated as a share of technogenic disturbance of the site surface (S_{surf}, %). It is calculated as a proportion of all areas covered with asphalt, structures, and man-made soils relative to the total site area. An index of screening the soil succession (S_{screen}, %) is suggested for evaluating the possibility of free moisture evaporation; it is calculated as a ratio between the total area of asphalt and buildings cover to the total site area.

For the purpose of computing the above-listed indices, the geoinformation system project incorporates areal, linear, and point objects with their proper and external databases and all other available information. The areal objects and their databases include buildings and structures with their number of stories and, when possible, their foundation depths; the project also contains the area and character of the vegetable cover, asphalt-covered sites and roads subdivided into categories (highways, streets, passages and their widths), areas with removed top-soil, etc. Thus, areal objects are delineated within a site and are used for calculating parameters of the surface condition (S_{surf}, S_{screen}). The linear objects with their databases include underground water and heating pipelines. Their databases contain the number, diameters, burial depths and volumes of the pipelines, and the norm heat losses, which are subsequently used for calculating the parameters Σ_{pipe} and $Q_{thermal}$. The point objects and their databases include sites of borehole drilling, sampling, outcrop descriptions, groundwater level measurements, etc.

The elaborated geoinformation system project will allow the determination of technogenic impact values from various sources. For instance, areas of soil capillary wetting can be determined depending on the areas of asphalt covers, influence zone from water pipelines, etc., even in a case when there are only the values of physical and physicochemical properties of the soils available.

THERMAL IMPACTS

The technogenic thermal impacts from heating mains were investigated by directly measuring soil temperatures and by computer simulation of thermal fields. The seasonal operation of heating mains requires the construction of different models at the ends of the winter and summer seasons.

For a more reliable comparison between the study results, the present authors used data obtained during specified periods, viz.: at the end of the summer (in September) and at the end of the winter (in March). The temperature measurements in boreholes and the thermal field simulation have resulted in constructing temperature variation curves in the soils down to a depth of 20 m, Figure 1.

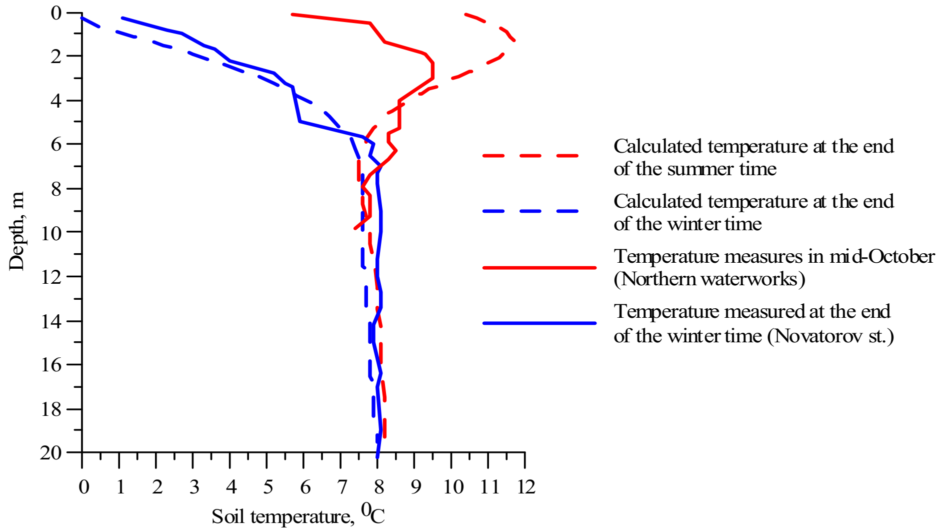

Figure 1. Comparison between calculated and measured soil temperatures

Based on the presented calculation and measurement results, the depth of a layer of zero annual variation amplitude can be deteremined. The temperature at the base of the annual variation layer, i.e., in the zero annual amplitude layer, is approximately 8^{0}C, whereas the thickness of the layer of considerable seasonal temperature variations in the soils (over 1^{0}C) is 7-8 m in Moscow.

The results of simulating the soil thermal fields were applied to construct plots of temperature variations with depth and for constructing geologic-lithological sections with equal-temperature contours during seasons in question.

Thermal fields in the vicinity of heating mains were computer simulated to determine the zones of influence from the mains upon the enclosing soils and the intensity of this influence, Figure 2. One can see in the model that the thermal impact upon the soil penetrates to a depth exceeding 20 m and up to 15-20 m sideways. The heating main affects stronger the underlying beds where the external climatic influence is lower. When comparing the soil heating regions during winter and summer seasons, the authors have found considerable seasonal temperature fluctuations, which embraced large volumes around the heating main. Three typical regions have been outlined, which originate around the heating main from the thermal impact upon the adjacent soils. These are as follows:

- Region of permanent soil heating up to a temperature above 25^{0}C (Figure 2, boundary 1), i.e., more than three-fold exceeding the temperature in the layer of zero annual amplitude;
- Region of soil temperature changes between 10 and 25^{0}C (Figure 2, boundary 2);
- Region of insignificant changes exceeding up to 1.2-1.3 times the temperature in the zero annual amplitude layer (Figure 2, boundary 3).

The dimensions of region 1 are relatively small and make up 2-4 m on the average at most heating mains. Region 2 is traceable within an interval of 4-11 m from the wall of the heating main channel. There, soil wetting in winter periods and soil drying in summer seasons were recorded depending on the heating main operation, amount of percolating atmospheric precipitation, and the depth of the groundwater table. The significant width of this zone and the sharp variations in the soil condition within it indicated that it was most unfavourable from the geological-engineering viewpoint.

It was found out in addition that the real heat losses exceed 1.2-fold the norm ones, which is explained by worsening the heat insulation of the pipelines with time.

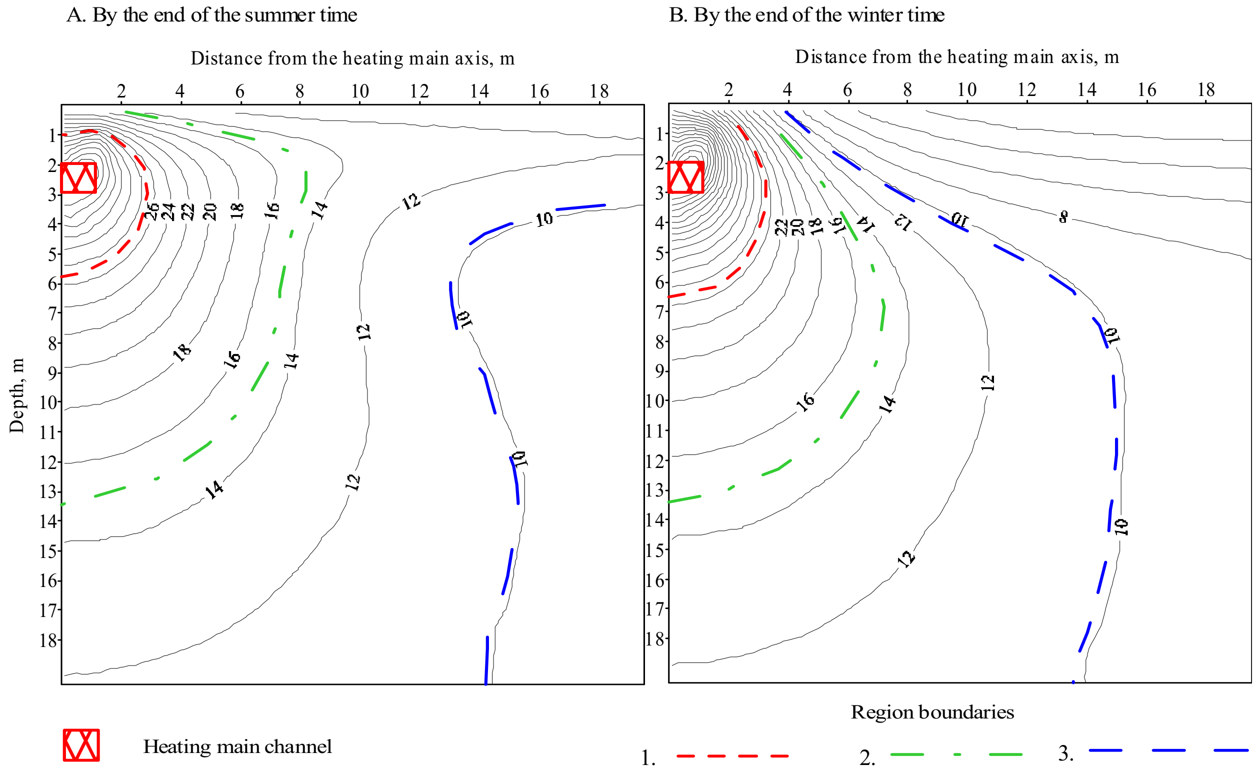

Figure 2. Calculations of the thermal impact from a heating main consisting of six 150-mm pipelines upon the enclosing soils; the boundaries between three outlined regions 1,2 and 3 are shown at the end of summer and winter.

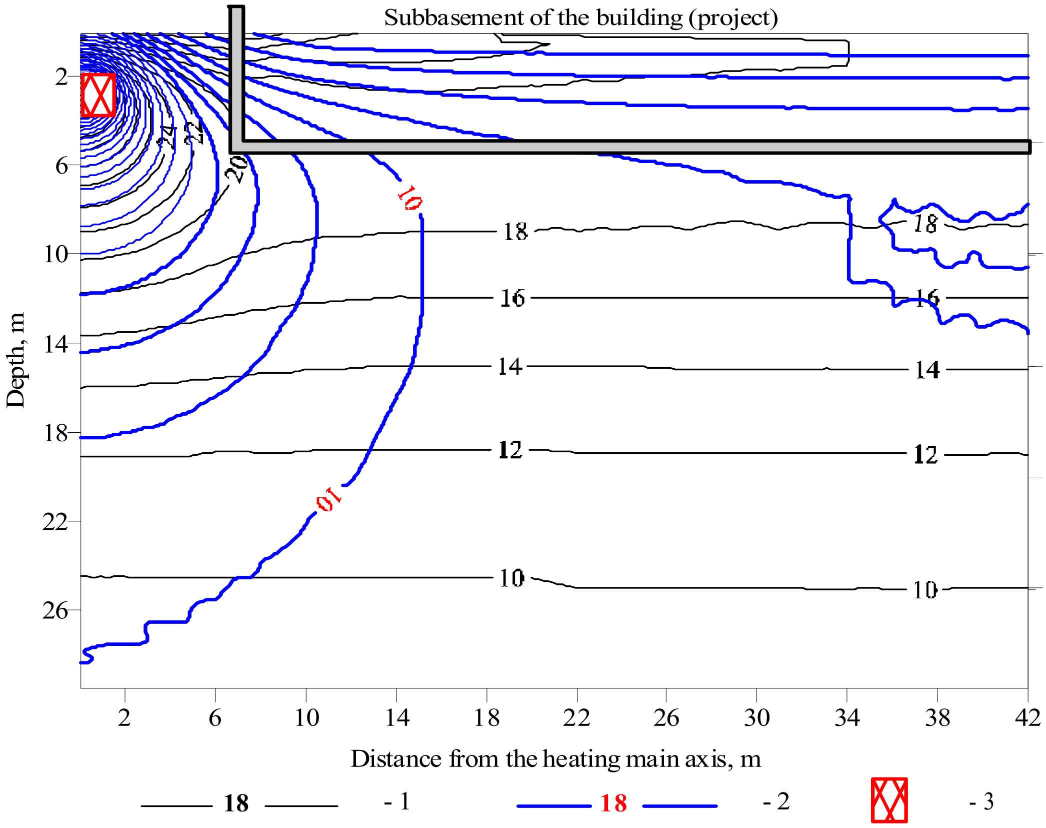

Figure 3. Calculations of the thermal impact from a heating main consisting of two 500-mm pipelines and from the planned building upon soils in the survey area (by the end of the winter time). 1. Calculated soil temperature contour lines at combined impact from the heating main and the planned building; 2. Calculated soil temperature contour lines at impact only from the heating main; 3. Heating main channel

In addition to the heating mains, there are other sources of thermal impacts in cities. Heated building basements represent the most common of them. The authors calculated, using the simulation possibilities, the combined effect from the heating main and from the planned building. Figure 3 shows the simulation results of the soil temperature field from the heating main alone and from combined effect of the planned building and the heating main.

It can be seen in Figure 3 that the temperature field completely changed when the combined effects of the building and the heating main are taken into account. First of all, a region between the heating main channel and the building has appeared where an additional soil temperature rise is predicted to be 6-8^{0}C after the building construction. It is expected that the seasonally frozen soil layer from this region (8 m wide) will disappear and, consequently, a complete percolation of the melt water into the soil. A region approximately 8 m in depth of permanent soil heating to double the temperature than the background value, i.e., up to 16-18^{0}C, will originate under the building basement. This may result in structural alterations in the soils and in activation of deformation processes. Hence, the heating main impact upon thermal field in the soil succession can increase many times due to construction of buildings and structures, which will be accompanied by formation of regions of permanent soil heating to temperatures exceeding twice the background values.

To analyze the changes in the pore space of the soils, specimens from boreholes drilled in different temperature regions around the heating main were compared, Figure 4. Borehole 3 is located in the temperature zone 2, boreholes 5 and 1 are in zone 3, and borehole 2 is beyond the limits of the heating main influence zone.

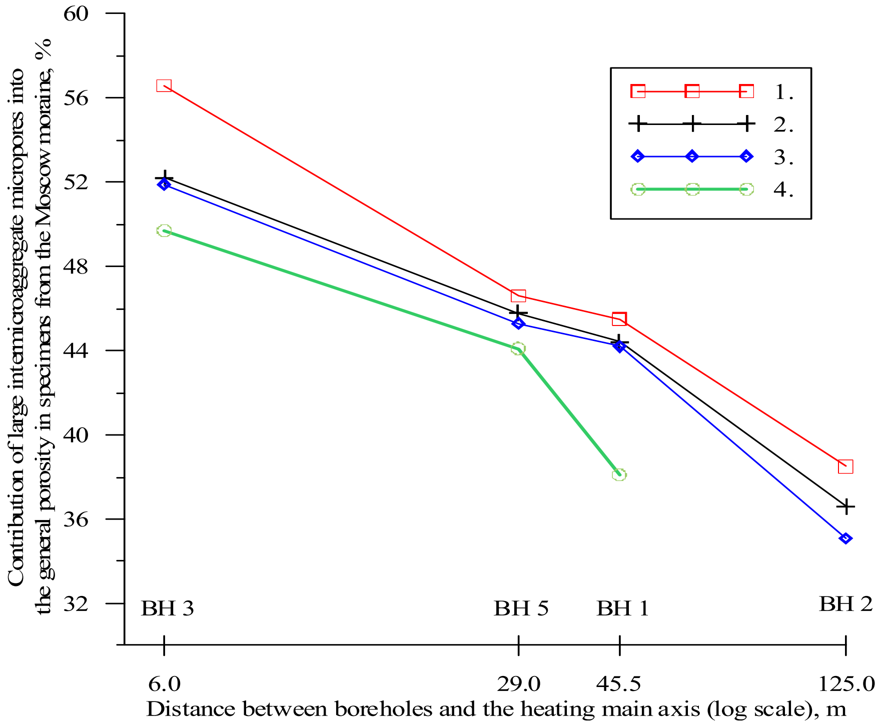

Figure 4. Changes in the contribution of intermicroaggregate micropores into the general porosity of the Moscow moraine gQ_{II} layer depending on the distance from the heating main in Novatorov st.; specimen collecting depths are: 1 - 4.0 m; 2 - 5.2 m; 3 - 6.2 m; 4 - 8.1 m.

The thermal impact from the heating main, results in a change in the soil microstructure parameters. The intermicroaggregate micropores are particularly sensitive to thermal impacts. Near heating mains, a stable growth in the proportion of large intermicroaggregate micropores in the total soil porosity and a decrease in the soil strength were recorded. This regularity can be explained by several causes. First, a temperature rise results in particle aggregation and, in closed systems, in a growth of the pore water pressure, which can bring about pore expansion. This gives rise to an increase in the proportion of the least resistant large intermicroaggregate micropores 10-69 µm in size. Second, reiterated wetting and drying cycles in moraine soils can also result in particle aggregation and bring about an increase of large intermicroaggregate micropores.

The influence of technogenic thermal impacts upon soils was investigated by comparing the thermal field simulation results and the indices of strength and deformation properties, which were determined by means of cone penetration testing (see Figure 5) and by an unconsolidated shear technique. It was found out that a region of considerable decrease in the unit sleeve friction resistance and in the shear strength occurs near the heating mains. This suggests a change in the structural bonds. The results obtained support data on the change in the pore space character in soils near heating mains.

Thus, considerable seasonal changes in the soil properties take place around heating mains, and two principal scenarios of technogenic thermal impact upon moraine soils may be realized in city territories. In an open system, i.e., with the possibility of free pore-moisture evaporation and percolation, there occur seasonal changes in the soil moisture content and in the soil strength. Conversely, in a closed system, where free evaporation of pore moisture is impossible from heated soils (for instance, asphalt covers, embankments, etc.), so a permanent growth of moisture content and decrease in soil strength and cohesion values takes place.

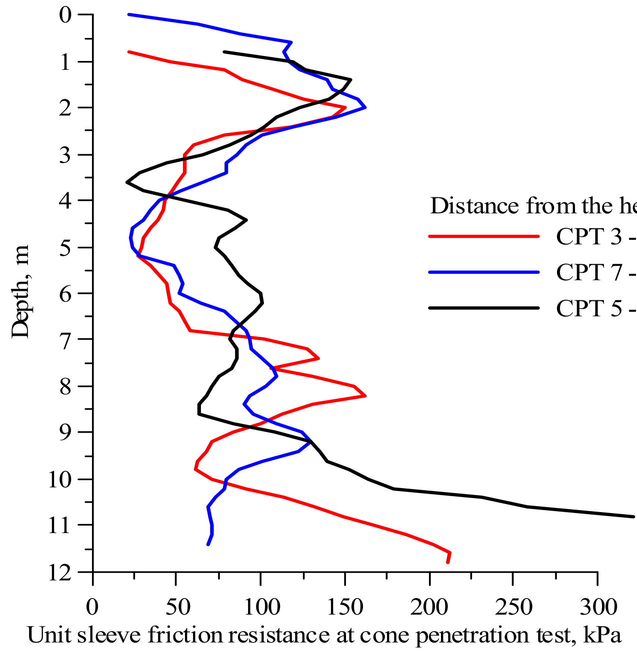

Figure 5. Plots of unit sleeve friction resistance at cone penetration tests (CPT) in Novatorov st.

Application of numerical methods of technogenic impact evaluation allows determination of the inferred zones of heating main influence and its intensity. This, in turn, provides for a possibility to purposefully examine and delineate soil masses that underwent anthropogenic alterations. Figure 6 shows the simulation results of thermal impacts, which demonstrate how many times the calculated average annual soil temperature (T_{av}) at a specified depth and distance from the heating main exceeds the background value (T_b).

Using this model, it is possible to explore borehole profiles and assign the depth and soil sampling intervals in such a way as to characterize the zones of the heating main influence.

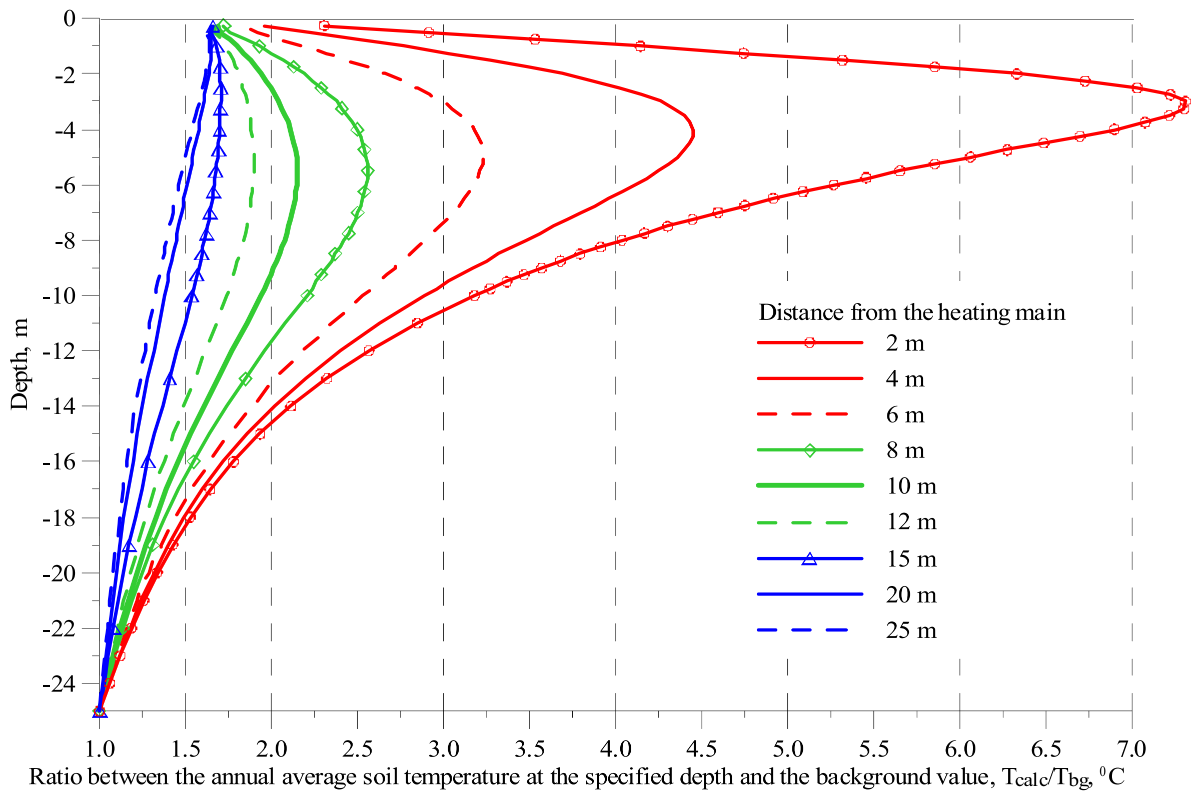

Figure 6. Calculation of heating main influence zones at heat losses of heating main channel, q = 70 W/m^2·hr

TECHNOGENIC MOISTURE FIELDS

Soil successions in urban areas display rather complex moisture fields, which determine in many respects the geological-engineering parameters of a succession. The moisture field is an intrinsic, in the given soil succession, distribution of soil moisture down the section and throughout the area that has become stable under action of internal and external factors and which is subject to regular seasonal and perennial variations.

Influence of structures and pipelines upon underflooding processes

Using the techniques elaborated by the present authors, several survey sites underlain by similar Quaternary deposits with moraine loam were studied (Koshelev, Korolev, & Sokolov 2003). No groundwater had been tapped in the Quaternary deposits prior to the build-up. Technogenic disturbance of the surface and impacts from underground pipelines were evaluated at all the sites. The survey sites are considerably different in terms of impacts from underground water pipelines as shown in Figure 7. The parameter Σ_{pipe}, l/m^2 values vary from 0.1 to 4.5 l/m^2.

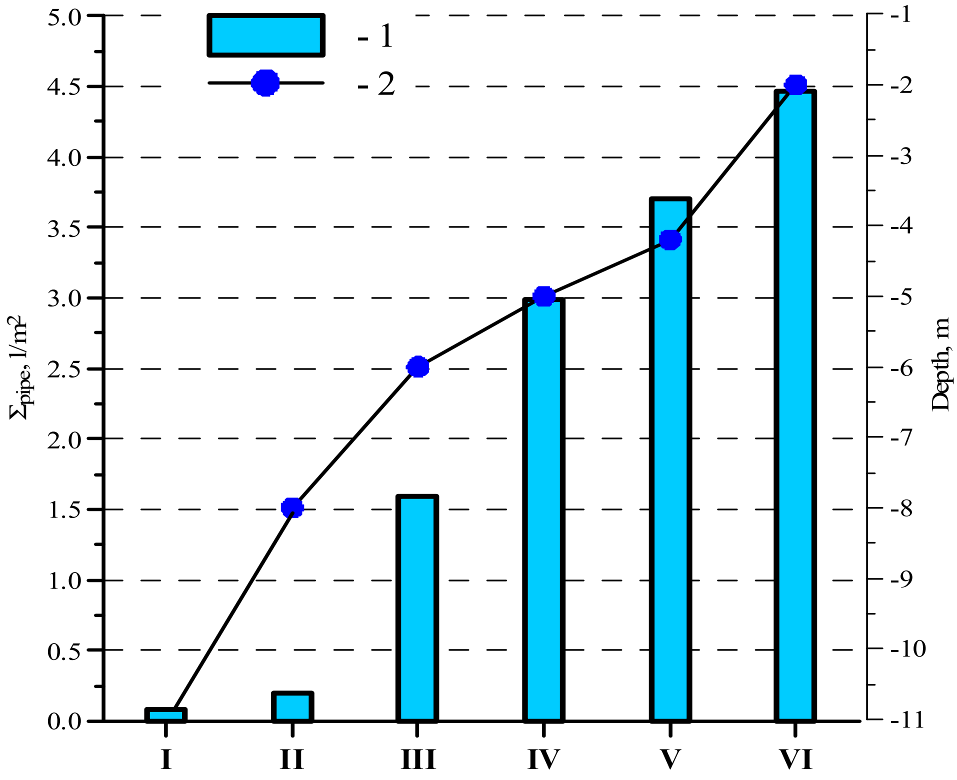

Figure 7. Comparison between groundwater table depth and impacts from water pipelines in various survey sites: 1 - impact from water pipelines in liters per square meter of the site area, Σ_{pipe}, l/m^2; 2 - groundwater table depth with reference to the ground surface, m. Survey sites: I - Udal'tsova st., 27; II - Udal'tsova st., 5; III - Leninskii ave. 98; IV - Leninskii ave. 116; V - Leninskii ave. 128; VI - Udal'tsova st., 3

Figure 7 compares groundwater levels measured in the process of the survey in winter time (from December through February) and the loads from water pipelines. An excess of a certain threshold value in the volume of water pipelines crossing the site results in occurrence of groundwater in the Quaternary deposits and in permanent groundwater table rise at increasing loads from the water pipelines (Σpipe, l/m^2). The rate of groundwater table rise during the 40-year period was 30-40 cm/year. Therefore, a technogenic groundwater horizon with the table depth of 2-7 m, originated in the study territory due to compact urban build-up.

Alterations in the moisture degree in soils

Underflooding of silty-clayey soils does not always result in formation of a groundwater or perched water horizon, and in this case a change in the moisture content will be the principal indicator of underflooding.

The authors developed a simple technique for revealing the main regularities in the formation and seasonal changes in the technogenic moisture fields. Koshelev *et al.* (2003) demonstrated that moisture fields in moraine deposits are the most stable by the ends of the summer and winter seasons. They determine the limits of annual moisture fluctuations and the general regularities in alterations of natural and technogenic moisture fields. With the purpose of analyzing the moisture contents in soil successions, a method has been elaborated for comparing the moisture degree of soils in a specific sampling point (Sr_i) with its average value ($\overline{Sr}$) down the whole borehole depth. Plots of normalized values of soil moisture degree versus its average value down the section (Sr_i - $\overline{Sr}$) were constructed, which allowed determination of the amplitude variation, the periodicity of moisture degree changes in the soil sequence and a comparison of the sites with one another. The average ($\overline{Sr}$) value in the plot was taken as equal to zero. Then, a negative normalized value indicates soil drying, whereas a positive one shows soil wetting. Comparison between the moisture fields in different soil successions and during different seasons boils down to analyzing the intensity and periodicity of moisture fluctuations. Changes in moisture degree were investigated within a depth interval between 1-2 and 15 m, which was determined by the thickness of the examined geological sections.

Low variability in the moisture degree down the sequence was recorded under natural conditions regardless of the season (Figure 8, plot A). The curves are very gentle, and the fluctuation amplitude is low. The maximum amplitude is 0.05 decimal units (d.u.), which means a change in the moisture degree ranging between 0.80 and 0.85 d.u. in most of the survey sites and does not result, as a rule, in a change of the soil consistence. Removal of the top-soil layer or covering the surface site with asphalt considerably increases as the seasonal variations in the soil moisture degree. The amplitude of moisture variations rises to 0.30 d.u., which indicates a seasonal change in the soil consistence within wide limits from solid to soft-plastic with corresponding changes in the soil physical and mechanical properties. Dramatic drying of soils in the upper portion of the section down to a depth of 5-6 m is characteristic of a soil succession with the top-soil layer removed (Figure 8, plot B) during summer season (curve 1) and sharp wetting of the soil, during autumn. This is displayed in the curve of moisture degree even for the end of the winter season (curve 2). All this suggests an increase in moisture exchange between the soil and atmosphere, and a strong dependence of the moisture field in a soil succession upon the atmospheric and climatic factors occurs. Clearly, high moisture fluctuations strongly affect the long-term soil properties. These can cause active soil weathering processes down to depths of approximately 15 m. An investigation of 10-year weathering influence of a soil succession stripped of the top-soil layer on the soil properties revealed a greater than two-fold deterioration of the strength properties.

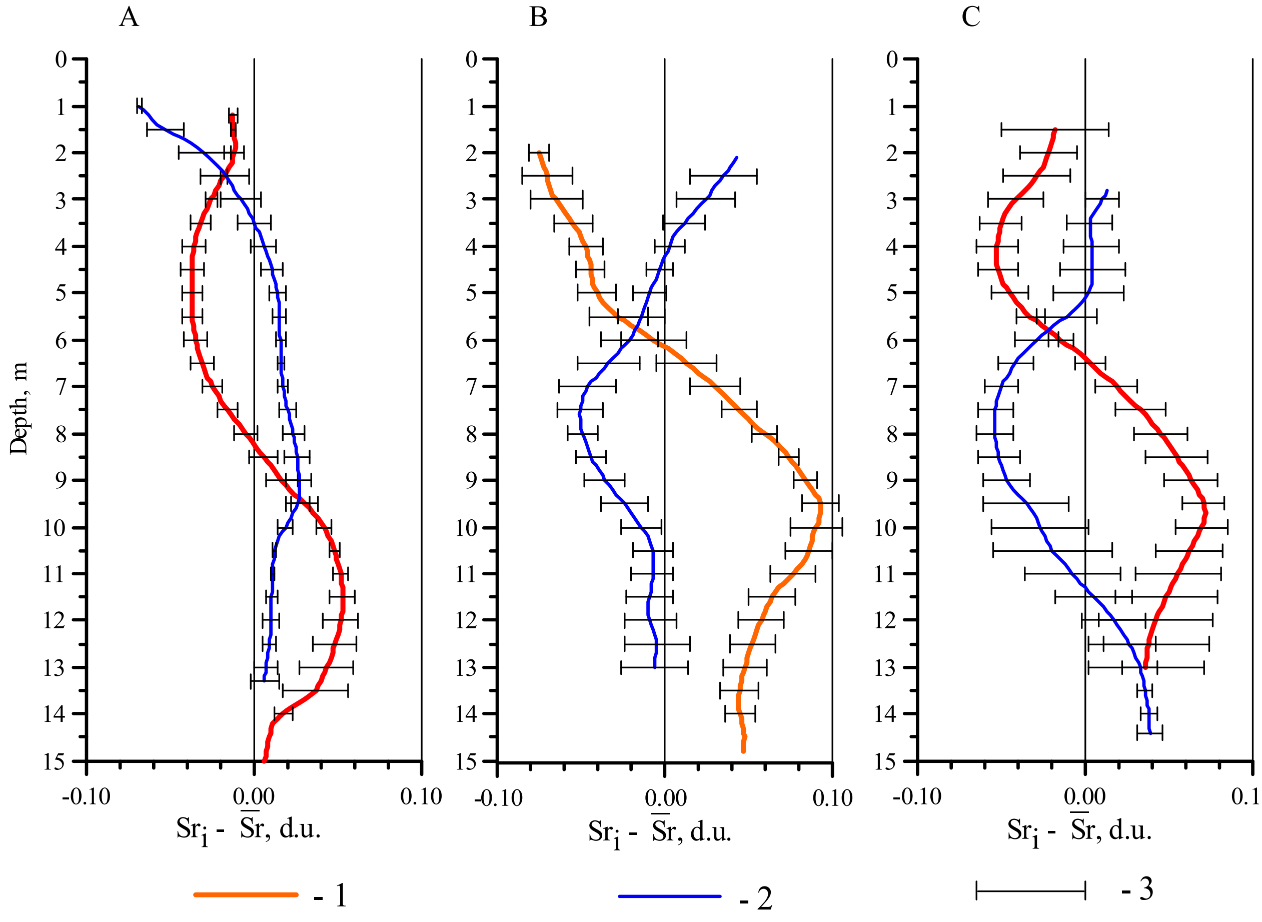

Figure 8. Variations in soil moisture degree $Sr_i - \overline{Sr}$ with depth at sites with various surfaces: A - natural surface; B - with stripped soil-vegetable cover; C - asphalted surface. Plots of moisture variation: 1 - by the end of the summer time; 2 - by the end of the winter time; 3 - standard deviation

Asphalt covers provide for stronger, than under natural conditions, heating of soil successions in summer season and their freezing in winter time (Figure 8, plot C). A distinct curve slope in the upper 2-3 m thick sequence is seen toward a moisture increase both during winter (curve 2) and summer (curve 1) seasons. This is explained by moisture capillary condensation directly under the asphalt cover in the absence of free evaporation. As a result, the soils acquire soft-plastic consistency even in summer.

Despite the differences in amplitudes, the variations in the moisture degree of soil successions show a permanent annual periodicity. This is closely related to the periodicity in soil temperature changes within the layer of annual temperature variations. The period, frequency, and the depth of fluctuations are, in the authors' opinion, the most important parameters of the fluctuation cycle of soil moisture. These parameters may be used for describing the technogenic moisture fields in soil successions. A change in the depth and frequency of variations will indicate additional technogenic impacts such as soil wetting from local underflooding sources or thermal impacts from heating mains. The soil moisture variations from technogenic disturbances of soil surface display a phase displacement relative to the natural conditions, which is explained by the great effect of climatic factors upon the moisture content. The technogenic factors act only as agents activating and considerably strengthening the climatic effects.

The formation of technogenic moisture fields in the vicinity of underground pipelines is accompanied by a change in the periodicity, frequency, and depth of moisture variations. The influence of water pipelines is related to local underflooding and water leakage. This is expressed by a decrease in the period and an increase in the amplitude of soil moisture fluctuations. For instance, in a case of free water evaporation from the soil surface, soil drying due to heating near heating mains was recorded in the upper portion of the sequence. Farther down the sequence, a ground-wetting region occurs particularly in winter and spring times due to melt water percolation, Figure 9.

On the whole, an increase in the amplitude of seasonal and off-seasonal moisture fluctuations was recorded at sites affected by technogenic impacts, and therefore the thickness of the layer increases where the ground weathering processes are active and where the ground property indices deteriorate.

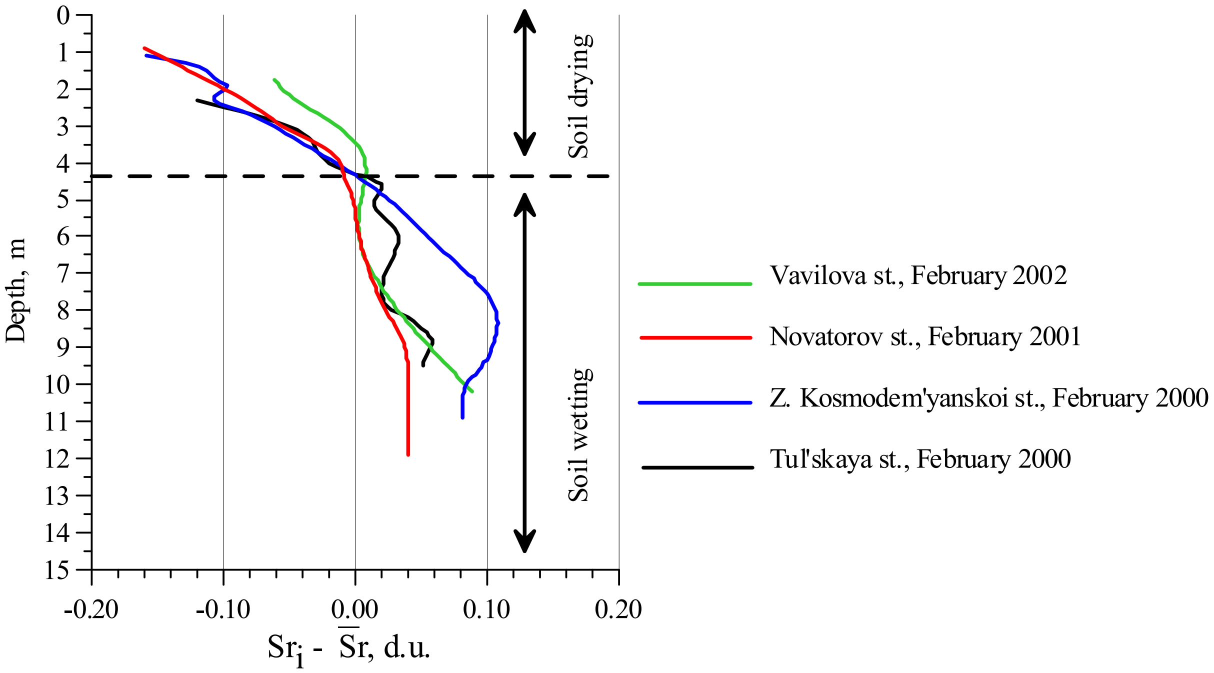

Figure 9. Variations in soil moisture degree

TECHNOGENIC HYPERGENESIS

Present-day technogenic impacts in residential zones are largely similar to natural impacts, since water and its chemical composition, as well as the temperature of groundwater and the ground are the principal acting factors. The authors therefore suggest a term technogenic hypergenesis for describing the whole set of these processes. Technogenic hypergenesis is transformation of ground composition, structure, and properties under effects of a totality of natural and technogenic factors, which are intrinsic in urban territories, under conditions that are close to natural.

In city territories, a complex combination of numerous technogenic impacts occurs even within a small area and they result in a change of chemical and mineral composition, structure, and properties of the soils. In the moraine deposits, there were recognized chemical compounds that are very sensitive to natural and technogenic impacts. They are indicators of technogenic hypergenesis and allow conclusions to be drawn on its rate and intensity. This group of compounds includes oxides of iron Fe_2O_3 and FeO, calcium CaO, carbon CO_2, and manganese MnO. The main processes of changing the moraine deposit composition in the city territory are leaching out of carbonates and redistribution of iron oxides down the sequence.

The performed studies (Koshelev, Korolev, and Sokolov, 2002) demonstrated that screening of the ground surface with asphalt covers and buildings gives rise to gleying of glacial deposits, which proceeds primarily as destruction of the ferruginous cement between mineral particles and decreases its strength. The gleying is accompanied by removal of cementing iron oxides from some portions of the succession and their redeposition in other portions where ferruginized interlayers originate. For instance, chemical analyses of samples collected from a highly ferruginized interlayer and from adjacent interlayers revealed that the ferruginized interlayer is drastically different in its composition from the enclosing soils, Table 1. It contains an anomalously high concentration of ferric oxide (Fe_2O_3), which is three times higher than that in the underlying and overlying loam. Manganese oxide (MnO) concentration shows a similar anomaly.

SEM investigations, as well as an analysis of moraine soil strength, revealed that coagulation and mixed contacts originate in non-ferruginized loam between silt and sand grains covered with clayey coats. In ferruginized soils, cementing bridges are seen between grains, which suggests preponderance of phase cementation contacts. Such contacts determine a high strength of the soil ($_{UCS}$ = 0.5 MPa, Table 1). Iron oxide (Fe_2O_3) removal from soils is accompanied by an increase in the total porosity from 24% to 30%, an increase in the maximum size of large intermicroaggregate micropores from 55.7 to 69.3 µm, and destruction of cementing structural bonds between mineral grains.

Table 1. Silicate analyses (%) of gQld moraine loam

Sampling point elevation, m MSL	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Iron modulus Fe^3+Fe^2+Mn / Al+Ti	Uniaxial compressive strength, Σ_{UCS}, (MPa)
135.6	69.96	0.75	10.54	4.68	0.30	0.04	1.24	2.64	0.44	0.12
135.4 (ferruginized interlayer)	62.43	0.71	8.25	15.68	0.30	0.15	1.25	2.68	1.80	0.50
135.2	65.21	0.73	9.85	4.86	0.31	0.06	1.84	5.37	0.49	0.10

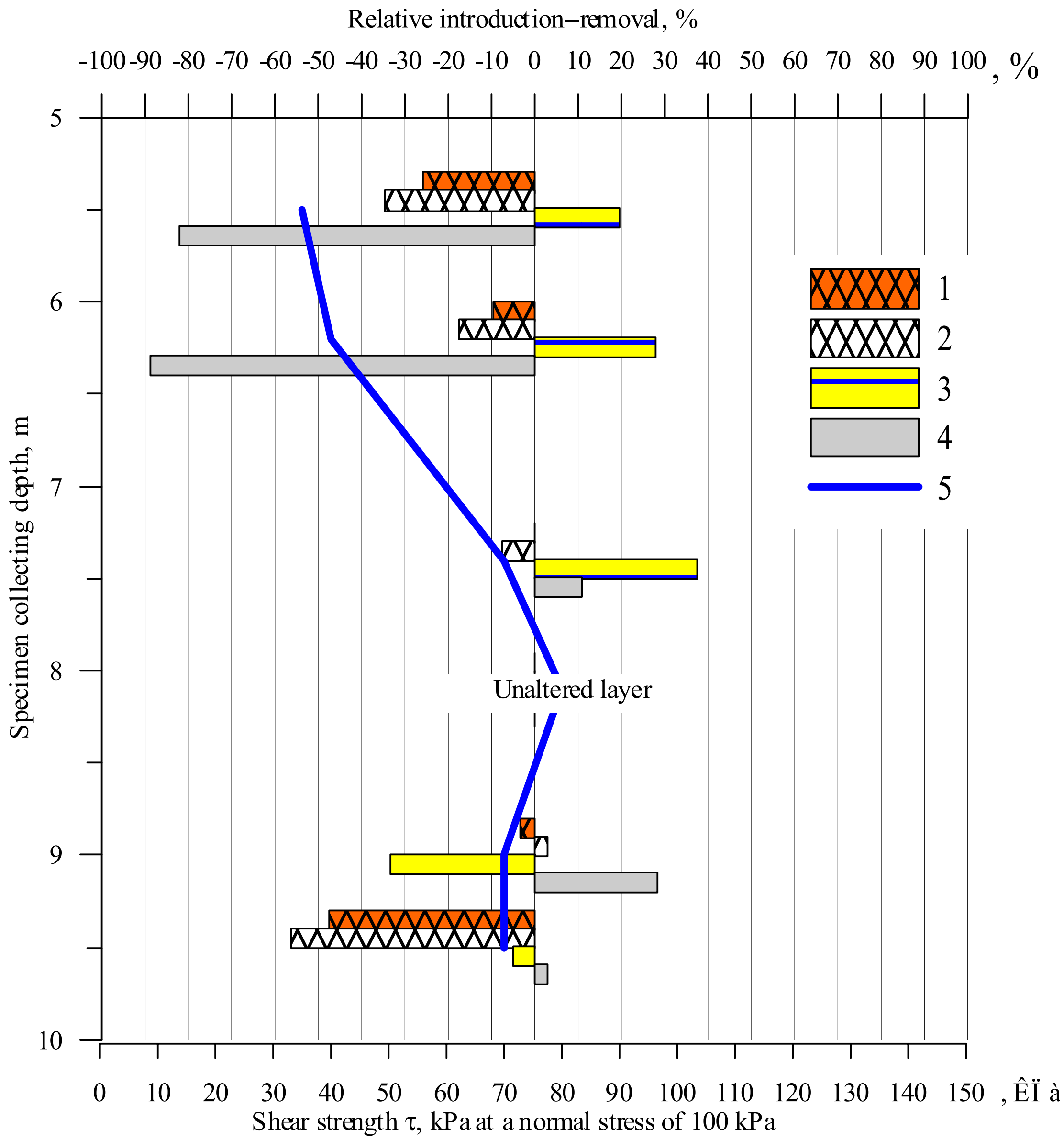

Figure 10. Plots of iron and calcium introduction and removal in gQ_1 moraine loam at the site in Nizhnyaya Krasnosel'skaya st.. Amounts: 1 - total iron oxides; 2 - Fe_2O_3; 3 - FeO; 4 - CaO; 5 - shear strength τ at a normal load of 100 kPa

The authors compared, with the purpose of examining the effect of heating mains upon the chemical and mineral composition of soils, the results of chemical analyses and the quantitative indices of moraine loams collected near large heating mains and away from them. The analysis of these results showed that carbonates were nearly completely leached out and the iron oxide concentrations considerably decreased at sites with complex combinations of various technogenic loads (hot and cold water leakage from pipelines, preponderance of asphalt covers, and dense build-up), which resulted in a decrease in the soil strength, Figure 10. Conversely, at sites with predominant thermal impacts, carbonate leaching out didn't occur regardless of distances from the main, although iron oxide redistribution in the soils was recorded.

CONCLUSION

The results obtained and the revealed regularities show that the geological environment within urban territories undergoes considerable and often irreversible alterations with anthropogenic changes. These alterations consist in a change in the soil composition and structure under various technogenic impacts that in turn cause a deterioration of the soil properties. Therefore, these factors should be taken into consideration when undertaking engineering-geological surveys and forecasts.

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REFERENCES

KOSHELEV, A.G., SOKOLOV, V.N. & KOROLEV, V.A. 2001. Change in clayey soil properties under technogenic thermal impacts. *Geoekologiya*, **6**, 519-530 (in Russian).

KOSHELEV, A.G., KOROLEV, V.A. & SOKOLOV, V.N. 2002. Specific features of chemical element migration in clayey soils under various technogenic impacts. *In: Proceedings of the Youth Conference "2nd Yanshin Readings: Contemporary Problems in Geology", Moscow*. Nauchnyi Mir, Moscow. 385-388 (in Russian).

KOSHELEV, A.G., KOROLEV, V.A. & SOKOLOV, V.N. 2003. Assessment of technogenic moisture fields in urban territories. *Geoekologiya*, **1**, 61-69 (in Russian).