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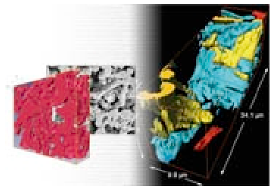

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Zoning of the Kazan City territory by the foundation soil stability to dynamic impact

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Abstract

The article presents the results of zoning of the Kazan City territory by dynamic instability of the foundation soils. The work is based on mathematical analysis of databases of the geological environment digital model constructed by the results of drilling more than one thousand boreholes. This GIS model incorporates all the environment components necessary to evaluate the occurrence possibility of soil dynamic instability patterns: spatial location of sands, their grain-size composition and the database of mechanical properties of soils and rocks. A complex of some criteria such as the soil occurrence depth, degree of humidity, relative density made it possible to distinguish the soil conditions subtypes and also to construct the map of potentially possible dynamic instability for the city territory.

Keywords

Kazan, zoning, foundation soil, stability, dynamic impact.

1 Introduction

In 2006-2008 the Department of General Geology and Hydrogeology in the Institute of geology and oil and gas technologies of Kazan Federal University (Russia) has developed a permanently operating geological environment model for the system of hydrogeological and geodynamic monitoring of Kazan city area [1].

Besides the available authors' field and experimental data results of geotechnical surveys made by various enterprises (data from over a thousand geotechnical boreholes) have been used.

The resulting digital model of the geological environment to 1:25 000 scale reflecting geological, geomorphological, hydrogeological and engineering geological conditions, including also maps of ground water levels and chemical composition, types of soil massifs, types and thicknesses of artificial soils, distribution of geological and anthropogenic processes and containing information of mechanical properties of soils in various units.

Input a scheme of loads from buildings and other structures onto the model made it possible to fulfill the city area zoning with respect to technogenic static loading.

At present the authors try to apply this model for the evaluation of risk of occurrence of unfavorable geological processes from the application of dynamic loads.

Kazan city area is located in the east of the East-European platform on the left bank of Volga river and at the mouth of Kazanka river. This area is characterized by the typical for platform regions geological structure: Archean-Proterozoic crystalline basement is overlaid by carbonaceous and terrigenous Devinian, Carboniferous and Permian rocks, and the upper part of the geological section is composed of the Neogenic-Quarternary alluvium incisions of Volga and Kazanka. The soils composing the units of Quarternary alluvial terraces serve as the bases for the majority of engineering structures. They are represented by interbedding of clays, loams and silts with varying consistency as well as of sands with different grain-size composition and saturation degree. Clay soils, as a rule, predominate in the upper part of soil units. The upper part of geological section in the historical part of the city and in low parts of the area is composed usually of reclaimed sands (aggravated and sand fills), more rare – of clay soils and heterogeneous reclaimed soils. Within the floodplain and low terraces of Volga, Kazanka and their minor tributaries groundwater level occurs at the depth not exceeding 3 m, whereas within high river terraces it is, as a rule, deeper than 15 m. The detailed description of composition and structure of soil units as well as their spatial location are presented in the "Results" section.

2 Methods of study

2.1 Zoning criteria

Analysis of the engineering geological conditions of the city area has been performed from the point of view of the possibility of negative consequences of dynamic loading not considering its real existence and intensity.

The survey of published literature containing the data about the consequences of dynamic loading of soil bases, allows to conclude that soil response is sufficiently influenced by the overburden stress directly related to soil depth. Thus, cases of occurrence of considerable strains from dynamic loading are practically unknown for the soils deeper than 10-15 m [2]. On this basis the studied soil thickness was limited by the upper 15 meters. Moreover, many observations and experiments of different authors demonstrated that the bases composed of cohesionless soils were more susceptible to deformations under dynamic loading. So, the occurrence of both natural and reclaimed sands of any grain-size composition within the upper 15 m of geological section has been admitted as the first zoning criterion of a potential dynamic instability.

Typical responses of sands to dynamic loading are additional compaction, decompaction, liquefaction and cyclic mobility [2].

Each of the mentioned response patterns has a specific set of criteria that should be considered in zoning purposes with respect to stability of soil bases to dynamic loading (Table 1):

1) Additional compaction is possible for sands of any saturation degree but at a certain relative density, and the critical values of the latter are determined primarily by grain-size composition [3]. So, the only criterion for prediction of soil compaction is its void ratio.

2) Decompaction occurs only in dense sands with low moisture content and critical void ratio being determined by their grain-size composition. Due to this fact the sites with possible decompaction of sands should be located basing on criteria like saturation degree and void ratio.

3) Liquefaction related to quick pore pressure build up and the abrupt loss of foundation bases bearing capacity is probable only to saturated sands of any grain-size composition. Thus, saturation degree of sands is the most important criterion for location of sites with probable liquefaction under dynamic loading.

4) Cyclic mobility followed by the shear strains accumulation is typical in dense saturated soils. So, the zoning criteria with respect to such a dynamic response pattern are void ratio (its critical values being determined by grain-size composition) and saturation degree.

Therefore the following criteria for zoning of the city area with respect to the type of potential dynamic instability of soils (additional compaction, decompaction, liquefaction and shear strains accumulation) have been used:

1) occurrence of sands within the upper 15 meters of geological section;

2) soil saturation ratio;

3) relative density of cohesionless soils.

The quantitative zoning criteria are presented in Table 1.

Table 1. The quantitative zoning criteria for sites with cohesionless soils.

Dynamic instability pattern	Void ratio		Saturation ratio
Additional compaction	Silty sand	>0.80	arbitrary
	Fine sand	>0.75	
	Gravelly, medium sands	>0.70	
Additional compaction	Silty and fine sand	≤0,60	0÷0,5
	Gravelly, medium sands	≤0,55	
Shear strains accumulation		≤0,60	0,8÷1
		≤0,55	
Liquefaction	arbitrary		0,8÷1

2.2 Zoning with application of GIS model

GIS model of geological environment of Kazan city area to the scale 1:25000 developed in ESRI – ArcGis 3.3 software has been used as a basis for zoning [1], [3]. This GIS model incorporates all the environment components necessary to evaluate the occurrence possibility of soil dynamic instability patterns listed in Table 1: spatial location of sands (in the plane and in the section), their grain-size composition and the database of mechanical properties of soils and rocks attributed to the layer of geotechnical boreholes (total 1057 boreholes 15-75 m deep).

At the first stage of the zoning process the sites with soil units containing natural and reclaimed sands to the depth of 15 m have been distinguished basing on the existing analytical and synthetic maps in GIS model. Then, different types of soil units were distinguished basing on their position in geological section and relatively to ground water table.

At the second stage the data of sands density and saturation ratio have been spatially attributed by corresponding of the data from specific points (geotechnical boreholes with soil mechanical properties database) to polygons (sites with a certain type of soil unit). In case of disagreement of the data between two adjacent point with respect to any of selected criteria resulted in subsequent division of the polygon.

In this way the city area has been divided into elementary sites (minimal taxons) characterized by that or those genetic type of sand with a certain grain size, void ratio, saturation degree and position in geological section.

At the third stage a certain type of dynamic instability pattern according to Table 1 has been attributed to each minimal taxon.

All the logical operations have been performed using "Master of spatial operations" module in ArcGis 3.3 as well as directly in the attributive table of the digital model.

3 Results

Figure 1 and Table 2 present the spatial location of different types of cohesionless soil units, some hydrogeological data and information about their areas within the city territory.

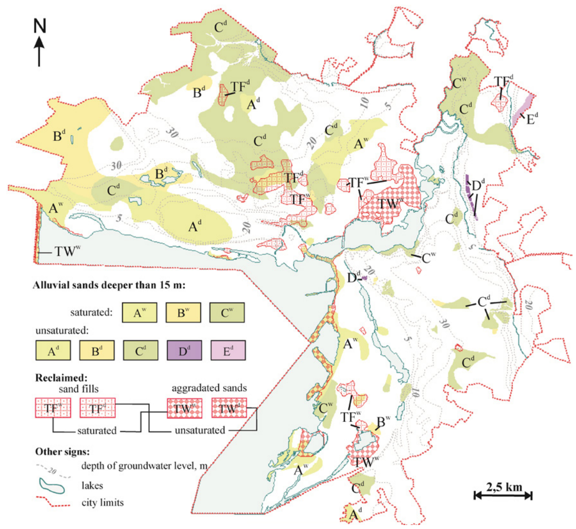

Figure 1. Map of cohesionless soil units types. Notation is given in Table 2.

Table 2. Types, origin and spatial position of soil units containing sands in Kazan city area

Geomorphological level (depth of ground water level, m)/ Structure of soil unit (letter notation in Fig.1)	City area, km^2
Low terraces of Volga and its tributaries (< 3–5 m)	
Sands (A^w)	10.6
Sands underlain by clay soils (B^w)	0.4
Interbedding of sands and clay soils with predomination of sands in the upper part of soil unit (C^w)	6.9
Sand fills (TF^w)	6.6
Aggravated sands (TW^w)	9.3
High terraces of Volga and Kazanka rivers (> 10–15 m)	
Sands (A^d)	16.2

Sands underlain by clay soils (B^d)	15.7
Interbedding of sands and clay soils with predomination of sands in the upper part of soil unit (C^d)	48.2
Sands underlain by rocks (D^d)	0.4
Interbedding of sands and clay soils with predomination of sands; at the bottom - rocks (E^d)	0.7
Sand fills (TF^d)	5.3
Aggravated sands (TW^d)	0.1

A major part of soil unit with exclusively natural sands concentrated in the upper portion of geological section is related to the combination of 3rd, 4th, 5th and 6th alluvial Quarternary terraces of Volga and Kazanka rivers (23,7% of the total city area). In these units silty and fine sands considerably prevail over medium- and coarse-grained ones. In most case they have low saturation degree due to their location over the ground water level.

Soil units with natural sands related to low terraces of Volga and its tributaries comprise only 5,2% of the city area. Silty and fine sands are also typical for these unit, however, they are mostly saturated due to shallow ground water level.

Reclaimed sands with various grain-size composition are related mostly to the 1st and 2nd terraces of large and small rivers where their thickness often reaches 5-10 m (4,6% of the city area). As a rule, they are saturated since these areas are located within the zone of hydraulic flooding.

Occurrence of reclaimed sands is not typical for the high terraces (1.5% and 0.1% of the city area for aggravated and sand fills, respectfully) where they are represented usually by sands of different grain-size composition with low degree of saturation.

Basing on the combination of criteria described above a map of zoning of Kazan city area with respect to dynamic instability of cohesionless soils has been developed (Fig.2).

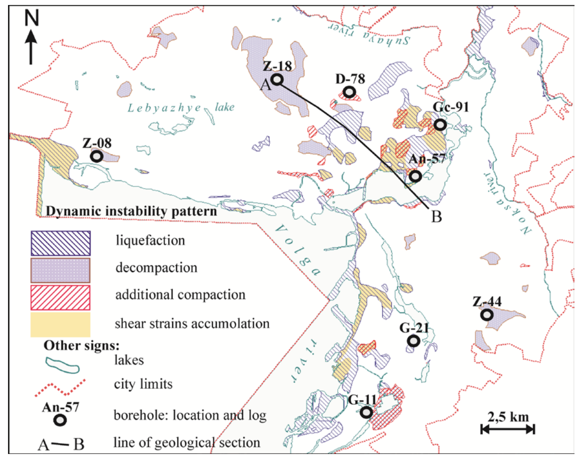

Figure 2. Map of Kazan city area zoning with respect to dynamic instability of cohesionless soils of various origin. Geological section is presented in Fig.3. Boreholes logs are given in Fig.4.

Results of zoning demonstrate that soil dynamic instability is typical mostly for Kazanka river floodplain and low terraces of Volga and Kazanka. All sands below ground water table are potentially susceptible to liquefaction independently of their origin, density and grain-size composition. Wherein shear strains accumulation and additional compaction is typical for considerable part of sands in low terraces section but decompaction is very improbable (fig. 3, 4). This is caused by their low density.

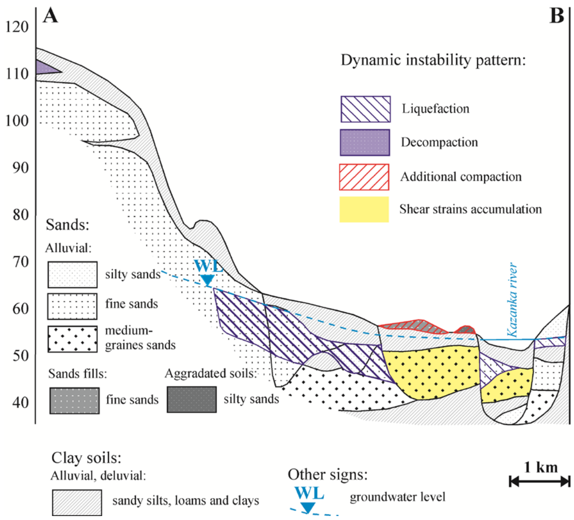

Figure 3. Position of dynamically unstable soils in geological section on the example of Kazanka river valley. The location of the section is shown in Fig.2

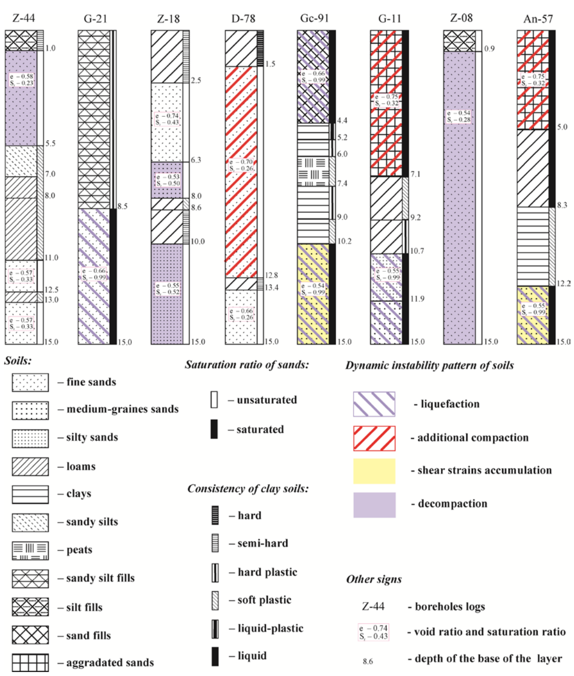

Figure 4. Geotechnical logs presenting the typical sections of cohesionless soil units and corresponding dynamic instability pattern. For boreholes location see Fig. 2

The majority of sands from high terraces section are usually stable under dynamic loading due to their high density and low moisture content, and only in few sites decompaction can be possible (both in natural and artificially modified sands) (fig. 3, 4).

Thus, the prevalent soil dynamic instability pattern is liquefaction, and the least typical – additional compaction possible mostly in sand fills and aggravated sands.

4 Conclusion

1) A preliminary zoning of Kazan city area with respect to dynamic instability of soil units has been performed basing on an integral approach considering for coincidence of several criteria.

2) 12,3% of the city area is prone to liquefaction of sands which is the prevalent pattern of soil instability here. Moreover, within approximately 4% of the city area a simultaneous appearance of liquefaction and shear strains accumulation in sands of low river terraces may occur.

3) Decompaction may occur in mostly unsaturated sand units of both natural and artificial origin (3,9% of the city area) located in the uppermost part of geological section of high river terraces.

4) Additional compaction of loose sands is the least typical pattern of dynamic instability (1,5% of the city area).

5) A simultaneous occurrence of dynamic additional compaction and shear strains accumulation in the same soil unit is possible due to the co-existence of both loose and dense sands at different depth.

6) Further specification of the zoning is possible after sufficient number of laboratory

and field studies.

Acknowledgments

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