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ENGINEERING - GEOLOGICAL CONDITIONS OF THE TOWN OF SILISTRA

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ABSTRACT
The town of Silistra is a cultural and business-administrative center, situated at the Danube riverside at km 375-377. It has been found during the I-st century and during the Rome and Turkish days it had played a role of an important stronghold. It extends at area of 7 square km and has 62 000 inhabitants.
Silistra town is constructed at the flooding terrace (T_0) of the River Danube, the slope section (S) and loess plateau (OAL). Loess delluvial is accumulated at the rearward part of the floodplain terrace. The slope is formed in Pliocene clays and sands, covered by delluvial loess. The plateau is built from Pliocene clays and loess complex (38 m) above. The town has been destroyed or burned down several times and as a result thick embankment has been generated.
Basing on geomorphological, litophacial and engineering-geological signs the following engineering-geological regions on the territory of Silistra have been separated: 1. Region with collapsible loess type II (loess plateau); 2. Region with active slope processes and collapsible loess type I (slope section); 3 Region with technogenerative, collapsible and alluvial soils (floodplain terrace). Ground waters are Karst-leaking one in the low-Cretaceous limestone and porous one in the alluvial terrace sediments and the slope Delluvial. Geological hazard at the territory of the town is determinate primarily from the high seismicity - VIII grade on MSK, presence of collapsible loess soils type I and II, thick anthropogenerated embankments (up to 9 m), shallow groundwaters and from erosion development at the Danube riverbank.

INTRODUCTION

Silistra town is constructed at quaternary sediments. They are characterized with great diversity of genetic types, facial variety and also they have different engineering-geological behaviour. The quaternary sediments genetic types are attended to definnite geomorphologic forms. Each geomorphologic formation has a typical lithologic texture, hydrogeological conditions and lithofacial bodies with equal physic-mechanical indexes could be identified within its bounds. Geomorphological formations are generated during the Neotectonic stage (2,5 million years to nowadays). They are an important indicator for the geodynamics in the region. Their footing is formed in Pliocene clays and Barem limestone. This approach for investigation, in compliance with the geological conditions in broad aspect, has been used in studying the engineering-geological conditions in Silistra.

Geologic research has been done in the region of Silistra town by numerous scientists. Among the first researchers have been Zlatarski (1927), Bontchev and Cheshitev (1953, 1954). Neogenetic sediments are very detailed investigated by Stancheva (1966), Stoikov and Breskovsky (1966), Popov (1986), Kojumdjieva, (1981, 1989), Problems on Quaternary are discussed in published materials by Jaranov (1961), Popov (1964, 1968), Minkov (1968), Philipov and Mikova (1967, 1977, 1983), Evlogiev (1988, 1993, 2000). Engineering-geological conditions in the region are studied by Kamenov, Iliev (1963); Minkov (1968), Minkov, Dontchev, Evlogiev (1984); Brutchev, et col. (1994); Karachorov, Evlogiev, Glavtcheva (1996), All this information is a basis for the current research. Number of stock materials have been considered, belonging to "Energoproject - Sofia", RPO - Varna, RPO - Rousse and Research Laboratory in Geotechnics - Rousse, having totally 110 lithologic and geotechnical drillings and 160 soil samples. Individual drilling studies and mapping in scale 1:5000 have been done additionally.

GEOMORPHOLOGIC FORMATIONS AND LITHOLOGIC STRUCTURES

Basic geomorphological forms in the region of Silistra town are the low floodplain Danube terrace, the loess plateau and the slope between them. The town is located mostly on the floodplain and the slope (fig. 1).

Low floodplain Danube terrace (T_0). Its surface in proximity to the river has an absolute elevation 12-15 m, and the terrace is rising up to 30 m to the south. The terrace is spread out between the Danube bank and the slope. It reaches the state border with Republic of Romania to the east, and includes Aidemir lowlands to the West. The terrain is plain with a low-grade to North. The erosion footing of the terrace has absolute elevation - from -6 to -8 m. It is formed in Barem limestone with strong massive structure and in Alb marls. Floodplain terrace is built of the following lithologic varieties:

- Above the footing lies alluvium of the terrace. The cross-section starts with coarse gravel, sand - filled, having layer thickness 5 to 13 m. Gray dust-sandy clays follow, with layer thickness 6 to 16 m.
- The central and back parts of the terrace are covered from delluvial clayey loess, light brown, with layer thickness 3 to 12 m. Contemporary soil is developed on the alluvial and delluvial deposits.
- The surface of the terrace is covered by a technogenetic embankment, represented by black humus clays or loess, mixed with fragments of construction materials. It has been generated as a result of ruining the old Rome settlement Durostorum. It has satisfactory area dissemination, with maximum thickness 9 m, which is getting thinner going southward up to 3 m.

Slope (S). It covers the terrain between the low terrace and the loess plateau. The slope is slanting in its low part (at absolute elevation 30-40 m), and is becoming abrupt in height (at absolute elevation 40-80 m). The structure is the following:

- Upper Pontian dust-sandy clays, Dackian sands and bottom-middle Roman clays, marls and sands.
- Pliocene sediments are covered by thin delluvial clayey loess, which reaches up to 16 m in its slanting part of the slope.

***Loess Plateau* (OAL).** It is rising southerly from the town with absolute elevation 80–127 m. It forms wide plains, incised by several gulches. The Loess plateau is called in the geomorphologic literature old abrasive level that is generated from the Dacian lacustrine-fluvial basin. The abrasive surface of OAL is developed in Middle Roman clays at the absolute elevation 88 m during the time - period 2,60-0,99 Ma BP. The following lithologic varieties are accumulated above its surface:

- Crust of weathering from red clays, formed above the Middle Roman clays, aged 0,99-0,80 Ma BP.
- Loess complex with 38 m thickness, covering the relief like a mantle. It is built from 8 dust-sandy loess horizons (the forth and seventh one are weathered), divided from 7 buried soils of loess-like clays. The loess complex is 0,80 Ma BP aged (Evlogiev, 2000).

ENGINEERING-GEOLOGICAL CHARACTERISTICS OF LITHOLOGIC VARIETIES

Fourteen types from the lithologic varieties have been found on the territory of Silistra, which build up the floodplain terrace, slope and loess plateau (Fig. 2). Physical - mechanical indexes of the lithologic varieties are determined in result of numerous drillings (25 per km^2 average) and laboratory testing. The lithologic varieties have been also preserved as engineering-geological varieties (soils) almost everywhere. They consist of dispersed and rocky soils. The technogenetic embankment, dellivial clayey loess, alluvial clays and gravel, Pliocene clays and loess complex were studied from the dispersed soils. The rocky engineering-geological varieties occur in depth. The values of the presented physical-mechanical and strenght indices are average for the engineering-geological varieties (Table 1).

Technogenetic embankment. It is found ubiquitously within the boundary of the floodplain terrace. It has maximum thickness 9 m, and it becomes thin up to 3 m to the south, near the backside of the terrace. It is built of black humus clays and loess, mixed with ceramic fragments and constructional wastes. The consistency of the embankment is considered as having semi-plastic (I_c=0,58) to solid-plastic (I_c=0,83) for the determined natural water content w_n=26,0-26,5 %. The embankment is more compact at the forehead of the terrace and it is characterized with volume density ρ_n=1,79 g/cm^3 , volume density of the skeleton ρ_d=1,42 g/cm^3 , specific density ρ_s=2,76 g/cm^3 , porosity n=48,6 %, water saturation level Sr=0,93 and total deformation module E=80.10^{5}Pa. The embankment is not firm in the central part and it has the following characteristics ρ_n=1,66 g/cm^3, ρ_d=1,32 g/cm^3, ρ_s=2,71 g/cm^3 n=51,3 %, Sr=0,66 and E=60.10^{5}Pa.

Contemporary soil. It is formed within the low terrace on alluvial clays and clayey loess. It is built of dusty clays and dust-sandy clays. It is black-colored and contains organic substances. The thickness of the layer varies between 0,3 and 2 m. It is often replaced by embankments, and as a result it is considered as not well sustained. The consistency of the contemporary soil is semi-plastic (I_c= 0,75). The physical indices have values as follows w_n=24,8 %, ρ_s=2,73 g/cm^3, ρ_n=1,89 g/cm^3, ρ_d=1,54 g/cm^3, n=45,1 % and и strenght indices - angle of internal friction φ=21°, cohesion c=0,14.10^5 Pa.

Dust-sandy clay (alluvial). It forms well sustained layer with 6-16 m thickness. It occurs at depth from 10 to 15 m. Dust-sandy clays are grey-colored, and turn to grey-beige in the upper part of the layer. They have semi-plastic consistency (I_c=0,60), plasticity index I_p=15,7, w_n=25,5 %, ρ_n=1,93 g/cm^3, ρ_d=1,54 g/cm^3, n=43,6 %, Sr=0,90, ρ_s=2,73 g/cm^3 and E=121.10^5 Pa.

Coarse gravel. It occurs under the alluvial clays. It forms layer with thickness between 5 to 13 m that becomes thinner to the backside of the terrace. The gravel in the footing of the layer consists of gravel with bigger size and sandy filling. The characteristics are ρ_d=1,90 g/cm^3, ρ_s=2,65 g/cm^3 n=28,3 %, E=600.10^5 Pa.

Collapsible loess type I. Clayey delluvial loess from the backside of the terrace and the slanting slope belong to this type. Its thickness is between 7 and 16 m. It does not collapse under geological load and drench. It shows collapsible properties under additional load. The initial load of collapsibility is higher than the geological load for the collapsible layer (p_{ini}>p_Y). It is characterized with w_n=18,3-21,5 %, ρ_n=1,72-1,85 g/cm^3, ρ_d=1,45-1,52 g/cm^3, ρ_s=2,73 g/cm^3 n=44,3-46,9 %, coefficient of relative collapsibility δ_{col2}=0,020 under p=2.10^5 Pa and δ_{col3}=0,025 under p=3.10^5 Pa, Sr=0,56-0,74 and E=114-135.10^5 Pa.

Non-collapsible loess. It forms thin delluvial covering of clayey loess in the center of the floodplain terrace and abrupt slope.

The clayey loess is between 3 and 9 m thick in the center of the floodplain terrace. It occurs immediately above the water level. It is under the influence of subsurface water, when the River Danube water level is at high water position. This type of loess is non- collapsible under additional load.

The abrupt slope is also covered with not powerful (3-5 m) non-collapsible clayey loess. It occurs above the accumulated on Pliocene clay water body. Physico-mechanical properties of the layer show the following values w_n=14,9 %, ρ_n=1,82 g/cm^3, ρ_d=1,58 g/cm^3, ρ_s=2,75 g/cm^3, n=42,5 %, δ_{col3}=0,012 under p=3.10^5 Pa and Sr=0,54. Shallow sliding rashes may occur there in case of violation on the slope stability from excavating works.

Collapsible loess type II. The surface part of the loess complex from loess plateau belongs to this engineering-geological variety. The thickness of the collapsible zone is 21 m. Here belong first loess horizon (L1), first buried soil (B1), second loess horizon (L2), second buried soil (B2) and third loess horizon (L3). The total collapsing under geologic load is up to 75 cm, according to Minkov (1968). The initial load for collapsing about the collapsible loess is lower than the geologic load (p_{ini}<p_Y). All apprehensions about the security of the terrain and the constructions on it in case of collapsing derive from the condition p_{ini}<p_Y . The indices of load-bearing will reduce its values up to three times in case of accidental moistening of the loess base. Depending on the depth of moistening several types of deformation could occur:

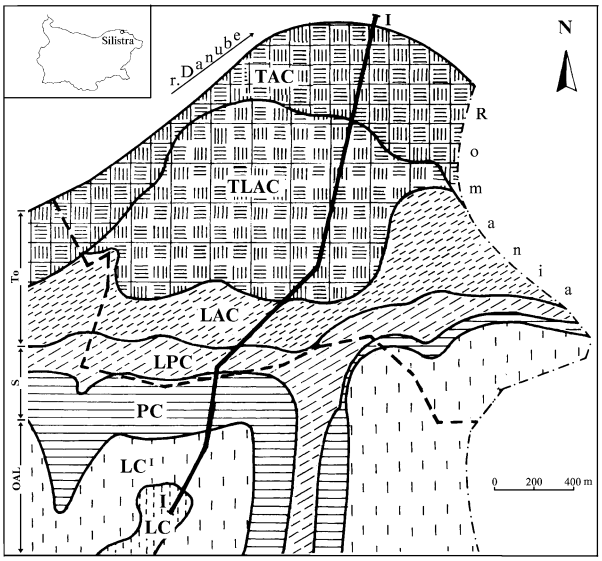

Figure 1. Engineering–geological map

I district - technogenetic, collapsible and alluvial soils: *1. Technogenetic-alluvial complex section (TAC): Technogenetic embankment – thickness up to 9 m, consistency semi-plastic, E=80.10^{5}Pa; Dust-sandy clay - thickness 6-16 m, consistency semi-plastic, E=121.10^5 Pa; Gravels - thickness 5-13 m, E=600.10^5 Pa; Water level 4-6 m. 2. Technogenetic-loess-alluvial complex section (TLAC): Technogenetic embankment – thickness up to 7 m, consistency solid-plastic, E=60.10^5 Pa; Non-collapsible loess - thickness 3-9 m, consistency solid-plastic; Water level 8-13 m. 3. Loess-alluvial complex section (LAC): Collapsible loess type I – thickness of the collapsible zone 6-8 m, δ_{col3}=0,025 under p=3.10^5 Pa, consistency semi-plastic, E=135.10^5 Pa; Dust-sandy clay – thickness 6-12 m, consistency semi-plastic, E=121.10^{5}Pa; water level 8-13 m.*

II district - slope processes, collapsible soils type I: *1. Loess-Pliocene complex section (LPC): Collapsible loess type I – thickness of collapsible zone 8-10 m, δ_{col3}=0,023 under p=3.10^5 Pa, E=150.10^5 Pa; Water level - 5-10 m. 2. Pliocene complex section (PC): Non-collapsing loess - thickness 3-5 m, δ_{col3}=0,012 under p=3.10^5 Pa; Clays and limestone clays - thickness 45 m, consistency semi-solid, E=200.10^5 Pa; Water level 5-10 m; Potential danger for development of shallow landslides and slope creeping occurrence.*

III district - collapsible soils type II: *1. Loess complex section (LC): collapsible zone 21 m, total collapsing 75 cm, δ_{colY}=0,035 under p_Y (geological load), E=150.10^5 Pa, water level 37 m. 2. Reduced loess complex section (LC^i) – thickness of the collapsible zone 6-21 m, E=150.10^5 Pa.*

Other indications: OAL – old abrasive level; S - slope; T_0 – low terrace

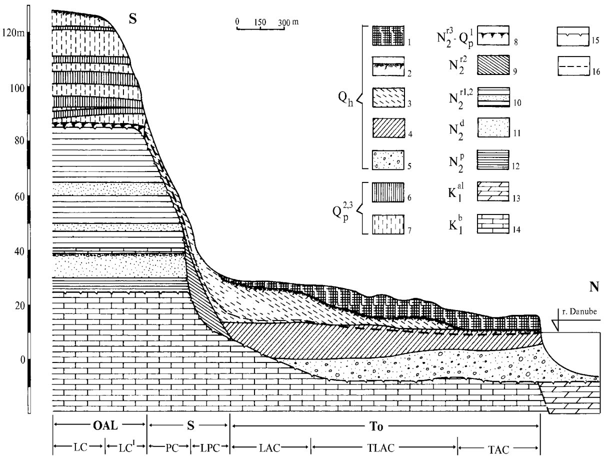

Figure. 2. Geological profile I-I

1 - technogenetic embankment; 2 -clay with organic substances (contemporary soil); 3 - clayey loess (delluvial); 4 - dust-sandy clay (alluvial); 5 - coarse gravel with sand filling (alluvial); 6 - loess-like clay (fossil soil); 7 - dust-sandy loess (eolic); 8 - sandy clay, brick-red (weathering layer); 9 - clay with grey nuts and lens sand (delluvial); 10 - alternation from clays, calcareous clays and sandy layers (lacustrine); 11 - fine to mean sand (lacustrine); 12 - dust-sandy clay, layered (lacustrine); 13 - sandy marls; 14 - limestones; 15 - erosive or abrasive surface; 16 - water level; Others: OAL - old abrasive level; S - slope; T_0 - low floodplain terrace; LC - Loess complex; LC^1 - reduced loess complex;PC - Pliocene complex; LPC - Loess Pliocene complex; LAC - Loess alluvial complex; TLAC - technogenetic loess alluvial complex; TAC - technogenetic alluvial complex; Q_h - Holocene; $Q_p^{2,3}$ - Middle and Upper Pleistocene; N_2^{r3}-Q_p^1 - Upper Roman Lower Pleistocene; N_2^{r2} - Middle Roman; $N_2^{r1,2}$ - Lower and Middle Roman; N_2^d - Dacian; N_1^p - Upper Pontian; K_1^{al} - Alb; K_1^b - Barem

1. In case of shallow moistening and presence of additional load from buildings there would be realized collapsing only in the active zone of the foundations - type I; 2. In case of moistening in depth collapsing could be provoked from geologic load only - type II; 3. In case of full water saturation of the collapsible layer both types of collapsing would be realized.

Loess horizons are built of dust-sandy loess and buried soils - of loess-like clays according to their granularity. The mean - average values of the physic-mechanical indices for collapsible zone are the following w_n=16,8 %, ρ_s=2,74 g/cm^3, ρ_n=1,68 g/cm^3, ρ_d=1,44 g/cm^3, n=47,4 %, δ_{colY}=0,035 under p_Y (geologic load), Sr=0,6; E=150.10^5 Pa.

Sandy marls. They fill the crest-like forms in the river course and the forehead of the terrace. Their thickness varies from several to 72 m. The physic-mechanical indices have the following values: ρ_s=2,67 g/cm^3, ρ_n=2,00 g/cm^3, ρ_d=1,65 g/cm^3, porosity index e=0,62, angle of internal friction φ=25˚, cohesion c=2,25.10^5 Pa, E_0=1400.10^5 Pa.

Limestone. It occurs at absolute elevation - 6 to - 8 m in the low terrace and at absolute elevation 25 m in the slope and loess plateau. Limestone here is dense, porcelain-like, strong, light-brown to white - colored, non-uniform carstified. It is stronger carstified in its upper part, and the cavities and caverns are hollow or filled with sand and red clay. Limestone has the following physical-mechanical indices: ρ_s=2,70 g/cm³, ρ_n=2,60 g/cm³, ρ_d=2,50 g/cm³, e=0,08 and strenght indices φ=33˚, c=40,0.10⁵ Pa.

Table 1. Mean average values of physicomechanical characteristics of lithological varieties.

District	Section	Soil description	Tickness	Number of samples	Water content	Density	Dry density	Porosity	Degree of saturation	Plasticity index	Consistency index	Modulus of deformation
	-	-	m	-	W_n,%	ρ_n, g/cm³	ρ_d, g/cm³	n, %	Sr, -	I_p, -	I_c, -	E, .10⁵ Pa
1	2	3	4	5	6	7	8	9	10	11	12	13
I district – technogenetic, collapsible and alluvial soils	TAC	technogenetic embankment	4,0-9,0	3	26,5	1,79	1,42	48,6	0,93	15,1	0,58	80
		dust-sandy clay	10,0-16,0	19	25,5	1,93	1,54	43,6	0,90	15,7	0,60	121
		gravlel with sandy filling	5,0-13,0	-	-	-	1,90	28,3	-	-	-	600
	TLAC	technogenetic embankment	3,0-7,0	3	25,9	1,66	1,32	51,3	0,66	14,8	0,83	60
		clayey loess (non-collapsible)	3,0-9,0	29	22,6	1,81	1,48	45,8	0,73	15,5	0,76	-
		dust-sandy clay	9,0-13,0	19	25,5	1,93	1,54	43,6	0,90	15,7	0,60	121
		gravlel with sandy filling	7,0-11,0	-	-	-	1,90	28,3	-	-	-	600
	LAC	clayey loess (collapsible type I)	6,0-8,0	17	21,5	1,85	1,52	44,3	0,74	15,8	0,71	135
		dust-sandy clay	6,0-12,0	19	25,5	1,93	1,54	43,6	0,90	15,7	0,60	121
II district - development of slope processes, collapsible soils type I	LPC	clayey loess (collapsible type I)	8,0-10,0	13	18,3	1,72	1,45	46,9	0,56	-	-	114
	PC	clayey loess (non-collapsible)	3,0-5,0	3	14,9	1,82	1,58	42,5	0,54	-	-	-
		clay and calcareous clay	45,0	9	17,6	1,98	1,68	38,5	0,77	16,9	1,12	200
III district - collapsible soilstype II	LC[I]	dust-sandy loess (type II)	6,0-21,0	8	16,3	1,68	1,44	47,4	0,50	12,5	0,95	150
	LC	dust-sandy loess (type II)	21,0	18	16,8	1,68	1,44	47,4	0,60	-	-	150

HYDROGEOLOGICAL CONDITIONS

The ground waters in Silistra region are cavern-carstic and porous-gained waters.

Cavern-carstic waters. They are accumulated in limestone complex, at the age of Barem (The suite of Razgrad). The lower aquifer consists of Lower Cretaceous argillaceous limestones and marls from the suites of Gornaoriahovitsa and Razgrad. The ground waters are formed in carst hollows and caverns of limestone. The formed unconfined underground aquifer has general flow strike to the North. Infiltration from precipitated and surface water feed the aquifer. In Silistra region natural sources of draining are absent, with the exception of Srebarna lake, feed from carst waters of Barem aquifer. Viewing from qualitative aspect the waters are hydrocarbonic-magnesium-calcium according to their chemical composition and neutral (pH=7-8). Their mineralization is 0.4-0.8 g/l in general and rarely at about 1 g/l.

Porous waters. They are accumulated in alluvial of the floodplain terrace, slope delluvial and Pliocene sandy layers.

Alluvial aquifer is two-layered, its lower part have higher water permeability (sands and gravel) and the upper part have lower water permeability (sandy clays). The waters formed in the aquifer are semi-confined and unconfined one. The fluctuation of the water table depends on the water level in the Danube River bed. It is characterized with rich water quantity. The values of conductivity are between 250 and more than 1000 m²/d. Highest values characterize the West Industrial zone of the town. Water feeding of the aquifer comes from high waters of the Danube River, Lower Cretaceous aquifer and from rainwater flowing in from the slope (slope waters) and accumulated above the Pliocene clays. It is drained away from the Danube River during mean and low water level and from existing water extracting equipment. The mineralization of alluvial aquifer is under 1 g/l, waters have hydrocarbonic, calcium and calcium-magnesium characteristics. The water table is at 4-6 m in depth in the forehead of the terrace. The presence of technogenetic embankment and shallow ground waters results in significant difficulties for foundation works of buildings and constructions in this part of the town. The water table is at 8 to 13 m depth in the center of the floodplain terrace. The water table is higher at the backside of the terrace due to feeding from rain water, flowing in from the slope (slope waters).The aquifer of the slope is fed from infiltrated surface waters and sandy layers of the Pliocene. The aquiclude of the aquifer consists of Pliocene clay. The slope waters are accumulated at the interface between Pliocene clays and loess delluvial. They occur at depth 5-7 m at the abrupt slope and 5-10 m depth at its low part.

HAZARDOUS PHYSICAL-GEOLOGICAL PROCESSES AND PHENOMENA

Endogenetic, exogenetic and technogenetic hazardous physico-geological processes and phenomena endanger the territory and infrastructure of Silistra. Endogenetic processes are earthquakes - Silistra is situated among three seismic epicenters - Shabla, Gorna Oriahovitsa and Vrancha. Exogenetic hazardous processes are the potential dangerous shallow earth creep, slope creeping, erosion of the Danube river bank, shallow ground waters, surface erosion, flooding and marsh occurring. Technogenetic hazardous processes are the occurrence of loess soils collapsing, generation of thick embankments and terrain violation by stone-pits.

Endogenetic processes

Earthquakes. According to the macroseismic districts in Bulgaria, Silistra belongs to a region with high seismicity - VIII grade of intensity under MSK and seismic coefficient k_c=0,15. The town has experienced powerful earthquakes and bore damages on the buildings: from Vrancha earthquake with magnitude 7.2 in 1977, again from Vrancha earthquake M=6.7 and 6.1 in 1990 and from the earthquake with Strajitsa epicenter M=5.3 in 1986. The earthquake in 1990 damages 16 objects, including 7 public buildings, and the rest of them have been residential blocks. The first ones are buildings above 50 years of age, built up in the central part of the town, having damages on supporting walls and partitions. The second ones are 4-5 storeyed buildings with steel-concrete frames, built up in the central and south part of the town. The damages were a result of not effective construction design, combined with unfavourable engineering-geologic conditions (Karachorov, Evlogiev, Glavcheva, 1992).

Exogenetic processes

Landslides. Potential dangers of occurrence of shallow earth creeping exist in the extent of the abrupt slope. Slope waters at depth 5-7 m are accumulated at the interface between Pliocene clays and delluvial loess. The terrain is not built up, but future excavating works could create conditions about formation of shallow landslides.

Slope creeping. It occurs in the region of the Pedagogic Institute, constructed at the abrupt slope. The building covers wide area, the foundations are on Pliocene clays and loess delluvial with shallow ground waters. The deformations on the construction of the building are due to worsen of soil consistency and occurrence of unabating creeping of the ground. Not constructed vertical planning of the building gives unfavourable impact.

River erosion. The course of the River Danube is formed in alluvial deposits of the floodplain terrace. This fact makes easier the development of erosive processes. They recruit in April and May, when the water level in the river reach up to 670 cm above the pegel (6,5 m). The biggest part of the Danube bank is erosion protected by supporting wall. The only exception is the west part, where the bank is exposed to active undermine and dilution.

Shallow groundwaters. Shallow ones are porous alluvial waters, accumulated in the sediments of the floodplain terrace. They occur at depth 4-6 m at the north part of the terrace and originate difficulties at the foundation of buildings and constructions.

Surface erosion. It is developed in the slope section of the town. During Holocene in result of surface erosion loess complex was deluted and was deposited secondary as delluvial clayey loess, showing the biggest thickness in the low part of the slanting slope. The absence of contemporary soil gives evidence that this process continues until today.

Floodings. The top water levels registered in th eDanube River are 740 cm above the pegel (in 1942), i.e. 13.9 m absolute elevation. Danube riverbank is at 15 m absolute elevation in the central and eastern parts of the town and it is sheltered by supporting walls. Flooding endanger west industrial zone, where there are sections with lower level at the riverside. Flooding from storm water do not endanger the territory of the town.

Marsh occurring. Occuring of temporary marshlands are observed in Aidemir lowland, on the west of Silistra. They are formed in the negative lowerings as a result of shallow ground water yielding, hydraulically tied to the Danube waters. The water is retained long time in the marshlands in result of colmatage of the negative formed beds.

Carst phenomena. Barem limestones are non-uniform carstified. Cavern carstic aquifer is formed in carst formations and caverns. The caverns are hollow or filled with sand, rarely filled with red clays. Carstifying in the upper layer of the carbonate horizon is intensive.

Technogenetic processes

Collapsibility. Loess soils are distinctive with their non-firming structure and structural non-stableness. They are inclined to collapsing under self-load and additional loads if moistened.

Technogenetic moistening have caused deformations of terrain and buildings in Kalipetrovo district, built at loess plateau - type II loess base. Constructing of industrial structures is assured by anti-collapsible preparation of the loess base when the collapsibility of the terrain is type II - most-frequently by heavy beetle and improving foundation conditions by deep excavations and realization of concrete-soil pillows. The foundation of the TV tower Silistra is accomplished in the following order: realization of 7.7 m deep excavation; densification with heavy beetle; constructing of concrete-soil pillow and foundation on it at elevation 119.30 m. Water protection measures have been taken at the end of constructing.

Deformations from technogenetic moistening could occur only in the active zone of the foundations of buildings and structures at the regions with type I loess base. Such deformations are registered in the south part of Silistra.

The seismic influences are "operating mechanism" for occurrence of collapsibility if a technigenetic moistening of loess ground are present.

Teechnogenetic embankment. Larger part of Silistra territory is constructed on technogenetic embankments. At the towns center they reach 9 m depth. The embankment is non-girm and it performed unfavorable soil ground for foundation purposes. The embankment is flooding by the ground waters at high waters in the north part of the town. Under these circumstances building construction at the embankment results in deformation of these building. The new building construction is implemented with deep excavations. If the embankment overcoming is not possible, then a pile foundation is implemented.

Violation on the terrain from clay-pits. Deep excavating works in the southern part of the town have been done for the needs of the Bricks factory in the slope section. A vertical angle of friction is formed 25 m in height. There exists a danger from gravitational sliding down of the ground massive from the slope.

PRELIMINARY DATA FOR ENGINEERING-GEOLOGICAL DISTRICTS DEFINING

It is developed preliminary engineering-geological districts defining on the territory of Silistra based on the determined geomorphologic-lythostratigraphical, engineering-geological and hydrogeological conditions and the hazardous physicogeological processes and phenomena that are caused. We call it preliminary because it is foreseen including of new areas (West industrial zone and Kalipetrovo district), thickening of drillings and increasing the number of tested soil samples. Here are defined three districts, according to engineering-geological conditions and geodynamic processes occurrence. The districts are sub-divided into 2 or 3 sections, according to defined differences in engineering-geological varieties (Fig. 1):

I district – technogenetic, collapsible and alluvial soils

It covers the territory of the town, situated within the bounds of the low floodplain terrace. It is built of collapsible loess, technogenetic embankment and alluvial deposits. Hazardous geological processes for this district are earthquakes, loess collapsibility (type I), thick technogenetic embankments, shallow ground waters, river-bank erosion, flooding, marsh occurring and carst. Three sections are separated at district I:

Technogenetic-alluvial complex section (TAC). It is situated in the northern part of the town, at the forehead of the floodplain terrace. It is built of non-firmed technogenetic embankment up to 9 m thick and alluvial deposits (dust-sandy clays and coarse gravel with sandy filling). The ground waters are shallow and occur at 4-6 m depth. The conditions for engineer structuring are difficult in the TAC section. The foundation is realized at high depth, and in case of impossible embankment overcoming, then a pile foundation is implemented. The shallow ground waters worsen the seismic conditions.

Technogenetic-loess-alluvial complex section (TLAC). It covers the central part of the floodplain terrace. It is also built of non-firm embankment 2-7 m thick. Underneath non-collapsible loess occurs, with thickness from 3 to 9 m and alluvial deposits. Loess is in the range of subsurface waters at high water in the river Danube. It is non-collapsible under additional load. The ground water table is settled at 8-13 m depth.

Loess-alluvial complex section (LAC). It covers the back part of the floodplain terrace. The technogenetic embankment has low thickness (up to 3 m), wherefore it is does not cause problems to foundation process of buildings and constructions. The LAC section is built of collapsible loess type I (7-12 m) and alluvial deposits. The loess does not collapse under geological load and moistening. It shows collapsible properties under additional load, in the active foundation zone of buildings and constructions only. For the collapsing layer the initial collapsing load in higher than the geological load ($p_{ini}>p_Y$). Ground waters are accumulated in delluvial loess - at depth 8-13 m. In occurrence of technogenetic moisture-overladen loess ground seismic influence provoke collapse development.

II district - development of slope processes, collapsible soils type I

It covers the slanting and abrupt slope between the floodplain terrace and loess plateau. It is built of non-collapsible loess, collapsible loess type I and Pliocene sediments. Porous slope waters are accumulated at the interface. Hazardous geological processes for the II district are earthquakes, landslides, slope creeping, collapsibility, shallow groundwaters, surface erosion and violation on the geological environment from clay-pit excavations. Based on differences in the engineering-geological conditions and geodynamic processes the district is divided into two sections:

Loess-Pliocene complex section (LPC). It is situated within the bounds of slanting slope. Its surface layer is built of collapsible loess type I, 11-16 m thick. The loess do not collapse under geological load and moistening. It shows collapsible properties under additional load. The initial load for the collapsible layer is higher than the geological load ($p_{ini}>p_Y$). The loess covers Pliocene clays and sands. The ground waters occur at 5-10 m.

Pliocene complex section (PC). This is the abrupt slope section. The loess cover is thin, non-collapsible and occurs on Pliocene clays, limestone clays and sandy layers.The ground waters are accumulated at the interface. In fulfillment of constructional or excavating works exist conditions for development of shallow landslides and slope creeping occurrence.

III district - collapsible soils type II

It covers the loess plateau territory. The loess has well defined collapsible properties. The most dangerous geological processes for the district are collapsibility and earthquakes. Two sections are defined depending on the thickness of the collapsible zone:

Loess complex section (LC). The loess complex is with its full litho-stratigraphy. The thickness of the collapsible zone is 21 m. The total collapsing under geological load is up to 75 cm. The initial load for the collapsible layer is lower than the geological load ($p_{ini}<p_Y$). The indices for load-bearing will reduce three times in case of accidental moistening of the loess ground. The ground waters are accumulated above the Pliocene clays (37 m).

Reduced loess complex section (LC^I). The LC thickness is reduced. Collapsible zone is 6 - 21 m thick.

CONCLUSION

Engineering-geological conditions of the Silistra town are complicated on the average. The soil ground of the town is built of thick technogenetic embankments, collapsible loess, alluvial clays and gravel, Pliocene clays and sands and rocky underplate from Barem limestone and Alb marls. Collapsible and technogenetic soils, causing the basic difficulties in building and constructions foundation, cover the most of the studied area. The porous waters are shallow. They are accumulated in the caverns of quaternary and Pliocene deposits and additionally complicate the geotechnical conditions. The determined engineering-geological conditions combined with geomorphologic terrain particularity are precondition for occurrence of particular geodynamic processes. The territory of Silistra is endangered from endogenetic (earthquakes), exogenetic (shallow earth creeping, slope creeping, erosion of Danube riverbank, shallow ground waters, surface erosion, flooding and marsh occurrence) and technogenetic (loess soils collapse, embankment settlement, stone-pit excavations) hazardous physico-geological phenomena and processes. Based on this geological environment the territory of Silistra is divided into three engineering-geological districts, subdivided into 2 or 3 sections each.

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