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VULNERABILITY OF SLOPING LANDS, UNDER DYNAMIC CONDITIONS

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Abstract: During recent years, a series of civil construction works have been started on all slopes from Iași Municipality. This study aims to analyse the stability of a perimeter from a southern slope of the city, in the area of Mihai Ciuca Street, Iași. For the development of a GF + 1 construction (ground floor and first floor) in this area geotechnical surveys were performed and soil samples were taken, which have been analysed by specific geotechnical methods. Starting from the values of the physical-mechanical parameters of the rocks, respectively from the aspects regarding the terrain geometry, different simulations were performed in order to identify its stability factor. These simulations took into account the presence or absence of construction, the existence of the current groundwater level or of a level close to the surface, as well as of the possibility of the occurrence of an earthquake. When we start from the hypothesis according to which all three factors act simultaneously on the researched land (the given construction load, the high groundwater level / current groundwater level and the earthquake), the values obtained are unfavourable. The results obtained for these situations indicate the following stability factors: 0.93 (when the groundwater is considered at the level of 3 m, with the loading of the construction and earthquake), respectively 1.2 (when the current groundwater level, load and earthquake are considered). These values are below the limit of the allowed stability coefficient of 1.25 (the value indicated by standards for the admissible safety factor, F_{sadm}). Also, the observations made on the field before, but also during the operation of the edifice exploitation, highlighted the punctual appearance of some geotechnical problems, which required the additional realization of some construction works (drains, retaining walls, gutters, etc.), imposing very high costs. The terrain continues to be modified by pushing phenomena on certain parts of the already existing construction, leading to the occurrence of cracks and infiltrations in the basement, to the deformation of a water tank or to the vaulting of the fence foundation. Without the adoption of specific measures to prevent the movement of land, there is the possibility of dynamization of the slope on certain parts and, consequently, this would lead to partial or total endangerment of the safety of the construction.

Keywords: slope stability, Bishop method, factor of safety, seismic conditions

1. INTRODUCTION

The chaotic expansion of the buildable perimeters, on different areas of Iași Municipality (especially on those with a high slope), has generated, in many cases, the activation of some slope processes (especially in the form of landslides). Iași Municipality has a rather turbulent history in terms of landslides. Thus, the Ursulea and Copou slopes underwent multiple remodelling over time, the first mentions of these movements being described by Macarovici, 1942. The author makes certain observations regarding the landslides that took place in the spring of that year, stating that they have existed in the past, the main trigger factor being the water (the author mentions that landslide phenomena occurred in a mostly rainy year). The slope of these perimeters is high, exceeding the value of 20%. These phenomena repeated in 1969, in the north-eastern part of Copou Hill (Băcăuanu, 1970), being registered approximately 20 ha of total or partial destruction of houses, roads, electricity network, water distribution, etc. Also, following the fall of a large volume of precipitation, in 1998 there were multiple landslides in the area of several slopes of Iași Municipality, but with more violent forms also on the north-eastern slope of Copou (Sărărie-Țicău, Târgușor), but also on the western one (Aurora, Bogdan, the Botanical Garden (Răileanu et al., 2001). The personal findings made during the recent years revealed that the slopes of the city of Iași show in many places signs of active movement (examples: in the Țicău area there is an inclined house on Crivăț street, springs appeared in the road network on Simion Bărnuțiu street, movements of the reinforcement works carried out in the '70s on Poligon street, on the other hand there are sheared drains and a displaced support wall on Toma Cozma street, the steps from the Copou Garden are deformed by the pushing of the land, etc.). The aforementioned slopes are modelled on deposits of Sarmatian age, belonging to the Formation with *Cryptomactra* (Ionesi et al., 2005).

Considering the fact that in Iași Municipality there are other less studied slope areas (in view of the fact that so far they did not present a special economic interest), which have characteristics similar to those of the areas presented earlier (high slope, belonging to the same type of formation), we consider that the idea of approaching this topic is opportune and up to date. Moreover, the overloading of these areas with different types of constructions, imprints another dynamic on the land, which can lead to punctual movements or on larger areas of the land, highlighting many problems over time. All these aspects require a careful monitoring of the respective perimeters.

1.1. General aspects

The choice to study the stability of a southern slope of the city of Iași appeared as a consequence of the performance of two drillings in the area of interest, made for a geotechnical study aimed at building a house with ground floor and first floor (Fig. 1, 2). This paper aims to develop some estimates regarding the local stability of this buildable location, in the area of Mihai Ciuca Street, Iași (Fig. 1). The analysis was performed starting from the physical and mechanical characteristics of the rocks encountered in this perimeter, respectively making some direct observations. The paper presents different simulations using the Bishop method, which involves the participation in the slope processes of the most important active factors: water, earthquake and land overload.

The researched area is located on the Racoviță Coast, in the southern part of the geomorphological unit Culoarul Bahlui, belonging to the Moldavian Plain (Băcăuanu, 1968). The hill has an average slope of 20% and has on its surface, for the time being, only a small number of houses built (Fig. 2).

1.2. Geology of the region

From a geological point of view, the area is characterized by the presence of clays belonging to formations from the Sarmatian age and to the sedimentary coverage of the Moldavian Platform (Ionesi et al., 2005). From a litho-stratigraphic point of view, the analysed deposits are a part of the Formation with *Cryptomactra* (Văscăuțanu, 1929) (Ionesi et al., 2005). It appears over the Volhinian, extending through the Lower Basarabian and the base of the Upper Basarabian (Ionesi et al., 2005).

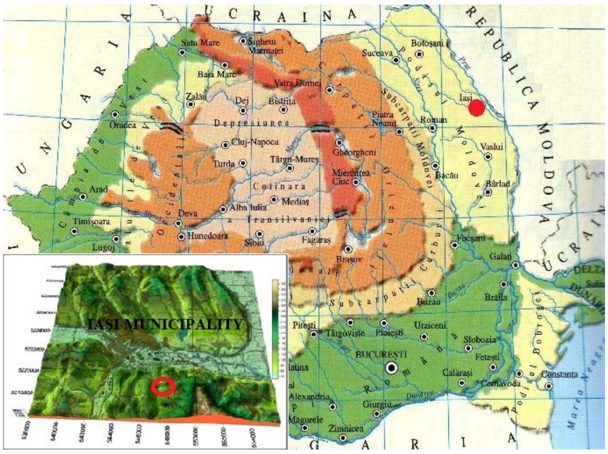

Figure1. Geomorphological location of the studied perimeter.


Figure 2. Detailed view of the researched area.

1.3. Geotechnical data

From a geotechnical point of view, the area falls into the category of terrains difficult to lay a foundation on, according to the provisions of the normative NP 074/2007.

The maximum frost depth on the study area is 0.9 m, corresponding to the zoning on the territory of Romania (STAS 6054 - 77).

From a seismic point of view, the studied area falls into a seismic hazard zone, described by a parameter called terrain acceleration for design, a_g, with a value of 0.2 g (according to P 100 - 1/2013) and seismic intensity of VIII on the MSK scale. Also, the local terrain conditions are described by values of the corner period Tc of 0.7 seconds.

2. MATERIALS AND METHODS

In order to study thoroughly and complete some aspects that refer to the geology of the region, four clay samples were collected for a micropaleontological analysis, as follows: PP1 (1.5 m) from an opening located on the terrain and PP2 (7.2 m) from drilling 1, PP3 and PP4 are collected from an outcrop opened downstream, at about 100 m, on the land of a future construction (Fig. 3). These samples were prepared for the study of microfossils by the method of water immersion, the method from which a complete residue (minerals and microfossils) was obtained for each clay. The resulting sediment was then analyzed under a microscope.

On the other hand, for a good knowledge of the characteristics of the terrain, different working methods specific to the geotechnical field were applied (SR EN 1997 – 1:2004). Thus, through different laboratory tests, the main physical properties of the rocks encountered in the field were found: granulometry (through the sedimentation method, STAS 1913/5-85), characteristic humidity (Casagrande's method, soil cylinder method, STAS 1913/4-86; STAS 1913/1-82), density (pycnometer method) (STAS 1913/3-76). Also, by using the direct shearing device, the parameters of shear strength, respectively the internal friction angle and cohesion were identified (STAS 8942/2-82). Laboratory tests were carried out on a number of 14 samples collected from meter to meter from geotechnical drilling made in this area (Stanciu et al., 2016; STAS 1242/1-89).

Regarding the choice of the calculation method, this was done considering the micro-relief, as well as the location of the future construction. The verification of the slope stability was performed using the Bishop method, considering the yielding surfaces of the terrain of circular-cylindrical shape. The Bishop method provides the following aspects (Silion et al., 1984, Stanciu et al., 2006):

- rupture occurs after a single yielding, cylindrical surface with horizontal axis;
- the sliding mass is discretized into vertical strips (i), taking into account the reactions between the strips;
- the safety factor is defined as the ratio between the available shear strength (τ_{fi}) and the mobilized one (τ_{ei}), equal to the tangential component of the total stress applied on the yield surface (τ_i) and is given by the relation (1):

$$Fs = \frac{\tau_{fi}}{\tau_{ei}} = \frac{\sum_1^n (\sigma_i - u_i) \cdot tg\varphi_i \cdot \Delta S_i + \sum_1^n c_i \cdot \Delta_{S_i}}{\sum_i^n \tau_i \cdot \Delta_{S_i}} \quad (1)$$

where σi is the total stress, considered to be uniformly distributed on the sliding surface afferent to a strip; u_i, the neutral pressure in the middle of the strip base; τ_i, the tangential stress induced by its own weight and external forces, at the level of the base of the strip, numerically equal to τ_{ei}, the shear strength necessary to be mobilized in order to ensure the limit balance (F_s = 1); φ_i and c_i, the parameters of the shear strength, Δ_{si}, the length corresponding to the strip (i) of the yielding surface.

For this study, a profile on the line of the highest slope was chosen, on which the future construction elements and the two drillings executed on the site were designed. The hypotheses taken into account were chosen considering the characteristics and geotechnical indices from the same drillings made in the field. The variants in which the simulations were performed were the following:

- unloaded slope, with hydrogeological level over 10 m;
- unloaded slope, with groundwater level over 10 m, but subject to seismic action;
- slope loaded with the construction and hydrogeological level over 10 m;
- slope loaded with the construction and groundwater level at -3 m;
- slope loaded with the construction, groundwater level at -3 m and earthquake (GT 014 – 1997).

For the construction proposed in the project, a load of approx. 40 KN / m^2 transmitted evenly over the entire built area was calculated.

Stability calculations were performed on several centres of rotation with different radii for each, and from these the most unfavourable situations were chosen, when the safety coefficient has the lowest values.

3. RESULTS AND DISCUSSIONS

3. 1. Geological results

The clays from which the four samples were collected have a layered appearance, are generally yellow in colour and are fairly well compacted. At the base of the outcrop, from the area on the property from the vicinity of the study area, we find grey clays with small grains of sand (Fig. 3, 4). The analysed samples reveal a relatively low content of microfossils, distributed according to the table 1.

The presence of this micro - fauna association confirms the belonging of the studied perimeter to the formation with *Cryptomactra*.

3.2. Geotechnical results

According to the first drilling (performed upstream, elevation of 95.3 m) it has in its composition, on the surface, a level of vegetal soil of 0.2 - 0.3 m, followed by a package of yellow clay, plastically solid, with silt or sand intercalations (2.8 m) and a layer of yellow-grey clay, with the same consistency, with bags and sand grains, present up to the level of the basal layer. As for the second drilling (88.5 m), it has similarities with the first one in terms of the types of deposits, respectively vegetal soil of 0.2 m, yellow clay (3 m) and yellow – grey clay, plastically solid.

Figure 3. Detail with the collection point of samples PP3 and PP4.

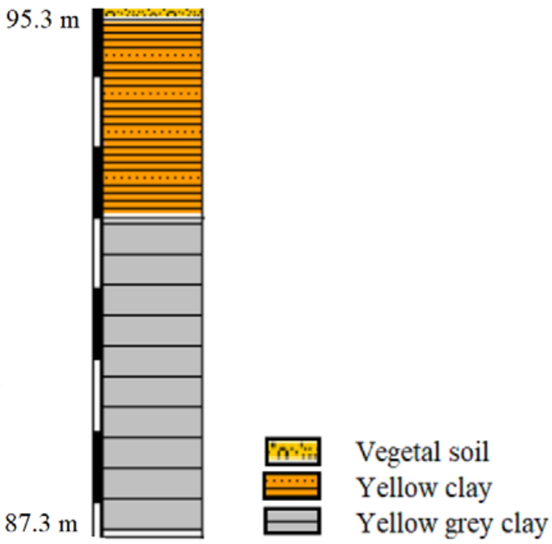

Figure 4. The litho-stratigraphic column of the researched terrain.

Table 1. Micro-fauna content of the analysed samples

Taxa	PP1	PP2	PP3	PP4
Fragments of *Cryptomactra*		f.		
Statoliths of *Mysidae*	f.r.	f.r.		r.
Globigerina bulloides	f.r		f.r.	
Ascidian spicules?	r.		r.	
Nonion sp.			f.r.	
Quinqueloculina akneriana	f.r.			

f.r.- very rare; r. -rare; m. -average; f.- frequent.

Groundwater is present on the site at depths of over 10 m, with variable levels, depending on the rainfall regime. It should be noted that during the last 10 years very little rainfall took place, so that rainwater did not have a great influence on the dynamics of the slope.

The most important physical-mechanical properties of the rocks analysed and calculated in the geotechnical laboratory are summarized in the following tables:

Table 2. Characteristic values of the physical-mechanical parameters of the yellow clay

Physical parameters

Parameter	Symbol	UM	Characterisitc values
Clay	A	%	49
Silt	P	%	35
Sand	N	%	16
Plastic limit	w_p	%	16
Liquid limit	w_l	%	44.5
Plasticity	Ip	%	28.5
Consistency	Ic	-	0.83
Moisture content	W	%	20.6
Volumetric weight	γ	kN/m^3	18.67
Soil porosity	n	%	42.65
Soil void ratio	e	-	0.74
Amount of water	Sr	-	0.74

Mechanical parameters

Parameter	Symbol	UM	Characterisitc values
Friction angle	φ	°	15
Cohesion	c	kN/m^2	17

Table 3. Characteristic values of the physical-mechanical parameters of the yellow-grey clay layer

Physical parameters

Parameter	Symbol	UM	Characteristic values
Clay	A	%	50
Silt	P	%	34
Sand	N	%	16
Plastic limit	w_p	%	16.5
Liquid limit	w_l	%	43.5
Plasticity	Ip	%	27
Consistency	Ic	-	0.85
Moisture content	W	%	20.4
Volumetric weight	γ	kN/m^3	18.9
Soil porosity	n	%	42.21
Soil void ratio	e	-	0.73
Amount of water	Sr	-	0.75

Mechanical parameters

Parameter	Symbol	UM	Characteristic values
Friction angle	φ	°	14
Cohesion	c	kN/m²	21

Regarding the most important physical-mechanical properties, used in calculations for the current study, they were identified in the geotechnical laboratory, by specific determinations, the most important results being centralized in the Table 4.

Table 4. The values of the geotechnical parameters used in the calculation

Lithological type	Friction angle φ°	Cohesion c, kN/m²	Volumetric weight γ, kN/m³
Yellow clay	15	17	18,67
Yellow-grey clay	14	21	18,9

The estimations performed, in all the variants initially proposed, highlighted favourable values of the stability factor Fs in static conditions, but they take unfavourable forms in dynamic conditions (Table 5). The terrain has the potential to slip in the hypothesis that the active factors that act simultaneously on it are the earthquake, the ground load and the groundwater level, either high (-3 m) or lower (current level of -10 m). The size of the safety coefficient, in this case, is 0.93 (for a groundwater level high at -3 m) (Fig. 5), respectively 1.20 (in case of maintaining the current groundwater level) (Fig. 6). It should be noted that when the seismic action occurs in the equation, the safety factors are remarkably lower (1.27, for unloaded slope, with groundwater level over 10 m depth and 1.20, for loaded slope, with groundwater level over 10 m depth), by comparison with the sizes of the coefficients that come from the other estimates. The respective results are at the limit of the standard value (the value indicated by STAS 3300 / 2-85 for the admissible safety factor, F_{sadm}, being 1.25). This is the situation in which the land is considered to be in balance. The results were compared with a value of the safety factor indicated by the current standards, admissible value Fs of 1.25. During the operation and arrangement of the terrain, many problems were registered. Among these, we mention the appearance of channels (torrents) 5 - 10 cm deep, caused by the processes of drainage of meteoric water on the slope, the appearance of slope springs, which were fed by the more abundant rains in spring, ground thrusts on some construction elements (especially on a water tank, which has deformed), water infiltration into the retaining wall made downstream of the perimeter. All these phenomena that occurred after the landscaping were partially or totally stopped by carrying out additional drainage works in the area where slope springs were formed, increasing the number of gutters and redirecting the main rainwater collector. Also, reinforced concrete walls have been made that support the ground in the areas where it exerts active pressures on some elements of the structure. In order to avoid the appearance of torrents on the slope, weeding was done with herbs that absorb a large amount of water and trees and trees with pivoting roots were to be planted. Although these measures imposed very high additional costs, they were a necessity. If they were not adopted, there is the possibility of revitalizing the slope in certain areas and, consequently, endangering the safety of an important part of the construction.

Table 5. Calculated safety factor values

Slope status	Groundwater level	Safety factor, Fs
Unloaded slope	10 m	1.99
	10 m + seism	1.27
Slope loaded with construction	10 m	1.97
	10 m + seism	1.20
Slope loaded with construction	- 3 m	1.43
	- 3 m + seism	0.93

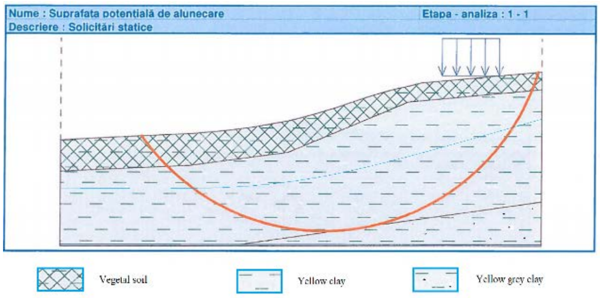

Figure 5. Schematization of a possible landslide in the situation where the presence of the construction, of an increased groundwater level (-3m) is taken into account (Geo5-Slope Stability program).

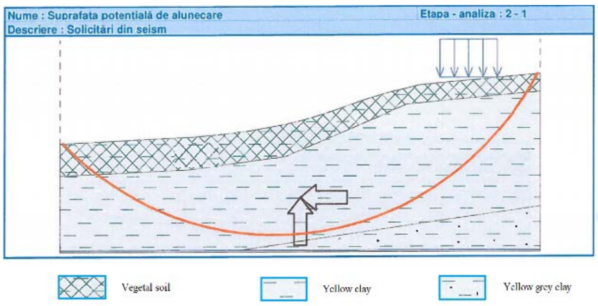

Figure 6. Schematization of a possible landslide in the situation where the presence of the construction, of the earthquake, of a current groundwater level (-10m) is taken into account (Geo5-Slope Stability program).

4. CONCLUSIONS

The evaluation of the stability of the Mihai Ciuca street perimeter highlighted the following results of the safety factor, Fs:

For four of the 6 simulations performed, the stability coefficients present values of over 1.25, the lowest results being obtained when the earthquake-specific parameters are introduced in the equation. Thus, for the situation in which the unfavourable values of the safety factor result from the concentration of all three environmental factors, respectively high groundwater level or low groundwater level, earthquake, terrain overload. The resulting safety factors are Fs = 0.93 (high groundwater level) and Fs = 1.20 (current groundwater level).

In order to correlate these results with others from similar areas in Iași, simulations will be performed, starting from the same hypotheses.

Considering the tendency of the land and the constructions carried out on the researched area, it is recommended that they should be closely monitored. It is necessary to limit the infiltration of surface waters by collecting them in an optimal manner. In addition to this fact, the existing drains must be made more efficient. Moreover, at the base of the slope, on the alignment of the fence, on contact with the rock, it is required a wall of weight of the gabion type, so that the soil no longer retains water (it must be directed gradually outwards to another collector).

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