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LANDSLIDES – A RESULT OF URBAN EXPANSION IN THE METROPOLITAN AREA OF IAŞI CITY, ROMANIA

BY

DANIEL ALUPOAE*

"Gheorghe Asachi" Technical University of Iaşi
Faculty of Civil Engineering and Building Services

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Abstract. Landslides occur as a direct result of the influence of both natural and anthropogenic factors over the foundation terrain. Expanding urban areas as well as the rising occupancy of the available construction spaces have led to changes in soil structure. Thus, areas that were previously considered inappropriate for building construction have now been reassessed and can be used to achieve the desired objectives, benefitting from new building materials and technologies.

The rapid development of the built environment, often chaotic, has some advantages but developers have to take into account the fact that it influences the surrounding areas, local and general stability of slopes, leads to hydrostatic level variation and not least changes the natural environment on site.

Landslides are a frequently encountered phenomenon in Romania, which has as main causes the lithological substratum, climatic conditions and human activity. The paper reviews a case study from the Iaşi city area, taking into consideration all of these aspects. In these respect, the paper characterizes the soil types present in the area and summarizes the causes that led to landslide appearance in the region.

In the presented case study a slope stability analysis is carried out taking into account the changes that have occurred in the groundwater flow regime and

*Corresponding author: *e-mail*: daniel_alupoae@yahoo.com

loading conditions, as a result of construction of buildings on that site. The analysis is done using a finite element program.

Finally the paper presents some conclusions resulting from studies both bibliographic and practical.

Key words: geomorphologic characteristics; hydrostatic level; finite element method; slope stability.

1. Introduction

Taking into account the geographical position, the existing relief and urban development activities in Romania many areas are often affected by landslides. The areas that are susceptible to land movement phenomena are the Transylvanian Depression and the hills of Oltenia, Muntenia and Moldova. Regarding the Moldavian region, 70% of landslides are stabilized and only 30% are active landslides.

Iaşi city is located in the geographical subunit Moldavian Plateau and is considered "the city of seven hills". As a result of urban expansion, the city developed both horizontally and vertically and now lies on nine hills at altitudes ranging from 40 m on Bahlui Meadow to 400 m on Păun and Repedea Hills (Alupoae *et al.*, 2011). Thus, many of the wooded areas located on the edge of the city become built areas causing an additional load on the slopes. Construction of new buildings, periods with heavy rains, poor management regarding water drainage, increase of hydrostatic level are some of the factors that led to slope instability phenomena.

2. Causes for the Landslide Phenomena in the Area

The main causes for the landslides that occur in the area are:

a) the change of hydrological working conditions through massive deforestation, earthworks and blockage restricting groundwater flow that can change the hydrostatic level;

b) the change of mechanical equilibrium inside the slope through torrential erosion and soil works (excavation);

c) the change of layers resistance conditions through excessive wetting caused by torrential rains or water seepage from the utility networks and the contraction and deep cracking (specific to clays).

In order to determine the effects of these changes, the physical and mechanical characteristics of the soil have to be studied. Thus it can be stated that this depends on the value of the safety factor, F_s.

3. Methods to Determine the Values of the Safety Factor

A number of rigorous or simplified methods were developed for the calculus of the safety factor over years. The hypothesis take into consideration different landslide surfaces: planar, circular (method of slices, Bishop, Spencer) or random (Fellenius, Janbu, Morgenstern and Price, Spencer). Also there are limit equilibrium techniques used to assess the stability of slopes under seismic conditions, like Sarma method.

The Fellenius method is frequently used, considers a circular failure surface and assumes that the interaction forces between the slices are equal to zero (Fig. 1).

Because these assumptions are made, Skempton and Hutchinson concluded that the method is irrelevant for deep circular sliding surfaces, is reliable for random sliding surfaces and in particular to the case of surfaces with a small curvature.

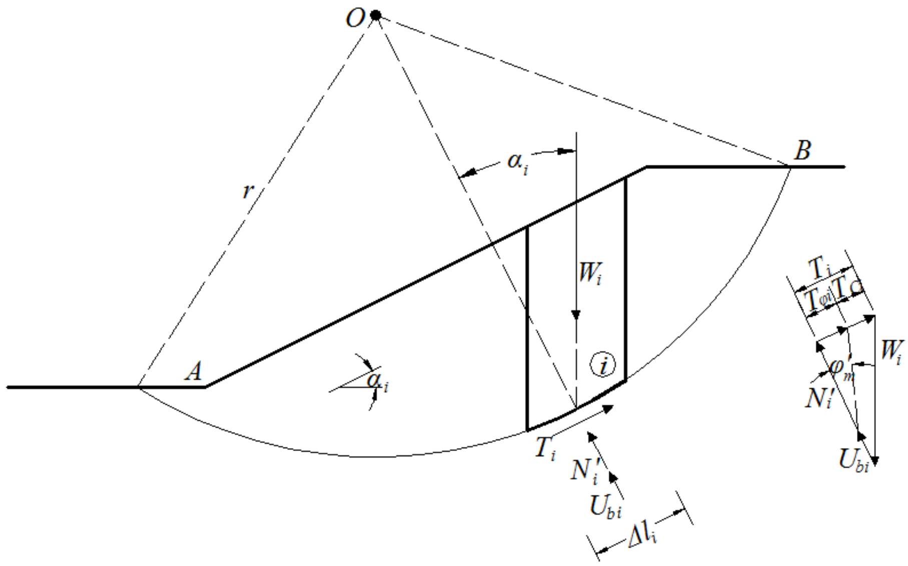

Fig. 1 – Fellenius model.

A method that is reliable is the Bishop Method. Bishop simplified method is more accurate and consists in neglecting only the shear forces at the intersection between the stripes during the evaluation of the safety factor (Fig. 2).

The difference between the coefficients, F_s, calculated with an approximate method, Bishop simplified, and the rigorous method that takes into account the shear forces, are negligible in the sense that there is a difference between the values of a few tenths or maximum 1%. So, it can be stated that the method provides results similar to those obtained with rigorous methods, for a circular surface (Farulla, 2001).

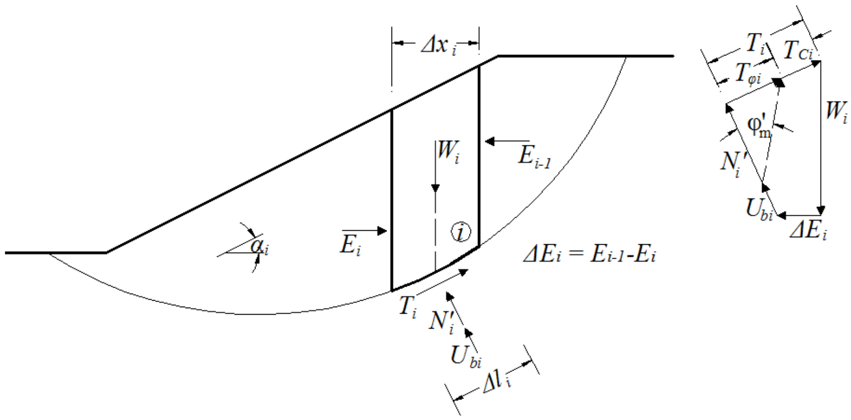

Fig. 2 – Bishop simplified model.

A comparison between different methods was made and the results are highlighted in Fig. 3. The Fellenius model, used to determine the safety coefficient in the case of circular surfaces, is closer to reality if the curvature

Landslide	Landslide surface	Safety factor Fs		
	a) Circular	Fellenius	Bishop	
Northolt	d/L = 0.14 ψ=64°	0.94	1.0	
Lodalen	d/L = 0.20 ψ=85°	0.79	1.00	
Drammen	d/L = 0.19 ψ=82°	0.79	1.00	
	b) random	Fellenius	Janbu	Morgenstern
Walton's Wood	d/L = 0.06	0.98	1.03	1.00
Guildford	d/L = 0.09	0.97	1.00	1.00
Sudbury Hill	L d d/L = 0.11	0.96	0.95	1.00
Folkstone Warren	d/L = 0.17	0.92	0.97	1.00

Fig. 3 – The values of safety factor, F_s, using different landslide methods.

surface is smaller and can be assimilated to a plane. Also the results obtained in the case of random sliding surfaces are accurate when compared to a rigorous method – Morgenstern and Price Method.

4. Case Study from Iaşi City, Romania

The site is situated in the West part of Iaşi City, near the Jewish Cemetery. Geomorphologically, the site presents a series of problems, being placed on a slope, with the gradient ranging from 14.7% to 21.5% (Alupoae *et al*., 2011).

Groundwater has been intercepted at depths ranging between –3.20 m and –5.50 m on the upper part of the slope and –9.00 m at the base. During periods with heavy rains the hydrostatic level rises and causes changes in the soil structure.

Because of the irregular stratification, permeable clays with fine sand films, intercalated on great depth and because of the limestone formations, the water moved chaotic in the slope affecting the structure of the layers.

To characterize the soil a series of drilling were made in the upper part of the slope (F_3), middle part (F_1) and at the base of the slope (F_5). The drillings revealed the following lithographical sequence (Tables 1,...,3).

Table 1
Soil Characteristics in the Upper Part of the Slope

Soil, F_3	D, [m]	E, [kN/m^2]	γ, [kN/m^3]	γ_{sat}, [kN/m^3]	c, [kN/m^2]	φ, [°]
Maroon clay	–1.3	15,000	19.3	20	77	13
Yellow maroon clay	–2.4	17,000	18.4	19.4	16	11
Dusty clay	–3.1	14,500	19.3	20	60	15
Yellow dusty clay	–5.0	20,000	19.5	21	125	20
Yellow sandy clay	–6.0	13,000	19.3	19.9	58	22
Yellow sandy clay	–7.3	17,000	19.6	20.2	25	31
Yellow clay	–9.8	13,500	20	20.4	50	31
Yellow clay with sand	–11.2	19,800	20.6	21	65	31
Yellow clay	–15.0	28,000	20.5	20.9	43	31
Marly clay	–16.0	20,000	20	20.8	150	20

Taking into account the soil characteristics a finite element analysis was made in order to verify the safety factor for the slope in the original state. The only load that was considered in the first analysis was the self-load combined with a function for a high hydrostatic level. As a result, the value for F_s in this case was 1.1875 (Fig. 4).

Table 2
Soil Characteristics in the Middle Part of the Slope

Soil, F_1	D, [m]	E, [kN/m^2]	γ, [kN/m^3]	γ_{sat}, [kN/m^3]	c, [kN/m^2]	φ, [°]
Yellow clay	–1.8	12,600	19.2	20.1	41	10
Yellow maroon clay	–3.1	16,500	20.3	20.4	58	18
Sandy clay	–4.7	21,700	19.7	20.2	11	23
Yellow clay	–5.8	12,000	19.5	20.2	71	21
Yellow-grey clay	–7.0	42,000	19.3	19.8	30	20
Yellow-grey clay	–8.5	15,000	19.5	20.1	43	26
Yellow-grey clay	–10.7	15,000	19.2	19.7	37	38
Yellow-grey clay	–13.0	37,000	20.8	21.1	63	38
Marly clay	–16.0	20,000	20	20.8	150	20

Table 3
Soil Characteristics at the Bottom of the Slope

Soil, F_5	D, [m]	E, [kN/m^2]	γ, [kN/m^3]	γ_{sat}, [kN/m^3]	c, [kN/m^2]	φ, [°]
Yellow clay	–2.3	17,000	20	20.8	90	14
Yellow-green clay	–4.6	15,000	19.3	20.4	72	17
Yellow-green clay	–8.7	19,000	20	20.5	30	20
Yellow sandy clay	–9.8	10,000	18.6	19.6	97	19
Grey clay	–10.6	22,500	19.9	21	65	16
Grey clay	–12.8	20,000	20	21	50	25
Yellow sandy clay	–15.7	13,000	18.8	19.5	16	18
Grey clay	–16.9	15,000	18.8	19.8	30	17
Dusty sand	–17.1	16,000	19	20.5	12	40
Marly clay	–18.0	20,000	20	20.8	150	20

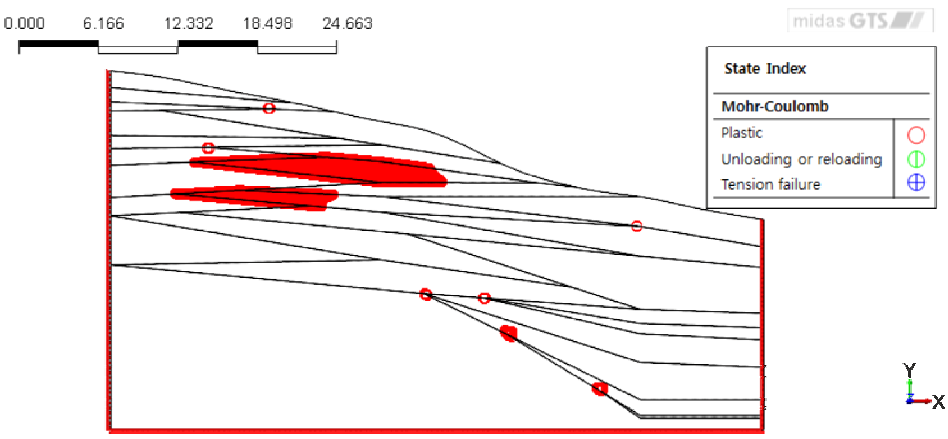

Fig. 4 – Plastic areas inside the analysed slope.

Fig. 5 shows the horizontal displacements on the slope, with a maximum of 4...5 mm.

The second analysis case considers the failure situation when small cracks appeared at the top of the slope. Tension failure points occurred as a result of torrential rains, soil nature and failure to respect the order of infrastructure works. These factors led to the development of a landslide and a settlement in the area.

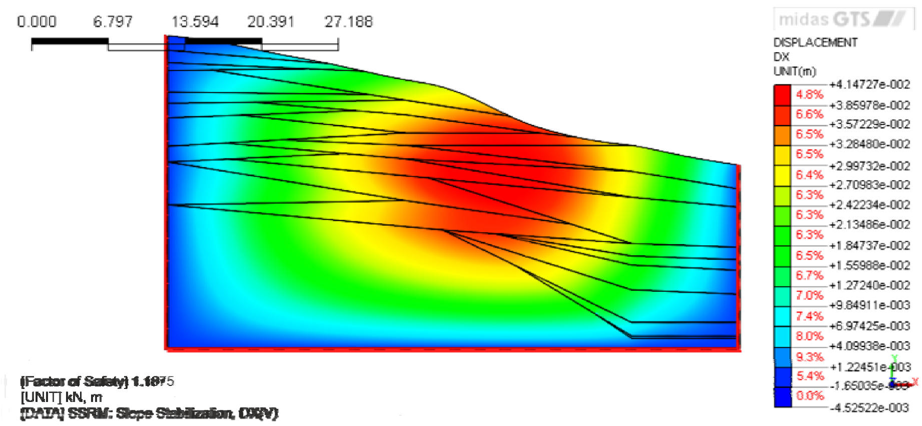

Fig. 5 – Horizontal displacement, DX, for the analysed slope.

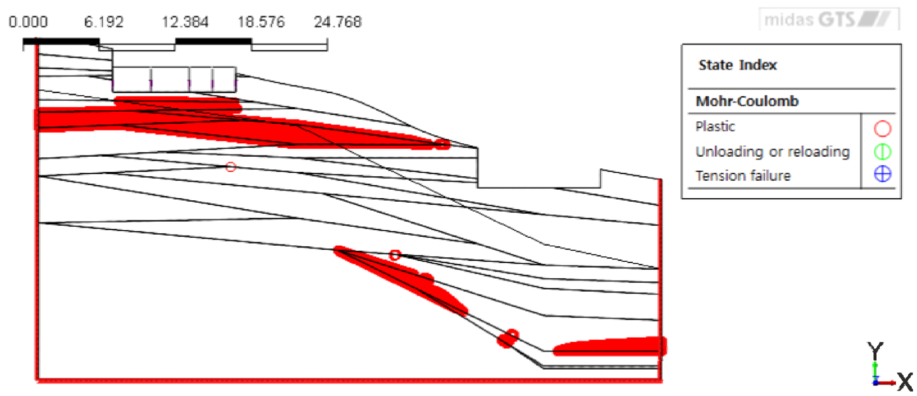

Fig. 6 – Plastic areas for the second hypothesis.

In Fig. 6, using a finite element analysis, are shown the plastic regions where the failure will occur. Also for the considered situation with overload from the constructions built on the upper part and the excavation works from the base of the slope the value of the safety factor decreased to F_s = 1.01, very close to the limit state. Also an increase of the plastic regions can be observed on the soil layers that are sensible to excessive wetting – sandy clay, yellow sandy clay.

To prevent the development of future landslide surfaces, a series of measures were taken namely

a) drainage works and controlled disposal of water from the site into the sewage network in order to lower the hydrostatic level in the area, especially during torrential rains;

b) reinforcing works using drilled piles at a depth of 15 m to reach the base layer of the slope.

4. Conclusions

Urban development and climatic factors are the main cause for the changes that occur in the morpho-dynamic equilibrium of the slope.

A series of methods are being used to determine the safety factor of the slope. The finite element analysis is one of the best ways to ensure an accurate determination of the plastic and failure zones that might occur due to a change in soil characteristics.

Slope stabilization methods are to be considered when the phenomenon is present on site but for new built areas it is better to prevent the appearance of the landslide by taking into account the soil geotechnical characteristics.

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ALUNECĂRILE DE TEREN – REZULTAT AL EXTINDERII URBANE ÎN ZONA METROPOLITANĂ A ORAŞULUI IAŞI, ROMÂNIA

(Rezumat)

Alunecările de teren apar ca o consecinţă directă a influenţei factorilor naturali şi antropogeni asupra terenurilor de fundare. Extinderea zonelor urbane cât şi încercarea de ocupare a întregului spaţiu disponibil în aceste zone au condus la modificări în

structura pământului. Astfel spaţiile ce au fost considerate în trecut improprii construirii de imobile acum au fost reevaluate şi astfel, beneficiind de noi materiale de construcţie şi noi tehnologii de execuţie, au putut fi folosite pentru realizarea obiectivelor deziderate de investitor.

Această dezvoltare rapidă a fondului construit, de multe ori haotică, aduce numeroase beneficii însă trebuie luat în considerare şi faptul că sunt influenţate vecinătăţile zonei construite, stabilitatea generală şi locală a amplasamentului, se modifică regimul de curgere a apei subterane şi nu în ultimul rând cadrul natural din amplasament.

În România, alunecările de teren sunt un fenomen foarte des întâlnit, ce are la bază substratul litologic, condiţiile climatice şi activitatea omului. Luând în calcul toate aceste aspecte, lucrarea face referire la zona municipiului Iaşi. Sunt caracterizate principalele tipuri de terenuri din zonă şi sunt sintetizate cauzele ce au dus la apariţia fenomenelor de alunecare.

În cadrul studiului de caz prezentat se efectuează o analiză de stabilitate a unui versant luând în calcul schimbările ce au survenit în ceea ce priveşte regimul de curgere a apelor subterane şi starea de încărcare provenită din mobilarea acestuia cu noi construcţii.

Se prezintă câteva concluzii care au rezultat atât din studiul de caz cât şi din elementele teoretice analizate.