Bulletin of the *Transilvania* University of Braşov
CIBv 2014 • Vol. 7 (56) Special Issue No. 1 - 2014

LANDSLIDES, A DIRECT RESULT OF HUMAN ACTIVITIES AND ENVIRONMENTAL FACTORS

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Abstract: *The expansion of constructed areas has revealed a major issue concerning soil – building interaction: a change in soil characteristics due to environmental and anthropogenic factors. The paper states the main effects of these factors over the foundation terrain and takes into consideration some methods used worldwide to counter their appearance. In order to better understand the risks of a chaotic built environment a case study from Iasi City, Romania is carried out. The paper presents a slope stability analysis using MIDAS GTS, a finite element program, to take into account different hypothesises that cause changes in soil behaviour under local loads. Finally, the paper presents the conclusions that necessarily follow the case study.*

Key words: *landslides, soil erosion, hydrostatic level, finite element method, slope stability.*

1. Introduction

Building a strong and sustainable construction is closely related to the environment in which they are located, respectively the foundation soil. The interest shown by researchers in this field of expertise has revealed a variety of rocks that can be used as foundation soil. Unfortunately not all of them are considered to be proper ground for building structures that today are higher and heavier. Thus, the study of soil characteristics and the necessary measures needed to reinforce the foundation soil is a general concern.

According to Silion 1971, in order to determine the soil behaviour under load a series of factors have to be considered: nature and genesis, physical and mechanical characteristics, the influence of natural and anthropogenic factors, mass efforts and deformations, and failure mode. This is as true today as it was then.

Also, global climate change caused significant modifications in local environmental conditions, a fact that negatively influenced the behaviour of the foundation soil under loads. A different precipitation level or temperature modifications meant moisture and hydrostatic level variation and finally soil structural changes, especially on difficult foundation soils.

Over time, in addition to natural factors, soil transformation processes were increasingly influenced by anthropogenic activity. At the moment, the changes

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caused by human activity, through industrial revolution and a chaotic expansion of the constructions, are a major cause of imbalances that occur over the surrounding environment. Fortunately it is the only one that can be entirely managed through a series of measures and a good knowledge of the impact that these actions have on the site, such as: loss of general and local stability, changes in groundwater flow regime and, not least, in the natural environment.

Engineering works interact with the environment and can be said that they affect it, but that are also influenced by the environmental characteristics of the area. In conclusion, it can be stated that there is a bi-univocal correspondence between the building and the environment in which it is located, so that if one is impaired, the other will certainly be affected.

2. The effect of the environmental and anthropic factors over the foundation soil

2.1. Specific phenomena

Both environmental and climatic factors play a crucial part over the foundation soil stability, mainly by moisture fluctuations. Bearing in mind the context of overcrowded areas and the presence of difficult terrains in the big cities, this aspect may prove to be decisive in the stability of the existing buildings.

In Romania, the risk factors that lead to instability phenomena are:

- lithological substratum;
- climatic conditions;
- anthropogenic activity;
- seismic activity.

Such an example is the Copou area of Iasi City where overcrowding caused by the lack of construction spaces, the existing foundation soil and human action led to a foundation settlement and thus to tilting buildings (Figure 1).

This phenomenon is a direct result of:

- a overload derived from the new construction, which led to additional tensions in the foundation soil;
- the increased humidity in the foundation soil and the filling layer above the soil cushion used as an improving method for the loess soil on the site;
- lack of systematization works, which enabled water infiltrations as a result of rainfall and utilities network seepage.

Fig. 1. *Tilt buildings*

Water bags were formed in the filling layer which supplied the permanent moisture of the cushion. The humidity of the cushion increased 3.14% above the optimum compaction humidity (19.40%). Also the filling layer recorded higher values for humidity: 25.07% ÷ 27.52%. All of these causes led to a differential settlement (Figure 2). [3]

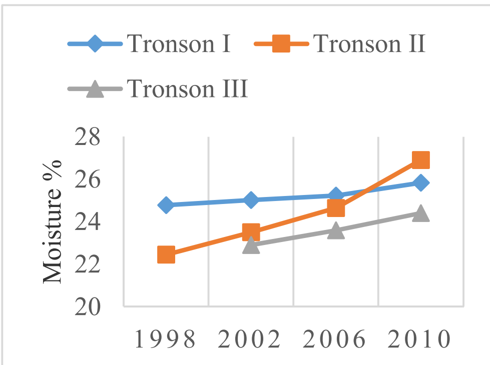

Fig. 2. *Variation of soil humidity*

Thus constructive measures have been imposed to stop the settlement: drainage network, horizontal and vertical systematization, execution of soil columns with lime and cement to reduce the moisture in the foundation soil.

After the measures were applied the settlement speed regressed from 0.213 mm/day after 9 days to 0.061 mm/day after 22 days and 0.006 mm after 83 days. [3]

Taking into account the risk factors, in Romania, the most common phenomena that threaten soil stability are:

- soil settlement;
- landslides;
- soil erosion;
- debris flow.

2.2. Measures to counteract the phenomena

In order to prevent these phenomenons, a series of measures need to be considered to improve the foundation ground:

- improving the characteristics of the soil by replacing the difficult soil - surface methods (cushions), or by deep foundations that transmit the efforts to a proper foundation ground (piles, columns);
- erosion and water infiltration control through: revegetation, revegetation and pre-stressed anchors, grids of reinforced concrete beams, precast concrete frames, gabions, geosynthetic materials, geotextile materials, soil-tire-vegetation method etc. (Figure 3).

The trend is to find solutions that can stop all of these phenomena, but at the same time that protect the environment.

Fig. 3. *Prevention of soil erosion and landslides*

Studies carried out by Lee et al. 2007 revealed that the most efficient soil erosion control systems are precast concrete frames and soil-tire-vegetation method. From a total soil erosion of 27665 g/m^2 in case of simple revegetation, it decreased to 419 ÷ 1292 g/m^2 using STV method. It was also determined that a system of mats of vegetation and geotextile material led to values of 2933 ÷ 3553 g/m^2 which are better than the values of a simple vegetation mat. [5]

Cheng et al., 2012 determined that the problems of soil loss and scour on the high gradient slope can be solved in STV, if the vegetation zone can be stabilized to have an effective growth of the vegetation. The test results on the 45° mudstone slope show that STV can work well on longer and steeper slopes.

3. Case study

The paper takes into consideration one of the failure hypothesis to demonstrate the influence that local risk factors have over the ground characteristics and construction stability. In Romania, landslides are a common phenomenon due to lithological substratum, climatic conditions and anthropological activities. Landslides are frequent in Transylvanian Depression and the hilly areas from Oltenia, Muntenia and Moldova. In regards to the last region, 70% of the landslides are stabilized or stabilizing and only 30% are active.

The case study follows a landslide using a finite element method. Three hypotheses that follow the actual landslide are presented.

3.1. Algorithm description

The finite element method is a precise numerical analysis method which satisfies the force equilibrium, compatibility condition, constitutive equation and boundary condition at each point of a slope. It simulates the actual slope failure mechanism and determines both the minimum factor of safety and the failure behavior. It can also reflect real in-situ conditions better than most methods. Moreover, it can determine the failure process without assuming any failure planes in advance.

Slope stability analysis evaluates the factor of safety using two types of methods: Strength Reduction Method (SRM) or Stress Analysis Method (SAM).

The SRM method seeks failure by reducing the (c, φ) material parameters simultaneously. Failure is governed using the force norm convergence criteria. The critical factor is the minimum factor of safety at which failure occurs. The method considers initial water level using a static value or user-defined function and robust contour features displaying actual deformation. [4]

The SAM method performs a stress analysis using finite element method, extracting the minimum/maximum values of the safety factor and a critical surface among the results of stress analysis obtained at the virtual sliding surface.

The Strength Reduction method is a finite element technique proposed by Zienkiewicz (1975). The method focuses on a point, A, of an element in a sloped ground structure in order to calculate the factor of safety of a slope as shown in figure 4. The stress state at this point is represented in a Mohr circle. To represent the sliding surface, the shear stress at the point is divided by a factor of safety, F, so that the Mohr circle for the stress state of the fictitious sliding surface becomes tangent to the failure criterion. Thus, the stress state of the point is corrected to the failure state. An increase in the number of points results in a global slope failure. As soon as a finite element solution diverges, the analysis stops and the limit value, F, becomes the minimum factor of safety for the slope. This method requires stability in numerical analysis and evaluates the actual failure behaviour.

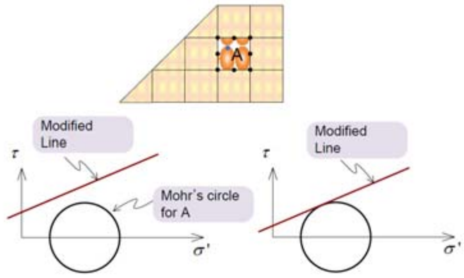

Fig. 4. *Strenght Reduction Method Principle*

In order to determine the minimum factor of stability, the modulus of elasticity (E) and Poisson's ratio (ν) are assumed to be constant. The cohesion (c) and friction angle (φ) are simultaneously reduced. The factor of safety for slope failure is determined on the basis of shear failure:

$$F_s = \frac{\tau}{\tau_s} \quad (3.1)$$

where:

τ – shear strength of slope material [kN/m^2];

τ_f – shear strength on the sliding surface [kN/m^2].

The value of τ_f can be found by using Coulomb criteria:

$$\tau_f = c_f + \sigma_n \cdot tg\varphi_f \quad (3.2)$$

where:

c_f şi φ_f – shear resistance parameters divided by a strength reduction factor (SRF), as follows:

$$c_f = \frac{c}{SRF}$$

$$\varphi_f = tg^{-1}\left(\frac{tg\varphi}{SRF}\right) \quad (3.3)$$

3.2. Hypothesis

The studied area is located in an excessive temperate-continental climate with heavy rainfalls during the summer and an average annual precipitation quantity per square meter 518 mm. Geomorphologically, the site presents a series of problems, being placed on a slope, with the gradient ranging from 14.7% to 21.5%. [1]

The stratification in that area can be summarized as follows:

- in high areas, topsoil clay followed by dusty clay, clay and loam that extend to depths of –(13.50 m÷15.80 m) and a base layer of grey clay;
- slope base: yellow clay fillings up to a depth of - 2.50 m followed by clays and loam with intercalations of adobe and dusty sand that stand on a layer of grey clay.

Because of the irregular stratification, permeable clays with fine sand films, the water moved chaotic in the slope affecting the structure of the layers.

The first hypothesis assumed a low hydrostatic level with no additional loads to determine the safety factor of the slope in the natural state. The only load that was considered in the first analysis was the self-load combined with a function for the hydrostatic level. As a result, the value for F_s in this case was 1.1875, confirming the equilibrium state (Figure 5).

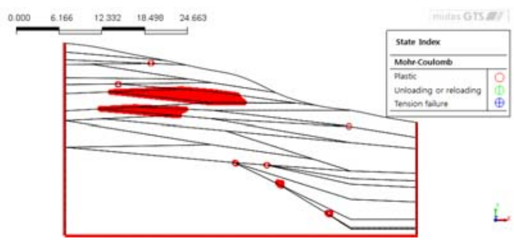

Fig. 5. *Plastic areas inside the analysed slope in the first hypothesis*

After the analysis was carried out using Mohr Coulomb failure criteria, the plastic areas inside the slope formed mainly in the sandy clay regions where the shear coefficients have low values ($c = 11…16$ kN/m^2, $\varphi = 18°…23°$). The failure tension cannot be observed in this analysis.

The second hypothesis assumes the situation when the landslide occurs: high hydrostatic level due to heavy rainfall, additional load coming from the buildings at the top of the slope and slope excavation executed at the bottom of the slope, as shown in figure 6.

All of these hypothesis were formed as a direct result of the actual site situation: 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.

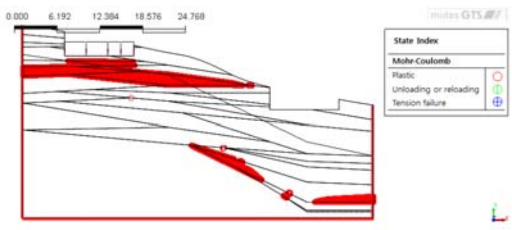

Fig. 6. *Plastic areas inside the analysed slope in the second hypothesis*

A concentration of plastic areas at the top of the slope can be observed and at the same time, a decrease of plastic zones due to a discharge caused by excavations at the bottom of the slope. Also there is a safety factor calculated value of 0.8534, which is equivalent to the loss of the equilibrium state on the slope.

In order to limit the phenomena a series of works were carried out in order to ensure the local stability of the area [2]:

- drainage works for the surrounding area in order to evacuate the water excess into the local sewage network; this measure aims to decrease the hydrostatic level on site under -7.0 meters where the moisture does not cause significant changes in soil characteristics;
- for the upper part of the slope, where

cracks developed due to the settlement and the landslide, reinforcing works using drilled piles at a depth of 15 meters to reach the base layer of the slope were carried; to ensure the piles at the top, a concrete beam was designed.

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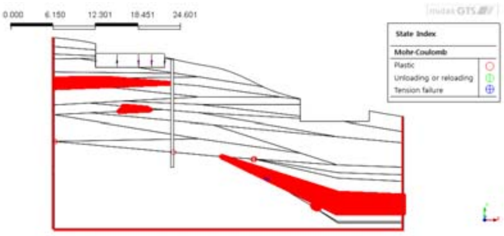

Fig. 7. *Plastic areas inside the analysed slope in the third hypothesis*

The third hypothesis follows the necessary measures that were stated above, as it is shown in figure 7. As a result, the landslide stopped progressing. The finite element analysis is consistent with the situation on site: the plastic areas are limited by the pile foundation and the decrease of hydrostatic level. Thus, the value of the safety coefficient considering the new local conditions is 1.4125, significantly improved towards the previous assumption.

The interventions carried out on site fixed the situation and what is most important, avoided a problem that could have become catastrophic for both the constructions that were built in the area and the environment.

Slope stabilization works could have been avoided if during construction all the risk factors were taken into account.

4. Conclusions

Climatic conditions, lithological substratum, anthropogenic and seismic activity are the main causes for soil failure.

In urban areas, with a high density of constructions on slopes, a change in the morpho-dynamic balance due to varying local conditions is often a cause for local stability loses. In such situations, a good knowledge of the area is required in order to prevent imbalances in the soil characteristics, which could affect the structural integrity of buildings.

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