Landslide Hazard Assessment of Oryahovo Area, Bulgaria

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Abstract

The Oryahovo town is located at high Danube coast, and has been affected by landslide. Many houses and streets in the town are heavily deformed by continually ongoing landslide movements. The slope is affected by deep-seated landslide from translational type, which is in stabilized or in condition of slow creep. In the landslide body are created shallow landslides of rotation and flow type occur, which create the major problems of the town. In this regard, the conditions and factors of landslide activity have been analyzed. For this purpose, are composed three profiles for slope stability, located about 850 m apart. Current level of sustainability of the land is determined by applying the Janbu in "effective stress". For the zoning of the landslide in Oriahovo were used the lowest values of the factor of safety along the three profiles. The calculations of slope stability in critical sectors of the town showed that the main factors of shallow landslides are groundwater fluctuation that is both of natural and/or man- made origin and the vibrations from heavy transport machines. An additional factor is seismic tremors that occurred from Vrancea seismic zone. The coefficient of stability decreases with 3 % from intensive traffic of heavy trucks through the town. On this basis, a Susceptibility hazard map of Oryahovo town has been compiled that represents the real situation of landslide hazard of the researched area. The map shows that the most endangered parts are the eastern ones and these above the ferry harbor of the town.

Keywords

Landslide hazard assessment • Slope stability • Landslide control

41.1 Introduction

Oryahovo Town is located in Vratsa Region, North Bulgaria (Fig. 41.1). It is built on a slope with a North-facing, with inclination towards Danube River. The difference between elevations of the plain and the river varies in the range 120–150 m. The slope inclination is ranging from 5 to 20°. The terrain has typical forms characteristic of landslide slope—rounded hills, numerous secondary landslide scarps and marshy areas. The main slope has a semi-circular scarp shape, with diameter of several kilometers, typical of large-scale landslides and deep-seated surface.

Groundwater level is in the range 2–4 m for the most part of the town in accordance to data from drilling studies of archival sources, but in some areas water is into a shallow drain to the surface, which is evidenced by the present marshy areas and hydrophilic vegetation.

Geological structure is represented by sediments with Neogene and Quaternary age. Neogene sediments are represented by Byala Slatina Formation, built of yellow sands with layers of conglomerates, aleurites and aleurite clays. Neogene sediments are covered by eolian formations with Quaternary age. Eolian formations are represented by loess and sandy loess with seams from clays. The thickness on Eolian formations reaches to 120 m eastward of the town.

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Fig. 41.1 Location of research area

Landslide affecting the slope between the plateau of the Danube valley and the river have deep-seated slip surface. It is formed in the Neogene clays that are situated below the loess strata. The inclination of the strata is to the North. Deep-seated landslide is of translational type according to the Cruden and Varnes classification (1996).

In different parts of the slope, however, shallow landslides are developed, which are formed in the re-deposited landslide material along the slope direction. They bear the scars of landslides from the rotational and rotational-flow type.

41.2 Factors of Landslide Activity

The main natural factors for landslides in the area of the town are the fluctuations of groundwater levels, which are related to precipitation and seasonal snowmelt. In many parts of the slope are established swampy places, which indicate the shallow groundwater. Water levels in the exploratory boreholes indicate that the water varies from 0 to 3 m from ground level.

The linear erosion of the Danube River is another important destabilizing factor. Such erosion is developed also along the Danube's tributaries and the gullies, passing through the town. Erosion undercuts and modify slopes, thus affecting stability conditions (Brankov 1983; Bruchev and Frangov 2000; Frangov 2012; Iliev-Bruchev 1994).

Seismic impact from the Vrancea epicentral area in Romania is a potential destabilizing factor in the region of the town. Influence on the activation of some deep landslides on the high bank of the Danube has been shown in other landslides near Lom, Dolni Tsibar, etc. where the geological structure is similar to that one in the region of Oryahovo (Bruchev et al. 2006, 2007).

Anthropogenic factors for landslide activation are associated mainly with construction works in the urban area as undercutting or overloading of the slope, water saturation due to leakage from the sewerage system. The vibrations from the heavy transport traffic through the town give an additional impact on the slope especially in areas where the ratio between passive and active forces in the slope is close to the limit of balance.

The study is based on series of calculations of slope stability. The calculations were made on the three profiles, located at both ends and the middle of the map (Fig. 41.3). For each of the main profiles are tested on three secondary profiles at the top, middle and bottom of the slope. Safety factors are determined using the Janbu. Values obtained for the factors of safety for each of the profiles are interpreted through the program "Surfer" to obtain the map of Fig. 41.3.

41.3 Zoning of Landslide Activity in Oryahovo

Field study found that almost all the houses in the town are cracked. Streets have 'wavy' shape at many places. Some parts of the streets have step-like subsided sectors. All these cracks and other deformations are caused by shallow landslide movements. These movements have different intensities due to the different dynamics in the body of the landslide slope. Preliminary assessment of landslide activity based on the size of the cracks and other deformations in buildings and road infrastructure, outlines areas of the city that are most affected (Fig. 41.2).

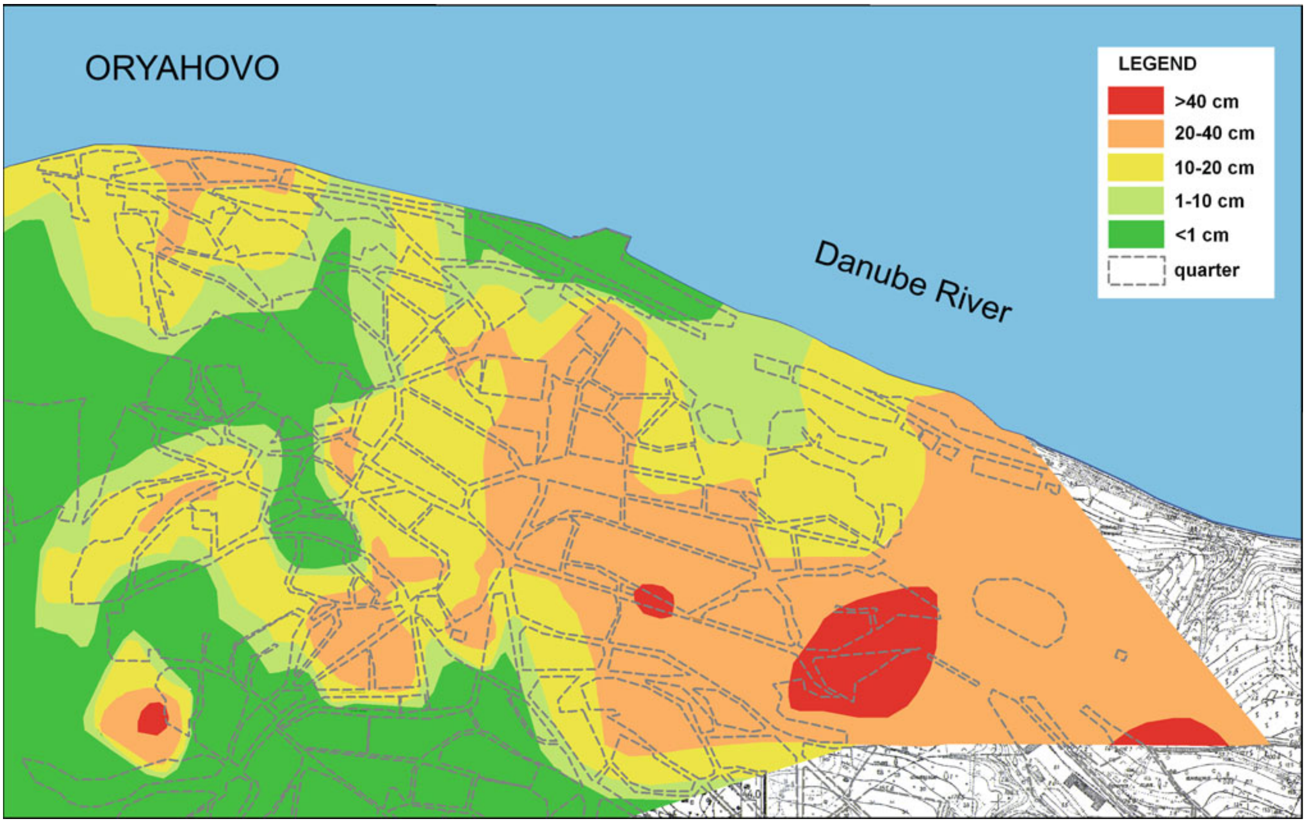

Fig. 41.2 Zoning of central part of Oryahovo town in accordance to the size of cracks and terrain deformations

This model is not sufficient to assess the real situation of landslide hazard and due to this reason it is not very convincing. Therefore we made 3 profiles through the town, which were made in series of calculations of slope stability method of Janbu in 3 conditions: with deep groundwater level, shallow (near surface) groundwater level and with a presence of vibrations from heavy machines.

The study is based on series of calculations of slope stability along profile lines crossing the slope from the plateau to the Danube bank. The slope stability is calculated for rotational type landslides. The projections of the centers of rotation are used for drawing the contours of slope instability.

The results are illustrated in Fig. 41.3. It can be seen that the most unstable areas are located along the Danube bank, i.e. just above the ferry harbor.

The calculation of the factor of safety f_s with the addition of shallow groundwater level and the impact of heavy trucks passing by on the way to the ferry showed reduction in the values of f_s. An example of how the rates of factor of safety decrease is shown in the Table 41.1. This profile is situated above the ferry where the most unstable zone is situated. The calculations are with static water level conditions (Fig. 41.3). It was concluded that in normal conditions $f_s = 1.03$, and then after addition of vibrations from heavy trucks the factor of safety f_s drops to 0.99, which is approximately 3–4 % reduction. Conversely, the drainage of the slope coefficient will increase stability factor with 29 %.

It should be noted that during strong earthquake impact, the factor of safety can decrease sharply and large areas will be affected by sliding. This is confirmed by the case in March 1977, when a number of landslides triggered in the eastern part of Oryahovo Town.

41.4 Discussion

Thus, the proposed zoning shows these parts of the town that are most prone to landslides and where preventive measures need to be focused. Obviously, if the slope has water saturation and the safety factor is closely to 1, then the slightest adverse effect would result in an active stage of sliding. Such effects may be frequent vibrations from heavy trucks traveling to or from the ferry port. Attention should be directed to water and sewerage systems which may cause leakage, to more efficient drainage of water by existing sloped drainage systems, to control surface runoff from gullies and redirect traffic through paths that are beyond the most unstable areas.

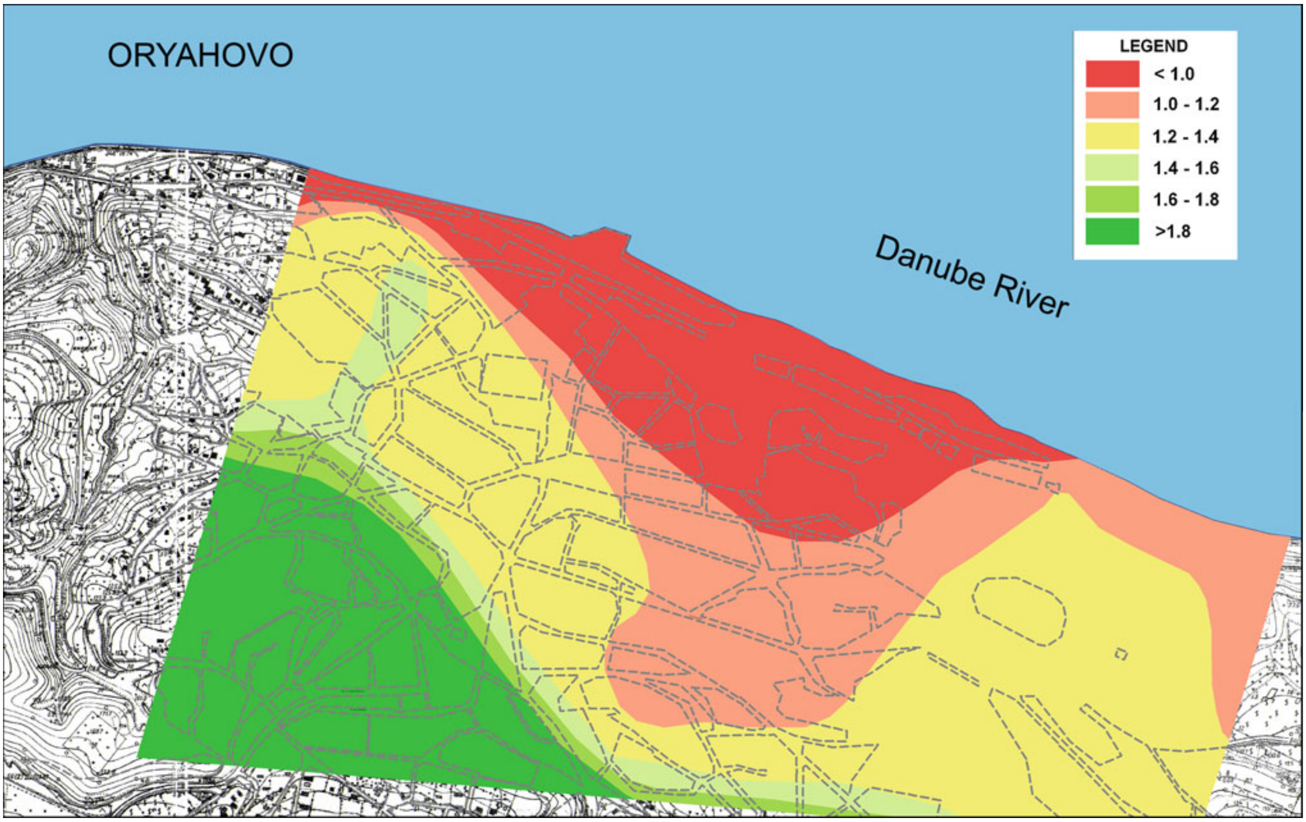

Fig. 41.3 Susceptibility map based on the factor of safety

Table 41.1 An example of impact of various conditions to factor of safety

Location	deep water level	shallow water level	shallow water level and heavy truck's vibrations
slope just above the ferry harbor	f_s = 1.33	f_s = 1.03	f_s = 0.99

It is obvious that preventive measures should start with the drainage of the slope body. But this will not be enough in some areas under extreme conditions and neglection of other destabilizing factors such as vibrations from earthquakes (e.g., Vrancea) and vibration intensive traffic through the town. In those areas the building of retaining walls is planned.

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