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MONITORING OF NATURAL HAZARDS ALONG ROADS AND RAILWAYS AND PROTECTION SYSTEMS

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Abstract: *Only with geodetic and geotechnical methods we can interpret the mechanism, type, scope, duration, dynamics and other characteristics of deformation processes of terrains around roads and railways. Geodetic and geotechnical monitoring is a system for monitoring, analyzing and controlling the steady state of the Earth's crust, terrains, buildings, and facilities. The monitoring shall be carried out before construction, during the construction period, and during the operation period, when there is a danger to the safety of the facility and buildings. The measurement accuracy depends on the minimum deformations to be recorded, the expected size, the speed of movement, etc. The appropriate measurement method is based on the accuracy with which the corresponding displacement of the observation point is determined. The chosen method is used without changes from the beginning to the end of defining the deformations, and the accuracy of the measurements in the individual epochs must be the same. The deformation survey of landslides and terrains with geodetic methods is of particular importance because it allows the identification of the minimum displacements that are critical to safety. Then according to those characteristics the appropriate methods - building a retaining wall, gabions, ground and cable anchors, covering the slope with steel mesh, etc., should be suggested by geotechnical engineers as geotechnical natural hazards protection systems and methods against the destructive natural process. Sometimes the geotechnical protection systems are not enough and it is necessary to build false tunnels. Different types of constructions for protection from natural hazards are discussed here. The article summarizes natural hazards, geodetic and geotechnical monitoring techniques and protection (prevention) systems.*

Introduction

The terrains around roads and railways, are subject to deformation by various factors. For the study of deformations, different methods are used. Among the instrumental methods for the study of geotechnical phenomena, geodetic and geotechnical (semi-geodetic) methods are one of the most commonly used. The use of instrumental methods implies the establishment of a special methodology and system for measuring, processing, analyzing and interpreting of the results. The horizontal displacements are determined by: triangulation, trilateration, triangulateration networks, traverse method, alignment method, etc. [1]. Differential, trigonometric, hydrostatic levelling, micro leveling, etc., are used to determine the vertical deformation, depending on the required accuracy and structural features and the possibility of access to the objects of study. Monitoring horizontal and vertical surface displacements with InSAR technology is often used [2]. Spatial displacements are determined by three-dimensional networks, GPS, photogrammetry, etc. Laser scanners are applied intensively for deformation monitoring applications [3,4]. Geodetic instruments for determining deformations include levels, total stations, GPS receivers and more. Geotechnical instruments include extensometers, inclinometers, piezometers, accelerometers, TDR system, etc. The natural hazards affect not only terrains along roads and railways, but also road and railway soil foundations can be affected. Changes in the straight part and curves can be detected by the GNSS method using mobile measurements. For the road and rail measurements and quality assessment are using different methods and models. The appropriate inertial measurement systems and hardware implementation are presented in [5]. Geodetic survey methods are the most commonly used instrumental methods for monitoring of the natural hazard. The implementation of monitoring is associated with the organization of special systems for measuring, processing and interpretation of results. Most often a geodetic network of reference and object points is built. Changes in the position of points from two or more measurement epoch over a period of time give us the size and direction of the displacements. Strain analysis includes the calculation of the deformation parameters and elements of the symmetric tensor, analysis of dilatation, total shear, etc., [6,7].

Natural hazards and protection systems

1. Rockfall and rockfall debris

According to Varnes's classification [8], types of movement of a piece of rock or block that moves on the surface of the slope are divided into five main groups: falls, topples, slides, spreads and flows. The sixth group (complex slope movements), “includes combinations of two or more of the other five types” [8]. The most susceptible to landslides are those geological formations in which there are tectonic faults, faults and cracked systems with unfavorable orientation. In order to determine the potential danger of a landslide, it is necessary to make a detailed structural analysis of the massif [9]. Detailed structural analysis includes clarification of the elements of each crack system, from which the collapse potential can be determined. Many authors of the rockfalls include the assessment of the condition of the rock massif, e.g. Rock mass rating [10]; Slope Mass Rating [11] and some of its varieties - Continuous Slope Mass Rating [12], Graphical Slope Mass Rating [13]; Slope stability probability classification [14]; Geological Strength Index [15]; Rockfall Hazard Rating System [16]; Modified Rockfall Hazard Rating System [17]; Rockfall Hazard Rating System for India [18]; Slope Stability Rating [19]; Q-slope [20,21], etc.

In order to design protective facilities in case of landslides, it is necessary to clarify the qualities of the rock massifs, as well as the movement and impact of the moving rock blocks. According to the research performed for each specific case, the appropriate safety equipment is designed. In practice, there are various solutions for the protection of transport infrastructure (roads and railways) from falling blocks, such as safety and trapping nets, berms, safety ditches and walls, pocket walls, reinforced embankments, anchoring and surface shotcreting, safety galleries, etc. (fig.1). A detailed description of the methods used for protection from the natural hazards can be found in [22]. Sometimes the protection systems are not enough and it is necessary to build false tunnels e.g rock fall protection gallery [23].

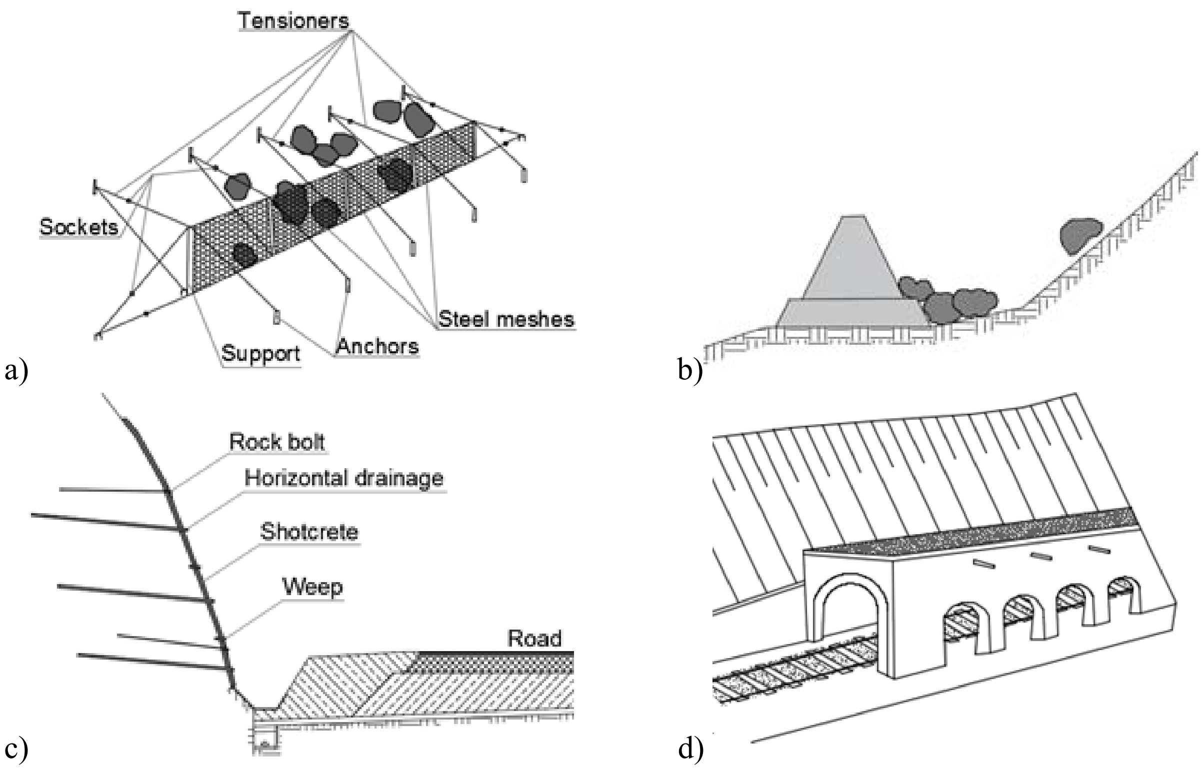

Fig.1. Rockfall protection facilities: a) Rockfall protection fence; b) Pocket wall; c) Installation of rock bolts and shotcrete; d) Rockfall protection gallery

2. Landslides

Landslides are one of the most destructive natural processes active in many areas of the world. The study of landslides is very important due to the material losses they cause, their environmental and social effects. There are a big number of methods to analyze slope stability and critical slip surface. The modern software together with the finite element method is often used for landslide stability assessment [24]. In many cases landslides, rock falls, rock fall debris, avalanches, and other types of mass movement occur in conditions that exclude the possibility of their prediction. In other cases, the prediction of some destructive processes is possible [25]. There are various factors that can affect the slope stability. The analysis of slope stability involves potential failure surface, calculating the factor of safety with equations such as those presented in [26]. Many authors in the technical literature classify landslides according to various characteristics. Other authors also present landslides according to the type of movement [27]. According to Varnes's classification, whose classification is most widely used in the English-speaking world the landslides are determined by the type of movement and the lithology. The velocity of movement is also a determining factor. The National Statistical Institute (NSI) publishes the official annual data on crisis events on the territory of Bulgaria in the section "Regional Statistics and Monitoring Indicators", subsection "Crisis Events" [28]. After an analysis, it is clear that landslides are due to 10,3% (or third place) of the crisis events of a natural nature. Leading are floods (56,9%) and wind storms (13,1%). Surface treatment of the landslide are lining, afforestation, fencing, drainage, injection and tamponing of cracks and cavities. Water protection and drainage of the landslide includes execution of surface drainages, ditches and shafts, dug drainage trenches, drainage wells and boreholes, etc. In [29] the article describes the different types of strengthening facilities used to reduce the erosion in mountainous terrain.

3. Avalanches

Damage from avalanches can lead to huge financial losses due to the clogging of important road and railway arteries, and buildings, as well as to the loss of human lives. The countries in the world with a high risk of avalanches are United States, Russia, Canada, Peru, Argentina, France, Austria, Slovakia, Italy, Switzerland, etc. Snow avalanches may be classified by various factors. In the USA avalanches are classified using five sizes [30]. In Japan is used a logarithmic scale based upon avalanche potential energy. In Europe, the EAWS (European Avalanche Warning Services) separates avalanche sizes into five size classes, based on the Canadian classification. In avalanche protection, various solutions are applied, the most common of which are: preparation of forecast maps for avalanche danger, the collapse of snow masses, for example by explosives, construction of sheds, galleries or tunnels, installation of protective fences and shields, afforestation of trees in avalanche-prone areas. The following table summarizes natural hazards, geodetic and geotechnical monitoring techniques and protection (prevention) systems.

Table 1

Natural hazards	**Geodetic and geotechnical monitoring techniques**	**Protection systems/Prevention**
Landslides	remote sensing ,GNSS, extensometers, srinclinomete, total stations, laser scanners, triangulation, trilateration, triangulateration networks, traverse method, alignment method, sTDR, piezometer	Anchors, retaining wall, gabions, counter-banquets, buttresses, retaining walls, revolts, retaining embankments reinforced with geosynthetics, reinforcement of the landslide with supporting structures- concrete or reinforced concrete retaining walls (cantilever or anchored), drilling and pouring piles or slot walls, slotted ribs, reinforced concrete wells, anchored reinforced concrete slabs
Rockfall and rockfall debris	Remote sensing, extensometers, rsinclinomete, total stations	Rockfall protection fence, Pocket wall, Installation of rock bolts and shotcrete, Rockfall protection gallery, False tunnels, Steel meshes
Avalanches	Remote sensing, laser scanners, photogrammetry	Steel meshes

Conclusions

In many cases natural and man-made hazards occur in conditions that exclude the possibility of their prediction. Geodetic and geotechnical monitoring techniques give us the magnitude, direction of the displacements, etc. On the base of this information different types of constructions for protection from natural hazards can be applied according to presented concepts.

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