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LANDSLIDE HAZARD AND RISK ASSESSMENT

Abstract:

The landslides as a phenomenon is a complex process that arises due to the presence of a number of influencing factors in a particular area, and can cause great damage to people and material goods. Due to the increasing need for the construction of residential and infrastructural facilities, combined with significant climate change in the form of extreme precipitation, the hazard and risk associated with landslides is increasing every year.

Therefore, the assessment of the landslides hazard and risk is becoming increasingly important in defining the conditions for the construction of facilities in certain areas, and in order to avoid the risks associated with landslide occurrence. Hazard and risk assessments should be systematically approached, taking into account all factors that can lead to the activation of the slip process. Hazard and risk assessments should first be done at the regional level, and after analyzing the results obtained, target more detailed surveys on local areas where the risk of landslides is most pronounced. At the regional level, maps of landslide susceptibility are made, followed by hazard maps and risk maps. At the local level, landslide cadastres are most often performed, as well as detailed geotechnical investigations, which represent the most exact method of hazard and risk assessment. By this approach to the definition of hazard and risk, significant savings are made in defining the way buildings are built in individual areas, and the risk of potential damage caused by activating the landslide is reduced.

Key words: landslide, hazard and risk, geotechnics

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1. INTRODUCTION

Landslides are one of the most significant geological exogenous processes in which slopes are formed. The cause of these displacements is the disturbed balance conditions that prevail in the soil or rock mass of the slope. The mechanism of this gravitational displacement, or the sliding mechanism, is usually complex, and the masses that are triggered by this mechanism can be small to those that, by their scale and consequences, represent natural disasters.

It is precisely because of the harmful consequences, in the material sense, and in particular the consequence of the loss of human lives, landslides represent a limiting factor for the use of existing buildings or infrastructure facilities, as well as for the design and construction of buildings. This problem is even greater as the needs for developing the overall human needs for living and working space as well as for modern infrastructure facilities increase. These needs require the hazard and risk assessment, elimination of limiting circumstances, including the presence of landslides on built slopes or slopes planned for construction, is one of the most common and most serious problems.

Hazard and risk assessments for landslides are conducted at the regional level, and after analyzing the results obtained, more detailed surveys on local areas where the risk of landslides is most pronounced are conducted. At the regional level, maps of landslide susceptibility are usually made, followed by hazard maps and risk maps. At the local level, landslide cadastres are most often performed, as well as detailed geotechnical research, which represent the most exact method of hazard and risk assessment.

2. LANDSLIDES

“The landslide is part of the geomorphologic environment limited by the surface and landslide depth, in which the gravitational displacement of the driven masses into the lower parts of the terrain occurs without losing contact of the sliding mass with a stable substrate.” [10]

Figure 1. Landslides in Northeastern Bosnia (K.Mandžić, 2014)

Landslides in the broader sense refer to mass movements on slopes and represent geo-hazardous events that can significantly affect the safety of people and their property. The basic classification of landslides (Landslide classification) is based on the type of landslide movement – landslide in the narrow sense, flowing, sloping, overturning and lateral spreading, and the type of material being moved - soil, rock or their mixture [5] .

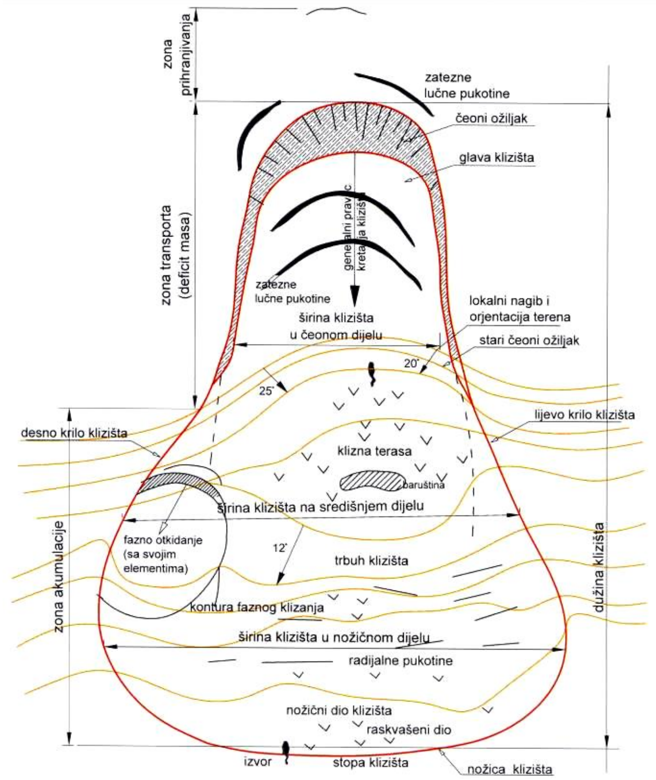


Figure 2. The general shape of landslides in the plan

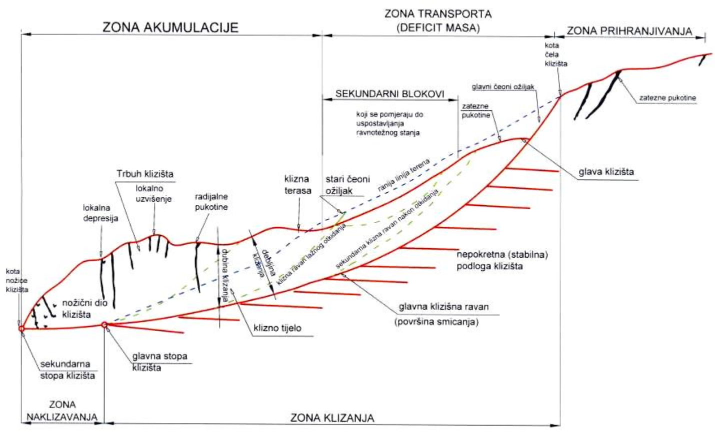


Figure 3. The general shape of landslides in cross-section

To determine the characteristics of the landslide and possibilities of their occurrence in the wider area, as well as the conditions under which instability can occur, it is especially important to pay attention to the following conditions:

- Geological,
- Engineeringgeological,
- Hydrogeological and hydrological,
- Geodynamic processes,
- Anthropogenic (technogenic).

The causes of landslide formation by their nature can be:

- Natural causes
- Technical or anthropogenic causes

There are a very large number of natural causes of slope formation on the slope, and among the most significant are:

- Physical and mechanical (surface) decomposition of rocks, which causes a reduction in shear resistance,
- The effects of surface and ground water on the slope, such as hydrostatic and hydrodynamic (filtration) pressures,
- Changing the hydraulic gradient caused by a sudden drop in the surface water level,
- The intersection of the riverbed causing the erosion processes that are the result of a balance disturbance (undercurrent),
- Slope geometry (slope angle),
- Stacked material on the slope from the previous landslide process,
- Significant discounting and degradation of the rock mass with unfavorable spatial position and other planar elements of the discontinuity sistem relative to the slope disposition
- The spatial position of the rocks of various physical-mechanical properties in the structure of the slope,
- Increase of soil pressures during large precipitation (snow weight and weight of soil in the soil after melting snow and heavy rains),
- Soil swamps and process frost - defrosting,
- Soil drying, when the srinking cracks in soil are created, so the surface water infiltration is greater and the soil decomposition is more intense in those cases,
- Natural seismic impacts (earthquakes) that can activate the old and cause new landslides,
- Microbs and so on.

Anthropogenic causes of origin can be accidentally or completely consciously created and are usually related to planned or unplanned construction and mining works. Technical operations on the slope cause disturbance of previously established balance, which usually causes excessive (sudden and rapid) landslide processes.

The most common anthropogenic causes of landslide formation are:

- Construction of buildings on conditionally stable and unstable slopes,
- Inadequate execution of earthworks such as: cutting of the slope, construction of embankments on the slope, excavation of open pit mines, channels, foundations, uncontrolled deposit of materials on the slope and other earth works that can lead to disturbance of the slope balance,
- Degradation of the terrain by degradation and cutting of vegetation,
- Filtration pressures caused by sudden decrease of water level in artificial reservoirs and canals,
- Dynamic load of traffic,
- Human caused seismic effects, such as blasting and vibration due to the operation of heavy machinery, etc. [10]

Figure 4. Examples of antropogenic causes of landslide formation (K.Mandžić, 2014)

3. HAZARD AND RISK IN GEOTECHNICS

Hazard and risk are concepts that overlap in the everyday speech with the usual identical meaning for normal living surroundings and situations. In professional geotechnical literature, hazard and risk are terminologically different. In some literature Hazard represents the likelihood of occurrence of potentially harmful natural phenomena. [14]

According to the ISO standard, the definition of hazard is: "Hazard is insufficiently identified risk, i.e. hazard that is not adequately assessed in terms of probability of occurrence and the consequences that can cause." In other words, the hazard is the name of an unfavorable event. [10]

In the geotechnical literature, risk represents the expected degree of loss of human life or the destruction of material assets in natural phenomena that signify the existence of hazard. [12]

The definition of risk by ISO standard is: "Risk is a quantified, objectified, computed or determined hazard with a defined probability of events and harmful consequences". Hence, the risk is the probability and quantum (numerical or descriptive) of the named hazard. [10] The sliding process on the slope represents a geotechnical hazard. Like any hazard, landslide has its own quantitative measure, expressed through risk that affects material goods and people. The effects of landslides, as a geotechnical hazard, can be reduced if the vulnerability and degree of risk are reduced. In order to achieve this, it is necessary to investigate the elements of the landslide hazard and identify the risk-affected entities (areas).The obtained data are used for the production of hazard maps and landslide risks, with clear zoning of the area in terms of hazard and risk, which are used for land use planning in these areas.

The consequences and damages caused by landslides are constantly increasing in Bosnia and Herzegovina. The total damage to Tuzla Canton in 2010 amounted to 17.5 million € (the city of Tuzla was 5.2 million €), while disaster after the weather accident in May 2014 € is 444.4 million € in the Tuzla Canton. The area of the Tuzla Canton is particularly sensitive to the occurrence of landslides in the rainy period, when it is known to have up to 1,000 landslides, varying in volume and level of activity.

After the May 2014 disaster (Tuzla Canton area):

- 9 people are slightly injured
- 7286 people evacuated
- 35 residential and 50 auxiliary facilities were destroyed
- Flooding of the basement room of 30 schools
- 6.742 landslides activated
- 397 objects were destroyed due to landslides, and 1,801 housing units and 494 additional objects were damaged
- Three schools were damaged by landslides [13]

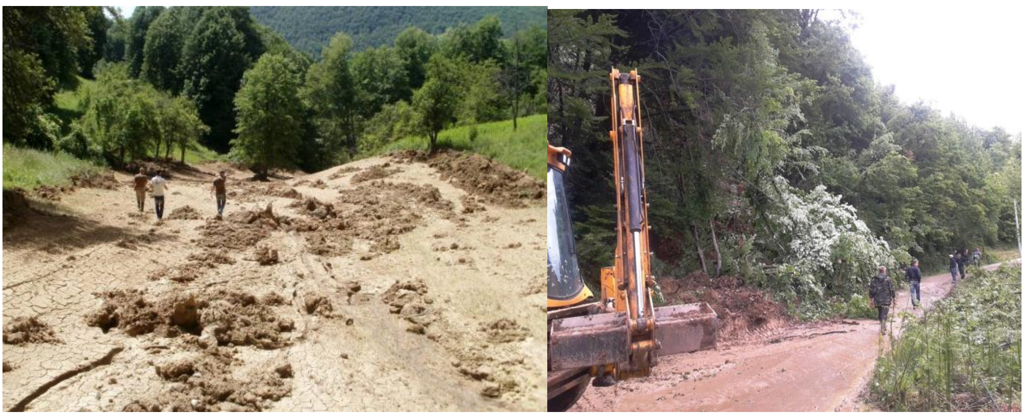


Figure 5. Examples of landslide formation in Tuzla Canton (K.Mandžić, 2014)

4. LANDSLIDE HAZARD AND RISK ASSESSMENT

4.1. Basic terms and definitions in landslide hazard and risk assessment

Terms related to the types of landslide zoning:

- **Triggernig factors** refer to factors that lead to landslide activation.
- **Zoning** refers to the separation of the surface of the investigated area into homogeneous zones (domains) and their ranking according to the degree of actual or potential susceptibility, hazard or risk.
- **Susceptibility** implies a spatial probability of occurrence of an event, is assessed qualitatively or quantitatively. (The terms potential and relative hazard are used for this term).
- **Vulnerability** is the degree of loss of value of a particular element or set of elements that are exposed to the occurrence of an adverse event. Often it is expressed in a scale of 0 (no loss) to 1 (complete loss).
- **Elements at Risk** are the population, objects, infrastructure, environmental characteristics, cultural values and economic activities in the area affected by the harmful event.
- **Geological Hazard** is a geological process or phenomenon that can lead to loss of life, injury or other health effects, property damage, loss of resources for life and services, social and economic disorders, or environmental damage.
- **Risk Management** is a systematic approach and uncertainty management practice in order to reduce potential damage and losses. [4]

In order to assess the risk of landslide occurrence for each new or existing urban area, it is necessary to:

- Assess the hazard by dividing the area into smaller units and determining the location, intensity and frequency of landslide occurence. The results are displayed on hazard maps or engineeringgeological maps, depending on area of research
- Assess the vulnerability of each zone. This implies the determination of location facilities, population density, infrastructure facilities, vital economic activities, main and secondary roads, etc.
- Calculate the expected losses or determine the degree of risk due to the hazard and vulnerability of the area.

The basic step for reduction of landslide hazard is formed by zoning the terrain by creating a hazard and risk map.

Ideally, the landslide map shows:

- Distribution of fossil, calm and active landslides
- Type of instability present on a slope such as rock fall, mud flow, overturning, lateral spacing, l
- Type of rock or soil affected by movement
- The likelihood of occurrence of instability determined by the size and extent of the sliding mass

- Evaluation of the impact of different movements on slopes on people, objects, roads, sewage water and other networks.

The zoning of the terrain by the landslide hazards requires a very detailed knowledge of the processes that were active or are still active in the given area and determination of the causes of the landslide occurrence based on the mechanisms that were characteristic for the earlier processes of landslide occurrence.

In order to carry out the risk analysis and to base the hazard data, it is necessary to have information on the existing or planned population density, infrastructure and economic activities in the area under study.

The methods for analyzing the landslide hazard, as well as the input data for making this map are conditioned by the size of the affected area, which can be:

- Regional area with maps 1: 100000 and lower
- Middle size area with maps 1: 50000 and 1: 25000
- Locally, with maps 1: 10000 and 1: 1000

The assessment of the landslide hazard can be done thru several methods. Through a clear mapping of landslides with surface borders, or through quantitative methods by assessing the landslide hazard using statistical analysis of the impact factors on the landslide, and also thru the deterministic methods (most accurate). The amount and accuracy of the collected data directly affects the accuracy of the created landslide hazard maps. [12]

Landslide hazard analysis for larger areas (regional and municipal) require the division of the area into homogeneous units within which the scoring of certain impact factors is performed, and the sum of points gives us the size of the hazard and risk for that area. For the quantitative assessment of the landslide hazard, deterministic methods for estimating landslide hazard may also be used, whereby the implementation of the stability analysis and calculation of safety factors for a given slope is primary. Such investigations of the hazard, at the local level, are related to the conduct of geotechnical research in the field.

Table 1 Recommended size of the zoning area, the methods for making a landslide map and its purpose depending on the scale of the map [9]

Scale	Areas of Use	Methods	Purpose
< 1:100.000	> 10.000 km^2	Heuristic approach*	Informing the ruling structures and the public
1:25.000 - 1:100.000	1.000 - 10.000 km^2	Heuristic approach* (Statistical methods)	Planning of regional development projects

1:5.000 - 1:25.000	10 - 1.000 km^2	(Heuristic approach) Statistical methods * (Deterministic approach)	Planning infrastructure objects
> 1:5.000	few acres - 10 km^2	(Statistical methods) Deterministic approach *	Planning and designing (buildings, roads, ...)

** Applicable methods, () may be applicable methods*

5. LANDSLIDE HAZARD AND RISK ASSESSMENT IN REGIONAL LEVEL

5.1. Creation of landslide susceptibility maps in small scale

The first official application of landslide zoning dates from the 1970s and is based on a qualitative approach, while those quantitative approaches are developed in the late 1980s. [6]

Three basic principles on which all the approaches to landslide zoning are based on:

“The past and present is the key to the future, assuming that the likelihood of landslides in the future is greater in (geological, geomorphological, hydrogeological and climatic) conditions similar to those where landslides occurred in the past and / or the present”; [19]

The main causes of the landslide can be identified and most can be mapped and the degree of landslide hazard can be estimated.

The landslide zoning is done with the goal of making maps that can be divided into four basic types. Simply put, it can be said that a particular type of zoning gives certain data as follows:

- Landslide Inventory Map - where landslides have already appeared;
- Landslide Susceptibility Map - where landslides may occur, and which areas are more susceptible to landslides occurrence;

These two types of maps present the basic for the creation of :

- Landslide Hazard Map - where and when landslides may occur, or what is the likelihood of a landslide in a particular area;
- Landslide Risk Map maps - which have the consequences (damages) of the possible landslide occurrence. [3] [5]

Many landslides are located in densely populated areas and directly threaten people and property. Given this high risk, the goal is to identify and classify risk areas by designing and mapping of landslide susceptibility map (LSM), which is recognized as one of the basic maps and priorities in risk assessment and prevention.

Landslide susceptibility maps represent the spatial likelihood of landslide phenomena. They are made in different scales, depending primarily on the purpose and size of the investigated area, as well as on the scale and details of available input data.

For landslide susceptibility maps in scale 1:100,000 heuristic approach based on engineering experience can be chosen as the optimal approach.

Adequate zoning of the terrain can assess the degree of landslide susceptibility, which is the first step toward the final goal - determining the zone of increased hazard and definition of risk on large area. These activities allow planning to reduce the level of vulnerability of people and property. Landslide susceptibility maps are just the first, but necessary step in systematically managing hazards and landslide risks.

In order to develop an adequate methodology for developing a landslide susceptibility map, Faculty of Mining, Geology and Civil Engineering-University of Tuzla, together with partners (Croatian Geological Institute Zagreb, JU Institute for Geological Research from Podgorica and Development Agency Žepče) launched the project "safEarth" (HR-BA-ME59), within the IPA-CBC Croatia-Bosnia-Herzegovina-Montenegro 2014-2020 IPA Program, implemented from June 1, 2017.

Creating landslide susceptibility maps (LSM) is an important step in defining spatial plans for areas in which there is possibility of landslides occurrence. Namely, the separation of areas subject to landslide is the basis of rational land use management, with an emphasis on safe and planned construction.

The main objective is to define a zone with critical landslide hazard, which creates the preconditions for widespread use of LSM in the region, for better management systems and risk prevention. Landslide susceptibility zones represent differences in the likelihood of a landslide occurrence in a given area, and it is not possible to predict in which time the landslide will be activated.

LSM has practical application in providing information to local authorities and citizens in areas such as spatial planning, protection of human health, biodiversity and nature. These maps are intended to be used before any major investment by individuals, municipalities, private companies, as well as major investments from the state relevance. [1]

Creating landslide susceptibility also allows:

- definition of zones that are currently or potentially most vulnerable,
- reduction of damage to property and human victims,
- reduction of costs of landslide rehabilitation,
- introduction of measures to reduce the intensity and number of anthropologically initiated landslides and enables the production of other, related basic documents (more detailed engineering-geological and geotechnical studies, spatial plans, conceptual projects for large infrastructure facilities, environmental impact studies, etc.).

Existing methods for making landslide susceptibility maps in small scale (<1: 100,000) include in the analysis different input data, which are often reduced to three basic sets of data in the form of factor maps. These are geological factors, geomorphological factors and cover / land use (Castellanos Abella & Van Westen, 2007; Hervás et al., 2010; Lima et al., 2017; Nadim et al., 2006).

In addition to the above data, the landslide cadastral map is necessary for certain methods of making landslide susceptibility maps (statistical approach). The availability of landslide data that has occurred varies from country to country and binds to the existence of a developed data collection system.

To create a landslide susceptibility map of a scale of 1: 100,000, the following factor maps are used as input data:

Slope angle map can be derived from the digital relief model - DEM (digital elevation model) obtained on the basis of a 1: 25,000 topographic map, the size of the grid cell is 20 * 20 m.

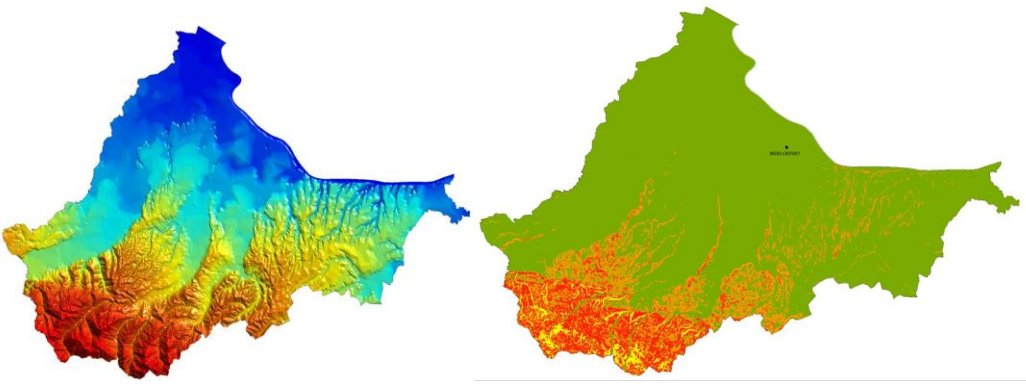


Figure 6. Digital elevation model (left) and digital elevation model reclassified (right)

Map of engineer-geological units is created on basic geological maps in the scale of 1: 100,000 which are used for the definition of engineering-geological units, and units are separated on the basis of engineering-geological features.

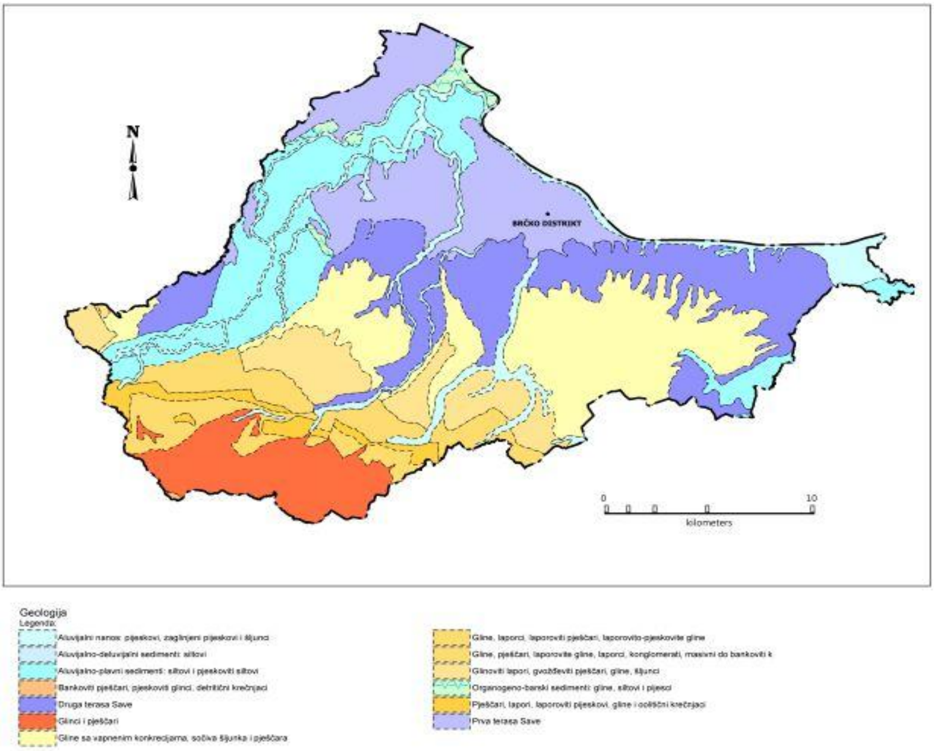


Figure 7. Example of Geological Map of Brčko distrikt BiH [7] [8]

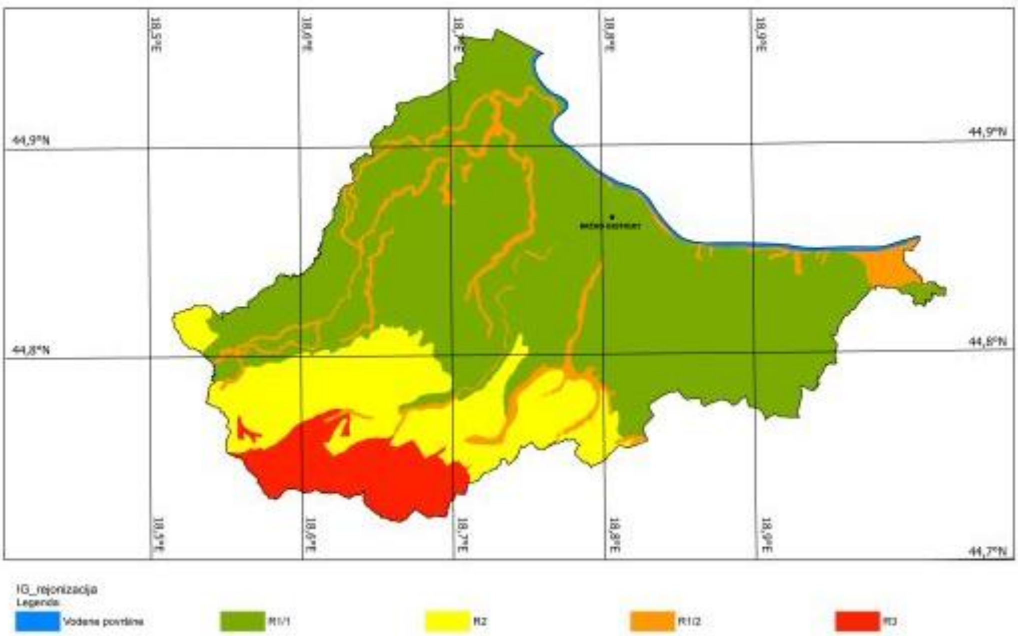


Figure 8. Engineering geological map of Brčko district BiH [1]

The land cover map is usually based on the CORINE Land Cover (CLC), in this case 2012 base. It represents the land cover for 2012, and is made according to the CORINE standards that define the output scale 1: 100,000, the minimum mapping area is 25 ha and the minimum width of the polygon 100 m. [1]

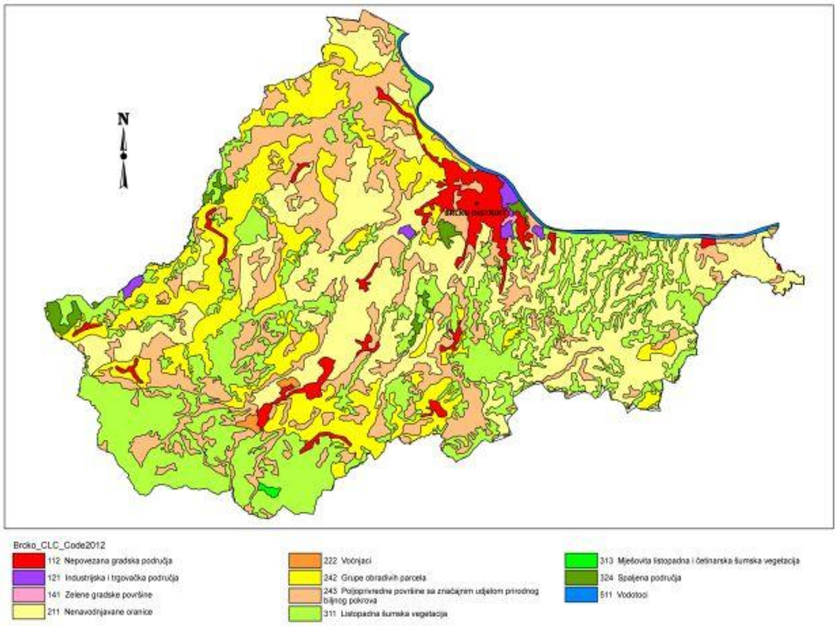


Figure 9. Land cover map of Brčko district BiH

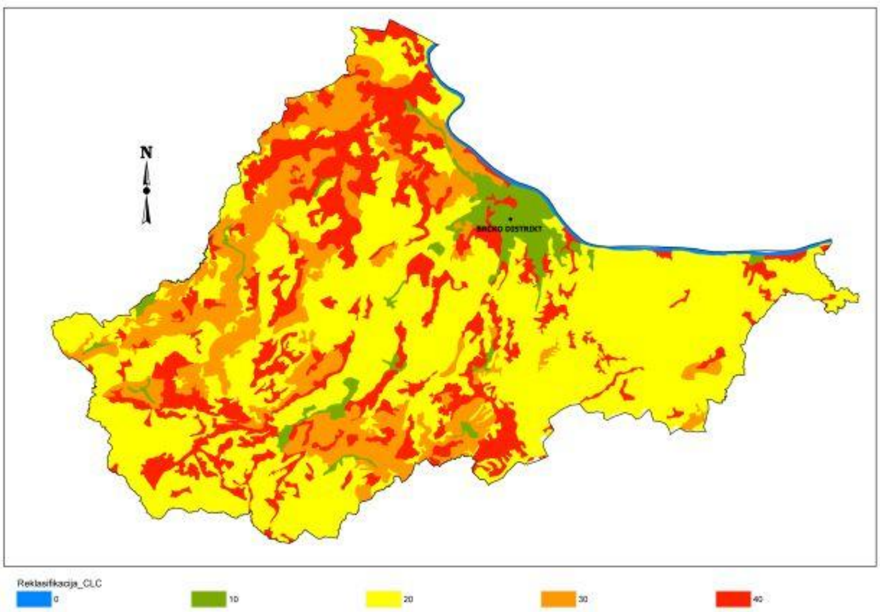


Figure 10. Land cover map of Brčko district BiH reclassified

5.2. Data processing and analysis

Generating a landslide susceptibility maps is carried out in GIS, and the whole process involves processing and analyzing data through the calculation of factor maps and reclassification of factor maps. The overlapping and execution of various mathematical calculations of factor maps can only be done with data in the format of the raster. Therefore, in the very beginning of factor mapping, vector data should be converted into a raster format (grid), and the grid cell size of all factor maps is reduced to the same level (20 * 20 m). In order to optimize the number of classes of factor maps, factor maps need to be reclassified. After that, each class joins a certain number of points. With them, it is definitely defined how each class of a particular factor contributes to sliding. The highest number of points is allocated to classes that represent the most unfavorable factors of the factors regarding the susceptibility to landslide, and the smallest number of classes that represent the most favorable factors of the factors. In doing so, the range of points for all factors is the same.

Table 2. Example slope reclassification and number of points associated with each class[1]

Class	Slope angle [°] marl	Slope angle [°] clay	Number of points
1	0 - 5	0 – 8	10
2	5 – 10	8 – 15	30
3	10 – 20	15 – 25	40
4	20 – 90	25 – 90	20

The influence of each individual factor on landslide susceptibility is defined by weight factors.
A landslide susceptibility map is a raster obtained by overlapping the reclassified factorial maps. Each grid cell is assigned the total number of points, which represents relative landslide susceptibility. Landslide susceptibility class’s show different spatial likelihood of landslide occurrence. [1]

Verification of the landslide susceptibility map can be performed on the basis of data on existing landslides. If such data are not available, they are not available or are too small; it is possible to create a landslide cadastre from the existing stereo par or LIDAR mapping.

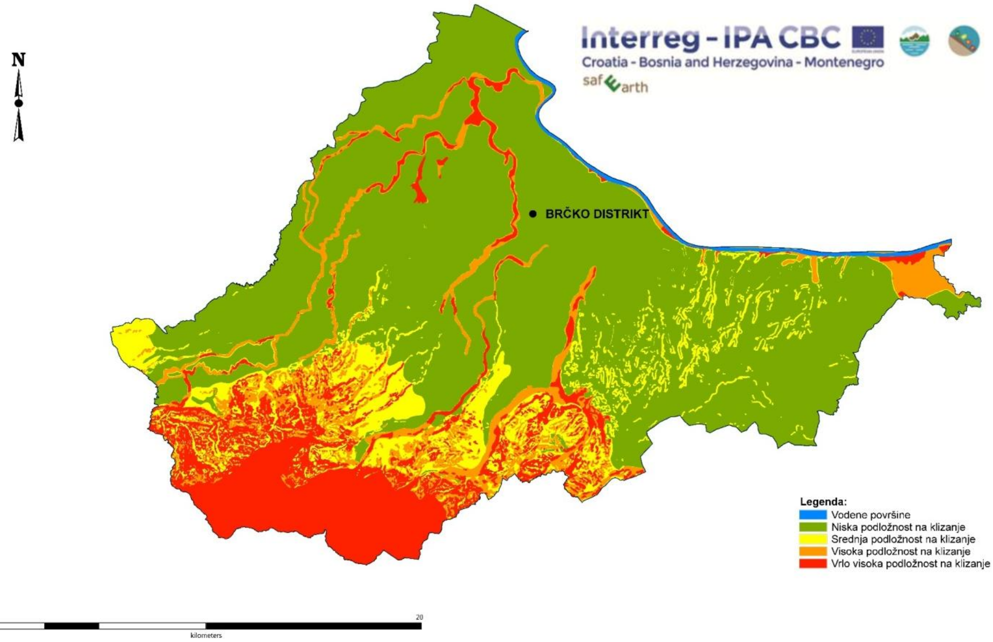


Figure 11. Landslide susceptibility map for Brčko district BiH (red color- very high landslide susceptibility, orange-high landslide susceptibility, yellow- middle landslide susceptibility, green- low landslide susceptibility, blue- water surfaces) [1]

6. LANDSLIDE HAZARD AND RISK ASSESSMENT IN LOCAL LEVEL

Landslide hazard and risk assessment for local level use the deterministic approach and it is most efficient for areas from few acres to area of whole municipality.

6.1. Landslide cadaster

For landslide hazard and risk assessment for whole municipalities, landslide cadastre is one of the most commonly used methods.

The former Yugoslavia had instructions for registration and research of unstable slopes and landslides. Based on these instructions, it is possible to generate forms that are most prevalent and efficient, representing records of the following data or databases:

- A database: contains information about the position of the object by type of map, administrative division and coordinates,
- B database: contains manifestations of appearance in terms of the type of material being moved by sliding, geometric elements of the phenomenon, slope geomorphology, engineering geological and hydrogeological models,
- C database: contains data on kinematics and model of occurrence, ie causes of landslide formation, deformation characteristics, stage and age of occurrence, identification of the relevant engineering geological model,

- D database: contains data on damages and forecasts, which implies damage to objects, provides basic data on further development of the phenomenon and records existing documentation. [10]

6.2. Contents and development of the landslide cadastre

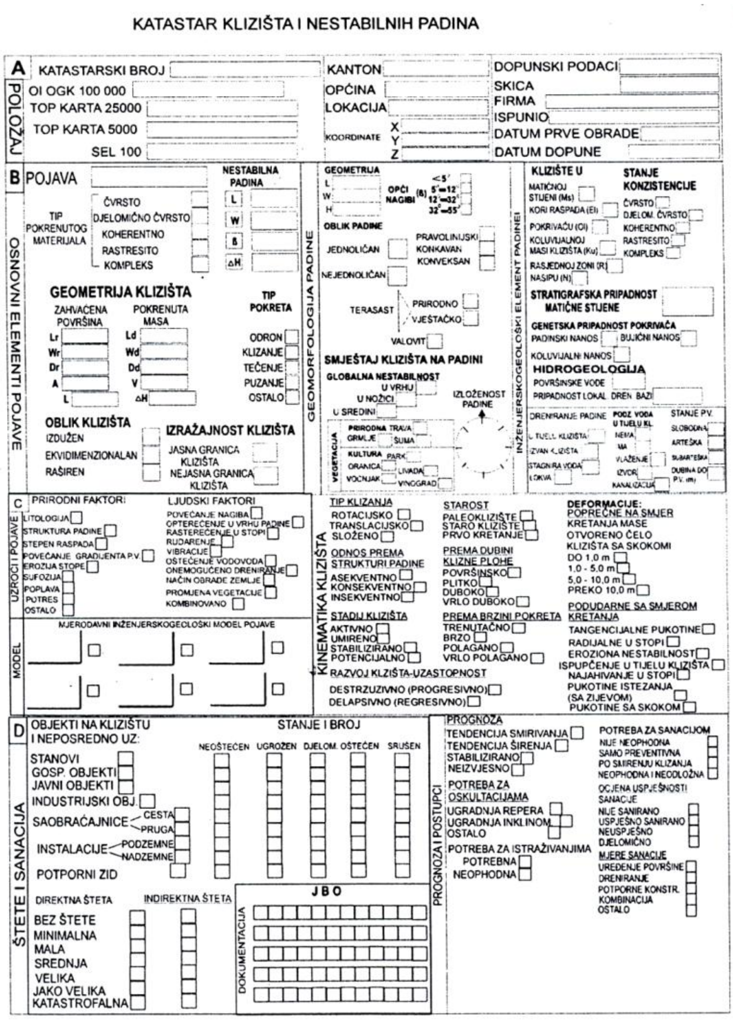
The study of the landslide must be regulated in a unique way, methodologically, so that one unique platform is created, which will enable the creation of a database for research and presentation at the local and international level.

The landslide cadastre is defined as a collection of basic data on landslides and on landslide surveys carried out according to all its characteristics. The formation of a landslide cadastre by a unique methodology represents the first and most important step in further work on the problems of landslide occurrence.

Landslide cadastre involves the collection of data on landslide elements. These elements can be registered in the field and measured, and on the basis of them the landslide is mapped to a suitable scale, in order to further identify and classify the landslide. The elements of the landslide differ from each other by their origin, way of reading, conditions of formation and development of the landslide, belonging to the type of landslide.

The qualitative and quantitative content of a database depends on subjective and objective circumstances. Here, first of all, is the level of knowledge of people dealing with landslides, the degree and method of landslide research and the economic basis on which data collection is based, which ultimately affects the level of landslide research.

It should be noted that there is no uniform form for the collecting of landslide data, on the basis of which the database is further formed. Thus, depending on the requirements and needs, one of the existing data collection forms can be selected or made. The collected data, which now make up the database, are further processed in software packages to obtain the desired data. These software packages need to be significantly developed.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POTRES
OSTALO
LJUDSKI FAKTORI
POVEĆANJE NAGIBA
OPTEREĆENJE U VRHU PADINE
RASTEREĆENJE U STOPI
RUDARENJE
VIBRACIJE
OŠTEĆENJE VODOVODA
ONEMOGUĆENO DRENIRANJE
NAČIN OBRADE ZEMLJE
PROMJENA VEGETACIJE
KOMBINOVANO
MODEL
MJERODAVNI INŽENJERSKOGEOLOŠKI MODEL POJAVE
KINEMATIKA KLIZIŠTA
TIP KLIZANJA
ROTACIJSKO
TRANSLACIJSKO
SLOŽENO
ODNOS PREMA STRUKTURI PADINE
ASEKVENTNO
KONSEKVENTNO
INSEKVENTNO
STADIJ KLIZIŠTA
AKTIVNO
UMIRENO
STABILIZIRANO
POTENCIJALNO
RAZVOJ KLIZIŠTA-UZASTOPNOST
DESTRZUZIVNO (PROGRESIVNO)
DELAPSIVNO (REGRESIVNO)
STAROST
PALEOKLIZIŠTE
STARO KLIZIŠTE
PRVO KRETANJE
PREMA DUBINI KLIZNE PLOHE
POVRŠINSKO
PLITKO
DUBOKO
VRLO DUBOKO
PREMA BRZINI POKRETA
TRENUTAČNO
BRZO
POLAGANO
VRLO POLAGANO
DEFORMACIJE:
POPREČNE NA SMJER KRETANJA MASE
OTVORENO ČELO KLIZIŠTA SA SKOKOMI
DO 1,0 m
1,0 - 5,0 m
5,0 - 10,0 m
PREKO 10,0 m
PODUDARNE SA SMJEROM KRETANJA
TANGENCIJALNE PUKOTINE
RADIJALNE U STOPI
EROZIONA NESTABILNOST
ISPUPČENJE U TIJELU KLIZIŠTA
NAJAHIVANJE U STOPI
PUKOTINE ISTEZANJA (SA ZIJEVOM)
PUKOTINE SA SKOKOM

D ŠTETE I SANACIJA
OBJEKTI NA KLIZIŠTU I NEPOSREDNO UZ:
STANJE I BROJ
NEOŠTEĆEN
UGROŽEN
DJELOM. OŠTEĆEN
SRUŠEN
STANOVI
GOSP. OBJEKTI
JAVNI OBJEKTI
INDUSTRIJSKI OBJ.
SAOBRAĆAJNICE CESTA PRUGA
INSTALACIJE PODZEMNE NADZEMNE
POTPORNI ZID
DIREKTNA ŠTETA
INDIREKTNA ŠTETA
BEZ ŠTETE
MINIMALNA
MALA
SREDNJA
VELIKA
JAKO VELIKA
KATASTROFALNA
JBO
DOKUMENTACIJA
PROGNOZA I POSTUPCI
PROGNOZA
TENDENCIJA SMIRIVANJA
TENDENCIJA ŠIRENJA
STABILIZIRANO
NEIZVJESNO
POTREBA ZA OSKULTACIJAMA
UGRADNJA REPERA
UGRADNJA INKLINOM.
OSTALO
POTREBA ZA ISTRAŽIVANJIMA
POTREBNA
NEOPHODNA
POTREBA ZA SANACIJOM
NIJE NEOPHODNA
SAMO PREVENTIVNA
PO SMIRENJU KLIZANJA
NEOPHODNA I NEODLOŽNA
OCJENA USPJEŠNOSTI SANACIJE
NIJE SANIRANO
USPJEŠNO SANIRANO
NEUSPJEŠNO
DJELOMIČNO
MJERE SANACIJE
UREĐENJE POVRŠINE
DRENIRANJE
POTPORNE KONSTR.
KOMBINACIJA
OSTALO

Figure 12. Example of landslide cadasre form from Croatia [10]

6.3. Geotechnical research in hazard and risk assessment

For landslide hazard and risk assessment for areas up to few acres, geotechnical research is one of the most commonly used methods. This type of risk management is used for planning and design of roads buildings etc.

All activities that are carried out on the study and research of existing and potential landslides at local level are aimed at obtaining a rational, i.e. economically and technically optimal solution for remediation or preventing the appearance of landslides.

The purpose of geotechnical research is to provide reliable information on the slope material in the construction area. This defines the impact of the construction object on the overall stability of the slope on which it is being built.

On this basis, we are able to project a rational solution to the foundation of the object, to examine the problems that can arise during the excavation phase of the slope, give a prognosis of its behavior in interaction with the ground and its impact on surrounding objects. There are several opinions related to the data that should contain geotechnical investigations, in order to analyze the slope stability and to approach the remediation on the slope. Basically, these data are related to the following facts:

- Geological conditions for the formation of soil and its detailed structure in the wider and narrower landslide area,
- Hydrogeological aspects of the area,
- Geotechnical characteristics of the soil in the slope, landslide area and beyond,
- Characteristics and type of landslide (if existing), its direction, intensity and speed of movement,
- Geodetic surveys
- Position, shape and properties of the potential sliding plane or landslide zone,
- Geomechanical tests of the soil in the terrain, sliding body and out of the landslide body,
- Possible causes of landslide and causing consequences.

The scope and content of geotechnical investigations is adapted to:

- Purpose of research,
- The size of the landslide or potential area for landslide occurrence due to the construction
- Complexity of the problem,
- Dangers and damages that may be caused by a slide,
- The degree of earlier research of the area and the knowledge of basic geological, hydrogeological and geotechnical aspects.

Systematic planning of geotechnical research works provides rational i.e. minimal costs, for providing basic information on the slope.

Phases of geotechnical research works are:

- Preliminary research
- Detailed research
- Supplementary or control research.

Preliminary research refers to the inclusion of data related to topographic, hydrological, climatological, geological and seismological characteristics of the slope area, as well as data related to existing building structures or infrastructure of any type, and even archaeological data or archival documentation.

Detailed research consists of numerous methods of geotechnical field research, and their number depends on the technical development of the environment in which they can be applied. [10]

The realization of this phase of the investigation is a much-demanding job and the most complex engineering task, because this phase includes:

- Selection of research methods,
- Planning and conducting appropriate field and laboratory experiments,
- Monitoring the results during the execution of works, including certain interventions in order to ensure the objective and quality of the performed research works,
- Determination of relevant geotechnical parameters.

Field and laboratory research need to be conducted in such manner to ensure the collection of valid data for risk assessment.

Data that are important for risk assessment on the slope are:

- Geological and geomorphological characteristics of the slope
- Hidrogeological conditions
- Engineering geological and geotechnical characteristics of the slope

The usual geotechnical field research works include the following methods:

- Probe ditch with sampling,
- Probe drilling with sampling,
- Standard Penetration Test (SPT) in boreholes,
- Static Penetration Test (CPT) in combination with boreholes,
- Creation of research wells,
- Creation of research galleries (horizontal ditches),
- Geophysical tests.

Figure 13. Probe ditch for sampling (left) and Probe drilling with sampling (right).

Laboratory testing of soil samples for stability assessment, in geomechanical laboratories, gives us:

- elevant shear strengths - cohesion (c) and angle of internal friction (φ),
- unit weight of soil,
- moisture content of samples,
- saturation,
- liquid limit, plastic limit and shrinking limit
- coefficients of permeability and porosity,
- compressibility module and other essential parameters.

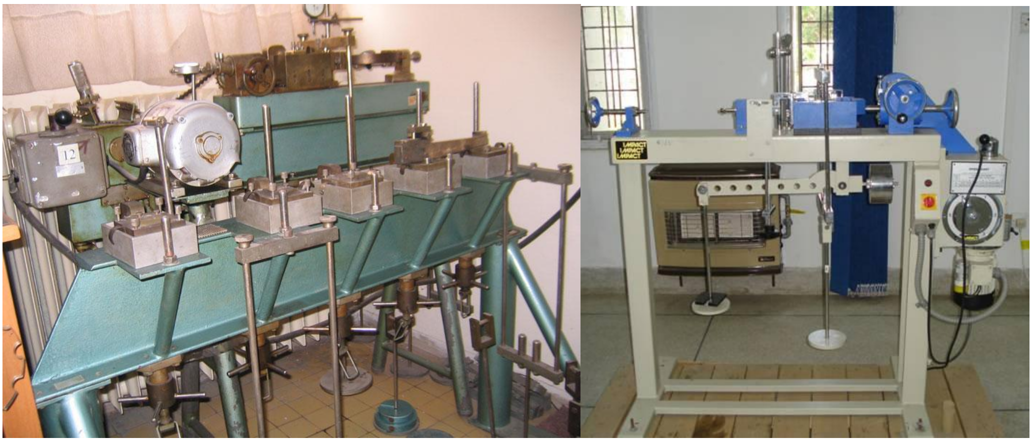

Figure 14. Shear device with defined shear plane (controlled force increment and controlled deformation increment.)

The results of field research and laboratory testing are presented in the form of report which has to include:

<u>The introductory part</u> (the scope and type of geotechnical problems for which research relates, phase of research, the author of the research program, previous information on the basis of which the research program was made).

<u>Main part of the report</u> (description of the location with the results of field investigations and laboratory research, plan of the investigated area with symbols of marked positions of investigative works, profiles of sampling pits, wells and CPT, geotechnical profiles along which investigative works were done). [10]

6.3.1. Interpretation of the results and risk reduction

When selecting resistant soil parameters and other conditions in analysis, a deterministic or probabilistic approach can be used.

With a deterministic approach, at each point in the soil for a given parameter, a value is assigned, which may correspond to the mean value or be greater or less than that value. By probabilistic approach, parameters are treated as random variables that move within a certain interval, and their occurrence is described by the distribution function. The deterministic approach is always more reliable for analysis, but it needs skilled researcher.

After analyzing the data obtained and defining parameters that are taken to calculate the stability of the slope, a stability calculation is preformed for the conditions in which the slope will be found after the execution of the construction works. Thus, in the stability calculation, the loads and impacts of all the constructions located at the site in question, as well as the constructions that will be subsequently built, are imposed. [10]

The quantitative stability estimate is given by the coefficient or safety factor Fs. There are several methods that set different principled approaches to the problem and on the basis of which explicit or implicit mathematical expressions are determined, which quantitatively determine the extent of the slope stability, and the degree of risk for the occurrence of landslide.

Since the safety factor is a quantitative assessment of the stability of one slope, this means that there is a certain value that represents the boundary between the stability and instability areas. This limit value that separates the two areas is Fs = 1. The unstable slope is the one for which the value of the safety factor Fs <1, and for the Fs> 1 values, we say that the slope is in the area of stability.

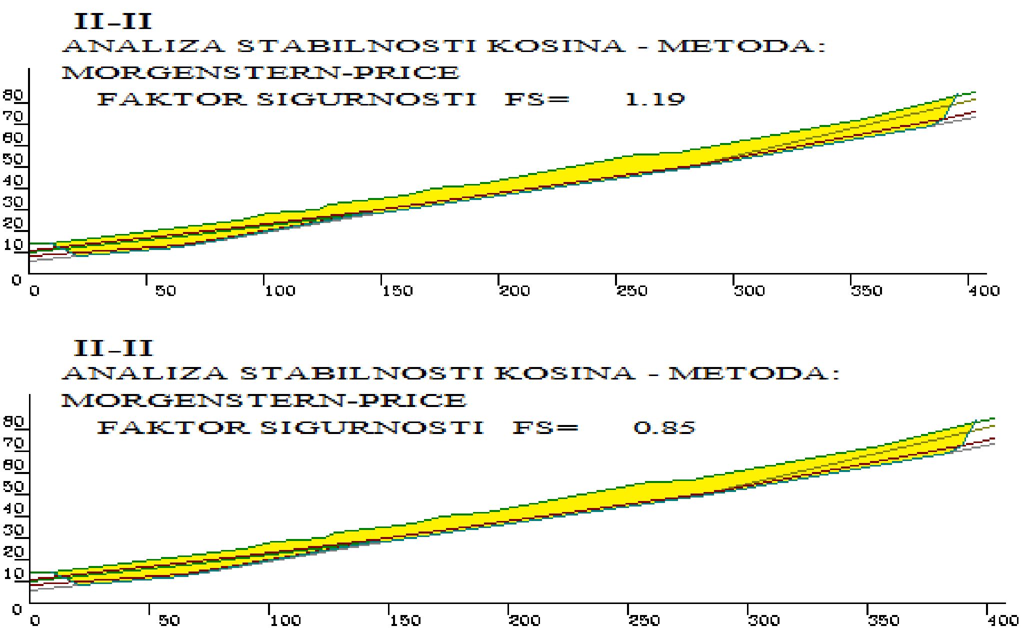

Figure 15. Calculation of safety factor for different conditions in the slope based on the geotechnical model.

Another category related to the safety factor is the so-called the required safety factor that usually has a value greater than 1 and depends on several factors:

- The significance of the object, where the required safety factor increases with the character of the object,
- The volume and reliability of the results of the performed works,
- Methods used to analyze and calculate the stability of the slope, where the value of the required safety factor is inversely proportional to the quality of the method, ie, its precision.

Table 3. Recommended safety factor for reccurence time of 10 years; forr higher risk and soft conditions increase od safety factor 10% (GEO 1984) [14]

FS allow		Risk of human losses		
		Negligible	Average	High
Risk of economic losses	Negligible	1.1	1.2	1.4
	Average	1.2	1.3	1.4
	High	1.4	1.4	1.5

FS for recurrency time of 10 years; for higher risks and soft ground conditions, add 10% increase in FS

Therefore, before any work on the slope is carried out, it is necessary to make clear and precise analyzes and assessments, in technical and economic terms, of such operations, which include possible remediation that would have to be undertaken before or after that. When it comes to urban environments, hazards and risks are much higher, so remediation is technically more demanding and significantly more expensive.

Analysis and assessment of safety factors can be performed on existing slopes, in order to check the stability of the slope (defined by the safety factor) in the current conditions. Also, the construction of new geotechnical facilities or any change in the current conditions in the slope must be verified through a stability analysis in order to define a safety factor for conditions in which the slope will be found after a change in equilibrium conditions.

Analysis and assessment of the slope conditions prior to the construction of geotechnical facilities is a very effective method of eliminating the hazard and risk associated with the occurrence of landslides on the slope. Such analysis enables the implementation of preventive measures, which implies the execution of remediation works and construction before activation of the landslide on the slope. The justification of this concept is based on the economic criterion, because in such cases, the analysis covered by the project work is done with peak and not residual values of the resistant soil parameters of the slope. The special significance of this preventive protection measures is in urban areas, as in this case the threat for existing buildings is reduced by the construction of new geotechnical objects in the slope.

Preventive measures include the following works and activities:

- Proper surface drainage from the slope and around the zone of the cut,
- Capture of the water source above excavation,
- Biological protection of newly built slopes,
- Removal of the route of the water supply and sewage network from the slope or from the part of the slope above the cuttings,
- The correct selection of the slope angle in function of time.

In addition to preventive remediation measures, if the landslide is activated, the risk to people and material goods becomes evident, permanent remediation measures are used. These measures represent the construction of remediation objects of different types, in and around the landslide, which will provide optimal results of the remediation, expressed through the elimination level of the landslide process slope stability. The choice of the remediation object type, its location and dimensions are demonstrated through the analysis of object stability, the estimation of the financial burden and the technical feasibility of the object within the entire system of remediation measures foreseen by the rehabilitation project. The very name of these measures suggests that it is a matter of remediation measures, which are need to for long period of time, and at least for the period of exploitation of the slopes and constructions on it, provide the required stability of the slope and exploitation safety of the objects. [10]

7. CONCLUSION

The landslides as phenomenon is a complex process that arises due to the presence of a number of influencing factors in a particular area, and can cause great damage to people and material goods. Due to the increasing need for the construction of residential and infrastructural facilities, combined with significant climate change in the form of extreme precipitation, the risk associated with landslides is increasing every year. Landslides can be significantly different in many elements of their occurrence, which in some cases leads to significant financial costs in their remediation. Assessment of hazard and risk associated with landslides is the basis for planning the urbanization of certain areas, but also for defining the vulnerability of certain areas on which the built settlements and infrastructural objects exist. Only systematic studies of hazard and risk can be preventive meausre in order to eliminate or significantly reduce the risk of landslides. The first step in analyzing the hazard and risk of landslides is research at the regional level, which should point to high risk zones. Hazard and risk analysis at the regional level, which clearly defines areas with a high risk for the landslide, allows to steer the research at the local level, ie defines areas where more detailed analyzes in the form of geotechnical investigations should be carried out. In this way, considerable savings are made of the financial resources required for the execution of geotechnical works, as most expensive but most accurate methods for hazard and risk assessment.. Systematic approach to landslide, as geotechnical hazard, can significantly reduce or eliminate the risk associated with the occurrence of landslides.

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9. QUESTIONS

1. How landslides effect people and urban developement?
2. Which are the main causes of landslide formation?
3. What are basic steps in order to assess the hazard and risk of landslide occurrence for each new or existing urban area?
4. How do we assess hazard and risk in regional level?
5. What approach is most common in hazard and risk assessment in regional level?
6. How do we assess hazard and risk of landslides in local level?
7. Which method is the most accurate in landslide hazard and risk assessment?
8. Why is it important to first do the regional, then local hazard and risk assessment?