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Landslide Causes and Corrective Measures – Case Study of the Sarajevo Canton

Amra Serdarevic[1,*], Fuad Babic[2]

[1]Faculty of Civil Engineering, University of Sarajevo, Sarajevo, BiH
[2]Development Planning Institute of the Sarajevo Canton, Sarajevo, BiH

Abstract The term "landslide" is well known to the general public and it is associated mainly with negative news of material and human casualties. This is why they are often mentioned in the media when they are already happened. Landslides are defined as the movement of soil or rock masses down the slope. It includes all forms of movement from landsliding, rolling of stones, falling rocks, rotational and translational sliding to the flow of different materials. Movements take place mainly on curved sliding surfaces. Moving of the mass on or along the slope (sliding) can be slow and barely noticeable in time, but it can also be very fast and destructive. The causes of landslides occurrence may be different, but in general, a landslide occurs when the active forces (mainly gravity) exceed the strength of soil materials and rocks that form the slope. Causes include factors that increase the effects of traction forces and factors that contribute to the weak or reduced strength of the slope material. Recently, mostly caused by extreme precipitation in a relatively short time, the numerous landslides in BiH have been activated. This paper presents the status and realization of landslide rehabilitation projects in Sarajevo Canton (SC).

Keywords Landslides, Corrective measures, Mitigation, Monitoring

1. Introduction

Landslides are defined as the movement of a different type of soil, rock or debris. Those movements happen down or along a slope. Slope movements could be caused by multiple factors like rainfall, snow melting, changes in groundwater level, soil erosion, earthquakes or by human activities. Inhabitants or homeowners occupy unstable areas, especially in low income countries or in development countries, usually because they don't have any other places to relocate. Negative effects of landslides are often reflected to local community, but consequences and high costs for implementation of the intervention measures frequently become the state problems. Before any activities, if possible, it is recommended to consult engineers, geologists and other experts, experienced in the successful realization of stabilization or risk mitigation of unstable slopes.

The occurrences and first records of landslides in the Sarajevo Canton (SC) were recorded during Austro-Hungarian rule as a consequences of some natural phenomena. More intense processing and landslides records start at the beginning of the 1970s.

The increased number of landslides in the city of Sarajevo dates from the end of the Second World War, more precisely, from the first cases of illegal construction of residential buildings in Sarajevo. The real explosion of the landslide events in the Sarajevo Canton took place after the end of the war in BiH in 1995. This paper presents an overview of landslide occurrence, situation with landslides in the Sarajevo Canton including few examples of landslide stabilization measures.

2. Overview of Landslide Characteristics

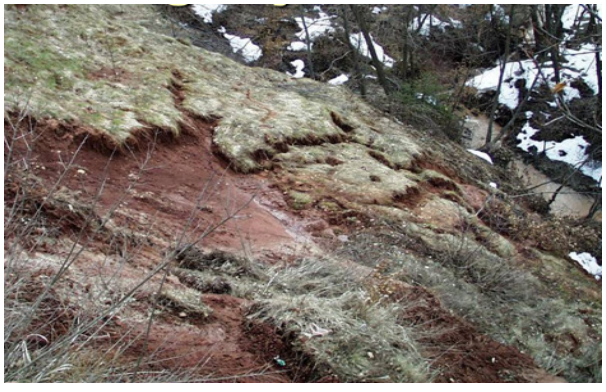

Figure 1. An example of one of type of landform typical for unstable terrain [1]

* Corresponding author:
amra.serdarevic@gf.unsa.ba (Amra Serdarevic)
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Generally, landslide is a term used to describe movement of rock, soil or debris usually by gravity down a slope or it is a term for typical landform with characteristic surface marks (Fig.1).

Terrain instability can be defined as general or local. General instability is defined in a wider zone that is unstable or conditionally stable, where there are many objects that are endangered. Soil movements are constantly present so radical stabilization measures are required. The problem at such sites is very often very complex, and the effects of local interventions are negligible (Fig.2).

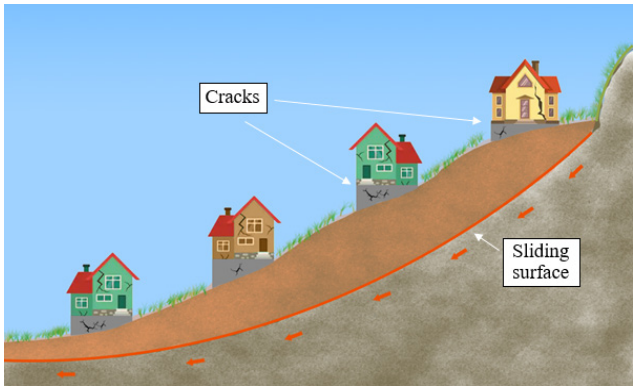

Figure 2. Schematic of a global unstable area

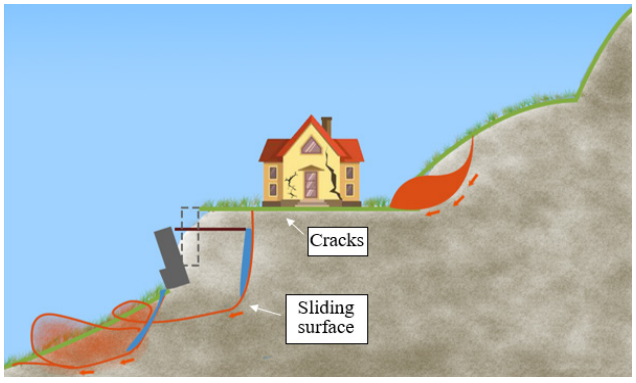

Figure 3. Schematic of local instability of terrain due to the illegal structure

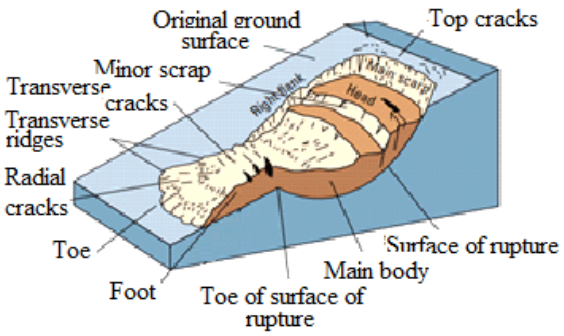

Figure 4. Illustration of the common terms for rotational landslide that has evolved into an earthflow [2]

Local instability is the instability of a smaller area, often caused by inadequate construction activities during the construction of buildings, roads, or infrastructures. The problem is less complex than in the case of general instability and required works are of smaller size and it is possible to act locally.

The basic parts and most common terms of a typical landslide are shown on Figure 4.

Different classification of landslides are associated with type of failures and mechanics of movement. Material in a landslide mass are rock and soil (earth) or debris (coarse material). The landslide can be classified by the type of the landslide mass displacement: fall, slide, spread, flow or topple [2,3]. Usually, landslides are described by using two terms that refer respectively to way of movement and type of landslide material (e.g. rock fall, rock slide, earth flow, debris flow) (Fig.5).

Figure 5. A rockfall/slide that occurred in Porodice Foht street in the Sarajevo Canton (2009.). with example of a rock curtain, a barrier commonly applied over hazardous rock face [1]

The landslide can appear anywhere around us in some manners. The traditional opinion for appearance of the landslide is related to the steep slope or unstable terrain.

Certain types of landslides are clearly defined like rockfalls on steep slopes, debris torrents or some other types. The triggers for landslides are various. The most common causes that can trigger landslide are precipitation, snowmelt, deforestation, earthquakes, volcanoes, wildfires, and certain dangerous human activities.

Sometimes, landslides are caused, or made worse, by a combination of several different factors. Effects of all of these causes vary widely and depend on factors such as steepness of slope, morphology or shape of terrain, soil type, underlying geology, and presence of people or structures on the affected areas. [2,3]

Primary cause of landslides is water and slope saturation and it depends of the precipitation, snowmelt, level of the ground-water, surface water, etc. Flooding also could cause landslides by slope saturation with water or undercutting banks of streams. Landslides could be a cause for flooding by block waterways or by rock sliding.

The most common triggers that destabilize the weak soil/earth layer include:

- Saturation of underlying weaker layer due to precipitation, snowmelt, and changes in ground-water

levels
- Liquefaction of lower weak layer by earthquake shaking
- Natural or anthropogenic overloading of the ground above an unstable slope/illegal construction of buildings
- Following an erosional disturbance at base of a riverbank/slope
- Plastic deformation of unstable material at depth
- Terrain cuts without or with inadequate insurance
- Loads of slopes with earth embankment or structures
- Damaged installations of water supply and sewerage
- Drainage of surface and groundwater from the slopes
- Unregulated drainage of water from road
- Inadequate drainage of terrains and supporting walls
- Uncontrolled felling of trees and soil cultivation on slopes.

Figure 6. Consequences of landslide in the Sarajevo Canton (Kromolj), caused by rainfall, and possibly made worse by sewage leakage [5]

It is important to recognize that landslide types and their characteristics. That categorization is related to recognition of expected development scenario, consequences and applicable correction measures and adequate interventions.

Generally, description and categorization of landslides include following characteristics:

1. ***Triggering mechanism*** for the most landslides are related to activities by natural or human activities such as undercutting of slope by natural process (e.g. streams or rivers erosion) or by human activities such as excavation, intense vibration, road building, maintenance and similar.
   Primarily, triggers are related to the intense rainfall or rapid snowmelt. Slops are saturated by water, groundwater levels rising and filling reservoirs, lakes, streams which could cause erosion at the base of slopes. Sometimes bulk material, located upslope are driven by gravity or triggered by water or ice occurring in cracks within the mass. Also, trigger for landslides could be a leakage from pipes or human – related disturbances (deforestation, illegal construction, etc.).
2. ***Effects*** could be divided into direct or indirect consequences or damages. The worst are life-threatening if movement are very rapid, but also very slow movement could be extremely damaging to structures, buildings, railways, roads.
3. ***Velocity of movement/ rates of traveling*** are from extremely slow (less 0,3m every 5 years) to moderately fast (1,5 m per year) to extremely fast/rapid, sometimes accelerating throughout the movement, depending of topographic and distance. Rapid movement such as falling material can be life – threatening (large rocks, huge amount of mudslides or debris, etc.)
4. ***Corrective measures/mitigation***: It could be divided into groups of *ad hock* intervention measures due to the accidental situation or long term measures. There are many options for stabilization of the landslides areas. Some example are related to the instrumental monitoring to detect movement and applied corrective measure on time. Adequate drainage and restoration of drainage pathways, construction of retaining walls with counterfort at the toe, rock curtains or slope covers or more sophisticated remedies in rocks which include anchors, bolts and dowels are some of commonly used, applicable corrective measures.
5. ***Predictability***: If some evidence of prior landslides or avalanches exists in an area, with some monitoring evidence, probabilistic scenario could be done (like cracks at tops of slopes, changes in slope inclinations near cracks recorded by tiltmeters, etc). Some occurrence is not possible to predict or stop by any engineering means because the triggering mechanisms are not preventable. It is very important for spatial plans to avoid settlements and road construction in valleys, unstable areas or below steep mountain slopes, glaciers or volcanoes. Some prevention activities could be adopted but warning system sometimes is not applicable due to the very fast movement of debris avalanches.

Following description of current situation given in the overview, the causes for landslide formation and measures of mitigation in the Sarajevo Canton are presented further in this document.

3. Landslides in the Sarajevo Canton

The landslides in the Sarajevo Canton area are mentioned in the city notes, from its early beginnings of planned construction under Austria-Hungarian rule. However, the number of landslides has increased significantly since 1995, caused by the war consequences in BiH, when the reconstruction of cities and infrastructure has begun. In this period, there was the attempt to implement mitigation measures for landslides according to the priorities and

conditioned by the situation on the ground.

By establishing the records on landslides, the problems that caused landslides were noticed. By analyzing the appearance of the landslide since 2000, the causes, characteristics and measures for mitigating the damage have been systematized.

The main causes for landslides in the Sarajevo Canton from 1995 to 2019 are:

- Illegal construction of private housing facilities throughout the Sarajevo Canton.
- Terrain instability as a result of warfare and detonation of explosive devices during the 1992-1995 operations.
- Massive, uncontrolled felling of forests and parks vegetation during the war in Sarajevo.
- Leakage from the water supply network (> 70% of losses is identified in the Sarajevo water network)
- Poor condition in drainage system of precipitation and fecal wastewater
- Damage on drinking water reservoirs located on the outskirts of the city of Sarajevo.

Several landslides have been recorded at the Sarajevo Canton, which are the result of natural phenomena. The landslides are located outside the populated areas of the city and there is no illegal construction on them. This type of landslide is mostly inactive, registered in the database and included in the geodetic monitoring network.

3.1. Reasons for Landslides in the Sarajevo Canton

The most important cause of the landslide occurrence in the Sarajevo Canton has been the expansion of the illegal construction of residential buildings. The problem of illegal construction has been present for over 50 years. The increase in illegally built facilities in SC is also a consequence of the migration of the population to larger cities after the war in BiH (1992-1995). Since 1995, there have been a triple increase in the number of illegal individual housing units in some locations.

How does a landslide appear due to illegal construction?

Uncontrolled construction affects the appearance of landslides in different ways and the landslide phenomenon is associated with:

- Construction of residential buildings on terrains that can not withstand heavy loads.
- Construction of residential and other facilities without quality geological explorations.
- Building objects without adequate project documentation.
- Lack of quality infrastructure.
- Impact of leaks from illegal connections to water-supply and sewerage.
- Construction of facilities for domestic animals and discharges of wastewater down the slope or near residential buildings.
- Inadequate drainage of rain water.
- Construction of inadequate septic tanks and wastewater discharges along the slope in the immediate vicinity of residential buildings.
- Poor construction of pavement constructions, especially in the slopes of the city, where there is no rainwater drainage
- Inappropriate cross-sectional and longitudinal slopes of road structures that cause the discharge of surface waters along the surrounding slopes.

All of these causes can be associated with the appearance of a landslide as a single, but may also occur in combination. However, which measures have been applied to prevent the landslide from being illegally constructed?

There is a very rare occurrence of the demolition of illegally constructed residential buildings. The "legalization" of residential buildings is mainly carried out, along with recording of potential landslides and implementation of mitigation and rehabilitation measures on the ground. Very often measures are related to the installation of the surface drainage channel, which leads to the stabilization of the terrain (Fig.7).

The occurrence of mass erosion and the movement of soil on large areas in the Sarajevo Canton area was caused by the seizure of forests during the war in BiH in order to provide heating energy because Sarajevo was under the siege, mostly without electricity, heating and water for four years.

The slides that appeared at these sites are the most difficult and largest in the area.

Also, a significant number of landslides are triggered due to leaks from the water supply and sewage systems. The water supply system in SC today records about 70% of losses due to poor network status.

Figure 7. Illustration of the mitigation measure with open channel for surface water drainage in the Sarajevo Canton (Brusulje) [1]

Some landslides have been launched near the reservoirs, caused by leaks from the same reservoirs. As all reservoirs in the Sarajevo Canton were built 30 years ago or more, there were cracks in structures of the water tanks.

The leakage from the water supply network has the strong impact on activation of already identified and inactive landslides or impact on formation of new landslides with a more progressive development.

3.2. Land Register – Database

In the period from 1996 to 2000, the total of 745 landslides were registered in the Sarajevo Canton, of which 234 landslides were active.

From this initial step, the database management and updating were established. The number of active and inactive or stabilized landslides at the municipalities of the Sarajevo Canton, for 2017, is shown in Table 1.

The advantage of the database is to timely investigate and implement measures to mitigate potential landslide launching. Thus, based on the identified landslides, the geological explorations were initiated for some locations, and also for some landslides the complete documentation was made at the level of a main project. The continuous monitoring is being carried out on a large number of landslides.

Observations on landslides are carried out before, during and after rehabilitation (Fig. 9).

There is a database of landslides in the Sarajevo Canton and it is regularly updated, although it is necessary to emphasize need for securing funds for software development tools as well as sufficient number of teams to visit and update the data.

Apart the Sarajevo Canton, the similar situation exists in other parts of BiH, so it is necessary to stress the importance of an integrated database at the entity level as well as at the state level, with continuous monitoring of the situation on the ground.

In the developing countries such as BiH, it is often neglected the need to allocate funds for geodetic monitoring and database/network creation, without which it is impossible to have well-coordinated plans and implementation.

Table 1. Data Base of Landslides in the Sarajevo Canton in 2017 [7]

Municipality of the Sarajevo Canton	Total number of landslides	Realized projects and measures (2017)	Potential hazardous landslides/ no correction measures
Centar	131	37	94
Stari Grad	114	15	99
Novo Sarajevo	106	18	88
Novi Grad	180	20	160
Ilidza	14	0	14
Vogosca	201	9	192
Ilijas	49	12	37
Trnovo	13	5	8
Hadzici	8	7	1
TOTAL	**816**	**123**	**693**

3.3. Landslides Survey

The landslides survey is one of the most important stages in dealing with landslides. This activity is an input of what and how we should treat the landslides.

Many examples from our practice have shown that mitigation measures can be ineffective and unprofitable if they are designed and operated without sufficient knowledge about the landslides. It is a mistake to conclude that remediation and approach to landslide problems can be solved with a template application of even with the most expensive mitigation measures.

Based on experience it can be concluded that if landslide studies were missing or they are insufficient, then the mitigation measures were mostly: wrong, insufficient, oversized and unreasonable.

Figure 8a. Lateral spreading damage - Stolacka street in the Sarajevo Canton under reconstruction [6]

Figure 8b. Rehabilitated landslide Stolacka street in the SC [6]

The figures 8a and 8b show the landslide rehabilitation and the state after the rehabilitation of Stolacka street. The situation is complex since the street is pretty long and located in the central part of Sarajevo, above the sports center “Skenderija”. Following identification of the five landslides, it was developed a restoration plan. In order to repair the major landslide, 8 anchors were installed, and a reinforced concrete retaining wall with counterforts was constructed. The total length of the supporting structure was 110 m and the average excavation depth was 5 m. The landslide remediation measures included also the drainage of surface water and reconstruction of the sewerage system. The total investment value of the described landslide remediation works was 250,000.00 EUR. The works were conducted within period of five months.

The question arises as to why research or landslide studies are needed? There are two important reasons for this activity.

- To determine the degree of vulnerability of an object that is affected or may be affected by the process of

sliding the terrain.

- To adequately choose and then perform the appropriate recovery works.

A practical example is a continuous survey carried out on the site of Dalmatinska Street, considered as one of the most difficult landslide in the Sarajevo Canton. The landslide remediation measures applied at the subject location included the installation of piles (approx. length 200 m), anchors (approx. length 450 m) and reinforcement of residential buildings foundations. The works lasted for 24 months and the rehabilitation cost was 750.000 EUR [7].

The presence of tenants created significant difficulties for restoration activities. The similar situation was with mechanization since the works needed to be carried out inside residential units.

Therefore for the above landslide example (Fig. 9), all tenants from the buildings were moved out, and Canton provided alternative accommodation during the works. The results of the long-term monitoring, after the rehabilitation, show acceptable stabilization of terrain.

Figure 9. Cracks on the building and marks for observation Dalmatinska street in the Sarajevo Canton [1]

3.4. Monitoring System

In areas where have been noticed traces of soil motion and cracks on objects, it is necessary to immediately establish monitoring, which has the task of indicating the displacement sizes, and their increment with time (Fig. 9).

The landslide monitoring is based on three methods of monitoring. Since 1999, the three types of monitoring have been applied in Sarajevo Canton: geodetic monitoring, piezometer monitoring, and installation of inclinometer for geotechnical monitoring system.

If sudden increase in movement of soil, or open cracks on objects are noticed, then it is necessary to intervene urgently, and make further decisions with the help of specialists in this field. This task can be accomplished through frequent field observations, then installation of glass tiles on cracks, and direct measurements of cracks in the field, where the measurements should be made between pre-fixed wooden pickets (Fig. 10).

To initiate any remediation, it requires development of geodetic layout, installation of measuring bases and benchmarks on the ground and walls of buildings. The next steps are damage record, monitoring and development of documentation for rehabilitation.

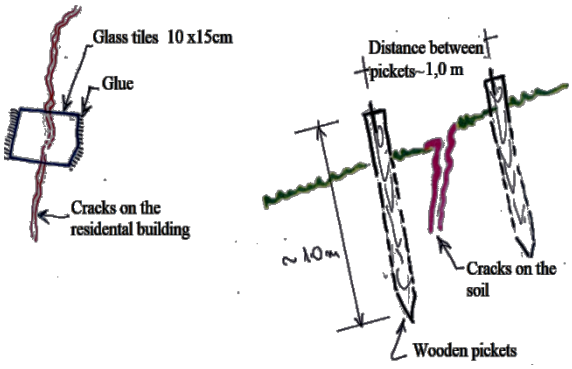

Figure 10. Marks for landslides monitoring (with glass tiles and pickets)

Every rehabilitated landslide site requires a regular maintenance in a long period of time, which is not the case with the most landslides. The landslides are neglected so very often there is blockage of drainage systems, drainage channels and cracking of gabion nets.

At the end of each calendar year, the Cantonal Government of Sarajevo submits a report on the situation in the Canton regarding landslides and conducted works including proposal of the Plan of activities for the next year.

4. Conclusions

Bearing in mind that landslides can happen everywhere around us, the certain patterns and descriptions are used for different activities about landslides and have to be used for landslides prevention and damage control.

Systematization of landslide type data, velocity of movement, trigger mechanism, effects, corrective measures / mitigation, predictability and warning system are basic data information, collected on site and recorded for longer period in order to implement an appropriate landslides management and activities for mitigation.

The research of numerous landslides in the territory of the Sarajevo Canton concluded that the causes of the occurrence of these events are also natural and anthropogenic caused by human activity on the slopes of the terrain.

- The most important natural causes are related to the very complex geological structure and the unfavorable engineering-geological and hydrogeological properties of surface coverings and geological substrates, and also for the influence of surface and ground waters, climate regime (type and length of precipitation) slope of terrain, etc.

- The most typical of the artificial causes are: Construction of residential buildings and facilities of communal infrastructure on the slopes, conditionally stable and unstable parts of the city without any previous geotechnical researches, undercutting of slops, and uncontrolled spillage of surface waters in the field, deforestation, damaged sewer and water supply network as a war consequences, etc.

The Sarajevo Canton as a priority attempts to suspend the illegal construction of residential buildings and implement corrective and mitigation measures.

According to the data of the Institute for Construction of the Sarajevo Canton, in the period from 1998 to 2018, about 23 Mil EUR was spent on correction measures and mitigation of the consequences from the landslides [7]. In addition, there is continuous work on improving the database, adequate data processing and the adoption of planned measures to improve the situation on the ground. Citizens of the Sarajevo Canton are timely notified about potential dangers from the landslides. However, despite all measures and caution, characteristic of topography and landslide patterns recorded over the years require continues efforts to be invested in dealing with this challenging issue.

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