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Landslides and slope stability evaluation in the historical town of Kruja, Albania

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Abstract

This paper describes the landslides and slope stability evaluation in the urban area of Kruja town, Albania. Kruja is a historical and heritage center, due to the existence of many important cultural monuments including Skanderbeg castle and Bazaar square etc. The urban area of Kruja town has been affected from the Landslides effects, in the past and also present. From this phenomenon many engineering objects such as buildings, roads etc. are damaged and demolished. From the engineering geological mapping at scale 1 : 5000 it is observed that many active landslides have dramatically increased in activity after 1980s. The landslide types found in the studied area are earth slides, debris flow, as well as rock fall and rock rolling. Also, from field works and laboratory analysis, the slope stability of whole urban areas has been determined; for this purpose the studied zone is divided into the stable and unstable areas, which helps to better understand the mass movement's activity as one of the most harmful hazards of the geodynamics' phenomena.

1 Introduction

The town of Kruja is located in central part of Albania on one of Skanderbeg's Mountain's slopes. It represents one of the most famous heritage and historic centers in Albania. In this town have frequently occurred mass movements from which many engineering objects are damaged and/or demolished. That is why the Civil Geological Center of Tirana during the period 2004–2008 (Muceku, 2008) has undertaken engineering geological mappings at scale 1 : 5000, for which numerous boreholes have been drilled, pits varying from 4.5–6.0 m to 10.0–12.0 m, in order to take soil and rock samples for laboratory tests. Also, a detailed estimation of lithological, geomorphologic, hydrogeological geofactors was completed. Furthermore, from this work, the distribution, geometry and characteristics of landslides are determined and the slope stability of the urban area concerned is assessed.

2 Geological setting

On the basis of numerous geological studies (Meço and Aliaj, 2000; Xhomo et al., 2002; Muceku and Zeqo, 2008), the studied zone is built from the Quaternary deposits, molasses rocks of Upper Miocene, flysch's rocks of Lower Oligocene (Pg_1^3) and limestone's rocks of Paleocene (Pg_1), Eocene (Pg_2) and Upper Cretaceous (Cr_2) (Fig. 1). The Quaternary deposits are represented by diluvium deposits, which have occupied the major part of studied area. They consist of silts and clays with fine sands, gravels-cobbles mixture, as well as breccia's rocks, varying in thickness from1.0–3.0 m up to 5.0–8.0 m. In south east of the area extend the molasses rocks are composed of massive sandstone interbedded by siltstones-claystones layers. They are transgressively situated on limestone rocks of Upper Cretaceous (Cr_2). As shown in Figs. 1 and 2 in the western part of the Kruja zone are spread out the layered limestone rocks of Upper Cretaceous (Cr_2), which are situated on lower part of studied geological profile. These rocks dip to east in an angle of 30–35°. Over these rocks lie with the stratigraphic break, the thin layered limestone rocks of Eocene (Pg_2) with the same dip angle of Upper Cretaceous limestones. In central part of the Kruja zone extend the flysch rocks of Oligocene (Pg_1^3), bounding on limestone's rocks (Pg_2) with normal contact. In eastern part on these rocks through intensive tectonic zone overthrust the limestone's rocks (Cr_2, Pg_1 and Pg_2), which dip to east in an angle of 50°. The flysch rocks are an interbed of the thin siltstone, claystone and sandstone layers. In relation to geological structure these rocks build an overturned syncline (Xhomo et al., 2002; Meço and Aliaj, 2000; Muceku and Zeqo, 2008) with limbs dipping 45–55° to the east (Fig. 2). It could be emphasized that the rocks mentioned above in upper part of lithological profile are affected from weathering crust formation processes, which was non-uniformly happened over the whole area.

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3 Geomorphologic characteristics

From geomorphological point of view, the urban area of Kruja town represents a hilly slope consisting of breccia's and flysch rocks with inclination angles ranging from 16–25° up to 30–40°. One of the slopes characteristic features is the concavo-convex profile, which is formed as result of the torrent operation and geodynamics phenomenon occurrences such as landslides and erosions. During rainfall, a considerable mass of debris and rock fragments flows down the slope through these drains and accumulates on the middle and lower levels of hilly zones. In some places of the studied area, the slope angle exceeds the angle of repose of the accumulated materials, and then the hill's slope's mass materials lie in limit's state condition ready to move down. The failed slopes are generally devoid of any vegetation, while the surrounding area is moderately covered with pine trees. From our investigations several failures are mapped. They have occurred in upper and center part of urban area and have played a main role in the modeling of terrain, forming a lot of escalations. These failures do mostly trend from north-west to south east and dip towards the hill slope.

4 Mass movements

The mass movement's activity is related to various factors, which triggered this phenomenon in the studied area. The main factors, which have initiated and favored this phenomenon are lithology (soils and rocks), morphology, (slope inclination and slope shapes), tectonics movement's zone, rainfalls and manmade works.

From several geotechnical investigations carried out on Kruja urban area was concluded that it is subject to landslides. According to Cruden and Varnes (1996), they are earth slide, debris flows and rocks rolling types.

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4.1 Earth slide

In center and southeastern part of the Kruja town have occurred 2 earth slides. The larger one is 500.0–550.0 m long, 200.0–320.0 m wide, 4.0–8.5 m thick (Figs. 3 and 5). It's occurred 1990 yr. During heavy rains period some sites in upper part of the landslide move slowly downwards on hills slopes. Over this slide are built the Kasmaj, Perlataj and Berberaj squares of the Kruja town, where about 12, 2–3 store buildings are demolished and about 47 others are affected by joint failure and cracks. This certainly constitutes a serious threat to human life for people who live in this area. Besides, this mass movement has affected transportation corridors and communication facilities. The upper part of the landslide body-crown is situated directly on the tectonic fractured zone (Figs. 2 and 7), which is one of the main factors favoring this phenomenon (Muceku, 2008, 2009), whereas the medium and lower part of the slide plane is situated on weathering crust of flysch rocks, which is 1.4–2.2 m thick (Figs. 3, 4 and 5). The slide's body consists of silts and clays with fine sands. The other (smaller) earth slide is 220.0 m long, 120.0 wide and 2.8–5.5 m thick (Fig. 7). On this slide a traffic road and green park are built, which are often damaged from its moving. Several geo-factors favor this mass movement. They are the soft rocks-flysch (interbed of the siltstone's, claystones and sandstone's layers), which are intensively disturbed by tectonic activity, as well as rainfall and underground waters. The tectonics zone works as a collector of the karstic water of limestone's rocks of Skanderbeg Mountain. These waters flow out in the form of spring water at the point of contact of soil and flysch rocks on landslide's crown, influencing the lowering of geotechnical properties of the soils and rocks. Furthermore, this area is very much affected by rainfall averaging 1800–20 000 mm yr^{-1} (Themeli and Mustaçi, 1996). The rainfall reached its climax in 1959 (3160.6 mm) and 1960 (3569.9 mm) (Naçi, 1974). The man-made works (foundation's excavation) have also affected the earth slide occurrences. Also, the morphology of the steep slopes on this area can also increase susceptibility to landslide events. Based on geotechnical investigations (Muceku, 2008) engineering's measures are taken on upper part

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of large landslide occurrences, including pile-based applications, for the protection of roads and 47 buildings at risk, which are part of the old Albanian culture.

4.2 Debris flows

As mentioned above, the studied area represents a mountain's zone, where slope inclinations vary from 16° up to 40°. In east of this zone extends the Skanderbeg mountain with very steep slope inclination varying from (32°–55° up to 85° (Figs. 6 and 7). From weathering crust processes of limestones, as well as rainfall's waters erosion and transportation on these slopes are accumulated the unconsolidated materials (gravels-cobbles mixture with no fines).

The debris materials are detached from upper parts of limestone's rocks of Skanderbeg Mountain and are accumulated on medium to lower part of its slope. Rock debris comes to rest in the run out zone, which includes gentler slopes, where boulders and blocks roll or bounce beyond the base of the acceleration zone. They are deposited in ephemeral streams and are ready to move down in form of debris flows (Fig. 6) that are open-sloped (Dahl et al., 2010). The debris materials have this dimension range: 120.0–250.0 m up to 350.0–400.0 m long, 50.0–100.0 m wide and 1.8–3.5 m up to 5.5–7.0 m. Two of these zones are located over Kruja town. The volume of debris accumulated in these cones is 28 000 m^3 and 12 000 m^3 respectively, constituting a present risk for this part of town.

The debris slide phenomena in this area have occurred several times in the previous years, such as debris flows of 2004 and 2010 that have damaged several buildings, green landscape in eastern part of Kruja town and also adjacent traffics roads. Barriers-stone masonry walls were built for protection against of debris flows in lower part of colluvium's cones. These protections only have reduced potential rock damages, without averting the debris flow in this area. Furthermore, since Kruja town is built on the down slopes of Skanderbeg Mountain with inclination angle 14–27°, with an unconsolidated debris source above town, ready to move down, that means a high risk is present.

4.3 Rock rolling

The rock toppling and rolling phenomena occur in the middle-upper part of Skanderbeg Mountain slopes, which are built by limestone's, flysch's and breccia's rocks. The blocks and stones are composed by limestone's and breccia's rocks in different sizes with irregular shape. As seen in Figs. 3, 4, 6 and 7 from rocks toppling, rocks fall and rocks rolling phenomena in urban area are found 23 breccia's and limestone's blocks, their volume varying from 3.2–4.5 m^3 up to 12.–20.0 m^3. They are situated on urban area's slope with inclination angle 16–27°. Most of them rest in unstable state conditions that occur oftentimes, due to of landslides and erosion's activities (Figs. 19 and 20). From this process some of large blocks during heavy rain events do roll down, damaging roads, green landscape and buildings. So, this phenomenon is a real risk to life and engineering objects such as buildings, roads etc. (Figs. 19 and 20).

5 Geotechnical conditions

The studied area represents one of the main towns in Albania due to its historical and cultural heritage, not to mention its touristic potential. Because of this it was necessary to conduct the engineering geological investigations related to slopes stability of this area. These investigations include the engineering geological mapping at scale 1 : 5000, drillings and pit works executed on the landslides body and also throughout hill slopes over urban areas. Therefore on the two earth slide bodies, 13 boreholes were drilled, including 37 more drilled on the slopes where urban areas are located; the depth range was from 8.0 m to 12.0 m and 42 other pits (4.5–5.5 m). From these works were taken 63 undisturbed and 16 disturbed samples of soil and rocks for laboratory testing, which were analyzed for physical and mechanical properties such as grain size distribution, atteberg limits (LL, PL), density (γ), specific density (γ_o), internal friction angle (φ), cohesion (c) and σ-uniaxial compressive strength of rocks. It is important to emphasize that 17 soil samples were analyzed in triaxial test (U, U). These results are briefly discussed here and given in Tables 1 and 2. Based on geofactor's criteria such as lithology and geotechnical properties the urban area is classified into several engineering geology zones. From lithology features there are three types of rocks that are breccia's, flysch's and limestone's rocks. Related to geotechnical properties the limestone's breccia's and flysch's rocks respectively are included in hard, weak and very weak rocks group (Romana, 1996). So, from these features the urban area has been classified into engineering geology zones built from basement of limestone's, breccia's and flysch's rocks. Moreover, based on terrain's morphology (slope inclination angle), soils thickness and physical mechanical properties of soils situated over bedrocks, each engineering geology zone was divided into several engineering geology sites (Fig. 8), which represent the homogeneous areas. In this paper we are treating the geotechnical conditions of unstable areas. These areas, normally found on hills slopes built by soils represented by inorganic clays and silts with sands content and gravels-cobbles mixture with no fines, that are situated respectively on flysch and limestone slopes with inclination angle range from 15–25° up to 28–35°.

On the other hand the stable slopes (northern part of urban area) are not discussed here, due to the fact that they are built by consolidated breccia's rocks with high safety factor. The geotechnical conditions of soils and rocks found in the studied area are analyzed according to engineering geology zones and sites. The studied area for this paper purpose is itemed as below.

a. *The engineering geology zone with basement built of breccia's rocks* (Fig. 8). This zone is spread out in north and center part of urban area. It represents a hill's slope, which dips to west with inclination angle 14–27°. The basement of this zone is composed of breccia's rocks 3.0–5.0 up to 12.0–15.0 m thick. According to geotechnical classification they are included in the weak rock group (Romana, 1996). From geotechnical investigation it is observed that this zone is a stable area (Muceku, 2008).

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b. *The engineering geology zone with basement built of limestone's rocks* (Fig. 8) is extended in eastern part of Kruja town on mountain's slope. Based on lithology characteristics and physical mechanical properties of soils and rocks, this zone is classified into two engineering geology sites that are diluvium soils and limestone's rocks. The engineering geology site nr. 1 is represented by diluvium soils (Fig. 6). It is composed of three geotechnical layers which are:

The geotechnical layer nr. 1, is represented by gravels-cobbles mixture with no fines.

The geotechnical layer nr. 2, is weathering crust of limestone's rocks.

The geotechnical layer nr. 3, is limestone's rocks.

The first geotechnical layer is situated on limestone's slopes of Skanderbeg Mountain with inclination angle 23–34°. It has originated from the upper part of mountain slopes as result of rock fall phenomena. In relation to Unified Soils Classification System (Samtani and Nowatzki, 2006), these soils are included in GP group and characterized with low geotechnical parameters in loose condition (Tables 1, 2).

The second geotechnical layer constitutes the weathering crust of limestone's rocks, which lies in upper part of lithological profile. It is fractured, creating many limestone's blocks ready to detach and roll down. This geotechnical layer is 1.5–2.5 m thick and in relation to geotechnical properties (Tables 1, 2) are involved in medium strong rocks (Romana, 1996).

The third geotechnical layers are composed from limestone's rocks (L), which are strong rock (Romana, 1996). In the case of engineering geology site nr. 2 only the second and third layers as explained above are observed.

c. *The engineering geology zone with basement built of flysch rocks* (Fig. 8). From field works and laboratory testing in this zone, five engineering geology sites (nr. 2, 3, 4, 5 and nr. 6) are distinguished (Fig. 8). They differ from one another due to their top layers, which consists of soils with different physical-mechanical properties (Tables 1, 2) and different slope inclination angles as well.

The engineering geology site nr. 2. It is built by three geotechnical layers, which are 4, 5 and 6 (Fig. 3). The geotechnical layer nr. 4 consists of inorganic clays of low to medium plasticity, 1.9–4.2 m up to 6.5–8.2 m thick. These soils are included into CL soils group (Samtani and Nowatzki, 2006). The geotechnical layer nr. 5 represents the weathering crust of flysch's rocks (FL), very weak rocks (Romana, 1996), 1.8–2.5 m thick. It is characterized by the same physical-mechanical properties in whole engineering geology zone. The geotechnical layer nr. 6 is built by the flysch rocks (FL), formed due to the interbed of thin claystones-siltstones with sandstones layers, weak rocks (Romana, 1996). It is found in the entire engineering geology zone with the same geotechnical properties.

In the engineering geology site nr. 3, 4, 5 and 6 we are analyzing only the top geotechnical layer (nr. 7, 8, 9 and 10), because of two deeper geotechnical layers (5 and 6) are treated to engineering geology site 2.

1. *The engineering geology site nr. 3.* The geotechnical layer nr. 7, is composed by inorganic silts and fine sands, 1.9–3.1 to 7.2 m thick. According to USCS (Samtani and Nowatzki, 2006) this soil are ML type.

2. *The engineering geology site nr. 4.* The geotechnical layer nr. 8 consist of inorganic clays of low to medium plasticity, 2.2–5.7 m thick, including to CL soils group (Samtani and Nowatzki, 2006).

3. *The engineering geology site nr. 5.* The geotechnical layer nr. 9 consist of inorganic clays of low to medium plasticity including to CL soils group (Samtani and Nowatzki, 2006). It ranges from 3.2–5.0 m up to 7.5–8.7 m thick.

4. *The engineering geology site nr. 6.* The geotechnical layer nr. 10 consist of inorganic clays of low to medium plasticity. It is included in CL soils group (Samtani and Nowatzki, 2006) and is 2.7–5.3 m thick.

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6 Slope stability analysis

According to slope stability evaluation of the urban area of Kruja town, the engineering geology mapping at scale 1 : 5000 has been carried out followed by field works and laboratory tests. For the analysis of the slopes the finite element software Phase2-FEM (Rocscience, 2011) has been used; the safety factor is verified using the limit equilibrium software Slide 6.0, (Rocscience, 2010). Uniform meshing and 6-noded triangles are also used in FEM analysis. Mohr–Coulomb failure criterion is chosen to model the soils and elastic-plastic material properties are used as required by the Shear Strength Reduction (SSR) analysis. The geotechnical parameters imputed in this model for each layer are: φ-internal friction angle, c-cohesion, E-elasticity module, υ-Poisson ratio, γ-density (Tables 1 and 2). In all cases the analysis is split in two stages. In stage 1 site stress is modeled using plastic analysis, and in stage 2 SSR are analyzed under the effect of a specified hazard. All the above parameters have been considered in each of the following conditions: (i) dry season, (ii) heavy rains, (iii) seismic activity using PGA hazard value from the Albanian Seismicity Map (Kuka, 2003), and (iv) both rain and seismic activity. The slope stability safety factor is verified with Slide 6.0 software using the rigorous methods (Spencer, 1967; Morgenstern and Price, 1965). These methods divide the slope into blocks and use equilibrium of both forces and moments for each block. The geotechnical parameters used in this model for each layer are: φ-internal friction angle, c-cohesion and γ-density (Tables 1 and 2). The equilibrium analysis in all cases is done using a polygonal search plane that corresponds to soil-rock contact in the lower part and is optimized automatically by the software at the curved parts. In all cases (except profile 1–1, engineering geology site nr. 1), the results of safety factors (Tables 3 and 4) computed from both software's models are almost equal, showing only a small difference (2–5 %). FEM results on Profile 1–1 (engineering geology site nr. 1), present the local failure and also a lack of convergence, therefore they give a nonrealistic Strength Reduction Factor SRF (equivalent to safety factor). From the resulted safety factor values (Tables 3 and 4, engineering geology site nr. 1) computed from

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equilibrium analysis the slope's stability zonation's maps are plotted. The results are summarized in Tables 3 and 4.

The analysis has been performed using no reduction factor, so the slope may be considered safe only when $S_F > 1.3$. For the values $1.0 \le S_F \le 1.3$, the slope's condition is critical and $S_F < 1$. the slope is unstable. The safety factor is calculated in accordance with geotechnical and seismic conditions of the studied area. The geotechnical conditions of urban area are related to lithological features, physical-mechanical properties of soils and rocks, as well as weather's characteristics. From the geotechnical investigation was concluded that the upper geotechnical layers are composed of different types of soils (GP, CL and ML) were much affected by weather's conditions. These soils in arid season (summer-autumn) have better geotechnical properties than in wet season (winter-spring). From many authors (Guzzetti, et al., 2003; Vieira et al., 2010) and from our investigations carried out for last 20 yr (Muceku, 2008) the majority of slope movements occur during the wet seasons (heavy rain). For that is very important to emphasize that this area is much affected from rainfall. The mean annual rainfall is 1800–2000 mm yr^{-1} (Themeli and Mustaçi, 1996). In particular years, the rainfall values have been as follows: 3569.9 mm in 1960, 2518.1 mm in 1962 and 2288.6 mm in 1960. Also, it is important to understand that most of the rainfall occurs in December–March period (Naçi, 1974). Furthermore, Albania represents a seismically active area in the Balkan region. It is characterized by a high seismic intensity (Papazachos et al., 2001), where have occurred many of earthquakes with small magnitude ($M < 4.5$), fewer medium-sized magnitude ($M = 5.5$–5.9), and rare strong earthquakes ($M > 6.5$). That is the reason, why we have taken under consideration the fact that the seismicity affects the slope stability of studied area. From the slope stability evaluation (Figs. 9, 10, 11, 12, 13 and 14) is concluded that southern part of Kruja urban area, presents a real risk to the inhabitants of this area. As, it is shown in Fig. 15, the urban area of Kruja town in case of arid periods has a safety factor $S_F \ge 1.45$ in whole area, besides engineering geology sites nr. 1 and 2, which are in critical state ($S_F = 1.03$–1.24). In saturated conditions (rainy days), our calculations point out that some areas (Fig. 16) such as engineering

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geology sites nr. 1 and 2 are in unstable conditions because safety factor $S_F \le 0.79$ and engineering geology sites nr. 4, 5 and 6 are in critical state (S_F = 1.01–1.21), whereas the engineering geology site nr. 3 is in stable state ($S_F \ge 1.58$). As above mentioned, the other factor that plays an important role in slope instability is seismic activity. The landslides triggered by earthquakes are the most unpredictable events and for this reason one of the most dangerous (Marcato et al., 2007). Therefore, a detailed slope stability analysis is completed for all hill's slopes of urban of Kruja town where debris flows, earth slide and rock block rolling have been noticed.

The seismic safety factor computed for engineering geology sites nr. 1, 2, 5, and 6 is $S_F \le 0.95$ (Figs. 10 and 14), indicating that these slopes are probably unstable (Fig. 17), whereas the engineering geology sites nr. 3 and 4 with S_F = 1.01–1.10 are in critical state. Also, considering that the studied area has been under the effects of rainfalls and seismic activity for a long time, we have taken into account the possibility that earthquakes will occur during or in few days after rainfalls. The computed safety factor in this case is $S_F \le 0.82$ (Figs. 9, 10, 11 and 12), indicating that the engineering geology sites (hill's slopes) for these conditions (earthquake after heavy rainfall) are unstable and very susceptible to landslides occurrences (Fig. 18).

Finally, after field, laboratory works and FEM slope stability analysis is concluded that:

a. In most of slopes' areas that are built from breccia's and limestone's rocks the mass movements have not occurred, therefore they are considered stable areas (Figs. 15, 16, 17 and 18).

b. The hills slopes that are located on the southern part of urban area, covered by inorganic silts and clays with very fine sands, which are situated on flysch rocks and characterized by shallow underground water tables (0.8–2.0 m), are considered unstable (Figs. 15, 16, 17 and 18).

c. Some areas of the hill's slope (east of urban area) on which are deposited the diluvium soils (gravels-cobbles mixture with no fines), over limestone's rocks are evaluated unstable (Figs. 15, 16, 17 and 18).

From the analysis is found that among the factors such as lithology and geomorphology a main role in mass movement's occurrences have played the underground water (after heavy rainfalls) and seismic activity.

7 Slope stability zonation map

The results obtained from field works, engineering geological mapping and the computation of safety factors in the urban area of Kruja town have led to the compilation of the slope stability zonation maps at scale 1 : 5000 (Muceku, 2008). This will help the town's planners and designers for the urban area development. This compilation has been based on the evaluation of geo-factors as lithology (soils and rocks type, soils thickness), geomorphology (slope inclination), landslide occurrences, hydrogeological conditions (underground water table, rainfall etc.), geotechnical properties of soils and rocks and slope stability safety factors.

The engineering geology zoning map, scale 1 : 5000 (Fig. 7) is divided into three engineering geology zones which are:

a. The engineering geology zone built from basement of breccia's rocks.

b. The engineering geology zone built from basement of limestone's rocks.

c. The engineering geology zone built from basement of flysch rocks.

Based on terrain's morphology (slope inclination angle), soil's physical-mechanical properties and soil's thickness, each engineering geology zone was divided into several engineering geology sites (Fig. 8) are homogeneous as geotechnical characteristics. From the slope stability analysis done for each engineering geology site, was calculated the safety factor S_F (SRF) for different geotechnical conditions of soil and rocks

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are (i) dry season, (ii) heavy rains, (iii) seismic activity and (iv) heavy rains and seismic activity (Figs. 15, 16, 17 and 18).

In accordance with safety factor values, the engineering geology sites were classified into three categories:

1. The engineering geology sites in unstable state $S_F < 1$.

   From the slope stability evaluation is concluded that a considerable area in southern and eastern part of Kruja town, in case of saturated conditions (rainy days) and seismic activity is in unstable state. That means these slopes are characterized by a landslide occurrence, in terms of earth slide, rocks rolling and debris flows types. In this category are included earth slides, engineering geology sites nr. 1 and 2 (Fig. 16, saturated conditions), engineering geology sites nr. 1, 2, 5 and 6 (Fig. 17, seismic activity) and engineering geology sites nr. 1, 2, 3, 4, 5 and 6 (Fig. 18, saturated and seismic conditions).

2. The engineering geology site in critical state $1.0 \leq S_F \leq 1.3$.

   The hills slopes in this category are in the limit equilibrium state. Here are included the engineering geology sites nr. 1 and 2 (Fig. 15, arid condition), engineering geology sites nr. 4, 5 and 6 (Fig. 16, saturated conditions) and engineering geology sites 3 and 4 (Fig. 17, seismic activity).

3. The engineering geology site in stable state stable state $S_F > 1.3$.

   The hills slopes are stable from the mass movement occurrences point of view. They are shown in Fig. 15 (engineering geology site nr. 3, 4, 5 and 6) and Fig. 16 (engineering geology site nr. 3). Also, in this category are involved the engineering geology zones built from basement of breccia and limestone's rocks (Figs. 15, 16, 17 and 18). Moreover, the slopes of first category are included in the area with high hazards due to the fact that they will be moved down in one of the soils geotechnical conditions (rains, seismic activity and both rains and seismic activity); the second category slopes are included in the area with medium-high

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hazards because they are ready to move down and the third category slopes are included in the stable area with no hazards.

8 Conclusions and recommendations

The Kruja urban area is subjected to an active mass movement, including earth slides, debris slides and rocks rolling phenomena.

These mass movements are triggered by rain and/or seismic activity. After a detailed analysis the engineering geology map is compiled, which is divided into engineering geology zones with basement built from breccia's rocks, flysch rocks and limestone's rocks.

A finite element analysis is performed using specialized software Phase2 (Rocscience, 2011) and the safety factor is determined for the most typical slopes. The results are verified using limit equilibrium software Slide (Rocscience, 2010). The difference in the results in most cases was 2–5 % proving the reliability of the analysis.

Based on safety factor "S_F" values, the engineering geology sites were classified as follows: unstable state ($S_F < 1$ with high hazard), critical state ($1.0 \leq S_F \leq 1.3$ with medium-high hazard) and stable state ($S_F > 1.3$ states with no hazard).

The conditions of the unstable areas need to be improved in order to prevent life loss, economic or cultural heritage damage. To protect the urban area against rock blocks rolling, it is necessary to remove them. For protection against debris flows phenomena, engineering measures such as benches and concrete walls should be used. To protect the Kasmaj, Perlataj and Berberaj squares against earth slides phenomenon, engineering measures such as piles and drainages systems should be used.

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Table 1. Physical properties of soils and rocks.

Site	Geotech. layer	Properties				
		LL (%)	PL (%)	Wn (%)	γ (kN m^{-3})	γ_o (kN m^{-3})
	nr. 1	–	–	5.0	19.0	26.14
nr. 1	nr. 2	–	–	0.41	27.1	28.9
	nr. 3	–	–	0.02	26.9	28.8
	nr. 4	29.5	20.2	23.7	19.0	26.86
nr. 2	nr. 5	–	–	7.3	21.8	25.60
	nr. 6	–	–	3.20	25.3	25.5
nr. 3	nr. 7	34.1	23.8	21.6	19.8	26.94
nr. 4	nr. 8	32.4	22.8	24.53	19.6	27.1
nr. 5	nr. 9	29.8	24.0	21.0	19.8	27.0
nr. 6	nr. 10	29.0	19.8	21.6	19.5	26.9

LL-Liquid limit, PL-plastic limit, Wn-natural water, γ-density, γ_o-specific density.

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Table 2. Mechanical properties of soils and rocks.

Site	Geotech. layers	Properties				Soils and Rocks
		ϕ (°)	c (kPa)	E (MPa)	υ	
nr. 1	nr. 1	39	0.0	27.0	0.32	GP
	nr. 2	54	1324	17 888	0.21	L
	nr. 3	56	9586	10 4001	0.19	L
nr. 2	nr. 4	18	22	7.55	0.33	CL
	nr. 5	28	94	146.6	0.25	FL
	nr. 6	36	189	1300	0.22	FL
nr. 3	nr. 7	18	28	29.55	0.29	ML
nr. 4	nr. 8	17	25	12.24	0.31	CL
nr. 5	nr. 9	19	30	35.25	0.28	CL
nr. 6	nr. 10	18	28	21.57	0.22	CL

φ – internal friction angle, c – cohesion, E – elastics module, υ – Poisson ratio, GP, CL, ML soils group, L – limestone rocks, FL – flysch rocks.

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Table 3. Slope stability analysis results computed by finite element (Rocscience, 2011).

Site	Safety factor for the condition			
	Dry	Rain	Seismic	Rain and Seismic
nr. 1	1.24	0.67	0.67	0.39[a]
nr. 2	1.03	0.79	0.68	0.50
nr. 3	2.06	1.58	1.10	0.82
nr. 4	1.56	1.21	1.01	0.74
nr. 5	1.45	1.01	0.88	0.59
nr. 6	1.63	1.21	0.95	0.69

[a] S_F taken from limit equilibrium analysis.

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Table 4. Slope stability analysis results computed by limit equilibrium (Rocscience, 2010).

Site	Safety factor for the condition			
	Dry	Rain	Seismic	Rain and Seismic
nr. 1	1.74	0.67	1.04	0.39
nr. 2	1.04	0.81	0.70	0.55
nr. 3	2.10	1.67	1.07	0.82
nr. 4	1.49	1.15	0.98	0.71
nr. 5	1.42	0.99	0.88	0.60
nr. 6	1.59	1.17	0.93	0.68

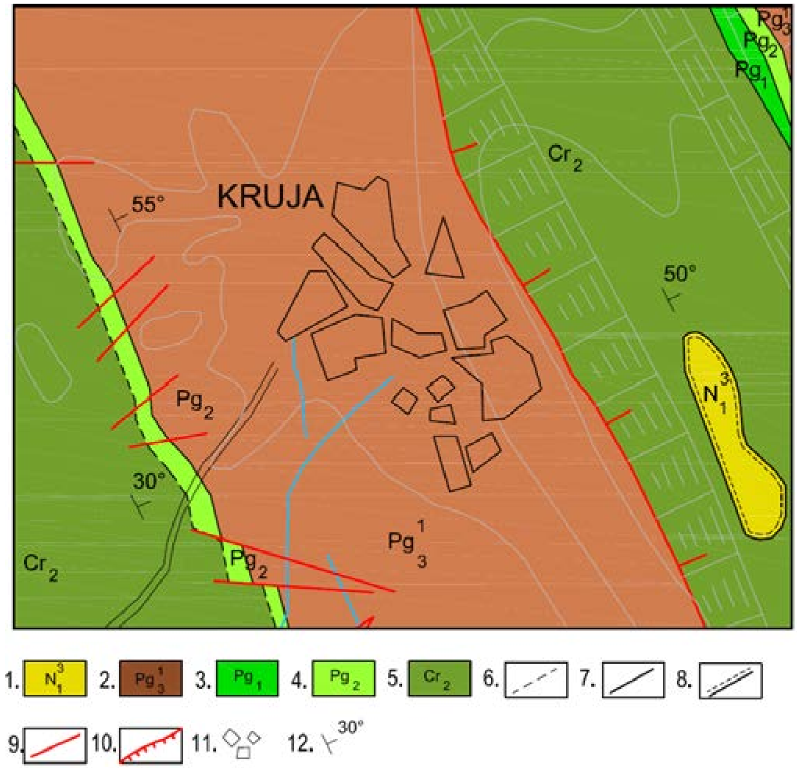

Fig. 1. Geological map of Kruja region (Xhomo et al., 2002). (1) molasses rocks-sandstones, claystones, (2) flysch rocks-interbed of siltstones-claystones with sandstones, (3, 4, 5) limestone's rocks of Paleocene (Pg_1), Eocene (Pg_2) and Upper Cretaceous (Cr_2), (6) stratigraphic break's boundary, (7) normal boundary, (8) transgressive boundary, (9) tectonics line, (10) overthrust tectonics, (11) Kruja town, (12) bedding with amount of dip.

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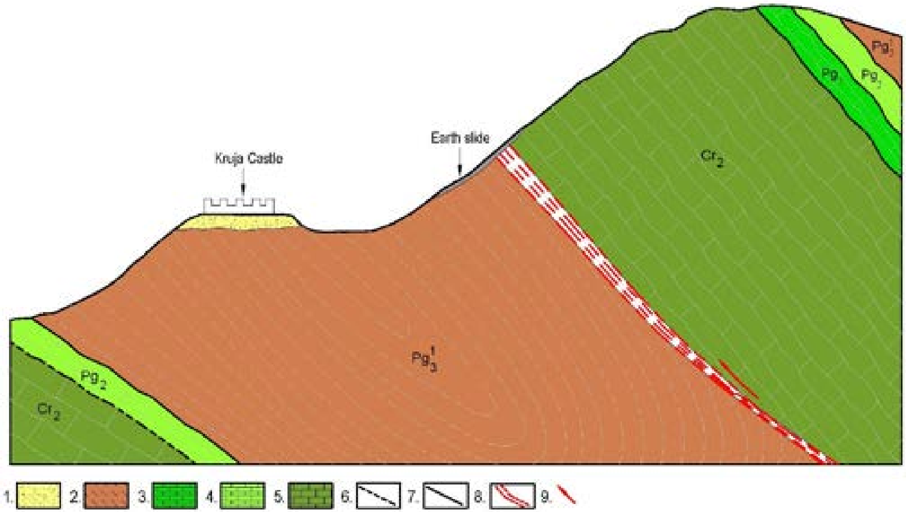

Fig. 2. Geological profile of Kruja region (Xhomo et al., 2002; Muceku, 2008). (1) breccia's rocks, (2) flysch rocks, (3) limestone rocks of Paleocene (Pg_1), (4) limestone rocks of Eocene (Pg_2), (5) limestone rocks of Upper Cretaceous (Cr_2), (6) stratigraphic break's boundary, (7) normal boundary, (8) overthrust tectonics, (9) mass movement direction.

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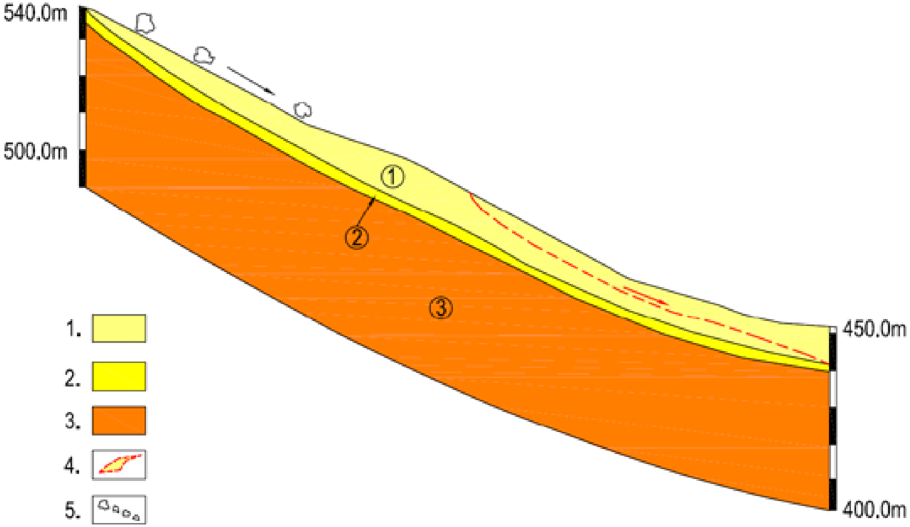

Fig. 3. Lithological profile of engineering geology site nr. 2. (1) inorganic silts and clays with fine sands, (2) weathering crust of flysch rocks (3) flysch rocks, (4) earth's slides body, (5) breccia's and limestone's blocks.

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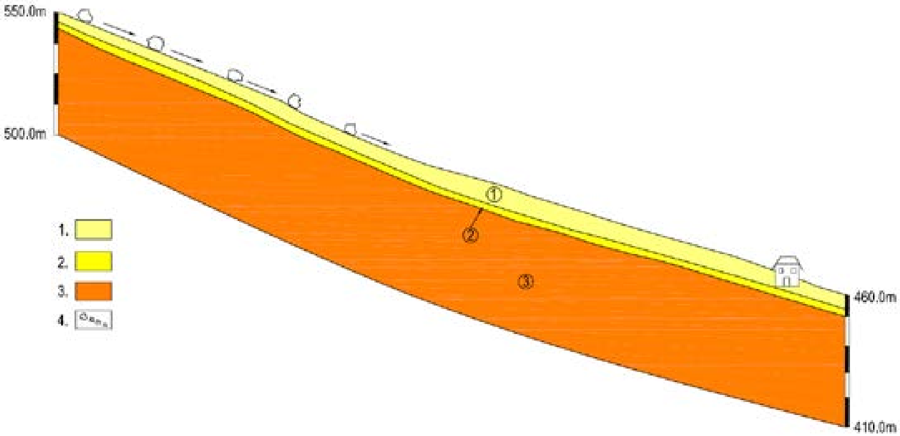

Fig. 4. Lithological profile of engineering geology site nr. 4. (1) inorganic silts and clays with fine sands, (2) weathering crust of flysch rocks (3) flysch rocks, (4) breccia's and limestone's blocks.

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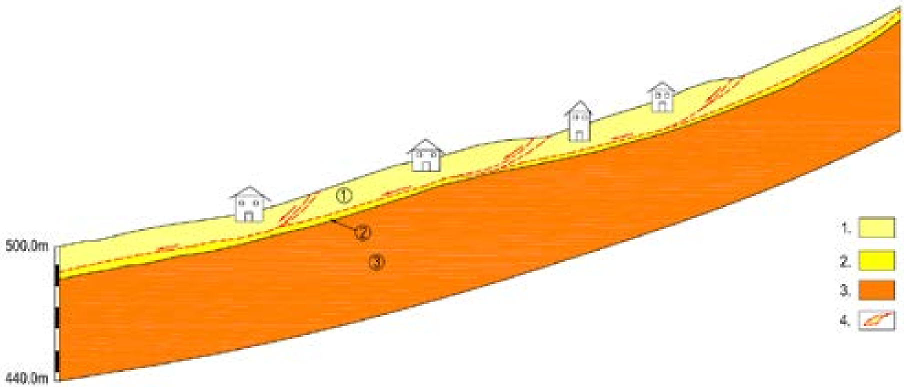

Fig. 5. Lithological profile of engineering geology site nr. 5. (1) inorganic silts and clays with fine sands, (2) weathering crust of flysch rocks (3) flysch rocks, (4) earth's slides body.

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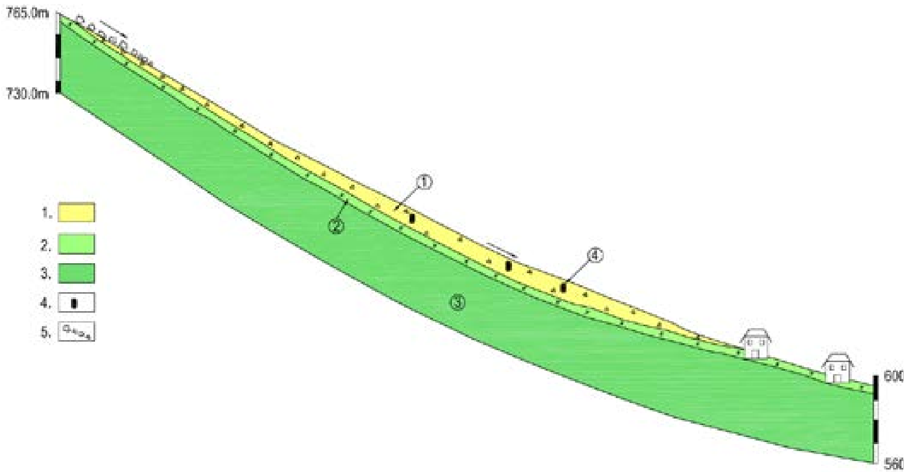

Fig. 6. Lithological profile of engineering geology site nr. 1. (1) gravels-cobbles mixture with no fines, (2) weathering crust of limestone's rocks, medium strong rocks, (3) strong limestone's rocks rock, (4) Barriers-stone masonry walls, (5) limestone's blocks.

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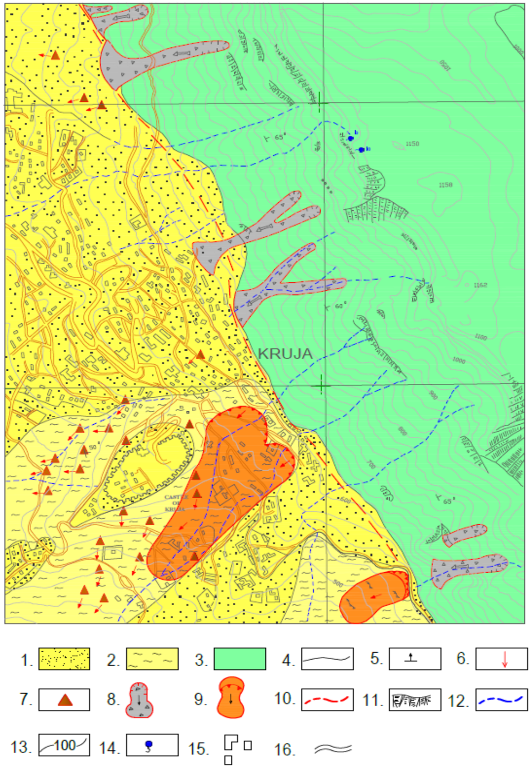

Fig. 7. Engineering geological map of Kruja town, scale 1 : 5000 (Muceku, 2008). (1) Breccia's rocks, (2) flysch rocks, (3) limestone's rocks, (4) lithological boundary, (5) strata dip angle, (6) slide direction, (7) rocks block, (8) debris flows, (9) earth's slides, (10) tectonics line, (11) limestone's cliff, (12) streams, (13) altitude line, (14) water spring, (15) buildings, (16) traffic road.

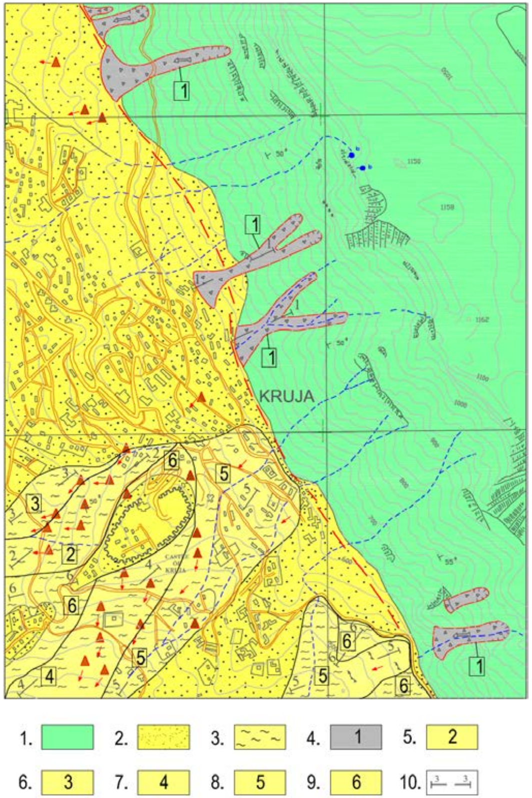

Fig. 8. Engineering geological zoning map of Kruja town, scale 1 : 5000. (1) engineering geology zone with basement built of limestone's rocks, (2) engineering geology zone with basement built of breccia's rocks, (3) engineering geology zone with basement built of flysch rocks, (4, 5, 6, 7, 8, 9) engineering geological sites, (10) profile trace.

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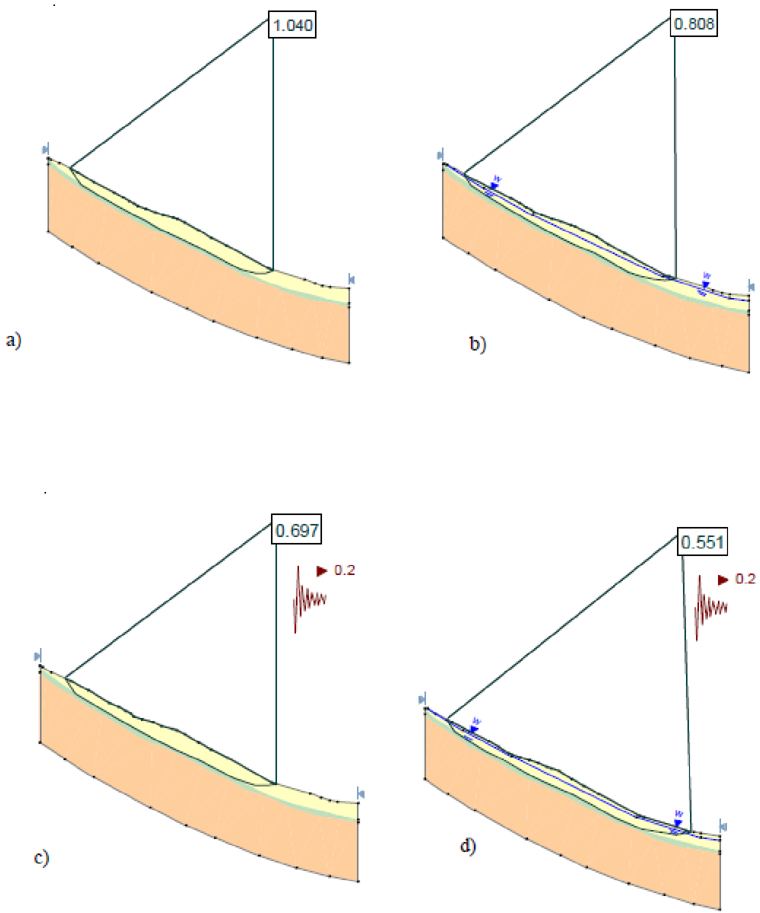

Fig. 9. Model of safety factor computed by limit equilibrium in engineering geology site nr. 2 in case of **(a)** arid, **(b)** wet, **(c)** PGA and **(d)** wet and PGA.

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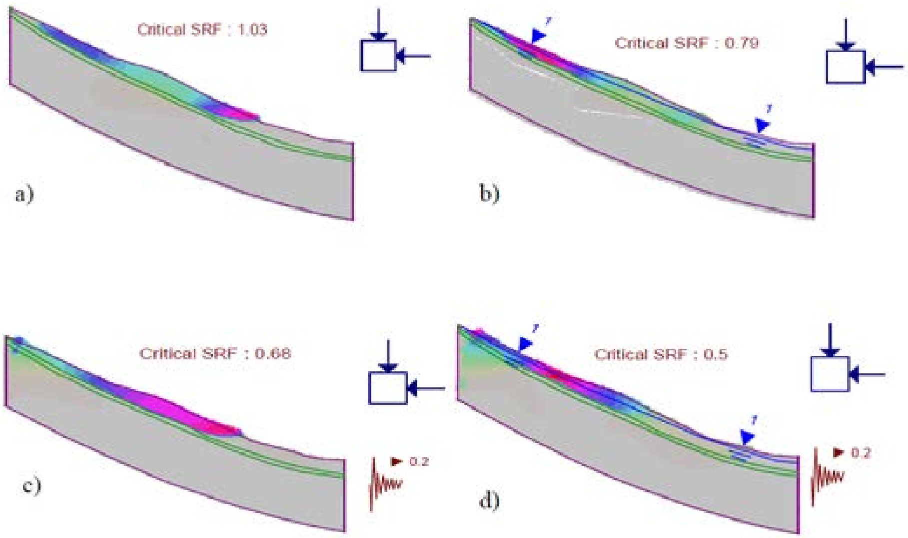

Fig. 10. Model of safety factor computed by finite element in engineering geology site nr. 2 in case of **(a)** arid, **(b)** wet, **(c)** PGA and **(d)** wet and PGA.

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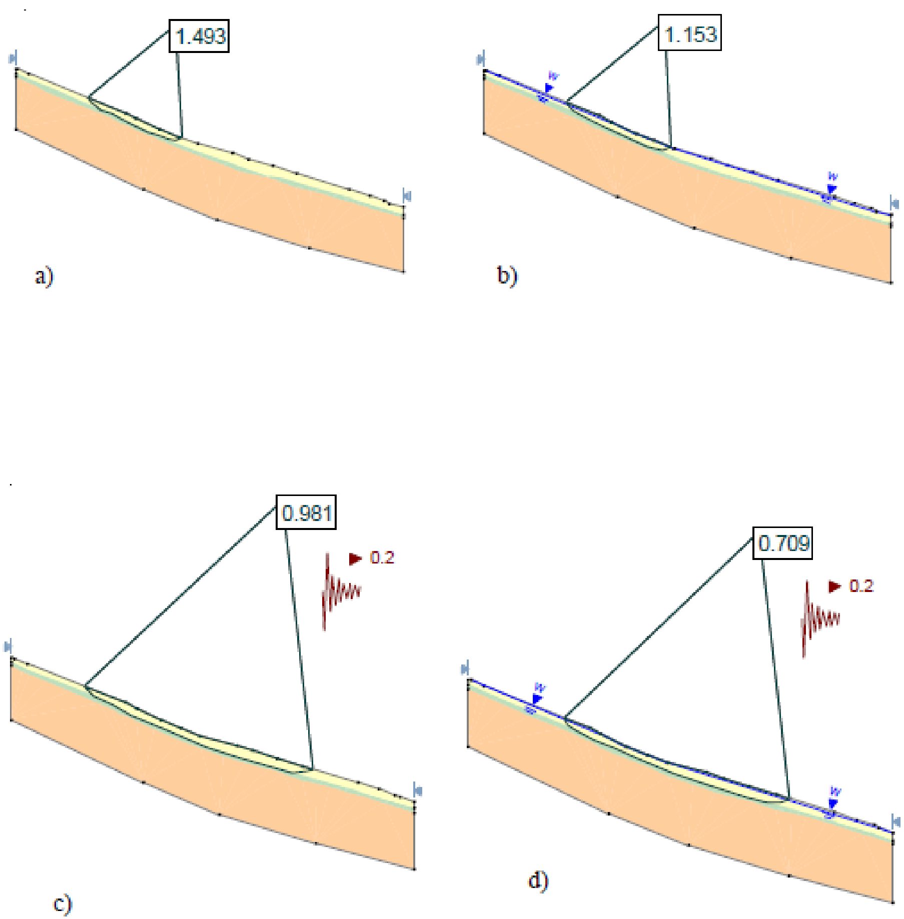

Fig. 11. Model of safety factor computed by limit equilibrium in engineering geology site nr. 4 in case of **(a)** arid, **(b)** wet, **(c)** PGA and **(d)** wet and PGA.

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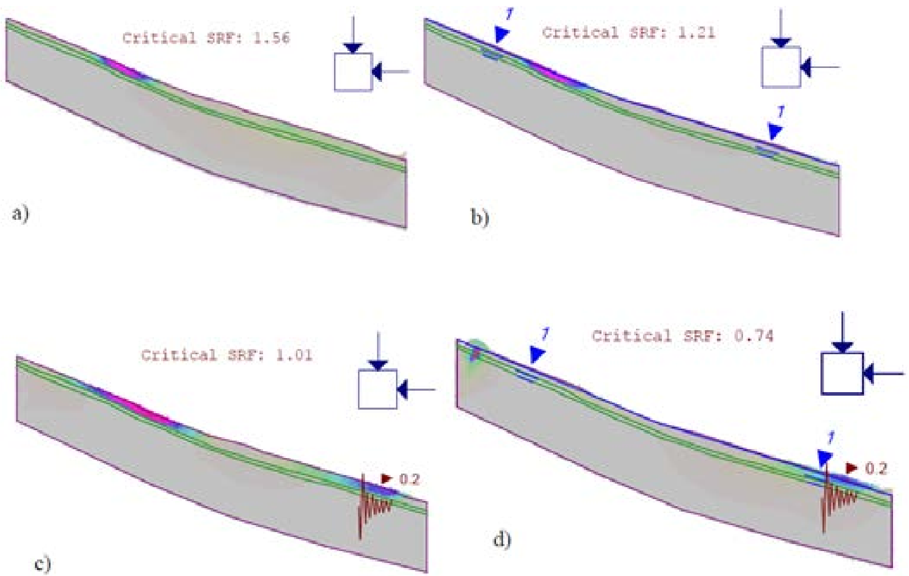

Fig. 12. Model of safety factor computed by finite element in engineering geology site nr. 4 in case of **(a)** arid, **(b)** wet, **(c)** PGA and **(d)** wet and PGA.

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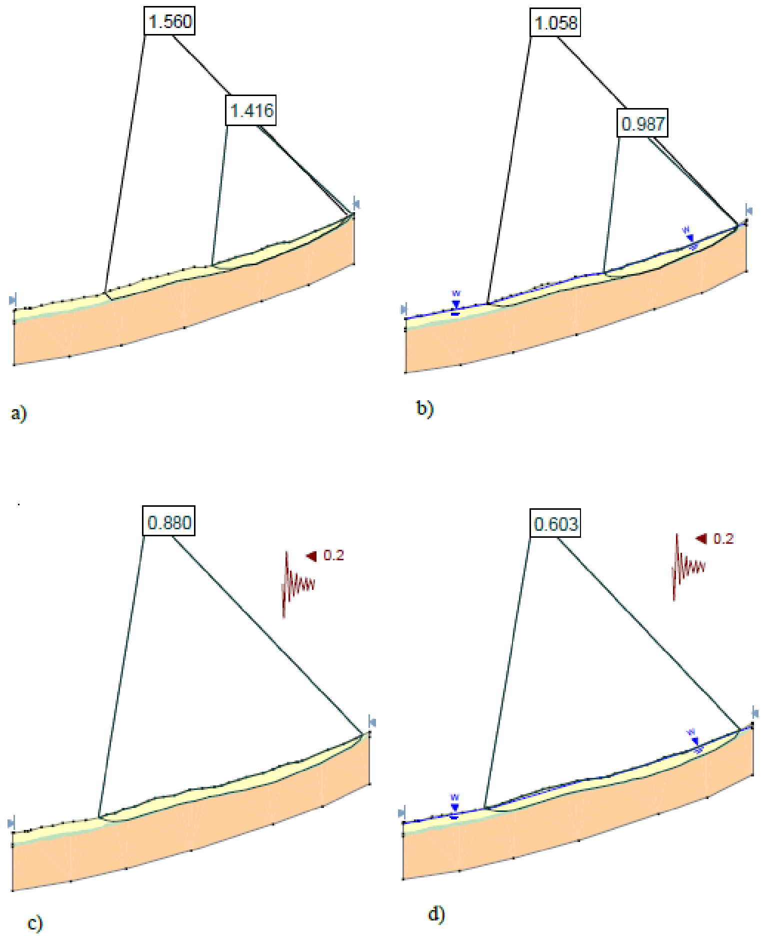

Fig. 13. Model of safety factor computed by limit equilibrium in engineering geology site nr. 5 in case of **(a)** arid, **(b)** wet, **(c)** PGA and **(d)** wet and PGA.

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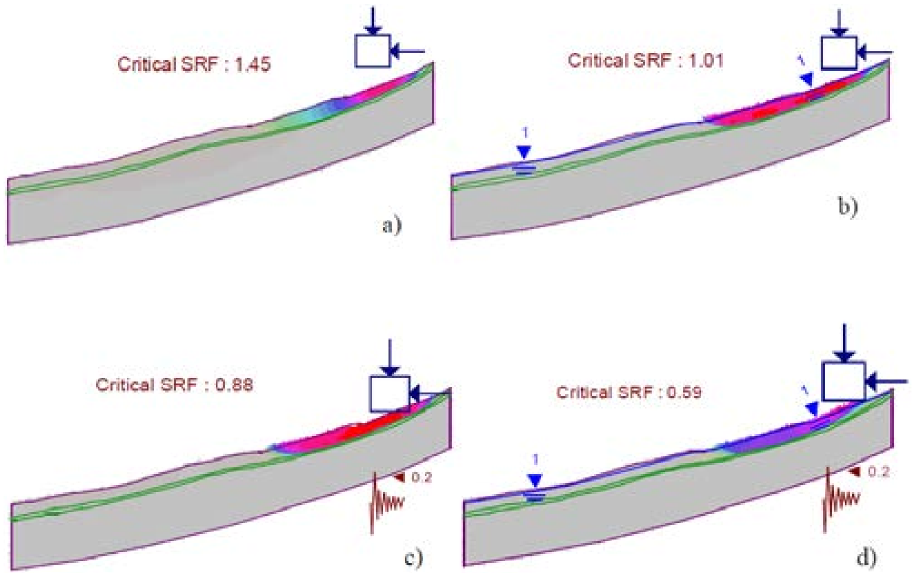

Fig. 14. Model of safety factor computed by finite element in engineering geology site nr. 5 in case of **(a)** arid, **(b)** wet, **(c)** PGA and **(d)** wet and PGA.

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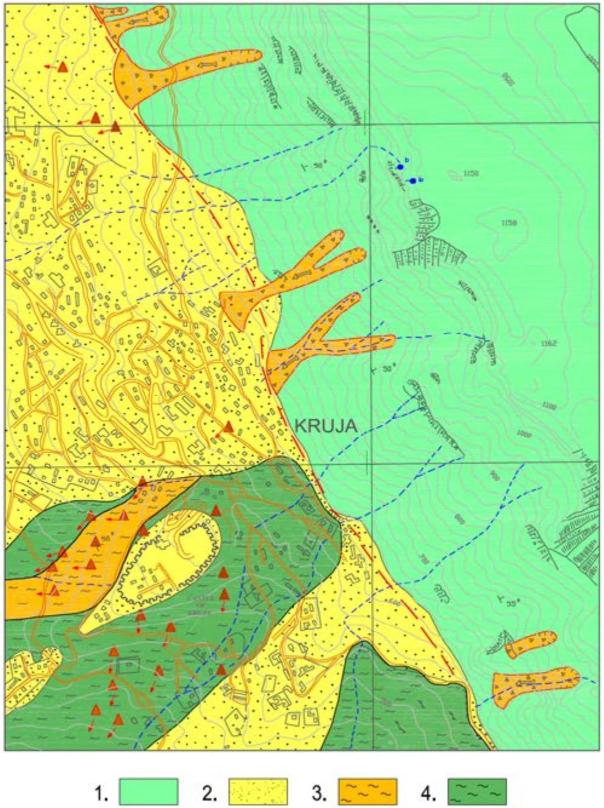

Fig. 15. Slope stability zonation map of Kruja town in case of arid period, scale 1 : 5000. (1) engineering geology zone with basement of limestones rocks, stable, (2) engineering geology zone with basement of breccia's rocks, stable, (3) engineering geology site in critical state, (4) engineering geology site in stable state.

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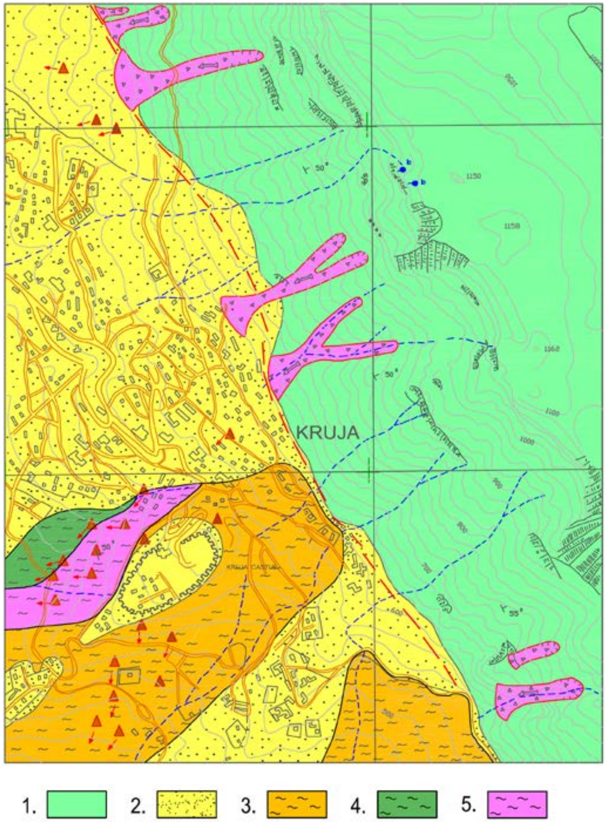

Fig. 16. Slope stability zonation map of Kruja town in case of rainy days, scale 1 : 5000. (1) engineering geology zone with basement of limestones rocks, stable, (2) engineering geology zone with basement of breccia's rocks, stable, (3) engineering geology site in critical state, (4) engineering geology site in stable state, (5) engineering geology site in unstable state.

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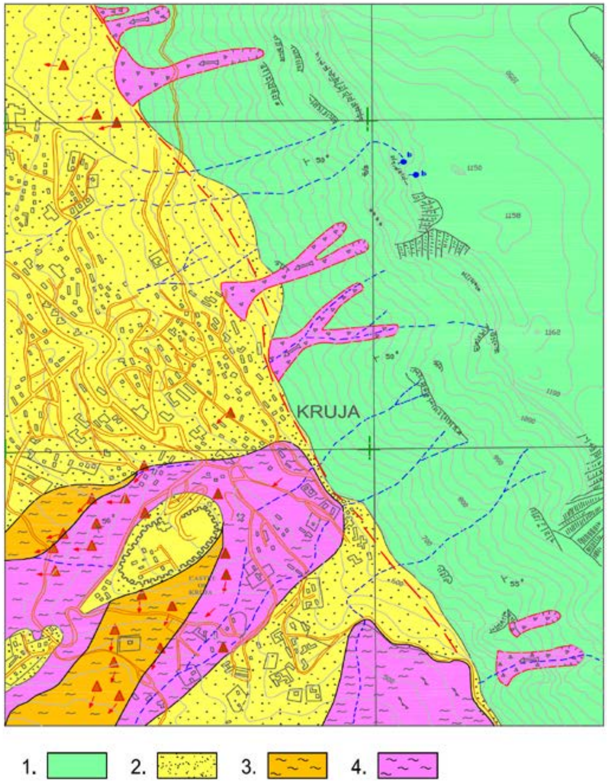

Fig. 17. Slope stability zonation map of Kruja town in case of seismic activity, scale 1 : 5000. (1) engineering geology zone with basement of limestones rocks, stable, (2) engineering geology zone with basement of breccia's rocks, state, (3) engineering geology site in critical state, (4) engineering geology site in unstable state.

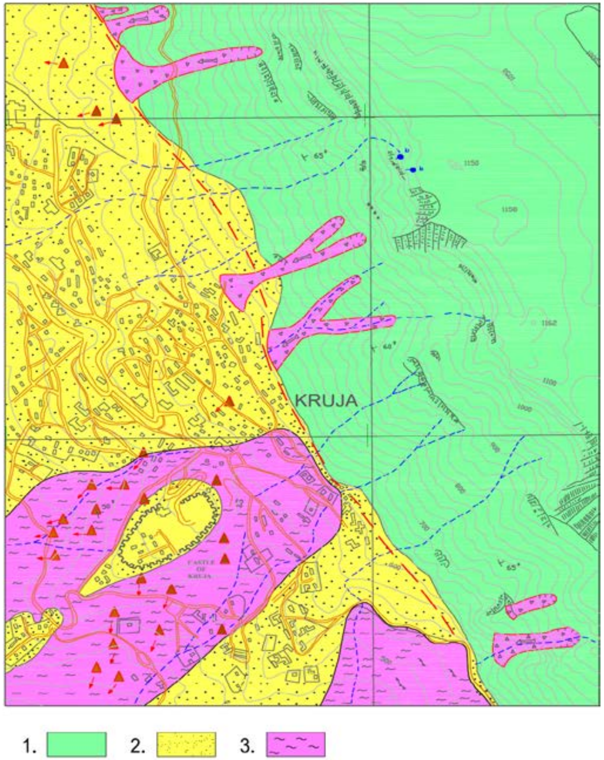

Fig. 18. Slope stability zonation map of Kruja town in case of the earthquakes and rainfalls occurrence at the same time, scale 1 : 5000. (1) engineering geology zone with basement of limestone's rocks, stable, (2) engineering geology zone with basement of breccia's rocks, stable, (3) engineering geology site in unstable state.

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Fig. 19. A breccia's block in unstable state condition.

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Fig. 20. A limestone block fell on Kruja urban area during heavy rain on 2010.

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