GEOTECHNICAL ZONATION MAPPING: A CASE STUDY OF THE GEOTECHNICAL EVALUATION IN DURRËSI HILLY AREA

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ABSTRACT

Mass movement, earthflow in particular, has greatly impacted the *built* environment, people, their homes and possessions, lifelines and industrial facilities in Durrësi hilly area. Consequently, many geotechnical investigations and an engineering geology mapping at the scale 1:1000 have been carried out from 1995-2019 for urban planning and development purposes with subsequent compilation of the engineering geology map at the scale 1:10000 and geotechnical zonation map at the scale 1:10000. The occurrence of mass movement depends on the interaction of various factors including landform, lithology, soil type, rainfall intensity and duration, drainage characteristics and vegetation cover. Information about the real distribution of mass movement, the lithologic profile of rocks and soil, soil erosion and tectonic zones could be obtained from the engineering geology map. The geotechnical zonation map was has been compiled based on slope stability evaluation. Based on the slope safety factor, the studied area was classified into these three geotechnical zones: i) unstable state SF < 1.0, ii) critical state $1.0 \leq S_F \leq 1.3$, and iii) in stable state SF > 1.3.

Keywords: earth flows, hills slopes, soils, weathering crust, weak and very weak rocks, unstable and stable slopes, critical state, dry season, heavy rains, safety factor, and seismic hazard

1. INTRODUCTION

Many geotechnical investigations have been carried out from 1995 - 2019 in Durrës (Muceku *et al*. 2003, Muceku, 2011, Muceku and Zaçaj 2013) involving geotechnical boreholes and lithological investigation and laboratory tests. The present paper discusses the results obtained from the engineering geology mapping (Muceku and Lamaj 2009; Muceku *et al.*, 2019) carried out in the hilly area in Durrësi for urbanistic purposes. This area extends along the Adriatic Coast, in the north of Durrësi and, it is the most beautiful natural area of the city. Its location and landscape make this area attractive to the companies involved in civil engineering. There has been an intensive and uncontrolled construction in the last decades on the slopes of the hills which has immensely affected earth flow, a type of mass movement. No preliminary engineering geological investigation has been carried out for these constructions. The occurrence of mass movement depends on the interaction of various factors including landform, lithology, soil type, rainfall intensity and duration, drainage characteristics and vegetation cover. As the *built* environment, people, their homes and possessions, lifelines and industrial facilities in Durrësi hilly area have continuously suffered from earth flow effects, a geology mapping at the scale 1:10000 has been carried (Muceku 2018) on the hill's area of Durrësi from 2010-2018 with subsequent publication of the engineering geology and geotechnical zonation maps at the scale 1:10000. Information about the real distribution of mass movement, the lithologic profile of rocks and soil, soil erosion and tectonic zones could be obtained from the engineering geology map. In addition, this area has been classified into three geotechnical zones based on fieldworks data, laboratory tests and the computations for the slope stability for an appropriate urban planning and urban development.

2. METHODOLOGY

Mass movement is one of the most dangerous geological phenomena, because it might occur rapidly and unexpectedly inundating entire towns in a matter of minutes. Many foreign and Albanian researchers (Cruden and Varnes 1996, Pardeshi *et al.* 2013; Muceku and Korini, 2014, Muceku *et al.* 2016) have investigated about mass movement. The geotechnical problems were defined by investigating in details landslides, geotechnical properties of soils and rocks, seismicity, hills slope, lithology, tectonics, groundwater etc. of the area.

Investigation procedure involved: i) desk study, ii) fieldworks and laboratory tests, iii) analysis, data processing and interpretation, and iv) compilation of the engineering and geotechnical-geological map, and geological engineering study. The first procedure involved the study of geotechnical reports, papers, and geological and engineering geological maps providing information about the area. The second procedure involved geotechnical and engineering geology investigation. The engineering geology and geotechnical zonation maps at the scale 1:10000 and 1:25000 (Muceku *et* *al.* 2003; Muceku 2011; Muceku and Zaçaj 2013; Muceku and Lamaj 2009; Muceku *et al.* 2019) was carried out for the investigation of slope stability and mass movement in particular. The lithological and geotechnical characteristics of soils and rocks, the depth of the rock, rock's weathering crust, geological structure and discontinuities, erosion condition, ground water, fluvial and coastal changes, tectonics activity and slope mass movements could be observed on the oriented profiles. Many geotechnical TrialPits 4.0-5.5m and boreholes 7.0-11.0m deep were carried out to collect soil and rocks' samples (undisturbed and disturbed). The samples were analyzed in laboratory for physical and mechanical properties such as grain size distribution, bulk density, moisture content, specific density, shear strength, oedometer modulus and uniaxial compression resistance. The underground water table was measured during the drilling process. Once the results were obtained, engineering geology map and geotechnical zonation map at the scale 1:10000 were compiled, accompanied by an explanatory text.

3. RESULTS AND DISCUSSIONS

The engineering geology works were carried out in accordance with the relevant phase of the investigation at the scale 1: 10000 with special attention to mass movements for urban development and planning purposes in Durrësi. Consequently, detailed investigation was carried out to provide information about: i) geomorphology, ii) geology, iii) hydrogeology, iv) mass movement, and v) physical and mechanical properties of the soil and rocks as reported in the forthcoming paragraphs.

Geomorphology

Geomorphologic data show that this area represents a hilly morphological unit, which consists of sedimentary formations-molasses rocks (combination of claystones, siltstones and sandstones layers) with a north-east extension. In addition, it is represented by Durrësi and Vrinasi-Kavaja hills' chain with elevation ranging from 50.0-120.0m to 187.0m (k. Currila). They are from 10-20m to 30-50m wide. The slope angle of this valley varies from 10^o - 25^o to 35^o - 40^o.

Geological Setting

The Figure 1 depicts the hilly area represented by Tortoniane (N^3_1t), Messinian (N^3_1m) and Pliocene (N^1_2h) molasses and Quaternary deposits (Xhomo *et. al*., 2002). The western limb of the Kryemëdhenj-Spitalla syncline is geologically made up of these hills. The upper part of lithological profile consists of claystones-siltstones deposits (Pliocene, N^1_2h), and the lower part consists of sandstones intercalated by claystones-siltstones deposits

Tortoniane (N^3_1t), Messinian (N^3_1m). The Quaternary deposits which are from 2.0-4.0m to 6.5-8.0m thick are represented by deluvial soils. They are generally found throughout of the hilly area, on molasses rocks.

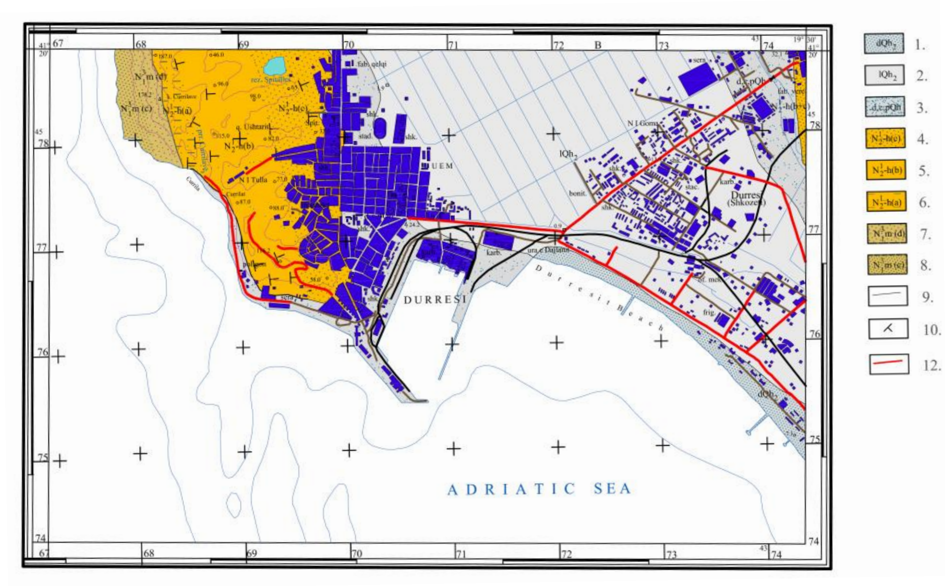

Fig. 1. A part of geological map of Durrës urban area (Xhomo *et. al*., 2002). 1. Deluvial deposit; 2. Swamp deposit; 3. Beach deposit: 4, 5 and 6. Pliocene Molasses, sandstone, claystone and conglomerate; 7 and 8. Messinian Molasses, claystone and siltstone; 9. Lithologic boundary, 11. Strike and dip of bed, 12. Urban road.

Hydrogeology

The Figure 2 depicts the hydrogeological profile of the area, which consists of two complexes (Muceku and Lamaj 2009; Muceku and Zaçaj 2013; Muceku *et al*. 2019); sandstones and siltstones and claystones intercalation. The underground waters are related to sandstones formations, which have formed the porous aquifer. The latter could be considered a moderate productivity aquifer (Struckmeier *at al.* 1995) with a discharge rate varying from 1.0 to 5.0 l/sec. The second complex is represented by siltstones-claystones. The latter formed an impermeable body of rock (aquiclude) which is considered nonproductive to ground water. Groundwater is recharged by rain. The Durrësi area is characterized by intensive rainfall events. Themelko and Mustaqi (1996) reported that the mean precipitation in this region is 1000–1200 mm yr^{-1}. The maximum precipitation has been recorded between October-November 342.3mm and December-February 380.3mm. Rain precipitation from March to May was 260.2mm, and from

June to September was 125.8mm. Therefore, the rainy season lasts between October and February, and most of the mass movement events have been recorded during this time period.

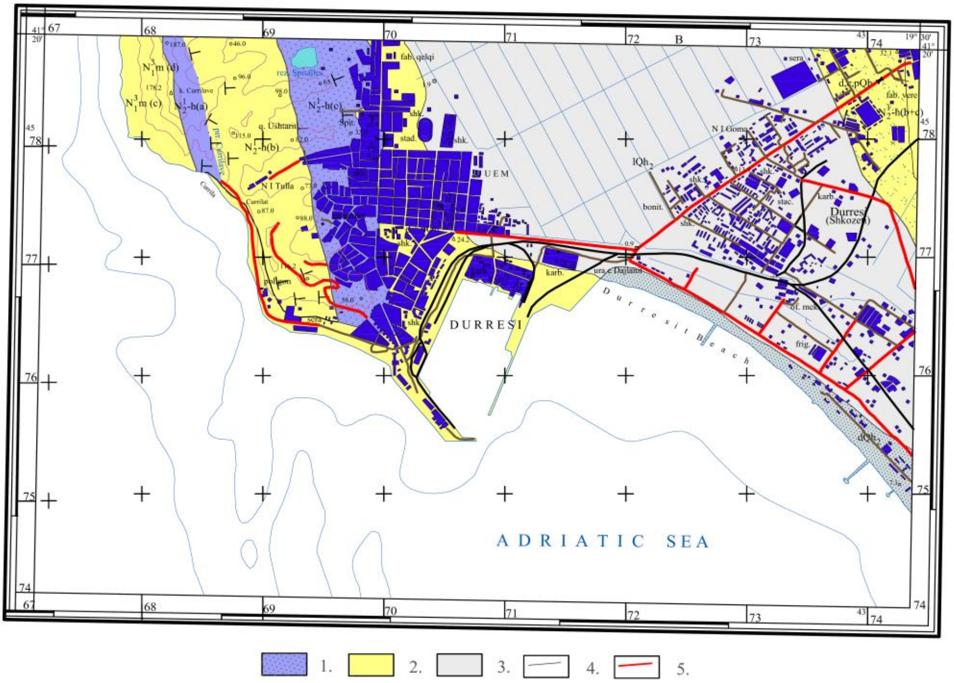

Fig. 2. A part of Hydrygeological Map of Durrës urban area. 1. Porous aquifer (moderate productivity aquifer)-sandstones and conglomerate; 2. Aquiclude (impermeable formations)-claystones and siltstones; 3. Swamp deposit-clays and silts; 4. Lithologic boundary; 5. Urban road.

Mass Movement

The area has a hilly relief with slope inclination ranging from 15-25^{o} to 35-45^{o}. It consists of weak and very weak rocks (Brown 1981). These rocks on the upper part are intensively weathered and covered from soils deposits, which are from 2.5-3.5 to 5.0-6.0m thick. In addition, the hilly slopes have been subjected to diluvium deposits, which consist of inorganic clays and silts with low to medium plasticity (ASTM 2011), medium consistency and water content. During the rainfall events, these formations (soils and the weathering crust) saturate. Being situated on steep slopes, these soils lose both their resistance and the stability of the slope. Consequently, they begin to move downwards. This mass movement mechanism has extremely affected the Durrësi hills slopes as reported by the engineering geology mapping at the scale 1:10000 and 1:25000 (Muceku *et al.*, 2003, Muceku 2011, Muceku and Zaçaj 2013, Muceku and Lamaj 2009, Muceku *et al.*, 2019). Mass movement is the source of destruction of many buildings in urban and suburban areas and agriculture area. Mass movement occurrences and their distribution proved that its activity is closely related to geomorphology, lithological formation, geological structure, geotechnical properties of bedrocks and soils, neotectonics active, orientation rain precipitations and manmade works. The data obtained from field works proved that the area is subjected to earth flow (Cruden and Varnes 1996).

Earth flow

The engineering geology mapping at scale 1:10000 and 1:25000 (Muceku *et al.* 2003, Muceku 2011, Muceku and Zaçaj 2013, Muceku and Lamaj 2009, Muceku *et al.*, 2019) showed that studied area has been intensively affected by geodynamics phenomena such as earth flow. There are many slopes of the hills which suffer from earth flows activity. Buildings and infrastructure have been damaged. The slopes of the hills in Durrës consist of weak and very weak rocks. They are combination of claystones and siltstones layers, which in upper part are intensively weathered. In addition, soil deposits from 2.5-3.5m to 5.0-6.0m thick overlay this formation (Fig. 2). These deposits are subjected to mass movement during the rainy season. Our investigation showed that earthflows have occurred on the slopes of the hills with angle more than 20^{o}. Here, soils and weathering crust of the molasses rocks prevail. Muceku and Zaçaj 2013 mapped 32 earthflows during the field works carried out from 2010-2013. They were small-medium in size, 20.0-50.0m up to 150.0-250.0m wide and 30.0-50.0m to 70.0-100.0m long, i.e., the area has moved downwards of about 109 000 m^2 of land, or 220 000-330 000m^3 of soil material from 2000 to 2018 (Fig. 1). The slide body consists of inorganic silts and clays with mixture of gravels-sands (ASTM 2011). The rupture surface extends in direction of movement and this type of mass movement is considered very active. The Figure 3 depicts the inclination angle of the slopes of the hills which ranges from 15-20^{o} to 30-45^{o}. Earthflow is also affected by the intensive rainfall events, anthropogenic activities (slopes excavation for construction purpose) and tectonics activities. As many residential houses, roads and arable land have been destroyed by the earthflow, engineering measures to prevent the area from the effects of the earthflow would be relevant.

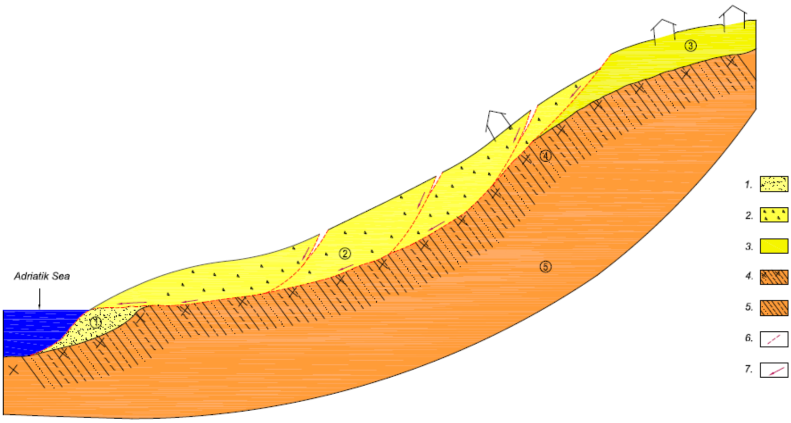

Fig. 3: Cross section of earth flow in Durrësi hills (after Muceku 2011) 1. Beach's sands, 2. Earth flow body 3. Deluvial soils, 4. Weathering crust of soft rock-claystones-siltstones rocks (molasses), 5. Very weak rock-claystones-siltstones rocks (molasses), 6. Slides plane, 7. Moving direction.

Physical and mechanical properties

Field investigation and laboratories tests helped us to determine the geotechnical condition of Durrësi hilly area. Figure 1 and 2, and Table 1 and 2 depict and show the Durrësi hilly area consisting of the geotechnical units of the soils and soft rocks.

Geotechnical unit of diluvium deposit consists of inorganic clays and silts with low to medium plasticity, "CL and ML" type (ASTM, 2011), beige-brown in color, stiff to medium consistency, and from 2.5-3.5m up to 5.0-6.0m thick. It overlays the weathering crust of the bedrocks.

Geotechnical unit of weathering crust of molasses rocks consists of silty fine sands "ML" and sandy clays "CL" (ASTM, 2011); brown to grey in color, hard to very hard consistency, and from 1.5-2.5m to 5.0 m thick. In addition, it overlays the weak and very weak rocks.

Geotechnical unit of weak and very weak rocks consists of claystones-siltstones intercalation with sandstones layers, weak to very weak rocks (Brown 1981). It is represented by molasses rocks.

Table 1 and 2 show the geotechnical properties.

Table 1. Physical and mechanical properties of geotechnical units of hills slopes soil

Geotechnic Unit	W_n	γ	γ_o	φ	c	E	Soils type
	%	kN/m^3	kN/m^3	(o)	kPa	MPa	USCS
1	28.2-30.1	18.6-18.8	26.8-27.0	17-18	15-18	3.8-4.1	CL-ML
2	33.5-36.8	17.8-18.5	26.8-27.0	14-15	8-10	2.4-3.0	CL-ML
3	13.1-18.4	19.8-20.0	26.4-26.6	25-27	75-100	41.2-47.6	CL-ML

(W_n-water content, γ-Bulk density, γ_d-Dry density, γ_o-Specific density, n-porosity, τ_c-unaxial compress strength)

Table 2. Physical and mechanical properties of geotechnical units of molasses rocks

γ kN/m^3	γ_o kN/m^3	n %	τ_c MPa	φ (o)	c MPa	E MPa	Rock type
23.40-25.73	25.20-26.95	4.5-7.6	3.4-5.8	30-32	0.10.172	65-90	Claystones-siltstone and sandstones

Engineering-Geological Mapping

Muceku *et al.*, (2019) said that the engineering-geological map at the scale 1: 10000 has been compiled based on lithological data, geodynamics phenomena and physical and mechanical properties of rocks and soils. The work was firstly focused along the oriented profile using a map at the scale of 1:5.000 to record the lithological surface characteristics of soils and rocks, erosion, slope mass movements, etc. All the technical data have been obtained via fieldworks and laboratory testing involving trial pits (3.0 - 5.0 m deep) and boreholes from 7.0-11.0m (hills area) to 25-30m (flat area) deep. Figure 3 depicts the area classified into several engineering-geological zones, which are considered as homogenous with regard to their geotechnical properties: i) *zone of the weak rocks* which is generally represented by the sandstones intercalated with claystones-siltstones layers (molasses Miocene, $N^3{}_1$), ii) *zone of the very weak rocks* which consists of claystones-siltstones rocks (molasses Pliocene, $N^1{}_2$h), iii) *zone of cohesionless soils* which consists of sand-clay (SC) and sand-silts mixtures SM, iv) *zone of cohesive soils* which is represented by inorganic silts (ML) and clay (CL) with very fine sands, and v) *zone of organic soils organic soils* which consists of organic silts and clays (OL), organic clays of medium to high plasticity (OH) and highly organic soil-peat (PT).

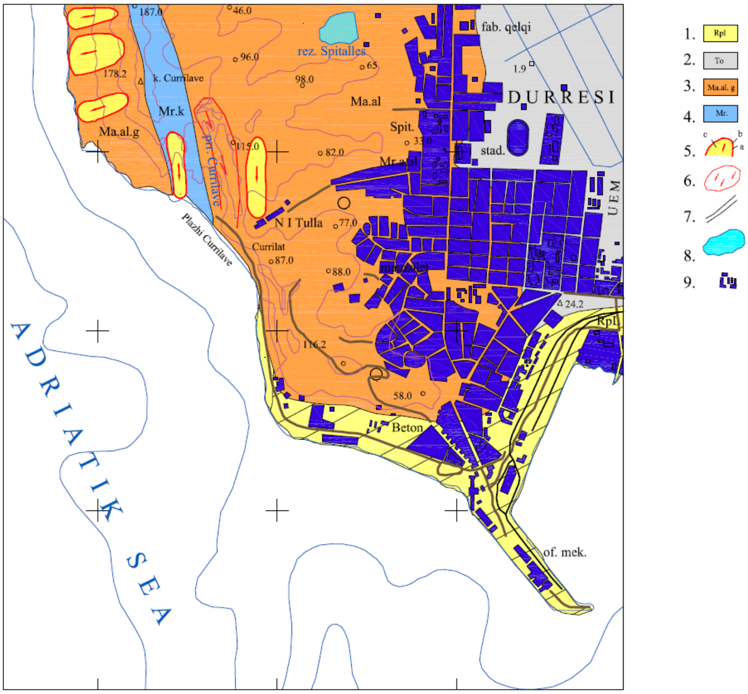

Fig. 4: Apart of engineering geological map of Durrësi area, at the scale 1:10000 (after Muceku 2008) 1. Beach's sands, 2. Organic silts and silty clays, 3. Very weak rocks-claystones-siltstones rocks (molasses Pliocene, $N^1{}_2h$), 4. Weak rocks-sandstones intercalated with claystones-siltstones layers (molasses Miocene, $N^3{}_1$), 5. Earth flow body, 6. Erosion place, 7. Road, 8. Artificial lake, 9. Durrësi towns buildings.

Slope stability of hilly areas

The Slide 6.0 software was involved and the methods reported in Spencer (1967) and Morgenstern and Price (1965) were applied for the calculation of the slope stability. The geotechnical parameters used in this model for each layer are the ϕ internal friction angle, c cohesion and γ density (Table 1 and 2). After several approaches, the surface with the minimum safety factor was finally displayed. The limit's equilibrium in static cases is recommended with safety factor $S_F > 1.3$. If the S_F value is $1.0 \leq S_F \leq 1.3$, the slope is considered critical. If the $S_F < 1$, it is unstable. In addition, Themelko and Mustaqi (1996) said that this area is affected a lot by rainfall averaging between 1000 and 1200 mm yr−1. Moreover, it represents one of the most seismically active areas in the Balkan region, (Papazachos *et al.*, 2001) where several medium – intensity earthquakes (M 5.5–5.9) and rare strong earthquakes (M ≥ 6.0) have occurred. Muceku and Korini (2014) and Muceku *et al.*, (2016) reported that strong earthquakes are the main source of mass movement. The safety factor

(S_F) has been computed based on the geotechnical properties of soils and rocks, slopes angles and seismic hazard (Kuka 2003) for the following conditions: i) dry season, ii) heavy rains, iii) seismic activity, and iv) both rain and seismic activity. Based on the geotechnical data obtained from the calculated safety, it could be concluded (table 3): i) the computed safety factor for the slope with angle $\alpha \geq 35^o$ in case of rain, seismic and both rain and seismic conditions is respectively $0.70 \leq S_F \leq 0.99$; $0.8 \leq S_F \leq 1.11$ and $0.45 \leq S_F \leq 0.58$ (Table 3, Figures 5- 7). This proves that these slopes are unstable and very susceptible to landslide occurrences. In case of dry condition, the computed safety factor for the slope with angle $\alpha \geq 35^o$ is respectively $1.35 \leq S_F \leq 1.41$. This shows that they are in stable state, ii) the safety factor calculated for the slope with angle α = 15-35^o in case of rain and seismic conditions is respectively $1.12 \leq S_F \leq 1.28$ and $1.26 \leq S_F \leq 1.45$ (Table 3). This proves that these slopes are in critical state. In case of dry condition, the computed safety factor for the slope with angle $\alpha \geq 35^o$ is respectively $1.35 \leq S_F \leq 1.41$. This shows that they are in stable state. In case of dry and both rain and seismic conditions, the safety factor calculated for the slope with angle α = 15-35^o is $1.50 \leq S_F \leq 1.67$ and $0.80 \leq S_F \leq 0.92$, respectively (Table 3). This shows that these slopes are in stable and unstable state, iii) the calculated safety factor for the slope with angle $\alpha \leq 15^o$ in case of dry, rain and seismic conditions is respectively $1.94 \leq S_F \leq 2.33$; $1.56 \leq S_F \leq 1.68$; and $1.47 \leq S_F \leq 1.55$ (Table 3). This proves that these slopes are in stable state, iv) in case of both rain and seismic conditions, the computed safety factor for the slope with angle $\alpha \leq 15^o$ is $1.06 \leq S_F \leq 1.26$. This shows they are in critical state (Table 3).

Table 3. Slope stability based on limit equilibrium analysis (Rocscience, 2010).

Slope category	Safety factor for the condition			
	Dry	Rain	Seismic	Rain & Seismic
1	1.35-1.41	0.70-0.99	0.81-1.11	0.45-0.58
2	1.50-1.67	1.12-1.28	1.26-1.45	0.80-0.92
3	1.94-2.33	1.56-1.68	1.47-1.55	1.06-1.26

1. The slope with angle $\alpha \geq 35^o$; 2. The slope with angle α = 15-35^o; 3. The slope with angle $\alpha \leq 15^o$;

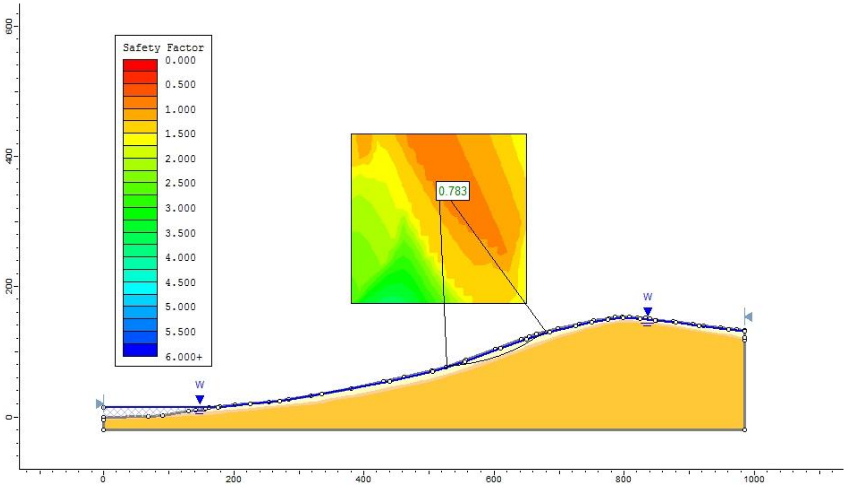

Fig. 5: Safety factor of hills slopes calculated in case of rainfall.

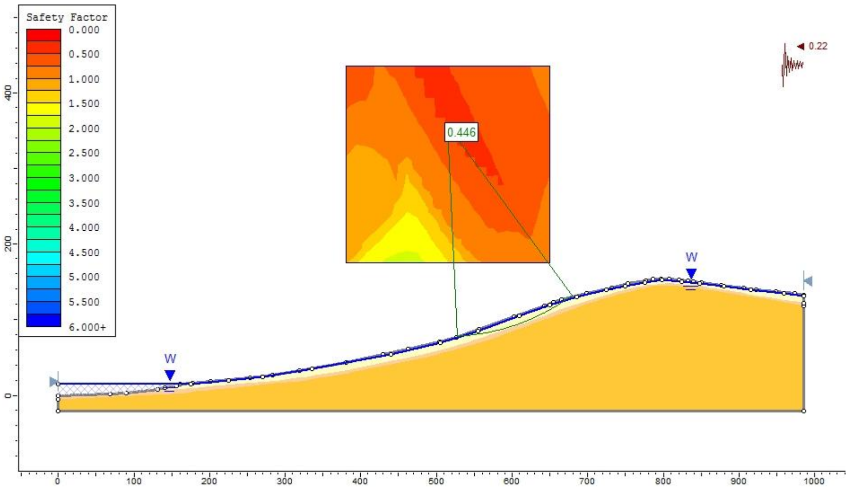

Fig.6: Safety factor of hills slopes calculated in case of rain and seismic activity.

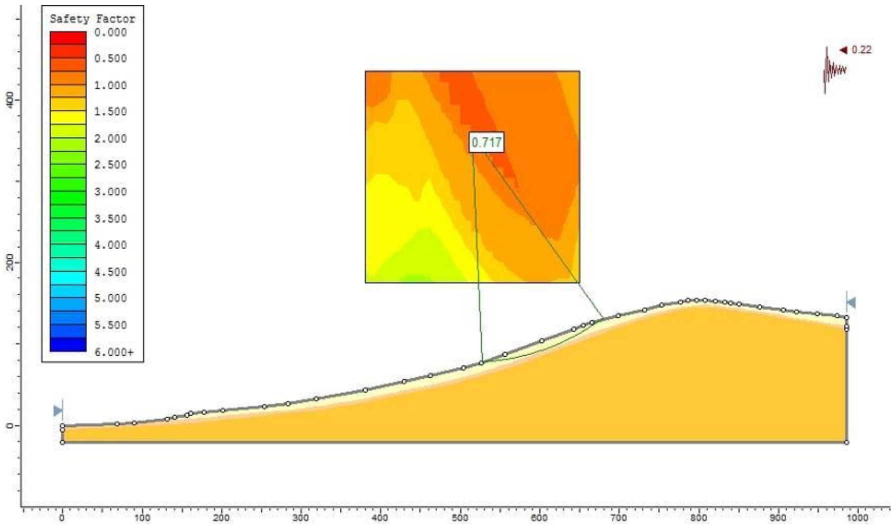

Fig.7: Safety factor of hills slopes calculated in case of seismic activity.

Geotechnical Zonation Mapping

Landslides hazard evaluation is of great importance for the hazard of mass movement, because an accurate estimation leads to appropriate risk management. Many methods have been applied for landslide hazard zonation, but no one method has been universally accepted for effective assessment of landslide hazards (Pardeshi *et al.*, 2013). However, the present paper is an attempt to landslide hazard mapping by application of the safety factor of slope stability. This method relays on computation of safety factor of the slope with angle $\alpha \geq 5^{o}$. Although this method is both very difficult to be applied and expensive because of the data collected from field works and laboratory tests, data calculation and interpretation, it is a reliable means to address the accurate landslide risk management and the landslide hazard management. The instability of the slopes of the hills has caused damages to several residential centers and villages, particularly during the rainy season due to mass movement. Consequently, an evaluation of the landslide hazard in the urban and suburban area of the Durrësi hilly area was considered of primary importance for the researchers and state institutions involved in the area. These scenarios are very important for the urban planning and development of the city in the hilly areas as they help the stakeholders to avoid the chaotic construction and take necessary engineering measures to avoid landslides events. The compilation of the aforementioned map had several objectives within the framework of mass movement hazard and management. Geotechnical zonation map-mass movement hazard map provide an overview of some geo-factors that might cause any expected damages due to the potential landslide hazard. These maps help us to consider what protective or reinforcement works might be applied to minimize the hazard level or foster urban planning and development. Finally, the mass movement hazard is the result of the interaction of several geo-factors such as slope morphology (shape and slope inclination), lithology (soils thickness), mass movement, soils and rocks geotechnical properties, rain fall and seismic activity. The present paper reports about the geotechnical zoning map at the scale 1:10000 (Figure 8 and 9), based on computation of safety factor of the hills slopes. Consequently, the area was classified into three hazard zones for these conditions: i) dry season, ii) heavy rains, iii) seismic activity; and iv) both rain and seismic activity. The hazard zones are: i) high hazard zone, with safety factor F < 1.0 of slope of the hills, b) moderate hazard zone, with safety factor $1.0 \leq S_F \leq 1.3$ of slope of the hills, and iii) low to no hazard zone with safety factor F > 1.3 of slope of the hills.

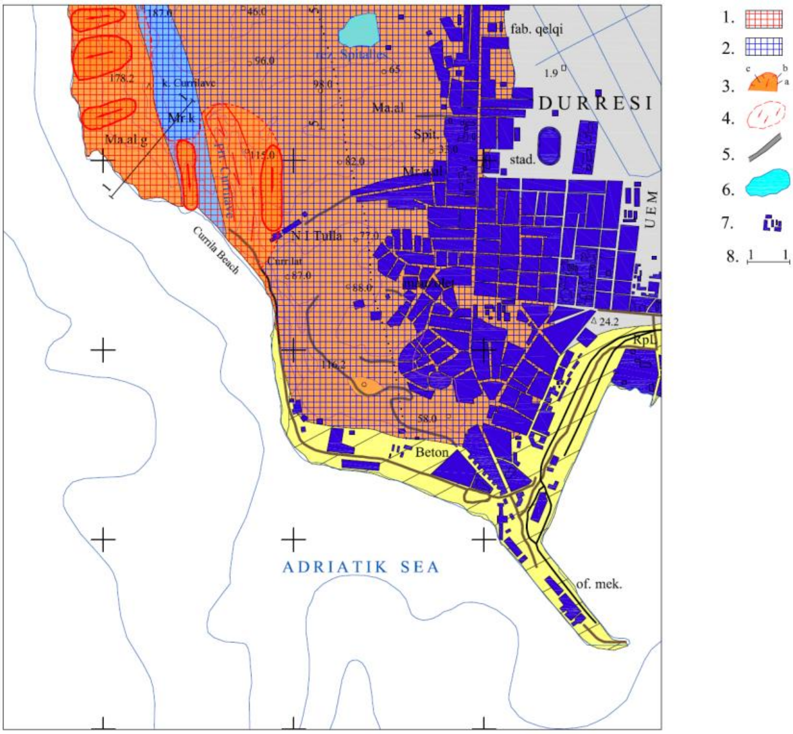

Fig. 8: A part of geo-hazard map of Durrësi Hills slopes, scale 1:10 000, prepared for rain condition. *1. Very high risk zone, 2. Risk zone, 3. Earth flow body, 4. Erosion area, 5. Road, 6. Artificial lake, 7. Durrësi buildings, 8. Cross section.*

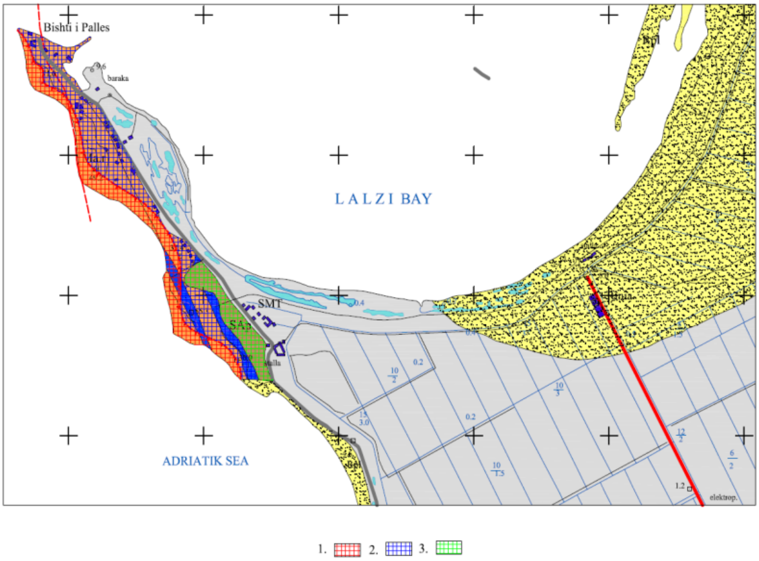

Fig. 9: A part of geohazard map of Durrësi Hills slopes, scale 1:10 000, prepared for rain condition. *1. Very high risk zone, 2. Risk zone, 3. Earth flow body.*

The high hazard zone is characterized by intensive mass movements. The protection of slopes of the hills requires engineering measures which are very expensive. The moderate hazard earthflow is represented by the slopes of the hills that are found in critical condition, which in case of activation of any geofactor such as rainfall, earthquakes and anthropogenic activity, the slopes of the hills might move downwards. Consequently, appropriate engineering measures prior to construction would be necessary. The third zone is represented by the slopes of the hills that are found in a stable condition. However, it should be noted that although this area is stabilized. However, if excavations are made on the slopes of the hills without prior geotechnical studies, the material at the base of the slope might be removed and sudden slope failure and mass movement might occur. Consequently, geotechnical studies prior to construction activities would be necessary.

4. CONCLUSIONS

Engineering geological data reported that earth flow, a type of mass movement, was caused by intensive weathering of the molasses rocks, the soils on hills slopes (2.0-4.0m up to 6.5-8.0m thick), artificial or natural increases in the slope’s steepness (slopes with inclination angle steeper than 15^{o}), wet climatic conditions intensive rainfall events and anthropogenic activities on the slopes of the hills. The types of landslides occurring in the hills Durrësi zone are earth flow type, small-medium in size, active during wet period and rapid moving.

The engineering-geological map at the scale 1: 10000 was compiled based on lithological data, geodynamics phenomena and physical and mechanical properties of rocks and soils. The area has been classified into several engineering-geological, which are considered as homogenous with regard to their geotechnical properties: i) *zone of the weak rocks* which is generally represented by the sandstones intercalated with claystones-siltstones layers (molasses Miocene, $N^3{}_1$), ii) *zone of the very weak rocks* which consists of claystones-siltstones rocks (molasses Pliocene, $N^1{}_2h$), iii) *zone of cohesionless soils* which consists of sand-clay (SC) and sand-silts mixtures SM, iv) *zone of cohesive soils* which is represented by inorganic silts (ML) and clay (CL) with very fine sands, and v) *zone of organic soils organic soils* which consists of organic silts and clays (OL), organic clays of medium to high plasticity (OH) and highly organic soil-peat (PT).

Geotechnical zonation map-mass movement hazard map provide an overview of some geo-factors that might cause any expected damages due to the potential landslide hazard. These maps help us to consider what protective or reinforcement works might be applied to minimize the hazard level or foster urban planning and development. Finally, the mass movement hazard is the result of the interaction of several geo-factors such as slope morphology (shape and slope inclination), lithology (soils thickness), mass movement, soils and rocks geotechnics properties, rain fall and seismic activity. The present paper reports about the geotechnical zoning map at the scale 1:10000 (Figure 8 and 9), based on computation of safety factor of the hills slopes. Consequently, the area was classified into three hazard zones for these conditions: i) dry season, ii) heavy rains, iii) seismic activity; and iv) both rain and seismic activity. The hazard zones are: i) high hazard zone, with safety factor $F < 1.0$ of hills slope, b) moderate hazard zone, with safety factor $1.0 \leq S_F \leq 1.3$ of hills slope, and iii) low to non- hazardous zone, with safety factor $F > 1.3$ of hills slope.

The engineering-geological and geotechnical zonation maps at the scale 1:10000 help us to consider what protective or reinforcement works might be applied to minimize the hazard level or foster urban planning and development.

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