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Geotechnical characteristics of the banks in the middle course of the Neretva River through the City of the Mostar

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Abstract: Regulation Plan for the historic town area of Mostar includes major aspects of preservation and development of historic town zones. Provisions of the Regulation Plan pertain to use of land and buildings, aiming to preserve and revive the traditional uses and protect the natural characteristics of the area [8]. In this respect, the historic area of the town of Mostar has been divided into ten zones according to the use of land and structures, and Zone 8 covers Neretva as a protected riverside zone. The study aimed to define causes and state of weathering, damage and stability of rocks, then to define the existing state in terms of geological structure, and visit the most critical sections that require improvement.

Key words: geological structure of banks, protected area, load defining, Bunur

Geotehničke karakteristike obale srednjeg toka rijeke Neretve kroz grad Mostar

Sažetak: Regulacijski plan povijesnog gradskog područja Mostar obuhvata najvažnije aspekte očuvanja i razvoja povijesnih gradskih zona. Odredbe Regulacijskog plana odnose se i na uporabu zemljišta i objekata, koja ima za cilj zaštititi i revitalizirati tradicionalni način uporabe kao i zaštititi prirodne karakteristike područja [8]. S tim u svezi, unutar granica povijesnog gradskog područja Mostar postoji deset zona koje su podijeljene prema uporabi zemljišta i objekata a Zona 8 se odnosi na Neretvu kao zaštićenu obalnu zonu. Istraživanje je imalo za cilj definiranje uzroka i stanja raspadanja, oštećenja i stabilnosti stijena, zatim definiranje postojećeg stanja u pogledu geološke grade, te obilazak najkritičnijih dijelova, na kojima je neophodna sanacija.

Ključne riječi: geološka građa obale, zaštićeno područje, definiranje opterećenja, Bunur

1. INTRODUCTION

Field reconnaissance of a wider area of the Neretva River found that this is the case of very cohesive fluvial conglomerates and breccias (highly developed river terraces – locally called "pechinas"). Cohesionless sandy materials are washed away by flow of water, forming consoles that gradually break away and form detached blocks closer to the river course.

A detailed observation of rocks established numerous causes of the damage, different in intensity of action and effects throughout the course of the Neretva River in Mostar.

Resistance, stability and durability of the rock mass depend on action of various factors, and especially on effects of abrasion and erosion of river water. We can particularly emphasize the strong impact of waves and pore pressure in the pore space of water. Complex and cyclic repetition of these processes is characterized by a specific structural and petrographic system. Differential and progressive effects of individual processes are only a part of complex conditions that loosen, weather and disintegrate the rocks.

2. THE MAIN FACTORS OF ROCK DAMAGE

2.1. The existing condition of banks of the Neretva River in the City of Mostar

The river terraces are developed as blocks separated from each other. Each river terrace block has the lower, underlying and upper, roof cover part. The shortest distance between the underlying and overlying part of a block is its thickness (Figures 1 and 2), [6].

Figure 1. A view of the upper roof cover part of a river block

Figure 2. A view of the lower underlying part of a river block

Between two blocks of a river terrace is a contact zone with mainly cohesionless grains of alluvium. As groundwater is routed through contact zones of river terraces, cohesionless grains of gravel and sand are washed away, forming specific voids up to developed caves (locally called "pechinas").

As voids between blocks of river terraces develop, these blocks become stressed in terms of support, and because of the development of tensile zones in the overlying part, they fail and break off toward the river bed. Such blocks can be seen in the riverbed and on the banks (Figures 3 and 4).

Figure 3. Detached blocks in the riverbed

Figure 4. Fragmented rocks on the right bank

3. HYDRODINAMIC LOAD OF BANK ROCKS BY WAVES

3.1 Defining the present state of influence on the banks of the Neretva River in the City of Mostar

Wind waves are defined by the height H, period T and length L. As they reach bank rocks, they deform in terms of height and length, and reflect. While reflecting, they deliver certain energy that is in an undisturbed wave:

$$E=\frac{1}{8}\rho g H^2 L$$

(where: ρ is water density, g - gravity, H - wave height and L - wave length) and it consists of potential and kinetic energy. This delivery may be through potential energy manifested in compressive load of the stationary wave which is approximately p = ϱ g H or through impact load if conditions for wave break on an obstacle or in its proximity exist. This impact load may substantially vary depending on the wave and obstacle geometries.

Figures 5. and 6. Influence of waves on banks at the Bunur site

Taking into account that the study area around Bunur, Figure 5, is exposed to gusts of bora, the dominant direction of waves is N and NE. Relevant winds can be obtained from wind data, and compressive load on rock is calculated from the potential hydrodynamic load on rock.

On the rock, unbroken wave has a theoretical maximum reach of one wave height from its midline, which is why its compressive load is the highest on the midline itself and is $p = \varrho g H$. If wave is deformed or broken on rock or in front of rock, then Hiroi (1967) equation can be used for normal breaking, (from Horikawa, 1878), $p = 1{,}5\varrho g H$ [4].

It is apparent that all specified expressions are semi-empirical and depend on local geometry. For a complex geometry of the bottom and bank rocks for different wave impact angles at certain sites (e.g. Bunur), exact values could be obtained only by investigation using a hydraulic model or by field measurements [3].

At the Bunur site (Figures 5 and 6), the river makes a left turn, which points to the fact that the left bank is more compact in geomechanical terms, and the river flow "reflects" toward the right side with weaker mechanical characteristics. Here, it is certainly necessary to emphasize the impact of increased flow through HPPs on Neretva during flood flows, in particular HPP Mostar, when waves can reach even several meters in size. Their impact on breakage of banks is certainly significant but also insufficiently investigated in the last 30 years or so.

During its remote and recent past, the unpredictable Neretva does not cease to disturb and confuse builders. In 1999, high water swept away a makeshift suspension bridge on the site of the collapsed Old Bridge, and damaged some structures downstream of the bridge. This powerful torrent was caused not only by heavy rains and swollen tributaries, but also by the mutually uncoordinated management of upstream hydroelectric power plants [9]. Even in old documents, the author Carl Peez noted: "Sometimes it happens that in summer Neretva almost cannot be seen at all in some places among the exposed overhanging rocks, if it rains heavily, the waves often rise to the city buildings and completely fill the riverbed between the 14 m high banks" [10].

Observing the wider area, we select a picture taken during construction of the New Bridge on the Neretva River. At the end of 2010, the bridge construction site was flooded with water of a recurrence rate greater than a 100-year high water [11].

Figure 7. Construction site of the New Bridge in 2010 [11]

Global erosion is a consequence of the bottom level lowering due to hydrometeorological and geomorphological changes and/or human activities in the basin. Short-term global erosion develops during floods, and long-term global erosion develops over a considerably longer period and includes progressive degradation of the riverbed and lateral displacement of banks. Presence of the bridge in the river cross section results in erosion due to flow constriction and local scours due to the influence of abutments or piers in the riverbed [12].

Observing the location of the New Bridge in Figure 8, it is evident that on the concave (right) bank there is a greater risk of bank erosion [13], and thereby a negative impact on the bridge pier foundation. Consequently, protection of the right bank was carried out near the river pier of the bridge by constructing rip rap of large stone blocks - Figure 9.

Figure 8. Location of the New Bridge on Neretva [11]

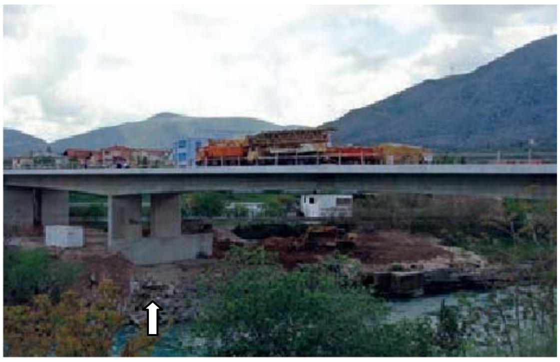


Figure 9. Protection of the right bank near the river pier of the New Bridge on Neretva [11]

On the left bank, the pier is founded on a shallow RC foundation slab on layers of bound conglomerates and breccias. The occurrence of isolated conglomerates and breccias is also visible in the river course. Since the formed conglomerate cantilevers fail over time due to the effects of water, the so-called passive anchors were made and shotcrete was applied on the left bank as protection against the effects of water (Figure 10).

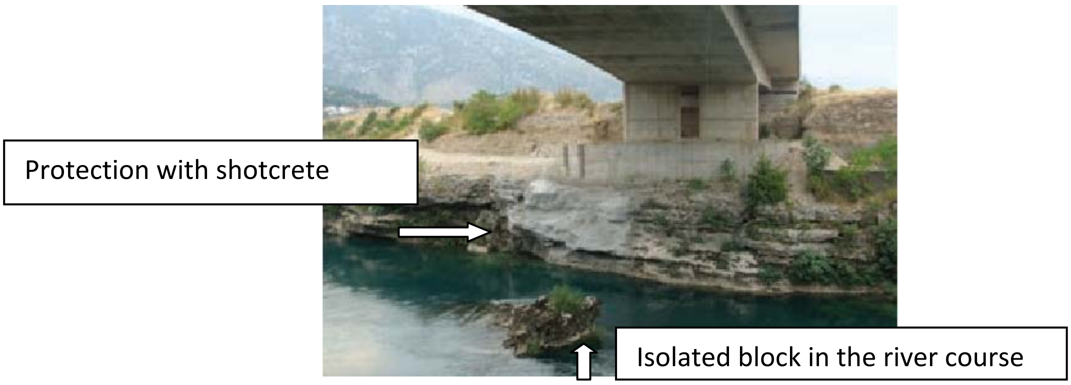


Figure 10. Protection of the left bank with shotcrete [11]

3.2 Processes acting on bank rocks to break off

It is primarily necessary to emphasize the influence of fatigue of materials, or in this case rock, because it is known that periodical repetitions of considerably smaller loads may cause failure too.

Because of other processes, the surface layer of stone certainly becomes significantly weaker, which is why the impact force of wave more easily fractures and breaks off fine particles, thus developing microabrasion that continuously and over a longer period of time becomes the cause of gradual disappearance of parts of rock.

Remains of such blocks can be seen in the present river course (Figure 11). The block of this river terrace is detached by natural processes.

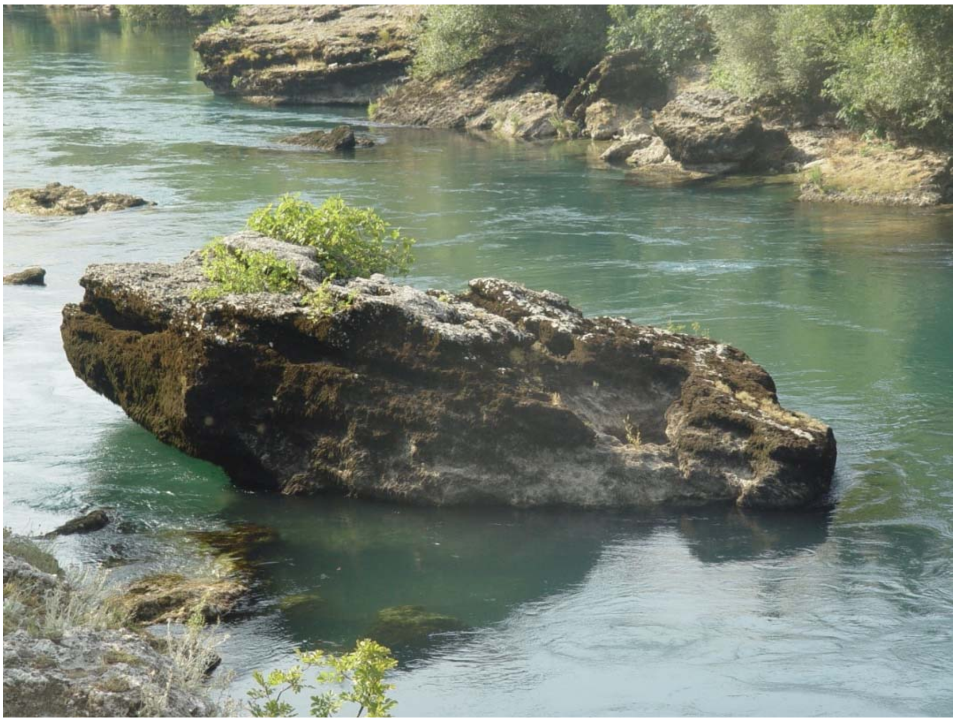


Figure 11. A detached block of river terrace in the riverbed [6]

All the mentioned processes that develop in bank rocks are exposed to effects of water, waves, sun, rain, and probably less frequently also frost.

According to Crnković and Rokić (1981), alternating heating and drying of water-saturated rock weakens intergranular bond and physical changes develop in the pore space of rock. These changes are explained as contraction and expansion of calcite when heated [5]. Such great pressures are possible probably only in the surface part of rock that is more intensely exposed to heating. Hence, such effects may have a powerful destructive impact in fragmentation of bank rocks.

We should especially emphasize the destructive effect of wind waves as a periodical occurrence in the form of hydrodynamic load on the natural vertical rock.

This load depends on the type and speed of wind, height and strength of waves, but also the type and morphology of rock.

4. GEOLOGICAL DESCRIPTION OF TERRAIN ORIGIN

The stratigraphic column of the region to which the studied location (Mostar valley) begins with limestone rocks of the Upper Cretaceous and Lower and Middle Eocene. They are bedded to thickly bedded, of excellent geomechanical characteristics with stable slopes formed at different gradients, even over 90 degrees.

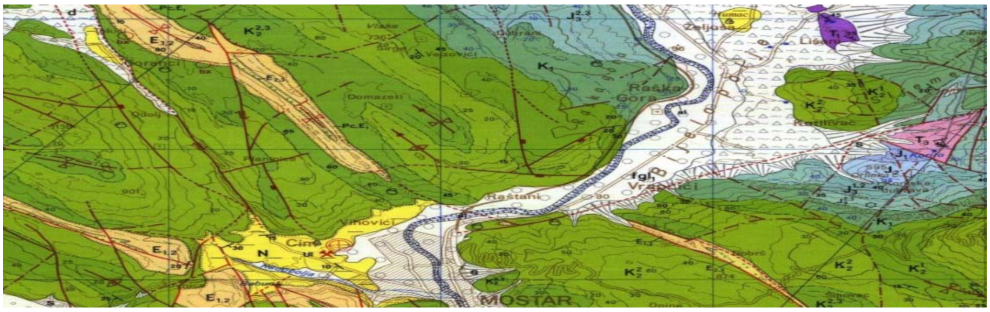
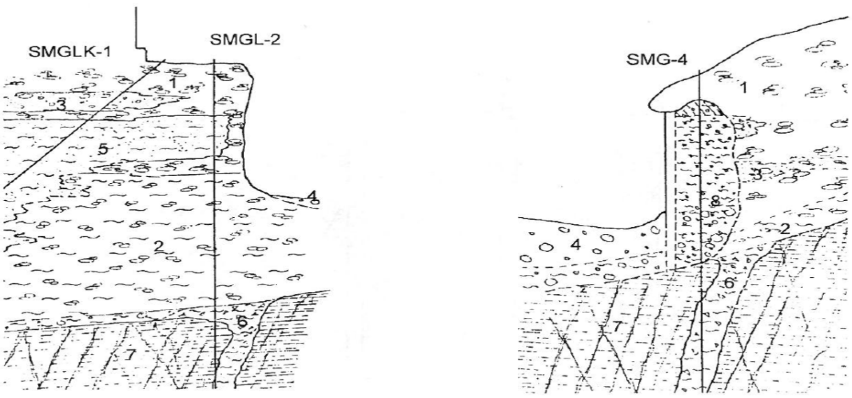


Figure 12. A detail from the geological map Mostar - the study area

River terraces (fluvial conglomerates and breccias) are developed close to river flows in the form of thick beds. Processes of degradation and weathering are often visible in the overlying part of the beds, and fast transformation into cohesionless sandy-gravely material in the underlying part. Groundwater is routed through these contact zones. As the river cuts its bed in fluvial conglomerates, the speed of water filtration in sides increases and loose material is washed out, creating the typical hollows. The formed underground voids cause the effect of cantilevers in river terraces, and they break off in the form of large blocks and fall into the riverbed.

In view of their physical and mechanical, or engineering geological characteristics, these deposits range from gravels as cohesionless sediments to solid thick-bedded conglomerates characterized by high strength and compactness, and they behave as solid rock masses. Between these two extremes, there is a whole range of intermediate variations depending on cementation levels and thickness of conglomerates.



1-solid compact conglomerate
2-conglomerate weakly bound
3-interbeds of gravel and sand in conglomerate
4-gravel and sand
5-marly clay with sand
6-marl debris in clay
7-marl with cracks
8-unhardened “prepacked” concrete

Figure 13. Cross section of foundation soil with solid conglomerates, the Old Bridge, according to [1]

The formed underground voids cause the effect of cantilevers in river terraces, and they break off in the form of large blocks and fall into the riverbed (Figures 14 and 15), [7].

Figure 14. A scoured layer of conglomerate susceptible to collapsing

Figure 15. An example of intervention

5. GEOMECHANICAL DESCRIPTION OF SOIL - ROCK

In the study area, conglomerates retain their grain size characteristics as well as composition and shape of grains, like surrounding gravels, which are hardened into conglomerates of varying strength, bed thickness and lateral extent through secondary cementation with calcium carbonate binder, with compaction and packing. The structure of conglomerates is stratified, and depending on cementation levels we can find layers of 20-50 cm up to thick beds 5 meters in thickness.

Highly cohesive conglomerates as solid rocks are most correctly classified according to some of rock classifications, e.g. RMR classification, acknowledging criteria of uniaxial compressive strength, RQD, state and orientation of fracture systems and groundwater conditions. Average values for highly cohesive conglomerates range within the following values:

- Uniaxial strength (MPa) = 20-40
- RQD = 15-50

Or:

- Bulk density: γ (kN/m^3) = 20-22
- Cohesion: c (kPa) = 100-200
- Internal friction angle: φ (°)= >35
- Modulus of compressibility: virtually incompressible

6. CONCLUSION

Under influence of various factors, the situation along the banks of the Neretva River in the City of Mostar, scouring and collapsing of rock mass, was found to have progressed in some places to such an extent that any further delay of improvement, by grouting, anchoring, construction of concrete supports or possibly filling with natural stone according to breakwater construction system, could seriously compromise the stability of the banks but also material and human resources.

This study is also an opportunity to scientifically better investigate the Neretva river terraces in its middle course. It seems that their basic *planetary* structure (large grain in the middle, surrounded by smaller grains bound by contact cement, associating to a system of a planet and moons) have resulted from dual origin of gravels in the river alluvium, namely fluvio-glacial and talus. Larger fluvio-glacial mature grains of gravel are bound to smaller semi-mature talus grains. (P. Marijanović)

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