Geotechnical risk assessment on Albanian historical bridges

M. Gega

Polis University, Department of Architecture and Civil Engineering, Tirana

Abstract

Historical bridges in Albania represent a testimony of Albanian ancient culture and construction mastery of XVI, XVII and XVIII century. Their importance is not only in the historical context where monuments such as Kollorcka and Shen Prodhomi (XVII century) bridges stand as first category monuments but they also represent a diverse area of study in the geotechnical aspect.

This study aims identification of their cause of foundation damages, monitoring of their actual conditions, analyses and evaluation of their geotechnical risks. It was noticed that damages arise from geological phenomena, change of hydrogeological conditions and human interventions.

Kollorcka Bridge placed in south –east of Gjirokastra (UNESCO World Heritage Site) is currently in very critical condition with uncovered wood pile foundation deriving form erosion activities and hydrological conditions change. Another example of these type of foundation in Albania was discovered during Maliq marsh drainage where wood pile foundations of the antique city (around 2000 year old) where found in very good conditions.

Meanwhile human activity in Shen Prodhomi XVII century stone bridge placed in Korca Albania, has complicated its serviceability and caused excessive dynamic load from a variety of transportation services contrary to its initial purpose. Materials aging and temperature changes set Shen Prodhomi in high sustainability risks.

Finally geotechnical, geological and hydrogeological conditions of the historical bridges will be investigated in order to set their potential geotechnical risk and suggest future interventions for their performance improvements.

Key words: *historical bridges, geotechnical risk, wood pile foundations, shallow foundations.*

1 Introduction

Albania due to its long history has developed different bridge systems for transportation, communication and cultural development. A full catalog with historical and recent facts of the Albanian historical roads and bridges was published (Shtylla 2013).In this catalog a variety from the oldest preserved Poshnja bridge that dates back to V-VI century late antiquity up to the Ottoman period arch bridges of XVII-XVIII centuries are presented. This paper involves investigations on geotechnical, geological and hydrogeological phenomena developed on historical bridges in Albania and more precisely on Kollorcka and Shen Prodhomi case studies. Previous situations such as erosion activities and dynamic load actions that have seriously damaged Kallmeti bridge foundations (Bozo et al 2006). Consideration is given to similar problematic situations such as geological conditions in one of Kamara bridge abutments placed in massive rock (with many cleavages) have damaged and displaced by a few centimeters of the bridge foundations (Gega & Bozo 2017). Another very important experience in this field are different intervention projects proposed and realized by Institute of Cultural Monuments in Albania with respect to historical bridges restoration requirements. Being this an ongoing process, there is a research gap in the field of geotechnical, structural and architectural design to support different private and public restoration initiatives.

2 Kollorcka Bridge

2.1 Historical setting

Fig. 1: Kollorcka Brige pier scour in the dry period of the year

Kollorca Bridge is a first category monument in Albania of the Ottoman period dating on 1820 placed over Drino River near Gjirokastra. It has an aesthetic design of five arches Bridge with a total longitude of 103 m and a maximum altitude form the river water level of 7.2m (IMK). Kollorcka Bridge has 4 squat piers with blocks of wooden piles foundations for resisting hydrological conditions. In these 4 piers small circular water discharging openings are used for water to flow inside them.

2.2 Geological and hydrogeological conditions

The first layer from 0-0.8ml is composed of alluvial deposits represented by not cemented gavel: 80 % rounded gravel with limestone, sands and 20% coarse and medium size grained sands with Qh1al age. Second layer from 0.8ml – 4ml is composed of river bed deposits represented by cemented light yellowish siltstones with rarely sand combinations. It should be noted that on these deposits of Qh2 age are placed Kollorcka bridge foundations. Cohesion of this layer varies from 200-500 kPa. Third layer from 4ml-200ml is composed of Flysch deposits of the upper Oligocene Pg 33 with cemented clayey - sands found under 200ml depth. These deposits build the basement of alluvial deposits in Drino River. Form the Albanian Topographical Map the presence of horizontal relief is found on the bridge area. Also the pile foundations are placed on stable alluvial deposits in 2.5-3m depth. Because of cemented clayey – sands of the basement of alluvial deposits Kollorca Bridge has resisted in time. In this geological formation the presence of groundwater level is up to the first layer at gravel deposits. In more than 200 years of existence of the bridge the climate changes of the recent years have influenced in hydrological conditions changes as well.

2.3 Analysis and evaluation of Kollorcka Bridge geotechnical risks

Resulting from Drino river flow velocity change the presence of pier scour Bozo & Muceku (2002) is investigated that causes serious damage in two of its piers. This hydrological conditions change has uncovered the wood piles in 2 of the piers but in one of them has also eroded the cohesive clays of the river bed. During the construction phase for improving soil structure interaction a pile cap with lintel beams is used to avoid wood pile foundation erosion (IMK) .It is thought that the main factors leading to this critical situation are decreases of groundwater level and total stop of river flow in summer time. While the level of the groundwater reaches to the soil surface in autumn and spring and river flow comes to its maximum by causing flooding activities such as the one of year 2014.

Fig. 2: Kollorcka Brige in 2014 flooding (IMK)

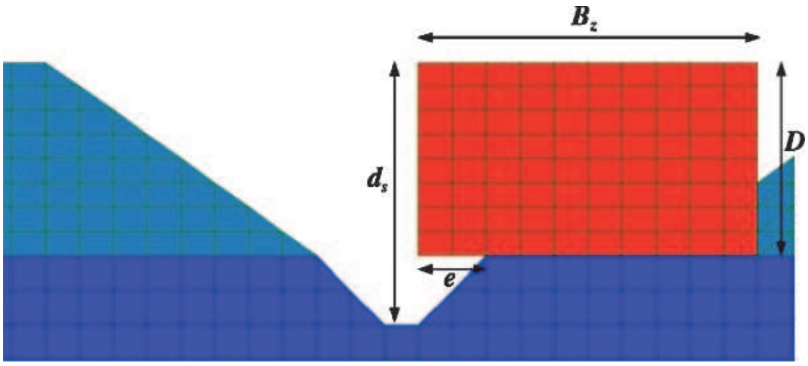

Fig. 3: Dimensionless scour depth ds/D and lateral erosion e/B_z (Zampieri 2017)

When ratio of the (ds/D) is lower than 1, scouring does not influence structural behaviour of stone arch bridges.While in case of lateral erosion under pier foundation cracking phenomena is observed at bridges arch (Zampieri 2017). From the current state the damages are only affecting the foundations of the bridge and have not showed any arch crack to the stone structure. So according to its initial purpose wood pile foundations has resisted very well to local scour but also have prevented lateral erosion and possible bridge settlements that can lead to the loss of equilibrium and structural damages. From the geological conditions Kollorcka bridge foundations are placed on the second layer of cohesive cemented siltstones. Different studies have stated different results about scour in cohesive soils when comparing it to non-cohesive soils, when soil properties testing are placed on the same pier condition and river flows (Sonia Devi 2017). Because of the lack of a general equation that include the required parameters for understanding the scour mechanism in cohesive soils we cannot judge if in our case the presence of cohesive soil decreases or increases the scour dimensions in our flow and pier conditions. The wood pile foundations have played an important role in the bridge resistance to harmful natural conditions such as temperature changes, hydrological, hydrogeological and potentially geological too. All this conditions change have resulted in the exposition of Kollorcka bridge wood piles.

Fig. 4: Exposed wood piles of diameter 12-18 cm (IMK)

This exposition deteriorates wood because it loses stiffness and all the stresses are transferred to the soil. If the interventions are not performed in time Kollorcka bridge wood loose its protection guaranteed by wood piles and it will be prone to lateral erosion and further displacement that can bring the total collapse of its two piers and finally the bridge itself. How harmful is the effect of wood deterioration depends on pile dimensions, spacing, and geological conditions. Also the interventions are immediate as bacteria can accelerate wood deterioration (Bettiol, et al. 2016).

3 Shen Prodhomi Bridge

3.1 Historical setting

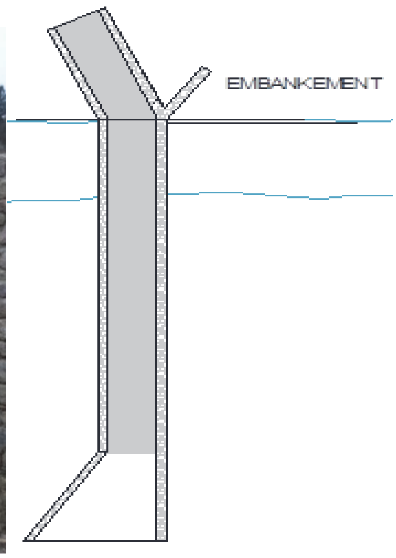

Fig. 5: Shen Prodhomi Brige (IMK) **Fig. 6:** Brige Plan

Shen Prodhomi XVII century bridge has a 51.70 m longitude and a 4.60m width. It is composed of 1 biger arch with 11.00 m spacing and a smaller one of 4 m spacing. In the river shore the brigde route has a 22° turn (IMK). In order to prevent the foundation damage in the other side a retainig wall is constructed. As shown in the bridge plan in the part where maximum spring flow accours it hits the retaing wall.As shown in fig. 7 the wall is considerably damaged up to 50 %.This leads to monitoration requirement on deteriorating factors affecting this retaining wall. Mainly the presence of erosion has created a dynamic load on the retaining wall structure by eroding underwater parts of the mortar and the wall stone in the same time. This wall requires immediate interventions as it also serves as a protection for the foundations of the Shen Prodhomi bridge.

Fig. 7: Shen Prodhomi Brige, retaining wall (IMK)

Further studies are required to investigate if erosion coming from the spring can be a threat in the future for the foundations. Similarly as in Kollorcka Bridge, change in hydrogeological and hydrological conditions can exert pressure on Shen Prodhomi Bridge foundations.

3.2 Geological and hydrogeological conditions

Geological profile shows that:

First layer is composed of alluvial deposits such as gravel, sand, sandy clay with cohesion varying from 80-130 kPa. Groundwater level is in this layer.

Second layer is composed of terrigenous sedimentary rock (basal conglomerate) with cohesion varying from 1-1.5 MPa.

Third Layer is composed of carbonate rocks.

Lower Cretaceous deposits depth varies from 100m-300m and are composed of terrigenous sedimentary rock and carbonate rock.

Terrigenous sedimentary rock

Grey basal conglomerate are the first layer noticed in the terrigenous sedimentary rock. The fragmented material is mainly composed of ophiolite, limestone and silicates material varying from a few cm up to 50cm with irregular sorting. They have low clay-sand cementation with ophiolites Robertson at al (2012) compound mainly.

Fig. 8: Shen Prodhomi geological profile

Carbonate rock

It is placed under the terrigenous sedimentary rock layer with compatibility. In the carbonate rock layer is found the combination of limestone conglomerate, fragmented limestone rich in ophiolite material, limestone-marl sequences and marl with reddish carbonate-clay cementation dating back to Barremian - Aptian age.

The foundations of Shen Prodhomi Bridge are placed on terrigenous sedimentary rock. As conglomerates they have very good resisting parameters 1-1.5 MPa. Also the presence of the retaining wall sets Shen Prodhomi foundations in good conditions. Human activity with the usage of heavy transportation vehicles have caused cracks in the arches of the bridge. Hydrological conditions and humidity has taken further the initial cracks. Also potential earthquake set Shen Prodhomi Bridge in difficult situations due to stone material fatigue from excessive dynamic load.

4 Conclusions

Arch stone bridges compose a good part of Albanian historical heritage. Because of their aging, geotechnical, geological, hydrogeological and hydrological conditions many of them show different level of damages. This study brings into investigation Kollorca and Shen Prodhomi Bridge.

Kollorca Bridge is in high risk because of its wood pile foundations damage on 2 of its central piers. Geotechnical assessment is performed and as a result immediate interventions on foundation reinforcement and total replacement are crucial for the bridge stability.

Shen Prodhomi Bridge doesn't show geotechnical risks. The resisting parameters of basal sedimentary rock have kept bridge shallow foundations in good conditions. Meanwhile human activity and hydrological conditions have seriously damaged the bridge structure and the retaining wall next to it. Restoration of the retaining wall is important for keeping the foundations in the current state.

5 Literature

Bettiol, G., Ceccato,F., Pigouni, A.E., Modena C., & Simonini, P. (2016)
Effect on the Structure in Elevation of Wood Deterioration on Small-Pile Foundation: Numerical Analyses, Int. J. Arch.Heritage, 10:1, 44-54

Bozo, L., Ahmetaj,L. & Allkja, S. (2006)
Influence of the deformation parameters of soils in selection of the static scheme Maliq's bridge (Proceedings of XIII Danube-European Conference on Geotechnical Engineering, Ljubjana)

Bozo, L., & Muceku ,Y. (2006)
Damage of the roads-bridges by erosion and remedial measures in Albania Proceedings of first International Conference on Scour of Foundations, USA.

Gega, M. & Bozo, L. (2017)
Analysis of bridge foundations damage in Albania, Int. J. Procedia Engineering. Vol 189, 275 – 282.

Instituti i Monumenteve te Kultures "Gani Strazimiri" Tirana, Albania (abbreviated in the manuscript IMK)

Robertson, A.H. F., Ionescu, C., Hoeck, V., Koller, F., Onuzi K., Bucur I. I. & Ghega , D. (2012)
Emplacement of the Jurassic Mirdita ophiolites (southern Albania): evidence from associated clastic and carbonate sediments, Int J Earth Sci (Geol Rundsch) Vol 101:1535–1558

Shtylla,V. (2013)
Rruge dhe Ura ne Shqiperi / Roads and Bridges in Albania, Gurten, Tirane.

Sonia Devi, Y & Barbhuiya, A K. (2017)
Bridge pier scour in cohesive soil: a review, Sadhana, Vol. 42, No. 10, 1803–1819

Zampieri, P., Zanini, M.A., Faleschini, F., Hofer, L. & Pellegrino, C. (2017)
Failure analysis of masonry arch bridges subject to local pier scour, Int.J. Engineering Failure Analysis Vol 79, 371-384.