Engineering Geology 209 (2016) 44–55

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Safety assessment of limestone-based engineering structures to be partially flooded by dam water: A case study from northeastern Turkey

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ARTICLE INFO

Article history:
Received 19 August 2015
Received in revised form 9 May 2016
Accepted 14 May 2016
Available online 16 May 2016

Keywords:
Natural stone
Retaining wall
Masonry bridge
Filling material
Saturated conditions

ABSTRACT

Turkey has been faced with an escalating energy demand and recurring droughts within the last few decades. The construction of the BAGISTAS 1 Hydroelectric Power Plant Dam, one of the dams constructed in order to solve these problems, resulted in the partial submersion of a number of pre-existing railway bridges and retaining walls of the Divrigi-Ilic-Erzincan Railway System (NE Turkey). Before the accumulation of dam water, the structural safety of these 86-year-old infrastructures, which were constructed using carbonate rocks, were investigated under saturated conditions. The maximum uniaxial compressive strength (UCS) losses under saturated conditions, after the application of freezing-thawing, and after wetting-drying cycles, were determined. For the mortar samples obtained from a drill core, the wet-to-dry UCS ratio was determined to be 0.82, suggesting a high durability performance. The natural filling material, which was used behind the retaining structures and as the railway embankment, was classified as the selective filling material, representing the best conditions for a filling material. The samples representing the retaining wall and filling materials had very high slake durability indexes, showing that they are very durable under the effect of water. The closed-form analysis for partially submerged retaining walls indicated that the structures are safe against overturning and have permissible internal wall stresses under operational conditions. In addition, the structural safety assessment of a masonry bridge was investigated using 3D Finite Element Modeling (FEM) under the designed train and expected earthquake loads, in both dry and partly immersed conditions. The results of the study showed that the strength reduction of masonry in saturated conditions, under the raised waters of the newly constructed dam, has an insignificant effect on the submerged sections and does not pose any danger to the overall structural performance.

1. Introduction

The use of natural stones as building material has been a tradition and common practice throughout human history. They have been extremely important for building civilizations as one of the most consumed natural building materials for the last few millennia. The quality of a natural building stone can be characterized by different features of the rocks, such as their strength, workability, durability, aesthetics, and availability. The strength and durability/weathering resistance are the two basic requirements of a stone for its usability as a building stone. Another important issue governing the usability of a rock as a natural building stone is its proximity to the construction site. In most cases, natural stone sources close to the construction site have been preferred in many buildings, reflecting the geology of the local area (Dreesen and Dusar, 2004; Torok, 2003; Xidakis and Diamantis, 1990). The main rock types that have been used as building stones are tuffs, basalts, granites, sandstones, and various carbonate rocks. Among these rocks, carbonate rocks have been extensively used as building stones because of their availability, workability, and attractiveness (Bell, 1993). In most cases, building stones are exposed to atmospheric conditions. Hence, besides strength, one of the initial requirements for a rock's usability as a building stone is its durability, which can be defined as the measure of its ability to endure and maintain its original size, shape, strength, and appearance over an extensive period of time under weathering conditions (Bell, 1993). The durability of rocks is commonly assessed by the determination of their water absorption capacity and their uniaxial compressive strength (UCS) under dry and saturated conditions (Bednarik et al., 2014), after freezing-thawing (Ruedrich et al., 2011; Bednarik et al., 2014), and wetting-drying cycles (Gokceoglu et al., 2000). The amount of strength and weight loss after the application of these cycles gives a good indication of the durability of the rocks. The performance of building blocks under wet conditions is of critical importance since structures are sometimes exposed to water contact for extended periods of time, such as increased dampness (e.g., rising), subsidence, or rising dam water reservoir levels (as in the case of this paper).

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http://dx.doi.org/10.1016/j.enggeo.2016.05.003

For the last three centuries, increased urbanization in Turkey has resulted in large numbers of infrastructure constructions. One of the most significant advances has been the construction of the railways. In earlier times, the rails were laid on infills, embankments, and cuttings, with railway bridges over the rivers and retaining walls when necessary (Koyama, 1997). With the advances in tunneling technologies, building railways to connect towns and cities isolated by mountains became possible (Koyama, 1997). From the early 1800′s until the mid-1900′s, most of these infrastructures had been constructed with natural building stones. The railway connecting the eastern and middle parts of Turkey, between Erzincan and Sivas, was constructed in the 1930′s, along the Karasu Valley, and it has been in use since 1938.

Within the last decades, Turkey's escalating energy demand and recurring droughts resulted in an extensive dam construction campaign across the entire country. One of these dams, BAGISTAS 1 Hydroelectric Power Plant Dam, has been recently constructed in the Karasu Valley. This construction resulted in the partial submersion of some of the existing railway bridges and retaining walls of the railway system under the newly constructed dam reservoir waters. In the literature, there is no standard geological engineering and/or geotechnical engineering procedures to assess submersion-related problems. For this reason, case studies on the partial submersion of bridges and retaining walls have attracted the attention of the engineering geology and geotechnical engineering communities, and have scientific value for the international engineering geology and geotechnical engineering literature. The main objectives of the present study are to assess the behavior of the building stones and infilling materials used in the engineering structures as a part of the Divrigi-Ilic-Erzincan Railway System, and to investigate the structural safety performance of the masonry bridges, retaining walls, and infills partially submerged under water. There are two bridges in the study area; one of them is of the stone arch masonry type, made of natural stone, and the other one is a reinforced concrete (R/C) bridge with masonry approach spans at the entrance to the bridge. The R/C bridge has been left outside the scope of this paper. The investigated stone masonry bridge and retaining walls, and their infills, are all constructed using carbonate rocks supplied either from the nearby rock quarries or from the excavation of railway tunnels. When considering the nature of the problem, the study presented herein is a serious scientific engineering geology case. During this study, both the assessment of the long-term durability conditions of the 86-year-old infrastructures and the prediction of their behavior in saturated conditions were carried out. The results are achieved by applying several in-situ non-destructive Schmidt hammer and laboratory tests. Although Schmidt hammer tests take readings from the stone surface that is exposed to weathering conditions, the readings provide a conservative lower strength limit of the existing natural stones. Additional point load tests, to obtain the uniaxial compression strengths, were carried out on stone and masonry core samples taken from the structures. The number of core samples were minimized due to the fact that core sampling is a semi-destructive test method and very difficult to obtain from a distant site. The structural safety conditions of both of the bridges were checked, but only the studies related to the masonry bridge are presented in this paper. During the safety assessments, 3D Finite Element Modeling (FEM) under the designed train and expected earthquake loads, for both dry and partly immersed conditions were checked and correlated (TEC, 2007). The response spectrum analysis with multiple mode-superpositions is a universal approach (Clough, 1962; Hudson, 1956; Joshi and Gupta, 1998) and the response spectrum in the Turkish Earthquake Code (TEC, 2007) is used for consistency with the earthquake zoning map (AFAD, 1996). The analytical modeling of masonry bridges can be found in the literature (Crisfield, 1985; Choo et al., 1991; Caglayan et al., 2012); however, the evaluation of stone masonry bridges that have been later submerged in dam water is unique to this study. The general approach followed in this study is shown in a flowchart in Fig. 1 and explained in detail under each heading below.

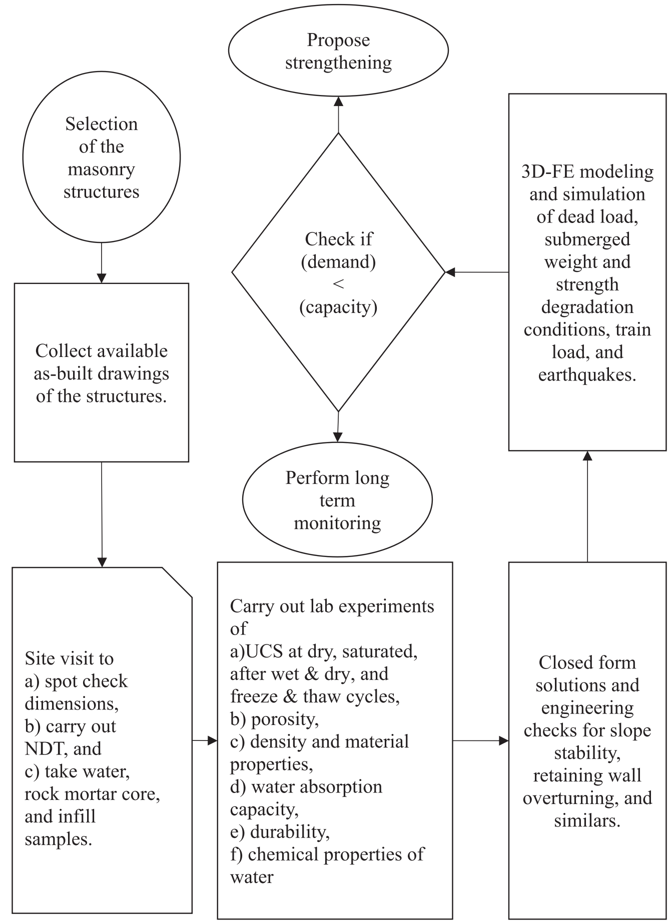

Fig. 1. Flow chart of the study.

2. Field investigations, in-situ tests and sampling

The present study was carried out in the Ilic district of Erzincan city, which is located in the eastern part of Turkey (Fig. 2). The investigated railway route's topographic altitudes were between 885 and 940 m. According to the Trewartha climate classification in this region, the winters are cold (−9.9 to 0 °C, with an average value of −3 °C, between the periods of 1971–2000), and the summers are warm to hot (18 to 22.9 °C for warm, 23 to 27.9 °C for hot, with an average value of 23 °C, between the periods of 1971–2000) (DMI, 2015).

The field investigations of the natural building materials used in the study area for the construction of one stone arch bridge, one hybrid bridge (stone and concrete), and three retaining structures are grouped as follows: (i) systematically-performed, in-situ Schmidt hammer tests; (ii) sampling for mineralogical investigations and the determination of engineering properties in both dry and saturated conditions; and (iii) determinations of in-situ unit weights of the filling materials and the classifications of these filling materials.

An L-Type Schmidt hammer was used during the tests. A total of 33 in-situ Schmidt hammer tests were performed in accordance with the standards suggested by ISRM (2007) (Table 1).

The Uniaxial Compressive Strength (UCS) values were predicted by applying the empirical equation, Eq. (1), suggested by Nazir et al. (2013) for an L-Type Schmidt hammer when used on limestone (Table 2).

$$\mathrm{UCS\ (MPa)} = 12.83 \times e^{(0.0487 \times \mathrm{Schmidt\ value})} \qquad (1)$$

The laboratory studies performed on the natural building stones include dry and saturated UCS tests, the determination of mineralogy, unit