Stability Analysis of a High Stone Retaining Wall: A Case of Eskipazar/Turkey

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***Abstract*— The use of natural stones in retaining wall has been a tradition and common practice throughout human history. Stone retaining walls are load bearing retaining walls, which have long been analyzed by considering the equilibrium of forces and moments applied to the wall treated as a rigid solid. Stone retaining walls can be designed for the provision of some slope stability. This paper provides a review of stability analysis of high stone retaining walls. This paper provides a review of stability analysis of high stone retaining walls using Geo5 software. The stone retaining wall examined in this study is located in Karabük (Turkey). The study area was located near of the North Anatolian Fault Line (NAF) which are the most important fault lines in Turkey. For that reason, the stability analyzes were carried out considering the earthquake situation. The stone retaining wall is made of traverten type rock. This rock is a commonly observed rock type. The height of the analyzed wall is 10 m. A 5 kPa uniformly distributed load was adopted in the stability analysis to accommodate for the heaviest loading condition during construction. The analysis with Geo5 found a wall factor of safety 1.78. At this value, it shows that the wall will stable although it is very high.**

***Index Terms*— Stone masonry walls, slope stability, Geo5, Turkey**

I. INTRODUCTION

Retaining walls are structures that hold the soil in an upright position. Today, Engineers often use retaining walls to mitigate existing landslides, prevent future landslides, mitigate excessive erosion, support bridge approaches, protect structures, and provide a greater "flat" surface for development. Structurally, the materials used to construct the retaining wall are must strength. Retaining walls can generally be classified as gravity/semigravity walls, cantilever walls, non-gravity cantilever walls, anchored walls, and mechanically stabilized earth walls. Gravity walls are commonly constructed of dry stacked or mortared stones, precast concrete blocks, cast-in-place concrete masses, or wire mesh gabions filled with stones, among other materials. Stone materials are extremely important for building civilizations among the most consumed natural building materials for the last thousands of years.

From a geotechnical stand point, retaining walls must are typically designed to an appropriate factor of safety for bearing, sliding and overturn. Simulations on drystone constructions fall into two categories [1]: (a) macro-mechanical approaches, where the masonry is treated as a continuous medium [2], [3], [4], [5], and (b) micro-mechanical approaches (finite- or distinct-element methods), where the wall is represented as a combination of blocks [6], [7], [8], [9], [10]. In addition, only a few recent experiments have been undertaken on drystone retaining structures [11], [12].

From a practical standpoint, the height of a stone retaining wall is limited. The taller the wall, the larger the mass of soil being retained; the more mass being retained by the wall, the heavier the wall must be to resist sliding and overturning. For a very tall gravity wall, it is difficult to achieve an acceptable factor of safety against sliding and overturning; in order to create a wall massive enough to retain such a large volume of soil, the wall must be made so thick that it would be impractical to construct [13].

Analysis of a very high stone retaining wall was conducted using Geo5 software in this study. Study area is a town and district of Karabük Province in the Black Sea region of Turkey (Figure 1). It is about 200 kilometres north of Ankara and about 100 km south of the Black Sea coast, or more precisely about 9 km north of the city of Karabük.

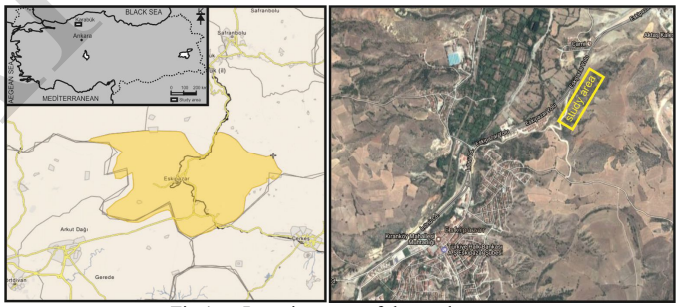


Fig 1. Location map of the study area.

II. GEOLOGİCAL AND GOMERPHOLOGİCAL PROPERTİES OF STUDY AREA

The study area was located near of the North Anatolian Fault Line (NAF) which are the most important fault lines in Turkey (Figure 2). The region is highly active in terms of earthquakes and so local settlements may be at potential risk from Slope problem. The investigation area is located in a region where Western Pontides and Central Sakarya come together along the Northern Anatolian Fault Zone (NAFZ). The study area is locoted in arround Eskipazar city. Located in the Western Black Sea region, Eskipazar is on 35 km southwest of the province of Karabük and has a distance of approximately 10 km to the Northern Anatolian Fault Zone, which is one of the most significant fault zones of Turkey.

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The field covers units of Western Pontide Zone, Armutlu-Almacık-Arkotdağı Zone and Sakarya Zone. Çalışma alanında açığa çıkan birimler Örencik formasyonuna ait gevşek konglomera kumtaşı ve kil taşlarıdır. [14], [15], [16], [17], [18], [19] (Figure 3).

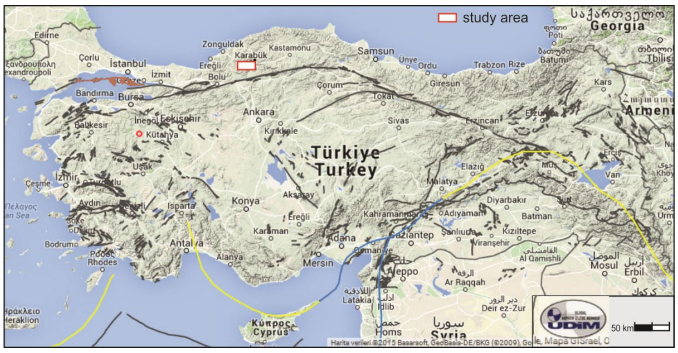


Fig 2. Active faults in the vicinity study area.

III. STABILITY EVALUATİON AND PROPERTİES OF THE RETAİNİNG WALLS

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 [20], [21], [22], 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 [23], [24].

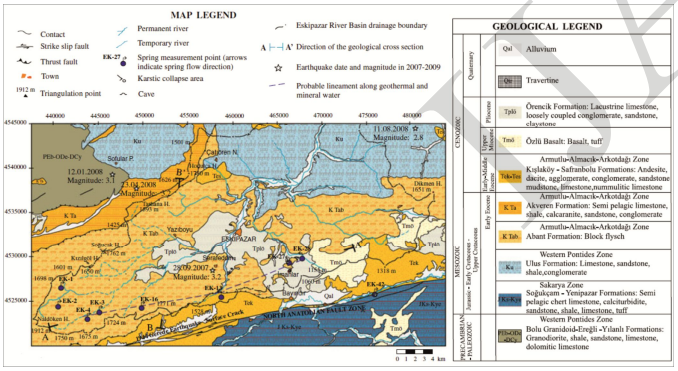


Fig 3. Geology map of the study area (Timur and Aksaray 2002).

The retaining wall analyzed in this study were of the stone masonry type, which commonly have low tensile and relatively high compressive strengths. And the Stone retaining wall was built from travertine. Walls are either inclined backwards in order to have their center of gravity closer to the infill. In addition, extended at the base to make use of the weight of the infill to generate an overturning action towards the infill in an attempt to counteract the horizontal trust of the infill. The total height of the wall constructed is 10. The active restraining height is 8 meters. Total length is about 60 m. (Figure 4). The retaining walls were constructed from travertine blocks. The reason why it is preferred stone retaining wall in study area is considered to contribute to landscapes and cultures. In addition, the travertines used in the construction of stone walls are quite special to the Eskipazar city. The founder of the republic of Turkey Mustafa Kemal Atatürk's monumental grave was built with the same stones. The mechanical characteristics obtained from the laboratory and field tests are represented in Table 1.

The geometry of the analysed stone wall is presented in Figure 5. A 5 kPa uniformly distributed load was adopted in the stability analysis to accommodate for the heaviest loading condition during construction. Groundwater was not anticipated to occur at the site Therefore, fully saturated conditions were not considered in the design model. Seismic design of retaining wall is most commonly performed by using the pseudostatic approach which has all the limitations of stress based design methods applied to earthquake engineering.



Fig 4. General views and geometric properties of the retaining walls.

Retaining walls are generally designed to meet three criteria: resistance to sliding, resistance to overturning, and adequate bearing capacity. Stability analyses and verification of the critical cross sections of the structures were carried out using the commercial software Geo5. Geo5 contains multiple programs for design of retaining walls and supporting structures. Stability analyzes were done with Gravity Wall module. Analysis of earth pressures in effective and total parameters in software. Also, Earthquake effect is analyzed in software. The results obtained from the analyses are presented

in Figure 6 and Figure 7. FOS against failure were computed using the Bishop method of analysis Figure 7. The analyses show that wall is stable with the current geometry. Slope stability verification was also performed using the bishop method. And the factor of safety was calculated as 1.78.

Table I: Soil properties adopted in design.

Material Properties	Backfill	Foundation Soil
Total unit weight γ (kN/m^3)	18.51	18.51
Cohesion c (kPa)	0	40
Friction angle ø (º)	30	12

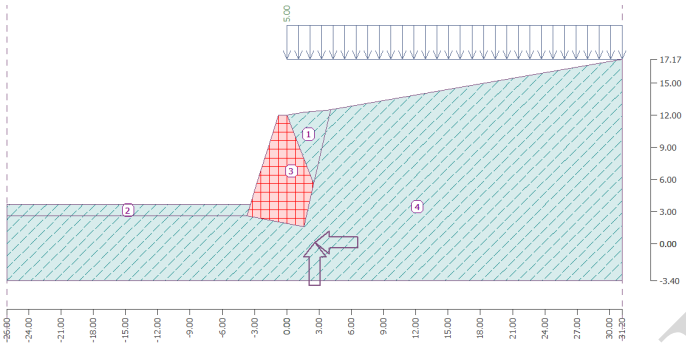


Fig 5. Geometry of the retaining walls.

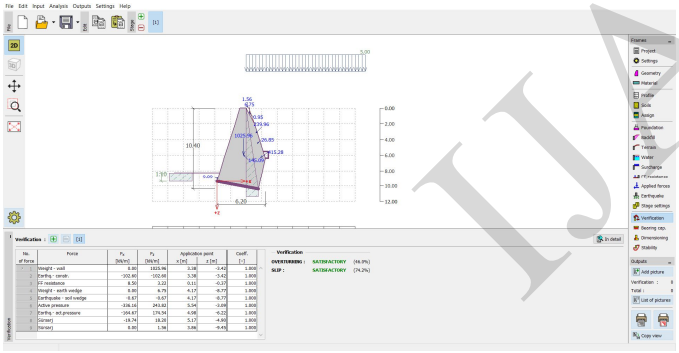


Fig 6. Vrification analysis results of the retaining walls

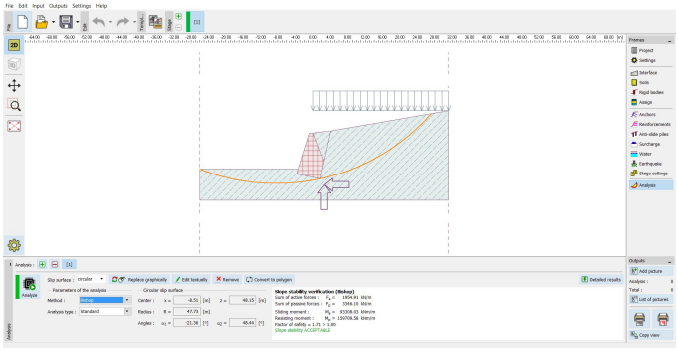


Fig 7. Slope stability analysis results of the retaining walls.

IV. CONCLUSİON

An analysis of the stability of a high stone wall constructed in a region very dangerous for earthquake hazard has been carried out with a commercial program. The analyzes made for the seismic situation show that the wall is stable. GEO5 programs software for such analysis is very useful and helpful.

REFERENCES

[1] Colas, A.S., Morel, J.C., Garnier, D. (2013) Assessing the two-dimensional behaviour of drystone retaining walls by full-scale experiments and yield design simulation Ge´otechnique 63, No. 2, 107–117 [http://dx.doi.org/10.1680/geot.10.P.115]

[2] Arya, A. S. & Gupta, V. P. (1983). Retaining walls for hill roads. Indian Roads Congress J. 44, No. 1–4, 291–326.

[3] Cooper, M. R. (1986). Deflections and failure modes in dry-stone retaining walls. Ground Engng 19, No. 8, 40–45.

[4] Villemus, B., Morel, J. C. & Boutin, C. (2007). Experimental assessment of dry stone retaining wall stability on a rigid foundation. Engng Struct. 29, No. 9, 2124–2132.

[5] Mundell, C., McCombie, P. F., Bailey, C., Heath, A., & Walker, P. (2009). Limit equilibrium assessment of drystone retaining structures. Proc. Inst. Civ. Engrs Geotech. Engng 162, No. 4, 203–212

[6] Dickens, J. G. & Walker, P. J. (1996). Use of distinct element model to simulate behaviour of dry-stone walls. Struct. Engng Rev. 8, No. 2–3, 187–199.

[7] Harkness, R. M., Powrie, W., Zhang, X., Brady, K. C. & O'Reilly, M. P. (2000). Numerical modelling of full-scale tests on drystone masonry retaining walls. Ge´otechnique 50, No. 2, 165– 179, http://dx.doi.org/10.1680/geot.2000.50.2.165.

[8] Powrie, W., Harkness, R. M., Zhang, X. & Bush, D. I. (2002). Deformation and failure modes of drystone retaining walls. Ge´otechnique 52, No. 6, 435–446, http://dx.doi.org/10.1680/geot.2002.52.6.435.

[9] Zhang, X., Koutsabeloulis, N. C., Hope, S. & Pearce, A. (2004). A finite element analysis for the stability of drystone masonry retaining walls. Ge´otechnique 54, No. 1, 57–60, http://dx.doi.org/10.1680/geot.2004.54.1.57.

[10] Claxton, M., Hart, R. A., McCombie, P. F. & Walker, P. J. (2005). Rigid block distinct-element modeling of dry-stone retaining walls in plane strain. J. Geotech. Geoenviron. Engng 131, No. 3, 381–389.

[11] Villemus, B., Morel, J. C. & Boutin, C. (2007). Experimental assessment of dry stone retaining wall stability on a rigid foundation. Engng Struct. 29, No. 9, 2124–2132.

[12] Mundell, C., McCombie, P., Heath, A., Harkness, J. & Walker, P. (2010). Behaviour of drystone retaining structures. Proc. Instn Civ. Engrs Struct. Build. 163, No. 1, 3–12

[13] M. M. Fontanese, "A Stability Analysis of The Retaining Walls of Machu Picchu" BS in Civil Engineering, University of Pittsburgh, 2007.

[14] Şaroğlu F, Herece E, Sarıaslan M, Emre Ö (1995) Yeniçağa-Eskipazar-Gerede arasının jeolojisi ve Kuzey Anadolu Fayı'nın genel özellikleri [Geology of the Eskipazar-Gerede region and general features of North Anatolian Fault Zone]. MTA report no. 9873, MTA, Ankara, TurkeyTokay 1973

[15] Alan I, Aksay A (2002) 1/100.000 ölcekli Türkiye jeoloji haritaları-

[16] Zonguldak F28 paftası [1:100,000 scale geological map of Turkey-Zonguldak F28 section]. Map no. 29, Geological Research Department, MTA (General Directorate of Mineral Research and Exploration), Ankara, Turkey

IJARE

[17] Timur E, Aksay A (2002) 1/100.000 Ölçekli Türkiye Jeoloji Haritaları Zonguldak-F29 Paftası [1: 100,000 scale geological map of Turkey-Zonguldak F29 section]. Map no. 30, Geological Research Department, MTA (General Directorate of Mineral Research and Exploration), Ankara, Turkey
[18] Sevin M, Aksay A (2002) 1/100.000 Ölçekli Türkiye Jeoloji Haritaları Bolu-G28 Paftası [1: 100,000 scale geological map of Turkey-Bolu G28 section]. Map no. 35, Geological Research Department, MTA (General Directorate of Mineral Research and Exploration), Ankara, Turkey
[19] Ekemen Keskin T. (2010) Groundwater changes in relation to seismic activity: a case study from Eskipazar (Karabuk, Turkey), Hydrogeology Journal (2010) 18: 1205–1218
[20] Dreesen, R., Dusar, M., 2004. Historical building stones in the province of Limburg (NE Belgium): role of petrography in provenance and durability assessment. Mater. Charact. 53, 273–287.
[21] Torok, A., 2003. Surface strength andmineralogy ofweathering crusts on limestone buildings in Budapest. Build. Environ. 38, 1185–1192.
[22] Xidakis, G.S., Diamantis, J.V., 1990. Building stones and geological environment in three ancient cities of Thrace, Greece. Environ. Geol. Water. Sci. 16 (1), 91–101.
[23] Bell, F.G., 1993. Durability of carbonate rock as building stone with comments on its preservation. Environ. Geol. 21, 187–200.
[24] Gokceoglu C., Turer, A., Nefeslioglu HA.,Turer, D., Meral, C. (2016) Safety assessment of limestone-based engineering structures to be partially flooded by dam water: A case study from northeastern Turkey Engineering Geology 209 (2016) 44–55.

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