YEG-Article-15/2026

Why engineering geological characterization of rock masses is vital for hazard assessment? - A rock slide case in Mudurnu, Türkiye

Arzu Arslan Kelam

METU, Department of Geological Engineering, Ankara, Türkiye

ararzu@metu.edu.tr

1. Introduction

Mudurnu is a county of Bolu Province located in northwestern Türkiye. It has been on major trade routes (i.e., the Silk Road and the Crimean Road) and has served as a trading town and a military base in the Byzantine, Seljuk, and Ottoman periods. Given its long history, there are historically valuable structures in Mudurnu, including traditional houses/mansions, mosques, a Turkish bath from the Ottoman period, and a wooden clock tower (Figure 1). Because of the value of such historical structures and the respectful lifestyle of people living within the region, Mudurnu is a candidate for the UNESCO World Heritage List. However, this historical settlement area suffers from regional rock slope instabilities along the valley where it is located. Assessment of these instabilities is necessary because of the potential consequences for the elements at risk, such as human life, houses, buildings, industrial facilities, and historically important structures (Figure 2). This article presents a stability assessment case for rock slopes in Mudurnu, which can guide future hazard assessment studies in the area, emphasizing the vitality of engineering geological characterization.

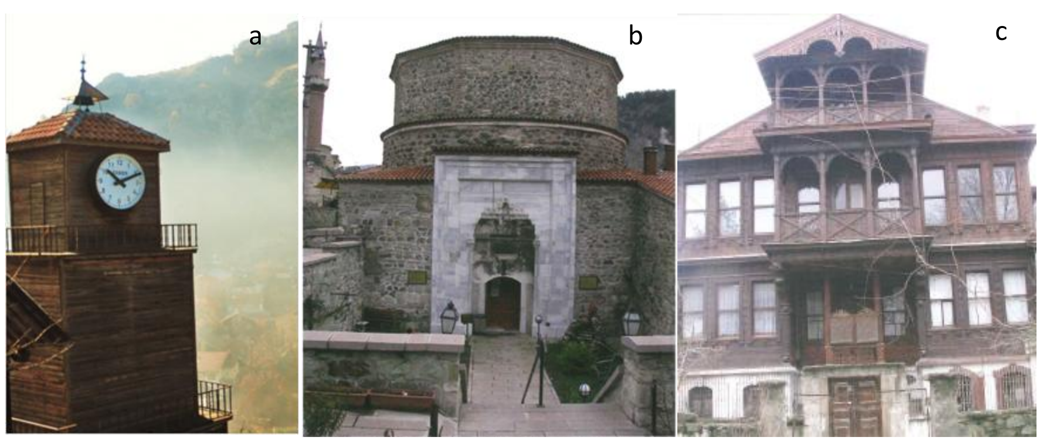

Figure 1 a) Wooden clock tower, b) Turkish bath, c) traditional Mudurnu house

Figure 2 Images of the rock slope and the houses under threat.

2. Methodology

This study focused on the western slope of Mudurnu valley where the rock mass is discontinuous Pelagic Limestone. Characterization of discontinuity properties is important, since they have a major influence on the geomechanical behavior of the rock mass (Palmstrom 2001). Moreover, spatial characterization of the rock is necessary because of its non-homogeneous, anisotropic, and discontinuous nature. However, in Mudurnu, field survey alone was not sufficient for collecting field data since access was limited due to the steep slopes, and the rather high elevation of the valley. Therefore, the engineering geological characteristics of the study area were evaluated using an Unmanned Aerial Vehicle (UAV), along with the conventional scan-line survey method. The data gathered from the point cloud were first checked with the scan-line survey measurements, where available, before using it for the entire valley. The discontinuity characteristics gathered by the scan-line survey were classified following the methods suggested by ISRM (2007). The 3D point cloud generated from the UAV images was employed to obtain the orientation, spacing, and trace length of discontinuity sets by utilizing the Discontinuity Set Extractor (DSE) method (Riquelme et al. 2014).

Given the geomechanical characteristics of the rock mass and the slope orientation, the types of failure change throughout the slope, and the associated risk changes along the valley. Engineering geological characterization was key to defining the variation of the rock mass properties. Detailed engineering geological evaluation resulted in the identification of 11 sectors that possessed similar geomechanical properties (Arslan Kelam 2022) (Figure 3).

Figure 3 Defined geomechanical sectors.

For the stability assessment, a two-step process has been followed. 1) a kinematic analysis to identify possible modes of failure, 2) a limit equilibrium analysis considering the back-calculated shear strength parameters. The kinematic analyses revealed the possible failure modes (i.e., planar, wedge, toppling, complex failures) at different sectors. To determine the mobilized shear strength parameters at the time of failure, back analysis was performed on failed blocks. Then, limit equilibrium analyses were employed to calculate the Factor of Safety and Probability of Failure at sectors for the possible failure modes. The stability analysis revealed that the rock slopes are more susceptible to planar failures than wedge failures. Sector 8 is the most critical sector for complex failure due to the combination of planar and wedge failures (See Figures 2b and 2c for close-up views of Sectors 6 and 8, respectively). In addition to static analyses, considering the proximity of Mudurnu County to the North Anatolian Fault Zone, dynamic analyses were performed using the Newmark sliding block method based on the Mw 7.2 Düzce earthquake records. Two strong ground motion station records were used: one from the station in Mudurnu, and the other in Düzce, which was closer to the earthquake epicenter. The permanent displacements along the sliding plane are given in Table 1. These analyses revealed that rock slopes where planar failure is possible are prone to large displacements triggered by large earthquakes (Arslan Kelam et al. 2025).

Table 1 Critical accelerations, and sliding block movements calculated based on Newmark rigid block analysis considering the November 12, 1999 Düzce earthquake (Mw=7.2) records from two different strong ground motion stations

Sector	Critical Acceleration	Displacement based on earthquake recorded in Mudurnu (cm)	Displacement based on earthquake recorded in Düzce (cm)
2	0.169	0.0	2.2
4	0.081	0.1	9.0
5	0.022	5.0	52.3
6	0.018	7.1	59.8
8	0.020	6.0	55.9

3. Conclusion

The results showed the significance of the assessment of rock slope instabilities in the Mudurnu. The detailed engineering geological characterization of the rock mass and identification of the complex rock slope failures will form the basis for future hazard and risk assessment studies.

Acknowledgments

I thank IAEG-YEG for their interest and the opportunity they provided. The work presented is a part of my Ph.D. Dissertation supported by the Scientific Research Projects Coordination Unit of METU (Grant No: BAP-03-09-2017-005), and by the scholarship program of the Scientific and Technological Research Council of Türkiye (TÜBİTAK) entitled 'International Research Fellowship Program for Ph.D. Students'. I am thankful to Prof. Haluk Akgün, Prof. Antoni Bobet, and Assoc. Prof. Mustafa Kerem Koçkar for their invaluable mentoring.

References

Arslan Kelam A (2022). Engineering geological characterization of the rock masses and their evaluation by spatial analyses, determination of the rock slope failure susceptibility zones and hazard assessment of Mudurnu (Bolu). Ph.D. Dissertation, Middle East Technical University (METU).

Arslan Kelam A, Akgün H, Bobet A, Koçkar M K (2025). Assessment of complex rock slope instabilities in Mudurnu, Türkiye, through kinematic and dynamic analyses: a case study. Rock Mechanics and Rock Engineering, 58:2223-2242. https://doi.org/10.1007/s00603-024-04271-0.

ISRM (2007). The complete ISRM suggested methods for rock characterization, testing and monitoring: 1974–2006. In: Ulusay R, Hudson JA (eds) Commission on testing methods. International Society of Rock Mechanics, Ankara, p 628.

Palmstrom A (2001). Measurement and characterization of rock mass jointing. In: Sharma VM, Saxena KR (eds) In-situ characterization of rocks. A.A. Balkema Publishers, London, p 97.

Riquelme A J, Abellán A, Tomás R, Jaboyedoff M (2014) A new approach for semi-automatic rock mass joints recognition from 3D point clouds. Comput Geosci 68:38–52. https://doi.org/10.1016/j.cageo.2014.03.014.

Author Responsibility Disclaimer

During the preparation of this work, generative AI and AI-assisted technologies were not used in the writing process. The author takes full responsibility for the content of the publication and for properly referencing all figures, tables, and information included in the article.