Journal of Geotechnical Geology

Journal homepage: geotech.iauzah.ac.ir

Zahedan Branch,
Islamic Azad University

Utilization of the Q-slope Empirical Classification System in Jointed Rock Slopes: A Case Study for Bonab-Malekan highway

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ARTICLE INFORMATION

Received 12 June 2018
Revised 21 November 2018
Accepted 05 December 2018

KEYWORDS
Jointed rock slope; Q-slope; Slope stability; Rock mechanics, Bonab-Malekan high-way project.

ABSTRACT

The Q-slope classification system is originally introduced by Barton and Bar (2017) for jointed rock-slope conditions description which is used for engineering judgment to evaluate slope stability. This study is attempted to use the Q-slope empirical classification system for assessment of jointed rock slopes stability in Bonab-Malekan highway project. To this end, 10 jointed slopes are observed in the high-way path which is required to investigate these slope stability conditions. According to the results of the stability analysis and sustainability possess based on Q-slope principle, a main part of the slopes are located in uncertain conditions (5 cases), 4 slopes is classified as stable and 1 slope indicate the failure condition and instability.

1. Introduction

Rock mass classification systems are used for various geo-engineering design and stability analysis. These are based on empirical relations between rock mass characteristics and engineering applications (e.g. tunnels, slopes, foundations, mining, excavatability, etc.). The main rock mass classifications benefits can be categorized as (Singh and Goel, 2011):

- Site investigations quality improvement by quantitative description of input data as classification parameters.
- Providing suitable information for geotechnical design purposes.
- Enabling effective engineering judgment for project communications.
- Provide a basic understanding about rock mass characteristics.

The first rock mass classification system in geotechnical engineering was proposed by Terzaghi in 1946 for tunnels with steel set support were classified the rock mass condition and support system concept in 7 different classes. Lauffer in 1958 present the stand-up time method for investigate the rock condition in unsupported tunnels were able to modify primary rock supports. Deere et al. (1970) by using the Terzaghi method suggested the rock quality designation (were known as RQD method) for evaluate rock mass quality. Deere and Deere (1989) modified the RQD system were used globally to primary estimation of rock mass quality based on drilling cores. Wickham et al. (1972) used geological description of rock mass classification which is named as rock structure rating (RSR) system. RSR is the first geology-based engineering classification method. Bieniawski (1973) is present more capable rock mass classification system basis of his experiences in shallow tunnels were excavated in sedimentary rock masses as geomechanics classification or rock mass rating (RMR) system. RMR is modified several times and final version of the RMR is presented in 1989 (Bieniawski, 1989). RMR is sometimes used as a foundation of new geo-engineering classifications. Barton and his

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colleagues in 1974 developed the Q methodology in the Norwegian geotechnical institute (NGI) which is known as rock tunneling quality index or Q system. Barton and Grimstad in 2014 have presented the Q system latest modification and tunnelling and rock cavern application in engineering cases (Barton and Grimstad, 2014). Palmstrom (1995) used intact rock uniaxial compressive strength (UCS) and jointing condition attempted to introduce the rock mass index (RMi) which is utilized for estimation of rock mass strength status. Hoek and Brown introduced the geological strength index; GSI (Hoek and Brown, 1997) based on geological conditions and jointed rock mass geometrical conditions which used for both hard and weak rock masses . GSI modified by Marinos and Hoek (2000), Cai et al. (2004), Marinos et al. (2005), and Hoek and Carter (2013).

By application RMR and Q systems in geotechnical engineering are caused to develop many classifications which are used for surface and subsurface purposes. For example rock mass strength or RMS (Stille et al., 1982), modified basic rock mass rating or MBR (Kendorski et al., 1983), mining rock mass rating or MRMR (Laubscher, 1977), simplified rock mass rating or SRMR (Brook and Dharmaratne, 1985), slope mass rating or SMR (Romana et al., 2003; Azarafza et al., 2017a), slope stability probability classification or SSPC (Hack et al., 2003), global slope performance index or GSPI (Sullivan, 2013) and Q-slope (Bar and Barton, 2017). The Q-slope is the newest classification system which is specifically developed for slope stability assessment with some simple assumptions. The presented study is used the Q-slope method for sustainability progress analyses were implemented on Bonab-Malekan high-way slopes as case study.

2. Q-slope system

The Q-slope classification system conducted of the 6 main parameters were 5 of them such as RQD, J_n, J_r, J_a and SRF which is used in classic Q method (Singh and Goel, 2011). The J_{wice} and modified SRF_{slope} are applied for Q-slope as well as presented in Eq. 1 (Bar and Barton, 2016; 2017).

$$Q_{slope} = \frac{RQD}{J_n}\left(\frac{J_r}{J_a}\right)_0 \frac{J_{wice}}{SRF_{slope}} \quad (1)$$

where, RQD is Deere's Rock Quality Designation, J_n is the number of joint sets, J_r is the joint set roughness, J_a is joint set alteration, J_{wice} is environmental and geological condition number, SRF_{slope} is three strength reduction factors from SRF_a (physical condition number), SRF_b (stress and strength number), and SRF_c (major discontinuity number) which is described by Bar and Barton (2017). Bar and Barton (2016) defined the O-factor which covers the J_r/J_a ratio as the orientation factor. In the Q-slope system, there is three elements were characterized as block size (RQD/J_n), inter-block shear strength (J_r/J_a) and active stress or external factors (J_{wice}/SRF_{slope}) which the minimum favourable shear strength is J_r/J_a and the average shear strength for wedges is evaluate as $(J_r/J_a)_1 \times (J_r/J_a)_2$. Q values are estimated based on the manual tables based on field investigations (Azarafza et al., 2017b) were estimated by several scholars and Barton team. Barton and Bar (2017) also present the 'stability chart' for investigate slope sustainability condition in easier way. Figure 1 is present the Barton's stability chart. As seen in this figure, the stability of the slopes related to slope angle (β) and Q-slope number form Eq. 1.

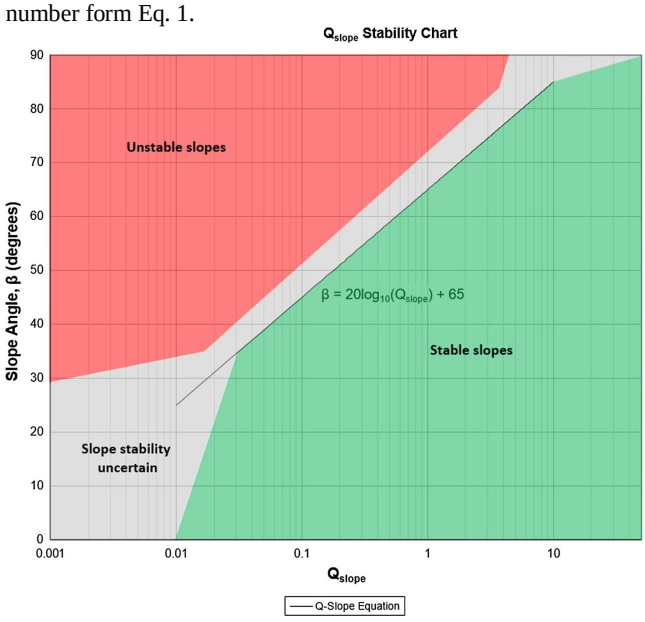

Figure 1. The stability chart for Q-slope (Bar and Barton, 2017)

3. Method and Materials

The presented study is used the Q-slope method for investigate the stability condition is 10 case slope along with the Bonab-Malekan highway project. Figure 2 is present the location of the project in Google map.

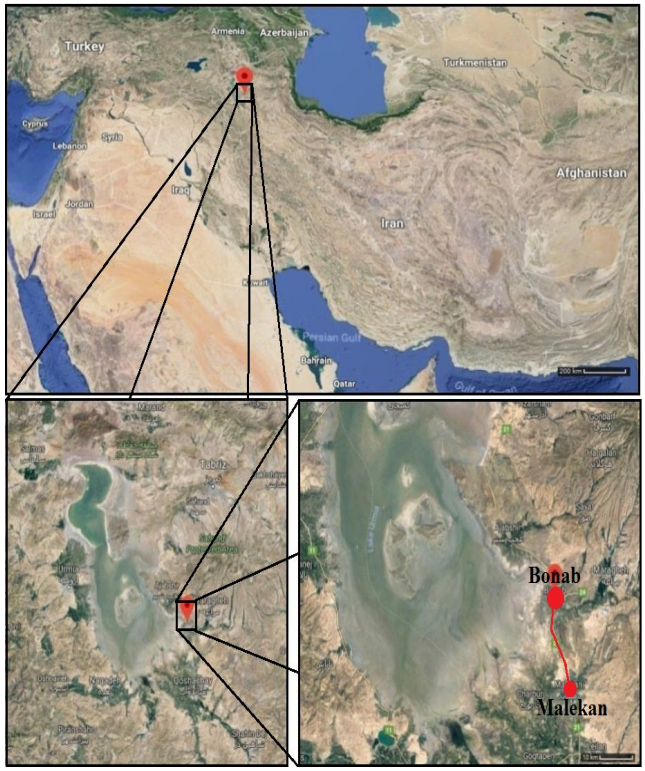

Figure 2. Location of the studied area in Google Earth

In term of geology, the project mainly covered by Quaternary alluvial despites related to the Urmia Lake sedimentary fans (Azarafza and Mokhtari, 2013; Azarafza and Ghazifard, 2016). But slopes are containing rocky outcrop of the limestone, sandstone and dolomolimestones relate the maragheh formation (Aghanabati, 2007). This study is founded on instability assessment several slope related to the Bonab-Malekan highway project were located in distance between Bonab and Malekan cities as 47 km path. Figure 3 is shows a view of the highway project. In this regard, 10 slopes are specified in the highway route range that associated with the main project. Therefore, it requires to slopes stability analyzed and results used for possible stabilization and future design.

Figure 3. A view of the Malekan highway

4. Results and Discussion

The main aim of the study is achieve acceptable and fast results in order to advance the goals of the project. For this purpose, experimental approaches have been used to analyze slopes stability and investigate the rock mass conditions. The Q-slope is the newest method developed for slope stability in recent years which gained many scholar interested. This method is used of stability analysis for the Bonab-Malekan highway project. During field survey in the project site, rock mass geometrical features and joint network properties was recorded for each slope and the Q values estimate based on Barton's team guide tables and stability chart were presented in Fig. 1. In the other hand, for the evaluation of the geotechnical engineering characteristics from these slopes, rock sampling was taken and rock mechanical tests are conducted for the samples to measured the strength parameters (e.g. cohesion, friction angle, Young's modulus, shear modulus, bulk body, Poisson's ratio, etc.). Figures 4 and 5 is present the results of the Q-slope stability evaluation based on Barton's stability chart. According to the results of the study conducted on the studied slopes based on Q-slope principle, a main part of the slopes are located in uncertain conditions (5 cases), 4 slopes is classified as stable and 1 slope indicate the failure condition and instability. As seen in this figure, the uncertain section is covered some local instability but it is keep general stable status for slope which is used as local instable slope. For theses slops geometrical modification is best stabilized method. But for unstable slope must used comprehensive stabilization methods.

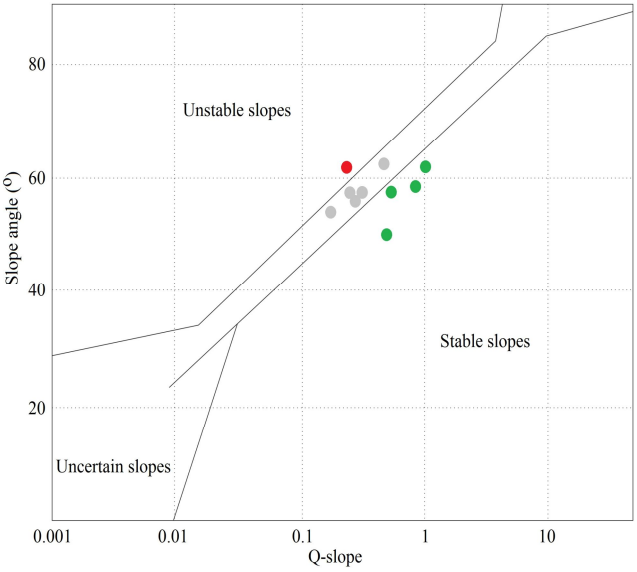

Figure 4. The results of the stability analysis by Q-slope

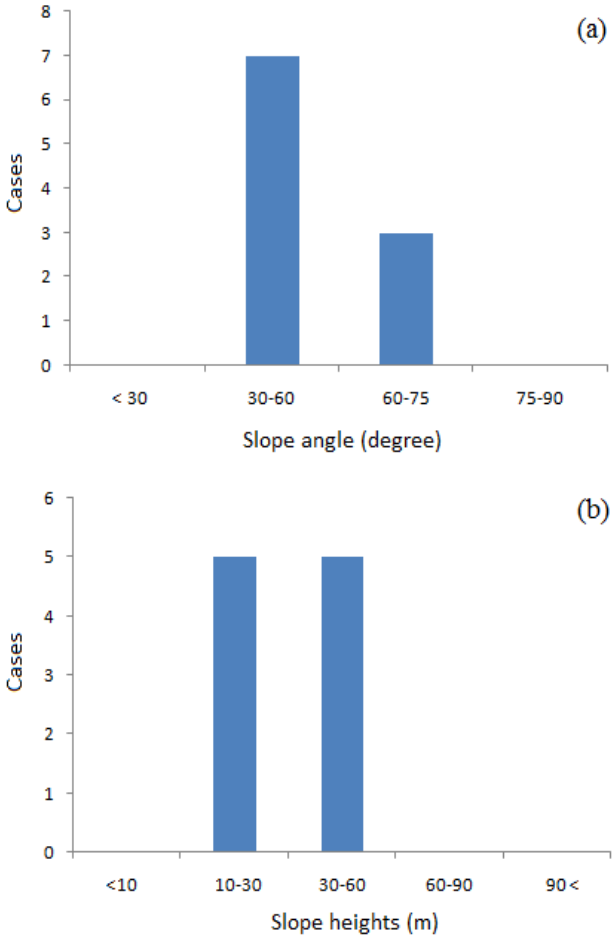

Figure 5. Data-set of the studied slopes for the Q-slope parameters: (a) slope angle variation, (b) slope height variation

5. Conclusion

Q-slope is one of the flexible empirical classification methods which are designed user friendly and solve jointed rock slope instability problems with several easy assumptions. In this study we attempted to utilized the Q-slope methodology for investigate the jointed rock slopes stability in Bonab-Malekan highway project. Ten slopes are specified in the highway route range that associated with the main project which it requires to slopes stability analyzed and results used for possible stabilization and future design. According to the results of the study conducted on the studied slopes based on Q-slope principle, a main part of the slopes are located in uncertain conditions (5 cases), 4 slopes is classified as stable and 1 slope indicate the failure condition and instability.

Acknowledgements

The authors wish to thank the Department of Civil Engineering, Bonab Branch, Islamic Azad University for preparing the analysis data.

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