Rock Mass Strength Analysis and Disturbance Factor Estimation of Heterogeneous Rock Masses for the Dam Foundation: A Case Study at Kanarwe River Basin, Kurdistan Region, NE-Iraq

Fahmy Osman Mohammed(✉), Ghafor Ameen Hamasur, and Diyari Ali Almanmi

University of Sulaimani, Sulaymaniyah, Iraq
Fahmy.mohammed@univsul.edu.iq

Abstract. Evaluating rock masses for dam foundations, especially heterogeneous rock (flysch), becomes imperative and requires accurate geomechanical classifications. The rocks at the Kanarwe River Basin (KRB), especially at a proposed dam site (Goma-Qazan near Khewata – Sura Qalat villages), mainly consist of interlaying massive carbonate rocks of the Aqra Formation with flysch rocks of Tanjero Formations. Therefore, selecting appropriate dam types is challenging and very risky. This study conducted a detailed survey of lithology, discontinuity condition, rock sampling and laboratory tests to determine the site suitable for dam construction using the quantitative GSI, Rock Mass Rating (RMR), and Dam Mass Rating (DMR) geomechanical classification systems for twenty units. A new procedure was suggested for quantifying stress relaxation and damage level (disturbance factor D) in rock masses. Calculating rock mass units' disturbance factor based on the joint spacing, strength index (Is50), and excavabilty methods are very proper to add as a new feature for RocLab software for evaluating foundation rock masses. The rock mass strength is calculated based on the RocLab software program. The maximum deformation modulus of rock mass (Em) is 33797 MPa for carbonate rock mass unit and 1348 MPa for flysch rock. The excavation in hard massive carbonate rocks required blasting led to disturbance and stress relaxing in the rock mass by 0.4. In contrast, excavation in flysch rocks required easy ripping, which led to disturbance and stress relaxing in the rock mass by 0.2. The geological strength index value results for rock masses units at the dam site reveal that the carbonate rocks are nearly between 74–76, but flysch rock is between 35–55.

Keywords: Disturbance factor · GSI · Volumetric joint counting · RocLab software

1 Introduction

Over the past few decades, climate change and population in semi-arid regions, especially in the middle east, have caused water shortages and increased the number of constructed dams [1]. Recently the Kurdistan regional government decided to build forty dams in

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the North of Iraq. The dam site selection of forty dams is not easy, and it needs a detailed study of geology, hydrology, metrological, satellite image and accurate geomechanical classification of a rock formation [2–5]. Additionally, the geomechanical classification of some sites in heterogeneous rocks is problematic because it comprises two or more lithologies with different mechanical properties [6–9]. Like this study, the dam's construction on heterogeneous rocks is rugged because it combines weak and strong rock layers [8, 10]. Calculation of mechanical properties for weak and hard rock layer need expertise, accuracy, and good fieldwork to select an appropriate value for uniaxial compressive strength (UCS), material constant(mi), and GSI [8, 11–13]. The study of rock masses for dam construction in north Iraq is minimal because of domestic problems and economic crises, so it mainly focused on assessing slope stability [14, 15]. The purpose of this study is to evaluate, strength analysis, and classify rock masses in Goma-Qazan proposed site for dam construction according to different geomechanical classification systems, including (RMR, GSI, and DMR). In addition, a new procedure was suggested to calculate the stress relaxation and damage level(disturbance factor) in rock masses. Finally, suggest convenient gravity dam types for the proposed site.

2 Location

The KRB is a part of the lesser Zab transboundary watershed within the Zagros Mountain Range. The basin outlet is 30 km away from the northeast of Sulaymaniyah city, with a catchment area of 1541 km^2 and an extension of about 71 km in length. The Mediterranean climate's hot summers and wet winters have an annual rainfall of more than 800 mm and an average temperature of 20 °C per year [16, 17]. The Stratigraphy of the area is composed of clastic rock, carbonate rocks near Chwarta [18] and igneous rocks in the Mawat-Penjween area [19, 20].

3 Geology and Tectonic Setting

The fieldwork reveals that the beds have an upstream direction with an average altitude of 070/39° (dip direction/dip angle). Also, it includes all units encountered at the dam site, which shows rock inter-tonguing between two different sedimentary rocks. The dam will be built on two sedimentary rock units of the Cretaceous age. The first unit is Rudist-rich limestone of the Aqra Formation belonging to the Cretaceous age. The second unit is a heterogeneous rock composed of three primary lithologies: detrital limestone, Silty sandstone, and Sandy siltstone of the Tanjero Formation belonging to the Cretaceous age [21].

The KRB is located within the main Zagros suture zone and imbricated zone (of the convergence of the Arabian plate with continental Eurasia [22–24]. It constitutes a seismically active, northwest–southeast-trending segment of the Alpine–Himalayan collisional belt [25].

4 Rock Mass Classification

The rock mass was evaluated at the proposed dam site based on four approaches: a geomechanical, hydrological, structural perspective, and reservoir filling by soil erosion. The geomechanical evaluation is the most critical part of this article, including a discontinuity survey, Drone survey, laboratory test (point load test) (Table 1), and applying different geomechanical classification systems (Table 2).

Table 1. The results of point load tests and average joint spacing

Lithology	IS_{50}	Average spacing(m)	Lithology	IS_{50}	Average spacing(m)
fossiliferous limestone	3.70	1.28	Sandstone	1.4	0.11
fossiliferous limestone	3.70	1.24	Silty sandstone	0.89	0.09
fossiliferous limestone	2.92	0.63	Sandy siltstone	1.40	0.15
fossiliferous limestone	4.45	1.17	Silty Sandstone	2.63	0.09
fossiliferous limestone	2.96	0.64	Silty Sandstone	1.20	0.09
fossiliferous limestone	2.17	0.80	Silty Sandstone	2.11	0.15
fossiliferous limestone	1.85	0.69	Silty Sandstone	1.42	0.10
fossiliferous limestone	3.57	0.86	Silty Sandstone	1.23	0.11
fossiliferous limestone	3.00	0.64	Sandy siltstone	0.91	0.09
fossiliferous limestone	2.20	1.07	Sandy siltstone	1.63	0.15

Table 2. Geomechinal classifications applied to the rock masses in the study area

No.	Rock mass classification system	Author
1	Quantified Geological Strength Index (GSI)	Hamasur (2009)
2	Geological Strength Index for heterogeneous rock	Marinos (2017)
3	Volumetric joint counting (JV)	Palmstron (2005)

Table 3. Summary of volumetric joint counting (Jv), rock quality designation, and average spacing for massive rock limestone

Geological units	*Rock mass unit	Jv ($1/m^3$)	Average Spacing (mm)	RQD	Block volume Vb (m^3)
Aqra Formation	1	2.35	1283	100	2.16
	3	2.42	1240	100	3.41
	5	4.77	629	98	0.25
	7	2.57	1165	100	1.8
	8	4.71	637	98	0.26
	10	3.75	800	100	0.58
	12	4.33	692	99	0.36
	14	3.48	861	100	0.7
	16	4.72	635	98	0.37
	18	2.80	1071	100	1.31
	20	4.68	641	98	0.28

*Note: Rock mass units 2, 4, 6, 9, 11, 13, 15, 17, and 19 are heterogeneous clastic; the mentioned characteristic cannot be calculated for them

4.1 Discontinuity Survey

First, the detailed discontinuity survey, accurate field observation and drone land survey, including a description of discontinuities (bedding, joint, fault etc.), orientation, spacing persistence, filling aperture, and groundwater condition, were done at the dam site to determine block volume and the mechanical properties of rock. One hundred twenty discontinuity measurements were taken from the left and right sides of hard carbonate and heterogeneous clastic rock units. However, the weathered surface in some heterogeneous rock cause restriction or difficult measurements of discontinuity attitude on such lithology. Secondly, the discontinuity measurements are processed and analyzed with a computer software based on equal-area stereographic projection, called DIPS V7.00. Finally, the volumetric joint count (JV) was calculated based on the discontinuity spacing of various sets and estimating the rock quality designation using the [26] and using the method for estimation of the average spacing of all discontinuity [27] as (Table 3).

4.2 Geomechinal Classification of Rock Mass

Based on the lithologic change, the rock description was done systematically along the left and right sides. The rock mass and discontinuity characterizations were based on RMR_{78} and RMR_{89} [28, 29]. The geological strength index values for carbonate units were determined based on Hamasur's (2009) GSI chart (Fig. 1); for flysch units, Marinos (2017) chart was used (Fig. 2). The dam foundation stability and deformability were evaluated based on Dam mass rating (DMR) system which includes (DMR_{STA}) DMR foundation stability and ($DMR_{DEF)}$ DMR Modulus of deformability foundation invented by Romana in (2004 and 2003).

4.2.1 Geological Strength Index (GSI)

Hoek first invented the geological strength index in (1994), then updated by [30–32]. The GIS system is based on visual interpretation of the rock structure (blockiness) of the rock mass from discontinuity sets relation and surface condition of the joint. This classification was later updated and modified to become a quantitative chart instead of a visual plotting [4, 6, 33–36].

This study prefers the quantitative GSI chart classification invented by Hamasur (2009) for the carbonate unis because it is the most updated GSI chart related to rock mass classification in Iraq. The heterogeneous units were classified based on the most updated chart invented by Marinos (2017).

5 Results and Discussion

5.1 Rock Mass Strength

Based on the GSI values for carbonate units range from 74–76 (Fig. 1), while the heterogeneous rock units range from 35–55 (Fig. 2) of the rock mass units, a clear contrast in the analysis of rock strength parameters between carbonate and flysch rocks at the site was found using RocLab software programming and the rock strength parameters were found for all units (Table 4). These results will affect the suitability and stability of the foundation for dam construction.

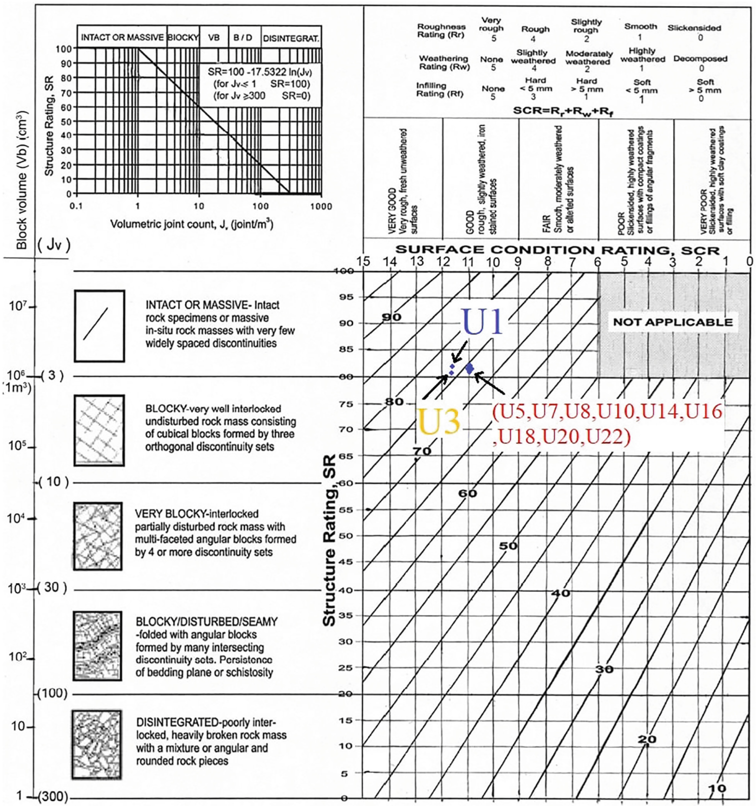
5.2 Excavation and Disturbance Factor

Calculating rock excavatability controls the rock mass's strength properties after excavation. Pettifer and Fookes's (1994) chart was applied to determine the excavation method. These methods are constructive for assessing the value of disturbance factor (D), which is used to estimate blasting damage level and stress relaxation during excavation at a dam site. It has an impact on the composition of rock mass deformation modulus(E_m) [37, 38] as in the following equation:

$$E_m(\text{GPa}) = (1 - D/2) \times (\sigma_c/100)^{1/2} \times 10^{(\text{GSI}-10)/40} \; [37, 38] \quad (1)$$

The new factor D "allows for the effects of blast damage and stress relaxation". The D factor can be estimated according to guidelines for tunnels, slopes, and pit quarries but not clarified for dam foundations, which is limited to the application in GSI classification and its program(RocLab program) for dam foundations. Excavations at dam foundations must be done carefully, D should be very low, but it cannot be zero because of decompression. Tentative guidelines for determining D value were invented in 2003 by Romana (Table 5), but these guidelines contain some ambiguities about types of rock, such as the term "good rock….etc.".

This study uses Pettifer and Fookes's (1994) classification (Fig. 3) to determine the disturbance factor for rock mass based on the excavation method for rock types at the dam foundation. It overcomes previous ambiguities in the tentative guideline of Romana (2003), RocLab software, and rock mass deformation modulus equation Hoek



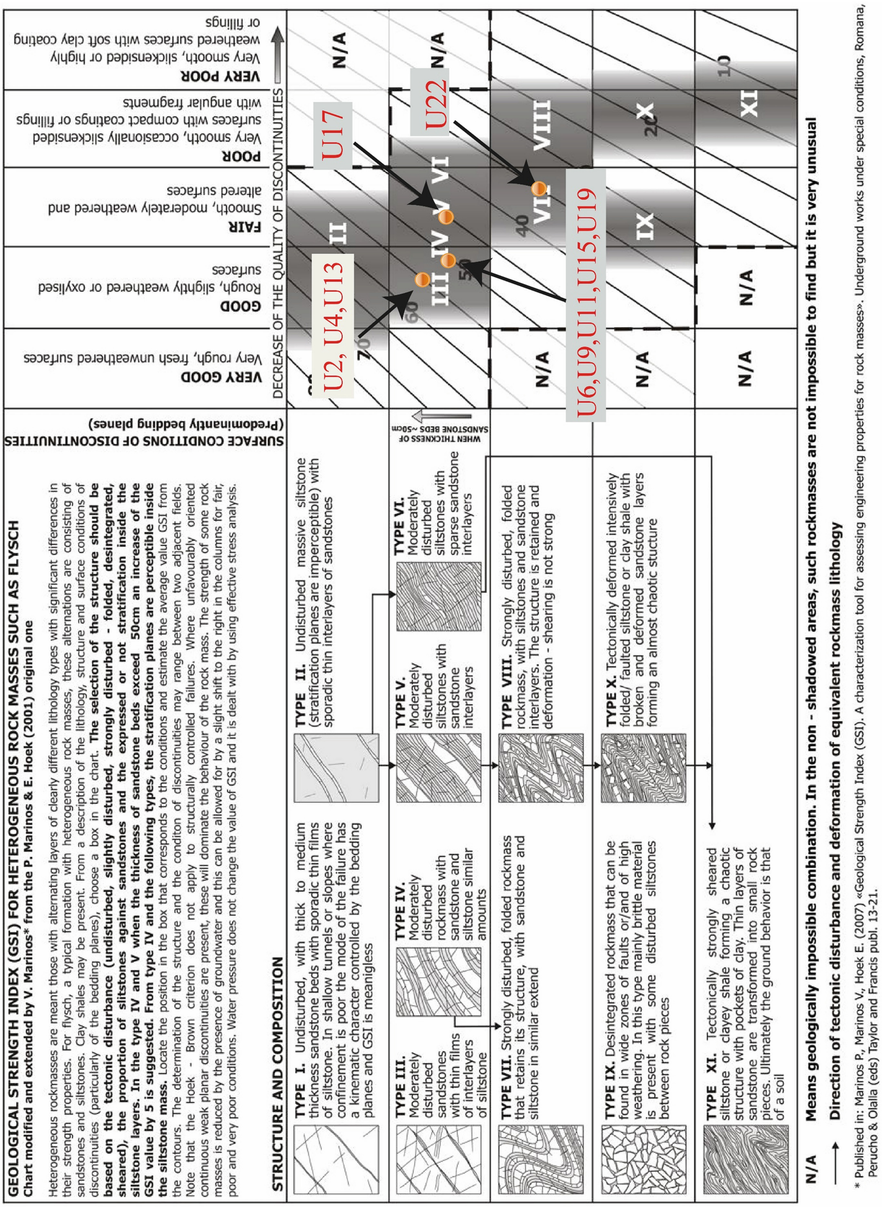
*U1, U2…. "etc." (rock units)

Fig. 1. Geological strength index for carbonate rock mass is determined from a quantitative GSI chart from Hamasur (2009)

et al. (2002) for determining the D value. These methods represent the 3D dimensional relation between discontinuity spacing and point load strength index Is_{50}, providing a more realistic assessment to determine the D value for the foundation.

The plotted results show that extra hard ripping to blasting is required for excavation in massive carbonate rocks. In contrast, easy ripping excavation is necessary to excavate in flysch heterogeneous rock. The excavation will be led to the di-stabilization rock slope and dam foundation.

Based on fieldwork, ambiguity in previous research in assigning a D value for rocks at the dam foundation, and also in the RocLab program that formatted based on Hoek and Brown (Eq. 1) that only assigned a D value for Slope and tunnel, a new value for the disturbance factor Table 6 was suggested. This chart is based on the combination of the excavation method at foundation types by Pettifer and Fookes chart (1994) and Disturbances factor values in (Table 5) which was proposed by Romana (2004).



*U2, U4…. "etc." is (rock units)

Fig. 2. Geological strength index values for flysch rock mass units determined from GSI-Chart Marianos (2017)

For this study, the 0.4 D factor is applied in the RocLab software for the massive limestone of the Aqra Formation, and 0.2 is used for poor rock mass or flysch rock of the

Table 4. Analysis of rock mass strength for rock mass units using the RocLab program

Geologic unit	Unit no.	Cohesion (MPa)	Friction Angle (degree)	Tensile Strength (MPa)	Uniaxial compressive strength (MPa)	Global strength (MPa)	Deformation modulus (MPa)E_m
Aqra Formation	1	6.04	36.21	−1.1	17.51	23.84	33797
	3	5.81	35.72	−0.97	15.97	22.67	32513
	5	4.8	36.03	−0.85	13.64	18.85	26848
	7	6.71	35.69	−1.12	18.39	26.17	37565
	8	4.7	35.69	−0.78	12.9	18.37	26363
	10	3.45	35.69	−0.56	9.34	13.42	19295
	12	2.72	35.51	−0.45	7.51	10.86	15638
	14	5.55	35.58	−0.91	15.05	21.62	31081
	16	4.67	35.51	−0.75	12.55	18.14	26108
	18	3.54	35.69	−0.59	9.6	13.8	19807
	20	3.26	35.5	−0.53	8.7	12.67	18246
Tanjero Formation	2	1.77	35.06	−0.05	2.02	6.84	2592
	4	1.87	35.6	−0.052	2.13	7.2	2730
	6	1.51	31.42	−0.073	1.95	5.4	2718
	9	0.92	31.42	−0.45	1.19	3.3	1664
	11	1.69	31.42	−0.08	2.18	6.03	3038
	13	1.87	35.06	−0.053	2.13	7.22	2739
	15	1.11	31.42	−0.05	1.43	3.98	2003
	17	0.58	27.5	−0.017	0.49	1.92	1348
	19	1.27	31.42	−0.06	1.64	4.55	2294

Table 5. Rock disturbance calculation based on excavation types [39]

Rock mass description [39]	Excavabilty types	Suggested value of Disturbance factor D
Good rock mass	Normal blasting	D = 0.4
Any rock mass	Controlled blasting	D = 0.2
Poor rock mass	Mechanical excavation	D = 0.2

Tanjero Formation based on (Table 6), which was invented as a new table for quantifying the Disturbance factor.

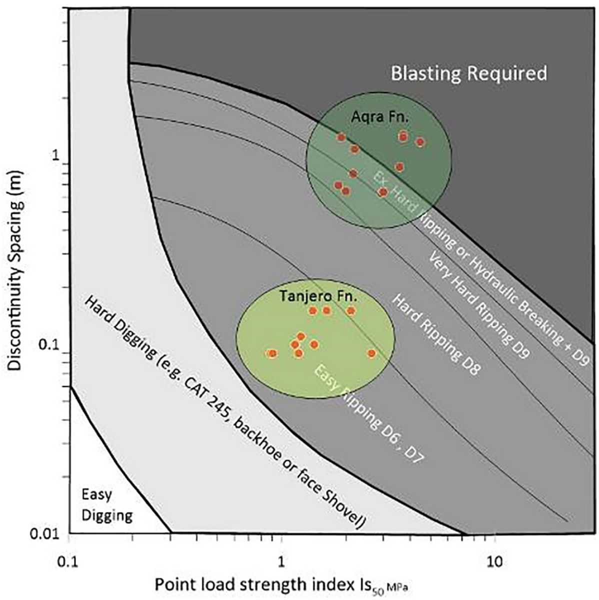


Fig. 3. Assessment of excavatability chart from Pettifer and Fookes (1994) includes rock units of this study

Table 6. Rock disturbance calculation for Dam foundation based on excavation types.

Excavation Method at the Foundation	Suggested value of D isturbance factor (D)
Easy Digging	0.0
Hard digging, Cat 245, Backhoe, or face shovel	0.1
Easy Digging- Hard ripping	0.2
Vary Hard Ripping-Extremely Hard ripping or Hydraulic brake	0.3
Blasting Required	0.4

6 Conclusion

An accurate rock mass evaluation was applied for the proposed dam site within the Kanarwe River Basin based on geological strength index geomechanical classification. A new procedure was suggested for calculating rock mass units' disturbance factor (D) based on the joint spacing, strength index (Is_{50}), and excavation method. The new quantification of the D factor in the RocLab program for dam foundation is crucial and led to a better estimation of rock strength parameters. The excavation in hard massive carbonate rocks required blasting led to disturbance and stress relaxing in the rock mass by 0.4. In contrast, excavation in flysch rocks required easy ripping, which led to disturbance and stress relaxing in the rock mass by 0.2. The results of the GSI value for rock masses in twenty-two units at the dam site reveal that the value of the carbonate rocks is nearly between 74–76, while flysch rock gives a lower value, 35–55.

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