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Assessment of Foundation Rocks of The Proposed Al-Baghdadi Dam Site in Al-Anbar Governorate, Western Iraq

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ABSTRACT

The current study aims to evaluate the foundation rocks of the proposed Al-Baghdadi dam site, which is located in Al-Anbar Governorate, Al-Baghdadi area. The study includes field, laboratory and office works for six stations along the dam axis in western Iraqi province of Al-Anbar Governorate. Six stations are selected in the study area along the axis of the dam. Rock Mass Rating (RMR), Dam Mass Rating. (DMR), and Geological Strength Index (GSI) are the three rock mass classification systems that have been chosen to use in assessment. The range of dam's stability-related DMR values is (60.201 - 67.009). The numbers show that the foundation rocks at the planned dam site are stable. The values of RMRBD89 fall between (60.3 - 67.1). In addition, to being desirable (moderate to good), the foundation rocks could be excavated for fill dams and rock dams. The Geological Strength Index (GSI) values varied from (44.5 to 60.5) and these values are considered moderate according to this classification. The mechanical characteristics of every rock unit from during Hook-Brown failure criterion are ascertained using RocLab program and their values ranged: Cohesion strength (0.795 - 1.303) MPa, Angle of internal friction (24.09 - 29.76), Tensile strength (-0.106 - -0.025) MPa, Compressive strength (0.613 - 2.033) MPa, Global force (2.484 - 3.198) MPa, and deformation coefficient (2451.45 - 7516.72) MPa. From the results mentioned above, it is found that the proposed dam location is safe and stable for constructing the fill dam.

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تقييم صخور الأساس لموقع سد البغدادي المقترح في محافظة الأنبار، غربي العراق

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الملخص

تهدف الدراسة الحالية إلى تقييم صخور الأساس لموقع سد البغدادي المقترح الواقع في محافظة الأنبار، منطقة البغدادي. شملت الدراسة الأعمال الميدانية والمختبرية والمكتبية لست محطات على طول محور السد في محافظة الأنبار غربي العراق، وكان الغرض من البحث المقدم هو تقييم صخور الأساس المتعلقة بمشروع سد البغدادي. وكانت مواقع الدراسة عبارة عن ست محطات على طول محور السد. تصنيف كتلة الصخور (RMR)، وتصنيف كتلة السد (DMR)، ومؤشر القوة الجيولوجية (GSI) هي أنظمة تصنيف الكتلة الصخرية الثلاثة التي تم اختيارها (استخدامها) في التقييم. يتراوح مدى قيم RMR المتعلقة باستقرار السد (60.201 الى 67.009). الأرقام تظهر أن صخور الاساس في موقع السد المخطط مستقرة. وتقع قيم RMRBD89 بين (60.3 و67.1). بالإضافة إلى كونها مرغوبة (متوسطة إلى جيدة)، يمكن حفر صخور الأساس لملء السدود والسدود الصخرية. تراوحت قيم مؤشر القوة الجيولوجية (GSI) من 44.5 إلى 60.5. تم التحقق من الخصائص الميكانيكية لكل وحدة صخرية من خلال معيار فشل Hook-Brown باستخدام برنامج RocLab وتراوحت قيمها: قوة التماسك (0.795 - 1.303) MPa، زاوية الاحتكاك الداخلي (24.09 - 29.76)، قوة الشد (-0.106 الى -0.025) ميكا باسكال، قوة الضغط (0.613 الى 2.033) ميجا باسكال، القوة العالمية (2.484 الى 3.198) ميكا باسكال، ومعامل التشوه (2451.45 الى 7516.72) ميكا باسكال. من النتائج المذكورة أعلاه تبين ان موقع السد المقترح بدرجة امان واستقرار لانشاء السد الاملائي.

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Introduction

Given the period that our country is going through a water crisis due to drought resulting from climate change and the lack of water imports, whether as a result of the lack of rainfall or due to water policy with neighboring countries, dams are therefore one of the solutions to exploit the quantities of water that can be obtained during the seasons in which this occurs. Built on rivers that run perpetually or in seasonal valleys, flood waves and dams serve a variety of functions, such as providing water for agriculture, controlling floods, power generation, industrial uses, and recreation, while also protecting the environment (Al-Jawadi et al., 2020). Additionally, dams need to be sufficiently safe from sliding, hold water, and be able to adjust to changes in the terrain without developing foundational or body cracks (Romana, 2003b).

They are put in place alongside large rivers to keep the adjacent low-lying populated areas safe from the threat of floods. We refer to them as protection dams. The main source of water in Iraq is the rivers, as the annual revenues, according to information sources, are 29 billion m3 for the Euphrates River, with a discharge of 920 m3/s (Kiwan, 1996).

A rock mass is a collection of rocky materials separated from each other by joints, often by bedding planes, faults, etc. Faults and stratification levels are handled individually and are less frequent than joints (Bieniawski, 1993).

Van Schalkwyk (1982), Di Salvo (1982), and Serafim (1988) have all emphasized the importance of using Rock Mass Rating (RMR) Rock Mass Rating for classifying rock mass foundations. They have stated that accurate rock mass classifications are essential for estimating shear and deformation resistance information. When comparing potential dam sites, dam engineers must consider various factors, including the site's suitability for the type of dam, the extent of foundation treatment required (such as grouting), and the challenges of excavation in different types of rock. Since conditions vary depending on the type of dam, there is no one-size-fits-all solution or set of rules. To calculate deformations, stresses, and strains in dams, it is crucial to assess the deformability of the rock mass. Additionally, past research on dams utilizing Dam Mass Rating and Rock Mass Rating has been evaluated, including the dam sites Basara near Delaizha village – Sulaimani district – Kurdistan (Hamasur, 2009).

Foundation conditions are dependent on geological character and strata thickness, which. are to carry dam weight, their permeability, inclination, and relation to the underlying strata, existing fissures and faults, this case study is focused focuses on assessing of foundation dam site.

Aims of study

The main objective of the research is to evaluate the foundation rocks of the proposed Al-Baghdadi Dam through the followings:

1- An assessment of rock masses at the suggested site of Al-Baghdadi Dam using different classification schemes including Rock Mass Rating (RMR), Dam Mass Rating (DMR), and Geological Strength Index (GSI).

2- Mechanical characteristics of rock masses {modulus of deformation, tensile strength, compressive strength, shear strength parameters, such as cohesion (c), and the angle of friction (Ø)} are after that estimated by RocLab program using the aforementioned Geological Strength Index (GSI) system in conjunction with the Hoek-Brown failure criteria.

Location of the study

Al-Baghdadi Dam project area is located on the Euphrates River in western Iraq, bordered by coordinates longitude (33^{o} 53’ to 33^{o} 59’) to the east and (42^{o}33’ to 42^{o}34’) latitude to the north, and at a height of 82 meters above sea level within the administrative borders of Al-Anbar Governorate in Hit District, Al-Baghdadi area. It is approximately 48 km away from Haditha Dam towards downstream, and 220 km west of the capital Baghdad. Figure (1) exhibits the location map of the study area

Materials and Methods

The phases include preliminary preparation, field, laboratory and office phases. A series of reconnaissance tours were carried out to familiarize the study area. Exposed strata were identified, the hydrology, composition, geomorphology and coordinates of the site are recorded using positioning devices (GPS), and a field geological survey is carried out on the suitability of the rocks as a foundation. For facilities such as dams, conducting a field engineering geological survey that includes describing the position of layers and fractures, the distance between discontinuities, weathering, layer thickness, resistance, etc., and modeling for the purpose of conducting laboratory tests related to the dam’s requirements.

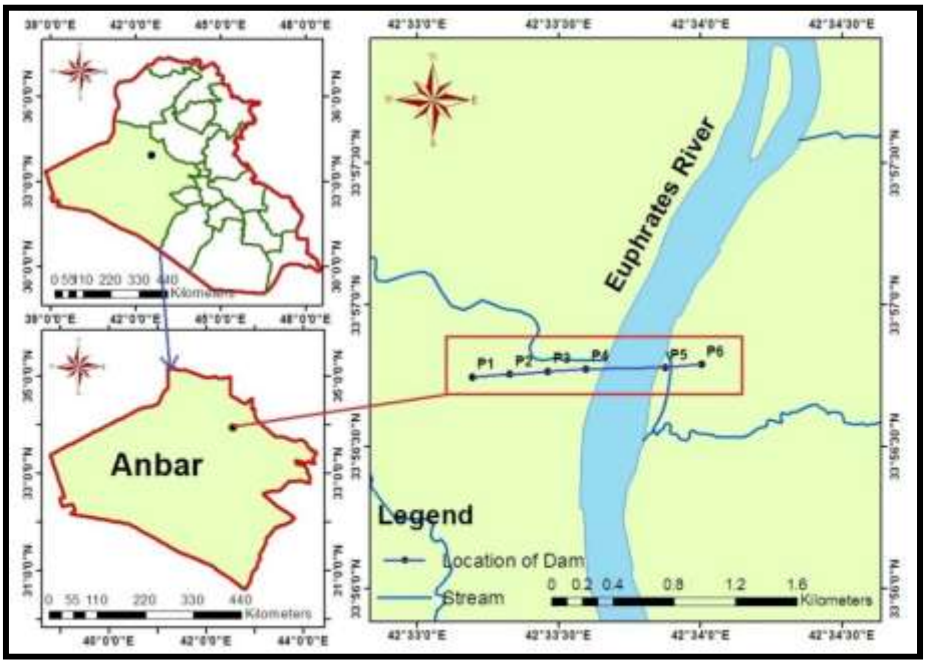

Fig. 1. Location map of the study area (Arc GIS)

Geology of the Study Area

When conducting a geological study on the area, it is highly important to shed light on its conditions and the factors affecting it geologically; that is, studying the successions and stratigraphy of the area, and the structural and tectonic conditions and factors affecting the rock layers and geological formations as well as determining the prevailing geomorphological situation in the area, which is the reflection and result of the interactions between internal factors represented by tectonic processes and rock quality, and external factors represented by the prevailing climate influences (Al-Badrani, 2005).

One of the key factors that distinctly affects the land while building reservoirs and dams is the geological condition of the area of study that comprises geomorphology, stratigraphy, hydrology, composition, and hydrogeology of study area. Since the dam area is situated on carbonate rocks like the Anah Formation and Euphrates Formation. Figure (2) shows the geological map of the study area, which could result in serious issues with dissolution or the formation of karstification and cavities, the stratigraphic and rocky location determines whether there will be engineering problems in future or not.

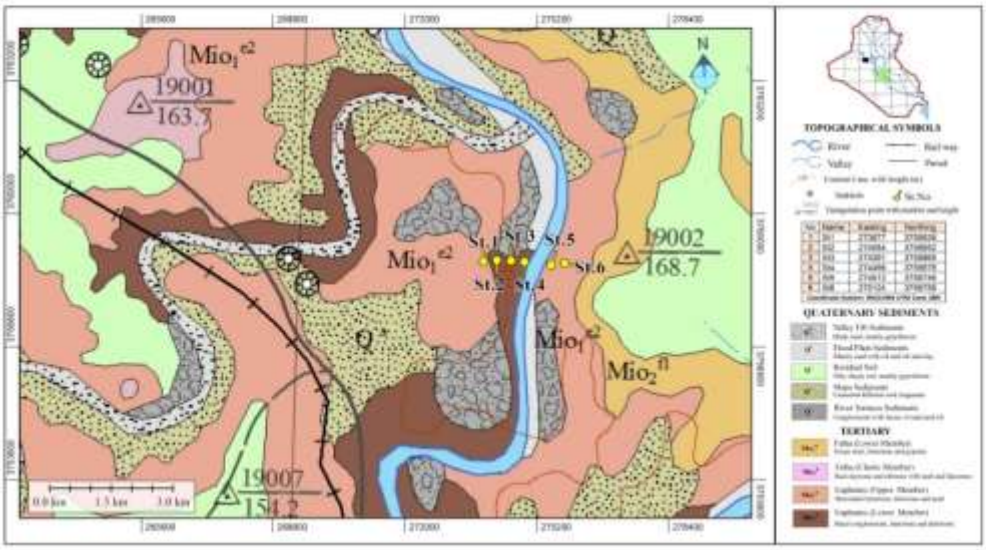

Fig. 2. Geological map of the study area (Sissakianand and Fouad, 2015).

Tectonism of the study area

The study area is located within the stable- shelf of the tectonic map of Iraq (Fig. 3). The area was affected by the second phase of the orogeny that began in the Miocene and reached its peak in the Pliocene, thus forming the Taurus and Zagros Mountains. The study area is far from the center of tectonic activity, so no folding of the rock layers occurred, but it contains tensile fractures, which requires weak forces compared to layer folding and shear fractures.

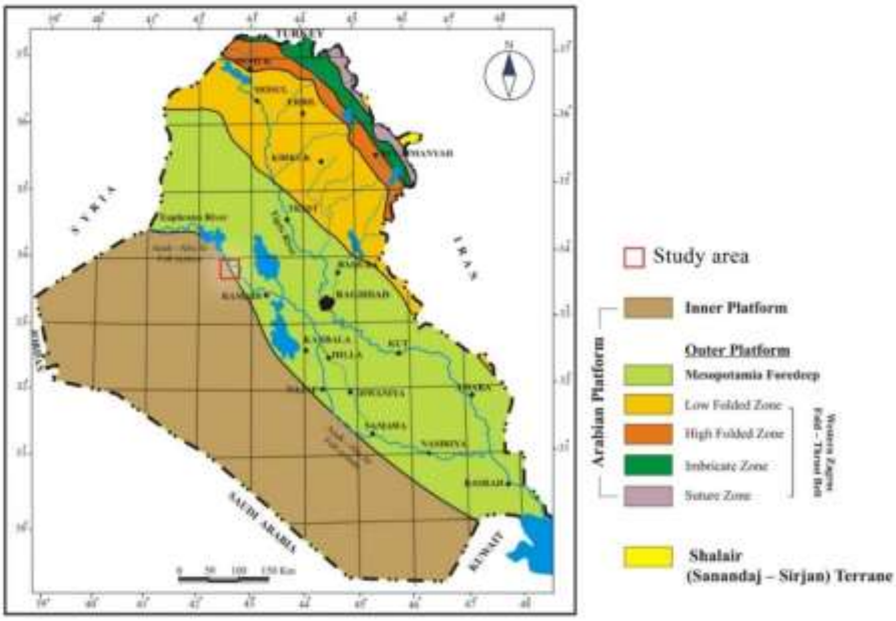

Fig. 3. Tectonic map of Iraq showing the study area (Fouad, 2015).

Rock Mass Rating (RMR)

Rock engineering has made extensive use of geometric classifications regarding rock masses, which aim to consider the most significant geological factors influencing the rock mass as well as its values of quality (Tzamos and Sofianos, 2006; Singh and Goel, 2011). These classifications have served as the foundation for the experimental design method. Many factors are included in this RMR classification:

$$RMR = R_1 + R_2 + R_3 + R_4 + R_5 + R_6 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where: R_1 to R_6 are as explained below.

1- Unconfined Compressive Strength (UCS) (R_1)

When determining the ratings for intact rock strength, UCS is a crucial factor. Numerous physical characteristics including sample size, sample preparation, and mineral composition have an impact on uniaxial compressive strength value related to rock materials. The strength regarding soft rock materials could be significantly decreased by such conditions through the use of unconfined compression test or a point load test (Bell, 1998). The results showed the compressive strength values as shown in the tables (5 and 6).

2- Rock Quality Designation (RQD) (R_2)

According to Pantaweesak et al. (2019), the percentage of core that is longer than 10 cm to the total length that are longer than 10 cm is known as Rock Quality Designation (RQD) calculated as shown by the equation:

$$RQD = \frac{\textbf{sum of core pieces} \geq \textbf{10 cm}}{\textbf{total drill run}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Palmestrom (1982) suggested estimating RQD by multiplying the number of discontinuities in a unit volume by the number of discontinuities exposed per meter with a length of discontinuities more than 10 cm in the event that the core is not available. The RQD value is computed in this way:

$$RQD = 110 - 2.5\, Jv \quad \text{.......} \quad (3)$$

where: *Jv* represents volumetric joint count or total number of the joints in a cubic meter. Palmestrom (2005) had made a new proposal for the equation. He took these random intervals into consideration to calculate the values of (*Jv*) through the following equation:

$$Jv = 1/S1 + 1/S2 + 1/S3 ..... + 1/Sn + Nr/5 \quad \text{.......} \quad (4)$$

where: Nr = random joints; S1, S2, and S3 are the average spacing in meters for the joint sets.

The results showed the RQD values as shown in the tables (5 and 6).

3- Discontinuity Spacing (R_3)

The status of discontinuities is determined by five factors: filling materials, weathering factors, aperture, persistence, and roughness. The quality of discontinuities is determined by a quantitative description regarding such five variables (Maazallahi and Majdi, 2021).

4- Condition of Discontinuities (R_4)

The status of discontinuities is determined by five factors: filling materials, weathering factors, aperture, persistence, and roughness. The quality of discontinuities is determined by a quantitative description regarding such five variables (Maazallahi and Majdi, 2021).

5- Groundwater Condition (R_5)

It considers that there may be water found along discontinuities. A rock mass's general humidity levels could be described as totally wet, dry, damp, flowing, or dripping. Developing a directional groundwater classification frequently requires identifying flow mechanism as well as governing elements within a rock mass. Cohesive minerals and fine pores make up intact rock mass. Intact rock's permeability is minimal because the pores are typically not interconnected. Permeability of intact rock mass and rock mass differs significantly depending on discontinuities (Maazallahi and Majdi, 2021).

6- Orientation of Discontinuities (R_6)

Discontinuities orientation is the last parameter to be taken into account for special engineering purposes for specific applications in tunneling, mining and foundations, while if the direction of the discontinuities is very suitable for the work under study, no points will be subtracted from the total. However, if they are inappropriate, the negative ratings in the tables (5 and 6) below will be applied. Classification increments for tunnels range from 0 to 12 and for foundations from 0 to 25.

Dam Mass Rating (DMR)

(Romana, 2003a and b) a new Geomechanics classification system, known as Dam Mass Rating, as an adaptation of Rock Mass Rating, giving guidelines for several practical aspects of dam engineering and the appraisal of dam foundation.

The DMR of the rock mass was computed as per Romana (2003b), where a relationship has been suggested:

$$DMR_{STA} = RMR_{BD\,(1989)} + CF \times R_{STA} \quad \text{.......} \quad (5)$$

Where:

DMR_{STA} = Dam Mass Rating related to the dam foundation stability

RMR_{BD} = Basic Dry RMR

CF = Geometric Correction Factor

R_{STA} = Rating of the adjusting factor for dam stability.

When the dip direction of the significant joint is not almost parallel to the downstream-upstream direction of the dam axis, the danger of sliding diminishes due to the geometrical difficulties to slide. It is possible to take account of this effect by multiplying the rating of the adjusting factor for dam stability R_{STA}, by a geometric correction factor CF:
CF is calculated as:

$$CF = (1- \sin |\alpha d - \alpha j|)^2 \quad \text{……………………………………………………} (6)$$

Where: αd = upstream-downstream direction of the dam axis

αj = dip direction of the significant discontinuity (here it is the bedding planes).

Once, the DMR_{STA} is computed, a correlation between the value of DMR_{STA} and the degree of safety of the dam against sliding is suggested as a rule of thumb as in Table 1.

Table 1: Correlations between DMR_{STA} and Safety Degrees (Romanna, 2003)

DMR STA.	Less than 30.	30 – 60.	Higher than 60.
Safety Degree.	Serious Concern.	Concern.	No Primary Concern.

Data regarding Rock Mass Rating (RMR) value of dam foundations should be gathered. As shown in Table (2), a few basic recommendations could be made in the interim for excavation of dam foundations and consolidation grouting (Romanna, 2003-a).

Table 2: Tentative guide-lines for the dam foundation excavation and consolidation grouting (Romanna, 2003-a)

Dam Type	Excavate to $RMR_{BD\,(+)}$	Consolidation Grouting Based on RMR_{BD}		
		Systematic	Spot	None
Earth	-	-	?	-
Rock fill	>20 (<30)	20-30	30-50	**> 50**
Arch	>50 (<70)	50-60	60-70	**> 70**
Gravity	**>40 (<60)**	**40-50**	**50-60**	**> 60**

(+) minimum (desirable)

When E_m fluctuates greatly throughout the foundation of the dam, or when E_c/E_m approaches specific levels (E_c being concrete's modulus of deformation), there are two scenarios that pose a risk to a concrete dam's normal nehavior. As shown in Table (3), Rocha (1976 and 1975 In Romanna, 2003a and Romanna ,2004) established the most frequently used guideline for the dams.

Table 3: Effects of Ec/ E_m on the behavior of the gravity dam (Modified from Rocha, 1976 and1975 In Romanna, 2003-a)

E_c/E_m	Impact on dam	Problem
Less than 1	Negligible	0
1-4	Negligible	0
4-8	Low important	0
8-16	Important	Some
Higher than 16	Very important	Moderate – Big

Because of deformability variations between dam and dam’s foundation, Table (4) shows different DMR_{DEF} ranges about different varieties of the potential difficulties in the dam.

Table 4: issues related to deformability in the concrete dams based on DMR_{DEF} that had been Romanna, (2004) (Roman, (2003-a)

DAM E_C (GPa)	Height (m)	Normal	Problems	Serious Problems
Arch 36 GPa	< 100	>50	40-50	<40
	100-150	> 65	50-65	<50
	150-200	>75	60-75	<60
Hard fill	< 50	>30	15-30	<15
10 GPa	50-100	>40	30-40	<30
Gravity	< 50	> 40	25-40	<25
CVC	50-100	> 50	40-50	<40
30 GPa	100-150	>60	50-60	<50
Gravity	< 50	>35	20-35	<20
RCC	50-100	>45	35-45	<35
20GPa	> 100	>55	45-55	<45

Geological Strength Index (GSI)

Evert Hoek invented the GSI Geological Strength Index system in 1994, and it has been used to determine the rock mass deformation coefficient and rock mass strength (Hoek, 2007). It is developed in the field of rock mechanical engineering in response to the need for reliable input data, particularly with regard to the properties of the rock mass required as input for numerical analyses or closed-form solutions for the building of tunnels, slopes, or rock foundations. The geological properties of the rock material and a visual assessment of the mass that forms it are directly used to pick criteria that are important for forecasting deformability and rock mass strength. By this approach, the influence of geology on the mechanical characteristics of the rock mass is maintained, but it may still be seen as a mechanical continuum. It provides a field method for characterizing the challenging-to-describe rock masses (Table 5).

The Geological Strength Index (GSI) value could after that be estimated with the use of the final rating, which is known as the RMR_{76} (Hoek et al., 2000) in the equation (7) below

$$GSI = RMR_{76} \text{ (for } RMR_{76} > 18) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \ (7)$$

For the value of RMR_{76} less than 18 can’t be utilized for estimating the Geological Strength Index (GSI).

23 is the minimal RMR_{89} classification value. The following method could be utilized for estimating the value of *GSI* using the predicted *RMR*:

$$GSI = RMR_{89} - 5 \ldots\ldots\ldots\ldots.. \ (8)$$

RocLab program:

One of the major obstacles encountered in the field of numerical modeling of rock mechanics is the problem of data input for rock mass properties. Therefore, this software "RocLab" provides a simple and intuitive implementation of the Hoek-Brown failure criterion allowing users to easily obtain reliable estimates of rock mass properties, and to visualize the effects of changing rock mass parameters on failure envelopes. “RocLab” can be downloaded (free) from www.rocscience.com. (Hoek et al., 2007).

Results

The properties of the six unique rock mass units that comprise Al-Baghdadi Dam axis are shown in Table (6). These units are observed in the field. Calculations are made for Dam Mass Rating (DMR), Rock Mass Rating (RMR), and Geological Strength Index (GSI) for each of the six rock mass units. As can be seen in Table (7). Based Rock Mass Rating (RMR_{BD}) is computed under the assumption that the rock mass is completely dry. Equation (6) is used to calculate the coefficient of friction (CF). It considered the direction of the major discontinuities; in this case, the bedding planes an attitude of 060°/3°, and the downstream direction of the dam axis is equivalent to 178°. The results of Geological Strength Index (GSI) estimations for limestone rock masses using the Hamasur (2009) chart are shown in Table (7). RocLab software is used to estimate the mechanical properties of the rock mass (friction angle, cohesion, compressive strength, tensile strength, modulus of deformation, and global strength) as seen in Figure (4) for unit no. 1 in the example. These six factors are compiled in Table (7). All rock mass units within the study region have been subjected to the implementation of the program.

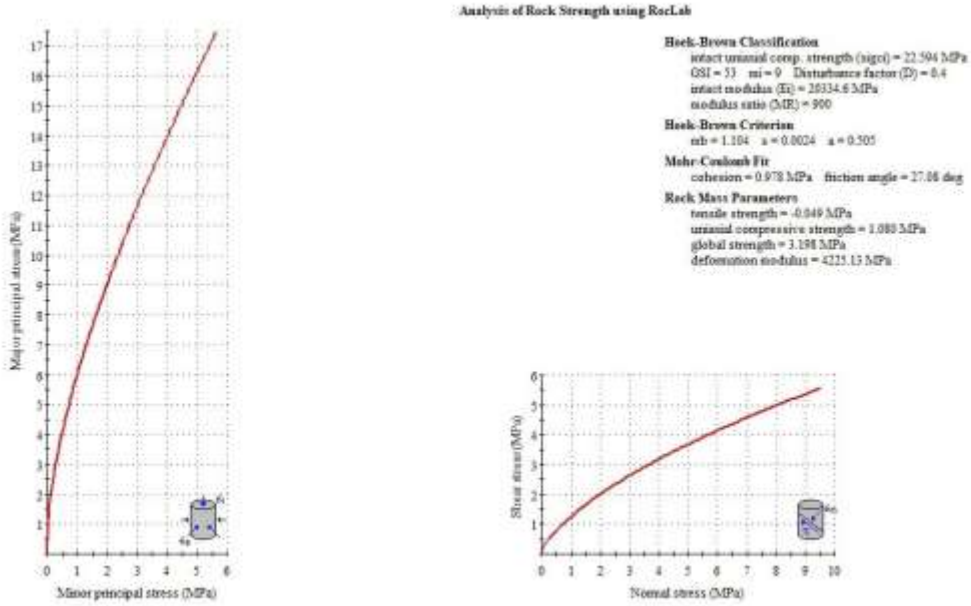

Fig. 4. Rock strength analysis for the unit no1 (Euphrates Formation) utilizing the RocLab program.

Discussion

The completion of Rock Mass Rating (RMR), Dam Mass Rating (DMR) and Geological Strength Index (GSI) rock mass classification systems and the application of RocLab program to ascertain mechanical characteristics of rock mass by Hoek-Brown criterion, rock mass units have been assessed in the following manner:

1- After the reservoir is filled, each rock mass safety unit against sliding is evaluated. "Fill dams; which depends upon every unit's DMR $_{STA}$, as it has been indicated in Table (7) compared with Table (9).

2- Assessing each rock mass unit to determine whether foundation excavation as well as consolidation grouting are required in the event that a dam is built. This is based on RMR_{BD1989} value, which is compared with Table (2) to get the results displayed in Table (7).

3- Ec/Em number indicates that there is no risk to the dam in the case when all of the rock mass units are evaluated for Ec/Em impact on the expected behavior of Al-Baghdadi Dam. Table (11) displays the evaluation's findings, which are ascertained by contrasting Em values with Table (3).

4- Through analyzing each rock mass unit for the problems of deformability, which relies upon DMR_{DEF} value of each one of the units, and comparing the value with Table (4), it is possible to identify the deformability problem types as indicated in Table (12).

5- The mechanical characteristics of each rock unit during Hook-Brown failure criterion are ascertained using RocLab program, so the results mentioned in the Table (8) and it is found that the proposed dam location is safe and stable for constructing the fill dam.

Table 5: Rock mass characterizations

Geologic units		**Euphrates Formation**		
ST. No		1	2	3
Rock type		Limestone Micritic		
Strength of the intact rock materials UCS 50MPa		22.594	22.452	25.935
RQD		95.867	94.64	96.665
Average of all discontinuities' spacing (m) = $\frac{1}{avg.fi}$		0.530	0.489	0.562
Discontinuities Condition		- length of Discontinuity = 2.3m - Aperture <5mm - Slightly- Rough surfaces - Soft filling - Slightly weathered	- length of Discontinuity = 4.6m - Aperture <5mm - Rough surfaces - Soft filling - weathered Moderately	- length of Discontinuity = 2.7m - Aperture <5mm - Rough surfaces - Soft filling - Slightly weathered
Ground water condition	RMR	Dry	Dry	Dry
	DMR (r_u)*	0.250	0.250	0.250
Dip (average)		060°/3°	060°/3°	060°/3°
**Strike and dip orientation of foundation rocks	Fill dam	Fair	Fair	Fair
Volumetric joint count (joint l/m^3) (Jv)		5.653	6.144	5.334
intact rock Modulus ratio (MR)		900	900	900
intact rock material constant (mi)		9	9	9

(ru)** = Water pressure ratio = 0.250 (average value, in the case where the rock is saturated, as in a case of dams for upstream parts) (Romanna, 2003-a)

Table 6: Rock mass characterizations

Geologic unit		Euphrates Formation		
ST. No		4	5	6
Rock types		Limestone Micritic	Limestone Micritic	Limestone Micritic
Strength of the intact rock material UCS(50MPa)		20.829	22.593	22.842
RQD		96.217	95.65	95.237
Avg. spacing of all of the discontinuities (m) = $\frac{1}{avg.fi}$		0.544	0.522	0.508
Discontinuities' Condition		- length of Discontinuity = 3.5m - Aperture <5mm - Slightly- Rough surfaces - Soft filling - weathered Moderately	- length of Discontinuity = 3.9 m - Aperture <5mm - Slightly- Rough surfaces - Soft filling - weathered Moderately	- length of Discontinuity = 2.5m - Aperture <5mm - Slightly- Rough surfaces - Soft filling - weathered Moderately
Ground water conditions	RMR	Dry	Dry	Dry
	DMR (r_u)*	0.250	0.250	0.250
Dip (average)		060°/3°	060°/3°	060°/3°
**Strike and dip orientation of foundation rocks	Fill dam	Fair	Fair	Fair
Volumetric joint count (joint l/m^3) (Jv)		5.513	5.74	5.905
intact rock Modulus ratio (MR)		900	900	900
The material constant of intact rock (mi)		9	9	9

(ru)* = ratio of Water pressure = 0.250 (average value, in the case where the rock is saturated, as in a case of dam for the upstream parts) (Romanna, 2003-a)

Table 7: Ratings of the rock mass parameters and rock mass classification system values

	Geologic units		Euphrates Formations					
	Rock mass units		1	2	3	4	5	6
	Strength of intact rock materials UCS(50MPa)		3.15	3.1	3.5	3.1	3.15	3.2
Rating of parameters	RQD		19	18.9	19.1	19.1	19.05	19
	Average spacing of all of the discontinuities (m) $= \frac{1}{avg.fi}$ Condition of discontinuities	RMR_{1976}	10	10	10	10	10	10
		RMR_{1989}	12	11.5	12.5	12.2	12.1	12
	Ground water condition	RMR_{1976}	11	9	12	7	7	9
		RMR_{1989}	15	13	17	11	11	13
	intact rock material Strength UCS50 (MPa)	RMR_{1976}	10	10	10	10	10	10
		RMR_{1989}	15	15	15	15	15	15
		DMR	**5	**5	**5	**5	**5	**5
	Strike and dip orientation of foundation rocks	Fill dam	-5	-5	-5	-5	-5	-5
	R_{STA}	Fill dam	-7	-7	-7	-7	-7	-7
	CF		0.013	0.013	0.013	0.013	0.013	0.013
	R_{STA} * CF	Fill dam	-0.091	-0.091	-0.091	-0.091	-0.091	-0.091
Rock mass classification system	$RMR_{(1976)}$	Fill dam	48.15	46	49.6	44.2	44.2	46.2
	$RMR_{B\ (1976)}$		58.15	56	59.6	54.2	54.2	56.2
	$RMR_{BD\ (1976)}$		53.15	51	54.6	49.2	49.2	51.2
	$RMR_{(1989)}$	Fill dam	59.15	56.5	62.1	55.4	55.3	57.2
	$RMR_{B\ (1989)}$		64.15	61.5	67.1	60.4	60.3	62.2
	$RMR_{BD\ (1989)}$		64.15	61.5	67.1	60.4	60.3	62.2
	DMR_{STA} ($RMR_{BD\ (1989)} + R_{STA}$ * CF)	Fill dam	64.131	61.409	67.009	60.301	60.201	62.101
	DMR_{DEF} ($RMR_{BD\ (1976)} - 5$)		48.15	46	49.6	44.2	44.2	46.2
	GSI (Geological Strength Index)		53	52	60.5	46.5	45	44.5

RMR= UCS, RQD, Spacing between joints, Condition of discontinuities, Ground water condition, and Orientation of discontinuities.
* Rating of avg. spacing of all of the discontinuities………. (Beinwaski,2011)
**In the DMR → Water rating (WR) = 5 in the case where the water pressure ratio (r_u) = 0.250 (Romanna,2003-a,2003-b and 2004)
Where: RMR represents Rock Mass Rating (Summation of rating of the 6 parameters).
$RMR_{1976\ or\ 1989)}$ = Rock Mass Rating of that version's year.
RMR_B represents Basic RMR, without any adjusting factor for the joint orientation.
DMR represents Dam Mass Rating.
$RMR_{BD\ (1989)}$ represents Basic dry RMR (adding first 4 parameters of the RMR_{B1989} plus 15.
$RMR_{BD\ (1976)}$ represents the Basic dry RMR (Adding first 4 parameters of the RMR_{B1976} plus 10.
DMR_{DEF} represents RMR of the relative deformability, with the WR (water rating) = 5, and no adjustment for the orientations of discontinuity
DMR_{STA} represents DMR of the dam stability.

Table 8: rock strength Analysis for the rock mass units with the use of the Roc Lab software.

Geologic unit	Unit number	Type of the Rock	Cohesion (MPa)	Tensile Strength (MPa)	Uniaxial compressive strength (MPa)	Friction Angle (degree)	Global strength (MPa)	Modulus of Deformation (MPa)
Fatha Formation	1	Limestone	0.978	-0.049	1.080	27.08	3.198	4225.13
	2	Limestone	0.954	-0.045	1.004	26.72	3.096	3941.34
	3	Limestone	1.303	-0.106	2.033	29.76	4.493	7516.72
	4	Limestone	0.795	-0.026	0.642	24.78	2.484	2552.52
	5	Limestone	0.837	-0.025	0.628	24.26	2.590	2506.46
	6	Limestone	0.837	-0.025	0.613	24.09	2.583	2451.45

Table 9: safety degree of the dam against the sliding from DMR_{STA} evaluations based on Table1.

Geological units	Unit number	Type of Rocks	*DMR_{STA}	**safety degree of dam against the sliding
			Fill dam	Fill dam
Euphrates Formation	1	Limestone	64.131	No primary concern
	2	Limestone	61.409	No primary concern
	3	Limestone	67.009	primary concern
	4	Limestone	60.301	No primary concern
	5	Limestone	60.201	No primary concern
	6	Limestone	62.101	No primary concern

Table 10: The tentative guide-lines for suggested AlBaghdadi dam foundation excavation and consolidation grouting. Based on Table 2.

Geological units	Unit Number	Type of Rocks	*RMR_{BD1989}	Foundation excavations	Consolidation grouting based on the RMR_{BD1989}
				fill dam	fill dam
Euphrates Formation	1	Limestone	64.15	Desirable	None
	2	Limestone	61.5	Desirable	None
	3	Limestone	67.1	Desirable	None
	4	Limestone	60.4	Desirable	None
	5	Limestone	60.3	Desirable	None
	6	Limestone	62.2	Desirable	None

Table 11: Effects of Ec / Em on suggested AL Baghdadi fill dam behaviors based on Table 3.

Geologic units	Unit number	Rock types	DMR_{DEF}	E_m (GPa)	E_c / E_m	Impact on the dam	Issues
						fill dam	fill dam
Euphrates Formation	1	Limestone	48.15	22.594	0.442	Negligible	None
	2	Limestone	46	22.452	0.445	Negligible	None
	3	Limestone	49.6	25.935	0.385	Negligible	None
	4	Limestone	44.2	20.829	0.480	Negligible	None
	5	Limestone	44.2	22.593	0.442	Negligible	None
	6	Limestone	46.2	22.842	0.437	Negligible	None

DMR_{DEF} (deformability RMR = RMR $_{BD1976}$ – 5), DMR_{DEF} values are from Table7.
E_m (rock mass Deformation modulus), based on "Romana, 2003-a", if RMR $_{BD}$ > 60 or DMR $_{DEF}$ > 55 E_m = 2 RMR – 100 has been utilized, and if the RMR $_{BD}$ < 60 or DMR_{DEF} < 55 $E_m = 10^{RMR-10)/40}$ has been utilized (Note: RMR = DMR_{DEF}). E_c / E_m and its guide-lines have been based upon Table3. Fill dam (Having E_c = 10GPa). The same guide-lines for fill dam.

Table 12: issues deformability in the suggested Al Baghdadi dam based upon DMR_{DEF} value and dam type and height based on Table 4.

Geologic unit	Unit number	Types of Rock	*DMR_{DEF}	Deformability issues	Dam height (m)
			Fill dam	Fill dam	
Euphrates Formation	1	Limestone	48.15	Normal	34.5
	2	Limestone	46	Normal	
	3	Limestone	49.6	Normal	
	4	Limestone	44.2	Normal	
	5	Limestone	44.2	Normal	
	6	Limestone	46.2	Normal	

*DMR_{DEF} (deformability RMR = $RMR_{BD (1976)}$ – 5), DMR_{DEF} values have been obtained from Table6.
fill dam (which has E_c = 10GPa). The height of suggested Al Baghdadi dam is 34.5 m the lowest point at river bottom.

Conclusion

The research's primary goal is to examine how various rock masses (or rock mass units) under a dam's foundation can be identified by the Rock Mass Rating (RMR), Dam Mass Rating (DMR), and Geological Strength Index (GSI) systems. The conclusion is as follows:

1- The stability regarding the foundation rocks in all units of rock mass is demonstrated by DMR_{STA} values (RMR associated with the dam's stability).

2- Depending on $RMRBD_{89}$ values, the excavation regarding the dam's foundations is assessed. It is found that such values indicate that the foundation rocks are desired and could be excavated up for filling dams; and grouting activities are not required.

3- The values of Ec/Em (dam deformation coefficient/ deformation modulus of the foundation rocks) indicate that there are no problems in the case of building fill dam.

4- The values of DMR_{DEF} (relative deformability RMR) indicate that there are no problems in all stations studied.

5- The results of Geological Strength Index (GSI) show that the stations studied range from fair to good.

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