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The Geomechanics Classification of Rock Mass with Using RMR and CRMR Method To Determine the Stability of Some Karst Caves in Haditha Area, Western Iraq

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ABSTRACT

The main goal of this study is to figure out how safe rock formations are that have buildings on them and are often visited for research or exploration. In order to do this, the rock masses will be measured with the RMR and CRMR systems. Field and laboratory data are used to gather for these two systems; the RMR system has six parameters, while the CRMR system has eight parameters. The classification method for rock masses is a valuable tool for both geologists and geotechnical professionals, as it enables them to address stability issues and recommend appropriate support systems for the rock masses. Rock masses are rated as fair by the Rock Mass Rating (RMR) classification, necessitating a support system. Ain Al-Dawaar appears into the good category, however the other two caverns fall into the fair group according to the CRMR approach. Therefore, a development process is required for all the caves.

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التصنيف الجيوميكانيكي للكتلة الصخرية باستخدام طريقة RMR و CRMR لتحديد استقرارية بعض الكهوف الكارستية في منطقة حديثة، غرب العراق

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الملخص

الهدف الرئيسي من هذه الدراسة هو معرفة مدى أمان التكوينات الصخرية التي تحتوي على مبانٍ وغالبًا ما تتم زيارتها للبحث أو الاستكشاف. من أجل القيام بذلك، سيتم قياس كتل الصخور باستخدام أنظمة RMR و CRMR. تُستخدم البيانات الميدانية والمختبرية لجمع بيانات هذين النظامين؛ يحتوي نظام RMR على ستة معلمات، بينما يحتوي نظام CRMR على ثمانية معلمات. تعتبر طريقة التصنيف للكتل الصخرية أداة قيمة لكل من الجيولوجيين والمهنيين الجيوتقنيين ، حيث إنها تمكنهم من معالجة مشكلات الاستقرار وكذلك التوصية بأنظمة الدعم المناسبة للكتل الصخرية. تم تصنيف كتل الصخور على أنها معتدلة من خلال تصنيف RMR ، مما يستلزم وجود نظام دعم. يظهر كهف عين الدوار ضمن الفئة الجيدة، لكن الكهفين الأخريين يقعان ضمن المجموعة المعتدلة وفقًا لنظام CRMR. لذلك، فإن عملية التطوير مطلوبة لجميع الكهوف.

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Introduction

Engineering geology is crucial for assessing the stability and support of the rock mass. This is due to the important information it gives, which is used in selecting the suitable support and developing the rock mass. Haditha area is located in the western of Iraq and is karst area. The area is geologically constituted of caves and sinkholes formed because of dissolving limestone. The method used to classify rock masses is (RMR), and (CRMR), method. Rocks differ from other engineering materials in that they contain discontinuities such as bedding planes, joints, faults, and other, which makes their structure discontinuous. Rock masses are discontinuous and often have heterogeneous and anisotropic properties (Zhang, 2017). In the past fifty years, a number of techniques for classifying rocks have developed. These systems are now widely used in underground engineering to estimate geomechanical characteristics and determine the best support system (Soufi et al., 2018). The classifications that are now most often used include Palmström's rock mass index (Palmström's, 1995), Q system) Barton, et al., 1974) and Bieniawski's RMR (Bieniawski, 1973).

Bieniawski (1976) developed the Classification Geomechanics for rock masses (RMR). This classification was also developed by this scientist in 1989 (Bieniawski, 1989). These classifications are used to determine the strength and support of rock masses. The purpose of this work is to study the existing caves in a Haditha area to determine the appropriate method for their support as well as their development.

The Geology of Study Area

geologically, Haditha area is situated on the stable shelf within west desert, western of Iraq. Haditha area is characterized by karst topography, caves, Mesa, and Valleys (for example, valley Haqlan). The Euphrates River Valley is the most important topographical phenomenon in the study area.

The carbonate dissolving process associated with karstification of the limestone produced caverns decorated with a variety of stalactites, stalagmites, and flowstones Fig. 4. Caves and karsts are found in the area of study mostly within the limestone of the Euphrates Formation. The Euphrates Formation is one of the widespread formations and covers large areas within the study area. De Boeckh first described it in 1929, and it was later modified by Bellen in 1957. The type locality of the Euphrates Formation is found near Wadi Al-Fahimi close to Anah, chalky and well bedded recrystallized limestone. Additionally, found in some subsurface sections were sands and anhydrites, which are probably tongues dating back to the Ghar and Dhiban formations, respectively (Bellen et al., 1959). The formation is primarily composed of limestone, and its texture ranges from oolitic to chalk. Corals and shells are also present in some localities. Moreover, there are beds of conglomerate limestone, breccia, and green marl. The five units of the (94-meter-thick) Euphrates formation is found at Well Anah-Z (Jassim and Goff, 2006).

Data and Methods

Several methods were used in the research, which are descriptive, analytical, and engineering geological investigation, and included a variety of data from surveys, investigations, field mapping, previous research and studies. Activities have been done including caves were tracked to determine their dimensions, length, width, and height, as well as to map and distribute rooms and channels that connect rooms with each other, as well as knowing the thickness of the layers, the thickness of the roof of each cave, and its distance or proximity to the roads. The thickness of the rock units was calculated to find the stresses applied to the walls and roofs of the caves. Rock samples were taken for petrological analysis, and also for compressive strength test. The techniques used to assess the rock's strength are uniaxial compressive strength (UCS) and the point load test. The geomechanical evaluation of the limestone that composes the caverns, including the RMR, roof thickness, and vibration source. To assess the stability of the rock masses, it is assumed that the cave in this case is a tunnel. Every rock bed was studied as a separate rock unit, indicated by the letter U.

Rock Mass Rating (RMR)

Based on his knowledge gained through his studies of shallow tunnels within sedimentary rocks, Bieniawski (1973) established a mechanical classification system for rock masses which it called RMR., (Kaiser, MacKay, & Gale, 1986). The classification underwent a number of significant changes in the ensuing years, including the lowering of the classification parameters from eight to six in 1974 and the lowering of the suggested support requirements in 1975. There are many other things that have been modified, in 1976, class boundaries were changed to even multiples of twenty, and in 1979, the ISRM (1978) rock mass description was adopted. This classification system has been modified throughout time, and its characterization approach has been altered since its inception (Somodi et al., 2021).

The RMR followed a well - established procedure, it contains the five parameters which include: RQD, UCS of the intact part of the rock, joint spacing and condition, Finally, the state of groundwater, (Bieniawski, 1989). Depending on the RMR rating system, rocks can be classified using a five-point ordinal rating scale ranging from "very good rock" (RMR = 81 – 100) to "very poor rock" (RMR < 21).

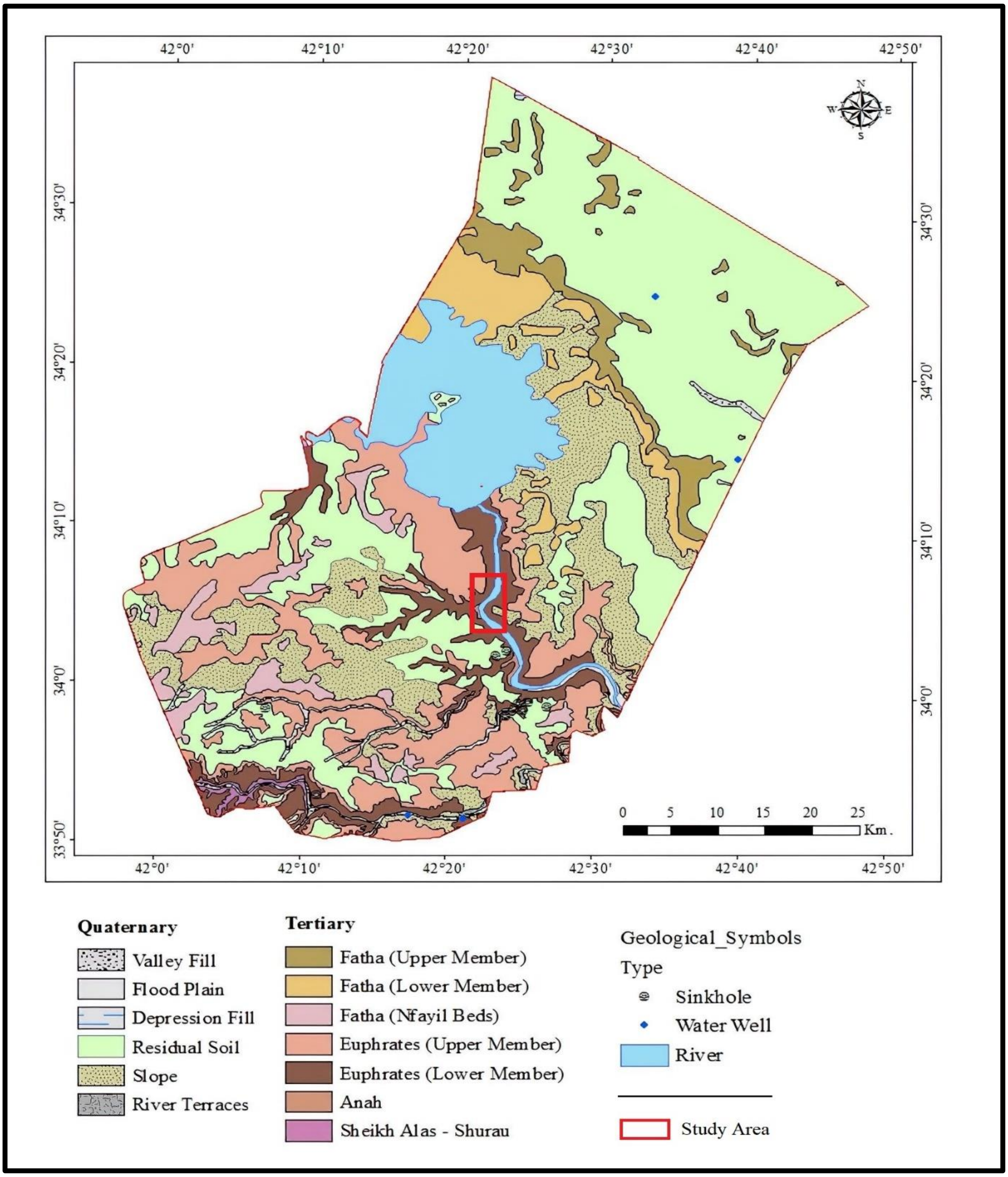

Fig. 1. Geological map of the study area

For each structural unit, the following six parameters (representing causative factors) are determined:

1. U.C.S of intact rock material.
2. Rock quality designation (RQD).
3. Joint spacing.
4. Joint condition.

4a: Joint length, persistence ,4b: Separation, 4c: Smoothness, 4d: Infilling, 4e: alteration / weathering

5. Groundwater conditions and orientation of discontinuities.

The intact rock strength, is an important parameter in RMR (Brook, 2020). Table 1 shows the ratings based on both UCS (the recommended method) and the point load strength index. Test method based on ASTM (ASTM C170/C170M –16; ASTM D5731 – 2016).

Table 1: Strength of Intact Rock Material (Bieniawski, 1984, 1989).

Qualitative description	Compressive strength (MPa)	Point load strength (MPa)	Rating
Extremely strong	> 250	8	15
Very strong	100-250	4-8	12
Strong	50-100	2-4	7
Medium strong	25-50	1-2	4
Weak	5-25	Use of UCS is preferred	2
Very weak	1-5	-do-	1
Extremely weak	< 1	-do-	0

Table 2 shows the specifics of the RQD rating. RQD was calculated using (Palmstrom, 2005) relationship:

RQD = (110-2.5Jv) ….1

Table 2: Rock Quality Designation (Bieniawski,1989)

	Condition	RQD (%)	Rating
A	Very poor	< 20	3
B	Poor	25-50	8
C	Fair	50-75	13
D	Good	75-90	17
E	Excellent	90-100	20

The term "discontinuity" refers to a variety of weak surfaces, including shear zones, bedding, joints and small faults. The distance between each pair of discontinuities is determined by measuring the linear distance between two adjacent and parallel discontinuities at a 90degree angle. Fig (2) (Edelbro, 2003) Table 3.

Table 3: Spacing of Discontinuities (Bieniawski, 1989) (ISO 14689-1, 2003)

Description	Spacing (m)	Rating
Very wide	> 2	20
Wide	0.6-2	15
Moderate	0.2-0.6	10
Close	0.06-0.2	8
Very close	< 0.06	5

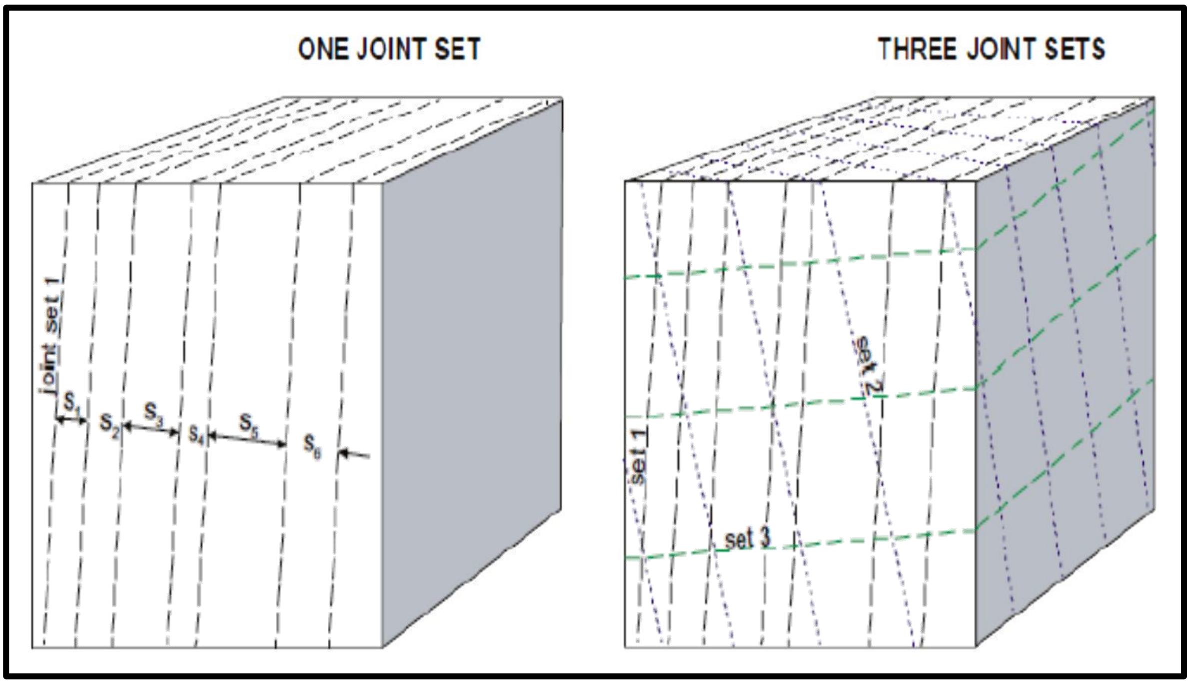

Fig. 2. Joint sets and joint set spacing (Palmstrom, 2005)

Joint spacing is the perpendicular distance along a line of measure between two subsequent discontinuities. (Tawil et al., 2021). The two tables (4 and 5) show the condition of discontinuities and groundwater condition. The rock mass rating, or RMR, is produced by summing the ratings of the five aforementioned parameters. (as shown in Tables 1 to 5) (Singh et al., 2011). The orientation of discontinuities parameter has a value of zero.

Table 4: Classification of Discontinuity Conditions Using the RMR System (Bieniawski, 1993).

Parameter*	**Ratings**				
Discontinuity length (persistene/ continuity)	<1	1—3 m	3—10 m	>10-20 m	
	6	4	2	0	
Separation(aperture)	None	<0.1 mm	0.1—1 .0 mm	1—5 mm	>5 mm
	6	5	4	1	0
Roughnessof discontinuity surface	Very rough	Rough	Slightly rough	Smooth	Slickensided
	6	5	3	1	0
Infillings (gouge)		Hard filling		Soft filling	
	None	<5 mm	>5 mm	<5 mm	>5 mm
	6	4	2	2	
Weathering discontinuity surface	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
	6	5	3	1	0

Table 5: Groundwater Condition (Bieniawski, 1989).

Inflow per 10 m tunnel length (L / min)	**None**	**< 10**	**10-25**	**25-125**	**> 125**
Ratio of joint water pressure to major principal stress	0	0-0.1	0.1-0.2	0.2-0.5	> 0.5
General description	Completely dry	Damp	Wet	Dripping	Flowing
Rating	15	10	7	4	0

Cave Rock Mass Rating

The method developed by (Kusumayudha, et al., 2021) known as Cave RMR (CRMR) was used to gather crucial data and indications about the cave's safety components. The five RMR parameters, as well as two additional parameters, the thickness of the ceiling and the distance to the source of the vibration, are used to complete this method, In other words, the Bieniawski RMR approach was updated in this study by including two other parameters.

The degree of the cave's collapse is determined from a geotechnical standpoint in cases where this method is used to verify the practical application of the caves, particularly with regard to the caves absorptive capacity if it is developed as a tourist attraction or used for other purposes like underground storage. The two additional parameters' values are listed below (Table 6): (Kusumayudha et al., 2021).

Table 6: Addition parameters and their Values and Rating

Parameter	Range of Values					
Cave roof thickness (m)	Values	1	1-5	5-10	10-20	20
	Rating	0	5	10	15	20
Distance to the source of vibration (m)	Values	50	50-100	100-200	200-500	500
	Rating	0	5	10	15	20

Table 7: Geotechnical Classification of the Cave Stability

Class	Description of rock mass	Sum of rating RMR	Increments CRMR	Geotechnical Stability
(I)	Very good	81-100	91- 120	Very good
(II)	Good	61-80	71-90	Good
(III)	Fair	41-60	51-70	Fair
(IV)	Poor	21-40	31-50	Poor
(V)	Very poor	< 20	< 30	Very poor

Results and Discussions

1. Evaluation of some caves in Haditha

According to research into and evaluation of the caves, it can be described as the following:

a. Ain Al-Dawaar Cave

Ain Al-Dawaar Cave is located in Aloos Village, easily accessible, can be classified as a horizontal cave. This cave is divided into two rooms, the primary and secondary rooms connected by a 10-m-long, 0.5-m-high tunnel. In this rooms their live bats, the length of the cave is 161 meters. The area of the cave is approximately 3750 square meters, and a volume of 27370 cubic meters (Fig. 3). The cave is dark inside, with only one opening. It has a sulfur smell, and this indicates the proximity of sulfur water to the bottom of the cave. From an engineering geological point of view, Ain Al-Dawaar Cave has a fairly stability Within the RMR classification, but it has good stability within the CRMR classification because of the distance of the cave from the main road. The depth of the cave reaches < 10 m from the surface, joint spacing in general is < 0.5 m. Thus, the risk of collapse is small, but there is a possible risk that the roof may fall in a small part of the cave due to the small thickness of this part and its height, which exceeds 8 meters, so the cave must be support according to a RMR classification, as in the Table (8).

Fig. 3. Ain Al-Dawaar Cave: (A)Inside the cave, (B)above the roof, (C)outside the cave, (D)in front of the cave entrance

b. Khafajia Cave

The Khafajia Cave is located in Khafajia area Within a hditha city. The cave entrance is close to residential area, and very close to a valley Khafajia. The cave from the inside contains stalactites and stalagmites of small scale as in the Fig. (4). The length of the cave is 180 meters and divided into three parts in the form of two rooms connected to each other by a tunnel whose length is about 55 meters and 5 meters wide. Khafajia Cave has two entrances every room has an entrance. The first entrance is 21m wide, the second entrance wide 18 m. The cave has a surface area of 2212.5 square meters and a volume of 14791.25 cubic meters the roof thickness of the cave about 2.6 - 5 m, there are many joints, with joint density of 0.57 m. can be found various animals such as bats. Cave has a fairly stability within the RMR and CRMR classification, But the cave must be support according to a RMR classification, as in the Table (8).

Fig. 4. b.Khafajia Cave: (A and C) Inside the cave, (B)stalactites, (D)measurement of discontinuities inside the cave

c. Subhani Cave

Cave is located in Subhani area Within a Hditha city. The cave entrance is very close to the road. Medium lighting and does not contain stalactites and stalagmites Fig. (5). The cave contains two entrances close to each other, separated by a rocky pillar. The cave Consists of one room divided into two parts according to the thickness of the rock cover (the thickness of the roof). The cave has a surface area of 925 square meters and a volume of 4115 cubic meters. From the stability, aspect of engineering geology it is estimated that this cave has a small risk of collapse, because the thickness of the ceiling is about 5-10 meters, despite the proximity of the cave to the source of vibration. Cave has a fairly stability within the RMR and CRMR classification, but the cave must be support according to a RMR classification, as in the Table 8.

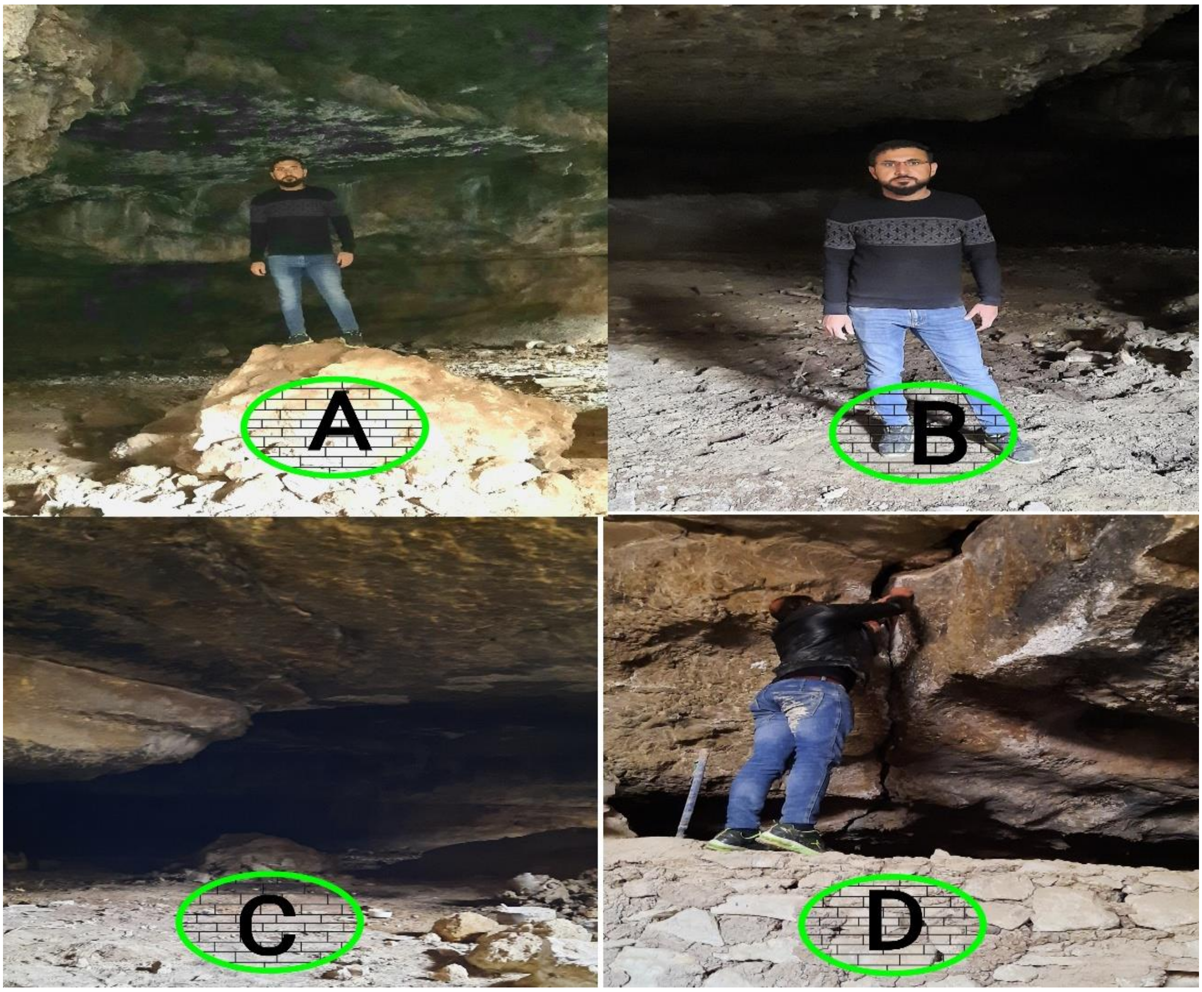

Fig. 5. (A, B and C) Inside the cave, (D) measurement of discontinuities inside the cave

2. Discuss the Results of the RMR and CRMR for Caves

An algebraic total of the ratings for each of the five parameters should be used to compute RMR, listed in Tables 1 to 5, The "rock condition rating," which takes into account the compressive strength (UCS) of unbroken rock material and the orientation of joints, is the total of the ratings for the five factors Tables 1 - 5.

Based on the seven previously described parameters, Cave RMR (CRMR) was designed to gather data and signals concerning the stability and safety of the caves. The result was as follows Tables 9 - 12. Based on the RMR classification the results show that Ain Al-Dawaar Cave = 56 is fair rock category, Al-Khafajia Cave = 56, including in Fair rock, AL- Subhani Cave = 55 classified as fair rock.

Table 8: Support based on RMR: (Bieniawski, 1973)

	Supports		
Rock mass class	Rock bolts (20 mm diameter, fully grouted)	Conventional shotcrete	Steel sets
Very good rock RMR = 81-100	Generally, no support required except for occasional spot bolting		
Good rock RMR = 61-80	Locally, bolts in crown 3 m long, spaced 2.5 m, with occasional wire mesh	50 mm in crown where required	None
Fair rock RMR = 41-60	Systematic bolts 4 m long, spaced 1 .5-2 m in crown and walls with wire mesh in crown	50-100 mm in crown and30 mm in sides	None
Poor rock RMR = 21-40	Systematic bolts 4-5 m long, spaced 1-1 .5 m in crown and wall with wire mesh	100-150 mm in crown and 100 mm in sides	Light to medium ribs spaced 1.5 m where required
Very poor rock RMR<20	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh; bolt invert	150-200 mm in crown, 150 mm in sides, and 50 mm on face	Medium to heavy ribs spaced 0.75 m with steel lagging and fore poling if required; close invert

Therefore, roofs and walls of cavities must be supported to use for certain purposes example, underground storage of solid materials. According to the Table 8 the elements that require support is systematic bolts 4 m long (20 mm diameter, fully grouted), spaced 1 .5-2 m in crown and walls with wire mesh in crown, while conventional shotcrete 50-100 mm in crown and 30 mm in sides.

Table 9: Shows the values of (Jv) and (RQD) and average spacing

Ain Al-Dawaar Cave	
(Nr= Number of Random joint) Nr/(5*$\sqrt{A}$) =	0.08
Volumetric joint Jv= 1/S1+1/S2+1/S3+1/S4+1/S5+Nr/5*$\sqrt{A}$ =	10.64
RQD=110-2.5Jv	83.397
Average spacing of all discontinuities (m)=5/Jv =	0.470
Khafajia Cave	
(Nr= Number of Random joint) Nr/(5*$\sqrt{A}$)=	0.040
Volumetric joint Jv= 1/S1+1/S2+1/S3+1/S4+1/S5+Nr/5*$\sqrt{A}$=	10.267
RQD=110-2.5Jv=	84.333
Average spacing of all discontinuities (m)=5/Jv =	0.487
Subhani Cave	
(Nr= Number of Random joint) Nr/(5*$\sqrt{A}$) =	0
Volumetric joint Jv= 1/S1+1/S2+1/S3+1/S4+1/S5+Nr/5*$\sqrt{A}$ =	9.958
RQD=110-2.5Jv	85.106
Average spacing of all discontinuities (m)=5/Jv =	0.502

Table 10: Rock mass units' characterization for the RMR-parameters

cave	Unite	UCS	RQD	SD	CD	GD
Ain Al-Dawaar Cave	U 1	Medium strong	Good	Moderate	12	dry
	U 2	Medium strong	Good	Moderate	8	dry
	U 3	Medium strong	Good	Moderate	10	dry
	U 4	Weak	Good	Moderate	10	dry
	U 5	Weak	Good	Moderate	10	dry
	U 6	Weak	Good	Moderate	10	dry
	U 7	Very strong	Good	Moderate	8	dry
	U 8	Weak	Good	Moderate	10	dry
	U 9	Very strong	Good	Moderate	8	dry
	U 10	Medium strong	Good	Moderate	10	dry
	U 11	Medium strong	Good	Moderate	10	dry
	U 12 &13	Medium strong	Good	Moderate	10	dry
	U 14	Weak	Good	Moderate	10	dry
Al-Khafajia Cave	U 1	Medium strong	Good	Moderate	12	dry
	U 2	Strong	Good	Moderate	8	dry
	U 3	Medium strong	Good	Moderate	12	dry
	U 4	Medium strong	Good	Moderate	8	dry
	U 5	Medium strong	Good	Moderate	10	dry
	U 6	Strong	Good	Moderate	10	dry
	U 7	Medium strong	Good	Moderate	10	dry
	U 8	Weak	Good	Moderate	10	dry
	U 9	Weak	Good	Moderate	10	dry
Al-Subhani Cave	U1	Weak	Good	Moderate	10	dry
	U2	Weak	Good	Moderate	10	dry
	U3	Weak	Good	Moderate	10	dry
	U4	Strong	Good	Moderate	8	dry
	U5	Weak	Good	Moderate	10	dry
	U6 +7	Medium strong	Good	Moderate	10	dry
	U8	Medium strong	Good	Moderate	10	dry
	U9 &10	Weak	Good	Moderate	10	dry

* SD = Spacing of Discontinuities, CD = Condition of Discontinuities
, GC = Groundwater Condition ,UCS =Uniaxial Compressive Strength

Table 11: Rating of the rock parameters and value of RMR1989 from comparison Table (10)

Cave	Layer	UCS	RQD	SD	CD	GC	RMR	Rock Class
Ain Al-Dawaar Cave	U 1	4	17	10	12	15	58	Fair rock (III)
	U 2	4	17	10	8	15	54	Fair rock (III)
	U 3	4	17	10	10	15	56	Fair rock (III)
	U 4	2	17	10	10	15	54	Fair rock (III)
	U 5	2	17	10	10	15	54	Fair rock (III)
	U 6	2	17	10	10	15	54	Fair rock (III)
	U 7	12	17	10	8	15	62	Good (II)
	U 8	2	17	10	10	15	54	Fair rock (III)
	U 9	12	17	10	8	15	62	Good (II)
	U 10	4	17	10	10	15	56	Fair rock (III)
	U 11	4	17	10	10	15	56	Fair rock (III)
	U 12 &13	4	17	10	10	15	56	Fair rock (III)
	U14	2	17	10	10	15	54	Fair rock (III)
Al-Khafajia Cave	U 1	4	17	10	12	15	58	Fair rock (III)
	U 2	7	17	10	8	15	57	Fair rock (III)
	U 3	4	17	10	12	15	58	Fair rock (III)
	U 4	4	17	10	8	15	54	Fair rock (III)
	U 5	4	17	10	10	15	56	Fair rock (III)
	U 6	7	17	10	10	15	59	Fair rock (III)
	U 7	4	17	10	10	15	56	Fair rock (III)
	U 8	2	17	10	10	15	54	Fair rock (III)
	U 9	2	17	10	10	15	54	Fair rock (III)
Al-Subhani Cave	U 1	2	17	10	10	15	54	Fair rock (III)
	U 2	2	17	10	10	15	54	Fair rock (III)
	U 3	2	17	10	10	15	54	Fair rock (III)
	U 4	7	17	10	8	15	57	Fair rock (III)
	U 5	2	17	10	10	15	54	Fair rock (III)
	U 6 &7	4	17	10	10	15	56	Fair rock (III)
	U 8	4	17	10	10	15	56	Fair rock (III)
	U 9 &10	2	17	10	10	15	54	Fair rock (III)

Table 12: Values of parameters geotechnical classification of the cave's stability

Cave	part	Cave roof thickness		Distance to the source of vibration		RMR	CRMR	Class
		Values(m)	Rating	Values(m)	Rating			
Ain Al-Dawaar Cave	1&5	5-10	10	200- 500	15	56	81	Good
	2	1-5	5	200- 500	15	56	76	Good
	3	5-10	10	200- 500	15	56	81	Good
	4	5-10	10	200- 500	15	56	81	Good
Khafajia Cave	1	1-5	5	<50	0	56	61	Fair
	2	1-5	5	<50	0	56	61	Fair
	3	1-5	5	<50	0	56	61	Fair
	4	1-5	5	<50	0	56	61	Fair
Subhani Cave	1	5-10	10	<50	0	55	65	Fair
	2	5-10	10	<50	0	55	65	Fair

Use CRMR the average value of all parts of Ain Al-Dawaar Cave = 79.75 is good rock category, Al-Khafajia Cave = 61, including in Fair rock, Al- Subhani Cave = 65 classified as Fair rock. Thus, from a geotechnical aspect, the stability of Ain Al-Dawaar Cave, Al-Khafajia Cave and Al-Subhani Cave, are suitable to be used for certain purposes example, underground storage of solid materials, but after developing.

Conclusions

1 - According to the RMR classification the results show that Ain Al-Dawaar Cave = 56 is fair rock category, Khafajia Cave = 56, including in fair rock, Subhani Cave = 55 classified as Fair rock.

2- Based on the results of CRMR show that Ain Al-Dawaar Cave = 79.75 is good rock category, Khafajia Cave = 61, including in fair rock, Subhani Cave = 65 classified as fair rock.

3- Caves can be used for some purposes such as underground storage or for tourism purposes, but after supported and developing them.

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