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Assessment of Rock Masses Exposed at the Khanas Dam Site in the Southeastern Part of Sheikhan Anticline, Northern Iraq.

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ABSTRACT

This study is based on assessing rock masses exposed on the banks of the Khanas Dam reservoir in the southeastern part of the Sheikhan Anticline in northern Iraq. The rock masses are of the Pila Spi Formation. The study includes field data, laboratory tests, and office work. During the study, seven stations were chosen and distributed on both banks, four stations on the right and three stations on the left, considering that the Pila Spi Formation is the dominant and representative geological formation of the study area, and it represents the foundation of the dam, Shoulders, and banks overlooking the reservoir. The rock masses of the Pila Spi Formation are represented by limestone, chalky limestone, and dolomitic limestone as a result of the diagenetic process. Three classifications are used to assess rock masses: Rock Mass Rating (RMR), Dam Mass Rating (DMRSTA), and Geological Strength Index (GSI). As a result of the classification of rock masses, they range between (50-61) on the right bank, while on the left bank, they range between (53-62). The results of the assessment of the stability of the Dam Mass Rating on the right bank range between (61-66), while on the left bank range between (58-67). The results of the geological strength index values for rock mass on the right bank are between 41-56, while the results on the left bank are between 48-57. The Roclab program was also used, through which the mechanical properties of rock masses, represented by cohesion strength(C) and angle of internal friction(Ø), are determined using the Hoek-Brown failure criterion. Cohesion strength on the right bank range is between (0.362-0.877MPa), while on the left bank, their values range between (0.385-0.869MPa). The angle of internal friction on the right bank ranges between (24.26°-28.15°), while on the left bank, the values range between (25.31°- 28.51°).

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تقييم الكتل الصخرية المنكشفة في موقع سد خنس في الجزء الجنوبي الشرقي من طية الشيخان، شمالي العراق.

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الملخص

تعتمد هذه الدراسة على تقييم الكتل الصخرية المنكشفة على ضفاف خزان سد خنس في الجزء الجنوبي الشرقي من طية الشيخان، شمالي العراق. وتمثلها صخور تكوين البلاسبي. وتشمل الدراسة البيانات الحقلية والفحوصات المختبرية، والعمل المكتبي. خلال الدراسة تم اختيار سبع محطات متوزعة على الضفتين، اربعة منها على الضفة اليمنى وثلاث محطات على الضفة اليسرى، باعتبار ان تكوين بلاسبي هو التكوين السائد والممثل لمنطقة الدراسة. ويمثل تكوين البلاسبي اساس السد والاكتاف والضفاف المطلة على الخزان. بالنسبة للكتل الصخرية المكونة من تكوين البلاسبي والمتمثلة بالحجر الجيري والحجر الجيري الطباشيري والحجر الجيري المتدلمت نتيجة العمليات التحويرية. فقد استخدمت ثلاث تصانيف لتقييم الكتل الصخرية، وهي كالاتي: تصنيف الكتلة الصخرية وتصنيف كتلة السد ومؤشر القوة الجيولوجية، وكنتيجة لتصنيف الكتلة الصخرية، فأنها تراوحت ما بين (50–61) على الضفة اليمنى، بينما على الضفة اليسرى حيث كانت ما بين (53–62)، وتراوحت نتيجة تقييم استقراريه تصنيف كتلة السد على الضفة اليمنى بين (61– 66)، بينما على الضفة اليسرى فكانت ما بين (58–67). اما نتائج قيمة مؤشر القوة الجيولوجية للكتل الصخرية على الضفة اليمنى فكانت بين (41–56)، بينما على الضفة اليسرى فهي ما بين (48–57). كما تم استخدام برنامج (الروك– لاب)، والذي يتم من خلاله معرفة الخواص الميكانيكية الصخرية المتمثلة بقوة التماسك وزاوية الاحتكاك الداخلي التي تم تحديدها باستخدام معايرة الفشل لـ (هوك – براون). حيث بلغت قوة التماسك (C) على الضفة اليمنى ما بين (0.326 –0.877) ميكا باسكال، بينما على الضفة اليسرى فقد تراوحت ما بين (0.689– 0.385) ميكا باسكال. تراوحت زاوية الاحتكاك الداخلي على الضفة اليمنى ما بين (28.15°– 24.26°)، بينما على الضفة اليسرى فان القيم تراوحت ما بين (25.31°–28.51°).

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Introduction

The study area is located about 56 km Northeast of Mosul City, in Al-Sheikhan District, represented by the Khanas Dam located within Sheikhan Anticline in its southeastern part. The coordinate of the studied area is between latitudes (36°55’ 301”) (36°45’ 150”) N and longitudes (43°25’09.11”) (43°25’36.888”) E, as shown in Figure 1 and Plate 1.

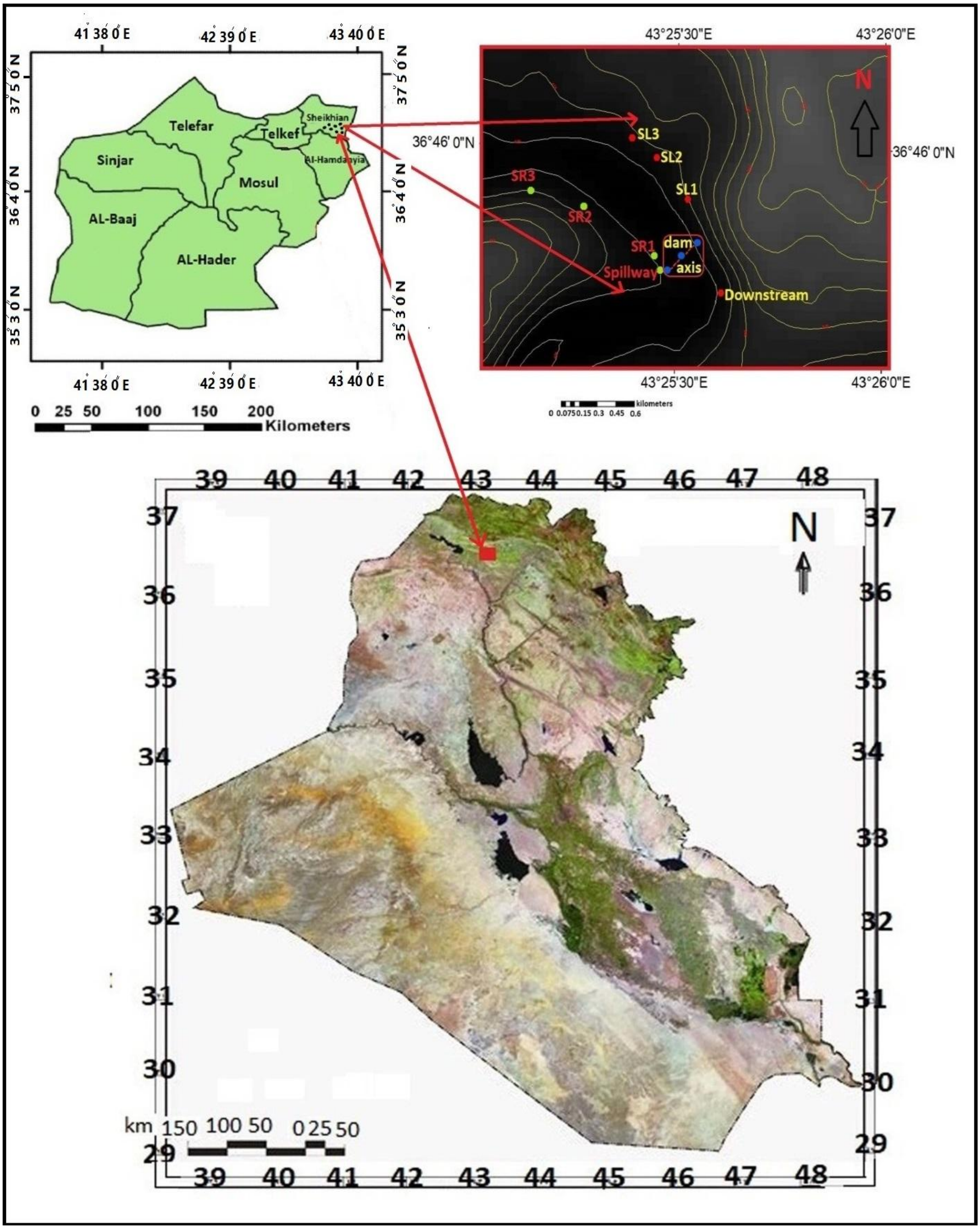

Fig. 1. Location map of the studied Area

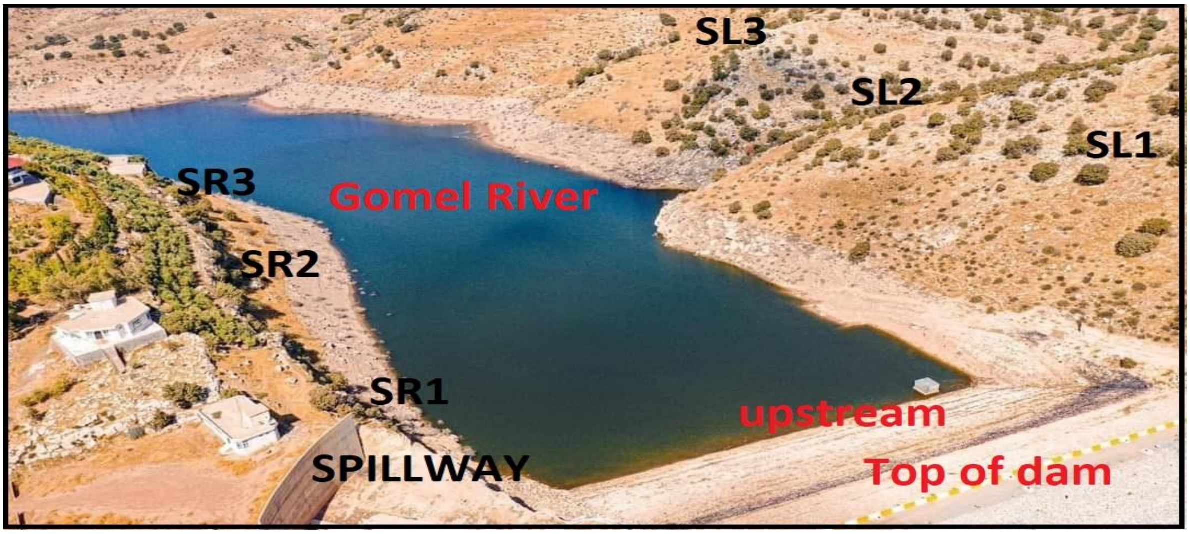

Plate 1: An aerial photo of the Khanas Dam, showing the locations of the stations distributed on both banks, right and left.

Geology of the study area

It is a very important factor and affects the rock masses located on the banks of the Khanas Dam. The dam is located in a complex geological area, with its flank located in the southeastern part, as the stream of the river is perpendicular to the axis of the fold from the time it enters the fold, then it continues vertically and deviates from the axis of the fold near the archaeological site of Khanas, where the axis of the dam is located.

Stratigraphy

It includes the exposed study rock, which is represented by limestone belonging to the Pila Spi Formation (Middle-Late Eocene). Fragile and disintegrated red clay deposits represented by the Gercus Formation (Middle Eocene) underlie the Pila Spi Formation. Recent deposits are at the top (Ahmed, 1980; AlHmedy, 2007).

Tectonically:

The study area is located within the unstable shelf with a foothill zone according to Jassim and Goff (2006) and Fouad (2012) within the Butmah-Ghemcheml subzone Taurus Mountains range (East-West trend). In the section in which the dam is located, the direction of the anticline axis deviates (E-NE) (W-SW). Al-Khatony (2009) also prepared a geological and structural map of the Sheikhan anticline, and it is modified by the projection of the axis of the dam (Fig. 2). The dip value of bedding planes on the right bank ranges between 20-24 degrees with very large differences in the dip direction. The amount of dip of the bedding planes on the left bank of the dam ranges between (22-26) degrees, with large differences in the amount of dip direction shown in Plates 2 and 3.

Khanas Dam is a water dam constructed on the Gomel River. It is used as a water harvester in the wet season of the year, and also for the purpose of controlling floods, as well as for irrigation. It is a small dam and does not generate electric energy. The study includes the assessment of the rock masses located on the banks of the reservoir; it is represented by the Gercus Formation and Pila Spi Formation, and recent deposits. A study of the effect of the erosion of the Gercus Formation on the Dohuk Dam, which is built on the Pila Spi Formation (Al-Talib et al., 2021). Therefore, the rock mass classification system must be assessed. The rock mass rating is a geomechanics classification developed by Bieniawski (1973) for tunnels and slopes, and foundations. The classification of the Rock Mass Rating is diverse, mostly frequent in subsurface works, very rarely in slopes, and essentially non-existent in foundation. (Romana,2003a) Thus, the suggested dam Mass Rating is a new classification used in the dam foundations as an adaptation to rock mass rating due to the difficulty use of RMR for dam foundation. In addition to previous studies related to dams, the use of rock mass rating and dam mass rating has been reviewed. Shaflei and Dusseault (2015) studied the Rock Mass characterization at the proposed Kangir Dam Site. Hamasur (2009) evaluated the rock mass engineering of the proposed Basara Dam Site. Singh (2020) studied the Dam Mass Rating of the rock mass of the Dhap Dam Site. Al-Jawadi (2013) studied the effect of structural discontinuities on the engineering structure at the Bekhme Dam site. Maleki (2011) studied engineering geological problems of Havsan Dam. Al-Jawadi et al. (2020) studied the possibility of constructing a dam in the Bandawaya Stream Valley in the plunge area of the Alqush and Dehkan anticlines, based on an evaluation of the rock masses. Zadeh et al. (2022) described the engineering properties assessment of the rock mass of the Darband Dam site using DMR. Ghart et al. (2023) evaluated the foundation rocks at the proposed Makhol Dam site. Badowi (2023) evaluated the geometrical and geoengineering characteristics of the Badush Dam site. Mohammed et al. (2023) evaluated the rock masses for the dam foundation in where Kanarwe River Basin, Sulaymainyah is a case study. Al-Jawadi et al. (2023) used the proposed reduction system of the rock mass strength in the evaluation of the Bekhme Dam site.

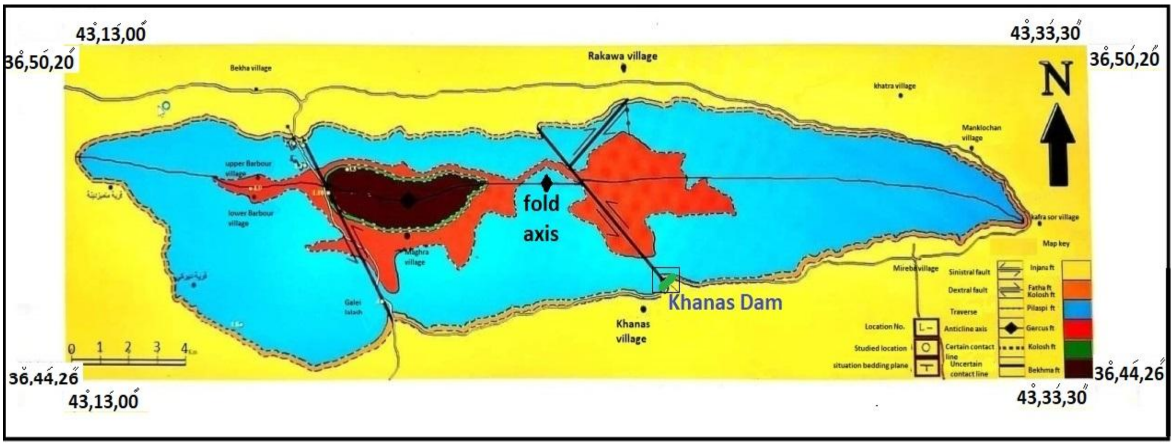

Fig. 2. Structural and geological map of the Sheikhan anticline (Al-Khatony, 2009)

Methodology

During the fieldwork, the largest amount of field information was collected for each station as a preliminary stage for the site investigation of rocks present on the two banks of the reservoir lake of Khanas Dam. This is done by measuring the dip direction/dip amount for the bedding planes and discontinuities, and determination of the volumetric joints through the discontinuities existing at the bed and determination of the Rock Quality Designation (RQD), as well as the determination of the Geological Strength Index (GSI) following Hoek and Marino's(2000) and after Hamasur (2009) through the intersection between structure rating and surface engineering investigation present by determination of the slope dip for rock mass and slope dip for Gercus Formation. Then determining the parameters required for evaluation of rock mass rating by RQD, uniaxial compressive condition rating, and determination of the rock mass thickness for each station, as well as the site strength, discontinuities situation for a prominent and distinctive joint represented by length of discontinuities and spacing of discontinuities, surface discontinuities (rough, very rough, smooth) aperture, and ground water condition, orientation of discontinuities, as well as these parameter involved in emulating the rock masses located on the banks and determining the stability for the each station on the two banks using the Dam Mass Rating in the same way as the stability of foundation. Additionally, finding the properties of rock mass by inputting the special parameters in the analysis of rock strength using the Roclab program. It is represented by uniaxial compressive strength (Ϭc) for intact rock and Geological Strength Index (GSI), and the value of the constant (mi) for intact rock by rock group, and estimated (Marino and Hoek, 2001). Since limestone is micrite, the estimated value is (9). The estimating disturbance factor for limestone is (0.4) (Hoek et al.,2002), and the Modulus Ratio (MR) value is between

(800-1000) with an average of (900), and the intact modulus (Ei) is obtained by multiplying the compressive strength by the modulus ratio. After entering these transactions, the following transactions will be obtained: Hoek – Brown criterion (mb, s, a). Mohor–Coulomb fit (Cohesion, Friction angle), Rock Mass Parameters: Tensile strength, Uniaxial compressive strength, Global strength, Deformation Modulus. shown in Figure 6 of the spillway station.

Engineering classification system

Rock Mass Rating System

It is a geomechanical system and was initially postulated by Bieniawski (1973) and is used in the subway, downhills, and foundations. It went through many developments during the following years (1973, 1974, 1975, 1976, and 1989) as given in Table 1. The Rock Mass Rating System uses six different parameters, which can be determined by field and through field observations, to laboratory tests (Bieniawski,1989), as follows: 1-UCS Unconfined compressive strength, 2-RQD-Rock Quality Designation, 3-Spacing of Discontinuities. 4-Condition of Discontinuities, 5-Ground Water condition, 6-Orientation of Discontinuities. The results for both banks are shown in Tables 4 and 5.

Table 1: Evolution of RMR rating (Modified from Milne et al., 1998)

RMR Parameters	Period				
	1973	1974	1975	1976	1989
Uniaxial Compressive Strength	10	10	10	15	15
RQD	16	20	20	20	20
Discontinuity spacing	30	30	30	30	20
Groundwater condition	10	10	10	10	15
Condition of Joints	34	30	30	25	30
Discontinuity strike and dip orientation in the tunnel	− (3−15)	− (0−15)	− (0−12)	− (0−12)	− (0−12)

The parameters affecting the evaluation of the rock masses are summarized as follows: the higher value of uniaxial compressive strength caused a higher quality of the rock mass, and vice versa. Rock quality designation depends on the volumetric joints in the m^3; the higher the value of volumetric joints, the lower the quality of the rock mass, and the lower the value of (jv), leading to a higher quality. The conditions of the discontinuities are represented by the persistence of discontinuities, the width of the aperture, infilling material, roughness of discontinuities, and weathering. All affect the evaluation of the rock mass. The effect of groundwater is negative; it reduces the cohesive strength of the rock and reduces the angle of internal friction. The highest rating of the rock is when it is dry. It decreases if it is damp, wet, dripping, or flowing.

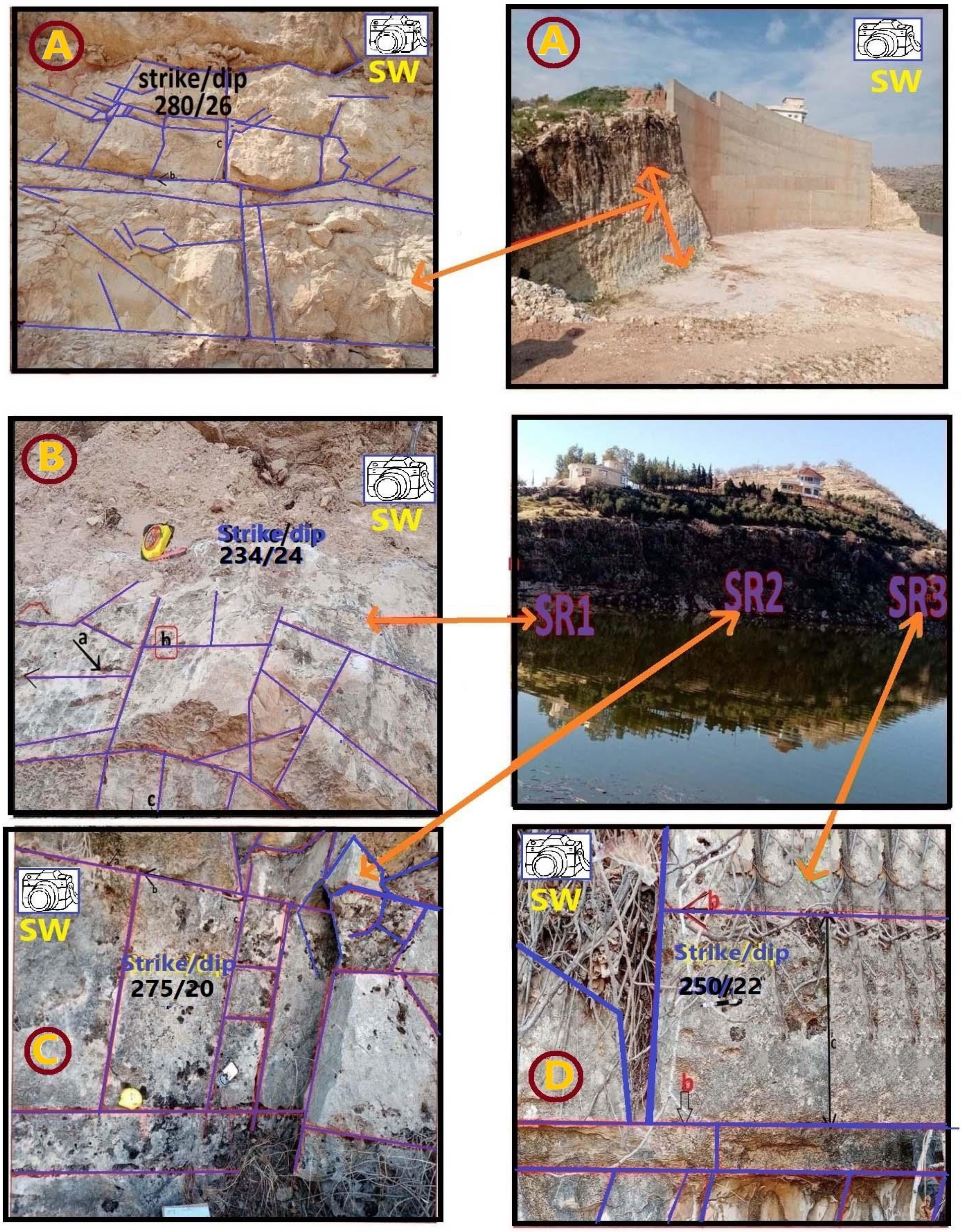

Plate 2: Pictures of A-Spillway station, B- First station (SR1), C- Second Station (SR2), and D- Third station (SR3), with shooting directions at the right bank of Khanas Dam.

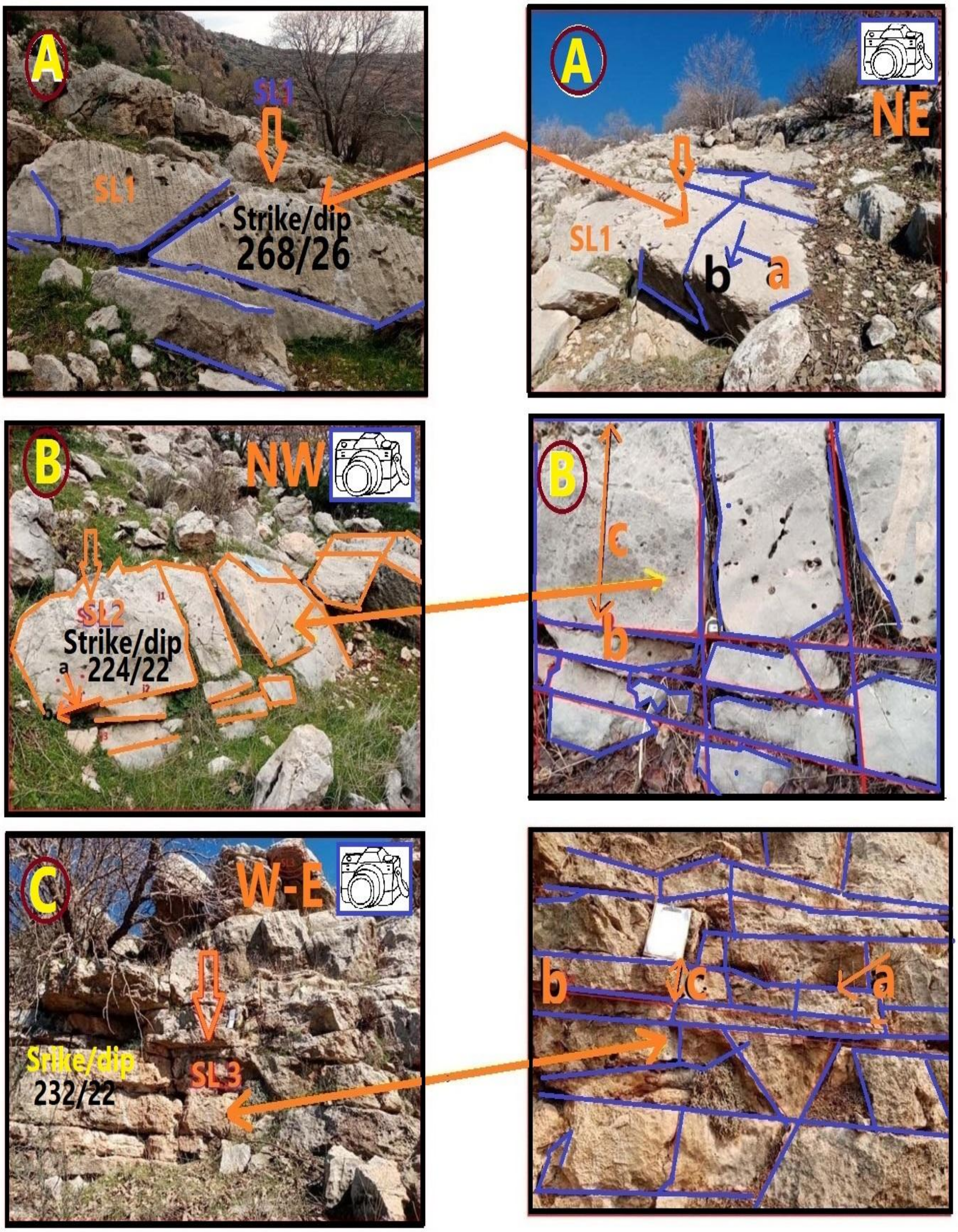

Plate 3: Pictures of A- First Station (SL1), B- Second Station (SL2), and C- Third Station (SL3), with shooting directions at the left bank of Khanas Dam.

Dam Mass Rating System (DMR)

It is known as the new geomechanical classification system created by scientists (Romana, 2003a). It is used in the foundations of dams and is better than the Rock Mass Rating system in the dam foundations for the following reasons:

1-Water pressure calculations are questionable as the water pressure ratio of voids changes along the length of the dam foundation.

2-There is no specific parameter that cares about the direction of joints. The idea of using a dam mass rating system is the same basis that is also used in studying the banks located towards the dam reservoir lake. The dam mass rating system is also used to evaluate the Rock Mass Rating located on the two banks of the Khanas Dam reservoir lake, which will be discussed in the following paragraph.

Stability Rocks for Khanas Dam Area

As stated by Snell and Knight (1991), the problem of the stability of the dam is dealt with systematically, taking into account all forces and pressures exerted dam. Depending on their study and other factors, a different set of adjustment factors must be applied. (Table 2) suggested by Romana (2003a) shows these new temporary adjusting factors that appeared according to the major discontinuity orientation. The numerical rating values originally proposed by Bieniawski were retained. When the dip direction of a joint is distinct and often not parallel to the inflow direction of the dam, the danger of sliding decreases because of the geometrical difficulties of sliding. It is possible to take into account this effect by multiplying the rating of the adjusting factor for dam stability (R_{STA}) by the geometrical correction factor (CF).

Table 2: Rating of the adjusting factor for the dam stability (R_{STA}) according to joints orientation"(Romana,2003a)

Type of Dam	VF	F	FA	U	VU
	Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
Fill	Others	10-30DS	0-10A	-	-
Gravity	10-60DS	30-60, 60-90A	10-30US	0-10A	-
Arch	30-60DA	10-30DS	30-60US, 60-90A	10-30US	0-10A
R_{STA}	0	-2	-7	15	-25

DS = dip Downstream, US = dip Upstream, A = any dip

The Dam Mass Rating of the rock block was calculated according to Rommana (2003b), where the relationship is as follows:

$$DMR_{(STA)} = RMR_{BD} + CF \times R_{(STA)}$$

Where, $DMR_{(STA)}$= Dam Mass Rating for the dam stability; (RMR_{BD})= the first four-parameters of Rock Mass Rating + water rating of 15)

$$CF = (1 - Sin\,|\alpha d - \alpha j\,|)^2$$

CF = Geometric correction factor

Where (α d) = inflow direction, (α j) = Dip direction of the significant discontinuity

The rating of the adjusting factor for dam stability (R_{STA}) is the adjusting factor for dam stability as in Table 2. Therefore, the DMR_{STA} is calculated, and the relationship between the value of DMR_{STA} and the degree of safety of the dam against sliding is suggested as a regional rule in Table 3 due to a lack of data that would allow such a correlation to be established (Romana,2003a). The results for both banks are shown in Tables 6 and 7.

Table 3: Correlation between (DMRSTA) and Degree of Safety (Romana,2003a).

DMR_{STA}	<30	30−60	>60
Degree of Safety	Serious Concern	Concern	No primary Concern

Geological Strength Index (GSI) For the Studied Area

The Geological Strength Index (GSI) was submitted by Hoek (1994), Hoek et al. (1995), and Hoek and Brown (1997) to overcome the deficiencies or shortcomings in Bieniawski for (very poor–quality rock blocks). The geological strength index evaluates the reduction in the strength of a rock block for different circumstances as determined through field notes. The rock block is characterized by visual viewing of a structure, in terms of blackness and surface condition of the discontinuities indicated by joint roughness and alteration (Hoek,1994). The geological strength index is expanded as experience is gained in its application to practical rock engineering dilemmas. During this current study, the geological strength index is evaluated through the following equation, through the Rock Mass Rating.

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

Alternatively, the quantitative modified geological strength index (Sonmez and Ulusay, 2002; Hamasur, 2009) is used. It is based on the relationship between the surface condition rating (SCR) of discontinuities along the X-axis on the chart and the structure rating along the Y-axis. This depends on the volumetric joint, with each being a limit whose value is calculated. The intersection of these values indicates the geological strength index of the rock block, as determined by the discontinuities present, as shown in figure (5). This index is calculated as follows:

Structure Rating (SR)=100 – 17.5322 *ln (j.v)*

Surface Condition Rating. (SCR)= R_r (rough)+R_w (weathering)+R_f (filling).

There is a difference between the values of the Geological Strength Index in Figure 3 and the values in Tables 4 and 5. Where it is relied upon, GSI = RMR_{89}-5.

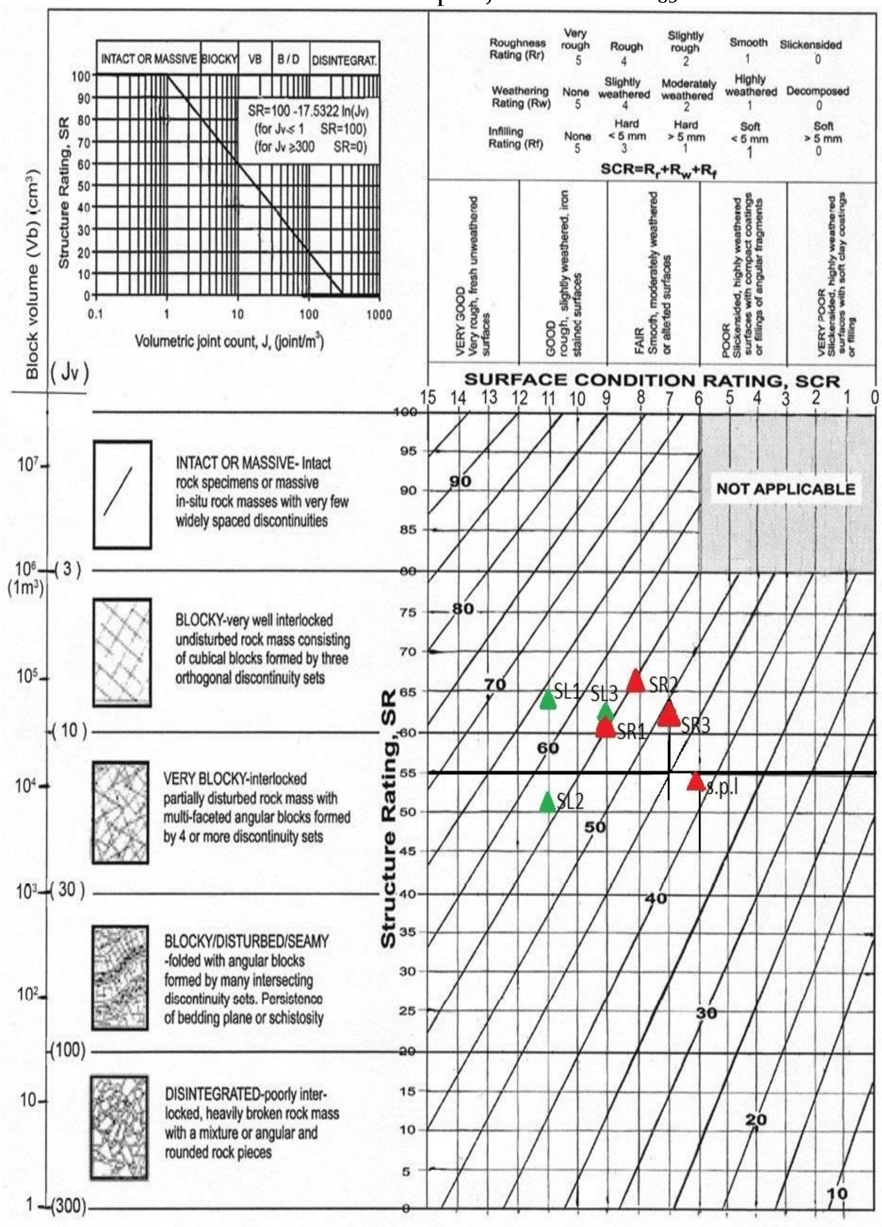

Fig. 3. The Quantitative modified geological strength index (SonmezandUlusay, 2002; Hamasur, 2009)

Table 4: Assessment of the (RMR) system in the spillway, first, second, and third stations at the right bank.

Geological Unit	Pila Spi Formation			
Rock mass unit	Spillway Station S.P.ST	First Right Station SR1	Second Right Station SR2	Third Right Station SR3
Height (above sea level)	478m	468m	492m	490m
The thickness of the unit (m)	0.40m	0.60m	0.69m	0.85m
Rock type	Limestone	Limestone	Limestone	Limestone
Strength of intact rock material USC(MPa)	16.600 MPa	10.61023 MPa	7.87425 MPa	20.642988 MPa
RQD	75.70%	87.3343%	92.680%	88.843%
The Average spacing of all discontinuities = $\frac{1}{Average\ j.v}$ According (Bieniawski,2011)	291.603mm	330.89mm	433.039mm	354.493mm
Condition of Discontinuities	1-Length of Discontinuities = (0.51) m 2- Separation = (3mm 3-Roughness rating = (rough) 4-Infilling soft filling (<5mm) 5-Weathering= (Moderate)	1-Length of Discontinuities = (0.60) m 2-Separation =(1mm) 3-Roughness rating = (rough) 4-Infilling soft filling (<5mm) 5-Weathering = (Slight)	1-Length of Discontinuities =(1.30)m 2-Separation(1mm) 3-Roughness rating =(very rough) 4-Infilling soft filling (<5mm) 5-Weathering =(Moderate)	1-Length of Discontinuities =(1.39) m 2-Separation= 1mm) 3-Roughness rating = (rough) 4-Infilling soft filling (<5m) 5-Weathering=(Moderate)
Groundwater condition	Dripping 4	Flowing 0	Damp 10	Damp 10
Volumetric joint count (joint vm^3)	13.71727	9.066279	6.92778	8.46277
RMR_{89}	50	51	61	57
Modulus Ratio of Intact rock (MR)	900	900	900	900
The material constant of intact rock (mi)	9	9	9	9
GSI	41	46	56	52

Table 5: Assessment of the (RMR) system in the first, second, and third stations at the left bank.

Geological Unit	Pila Spi Formation		
Rock mass unit	First Left Station SL1	Second Left Station SL2	Third Left station SL3
Height (above sea level)	506m	483m	496m
The thickness of the unit (m)	0.50m	0.40m	0.50m
Rock type	Chalky- limestone	Limestone	Limestone
Strength of intact rock material USC(MPa)	8.2018 MPa	11.97158 MPa	22.1267 MPa
RQD	91.3428%	71.173%	86.75%
The Average spacing of all discontinuities = $\frac{1}{Average\ j.v}$ According (Bieniawski,2011)	535.98mm	257.55mm	430.10mm
Condition of Discontinuities	1-Length of Discontinuities = (0.75) m 2-Separation (>5mm) 3-Roughness rating = (rough) 4-Infilling soft filling = (None) 5-Weathering = (Moderate)	1-Length of Discontinuities = (0.69) m 2- Separation (>5mm) 3-Roughness rating = (rough) 4-Infilling soft = (None) 5-Weathering = (Moderate)	1-Length of Discontinuities = (0.75) m 2-Separation (> 5mm) 3-Roughness rating = (rough) 4-Infilling soft filling(>5m) 5-Weathering = (Moderate)
Groundwater condition	Damp 10	Damp 10	Damp 10
Volumetric joint count (joint vm^3)	7.462857	15.530	9.3
RMR_{89}	62	55	53
Modulus Ratio of Intact rock (MR)	900	900	900
The material constant of intact rock (mi)	9	9	9
GSI	57	50	48

Table 6: Assessment of the (DMR_{STA}) system in the spillway, first, second, and third stations at the right bank.

Geological Unit	Pila Spi Formation			
Rock mass unit	Spillway Station S.P.ST	First Right Station SR1	Second Right Station SR2	Third Right Station SR3
Height (above sea level)	478m	468m	492m	490m
Rock type	Limestone	Limestone	Limestone	Limestone
Strength of intact rock material USC(MPa)	16.600 MPa	10.61023 MPa	7.87425 MPa	20.642988 MPa
RQD	75.70%	87.3343%	92.680%	88.843%
The Average spacing of all discontinuities = $\frac{1}{Average\ j.v}$ According (Bieniawski,2011)	291.603mm	330.89mm	433.039mm	354.493mm
Condition of Discontinuities	1-Length of Discontinuities = (0.51) m 2-Separation = (3mm) 3-Roughness rating = (rough) 4-Infilling soft filling (<5mm) 5-Weathering = (Moderate)	1-Length of Discontinuities = (0.60) m 2-Separation= (1mm) 3-Roughness rating = (rough) 4-Infilling soft filling (<5mm) 5-Weathering= (Slight)	1-Length of Discontinuities = (1.30) m 2-Separation= (1mm) 3-Roughness rating = (very rough) 4-Infilling soft filling (<5mm) 5-Weathering= (Moderate)	1-Length of Discontinuities = (1.39) m 2-Separation = (1mm) 3-Roughness rating = (rough) 4-Infilling soft filling (<5mm) 5-Weathering=(Moderate)
(first four parameters) of RMR	46	51	51	47
$RMR_{BD\ (89)}$= Four first five parameters of the Rock Mass Rating +15	61	66	66	62
Dip direction/dip for significant joints αj	190/26	144/24	185/20	160/22
Average of dip direction /dip amount	170/23			
The direction of the Dam axis	40NE			
Dip direction of upstream-downstream αd	130SE			
$R_{STA\ =}$ (Fill Dam)	-2			
CF= $(1\text{-Sin}\ \lvert αd\text{-}\ αj\ \rvert)^2$	0.4131759112			
(CF ×R sta)	-0.8263518224			
$DMR_{STA}=RMR_{BD}+CF\times R_{STA}$	60.1736	65.1736	65.1736	61.1736

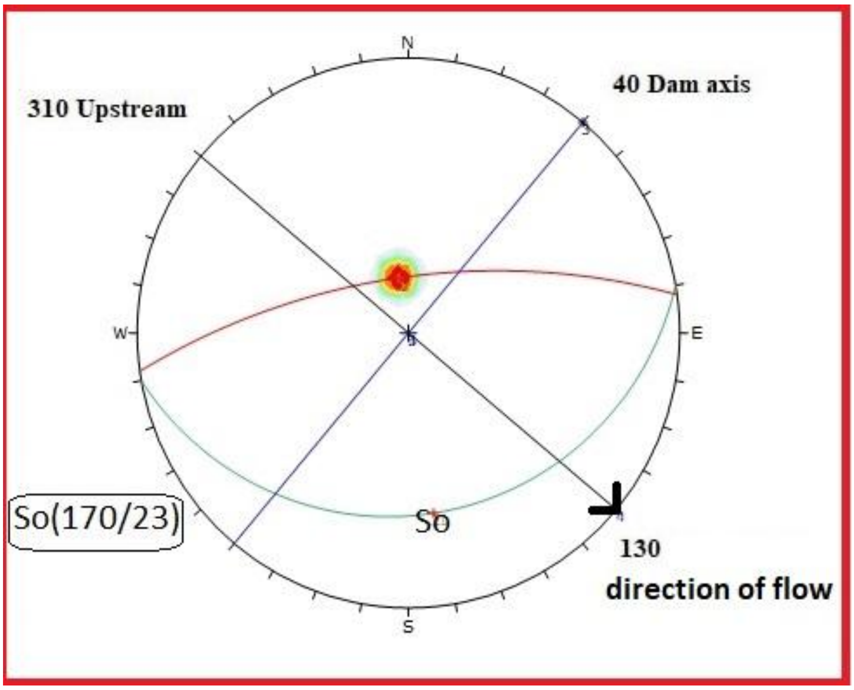

Fig. 4. Spatial projection showing the dip direction of bedding planes, the axis of the dam, and the direction of flow from upstream to downstream of the Gomel River, represented by the spillway, first, second, and third stations of the right bank of Khanas Dam.

Table 7: Assessment of the (DMR_{STA}) system in the first, second and third stations at the left bank.

Geological Unit	Pila Spi Formation		
Rock mass unit	First left Station SL1	Second left Station SL2	Third left Station SL3
Height (above sea level)	506m	483m	496m
Rock type	Chalky - Limestone	Limestone	Limestone
Strength of intact rock material USC(MPa)	8.2018 MPa	11.97158 MPa	22.1267 MPa
RQD	91.3428%	71.173%	86.75%
The Average spacing of all discontinuities = $\frac{1}{Average\ j.v}$ According (Bieniawski,2011)	535.98mm	257.55mm	430.10mm
Condition of Discontinuities	1-Length of Discontinuities = (0.75) m 2-Separation (>5mm) 3- Roughness rating = (rough) 4-Infilling soft filling = (None) 5-Weathering= (Moderate)	1-Length of Discontinuities = (0.69) m 2-Separation = (1mm) 3-Roughness rating = (rough) 4-Infilling soft = None 5-Weathering= (Moderate)	1-Length of Discontinuities =(0.75) m 2-Separation (> 5mm) 3-Roughness rating = (rough) 4-Infilling soft filling (>5mm) 5-Weathering= (moderate)
(first four parameters) of RMR	52	45	43
$RMR_{(89)}$= Four first five parameters of the Rock Mass Rating + 15	67	60	58
Dip direction/dip for significate joints αj	178/26	136/22	142/22
Average of dip direction /dip amount		152/23	
The Direction of the Dam axis		40NE	
Dip direction of upstream-downstream αd		130SE	
$R_{STA} =$ (Fill Dam)		-2	
$CF= (1-\text{Sin} \lvert αd- αj \rvert)^2$		0.1403300998	
(CF × Rsta)		-0.2806601997	
$DMR_{STA}=RMR_{BD}+CF \times R_{STA}$	66.4386	58.4386	57.4386

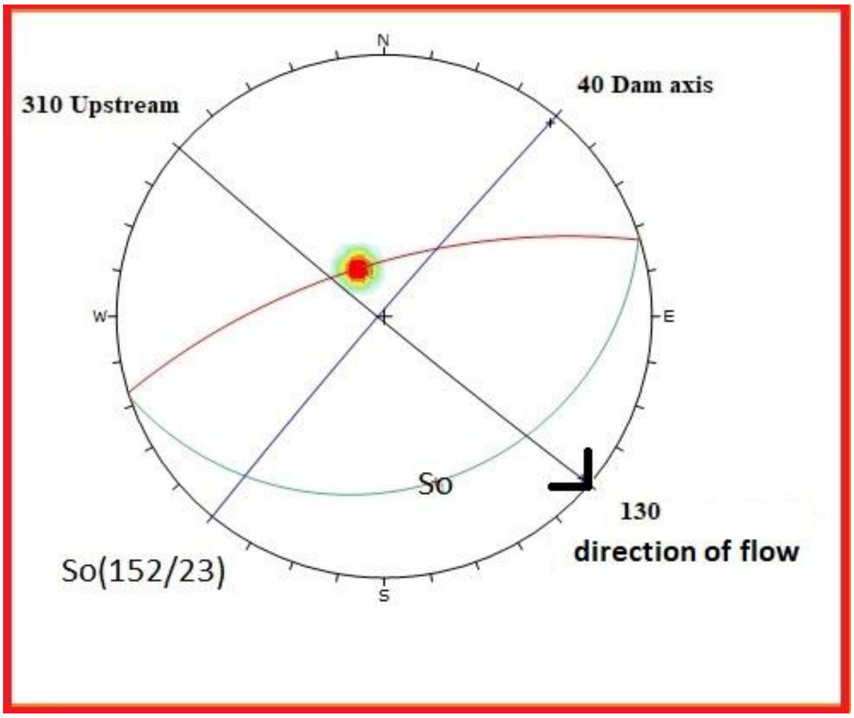

Fig. 5. Spatial projection showing the dip direction of bedding planes, the axis of the dam, and direction of flow from upstream to downstream of Gomel River, represented by the first, second, and third stations of the left bank of Khanas Dam.

Table 8: Analysis of rock strength for stations at the right bank (Pila Spi Formation) using the Roclab program.

Geological Unit	**Pila Spi Formation**			
Rock mass unit	Spillway Station S.P.ST	First Right Station SR1	Second Right Station SR2	Third Right Station SR3
Height (above sea level)	478m	468m	492m	490m
Rock type	Limestone	Limestone	Limestone	Limestone
Strength of intact rock material USC(MPa)	16.600	10.61023	7.87425	20.642988
GSI	45	46	56	52
Values of the constant mi for intact rock	9	9	9	9
Disturbance Factor	0.4	0.4	0.4	0.4
Modulus ratio (MR)	900	900	900	900
Ei= Modulus of elasticity of intact rock Ei= MR *σ_{CI}	14940	9549	7086.82	18578.7
Cohesion	0.615MPa	0.401MPa	0.362MPa	0.877MPa
Friction angle	24.26°	24.61°	28.15°	26.72°
Mb	0.772	0.808MPa	1.262MPa	1.056MPa
S	0.0009	0.0010	0.0035	0.0021
a	0.508	0.508	0.504	0.505
Rock mass parameters				
Tensile strength	-0.019MPa	-0.013MPa	-0.022MPa	-0.042MPa
Uniaxial compressive strength	0.462MPa	0.316MPa	0.459MPa	0.923MPa
Global strength	1.903MPa	1.249MPa	1.207MPa	2.846MPa
Deformation modulus	1841.60MPa	1257.81MPa	1769.93MPa	3623.45MPa

Table 9: Analysis of rock strength for stations at the left bank (Pila Spi Formation) using the Roclab program.

Geological Unit	**Pila Spi Formation**		
Rock mass unit	First left Station SL1	Second left Station SL2	Third left Station SL3
Rock type	Chalky-Limestone	Limestone	Limestone
Strength of intact rock material USC(MPa)	8.2018MPa	11.975186MPa	22.12670MPa
GSI	57	50	48
Values of the constant mi for intact rock	9	9	9
Disturbance Factor	0.4	0.4	0.4
Modulus ratio (MR)	900	900	900
Ei= Modulus of elasticity of intact rock Ei= MR *σ_{Ci}	7381.26	10777.7	19914.03
Cohesion	0.385MPa	0.489MPa	0.869MPa
Friction angle	28.51°	26.02°	25.31°
Mb	1.320	0.966	0.883
S	0.0040	0.0016	0.0013
a	0.504	0.506	0.507
Tensile strength	-0.025MPa	-0.020MPa	-0.032Mpa
Uniaxial compressive strength	0.511MPa	0.468MPa	0.755MPa
Global strength	1.291MPa	1.566MPa	2.746MPa
Deformation modulus	1955.11MPa	1847.75MPa	2994.44MPa

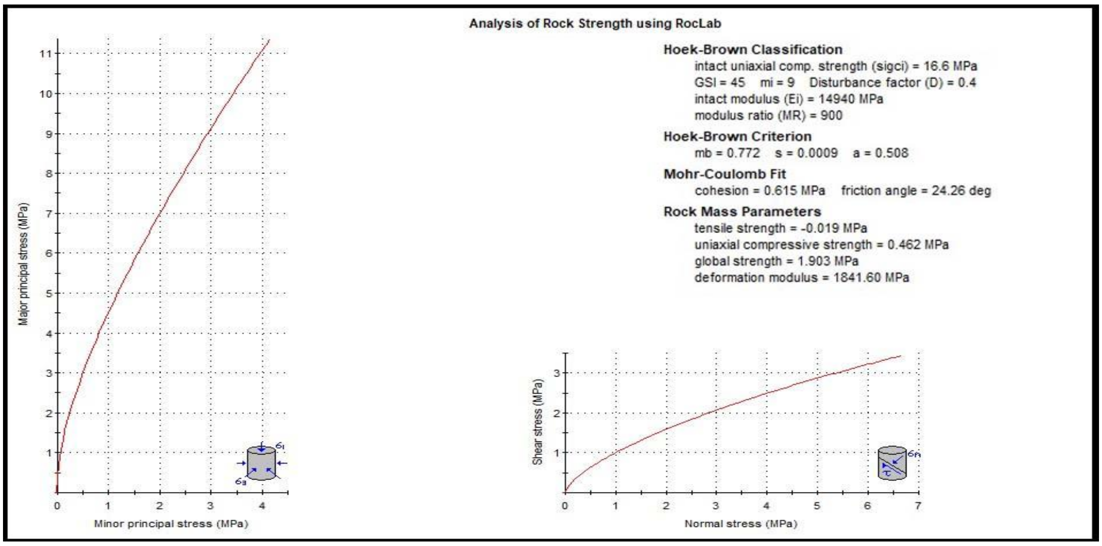

Fig. 6. Analysis of rock strength for spillway station (Pila Spi Formation-limestone), using RocLab program.

Conclusion

The following conclusions are reached to evaluate the rock masses belonging to the Pila Spi Formation rocks, which represent the foundation rock of the dam and the reservoir area.

Assessment of the rock masses according to the Rock Mass Rating System (RMR) is fair for rock masses, except second station on the right bank and except for the first station on the left bank of the dam, which have good rock masses.

The degree of safety using the Dam Mass Rating System (DMR_{STA}) of the rock masses of the right bank of the dam is (a nonprimary concern), while on the left bank of the dam is (concern), except the first station on the left bank of the dam is (nonprimary concern).

According to the Geological Strength Index (GSI), the rock masses are of fair quality on the right bank of the dam, except for the second station is of good quality, while the rocks on the left bank are of fair quality, except for the rocks of the first station are of good quality.

According to the results of the Uniaxial Compressive Strength obtained through the RocLab program, the right bank rocks have (0.462MPa), (0.316MPa), (0.459MPa) and (0.923MPa) for the (spillway, first, second, third) stations respectively, while the values of (USC) on the left bank are (0.511 MPa),(0.468 MPa)and(0.755 MPa) for the (first, second, and third) stations respectively..

According to the results of Tensile Strength obtained using the RocLab program, for the right bank rocks have (-0.019 MPa), (-0.013 MPa), (-0.022 MPa) and (-0.042 MPa) for the (spillway, first, second and third) stations respectively, while the values of Tensile strength on the left bank rocks are (-0.025MPa), (-0.020MPa), and (-0.032MPa) for the (first, second and third) stations respectively.

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