SLOPE STABILITY ASSESSMENT WITHIN AND AROUND THE RESERVOIR OF THE PROPOSED BASARA DAM, SULAIMANIYAH, NE IRAQ

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ABSTRACT

The study of the slope stability within and around the reservoir of the proposed Basara dam near Delaizha village, Sulaimaniyah District, Kurdistan Region, NE Iraq is carried out. To evaluate the stability of slopes in the studied area, sixteen stations were selected within and in the vicinity of the reservoir area, fourteen stations in the rock slopes, and two stations in the soil and talus sediments.

In this study, the stability of the rock slopes have evaluated by a new system, known as Landslide Possibility Index (LPI), as well as the approach of Hoek and Bray for those stations that are near the proposed dam site and need a detailed study. Moreover, the soil and talus slopes have evaluated by conventional methods.

The application of the LPI system leads to the conclusion that the possibility of failures and the degree of hazard in the eight rock slopes, Stations No. 2, 5, 8, 9, 11, 12, 13 and 15 is **Moderate**, while in the six remained rock slopes, Stations No. 1, 3, 4, 6, 7 and 10; the possibility of failures and the degree of hazard is **High**.

Detailed study of rock slopes in the vicinity of the proposed Basara dam (Stations No. 1 and 2) revealed that they are unstable, where toppling, rock fall, rock rolling have occurred. Further failures will occur in the future, which might affect the stability of the dam, because during toppling and/ or rock fall; some of the blocks may roll down into the reservoir of the dam, when it is filled by water, where the consequences will be very hazardous.

The study of the soil and talus slopes revealed that soil slump had occurred in Station No. 14, which is recognized by leaning of the trees down slope and the moved soil left a scar due to movement. While in the talus slope (Station No. 16) rock rolling and falling have occurred, because the slope has a direct contact with the valley floor and being continuously under-cut by water currents during floods, thus the water currents have removed, the fine materials between large blocks.

تقييم استقرارية المنحدرات داخل وحول خزان سد "باسرة" المقترح، السليمانية، شمال شرق العراق

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المستخلص

تم في هذا البحث دراسة استقرارية المنحدرات داخل وحول خزان سد "باسرة" المقترح، الواقع بالقرب من قرية ديليزة في محافظة السليمانية، إقليم كوردستان، شمال شرق العراق. تم اختيار ستة عشر محطة داخل منطقة الخزن والمناطق القريبة منها، وذلك لتقييم استقرارية المنحدرات في المنطقة، أربعة عشر محطة تقع في المنحدرات الصخرية، بينما تقع محطتين في التربة والترسبات المنجرفة (Talus) (مزيج من القطع أو الكتل الصخرية والتربة).

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تم تقييم استقرارية المنحدرات الصخرية بأحد الأنظمة الجديدة والمعروفة بدليل إحتمالية الإنزلاق الأرضي (Landslide Possibility Index, LPI)، بالإضافة الى وسيلة Hoek and Bray لتلك المحطات القريبة من موقع السد والتي تتطلب دراسة مفصلة، بينما تم تقييم المنحدرات المتكونة من التربة والترسبات المنجرفة بالطرق التقليدية.

من خلال تطبيق نظام LPI، وجدنا بأن احتمالية الإنهيالات ودرجة الخطورة في ثمانية منحدرات صخرية (المحطات رقم 2، 5، 8، 9، 11، 12، 13 و 15) تكون **متوسطة** بينما في المنحدرات الصخرية الست المتبقية (المحطات رقم 1، 3، 4، 6، 7 و 10) تكون **عالية**.

أظهرت الدراسة التفصيلية للمنحدرات الصخرية القريبة من السد المقترح (المحطتين رقم 1 و 2) بأنها غير مستقرة، حيث حدثت إنهيالات من نوع الانقلاب والسقوط الصخري والدحرجة الصخرية ومن المتوقع حدوث المزيد من الإنهيالات في المستقبل والتي ستؤثر على استقرارية السد، لأنه أثناء الانقلاب والسقوط الصخري، فإن بعض الكتل الصخرية ستتدحرج أو تزحف الى الأسفل وتسقط في خزان السد خصوصا بعد المليء، والعواقب تكون خطرة جدا.

أظهرت دراسة المنحدرات المتكونة من التربة والترسبات المنجرفة بأن الهبوط الترابي (Soil slump) قد حصل في المحطة رقم 14، حيث تم التعرف على هذا النوع من الانهيال من خلال ميلان الأشجار أسفل المنحدر وترك أثر نتيجة للحركة. في حين حدثت في المنحدرات الجرفية (المحطة رقم 16) إنهيالات من نوع الدحرجة الصخرية أو السقوط الصخري والدحرجة معا، لكون المنحدر في تماس مباشر مع قاع الوادي، وهذا بدوره يؤدي الى تعرية مستمرة من قبل التيارات المائية إثناء السيول الجارفة وإزالة المواد الناعمة من بين الكتل الكبيرة.

INTRODUCTION

Evaluation of the unstable slopes within and around the margin of the reservoir area of the proposed Basara Dam is considered; as a necessary task, due to their effect on the stability of the dam. Many engineering projects have failed by catastrophic landslides, such as the Vajont slide in Italy on October 9, 1963, which resulted in the destruction of the Vajont Dam (Blyth and de Freitas, 1985). Many researchers studied the effect of the unstable slopes on the stability of the dams. Sissakian *et al*. (2006), studied the unstable slopes of the western limits of the Makhool Dam reservoir, which is located on the Tigris River, and they referred to the occurrence of landslides and increasing of the possibility of sliding after filling the reservoir. Schuster (1979) also had pointed out that the reservoir induced landslides phenomenon is very common, so the expected landslides will affect on the stability of the dam.

▪ Location and Geological Setting

The study area is located in Sulaimaniyah Governorate, Kurdistan Region, NE Iraq, about 25 Km to the southwest of Sulaimaniyah city (Fig.1). Tectonically, the studied area is located near the southwestern boundary of the High Folded Zone, which is characterized by high mountains and intense folding resulted from Alpine Orogeny. All the existing geological formations in the studied area are shown in the geological map (Fig.2), where the oldest one is Kolosh Formation and the youngest one is Mukdadiya Formation.

▪ Bulk of the Study

In this study, 14 stations in rock slopes (Stations No. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 15) were selected; within and in the vicinity of the reservoir area. Moreover, 2 stations (Stations No. 14 and 16) in the soil and talus sediments were selected (Fig.2). The possibility of landslide occurrence within the 14 mentioned rock slopes was evaluated; by using the Landslide Possibility Index (LPI) system (Bejerman, 1994), who evaluated rock slopes stability of 2831 m of road, near Los Molinos dam (Cordoba, Argentina) (Bejerman, 1998). This system uses rating, which establishes the failure possibility and to indicate the need for a detailed study. Further study was carried out for those stations, which need a detailed study to determine the type of failure using Hoek and Bray (1981) method.

Fig.1: Location map of the studied area

LANDSLIDE POSSIBILITY INDEX (LPI)

The Landslide Possibility Index (LPI) allows assessing the landslide possibility for rock slopes cut in mountainous roads (Bejerman, 1994). This estimation system takes into consideration characteristic features of the slope estimated in the field, and later integrated in the LPI-chart, such as that shown in Form (1).

The main features to be considered are:

1- Slope height
2- Slope angle
3- Grade of fracture of the rock mass
4- Grade of weathering of the rock mass
5- Gradient of the discontinuities
6- Spacing of the discontinuities
7- Orientation of the discontinuities
8- Vegetation covers
9- Water infiltration
10- Previous landslides

Form (1) shows the estimated values for each of these characteristics. After each factor is quantified, the obtained values are added up in order to determine the LPI for the slope. The LPI index establishes the failure possibility by defining the six categories (Table 1).

Table 1: Failure category for each LPI category (After Bejerman, 1994)

LPI Category	Failure Possibility	LPI
I	Small	0 – 5
II	Very low	6 – 10
III	Low	11 – 15
IV	Moderate	16 – 20
V	High	21 – 25
VI	Very high	> 25

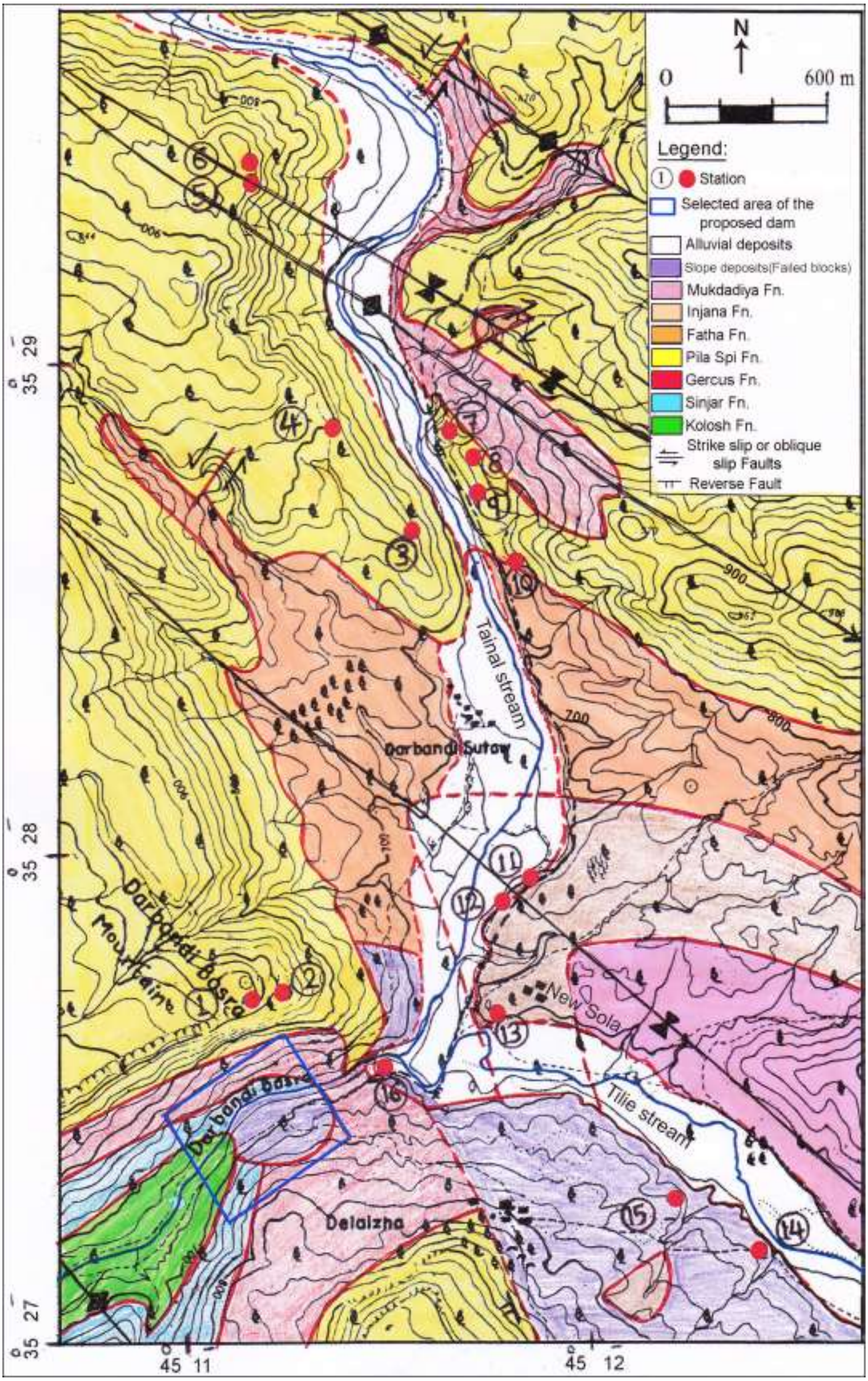

Fig.2: Geological map shows locations of the studied assessed slopes (stations with serial numbers) (Modified from Hamasur, 2009)

Form 1: Chart of Landslide Possibility Index Features
(After Bejerman, 1994)

NUMBER SLOPE [| |] PAGE [| |]

KILOMETER [| | | |] DATE [| | | | |]

1. SLOPE ESTIMATE HEIGHT (m)

1 ----------- 8	1
9 ----------- 15	2
16 ---------- 25	3
26 ---------- 35	4
> ---------- 35	5

2. SLOPE ESTIMATE ANGLE

< 15°	0
15° ------ 30°	1
30° ------ 45°	2
45° ------ 60°	3
> 60°	4

3. GRADE OF ESTIMATE FRACTURE

Sound	0
moderately fractured	1
highly fractured	2
completely fractured	3

4. GRADE OF ESTIMATE WEATHERING

Fresh	0
slightly weathered	1
moderately weathered	2
highly weathered	3
completely weathered	4
residual soil	5

5. GRADIENT OF ESTIMATE THE DISCONTINUITIES

< 15°	0
15° ------ 30°	1
30° ------ 45°	2
45° ------ 60°	3
> 60°	4

6. SPACING OF ESTIMATE THE DISCONTINUITIES

> 3 m	0
1 --------- 3 m	1
0.3 ------- 1 m	2
0.05 --- 0.3 m	3
< 0.05 m	4

7. ORIENTATION OF THE ESTIMATE DISCONTINUITIES

favorable	0
unfavorable	4

8. VEGETATION ESTIMATE COVER

void	(< 20%)	0
scarce	(20 - 60%)	1
abundant	(> 60%)	2

9. WATER INFILTRATION ESTIMATE

inexistent	0
scarce	1
abundant:	
permanent	2
seasonal	3

10. PREVIOUS LANDSLIDES ESTIMATE

Not registered	0
registered (small volume)	1
registered (high volume)	2

1 + 2 + 3 + 4 ± 5 + 6 + 7 + 8 + 9 + 10 = [|]

I (small) (0 – 5)	III (low) (11 – 15)	V (high) (21 – 25)
II (very low) (6 – 10)	IV (moderate) (16 – 20)	VI (very high) (> 25)

The LPI value is obtained by adding the estimations of attributes 1 to 10. If the orientation of the discontinuities is favorable, subtract the estimation of gradient.

OBSERVATIONS:

If the orientation of the discontinuities is favorable (in the opposite direction of the slope), then the value of the estimation for the discontinuity gradient is subtracted from the total LPI in order to correct the LPI value, which in this case, contributes to the stability of the slope. It should be noted that the assessment of the LPI category does not establish how much or when the rock may slide and which method for stabilization should be used.

With the defined LPI for each rock slope, the land sliding hazard of the rock slope can be evaluated. The hazard categories considered by Bejerman (1998) are shown in Table (2).

LANDSLIDE SUSCEPTIBILITY OF THE ROCK SLOPES

In this study, 14 rock slopes (Stations No. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 15) were evaluated with reference to their possibility of landslides by means of the LPI. The ten characteristic features for each rock slope; in the fourteen stations were estimated according to Form (1), and the results are summarized in Table (3).

The data in Table (3) shows that the possibility of failure and the degree of hazard in the eight rock slopes (Stations No. 2, 5, 8, 9, 11, 12, 13 and 15) is "Moderate", while in other six slopes (Stations No. 1, 3, 4, 6, 7 and 10) the possibility of failure and the degree of hazard is "High".

The proposed dam site is at elevation of 670 m (a.s.l.) and the proposed height of the dam is 60 m, so the upper level of the water in the reservoir of the dam will be at elevation of 730 m (a.s.l.) (Hamasur, 2009).

From comparison of the height of the upper level of the water in the reservoir and elevation of the rock slopes (Table 3), some of the evaluated rock slopes will be inundated by water; after filling of the reservoir; as in the Stations No. 9, 10, 11, 12 and 13, and they become less stable and more liable to failure. The toe of the rock slopes in the stations: 7 and 15 is already inundated by water, and then this new situation (inundation of the slope toe) promotes the occurrence of failures; due to the effect of water pressure, which causes the reduction of shear strength.

Stations No. 1 and 2 lie at elevation 940 and 895 m (a.s.l.), respectively, their possibility to failure is "High" and :Moderate", respectively (Table 3) and they are located at the right bank near the proposed dam site. If large blocks (about tens of tons; in weight) fall down near to the Stations No. 1 and 2, then dangerous situation may be occurred and affect the stability of the dam through creating water waves near the dam site; due to increasing the acceleration of the expected and falling blocks from the high altitudes, therefore, these two stations need a detailed study.

Table 2: Landslide hazard category (after Bejerman, 1998)

LPI Category	Hazard Possibility
I – II	Low
III – IV	Moderate
V – VI	High

Table 3: Summary of Landslide Possibility Index (LPI) System of the fourteen rock slopes in the study area

Characteristic Features of the Slop	Rock Slop Stations													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**15**
1- Slope height	5	5	5	5	5	5	3	1	2	2	1	1	1	3
2- Slope angle	4	4	4	4	4	4	4	4	4	4	4	4	4	2
3- Grade of fracture of the rock mass	1	1	1	1	1	1	2	1	1	3	1	1	1	1
4- Grade of weathering of the rock mass	1	1	1	2	1	1	2	1	1	2	1	1	2	3
5- Gradient of the discontinuities	+ 4	+ 1	+ 3	+ 3	+ 1	+ 4	+ 3	+ 4	+4	+4	+ 4	+ 4	+ 4	+ 2
6- Spacing of the discontinuities	1	1	2	1	1	1	2	1	2	3	0	0	1	2
7- Orientation of the discontinuities	4	4	4	4	4	4	4	4	4	4	4	4	4	4
8- Vegetation cover	0	0	0	0	0	0	0	0	0	0	0	0	0	1
9- Water infiltration	0	0	0	3	0	0	0	0	0	0	0	0	0	0
10- Previous landslides	2	2	2	2	2	2	1	1	2	1	2	2	2	2
LPI	22	19	22	25	19	22	21	17	20	23	17	17	19	20
LPI category	V	IV	V	V	IV	V	V	IV	IV	V	IV	IV	IV	IV
Failure Possibility	H	M	H	H	M	H	H	M	M	H	M	M	M	M
Hazard category	H	M	H	H	M	H	H	M	M	H	M	M	M	M
Elevation (m) (a.s.l.)	940	895	770	808	888	890	736	759	727	726	710	705	708	735
Max. dam height (m) (a.s.l.)	730	730	730	730	730	730	730	730	730	730	730	730	730	730

H: High, M: Moderate

▪ **Detailed Stability Study of Stations No. 1 and 2**

It appears from the Fig. (2) that Stations No. 1 and 2 are very close to the proposed dam site. Geological mapping of the slope, bedding plane and discontinuities' measurements were carried out; including measurements of slope height and attitude, attitude of bedding planes and their thickness, attitude and spacing of discontinuities.

The discontinuities were classified according to the relationship between the attitude of the discontinuities and strata with respect to three orthogonal tectonic axes (a, b and c) according to Hancok and Atyia (1979) classification. The slopes are classified here according to Al-Saadi (1981) classification.

The release surfaces facilitate movements of the detached rock mass, because they separate it from the surrounding rocks (Hoek and Bray, 1981, and Al-Saadi, 1988 and 1991). In this study, the release surface terms were used in the same manner of Al-Saadi (1988 and 1991) , and as follows: The lateral release surfaces (L.R.S) are those surfaces, along which the detached mass moves, whereas the back release surfaces (B.R.S) are those surfaces, along which the detached mass moves away from them. The inclination of slope and the discontinuity (bedding planes and joints) in this study are expressed as follows: the slope or dip direction is written to the left and their amount (slope angle or dip angle) to the right, for example 215°/35°.

─ **Station No. 1:** It is located at the right bank near the proposed dam (Fig.2), at elevation of 940 m (a.s.l.), and at a height of 210 m above the water level; when the reservoir is filled. There are two slopes in this station, the general slope inclination is 160°/90° and that of the side slope is 090º/90º. The bedding planes are dipping with an average value of 079°/12°. Therefore, the general slope is orthogonal (divergence angle d1 = 81°), left emergent and discordant slope, while the side slope is a daylight, parallel (d2 = 11°), left emergent and concordant (Figs.3 and 4). The rocks of the the Station No. 1 are composed of dolomitic limestone of Pila Spi Formation. The bedding thickness ranges from (0.4 – > 2) m, they are dissected by two sets of joints, they are ac-joint set and bc-joint set (Figs.3 and 4), their spacing ranges from (0.5 – > 3) m, and their persistence is more than 20 m.

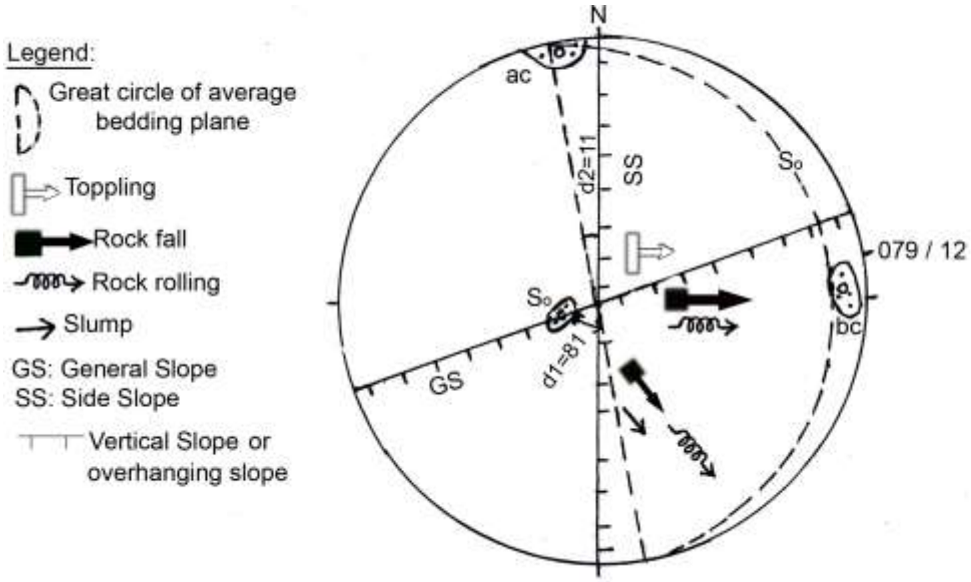

Fig.3: Stereographic projection shows the relationship between the slope, discontinuities and type of failure, in the Station No. 1

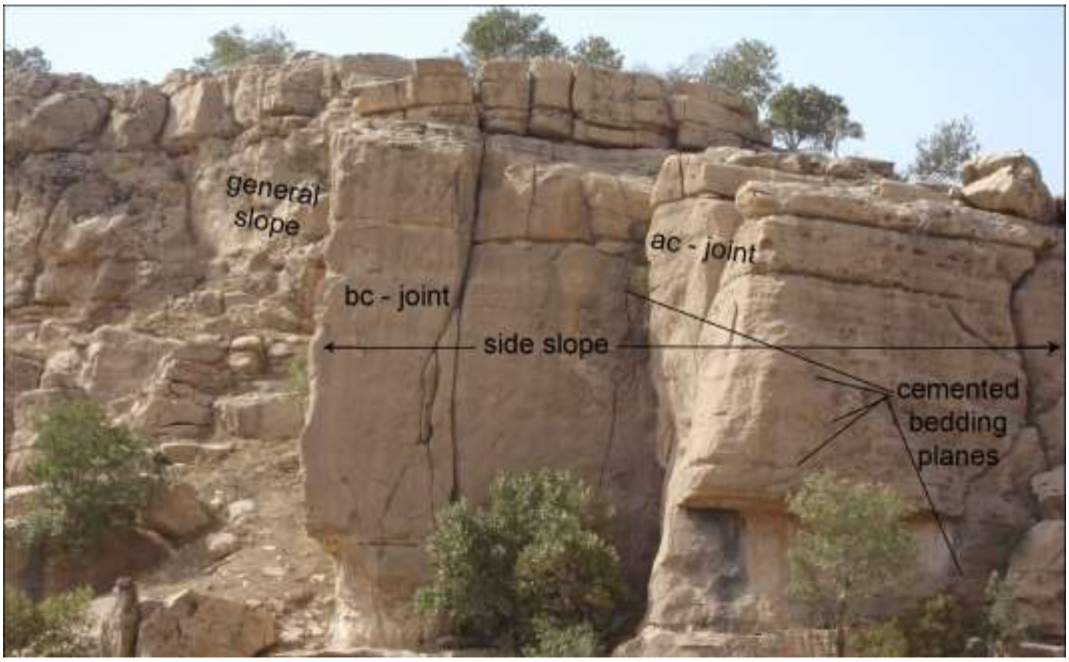

Fig.4: Unstable vertical slopes in the Station No. 1 within the Pila Spi Formation (The trees are about 4 – 6 m in height) (Photo direction is westwards)

The side slope (090°/90°) is unstable, wherein rock fall and toppling have occurred. Because the bedding planes below the upper part of the vertical slope are well cemented (having high cohesion), therefore, the effective spacing, which depends on the length of discontinuities and the size of the intact rock within a block that actually influences the height (h) or width (b) of the block of the bedding plane. Accordingly, leads to form high blocks up to 20 m in height and (2 – 3) m in width (Fig.4). The blocks are resting at an angle of 12° on the basal plane (bedding plane here), the ratio of b/h = 2.5 m/ 20 m < tan 12° (0.125 < 0.212). This leads to the weight vector of rock blocks to fall outside their base (Fig.5), then they are liable for toppling; when the cohesion on all discontinuities becomes zero, even blocks of less than 20 m in height may be subjected to secondary toppling by mechanism of failure by horizontal stress in σ_3 direction (perpendicular to free face) as mentioned by Evans (1981).

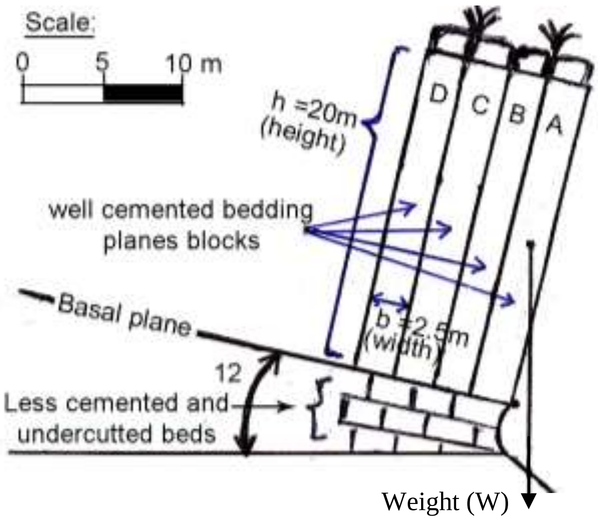

Fig.5: Geometry of rock blocks on inclined bedding plane (basal plane) at an angle 12° at the side slope in the Station No. 1

During toppling, the bedding planes act as basal plane, bc-joint acts as back release surface and the ac-joint acts as lateral release surface. Plane sliding does not occur because the friction angle of the bedding plane is greater than the bedding plane angle (12°).

The general slope (160°/90°) is also unstable, wherein the rock falls and secondary toppling (due to mechanism of failure by undercutting of dolomitic limestone beds below basal plane) have occurred, also due to the steepness of the slope further blocks fall and topple and they may be roll on the slope, then some blocks may reach the Basara stream.

It is worth mentioning that it appears from Fig. (2), there is a continuous high cliff of dolomitic limestone of the Pila Spi Formation to the left of the Station No. 1, due to occurrence of rock falls and toppling in the cliff and in the Station No. 1. The fallen blocks may rest on the dam site and some of them may reach to the water; after filling the reservoir, forming water waves, their amplitude depends upon the size of the fallen blocks, and this may create some hazards at the dam site or in the reservoir.

− **Station No.2:** It is located at a distance of 100 m to the east of the Station No. 1 (Fig.2), it has elevation of 895 m (a.s.l.), and a height of 165 m above the water level, when the reservoir is filled. There are two slopes in this station, inclination of the general slope is 090°/70°, and of the side slope is 160°/90°. The bedding planes are dipping with an average of 084°/24°. Therefore, the general slope is parallel (d1 = 6°), left emergent and concordant, while the side slope is orthogonal (d2 = 76°), left emergent and discordant (Fig.6).

The rocks of the Station No. 2 are composed of dolomitic limestone of Pila Spi Formation. The bedding thickness ranges from (0.4 – > 2) m, they are dissected by two sets of joints, they are ac-joint set and bc-joint set (Fig.6), their spacing ranges from (0.5 – 2.5) m, and their persistence is more than 10 m, especially of bc-joint set.

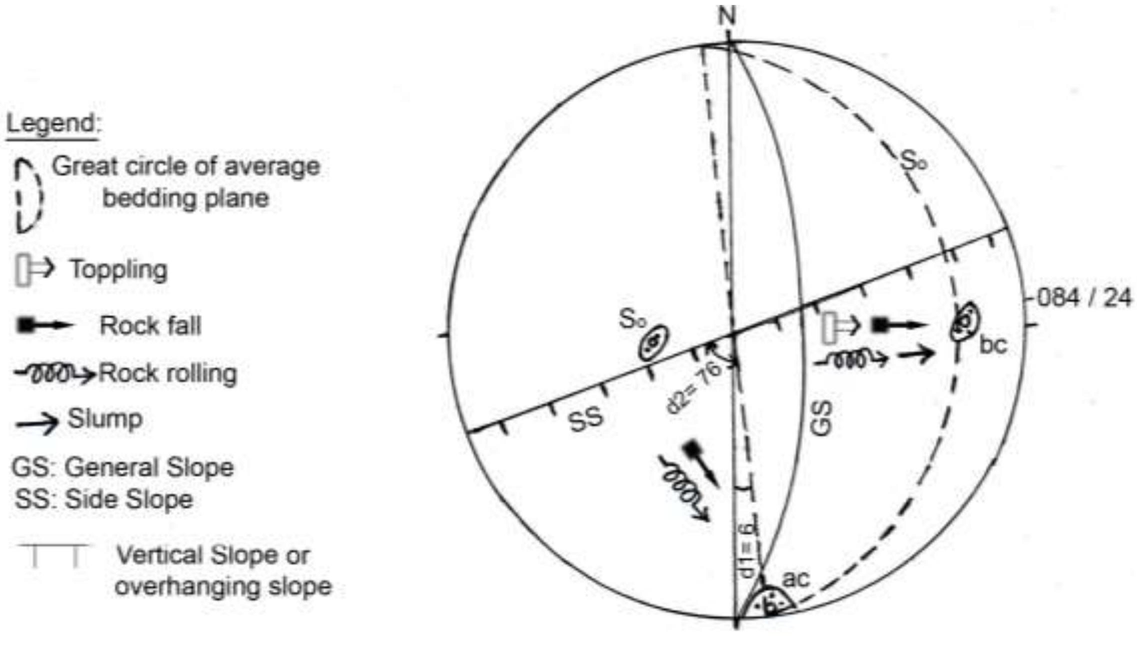

Fig.6: Stereographic projection shows the relation between the slopes, Discontinuities and type of failure in the Station No. 2

The two slopes in the Station No. 2 are unstable, many previous failures (toppling, rock fall, rock rolling and slumping) have occurred (Fig.7). The height of the upper steep part of the general slope (090°/70°) is about 10 m, and the lower part is inclined at angle ranges from (35° – 40°). The height of the upper part of the vertical side slope is more than 20 m (Fig.8). Some of the bedding planes are very tight (having high cohesion), this leads the effective spacing of the bedding to form blocks of about (5 – 7) m height and (0.5 – 2.5) m width (Fig.9), and they are resting on the basal plane (bedding plane) at an angle of 24° (Fig.10).

Fig.7: Fallen blocks on the general (main) slope at the Station No. 2
(the trees are about 2.5 – 4 m in height) (Photo direction is west wards)

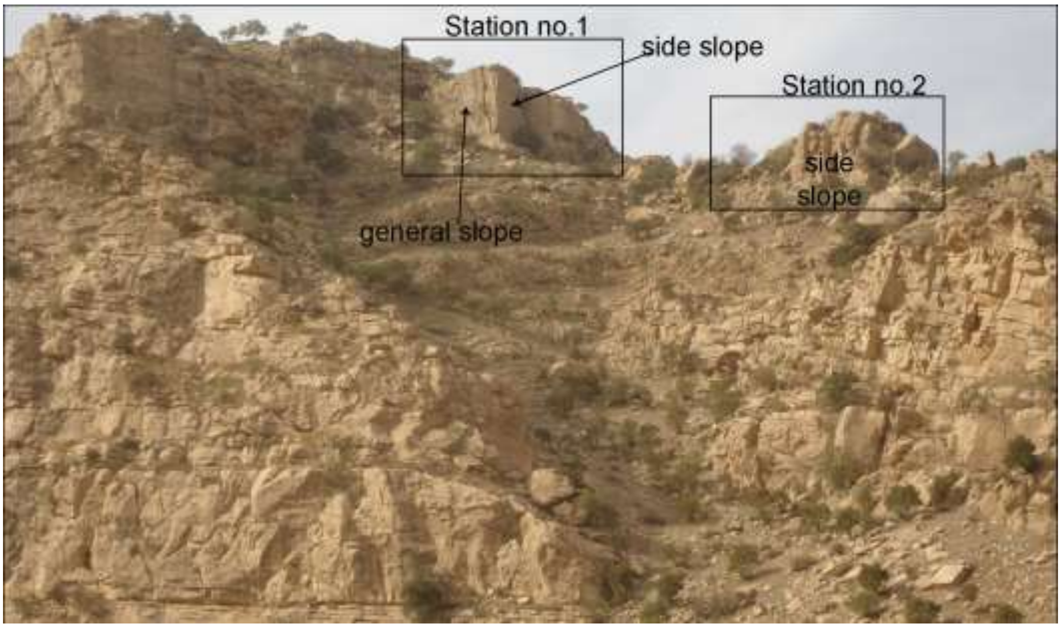

Fig.8: The side slope of the Station No. 2, also the Station No. 1 appears in this photo
(Photo direction is 340º)

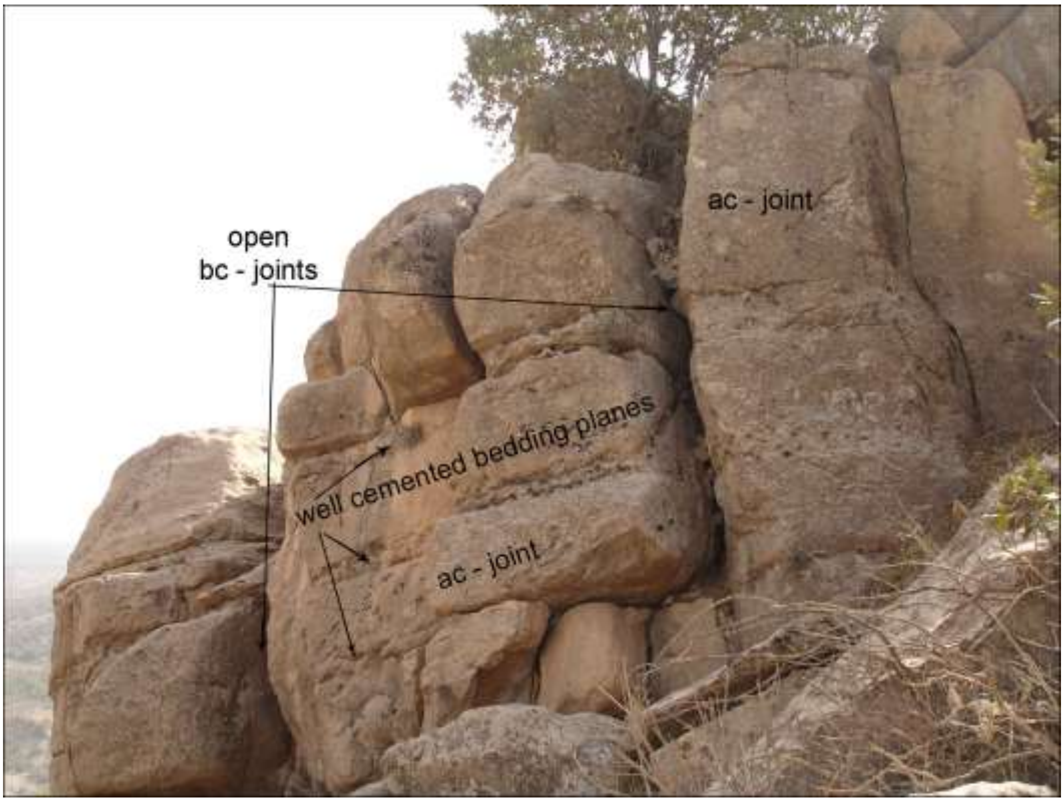

Fig.9: Very tight bedding planes, forming blocks of about (5 – 7) m in height in the Station No. 2 (the trees are about 3 – 4 m in height) (side view photo of the general slope in direction of 150º)

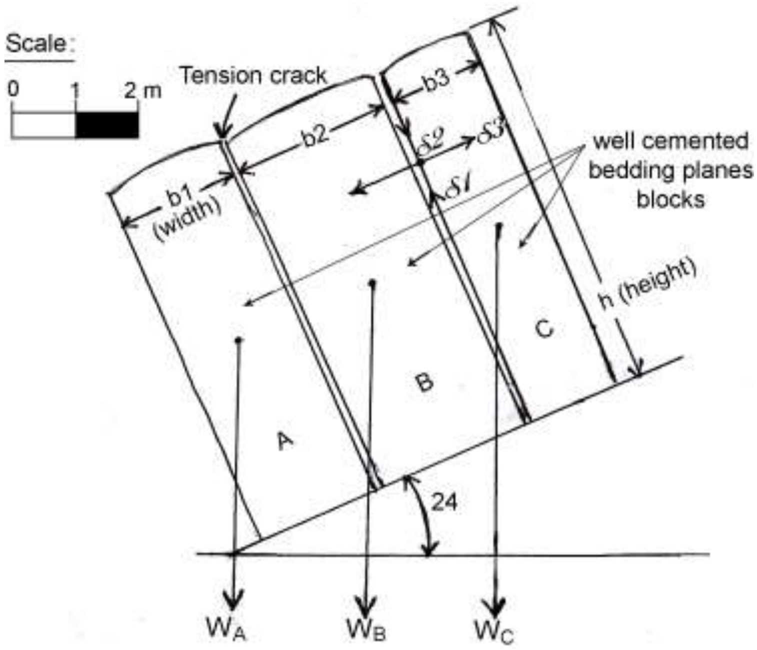

Fig.10: Geometry of rock blocks on inclined bedding plane (basal plane) at an angle 24º at the general slope in the Station No. 2

The weight vector of some rock blocks falls outside their base (b/h of rock blocks < tan 24°) or at critical state (Fig.10), then toppling or secondary toppling (tension crack toppling and slumping) as mentioned by some authors (Goodman and Bray, 1976) may occur in the general slope. The mechanisms involved in such toppling failure are the toppling induced by tension crack water pressure, when filled with water, and failure by horizontal stress in $б_3$ direction (perpendicular to the free face) plays a great role (Figs.10 and 11). The joints in the $б_3$ direction are invariably (always) open, indicating a fully stress relieved environment in this direction (Evans, 1981). This case is seen for bc-joint set as in Figs. (11 and 12). These states could act with some other primary failure mechanism to initiate toppling. Furthermore, rock fall may occur in the upper part of the slope. After the rock blocks are toppled and the fallen blocks may roll on the lower part of the slope (Fig.7). Rock fall followed by rock rolling is the dominant mode of failure in the side slope due to the steepness of the slope, and toppling failure may occur, but in small number because the basal plane is not inclined in the direction of the side slope. However, plane sliding does not occur in the general slope, because the average bedding plane angle (24°) is less than the friction angle of hard dolomitic limestone, which is more than 35° (Hoek and bray, 1981).

Fig.11: Tension crack represents bc-joint, is an indication of instability in the Station No. 2 (Photo was taken above the bedding plane)

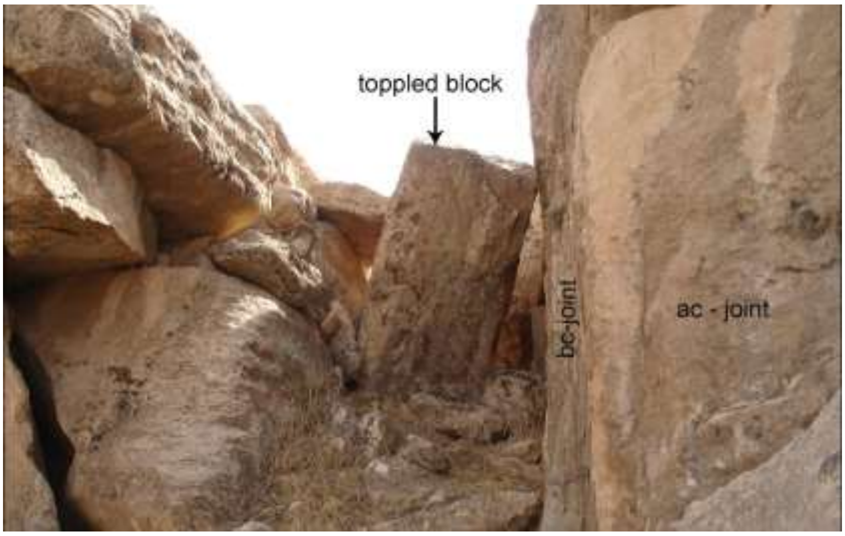

Fig.12: Large tension crack shows opening of bc-joint, ac-joint and toppled block in the Station No. 2 (Photo direction is 170º, parallel to the bc-joint)

EVALUATION OF SLOPE STABILITY IN SOIL AND TALUS SLOPES

Two slopes were selected in soil and talus; they are the Stations 14 and 16. These stations are unstable, where soil slump and rock debris fall have occurred and further failures will occur. Brief information about the stability of each station is discussed, hereinafter:

- **Station No. 14**

It is located nearby the left bank of Tele stream, to the east of Delaizha village, and at elevation of 715 m (a.s.l.) (Fig.2). The slope is at height of 20 m above Tele stream, and the inclination of the slope is 045°/(25 – 30) °. The slope is covered by brown clayey soil with some cobbles and small blocks of limestone. The slope is unstable and was subjected to shallow creep that left a scar in the slope (Fig.13). Such failure, most probably had occurred after heavy rainfall, because normally water causes reduction in the soil friction angle and cohesion and then reduction in the soil shear strength. More creep may occur in the future if torrential rainfall occurs again.

After filling the reservoir of the proposed dam, the Station No. 14 will be inundated, then more creep or slide may occur, and large amount of slope materials will be carried by the water, this will give increase in the rate of sedimentation in the reservoir (siltation).

It is worth mentioning that those slopes, which extend from the Station No. 14 for a distance of 1000 m to the northwest, besides the left bank of Tele stream are composed of a mixture of large limestone blocks and soil, they may be subjected to creep and slide after filling of the reservoir.

Fig.13: Soil slump shows the scar of moved mass in the Station No. 14
(Photo direction is 230º)

▪ **Station No. 16**

It is located near the converging of Tainal and Tele streams (near the inlet to Darband Basara), on the left bank of Basara stream, and at elevation of 690 m (a.s.l.) (Fig.2). The slope is covered by a mixture of large limestone blocks and clayey soil, silt and sand (Fig.14), fallen from the left cliff of the Pila Spi Formation, and mixed with the weathering products of the underlying Gercus Formation. The slope is unstable, because the toe of the slope has a direct contact with the valley floor and being continuously undercut by water currents during floods, thus the water currents wash out fine materials between the large blocks, and then rolling them to Basara stream valley. Further rolling may take place after filling of the reservoir.

Fig.14: Unstable large blocks of former failures from limestone cliff of the Pila Spi Formation at the Station No. 16 (Photo direction south wards)

CONCLUSIONS

The followings could be concluded from this study:

- The Landslide Possibility Index (LPI) system is considered as a rapid method in evaluating the degree of failure possibility in the rock slopes; it was used in the studied area indicating **Moderate** and/ or **High** degrees.
- Rapid evaluation of the landslide hazard degrees in the rock slopes of the studied area indicated **Moderate** and/ or **High** degrees, after evaluation the degree of landslide possibility.
- This study concluded that the possibility of failures in eight rock slopes (Stations No. 2, 5, 8, 9, 11, 12, 13 and 15) is **Moderate** and the degree of hazard is **Moderate** as well, while in

other six rock slopes (Stations No. 1, 3, 4, 6, 7 and 10) the possibility of failure is **High** and the degree of hazard is **High** as well.

- The LPI system shows that; as the vegetation cover is high in the rock slopes, as the possibility of failure is also high because the growth of plant roots causes widening of the rock fractures.
- The detailed study of rock slopes; near the proposed Basara dam site (Stations No. 1 and 2) shows that these slopes are unstable, where toppling, rock falls and rock rolling have occurred and further failures will occur in the future, which can affect the stability of the dam, due to the creation of water waves by the rolling rock blocks into the reservoir after construction of the dam and filling of the reservoir.
- Further creep may occur in the soil slope (Station No. 14) and in the extensive areas along and around this station, because they are covered by soil or mixture of soil and rock blocks. The toe of these slopes will be inundated after construction of the dam and filling of the reservoir, this will give rise to reduction in the shear strength of the soil, hence more creep or flow in the soil or talus slopes may occur.

RECOMMENDATION

This study recommends that the stabilization of the unstable slopes is necessary for increasing the stability of the proposed dam. Different types of failures require different methods of stabilization; therefore, a detailed study of modes of failure in all unstable slopes should be performed, before construction of the dam.

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