THE INFLUENCE OF UNSTABLE SLOPES ON THE STABILITY OF MAKHOOL DAM – CENTRAL IRAQ

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ABSTRACT

Makhool dam (under construction, which is stopped neither to) is located on the Tigris River about 30 km northwest of Baiji town. The reservoir extends to Sharqat vicinity. The exposed rocks within the reservoir area belong to the Fatha and Injana Formations. The former consists of marl, claystone, limestone and gypsum in cyclic nature. Whereas, the latter consists of claystone, siltstone and sandstone, in cyclic nature too. The western limits of the reservoir are bounded by scarps which belong mainly to Makhool and Khanoogah anticlines. Major parts of these scarps suffer from unstable slopes, along them many mass movements are developed. Moreover, the scarps are potential areas for development of mass movements, which will increase after construction of the dam, due to major change in water level. This will consequently change the properties of the exposed rocks and soils in the banks of the reservoir. The expected mass movements will influence on the stability of the dam, especially if they took place together at once.

The slopes and scarps of the western limits of the reservoir are divided into five zones. For each zone different characters are mentioned with estimating conditional and average probability of landslides occurrence. Moreover, unique terrain units are defined.

تأثير المنحدرات غير المستقرة على سد مكحول _ وسط العراق

فاروجان خاجيك سيساكيان ، صفاء الدين فخري فؤاد و هالة عطا الموسوي

المستخلص

يقع سد مكحول (تحت الإنشاء ومتوقف حاليا) على نهر دجلة بمسافة 30 كم شمال غرب مدينة بيجي وسيمتد الخزان الى مدينة الشرقاط. الصخور المنكشفة في منطقة الخزان تعود الى تكويني الفتحة وانجانه. تكون الصخور الجبسية والطفل والطين والكلسية التكوين الأول بينما يتألف الثاني من الصخور الرملية والغرينية والطينية. ان الحدود الغربية للخزان تتألف من منحدارت وجروف صخارية ضمن تركيبي مكحول وخانوكة. وان معظم الأجزاء الكبيرة من هذه الجروف تعاني من عدم استقرارية المنحدرات حيث توجد العديد من ظواهر الانهيال. كما ان هذه الجروف الصخارية تعتبر مناطق مناسبة لحدوث هذه الظواهر خاصة بعد امتلاء الخزان حيث ستزداد بسبب ارتفاع مستوى الماء والذي بدوره سيغير الخواص الميكانيكية للصخور والتربة الموجودة على الجروف الصخارية.

ان ظواهر الانهيال المتوقعة ستؤثر على استقرارية السد وخاصة اذا ما حدثت اعداد كبيرة منها في وقت واحد. تم تقسيم المنحدرات والجروف الصخارية الموجودة على الحدود الغربية للخزان الى خمسة انطقة. تم وصف خصائص مختلفة لكل نطاق مع ذكر الاحتمالية الشرطية ومعدل الاحتمالية لحدوث حركات الانهيال. كما تم تعريف الوحدات الخاصة لتضاريس المنحدرات.

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INTRODUCTION

Makhool dam, which is under construction, is located on the Tigris River, 30 km northwest of Baijy town and about 15 km downstream from the junction of the Lesser Zab River with the Tigris River (Fig. 1).The reservoir of the dam will extend to Sharqat vicinity, with maximum water level of 150 m (a.s.l.). The western limits of the reservoir are bounded by scarps which belong mainly to the flanks of Makhool and Khanoogah anticlines. Whereas, the eastern limits of the reservoir are bounded by gentle slopes that rise very gently towards northeast and north. This asymmetrical situation of the western and eastern limits of the reservoir, as compared to the location of the Tigris River, nowadays will lead to development of deeper parts of the reservoir alongside its western limits, which means strong asymmetry in the floor of the reservoir. Consequently, the amount of water (in the reservoir) alongside the western limits will be much bigger than that present alongside the eastern limits, if compared from the axial part of the reservoir.

The influence of the existing unstable slopes, along the western limits of the reservoir is studied, in order to elucidate what hazard they could cause to the dam. Moreover, the probability of landslide occurring is calculated too, after dividing the area into five zones of unique terrain conditions.

METHOD OF WORK

The main aim of this study is to evaluate the steep slope scarps that are located along the western limits of the reservoir and the hazard they may cause to the stability of the Makhool dam. In order to achieve the aforementioned aims the following materials and data were studied and evaluated:-

- Topographic maps 1:25 000 on scale.
- Geological maps 1:25 000, 1: 100 000 and 1:250 000 on scale.
- Aerial photographs 1: 42 000 on scale.
- Different geological reports and papers, concerning the involved area.
- Terrestrial photography.

Moreover, field work was carried out to visit the unstable slopes and susceptible areas for mass movements, which occur densely along the scarps that bound the reservoir. Different measurements were carried out, like height of scarps and their slopes, size of involved areas, length and width of cracks, etc. The type and activity of the existing mass movements phenomena was checked in the field too.

Terrestrial photography was applied to those areas which are unaccessible, due to very steep scarps and the presence of the Tigris River which flows directly along the foots of the scarps. The scale of the photographs was indicated from comparing them with the existing topographic maps 1:25 000 on scale. The size of individual involved area, height of scarps, size of blocks, type of mass movement for some unaccessible slopes were measured from terrestrial photographs.

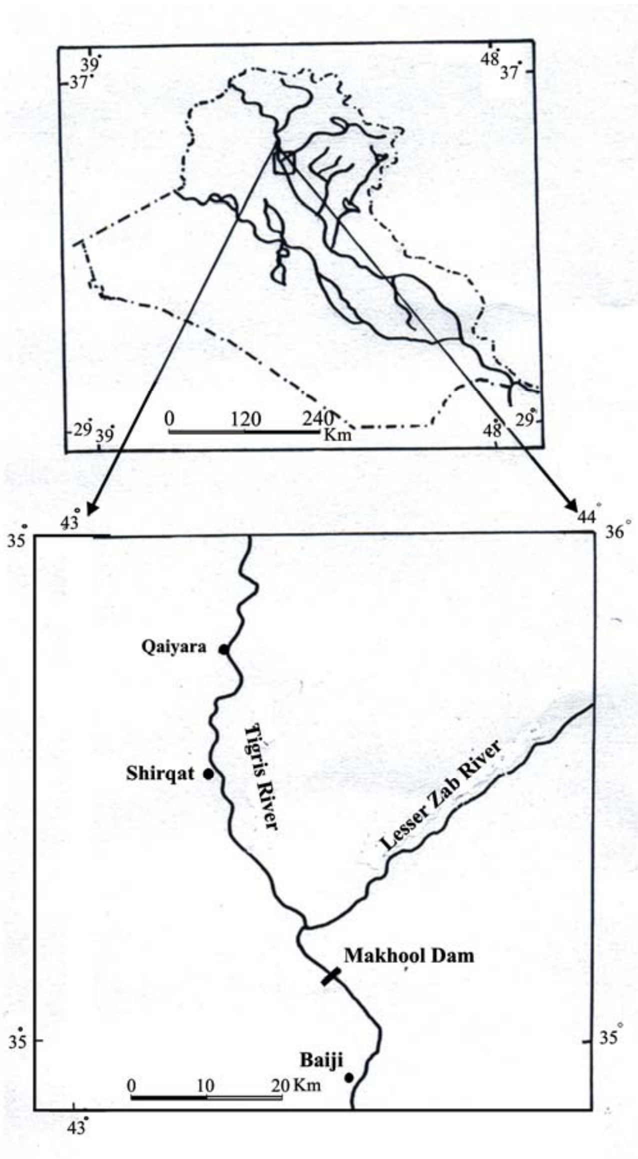

Fig. (1): Location map of the studied area

GEOLOGICAL SETTING

The studied area is located within the Low Folded Zone (Buday and Jassim, 1987). The exposed rocks in the dam site and the reservoir belong to the Fatha and Injana Formations (Al-Mubarak and Youkhanna, 1976 and Fouad, 2002). The two formations (Fig. 2) are briefly described:-

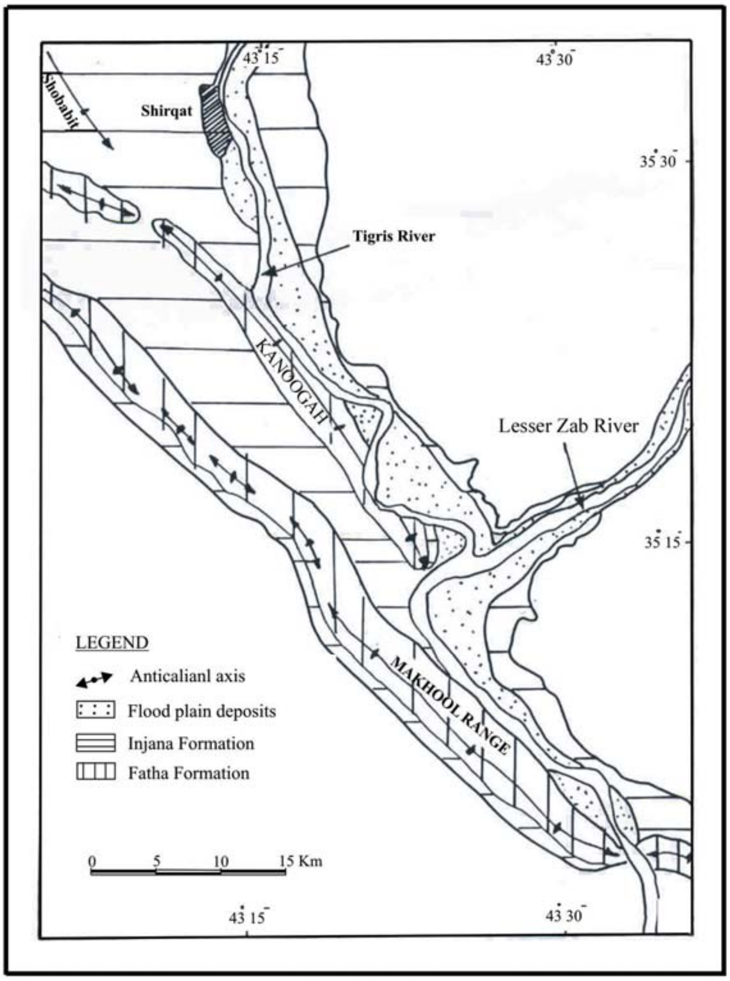

Fig 2: Geological map of the studied area (modified from Zwaid, 1995)

- Fatha Formation (Middle Miocene), consists of cyclic marine deposits. Each cycle consists of green marl, claystone, limestone and gypsum. The thickness of each rock type varies in different cycles, usually ranges from (1–20) m, except the limestone which does not exceed 6 m.
- Injana Formation (Upper Miocene), consists of cyclic continental deposits. Each cycle consists of claystone, siltstone and sandstone. The thickness of each rock type varies in different cycles, usually ranges from (1–15) m. The three rock types very commonly grade to each other both vertically and laterally.

The main structures (Fig. 2) in the studied area are:-

- Makhool anticline, the main trend is NW–SE, only the northeastern limb is within the studied area. The dip of the beds ranges from (15°–40°) NE. The southwestern abutment of the dam is on this limb, within the Fatha Formation. Many mass movement phenomena are developed along the northeastern limb (Sissakian et al., 2002).
- Khanoogah anticline, the main trend is NW–SE, large parts of this anticline are within the studied area. The dip of the beds range from (15°–40°) NE. The northeastern limb and part of the axial part form large parts of the western limits of the reservoir. They exhibit steep scarps along which different mass movement are developed (Sissakian and Fouad, 2000).

UNSTABLE SLOPES

The western limits of the reservoir are formed mainly by cliffs and steep slopes of Makhool and Khanoogah anticlines (Fig. 3). These are divided into five zones, which represent different **unique terrain units**, starting from the dam site to upstream, their characteristics are tabulated in Table (1). The five zones are described hereinafter.

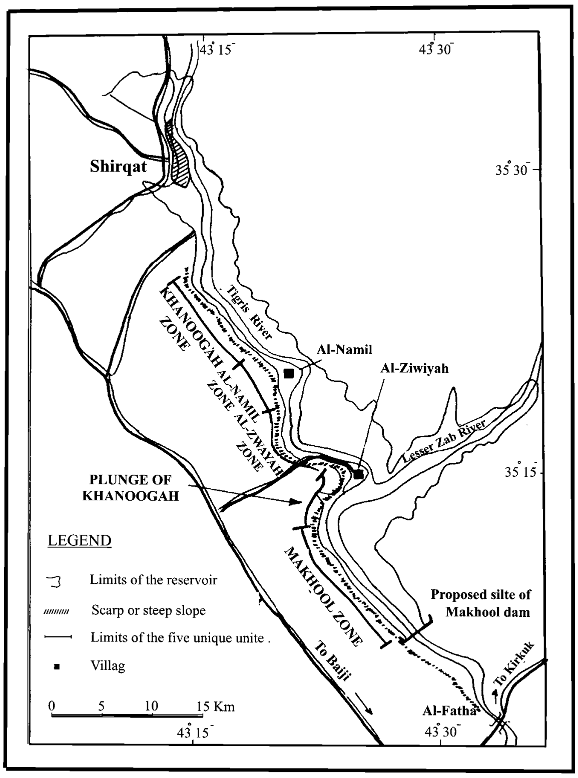

Fig. (3): Location of Makhool dam and reservoir, with limits of the five zone (unique terrain units).

Table 1: Characteristics of the five zones

Zone Name	Length (km)	Total area (km^2)	Coverage area of single mass movement (m^2)	Max. elevation (m)	Slope amount	Dip direction & amount	Type of mass movements and susceptibility for future mass movements
Makhool	8	3.2	9375 – 60000	200	$45^\circ – 71^\circ$	$15^\circ – 40^\circ$ NE	Land slides and rock fall, very highly susceptible area for future mass movements
Plunge of Khanoogah	6	2.25	7500 – 52500	200	$15^\circ – 23^\circ$	$10^\circ – 20^\circ$ NE & SW	Land slides, mud flow and rock fall, medium susceptible area for future mass movements
Al-Namil	6	1.95	2500 – 5000	225	$45^\circ – 73^\circ$	$15^\circ – 40^\circ$ NE	Land slides and rock fall, low susceptible area for future mass movements
Al-Ziwiyah	8.5	2.98	3125 – 150000	230	$42^\circ – 67^\circ$	$15^\circ – 20^\circ$ SW	Land slides, mud flow and rock fall, highly susceptible area for futrue mass movements
Khanoogah	11	4.13	20000 – 112500	300	$45^\circ – 77^\circ$	$13^\circ – 45^\circ$ NE	Land slides, mud flows and rock fall, very highly susceptible area for future mass movements

1- Makhool Zone

It starts from the dam site and extends for about 8 km, upstream. The inclination of the slopes range from (45^o–71^o), whereas the dip ranges from (15^o–40^o) NE. The thick gypsum beds (5–15) m, which are underlain by limestones and marls will easily slide down, after rising of the water level in the reservoir. The steep slopes, high dip amount, thick gypsum beds and rising water level will make the area very highly susceptible for future mass movement occurrence. Knowing that many mass movements already exist in the area (Sissakian et al., 2002) (Figs.4&5).

2- Plunge of Khanoogah Zone

It starts from the area of the plunge of the syncline between Makhool and Khanoogah anticlines and extends upstream for about 6 km, crossing the plunge of the Khanoogah anticline (Fig. 3). The total involved area is about 2.25 km^2. The expected mass movements, after filling of the reservoir are landslide, mud flow and rock fall. Few toppled blocks occur now. The susceptibility of the area for future mass movements is medium, because the dip of the beds is low to medium, moreover the existence of rocks of the Injana Formation will decrease the susceptibility. Only mud flow phenomenon may increase.

3- Al-Ziwiyah Zone

It extends from the plunge area of Khanoogah anticline, upstream to about 8.5km, crossing Al-Ziwiyah village till the main large meander of the Tigris River near Al-Namil village (Fig.3). The total involved area is about 2.98 km^2. The expected mass movements, after filling of the reservoir are landslide, mud flow and rock fall. Many large landslide and rock fall phenomena occur now (Sissakian and Fouad, 2000) (Fig.5), especially near Qasir Al-Binit. The susceptibility of the area for future mass movement occurrence is high, due to existance of very steep slopes with thick gypsum beds (up to 13m), which are underlain by thick red claystones (up to 8m). The only disadvantage factor, which had decreased the susceptibility of future mass movement occurrence (from very high to high), is the dip direction of the beds. The dip direction is either slightly against the slope of the scarp or is almost horizontal (the axial part of the anticline).

4- Al-Namil Zone

It extends from the area where the Tigris River forms large meander, off Khanoogah anticline and extends for 6 km upstream, till the end of the meander (Fig.3). The total involved area is 1.95 km^2. The expected mass movements, after filling of the reservoir are landslide and rock fall. The susceptibility of the area for future mass movement occurrence is low. The main reason for that is the water level in the reservoir (150m a.s.l.) will not reach the base of the scarp, but will remain (400 – 600) m far. This will decrease the influence of the water on the stability of the slope.

Fig. (4): Unstable slope along Makhool anticline

Fig. (5): Unstable slope near Al-Ziwiyah

5- Khanoogah Zone

It extends from the area where the meander of the Tigris River ends and extends for about 11 km, upstream till the end of the scarp (Fig. 3). The total involved area is about 4.13 km^2. The expected mass movements, after filling of the reservoir are landslide, mud flow and rock fall. Knowing that the scarp is under the influence of very high under cut erosoin by the Tigris River. This has caused extremely unstable scarp (Figs. 6 & 7), with tens of different mass movements phenomena. Majority of them are recent and active. Although other tens are very old and stable. The susceptibility of the area for future mass movement occurrences is very high. This is due to high dip of the strata, steep slopes, strong under cut erosion of the Tigris River, thick gypsum beds (up to 13m), which are underlain by claystone and existence of tens of mass movements phenomena.

Fig. (6): Unstable slope near Khanoogah village

Fig. (7): Unstable slope along Khanoogah anticline

MODELING OF SLOPES

Bayes theorem (Carrara et al., 2000) is used in hazard modeling of the existing slopes along the western limits of the reservoir. For each of the aforementioned five zones the landslide frequency (LF) and conditional probability (P) is calculated, depending on the available data, which are tabulated in Table (1), depending on the following equations:-

LF = landslide area / UCU area --------------------- **(1)**

Where LF = landslide frequency
Landslide area = measured area of single landslide or other type of mass movement
UCU area = total measured area of one zone

P (L/UCU) = landslide area / UCU area ---------------------- **(2)**

Where P = conditional probability
L = landslide occurrence

P (L/ER) = landslide area / ER area ---------------------- **(3)**

Where ER = the average landslide probability over the entire investigated region

In applying the aforementioned equations the following data are acquired (Tables 2 & 3).

Table 2: landslide frequency and conditional probability of the five zones

Zone Name	LF	P			
		$L^* = 5$	$L^* = 10$	$L^* = 25$	$L^* = 50$
Makhool	0.3–1.8	11.52	5.76	2.3	1.15
Plunge of Khanoogah	0.3–2.3	10.35	5.17	2.07	1.03
Al-Namil	0.12–0.25	9.75	4.87	1.95	0.97
Al-Ziwiyah	0.1–3.0	17.88	8.94	3.57	1.78
Khanoogah	0.5–2.7	22.3	11.15	4.46	2.23

*** supposed values for landslide occurrence**

Table 3: Average landslide probability of the five zones

Zone Name	ER			
	L^*= 5	**L^*= 10**	**L^*= 25**	**L^*= 50**
Makhool	13.92	6.96	2.78	1.39
Plunge of Khanoogah	14.29	7.14	2.86	1.43
Al-Namil	14.13	7.06	2.83	1.41
Al-Ziwiyah	8.64	4.32	1.76	0.86
Khanoogah	14.37	7.18	2.87	1.44

From reviewing Tables (2 and 3) it is clear that the conditional probability of the five zones is directly proportional with the assumed susceptibility of mass movement occurrence, in future for each zone. Moreover, the conditional probability and the average probability of the five zones are high. This means that in future, after filling of the reservoir, the slopes will suffer highly from mass movement phenomena.

In defining the **unique terrain unit** (Carrara et al., 2000) for each of the five zones, the following parameters or variables were used:-

(1) Rock type
(2) Slope degree
(3) Dip direction and amount
(4) Height of the slope
(5) Stability of the slope
(6) Relation of the reservoir level with the scarps foot

The aforementioned parameters of the five zones are tabulated in Table 4. In reviewing the six parameters it is clear that some of the five zones have similarity in few parameters, but they never have similarity in all parameters. Therefore, they are correctly divided into five zones and each zone has its **unique terrain conditions**.

Table (4): Parameters defining the unique terrain conditions of the five zones

Zone Name	**Unique Terrain Conditions**					
	Rock type	**Slope degree**	**Dip direction and amount**	**Height of the slope**	**Stability of the slope**	**Relation of the reservoir level with the scarp**
Makhool	Gypsum, limestone and claystone	$45^{\circ} – 71^{\circ}$	$15^{\circ} – 40^{\circ}$ NE	50m	Unstable	On the foot of the scarp
Plunge of Khanoogah	Gypsum, limestone and claystone and sandstone	$15^{\circ} – 23^{\circ}$	$10^{\circ} – 20^{\circ}$ NE & SW	50m	Slightly unstable	On the foot of the scarp
Al-Namil	Gypsum, limestone and claystone	$45^{\circ} – 73^{\circ}$	$15^{\circ} – 40^{\circ}$ NE	50m	Almost stable	400 – 600m far from the foot of the scarp
Al-Ziwiyah	Gypsum, limestone and claystone	$43^{\circ} – 77^{\circ}$	Horizontal $15^{\circ} – 20^{\circ}$ SW $13^{\circ} – 35^{\circ}$ NE	80m	Highly unstable	On the foot of the scarp
Khanoogah	Gypsum, limestone and claystone	$45^{\circ} – 71^{\circ}$	$13^{\circ} – 45^{\circ}$ NE	75 – 150m	Extremely unstable	On the foot of the scarp

INFLUENCE OF THE UNSTABLE SLOPES ON THE STABILITY OF THE DAM

Reservoir induced landslides are very common phenomenon (Schuster, 1979). The slopes which extend along the western limits of the reservoir will suffer from different types of mass movements. This is due to water saturation of the rocks (after filling of the reservoir), consequently this will lead to a decrease of the cohesion and internal friction angle (Zaruba and Mencl, 1969). Moreover, the existing mass movement phenomena, on the slopes and scarps, even the old movements may be reactivated after saturation of the rocks by water (Cotecchia, 1978).

The existing unstable slopes and those which may turn unstable, in the future after filling of the reservoir will exhibit large landslides, rock falls and flows. This is due to many reasons like water saturation, under–cut erosion of the scarps and rejuvenation of old mass movements. Large slided or fallen blocks may influence on the stability of the dam, by means of initiating large waves. The danger will increase by increasing the size of the moved body, the distance from the dam and velocity of movement. Knowing that the average velocity of the slide, flow and fall are (10–20) km/hr, 100 km/hr, and 200 km/hr, respectively (Nemcok et al., 1972).

When reviewing the maximum expected sizes of mass movements (Table 1) and comparing them with their expected average velocity of movement it is clear that their influence on the stability of the dam must be taken into consideration, especially if few movements took place at the same time. Such occurrences could be expected when reviewing the average landslide probability (Table 3) and unique terrain conditions (Table 4) for each of the five zones.

CONCLUSIONS

The following could be concluded from this study:

- The western limits of the reservoir are formed by steep slopes and scarps, which extend for about 40 km.
- The majority of the slopes and scarps suffer from different types of mass movements and are considered as unstable slopes.
- The western limits of the reservoir are divided into five zones, each of them has its unique terrain conditions.
- The average landslide probability is medium to high. The probability increases to high when decreasing the landslide occurrence.
- The unstable slopes will influence on the stability of the dam.

RECOMMENDATIONS

The following are recommended:

- To map very carefully and in detail all existing mass movements phenomena, by using modern geohazard mapping and GIS technique.
- To estimate the size of maximum expected moved blocks and their average velocity. Consequently, estimate the height and speed of the initiated wave and its impact on the dam.

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