The Environmental Significance of Rock Slope Instability in Parts of Al-Qadsiya Lake Slopes, West of Iraq

Saad Numan Al-Saadi and Saad Abbas Al-Hamdani *

ABSTRACT

This paper deals with the environmental hazards that result from failure in the western steep slopes of a peninsula in Al-Qadsiya Lake, west of Iraq, which is a proposed tourist site. The environmental hazards are represented by continuous slope failure and erosion that lead to slope retreat, and reduction of the area proposed as a tourist site.

Field surveys showed that the studied carbonate rock slopes are full of caves and failures, which include (from the most to the least abundant) rockfall, sliding, toppling, rockroll and disintegration. The study has also shown that the main factors for failure are the presence of steep slopes, water, weak layers, and discontinuities.

A failure map (scale 1:5000) was prepared for the first time showing the types, distribution and direction of slope failure. Some remedial measures are proposed to prevent slopes’ failure and to protect the area from such environmental hazards.

1. INTRODUCTION

1.1 Location of the Study Area

The study area lies in western Iraq, about (290)km west Baghdad, (20)km northwest of Haditha town and (15) km west of Al-Qadsiya Dam in Al-Anbar Governorate (Fig.1). It occupies the northern strip of the western slopes and coasts of a peninsula in Al-Qadsiya Dam Lake. This strip is about (4.5) km long and (25-50)m wide. Its width is influenced by the rise and fall of the lake water level, which reaches (147)m above mean sea level during the storage season and falls below (136)m during the drainage time.

1.2 Aims of the Study

The study area was chosen in the southwestern parts of the peninsula in Al-Qadsiya Lake, which is a proposed tourist site (village), because of the abundance of failures in its western rock slopes and erosional activity of water on them, which impose environmental hazards on the human life, the coasts, the slopes and the areal extension of the peninsula. The aim of this study, therefore, is to evaluate the influence of slope failure and erosion on 1) slopes retreat, and on 2) the possibility of using the Peninsula for tourism purposes and 3) finally to propose some remedial measures to stabilize the slopes and protect the area from such environmental hazards.

1.3 Previous Studies

There is one general geological study of Haditha area (Mehdi et al., 1986). There is no special previous study of the slope stability and its environmental influence on the peninsula. There is one engineering geological study (Sissakian et al., 1986), in which two engineering geological maps were prepared at 1:100,000 and 1:25,000 scales. Slope stability was not involved in that study but some types of slope failures were mentioned in brief. There is a huge number of publications on slope stability in the world (Al-Momani and Al-Saadi, 1998; Al-Saadi and Tokmachy, 1998; Lui et al., 1992; Mahraj,1993). There are also many papers on landslide hazard mapping in the world (Anbalagan, 1992; Pachauri and Pant, 1992).

1.4 Field and Laboratory Work

In this study, a detailed survey of rock slope stability was carried out for a strip, which is (4.5)km long and a
detailed failure map was prepared at a scale of 1:5000 for the first time using a topographic map (1:10,000) as a base map and it was enlarged to scale of 1:5000. The types, distribution and directions of failures are indicated on the map, in addition to caves sites.

Detailed slope stability was studied in 27 stations (Fig.1), which involved all types of failures in the area. In each station, the slopes height and attitude, the attitude of strata, discontinuity survey, description of lithology and weathering state were carried out according to Anon (1972). Three rock samples from each site were collected to test their compressive strength, which is derived from point load test for all stations and for direct shear test on the materials which are liable to sliding to find their shear strength parameters (\(\Phi\)) and (c). In this paper, only three stations are chosen here as representatives of the main failures modes in the area.

Figure 1) Location and geologic map of the study area of a peninsula in Al-Qadisiya Lake. Geology of the area is after Mehdi et al.(1986).
1.4 Office Work

This involved the preparation of failure map in its final form, field data were represented by stereographic projection, and all influencing factors on slope stability were analyzed.

1.5 Climate of the Study Area

According to (Climatological Atlas of Iraq, 1989 and the Meteorological Atlas, 1999) the study area is an arid area characterized by contrasting temperatures between day and night, summer and winter. The average temperature in January is (8 °C) and in July is (34 °C). The temperature in the summer occasionally rises above (45 °C) and sometimes in the winter falls below the freezing temperature. The average annual rainfall is (100) mm. The prevailing winds are westerly and northwesterly.

2. Geology of The Study Area

2.1 Tectonic and Structural Setting

The study area lies in the stable shelf. It is characterized by horizontal strata that contain local undulations in different directions from which the term (undulated limestone) was used to describe the rocks of
the area. The strata are cut by some faults in different directions but dipping mainly in north and south directions (conjugate) accompanied by drag.

2.2 Geomorphology of the Area
The peninsula is characterized by hilly and undulating ground surface. The local hills rarely rise more than (10)m above the surrounding ground. The ground level near the edge of the western cliffs exceeds (150)m above mean sea level. It slopes eastwards and decreases to about (130)m above mean sea level (Fig.3). The peninsula surface is widely dissected by valleys of dendritic pattern that slope eastwards. The peninsula is a plateau whose western side forms cliffs, they slope generally westwards, but locally these steep slopes are inclined in different directions (south, west, north) because the coast forms gulls that enter the peninsula eastwards, these are opposed by rocky tongues (hills) that enter the lake westwards (Fig.1).

2.3 Stratigraphy of The Area
The upper part of the Euphrates Limestone Formation (Lower Miocene) is exposed in the study area, mainly in the western slopes of the peninsula. The ideal section of this part of the formation as in middle part of the study area consists of three units, which are (from the oldest to the youngest) (Fig.2):
1. 1-Green to yellowish green marl and marly limestone containing small angular rock fragments of limestone and called (Brecciated marl). It is (2-7)m thick.
2. 2-White to light gray, fine-grained massive chalky limestone. It is (5-10)m thick.
3. 3-Brown to yellowish brown, fine grained, thin-medium bedded strong to very strong dolomitic limestone. It is (2-5)m thick.

In many parts of the cliffs some units specially the upper and the middle units are partially or wholly missing. The Euphrates Formation is unconformably overlain by Quaternary deposits represented by either 1) Brown gypsiferous soil layer about (2)m thick and 2) Rock blocks of various sizes filling the valleys and the different parts of the western slopes, as mass wasting and water erosional products.

3. RESULTS
3.1 The Failure Map
It is clear from the failure map of the study area (Fig.3) that the western carbonate rock slopes of the peninsula contain a large number of caves, which almost exist in the lower half of the slopes. This part of slopes is more liable to inundation by water, in addition to the presence of the weakest rock layers such as marl in the lowest part and the chalky limestone in its middle part.

The main types of failures in slopes are (from the most to the least abundant) 1) Rockfall (38.5%), 2) Plane sliding (20.5%), 3) Toppling (18%), 4) Rockroll and slumping (18%) and 5) Local disintegration (5%). Some stations involve more than one type of failure, therefore, these calculations have been made relative to the total number of failure. The failures that occurred (or likely to occur) are widely spread along the western slopes of the peninsula.

3.2 Examples of The Three Main Failure Types
Three stations (No. 7, 8 and 10) representing the main types of failure (rockfall, sliding, and toppling) are presented here.

Slopes inclination and dip of strata or joints are represented here by two numbers like 284/70. The number to the left indicates directions and that to the right indicates an angle.

1. Rockfall (Station No.7)
This type of failure abounds in steep slopes (vertical, semi vertical and overhanging slopes) under the influence of weathering, erosion and discontinuities in the carbonate rocks that form these slopes as in station No.7 in the southern part of the study area (Fig.3).

The slope height at station 7 is (7)m and it is inclined 284/90-OH, while the dip of strata (So=284/28) (Fig.4). The rocks at the station are white to light gray and light yellow to olive, fine to medium grained, medium, thickly to very thickly bedded, with two sets of closely spaced to widely spaced joints, slightly to moderately weathered, chalky limestone.

In addition to bedding planes, there are two sets of open and closed joints, which are (J1) with spacing that ranges between (15-80)cm and persistence that ranges between (10-65)cm; and (J2) with spacing between (8-70)cm and persistence between (5-65)cm.

Rockfall has occurred at this station like the fallen rock block A in Plates 1 and 2, which was rotated half revolution after falling so that its back side became frontal. Its dimensions are (5mx4mx2.5m) parallel and normal to the bedding, respectively.
Figure (3): Failure map of the southern part of the western steep slopes of the peninsula in Al-Qadsiya Lake.
Figure (4): A-Stereogram illustrating the relationship between slope, bedding and discontinuities at station 7.
B-Schematic block diagram illustrating the rockfall from the roof of cave at station 7.

\( S_0 \)=poles to bedding planes. \( J_1 \) & \( J_2 \)=Poles to joints in sets 1 & 2.

It consists of chalky limestone, but it also contains two lenses of brown dolomitic limestone of the upper unit of the Euphrates Limestone. There is a cave (5)m deep, (3)m wide, and (2)m high in the lower part of the slope. This cave might have helped the fall of block A, because the water acted to erode the rocks in the lower part of the slope (specially the soft marl unit) and converted it to overhanging slope. With the help of water solving action, block A was detached and fell. It is observed that its lower part is submerged when the lake water level rose with further possibility of weakening by weathering under water (Plate 2).

2. Plane Sliding (Station 8)

This type of failure exists in many parts of the study area (Fig.3), where its conditions are fulfilled, which are: 1) the bedding planes (or joints) dip down slope at an angle \( \theta=32^\circ \) smaller than the slope angle \( \alpha=60-90^\circ \) (daylighting slope), and equal to, or larger than its friction angle \( \Phi=5-28^\circ \). 2) The cohesion across the discontinuities becomes zero. 3)The presence of suitably oriented release surfaces like joints (Hoek and Bray, 1981).

Station 8 is an example of plane sliding in the area. It lies in southern part of the coast (Fig.3). Slope’s height at this station is (10)m and its inclination is 200/70°. The strata dip 200/32°, therefore, the slope is daylighting (Fig.5; Plates 3 and 4).

The rocks at this station are light grayish olive and light yellow, fine-medium grained, thickly-very thickly bedded, very closely to closely spaced open and closed joints, slightly to moderately weathered, Marly limestone and Marl.

In addition to the bedding planes, there are two sets of nearly vertical joints, which are \( J_1 \) striking NW-SE whose spacing ranges between (4-12)cm and their persistence ranges between (3-65)cm; and \( J_2 \) striking NE-SW with spacing between (3-18)cm and persistence between (3-50)cm.

Plane sliding has occurred at this station along bedding plane as the slid mass A appears in Plates (3 and 4). It does not need lateral release surfaces because the surrounding layer parts are eroded. The slope has many scars (S) of previous sliding failure and block (B) is liable to future sliding (Plate 4). Joints of \( J_1 \) acted as back release surface and those in \( J_2 \) acted as lateral release surfaces (Figure 5; plate 4). Since the dip of strata \( \theta=32^\circ \) is less than the slope angle \( \alpha=70^\circ \) and larger than the friction angle of strata \( \Phi=28^\circ \) and lies within the area of potential sliding (Figure 5) the remaining parts of the strata like block (B) are liable to plane sliding whenever cohesion becomes zero. When the lake water level rises as in plate (4), the water acts to lift the detached blocks like (A) because of buoyancy, and reduces the friction angle so that such block might slide further to lower land in the lake.
Plate (1): Exhibiting the fallen block (A) and the cave at station 7. Date of photograph: 24/11/1998. The lake water level was 40m above mean sea level.

Plate(2): The rise of water level to 146m above sea level covered the lower part of the fallen block (A) at station 7. Date of photograph: 10/3/1999.
Figure (5): (A) Stereogram illustrating the relationship between slope, bedding and discontinuities at station 8 where sliding has occurred. (B) Schematic block diagram illustrating the relationship in (A) leading to plane sliding.

Plate (3): Showing the general slope (g.s) and the slid block (A) at station 8 when the lake water level was at 140m above mean sea level. Date of photograph: 24/11/1998.
Plate (4): Station 8 after the water level has risen to 146m. Block (A) is partially submerged. (S) is a scar of previously slid masses. Block (B) is liable to sliding in the future. Date of photograph 10/3/199.

Figure (6): (A) Stereogram illustrating the relationship between slope, bedding and discontinuities at station 10 where toppling has occurred. (B) Schematic block diagram illustrating the influence of undercutting on block geometry leading to toppling.
Plate (5): Showing the toppled block and toppling direction (the arrow) at St.10. The lake water level was 140m above mean sea level. Date of photograph: 24/11/1998.

3. Toppling (Station 10)

This type of failure occurs in many parts of the study area (Fig.3). It is almost a secondary block toppling that occurs as a result of undercutting as described by Evans (1981). It occurs whenever the weight vector of rock block becomes outside its base as in the case of undercutting.

Station 10 shows one example of toppling in the southern part of the area (Fig.3). The slope at this station is (5) m high, and its inclination is 332/40°, and the strata dip 332/10° (Fig.6; plate 5).

The rocks at this station are light grayish and yellowish olive, fine-medium grained, medium-thickly-very thickly bedded, very closely spaced to moderately spaced joints open and closed, slightly weathered, marly limestone.

In addition to the bedding planes, there are two sets of joints, which are (J1) whose spacing ranges between (5-60) cm and their persistence ranges between (10-200) cm, and (J2) whose spacing ranges between (5-35) cm and their persistence ranges between (10-95) cm.

Secondary toppling due to undercutting has occurred at this station because water erosion of the lower parts of strata below the toppled block was deep to the extent that let the weight vector of the block becomes outside its base leading to its rotation and toppling (Plate 5; Fig. 6). The height of the toppled block is (3.20) m and its upper (1.20) m consists of gypsiferous soil and the lower (2)m consists of Marly Limestone. The 2 m-deep joints in (J1) acted as lateral release surfaces, while those in (J2) which are 1m – deep acted as back release surfaces and the bedding plane acted as basal surface although secondary toppling might not need basal surfaces.

4. Rockrolling and Slumping

These types of movement of the detached blocks almost follow one of the basic failure types (rockfall, sliding and toppling). Rock rolling and slumping widely occur in most parts of the study area, mainly in the lower more gentle parts of rock slopes which are covered in some places by rock blocks. The detached blocks continue their rotation down slope (rolling), or their shear movement along their lower surfaces (slumping) probably when they are slippery enough until they come to rest. They usually stop when slope inclination
decreases or when they face obstacles like surface roughness as that imposed by block covered slopes.

5. Local Disintegration (Station 22)

This breakdown of rock masses into small pieces up to (10) cm diameter is limited in the study area. Station 22 shows an example of local disintegration of the weak Marly Limestone. These rocks are thinly bedded and closely to very closely jointed and show large pores. The disintegration might happen due to regularly repeated cycles of wetting and drying and wide temperature variations in the area.

![Figure(7): Schematic block diagram illustrating local disintegration at station 22.](image)

3.3 Factors that Caused failures:

This study revealed that the main factors caused slope failure are:

A. **Slope Inclination**: It is noticed that most slopes are very steep being vertical or nearly vertical to overhanging in the upper parts of the western cliffs of the peninsula. Such steep slopes are quite favorable for all kinds of failure specially rock fall.

B. **The Water**: This factor has played a major role in rock slope instability, because CO₂-rich rain water help to dissolve the soluble carbonate and lake water to weaken them by weathering rocks, especially along weakness planes like the discontinuities and eroding the lower parts of the slopes (mix corrosion) leading to undercutting and forming overhanging slopes and caves. Water action to weaken the shear strength parameters of the rock masses (both φ and c) is well known (Hoek and Bray, 1981).

C. **The Rock Type**: This factor also played a major role in rock slope instability because different types of carbonate rocks exist in the area. This variation is reflected by strength variation from weak to very strong. In addition, the presence of weaker rock types (the marl and marly limestone) in the lower parts of all slopes helped the differential weathering and erosion that led to undercutting and promoted rockfall and toppling.

D. **The Discontinuities**: These include bedding planes, joints and faults. All discontinuities played an important role in rock slope instability and helped the rapid detachment of rock blocks by acting as sliding surface like bedding planes, or lateral and back release or basal surface during failures.

E. **The Local Structure**: Because of local variation, the strata in the slopes are either horizontal or dipping down slope, up slope, or dipping laterally, such situations give wide relationships between the slopes and strata and help the occurrence of different modes of failures.

F. **The Climatic Conditions**: The wide range of daily and seasonal differences in temperature increases mechanical weathering. High evaporation during the summer and high temperature lead to dry the rock masses and help slope stability. On the other hand, water storage in the lake and the rise of its water level in the winter decrease the stability. Therefore, the climate and the oscillation of the lake water level play an important role on the slope stability in the area.

4. Conclusions:

A- The western rock slopes of the peninsula in Al-Qadisiya Lake, west of Iraq, which is a proposed tourist site, are subjected to the following types (from the most to the least abundant): rockfall (38.5%), plane sliding (20.5%), Toppling (18%), 4) Rockroll and slumping (18%) and local disintegration (5%).

B- The caves are widespread in the lower parts of the slopes and this helps to activate slope failure and retreat.

C- The lake water, especially during the storage season where its level rises, plays a basic role in activating failures and forming and enlarging caves.

D- The discontinuities like bedding planes, joints and faults play an important role in the detachment of rock block during all kinds of failures such as sliding surfaces or back and lateral release surfaces and basal surfaces.

E- The presence of carbonate rocks in the area, which are liable to mixcorrosion process, in addition to the presence of weak rocks like marl and marly limestone increased the hazards of failure which are brought about by differential weathering and erosion.

F- The continuous occurrence of failures at the present
high rate leads to the following environmental hazards:

a. Harm on human life in the site and at lake coasts.
b. Harm on civil installations on the peninsula near the cliff edges.
c. Slope retreat and reduction of the favorable area for tourism in the peninsula.

5. Recommendations

A- If civil structures are constructed on the peninsula, it is preferable to keep away from the cliffs’ edges by not less than (100) m to avoid imposing additional load on the slopes and to prevent failure activation.

B- For more precise determination of subsurface caves, a microgravity survey is recommended.

C- The unstable slopes must be stabilized by the following methods:

a. Removal of unstable blocks.
b. Grouting of open joints and cracks by materials, which are insoluble in water and non-contaminating to the environment like cement (mixed with water), to prevent water leakage inside the rock mass.
c. Using concrete with rock blots during water level fall season to treat the problem of sliding by spreading a layer of concrete on the daylighting slope. To treat the problem of toppling, the undercut parts of the slope can be filled with rock blocks and concrete to widen the base of blocks liable to toppling.
d. For rockfall it is preferable to flatten the slope and decreasing its inclination, and removal of the overhanging parts and spreading concrete on the slope face.
e. Using large rock blocks (rip rap) on the slopes and grouting them with cement to protect them from wave action of the lake and decreasing erosion at slopes toe.

REFERENCES


الصخيرة المنحدرات في الاستقرار البيئي الأهمية

العراق الغربي القدسي بحيرة مين أجزاء في الحمدني العباس وسعد نعمان، سعد *

تنتجم البيئة المخاطرة التي البيئة المنحدرات في الجزيرة والشبه السياحية كموقعاً والمقترحة. بازل البيئة المخاطرة تتمثل واقعة المنحدرات تراجع التي تؤدي إلى المنحدرات الحالية الاستثمارية سياحية الكاربونية الصخيرة وانفكاب الراقية (ويفة) الأكثر وفيرة والقليل (واختصاراً الصخرية والدحيرة والانقلاب والانزلاق الصخري الهيكلي والعضل والبيئة الرئيسية وجوانب الحالة والظروف والانقطاعات المشددة والطبيعة والمياه الحادة بعلي المنحدر والبيئة خارجية رسم تم).

*الجيولوجيا، قسم جامعة العلوم، بغداد كلية العراق الغربي القدسي، 