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للعام الدراسي ٢٠٢٣-٢٠٢٤

بإشراف

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Project of Research

Structural and engineering analysis of the rock structures of the Injana-Tar Al-Sayyid Formation, Holy Karbala Governorate

By Student.

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B.Sc. Earth Sciences

Scholar year 2023-204

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1445 Hijri 2024 Gregorian

اقرار المشرف

أشهد بان موضوع البحث الموسوم.. والمنجز من قبل الطالب ....قد اجري تحت اشرافنا في قسم علم الارض كلية العلوم جامعة بابل كمتطلب جزئي لنيل شهادة البكلوريوس في علوم الارض وذلك للفترة من 2023/10/1 ولغاية 2024/4/1

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الاسم الثلاثي للسيد المشرف

اللقب العلمي:

التاريخ:

بسم الله الرحمن الرحيم

هُوَ الَّذِي جَعَلَ الشَّمْسَ ضِيَاءً وَالْقَمَرَ نُورًا وَقَدَّرَهُ مَنَازِلَ لِتَعْلَمُوا عَدَدَ السِّنِينَ وَالْحِسَابَ مَا خَلَقَ اللَّهُ ذَلِكَ إِلَّا بِالْحَقِّ يُفَصِّلُ الْآيَاتِ لِقَوْمٍ يَعْلَمُونَ).

صدق الله العظم

سورة يونس- الآية 5.

الاهداء

الى خالق اللوح والقلم وبارئ الذر والنسم وخالق كل شي من العدم الى من بلغ الرسالة وادى الأمانة .. ونصح الأمة .. الى نبي الرحمة ونور العالمين الى السادات الاطهار وعروته الوثقى .. اهل بيت النبوة الى مراد قلبي والاقرب لي من نفسي المغيب عن الابصار والكامن بعين البصيرة الى بقية الله الاعظم.
صاحب العصر والزمان (عجل الله تعالى له الفرج) الى تلك الحبيبة ذات القلب النقي ... الى من اوصاني الرحمن بها برا واحسانا الى من سعت وعانت من اجلي الى من كان دعائها سر نجاحي .. امي الحبيبة الى من اشاركهم لحظاتي . . الى من يفرحون لنجاحي وكانه نجاحهم .. اخوتي بكل حب اهديكم هذا الجهد المتواضع

شكر وتقدير

اقدم شكري الجزيل الى عميد وعمادة كلية العلوم جامعة بابل لرعايتهم العلمية والتربوية القيمة طيلة فترة دراستي وإنجازي بحث التخرج.

شكري وتقديري العميق لأستاذي المشرف على البحث الاستاذ الدكتور جعفر حسين علي الزبيدي لاقتراحه موضوع البحث و توجيهاته العلمية النظرية القيمة ومساعدته العملية المتواصلة وخروجه معي في العمل الحقلي وتعاونه واخذ البيانات من منطقة البحث بشكل

صحيح وسليم بالإضافة الى توفير المصادر العلمية المفيدة في البحث.

كما أود أن أشكر رئيس قسم علم الارض التطبيقي الدكتور مهند راسم عباس الجبوري على تشجيعه المستمر ومتابعته مراحل انجاز البحث.

والشكر موصول الى جميع أساتذة القسم الذين بذلوا كل جهد ووقت وعلم طيلة فترة اربعه سنوات مدة دراستي في القسم، والذي تمكنت من خلالهم انجاز بحث التخرج المتواضع هذا اقدم امتناني ومحبتي الى جميع زملائي الذين رافقوني فترة دراستي في قسم علم الارض وخاصة الزملاء الذين دعموني في انجاز العمل الحقلي لبحث التخرج

واقدم الشكر والتحية لجميع المعيدين والموظفين في القسم لجهودهم العلمية والعملية الرائعة طيلة فترة دراستي في القسم.

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ABSTRACT

Tar Al-Sayyed area (a tourist area), locates in the west of Karbala Governorate- Middle of Iraq, it is characterized by a rock cliff with abundance of naturally-forming caves locally known as Al-Tar caves. Field studies revealed the abundance of rock slope failures, the dominant types are rock fall, secondary toppling, and local disintegration followed almost by rolling. Slope stability assessment was carried out by stereographic projection. Secondary toppling mechanisms (generally due to the effects of differential weathering and or erosion, and undercutting) include multidirectional toppling, tension crack toppling and toppling & slumping mechanisms. Some treatment measures are proposed to .stabilize the slopes and protect the visitors in the area

1.Introduction

1-1 Location of the Study Area

The study area located in Tar Al-Sayyed in Karbala Governorate, 30 km west of Karbala city, middle of Iraq. The study area consists of region(AL-tar Caves) is located between longitudes (043º 46' 832"-043º 46'720") E, and latitudes (32º 28'893"– 32º 28'450") N, with area (48km^2) Figure (1-1) showes the stations of the study area**.**

1-2 Aims of the study:

This study aims at making an engineering geological evaluation of rock slope stability in the area by locating sites of past failures and those which are likely to occur in the future , its mechanism , types , and all factors influencing slope instability .This requires ;-

1-Locating unstable parts of the cliff and determining the modes of failure .

2-Proposing some treatment measures to stabilize the rock slopes .

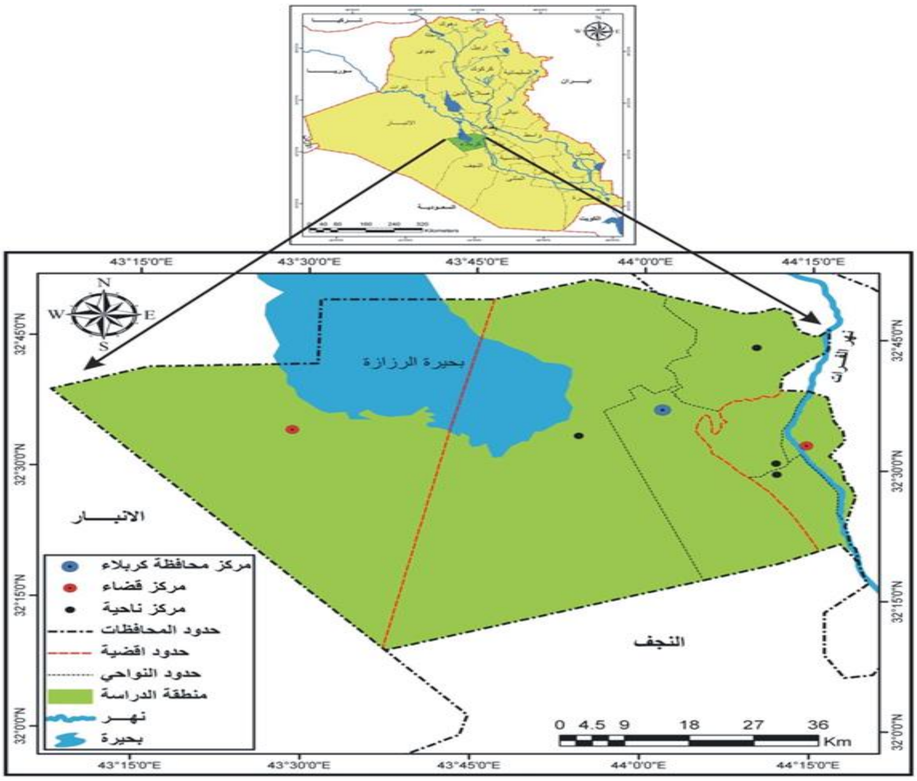


Figure (1-1) site map of the study area

1-3 Previous Studies

The previous study area has been dealt with various authors :-

1- Lateef and Barwari (1984), carried out regional geological mapping of

Karbala- Najaf area, in order to obtain data for final maps of scale 1:250 000 and 1:100 000. They divided the stratigraphic sequence into lithologic units and did not certain Formations.

2- Barwari and Slewa (1995), carried out field work in order to obtain data for geological map of Karbala province of scale 1:250 000.

3- Al-Basrawi (1996), studied hydrogeology of Razzaza lake.

4- Al –Baidari (1997), studied the sedimentology and geochemistry of Injana Formation rocks in Karbala –Najaf area.

5- Sissakian (1999), studied the Nfayil Formation of the area between Tar Al-Sayyed and Tar Al- Najaf.

6- Dawood (2000), mentioned that the lenticular Celestite mineralizations are concentrated in clastic rocks of Injana and Dibdibba Formations. For geological map of Karbala province of scale 1:250 000.of Tar Al-Sayyed.

7- The Study of Al-Khateeb and Hassan (2005), studied the distribution of

Celestite mineral in the area between Najaf and Karbala ,(Al-Biadhani, 2005). The possibility of using coarse and fine natural aggregates that do not match the requirements of the Iraqi Standard (45/1984) and their effect on the two most important characteristics of soft and solid concrete, namely: 7 days, 28 days and 90 days depending on the American standard The results obtained from the non-conforming aggregates showed that they could give good workability and resistance using the(ASTM). Finally, the study gave a proposal for a new Iraqi specification for the inclusion of coarse and fine aggregates in Iraq.

8- Arriyer, (2009), The results showed a decrease in the compressive strength of the concrete mixtures with the unbroken aggregate of the aggregate in the gradient of concrete mix by (6%) and for (28) days while the resistance Compaction of concrete mixtures with broken aggregates by gradient higher than (3%) of those containing a series of debris.

9- Al-Rawi (2018), The validity of the sands of the Dabdaba formation for construction purposes in the area of Al-Sayyed in Karbala governorate / central Iraq, The study included finding the geotechnical properties of the study area models. Five samples of sand were taken from different sites and the physical tests were carried out (moisture content, the percentage of moisture content ranged from (1.132% -5.329%). The specific gravity ranged between (2.069-2.229), The results of the grain size analysis of all samples of the study area showed that they did not match the requirements of the Iraqi Standard (QST44/1984) for concrete.

1-4 Geology of the Study Area

1-4-1 Stratigraphy of the Study Area

The exposed units from the older to the younger , Figure (1-2).

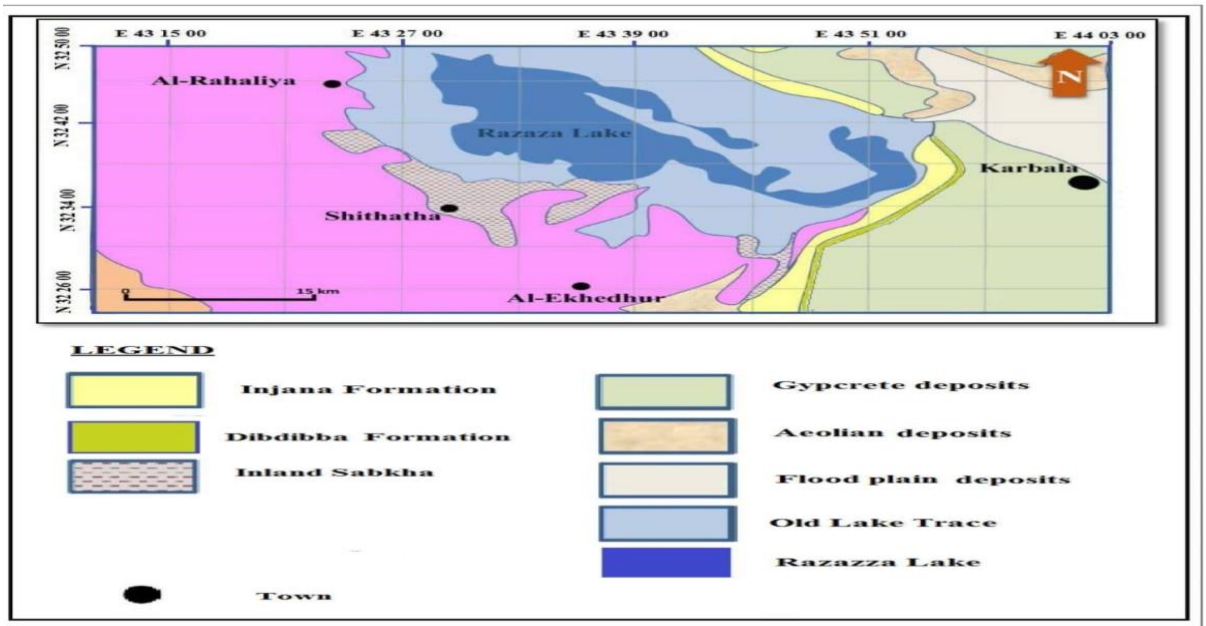


Figure (1-2) GEOSURV, 1996 **:** Geological map of Shithatha quadrangle, sheet NI-38-13 and Karbala quadrangle, sheet NI-38-14 Scale 1:250000

1-4-1-1-Tertiary deposits

A- Injana Formation (lateMiocene)

B- Dibdibba Formation (Pliocene- Pleistocene)

A-Injana Formation (late Miocene)

Hassan (2007), studied the stratigraphy of Karbala-Najaf area, central
Iraq and divided Injana Formation into two main units:

1-Lower Clastic Unit:-

It consists of alternation of different clastic rocks (claystone, sandstone and siltstone) or admixture of these rocks in different ratios. Thin beds of marly limestone are also recorded, two or three times up to 0.3 m in thickness, some Celesite-bearing beds are recorded in places (Al-Khateeb and Hassan, 2005). Cementing materials are clay or carbonate. Solution of diagenetic processes occasionally filled the bedding planes and fractures, forming very thin beds or local aggregate of secondary gypsum. Generally, the claystone and silty claystone or siltstone beds are brown to reddish brown in color, medium tough to tough and cliff-forming, while the sandstones are heterogeneous, micaceous, lithic, cross bedded of grey color. Generally, the sequence shows fining upwards cycles. The thickness of this unit reaches up to 25 m. The succession of this unit shows some lateral and vertical variations. (Hassan, 2007).

2-Upper Cave-Forming Claystone Unit:-

It is informally named the Cave-Forming Claystone Unit (Al-Khateeb and Hassan, 2005). It consists of claystone, occasionally silty, brown to reddish brown, Conchoidally fractured, massive, tough, cliff-forming, changes laterally or vertically to silty claystone. The thickness of this unit reaches 6.0 m or more in some places. It has a wide geographic extension along both Tar Al-Najaf and Tar Al-Sayyed, for about 170 Km. The wide geographic extension of the fine sediments (claystone). without remarkable lateral lithological variation indicates low energy fluvial depositional current, as compared with the Lower Unit. This unit is highly jointed. It is overlain by highly permeable coarse grained sandstone of Dibdibba Formation. Some of these joints are enlarged gradually due to water erosion from the overlying beds forming a well-developed caves, which reach (1×2) m, or more (Al-Khateeb & Hassan, 2005).

B-Dibdibba Formation (Pliocene- Pleistocene) :-

Hassan (2007), studied the stratigraphy of Karbala-Najaf area, central Iraq and described Dibdibba Formation. It is widely exposed in the upper part of both Tar Al-Najaf and Tar Al-Sayyed forming the main plateau. The thickness ranges from one meter or less to more than 18m.Lithologically, the formation consists of sandstone and pebbly sandstone. The sandstone differs from place to another; the main color is brown but it could be gray, yellow and white or yellowish brown. Other physical properties such as grain size, sorting, roundness, spheresity are also varying in some manner.

The major components of the sandstone beds in this formation are quartz, chert, rock fragments and feldspar, (Hassan, 2007), (Buday,1980). The ratio of these components differs from place to another.

The cementing materials are clayey, in the friable sandstone and calcareous or gypsiferous, in the medium tough sandstones. Some claystone and siltstone beds are recorded, particularly in the eastern and southeastern parts of the area. (Hassan, 2007).

1-4-1-2 Quaternary Deposits

These deposits cover most of the study area, and can be described as follows(Alrawi,2018):-

A- Aeolian Deposits

Sand sheets and sand dunes are developed mainly on the Karbala-Najaf plateau. They are composed of sand deposited down wind from a natural source. Size and shape of these eolian deposits are variable but the most common type of sand dunes in the studied area is shrub dunes which are scattered on the surface of the plateau and generally of (1×0.8×0.5)m (length, width and height respectively) dimensions. Sand is the main constituent of dunes and it is of fine-grained derived from Dibdibba Formation. (Al-Khateeb & Hassan ,2005).

Other types of sand dunes are barchan type which are composed of well sorted sand of small sizes. Its height doesn't exceed (1m) of NW-SE direction. Sand sheets and sand dunes are generally active. (Al-Khateeb & Hassan, 2005), (Al-Tawash, 1996).

B- Wadi Fill Sediments

This type of sediments was deposited by the influence of non perennially rivers, that's flowing to Al-Razzaza depression. This type of sediments is composed of poorly sorted admixture of silt, sand and gravel (pebble), (Al-Khateeb & Hassan, 2005).

C- Colluvial sediments

These sediments occur along restricted zone at lower part of Tar Al-Sayyed between the edge of the cliff and Al-Razzaza low land (Lateef and Barwary , 1984) .

1-5 Tectonic and Structure of the Study Area

Generally, the studied area is located in the unstable shelf along Mesopotamian zone, as in Figure (1-3)(fouad,2009). Henson (1951),mentioned that Euphrates-Abu-Jir fault zone represents the boundary between the stable and unstable shelves. Al-Amiri (1979), recorded long and short lineament of NW-SE direction. He mentioned that the fault zone was composed of a system of strike -slip faults of NW-SE trend complicated and probably shifted. The most outstanding previous structural work by Hassan & Al-Khateeb (2004), they considered most of the depressions and ridges were developed due to the effects of the Abu- Jir faults.

They described the surface structural features as follows:-

1- The exposed uppermost part of Injana Formation and Dibdibba Formation show undulation along the scarp of Tar Al-Sayyed.

2- The presence of a numerous sulfurous, gaseous and water seepages which indicate fault zone. (Hassan & Al-Khateeb, 2004), (Jassim & Goff, 2006).

3- Abu-Jir fault passes through the area as a fault zone responsible for configuration of the ridge of Tar Al-Sayyed that are higher both topographically and stratigraphically than the surrounding area. The depressions were developed due to the effect of Abu-Jir fault zone where such phenomena are common in a normal strike-slip fault, (Hassan & Al-Khateeb, 2004).

4- Field observations in the study area show that the strata are horizontal to subhorizontal.

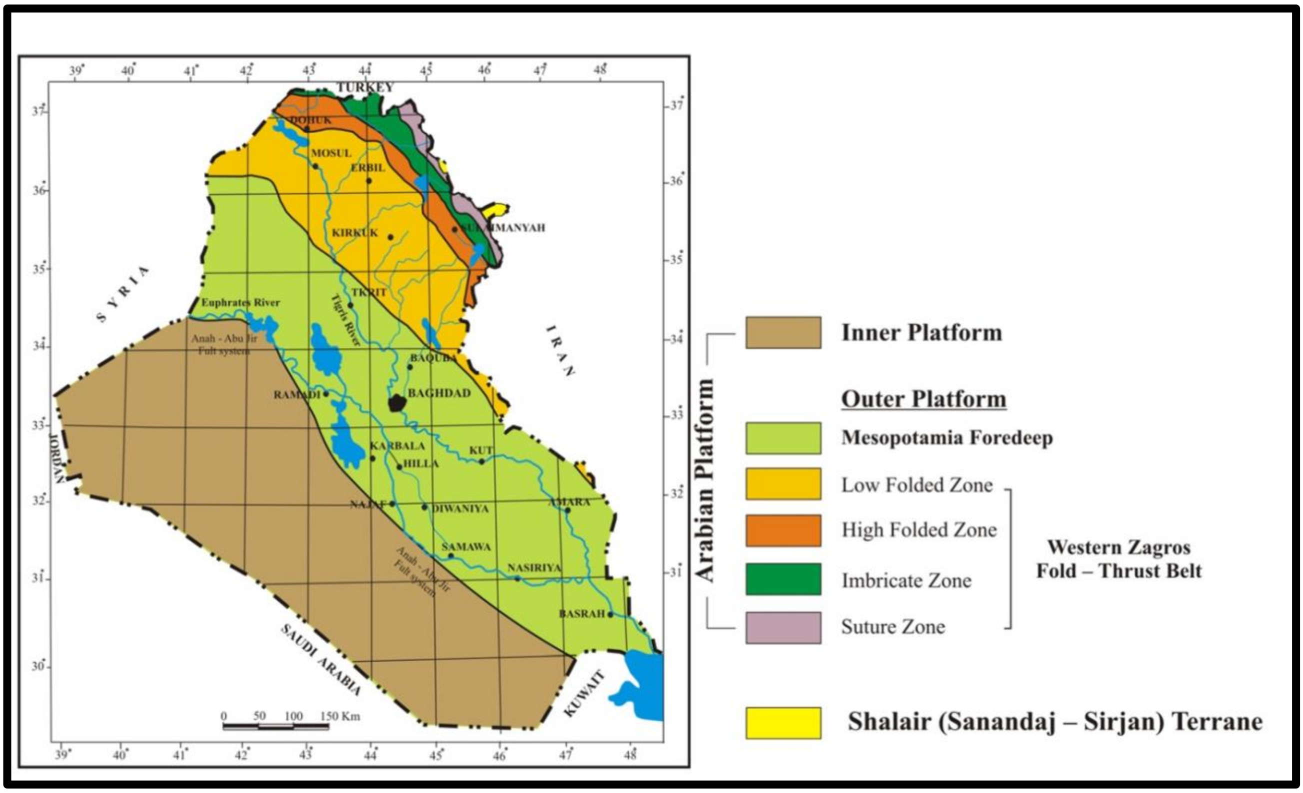


Figure (1-3) Fouad, S.F., 2009. Tectonic Map of Iraq, 3rd edit., scale 1: 1000 000, Geosurv, Baghdad, Iraq (in press)

1-6 Geomorphology of the Study Area:-

According to Al-Khateeb & Hassan, (2005), the study area displays a lot of landforms such as:-

1- The Karbala plateau

2- Al –Razzaza low land

3- Rock cliffs

4- Mesas and Buttes

1- The Karbala Plateau:-

The plateau occupies the area extending between Al-Najaf and Karbala cities and further to the north of the latter. Bordered from the east by the Mesopotamian plain and from the west by Al-tar caves (Al-Khateeb & Hassan, 2005).

2- Al-Razzaza Low Land (Depression) :-

It represents a large depression of internal drainage, this depression is filled by water. The depression is composed of fine sand with silt and clay admixture. (Al-Khateeb & Hassan, 2005).

3- Rock Cliff:-

It is a cliff or steep rock face, the only scarp present in the studied area is Tar Al-Sayyed which is characterized by steep cliff composed of alternating claystone, siltstone, sandstone and thin beds of limestone. This scarp is separating Karbala-Najaf plateau from the adjacent low land (Al-Razzaza depression). Its height reaches (50m) relative to the surrounding area, (Al-Khateeb & Hassan, 2005). The scarp is considered as the most conspicuous feature in the area.

The upper part of the scarp is cave-forming area, while the lower part is characterized by a slope-wash sediments with some rock boulders and rock fragments (Al-Khateeb & Hassan, 2005).

4- Mesas and Buttes:-

They are flat topped cut-off on one or more sides by steep escarpments, generally they occur in flat lying structures. Layers in mesas, buttes and hills are essentially horizontal in attitude, beside the area between Tar Al-Sayyed and the adjacent lowland. Some scattered hills are developed in the area adjacent to Tar Al-Sayyed. The main layers of mesas, buttes and hills are marl and limestone of Nfayil Formation and alteration of claystone, siltstone and sandstone of Injana Formation.

These geomorphologic landforms are formed due to differential erosion and representing remnants of the plateau due to backward erosion. (Al-Khateeb & Hassan, 2005).

In addition to the major landforms, (Hassan &Al-Khateeb, 2004), indicate that the area displays a number of circular to elliptical topographic depressions in addition to uplifted parts that are relatively higher both topographically and stratigraphically than the surrounding.

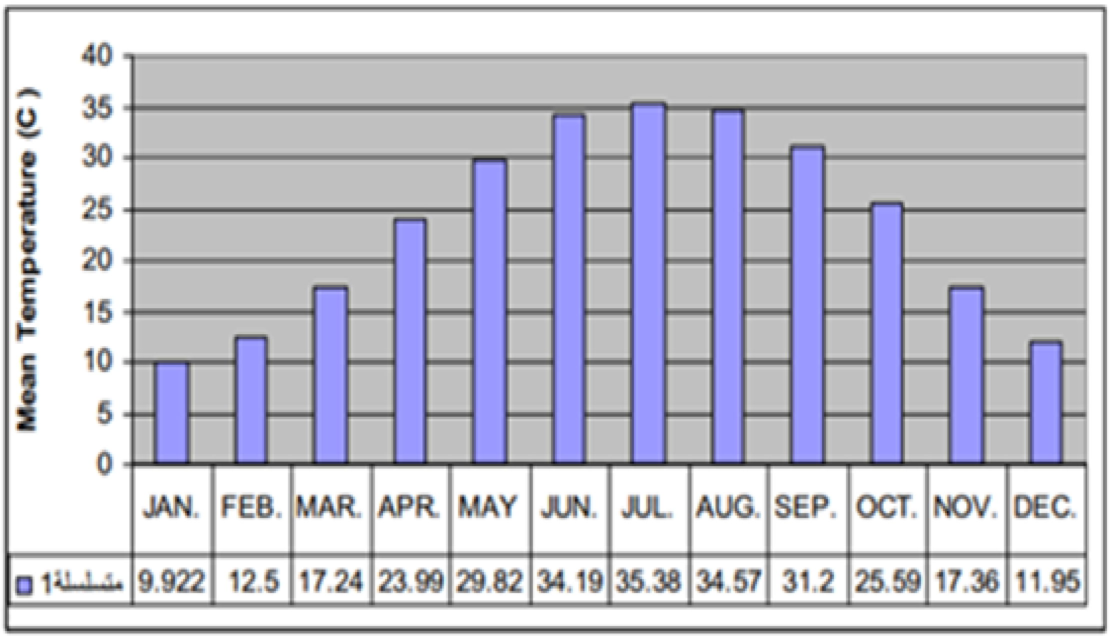
The prevailing drainage pattern in the area is dendritic pattern due to the presence of horizontal layers and homogeneous rock on the up land. In addition, there are some sub parallel drainage pattern, where slope has almost consistent inclination.

1-7 Hydrology and Hydrogeology of the Study Area:-

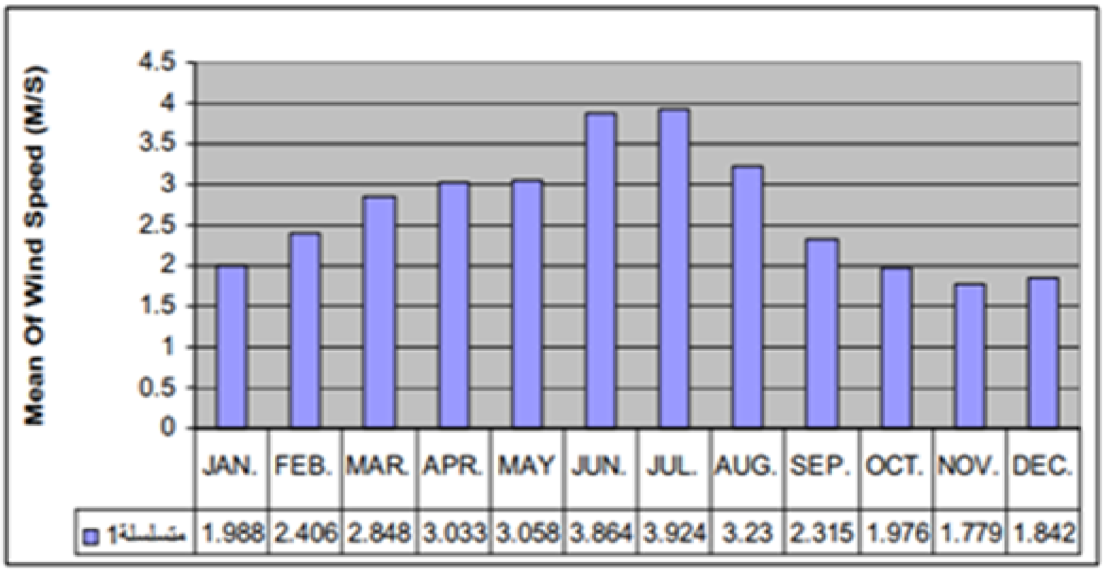
Al-Basrawi (1996), mentioned that the rainfall is regarded as a principal resource of surface water with very little amount. While, most groundwater flowing from western desert to Al-Razzaza lake and Karbala city, the presence of claystone layers within Injana Formation act as isolating strata and prevent movement of groundwater to Karbala city. Field observations in the study area show that the groundwater table lies almost below the toe of the studied slopes, and restricted to Injana Formation. The groundwater table of Maqam Al-Qattara lies almost below the toe of Al- Tar caves, and therefore does not cause instability of these slopes.

1-8 Climate of the Study Area:-

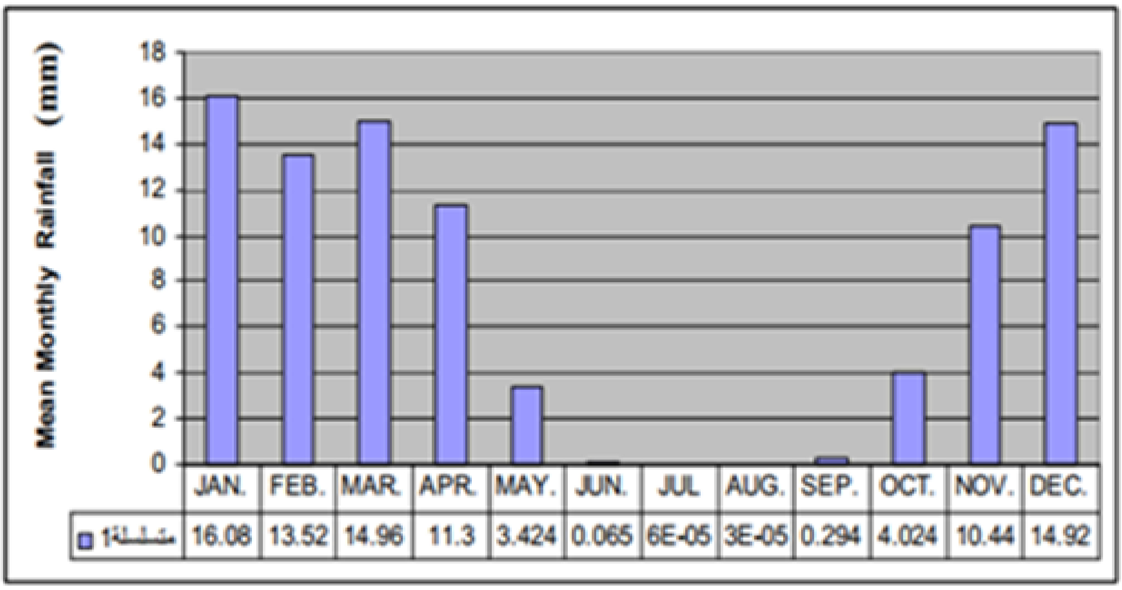
The study area is characterized by arid, hot and comparatively high summer temperature, moderate humidity and high evaporation, the rain is limited to winter and comparatively low temperature. Moreover, all seasons are dusty (Iraqi Meteorological Atlas, 1989). Figure (1-4a) is a histogram showing the mean monthly temperature for the period (1976-2008) for Karbala station. It shows that max. mean of temperature about (35° C) occurs in July and August, lowest mean of temperature about (10° C) occurs in December and January. Figure (1-4b) is a histogram showing the mean monthly wind speed for the period (1976-2008) for Karbala station. It shows that max. mean of wind speed about (3.9M\S) occurs in June and July, lowest mean of wind speed about (1.8M\S) occurs in November and December, with general direction is NW-SE. Figure (1-4C) is a histogram showing the mean monthly rainfall for the period (1976-2009) for Karbala station. It shows that max. mean of rainfall about (16mm) occurs in December, January and March, lowest mean of rainfall about (zero mm) occurs in July and August. Climatological data reveal very low rainfall in the study area, this supports the stability of slopes in the area(AL-Hussainy,2011).



Figure(1-4a) Mean monthly temperature for the period (1976-2008),iraqi Meteorological organization in karbala station.



Figure(1-4b) Mean wind speed for the period (1976-2008),Iraqi meteorological organization in Karbala station.



Figure(1-4c) Mean monthly rainfall for the period (1976-2008),Iraqi meteorological organization in Karbala station.

Theoretical Background and Laboratory Tests

2-1 Definition:-

The rock slope failure is defined as the down slope movement of a rock mass under its own weight and it involves a change in position of the rock mass vertically , horizontally and obliquely. (Blyth and De Freitas, 1984).

2-2 Classification of Rock Failures :-

Failures can be classified in many ways . Generally, one way is based on the type of movement. Accordingly the failures of rock slope mainly occur in (Hoek and Bray,1981):-

1- Sliding
2- Toppling
3- Rock fall

2-2-1 Sliding:-

Sliding is a shear movement of rock mass down slope, the failure occurs upon a surface that lies inside the rock mass and called a "failure surface" or "slip surface", it is divided into two types according to the shape of the slip surface:-

2-2-1-1 Translational Sliding:-

Translational sliding involves shear movement on planar surfaces along straight path and they are divided into two types:

A- Plane Sliding:-

This type of a failure occur if ,the following geometrical conditions are satisfies ,according to Wyllie and Mah, (2004) based on Hoek & Bray, (1981), these are:

1- The plane on which sliding occurs must strike parallel or nearly parallel (within approximately ± 20°) to the slope face.

2- The sliding plane must "daylight" in the slope face, which means that the dip angle of the plane (Ψ_p) must be less than slope inclination (Ψ_f) that is $\Psi_p < \Psi_f$.

3- The dip angle (Ψ_p) of the sliding plane must be equal or greater than the angle of friction (ϕ) of this plane, that is $\Psi_p \geq \phi$.

4- The upper end of the sliding surface either intersects the upper slope, or terminates in a tension crack.

5- Release surfaces that provide negligible resistance to sliding must be present in the rock mass to define the lateral boundaries of the slide, (Figure 2-1- a & b).

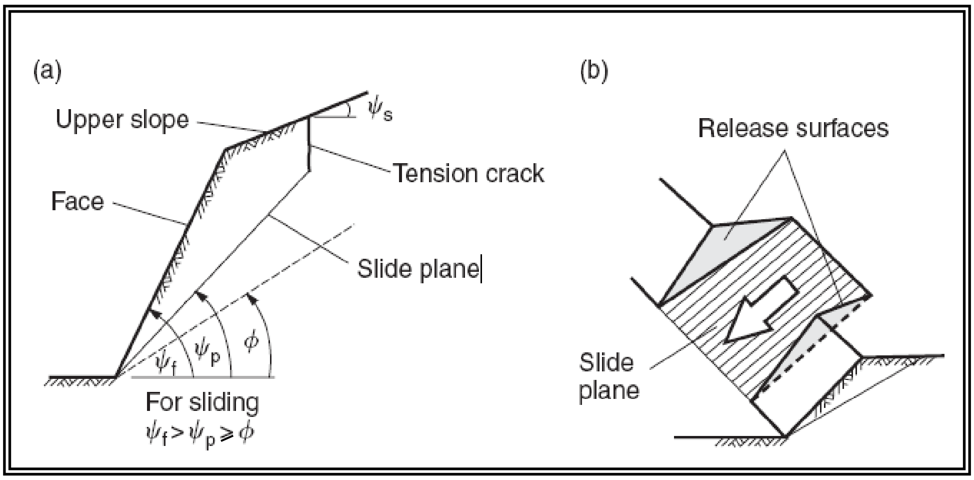


Figure (2-1) Geometry of slope exhibiting plane failure: (a) cross-section showing planes forming a plane failure (b) release surfaces at ends of plane failures. Wyllie & Mah, (2004) .

B- Wedge Sliding:-

Wedge failure is concerned with the slope failure of a rock mass containing discontinuities striking obliquely to the slope face where sliding of a wedge of rock takes place along the line of intersection of the two planes. The general conditions for wedge failure are as follows:- Wyllie and Mah, (2004) based on Hoek & Bray, (1981).

1- Two planes will always intersect in a line .

2- the plunge of the line of intersection must be flatter than the dip of the face , and steeper than the average friction angle of the two slide planes ,that is $\Psi_f > \Psi_i \geq \phi$, (Figure 2-2-a & b).

3- The line of intersection must dip in a direction out of the face for sliding to be feasible .

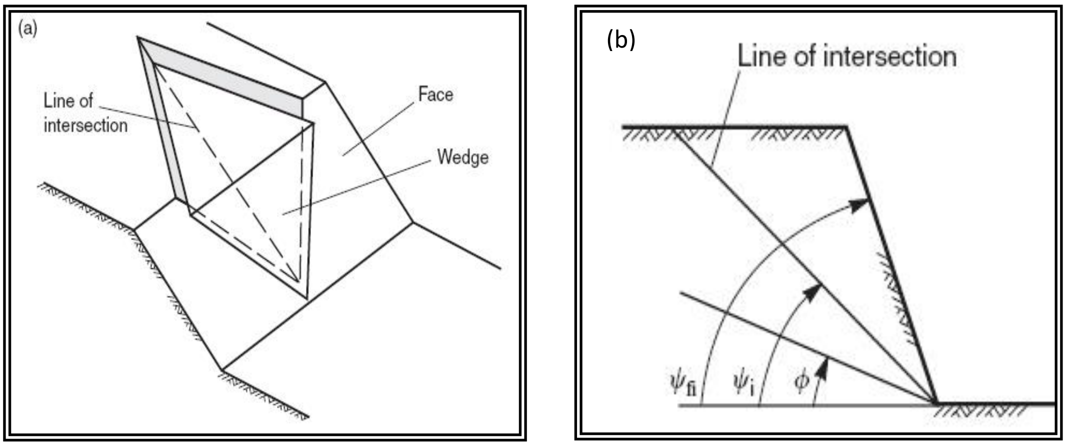


Figure (2-2) Geometric conditions for wedge failure: (a) pictorial view of wedge failure (b) view of slope at right angles to the line of intersection. Wyllie & Mah, (2004).

2-2-1-2 Rotational Sliding:-

This type of sliding is characterized by shearing along a slip surface which is curved in a section parallel to the movement direction . The slide mass is free to find the surface of least resistance through the slope material (Hoek and Bray,1981) . It occurs in weak material such as highly weathered or closely fractured rock, rock fills and soil ,(Wylli and Mah , 2004. (Figure 2-3).

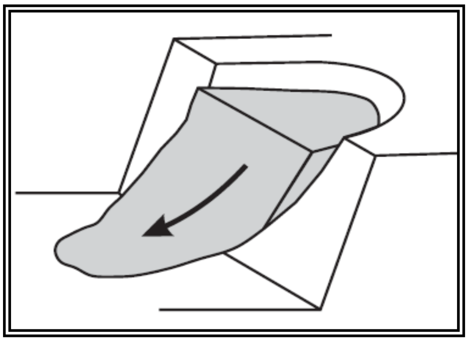


Figure (2-3) Pictorial view of circular failure. Wyllie & Mah, (2004).

2-2-2 Toppling:-

Toppling is a mass movement process characterized by the downslope overturning ,either through rotation or flexure of interacting blocks of rock . Slopes with well developed discontinuities or a pervasive foliation dipping steeply into the slope and trending parallel or subparallel to the slope crest are generally considered susceptible .

Toppling can occur at all scales in all rock types .(Pritchard and Savigny ,1990). Toppling involves rotation of columns or blocks of rock about a fixed base axis. Consider a block of rock resting on an inclined plane at angle (Ψ), (Figure 2-4). In this case, the dimensions of the block are defined by height (h) and a base length (b) and it is assumed that the force resisting downward movement of the block is due to friction only, cohesion (c) =0.

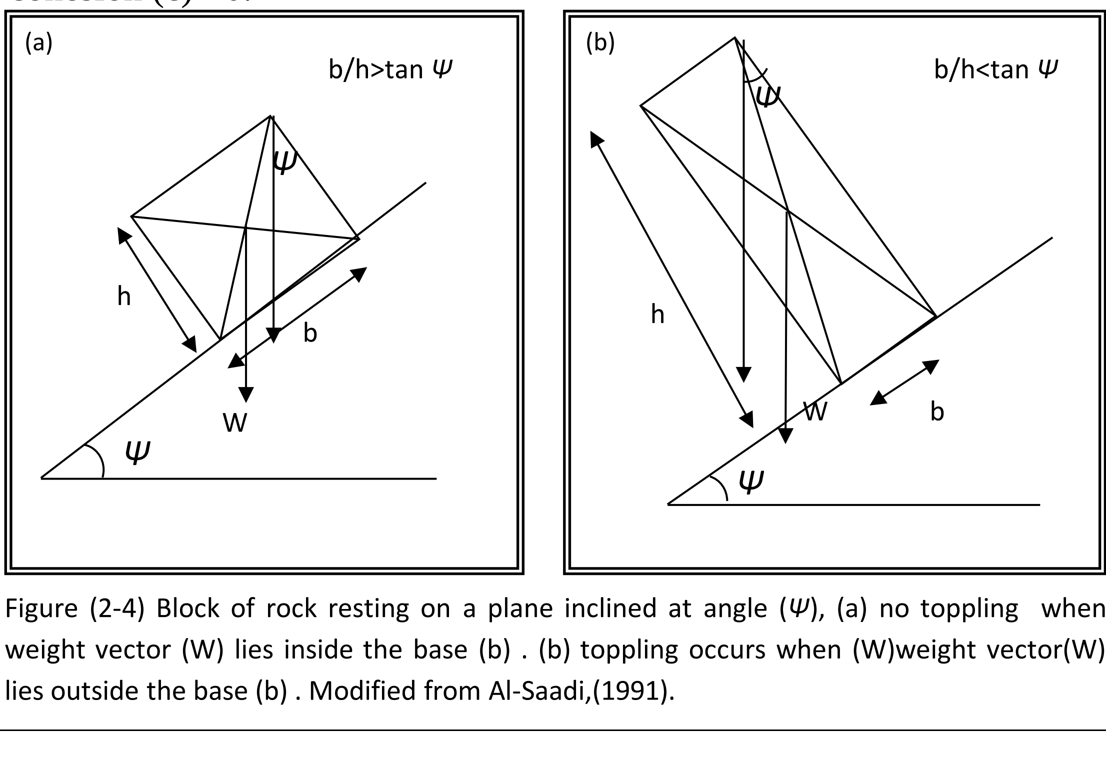


Figure (2-4) Block of rock resting on a plane inclined at angle (Ψ), (a) no toppling when weight vector (W) lies inside the base (b) . (b) toppling occurs when (W)weight vector(W) lies outside the base (b) . Modified from Al-Saadi,(1991).

When the vector representing the weight (W) of the block falls within the base (b), (Figure 2-4-a), toppling will not occur and the ratio b/h>tan Ψ, but sliding of the block will occur if the inclination angle of the plane (Ψ) is equal or greater than the angle of friction (ϕ). However, when the block is tall and slender and the ratio b/h is <tan Ψ, (Figure 2-4-b), the weight vector (W) will fall outside the base (b) and, when this happens, the block will topple. It rotates about its lowest contact edge (base axis). (Al-Saadi,1991) and (De Freitas and Watters, 1973).

2-2-2-1Conditions for Toppling and Sliding

According to Hoek and Bray (1981) , the conditions for sliding and/or toppling for this single block are defined in, (Figure 2-5), the four regions in this diagram are defined as follows:-

- Region 1: $\Psi<\phi$ and b/h> tan Ψ, the block is stable and will neither slide nor topple.
- Region 2: $\Psi>\phi$ and b/h> tan Ψ, the block will slide but it will not topple.
- Region 3: $\Psi<\phi$ and b/h< tan Ψ, the block will topple but it will not slide.
- Region 4: $\Psi>\phi$ and b/h< tan Ψ, the block can slide and topple

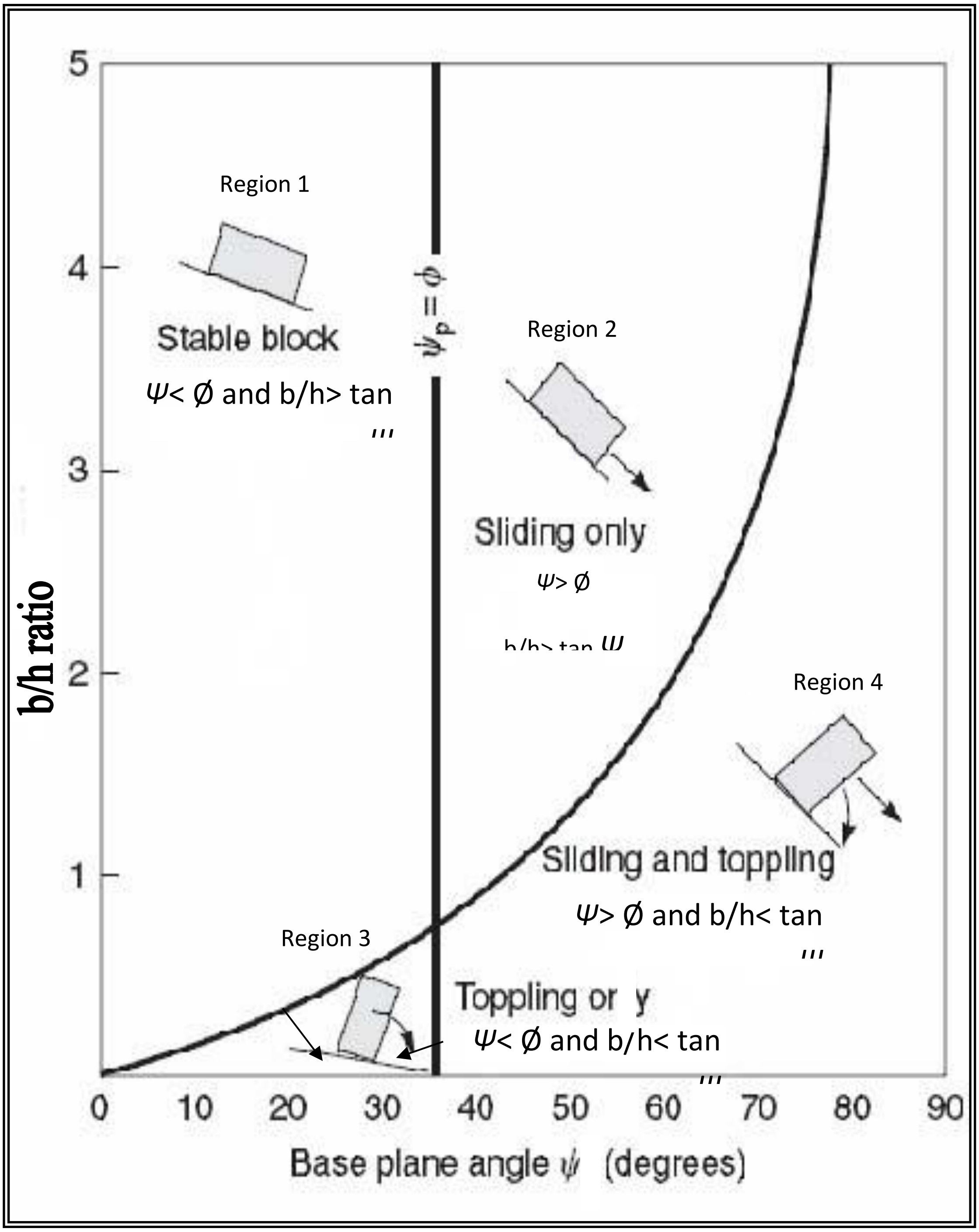


Figure (2-5) Identification of sliding and toppling blocks, conditions for sliding and toppling of block on an inclined plane. Wyllie & Mah, (2004).

Goodman and Bray (1976) have described a number of different types of toppling failures . There are three principal toppling modes and six secondary toppling modes as follows :-

2-2-2-2 Principal Toppling Modes:-

1- Block Toppling:-

As illustrated in, (Figure 2-6-a), block toppling occurs when, in strong rock, individual columns are formed by a set of discontinuities dipping steeply into the face, and a second set of widely spaced orthogonal joints define the column height. Typical geological conditions in which this type of failure may occur are bedded sandstone and columnar basalt in which orthogonal joints are well developed.

2- Flexural Toppling:-

It is a mode of failure involving the bending of interacting rock columns formed by a single set of steeply dipping discontinuities , such as regular bedding planes ,foliation or joints,(Adhikary, et al,1997). The process of flexural toppling is illustrated in, (Figure 2-6-b), that shows continuous columns of rock, separated by well developed, steeply dipping discontinuities, breaking in flexure as they bend forward. Typical geological conditions in which this type of failure may occur are thinly bedded shale and slate in which orthogonal jointing is not well developed. Generally the basal plane of a flexural topple is not as well defined as a block topple .

3- Block-Flexural Toppling

It is characterized by pseudo-continuous flexure along long columns that are divided by numerous cross joints, instead of the flexural failure of continuous columns resulting in flexural toppling, as illustrated in

(Figure 2-6-c). Toppling of columns in this case results from accumulated displacements on the cross-joints.

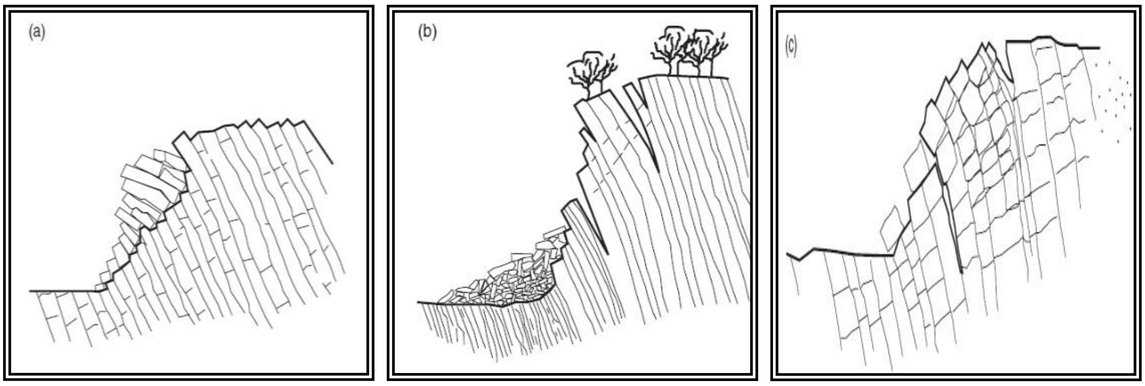


Figure (2-6) Common classes of toppling failures: (a) block toppling of columns of rock containing widely spaced orthogonal joints; (b) flexural toppling of slabs of rock dipping steeply into face; (c) block-flexure toppling characterized by pseudo-continuous flexure of long columns through accumulated motions along numerous cross-joints. Goodman and Bray, (1976).

2-2-2-3 Secondary Toppling Modes:-

Figure (2-7), illustrates a number of possible secondary toppling mechanisms. In general, these failures are initiated by some undercutting of the toe of the slope, either by natural agencies such as scour or weathering, or by human activities. In the described cases, the principal instability mode is the sliding and slumping of some parts of the slope while the toppling of some free rock blocks is induced as a consequence of the principal movement, the secondary toppling modes include:-

1- Slide Toe Toppling:-

Figure (2-7-a), shows a rock slope made up of different geological formations. Two mechanisms can be noted, the upper part of the slope has sliding phenomenon in progress, the lower formation is like a blocky system and indicates block toppling movement in the lower mass.

2- Slide Base Toppling:-

Figure (2-7-b), shows a soil slope lying on a steeply dipping layered rock mass. Regressive rotational sliding and slumping movements induce a shear force along the top of the rock mass able to provoke flexural toppling of the subvertical rock layers.

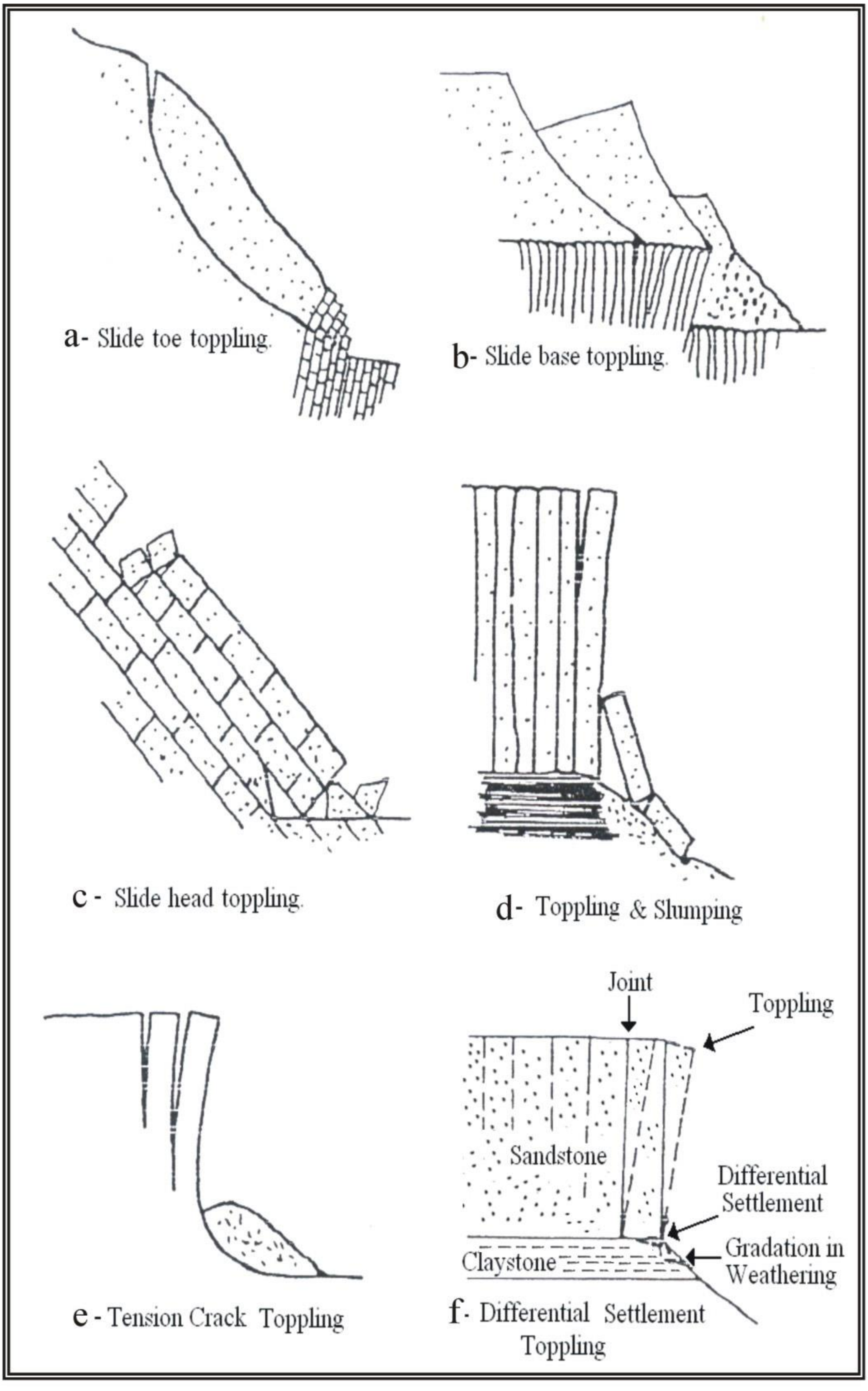


Figure (2-7) Secondary toppling modes (a-b-c-d) from Goodman & Bray (1976) and (e) From Hoek & Bray, (1981), and (f) from Evans, (1981), in Shakir, (2006).

3- Slide Head Toppling:-

Figure (2-7-c), shows a layered rock slope with a cross joint system which isolates thin and high rock blocks. Toe erosion or excavation work induces a sliding movement in the upper layers, in the upper part of the slope. The rock blocks which are not involved in the sliding movement topple into the new void at the slide head.

4- Toppling and Slumping:-

Figure (2-7-d), shows sandstone and shale formations. The shale is usually significantly weaker and more susceptible to weathering than the sandstone, while the sandstone often contains vertical stress relief joints. As the shale is weathered, it undermines support for the sandstone and columns of sandstone, with their dimensions defined by the spacing of the vertical joints, topple from the face and subsequently slump .

5- Tension Crack Toppling:-

Figure (2-7-e), shows that the tension cracks are generated in cohesive material in steep slope and may free potential blocks. This phenomenon can arise in soft rocks, such as those quoted by Goodman and Bray (1976), chalk, volcanic rocks, stiff clay and damp sand.

6- Differential Settlement Toppling:-

Figure (2-7-f), shows the vertical columns of hard, jointed rock are toppling due to weathering gradation within the underlying weak rock bed. The differential settlement mechanism involves stress relaxation in the basal softer rocks, whereby the overburden load is redistributed to the fresher material, thus reducing the amount of differential settlement likely to occur. The lateral constraints provided by horizontal stress may temporarily inhibit this mechanism (Evans, 1981).

New types of toppling failure were described by number of researchers as follows :-

- -Al-Saadi (1991), described new type of toppling and called it (composite base toppling when the basal surface is composite consisting of two intersecting discontinuities). (Figure 2-8).

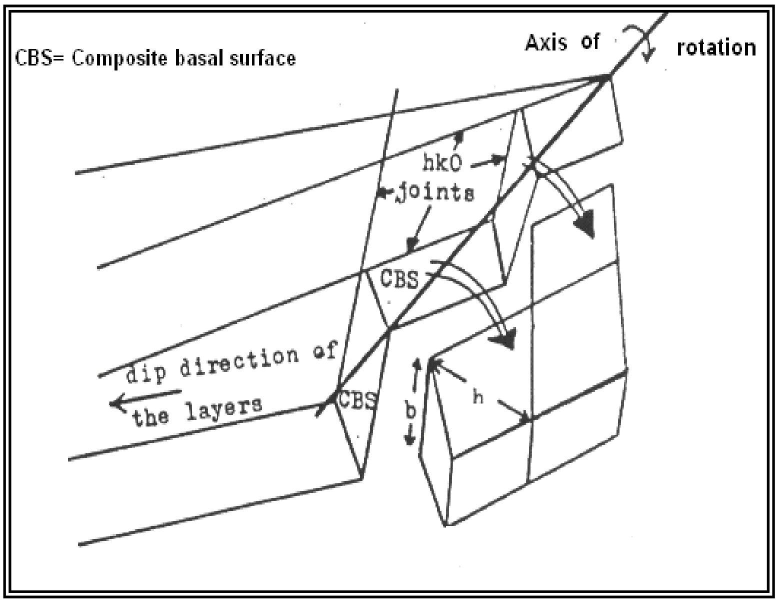


Figure (2-8) Composite-base toppling from (Al Saadi, 1991).

- Al-Saadi and Al-Tochmachy (1998) , described two new types of failure by undercutting, the first was (sliding-side topple) , in this type the failed block has lateral release and sliding surface at the same time, (Figure 2-9-a). The second type was (back toppling), In this type block toppling has occurred in a direction opposite to the dip direction of the layers and up slope toward the rock mass relative to the slope, and this is adverse to the well known condition of toppling failure in which the movement of the toppled block takes place down slope and out of it, (Figure 2-9-b).

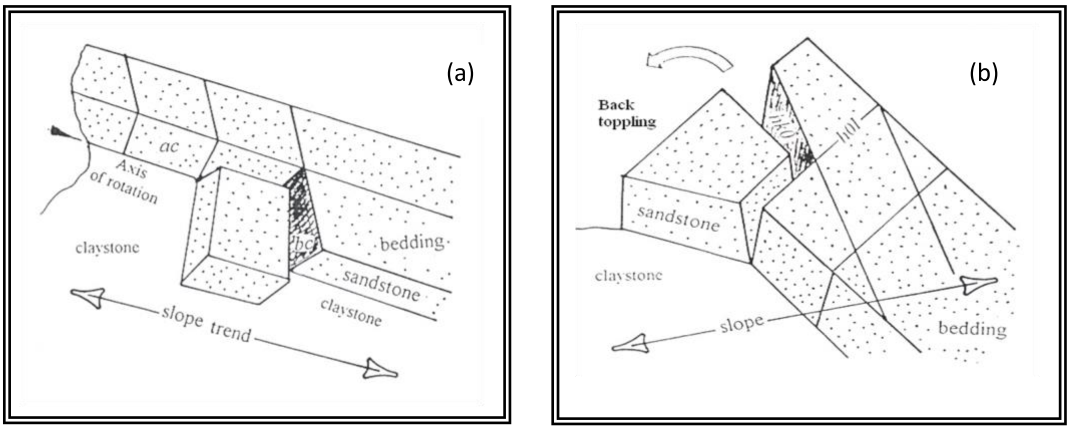


Figure (2-9) a-“Sliding- Side Toppling” b-“Back Toppling”. (Al-Saadi & Tochmachy, 1998).

- Al-Saadi and Al-Momani, (1998), described another type of toppling called (multidirectional toppling). This multidirectional toppling is characterized by repetition of toppling of the same block in different directions, (Figure 2-10).

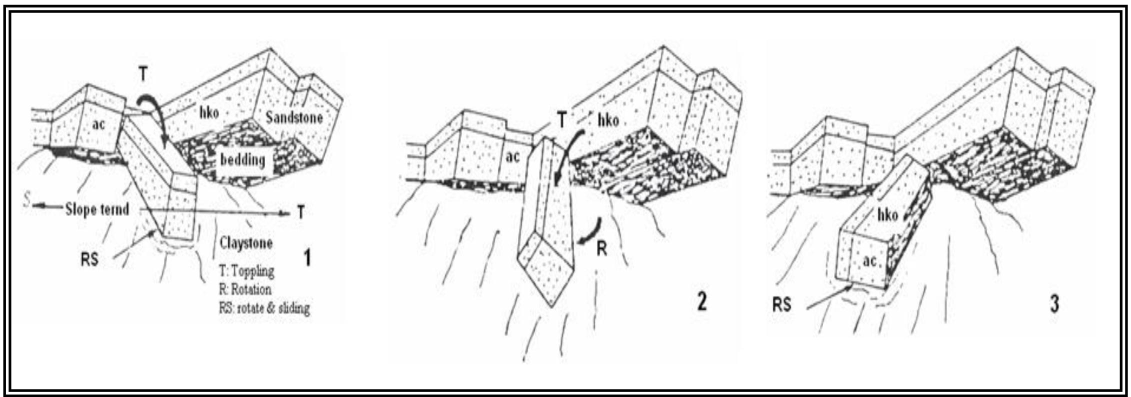


Figure (2-10) "Multidirectional Toppling "from , Al-Saadi & Al-Momani, (1998).

2-2-3 Rock Fall:-

Rock fall involves fall of a rock mass following initial detachment from a very steep rock slope , its disintegration and subsequent movement which may involves bouncing ,rolling and sliding generally down the steep source rock slope , (Evans, 2003) .It consists of free falling blocks of different sizes which are detached from a steep rock wall ,(Bromhead,1992).

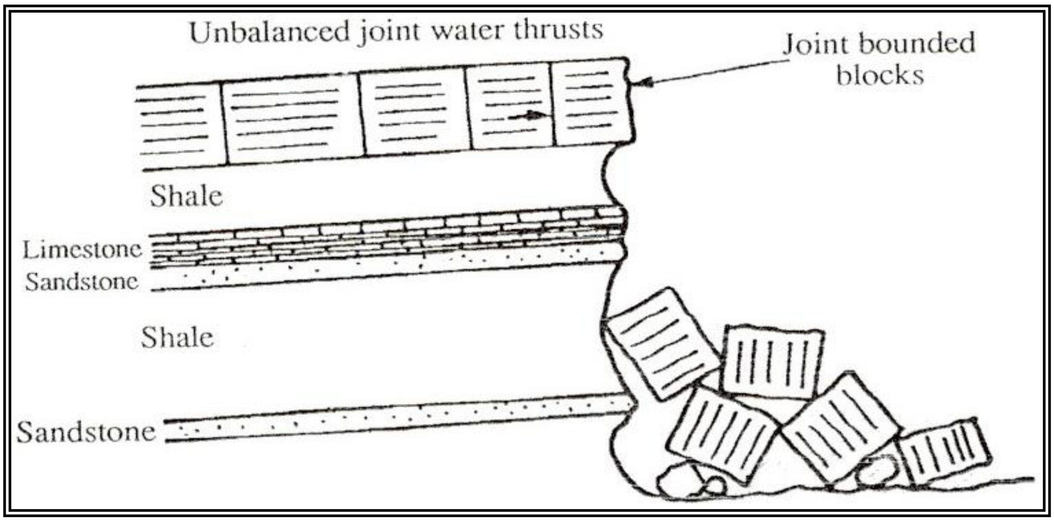


Figure (2-11) Rock fall from, Bromhead, (1992).

The start of rock fall movement involves an initial block detachment from the surrounding mass followed by free fall down slope. This condition is induced by a rock slope failure. The initial block velocity, at the start of the free falling movement, depends on the instability mode and on the block displacement which occurs before the block is thrown into the air.(Giani, 1992).

The principal rock slope instability mode may be induced by:

1- Water pressure in joints.

2- Earthquake shaking or blast vibrations.

3- Pressure due to ice formation in joints.

4- Slope excavation or slope surcharging.

A block detached from a rock face may have the following types of movement during flight. (Giani, 1992).:-

1- Free falling

2- Bouncing

3- Rolling

4- Sliding

One should consider that, due to the geometrical irregularity of the slope surface and of the block, the pure sliding or rolling movement modes can be transformed into a bouncing mode.

Bouncing is a movement that occurs when the falling block impacts with the slope surface. Clean faces of hard unweathered rock are the most dangerous because they do not retard the movement of the falling or rolling rock to any significant degree. On the other hand, surfaces covered in soil or gravel absorb a considerable amount of the energy of the falling rock and, in many cases, will stop it completely. This is why gravel layers are placed on catch benches in order to prevent further bouncing of falling rocks.

Ritchie (1963), described the effects of slope angle on the path that rock falls tend to follow. For slopes steeper than 75^{o}, the rocks tend to stay close to the face and land near the toe of the slope. For slope angles between about 55^{o} and 75^{o} falling rocks tend to bounce and spin with the result that they can land a considerable distance from the base. For slope angles between 40^{o} and 55^{o}, rocks will tend to roll down the face, while, the vertical slope the block has free fall mode of rock fall. Figure (2-12) shows the ditch (one of protection method) chart developed from field tests by Ritchie (1963).

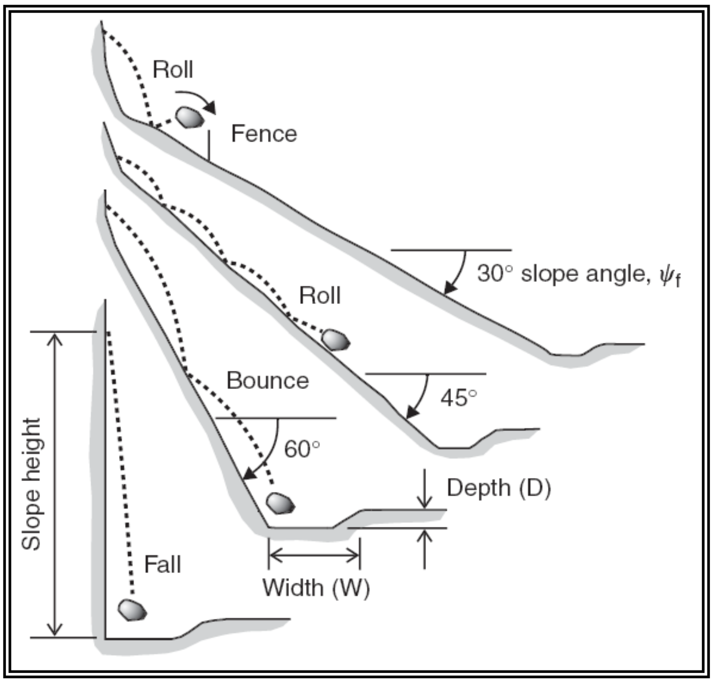


Figure (2-12) Ditch design chart for rock fall catchments, Ritchie, (1963), in Wyllie &Mah, (2004).

2-3 Factors Affecting Rock Slope Stability

Slope failure , whether in rock or in soil ,can be attributed to a number of causes .However it is rare that a given failure can be attributed to any single cause .Usually a number of causes exit simultaneously to eventually trigger the slope failure , (Kliche ,1999) . Al-Saadi, (1981), mentioned that several factors influence the stability of rock slopes , they can be grouped into two categories :-

A- Natural Factors

B- Artificial Factors

2-3-1Natural Factors

1- Structural Factors:-

The stability of rock slopes is significantly influenced by the structural setting of the rock in which the slope is excavated which refer to naturally occurring breaks in the rock such as bedding planes ,joints and faults which are naturally called discontinuities .The properties of discontinuities relative to stability include orientation ,persistence ,roughness and infilling . (Wyllie and Mah, 2004).

2- Weathering:-

The process of weathering represents an adjustment of the minerals of which a rock is composed to the conditions prevailing on the surface of the Earth. As such, weathering of rocks is brought about by physical disintegration, chemical decomposition and biological activity. It weakens the rock fabric and exaggerates any structural weaknesses, all of which further aid the breakdown processes. Weathering also is controlled by the presence of discontinuities in that they provide access into a rock mass for the agents of weathering. Some of the earliest effects of weathering are
seen along discontinuity surfaces. The type and rate of weathering varies from one climatic regime to another. In humid regions, chemical and chemico-biological processes are generally much more significant than those of mechanical disintegration. The degree and rate of weathering in humid regions depends primarily on the temperature and amount of moisture available. An increase in temperature causes an increase in weathering. On the other hand, in dry air, chemical decay of rocks takes

place very slowly. Weathering leads to a decrease in density and strength, and to increasing deformability . Weathering can affect a reduction in the strength of slope material, leading to sliding. The necessary breakdown of equilibrium to initiate sliding may take decades (Bell ,2007).

3-Water Effects:-

Water is required for most –indeed possibly all- weathering processes both physical and chemical. (Small & Clark, 1982). The presence of water (ground water, rainfall,..) in a rock slope can have a detrimental effect upon stability for the following reasons:

1- Water pressure reduces the stability of the slopes by diminishing the shear strength of potential failure surfaces. Water pressure in tension cracks or similar near vertical fissures reduces stability by increasing the forces that induce failure.

2- Changes in moisture content of some rock, particularly shales and claystone can cause accelerated weathering and a decrease in shear strength.

3- Freezing of ground water can cause wedging in water-filled fissures due to temperature dependent volume changes in the ice. Also, freezing of surface water on slopes can block drainage paths resulting in a build-up of water pressure in the slope with a consequent decrease in stability.

4- Erosion of weathered rock by surface water, and of low strength infillings by ground water can result in local instability where the toe of a slope is undermined, or a block of rock is loosened. (Wyllie & Mah, 2004) and ,(Bell , 2007)

4- Geomorphology and Topography:-

The geomorphologic and topographic factors have very important influence upon the stability of rock slopes. Hoek & Bray (1981) pointed out that the combined roles of slope characteristics (slope height and slope angle) with the orientation of discontinuities, determine the initial stability of slopes. Therefore, many slopes are stable at steep angles and large heights of several hundreds of meters, while many gentle slopes fall at low heights of only few of meters. This difference is due to the fact that the stability of rock slopes varies with inclination of discontinuity surfaces, such as faults, joints and bedding planes, within the rock mass (Figure 2-13). When these discontinuities are vertical or horizontal, simple sliding can not take place and the slope failure will involve fracture of intact blocks of rock as well as movement along some of the discontinuities. On the other hand, when rock mass contains discontinuity surfaces dipping down slope face at angles between of 30 and 70, sliding can occur and the stability of these slopes is significantly lower than those in which only horizontal and vertical discontinuities are present, (Figure 2-14).

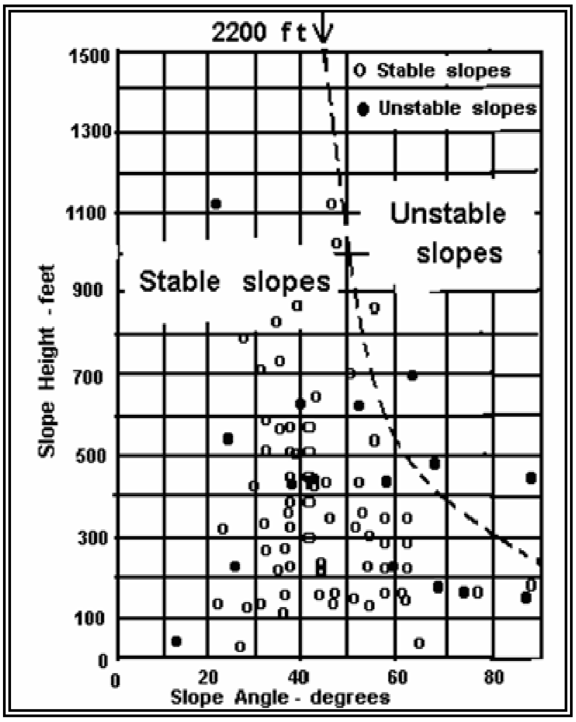


Figure (2-13) Slope height versus slope angles relationships for hard rock slopes. form Hoek and Bray (1981)

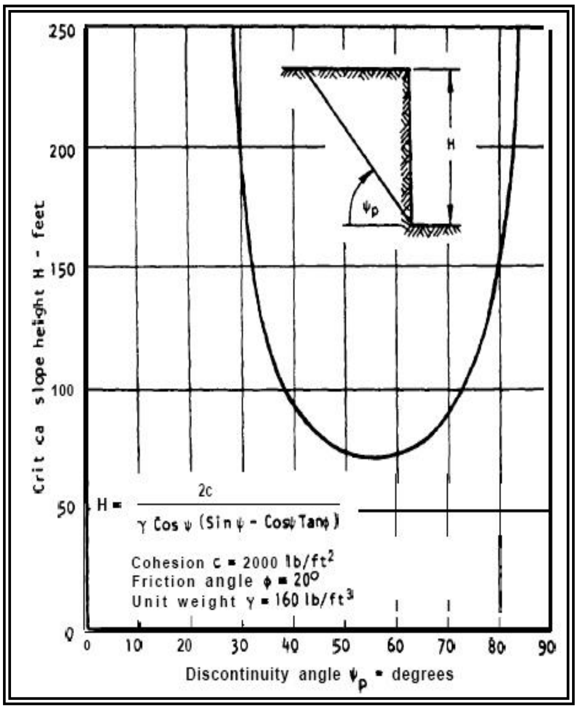


Figure (2-14) Critical height of a drained vertical slope containing planar discontinuity dipping at an angle Ψ_p. form Hoek and Bray, (1981).

5- Gravity:-

Failed rock mass tends to move down slope under the influence of gravity, a rock block resting on an inclined plane surface, the weight vector (W) of this block is resolved into two components, the shear component that acts down slope and tends to cause sliding is (W $\sin\Psi_p$), while the normal component which acts across the block basal plane and which tends to stabilize the block is (W $\cos\Psi_p$). The block will just on the point of sliding or in condition of limiting equilibrium when the disturbing force acting down the plane is exactly equal to the resisting force. (Hoek & Bray, 1981), (Blyth and De Freitas, 1984). (Figure 2-15).

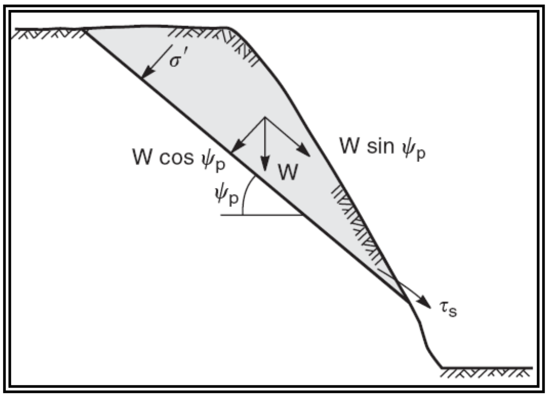


Figure (2-15) Gravity influence upon slope stability. Form Wyllie & Mah, (2004).

6- Seismic Activity and Vibration:-

Earthquakes affect the stability of slope in two ways .First , seismic shaking may cause loss of cohesion and/or reduction of the frictional strength of the substrate by shattering of rock mass or liquefaction in soft ,saturated soils . Widespread shattering has been reported from the epicentral areas of many large earthquakes associated with thrusting, and appears to be especially severe in topographic slopes located on the hanging wall . Coalescence of cracks during earthquakes gives rise to increased substrate permeability and has caused the release of vast volumes of groundwater from epicentral areas. Second, addition of seismic accelerations to the ambient, gravitational acceleration results in short-lived and episodic changes of the normal and shear stresses in hillslopes during earthquakes. These changes may be sufficient to cause failure. (Meunier ,et al ,2008).

Wyllie & Mah (2004), Mentioned that the following five slope parameters have the greatest influence on stability during earthquakes:

1- Slope angle: Rock falls and slides rarely occur on slopes with angles less than about 25°.

2- Weathering: Highly weathered rock comprising core stones in a fine soil matrix, and residual soil are more likely to fail than fresh rock.

3- Induration: Poorly indurated rock in which the particles are weakly bonded is more likely to fail than stronger, well-indurated rock.

4- Discontinuity characteristics—Rock containing closely spaced, open discontinuities are more susceptible to failure than massive rock in which the discontinuities are closed and healed.

5- Water: Slopes in which the water table is high, or where there has been recent rainfall, are susceptible to failure.

Vibration : Blasting, earthquakes and the operation of heavy plant and machinery can all produce sources of vibration that might influence slope stability.

2-3-2Artificial Factors:-

Human activities account for many landslides. The construction of highway, hillside housing developments, dams, reservoirs, drainage and utility structures normally involve the movement of substantial amounts of soil or rocks on slopes. If the operation consists of addition of material to the top of the slope or the removal of soil or rock from its base, then the slope is nudged toward failure. In extreme cases, failures take place during or immediately following the construction process. (Bolt et. al., 1975).

2-4 Improvement of Slope Stability and Protection:-

2-4-1 Improvement of Slope Stability:-

After analyzing the slope stability for each station in the studied area and diagnosing of the possible mode of failure of the rock slope, the slope could be improved in the following ways:

1- Removal of Unstable Rocks:

Stabilization of rock slopes can be accomplished by the removal of potentially unstable rocks. In general, rock removal is a preferred method of stabilization because the work will eliminate the hazard, and no future maintenance will be required. Methods of improvement include:-

A- Re-sloping and unloading:

Where overburden or weathered rock occurs in the upper portion of a cut, it is often necessary to remove and cut this material at an angle flatter than the more competent rock below it. Removal of loose rock on the face of a slope is not effective where the rock is highly degradable, such as shale. In these circumstances, exposure of a new face will just start a new cycle of weathering and instability. For this condition, more appropriate stabilization methods would be protection of the face with shotcrete and rock bolts. (Wyllie & Mah, 2004).

B- Trimming:

Failure or weathering of a rock slope may form an overhang on the face, which could be a hazard if it were to fail. In these circumstances, removal of the overhang by trim blasting may be the most appropriate stabilization measure. (Wyllie & Mah, 2004).

C- Scaling:

Scaling describes the removal of loose rock, soil and vegetation on the face of a slope using hand tools such as scaling bars, shovels and chain saws. (Wyllie & Mah, 2004).

2- Slope Height Reduction:

By reducing the height of the slope or depth of excavation, this may not be possible in some situations. (Ramamurthy, 2008).

3- Using Rock Bolts, Anchors, and Concrete Walls or Shotcrete:

By providing rock bolts or rock anchors distributed over slope and orienting them as advantageously as possible with respect to the location and attitude (strike and dip) of the joints. If tensioned rock bolts are used to support closely fractured rock, the fractured rock may degrade and ravel from under the reaction plates of the anchors, and eventually the tension in the bolts will be lost. In these circumstances, a reinforced concrete wall (reaction wall) can be constructed to cover the area of fractured rock, and then the holes for the rock anchors can be drilled through sleeves in the wall. Finally, the anchors are installed and tensioned against the face of the wall. The wall acts as both a protection against raveling of the rock, and a large reaction plate for the rock anchors. Where necessary, reinforced shotcrete can be substituted for concrete. (Kliche,1999) , (Wyllie & Mah, 2004).

2-4-2 Protection of Slope Stability (Against Rock Fall):-

An effective method of minimizing the hazard of rock fall is to let the falls occur and control the distance and direction in which they travel. Protection methods are always used in areas of extreme rock fall hazard where stabilization of the slope would be very costly.

1- Barriers :

A variety of barriers can be constructed either to enhance the performance of excavated ditches , or to form catchment zones at the toe of the slope. The following is the commonly used barrier .

- Gabions or concrete blocks are effective protection tools for falling rock. Gabions are rock filled, typically measuring 0.91m by 0.91m in cross-section, that are often constructed on-site with local waste rock. Advantages of gabions are the ease of construction on steep hillside and where the foundation is irregular, and their capacity to sustain considerable impact from falling rock. (Wyllie & Mah, 2004).

2- Ditches:

Catch ditches at the toe of the slope are often a cost-effective means of stopping rock fall, provided there is adequate space at the toe of the slope**.** (Wyllie & Mah, 2004).

3- Wire Mesh:

Wire mesh hung on the face of a rock slope can be an effective method of containing rock falls close to the face and preventing them from bouncing on to the road by absorbs some of the energy of the falling rock. For installations covering a high slope where the weight of the lightweight mesh may exceed its strength, the mesh can be reinforced with lengths of wire rope. In all cases, the upper edge of the mesh should be placed close to the source of the rock fall so the blocks have little momentum when they impact the mesh.

The mesh is not anchored at the bottom of the slope or at intermediate points. The freely hanging mesh permits rocks to work their way down to the ditch, rather than accumulating behind the mesh; the weight of such accumulations can fail the mesh, (Wyllie & Mah, 2004).

2-5Methodology:

Methodology includes four stages of work:

2-5-1 Data Collection Stage

All of the available publications about the study area (journals, papers, theses, reports, maps including topographic and geologic maps and satellite images) were collected and studied , in order to gain better idea about the study area .

2-5-2Field Work Stage

In this stage there are one geologic work periods for 1 days from (29^{st} February2024) for twenty three sites (stations) (Figure 1-2) to study rock slope failures, their types , mechanisms and effects in Tar Al-sayyed slopes , the following steps were carried out at each station :

1- Measuring the slope direction, angle and height.
2- Measuring the dip (direction and angle) of strata.
3- Engineering description of rocks according to :-

- The reports suggested by the Engineering Group of the Geological Society of London (Anon,1972 and 1977).
- Carrying out a general surveying for the discontinuities including kinds, direction & dip angle, and the distance between these discontinuities, and their persistence along bedding plane.

4- Determination of the types of the present and probable failures.

3-1-4- Office Work Stage

The presentation and interpretation of data collected from the field and the results of laboratory tests for rocks and soils included in this stage . Field measurements (attitude readings for discontinuities and slopes) are presented and analyzed by Schmidt Net of Stereographic Projection for all stations , using Stereonet for windows V.1.2 , 2003 program .After all , rock and soil tests results of data will be represented and analyzed by Schmitt net of stereographic projection of bedding planes, slopes and discontinuities of all stations.

Rock Slope Stability Assessment in the Study Area

3-2 Engineering Geological Description of Rocks:-

In order to describe the rocks in all selected stations in the study area in terms of engineering geology, the description is based on the report suggested by the working party of the Engineering Group of the Geological Society of London (Anon, 1972 and 1977).

According to the scheme of description adopted by the working party , the ROCK NAME (in capital) is preceded by prefixes and followed by suffixes as follows :-

<u>Prefixes</u>

Colour

Grain size

Texture and structure

Discontinuities within the mass

Weathered state

Alteration state

Minor lithologic characteristics

ROCK NAME

Suffixes

Estimated mechanical strength of the rock material

Estimate of mass permeability

Other terms indicating special engineering characteristics

1- Colour :-

Rock colour is a property that easy to appreciate but difficult to quantify .It may be expressed in terms of three parameters ,the ***hue*** (basic colour or a mixture of basic colours),the ***chrome*** (Brilliance or intensity of colour) and the ***value*** (lightness of colour), (Anon, 1972). A simple subjective scheme would involve choice of a colour from column (3)in the

(table 3-1), supplemented if necessary by a term from column (2) and /or column (1).

Table (3-1) Colour description of rocks (Anon,1972).

1	2	3
Light	Pinkish	Pink
Dark	Reddish	Red
	Yellowish	Yellow
	Brownish	Brown
	Olive	Olive
	Greenish	Green
	Bluish	Blue
		White
	Grayish	Grey
		Black

2- Grain Size:-

The same descriptive terms for grain size ranges should be applicable to all rocks , and the size ranges used for soils would appear to be suitable for this purpose , (Anon,1972).

Table (3-2) Grain size description for rocks (Anon, 1972).

Equivalent soil grade	Term	Size of component particles
Boulder & cobbles	Very coarse-grained	> 60 mm
Gravel	Coarse-grained	2 mm - 60mm
Sand	Medium grained	60 microns-2mm
Silt	Fine-grained	2 microns-60 microns (Grains larger than 10 microns visible using x 10 hand lens)
Clay	Very fine grained	< 2 microns

3-Bedding Planes:-

Based on Anon(1972), and according to their thickness, rocks strata are described in the (table 3-3), the following scale should be used.

Table (3-3) Bedding plane scale description for rocks (Anon, 1972).

Term	Spacing
Very thickly bedded	>2m
Thickly bedded	600mm - 2m
Medium bedded	200mm - 600mm
Thinly bedded	60mm - 200mm
Very thinly bedded	20mm - 60mm
Laminated (sedimentary rocks)	6mm - 20mm
Thinly Laminated (sedimentary rocks)	< 6mm

4- Joints:-

The description of joints according to Anon (1972) includes the orientation of joints , dip and their characteristics such as spacing , their persistence on bedding plane , opened or closed ,Table (3-4) is used for describing the spacing of joints.

Table (3-4) Joints spacing description (Anon, 1972).

Term	Spacing
Very widely spaced	> 2m
Widely spaced	600mm - 2m
Moderately widely spaced	200mm – 600mm
Closely spaced	60mm - 200mm
Very closely spaced	20mm - 60mm
Extremely closely spaced	< 20mm

5- Weathering :-

Weathered state described according to the effect of weathering on the resistance of rocks and other characteristics such as loss of strength, opening in joints and discoloration .There are six grades of weathering are shown in (table 3-5) based on Anon(1972).

Table (3-5) Weathering description (Anon, 1972).

Term	Grade symbol	Diagnostic features
Fresh	W I	Parent rock showing no discoloration, loss of strength or any other weathering effects.
Slightly weathered	W II	Rock may be slightly discolored, particularly adjacent to discontinuities, which may be open and will have slightly discolored surface, the intact rock is not noticeable weaker than the fresh rock.
Moderately weathered	W III	Rock is discolored, discontinuities may be open and will have discolored surfaces with alteration starting to penetrate inwards. intact rock is noticeable weaker, as determined in the field, than the fresh rock.
Highly weathered	W IV	Rock is discolored, discontinuities may be open and have discolored surfaces, and the original fabric of the rock near to the discontinuities may be altered. Alteration penetrates deeply inwards, but corestones are still present.
Completely weathered	W V	Rock is discolored and changed to a soil but original fabric is mainly preserved. There may be occasional small coretsones. The properties of the soil depend in part on nature of the parent rock.
Residual soil	W VI	Rock is discolored and completely changed to a soil in which original rock fabric is completely destroyed. There is a large change in volume.

6- Strength:-

Determination of the mechanical strength of the rock sample, indirectly measured compressive strength from point load test for rock samples for measuring stations . (Table 3-6), showing the terms and a scale of strength, (Anon,1972).

Table (3-6) Description of strength for rocks, (Anon,1972),and modified after (Hawkins,1986).

Term	Compressive strength MN/mm^2(MPa)
Extremely strong	>200
Very strong	100-200
Strong	50-100
Moderately strong	12.5-50
Moderately weak	5-12.5
Weak	1.25-5
Very weak (soil)	<1.25

7-**"ROCK NAME"** should be written in capital letters .Then , rock name followed by suffixes which include, the compressive strength.

8- Permeability based on discontinuity spacing .Table (3-7) provides generalized values for jointed rocks . (Anon,1972).

Table (3-7) Description of permeability values after (Anon,1972) and modified after (Hawkins,1986).

Rock Mass Description	Permeability	
	Term	K in m/s units
Very closely to extremely closely spaced joints	Highly permeable	10^{-2} - 1
Closely to moderately widely spaced joints	Moderately pemrmeable	10^{-5} - 10^{-2}
Widely to very widely spaced joints	Slightly permeable	10^{-9} - 10^{-5}
Unjointed ,solid	Effectively impermeable	< 10^{-9}

9- Other terms idicating special engineering characteristic .

After an engineering geological description finished for all station, the stability of slopes has been analyzed graphically by stereographic projection using Schmidt net. The stereographic projection figures are plotted manually and by using computer program like (Stereo winful 1.2 and Microsoft office). Then, the factors that influencing rock slope stability are determined and treatment procedure to stabilize the slopes are suggested.

The attitude (inclination or dip) of slopes or layers is referred to by two numbers representing the direction (Azimuth to the left) and the angle (in degrees to the right), also, in case of overhanging slope, the letters (OH) are used and the letters (R.m) are used for (rock mass). Release surfaces terms, that help in detachment and movement of rock block, are used and classified according to their position with respect to the detached block, (Hoek and Bray, 1981), (Al-Saadi, 1991), as follows:-

1- Back release surfaces (BRS)

2- Lateral release surfaces (LRS)

3- Composite back release surfaces (CBRS)

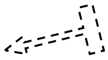
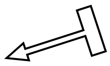
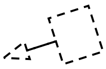
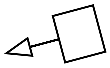
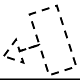
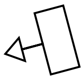
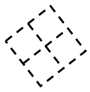
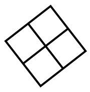
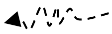
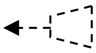
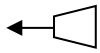
4- Basal surface (BS)

The symbols that used to represent the data on the stereographic projection are based on / or modified from (Al-Saadi, 1981), (table 3-8 and table 3-9).

Table (3-8) Types of great circles and poles used to represent the collected field data on stereogram, modified from (Al-Saadi, 1981).

Symbol	Description	Symbol	Description
GS	Cyclographic trace (great circle) of a general slope	R.m	Rock mass
SS	Cyclographic trace of a side slope	L.S	Left side slope
OH or VS	Cyclographic trace of vertical slope (VS) or overhanging slope (OH)	R.S	Right side slope
		L.s	Lower slope
S_0	Cyclographic trace of mean orientation of bedding plane (S_0)	U.s	Upper slope
		L.p	lower part
S_1, S_2 ●	Pole to joint plane, join sets	U.P	Upper part

Table (3-9) Symbols of types of failure and photo direction used and represented on stereogram, modified from (Al-Saadi, 1981).

Types of failure	**Symbol**	
	Possible	**Present**
Toppling		
Rock fall		
Plane sliding		
Granular disintegration		
Rolling		
Slumping		
Photo direction		

3-2 Station No. (1):

This station lies at latitude (32° 28' 28.78" N) and longitude (043° 46'.08" E), within Injana Formation, (Figure 1-2, plate 3-1). The slope is (6.0m) high, (9m) long along its trend , and its inclination is (280/88°). The bedding plane is faint horizontal to sub horizontal inclination is (210/6°). . Below the main rock slope, there is soil slope with inclination 20 ° NW covered by detached blocks.

Plate (3-1) The slope of station No. (1) (a) Front view showing detached rock blocks and discontinuities , Photo direction is SE (b) Top view showing tension crack. Photo direction is SE.

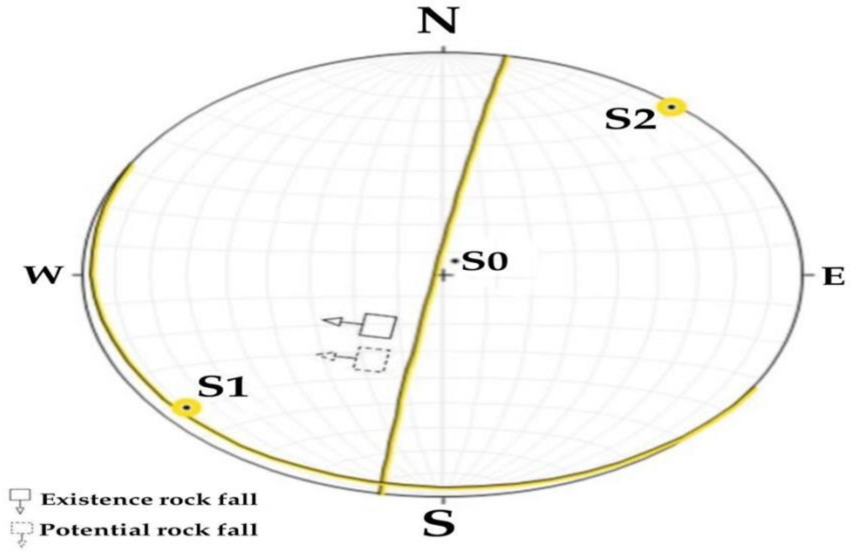
The rock mass layers consist of (2.75m) thick layers which are exposed. They are light pinkish orange , medium grained ,very thickly bedded, widely jointed, moderately weathered, pebbly SANDSTONE, moderately strong (σc=14.85MPa) and Slightly permeable .

The rock mass layers are cut by two sets of joints in (S1&S2), (Figure 3-1).The average dip of S1 is (050 /82 º) , and that dip of S2 is (220/88º). The spacing of joints in (S1)) ranges between (0.5-1.0m), their persistence reaches (2.75 m) and they are almost open up to (0.1m). The spacing ranges in joints (S2) between (1.0-1.6m), their persistence reaches (2.75 m) up on the upper surface rock mass and they are almost open up to (0.02m), (Plate 3-1-a).

There is a composite tension crack that consists of joints in (S1&S2) at the top of the slope, it is (4.80m) long, (0.3m) wide and (1.60m) deep, (plate 3-1-b).

The composite tension crack is open at the top slope . This makes the slope active and unstable, the rock slab bounded by this tension crack is likely to topple in the future by tension crack mechanism accompanied by undercutting due to differential erosion .

of



Secondary toppling could also includes, toppling and slumping mode. Joints in (S1) set acted as back release surfaces (BRS) of the toppled block while (S2) joint set acted as lateral release surfaces (LRS). The inclined soil slope (below the main rock slope), and its surface acts as a surface of slumping for the detached blocks .

3-3 Station No. (2):

This station lies (50m) NW of station 1, at latitude (32^{o} 28.$^{'}$ 826$^{''}$ N) and longitude (043^{o} 46.$^{'}$ 836$^{''}$ E), within Dibdibba Formation, (Figure 1-2, Plate 3-2). The slope at this station consists of two slopes: general slope (the first slope) which is (7m) high , (20m) long parallel to its trend and its inclination is (100/82^{o}-OH). This slope changes to , right side slope (R.S the second slope) which is (1.60-1.90m) high , (10m) long along its trend and its inclination is (310/4^{o}). The average dip of strata is (108/4^{o}), therefore, the slopes are subhorizontal-layer slopes, (Figure 3-3). Below the main rock slope, there is a soil slope which is inclined about 40 ^{o}NW.

In the upper part of the slope a (1.30m) thick layers are exposed, they are light pinkish orange, medium grained, medium-thickly bedded, widely-moderately widely jointed, moderately weathered, pebbly SANDSTONE, strong (σc=90.0 MPa),Slightly to moderately permeable.

The underlying rock layer in the lower part of the slope (lower limit invisible) is exposed up to (0.6m) thick layers are light pinkish orange , medium grained , moderately bedded , moderately-highly weathered , SANDSTONE , very weak (failed in point load test).The lower part of the slope is largely exposed to undercutting leaving parts of the upper

slope overhanging.

Plate (3-2) The slope of station No. (2) (a) Front view showing detached rock block& discontinuities . Photo direction is SE (b) side view showing side slope and large toppled slabs. Photo direction is NE.

The pebbly sandstone layers are cut by three sets of subvertical joints in (S1,S2). The average dip of S1 is (050/88 º) , that of S2 is (190/ 84 º) , The spacing of joints in (S1) ranges between (0.75-1.5m); their persistence reaches (1.30m) on the bedding plane and they are almost tight to open up to(0.02m). The spacing of joints in (S2) is about (1-1.5m), their persistence reaches (1.3m) on the bedding planes they are almost tight .

The overhanging parts are unstable and liable to failure in the future by secondary toppling type, by undercutting mechanism. Joints in (S1&S2) may act as Composite back release surfaces (CBRS), Joints in (S1) acted as back release surfaces (BRS) for the side slope and caused toppling for the large detached slab while those in joints (S2) acted as lateral release surfaces (LRS) . Rock fall has occurred in this station and likely to occur in the future in both slopes .The inclined soil slope helps rolling of detached rocks.

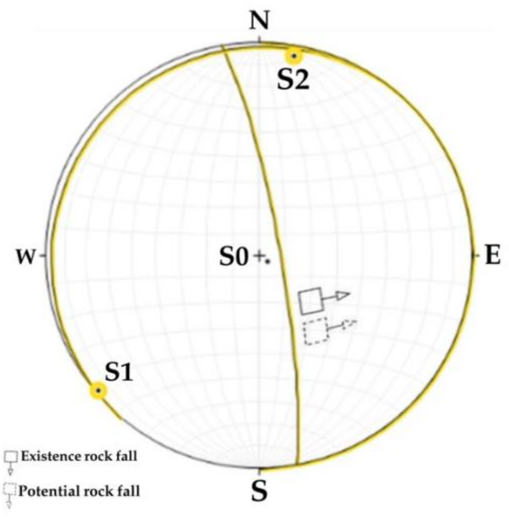


figure (3-2) Stereographic projection of discontinuities, slope and type of failure for station No2 in Tar – Al-Sayyed area

3-4 Station No. (3):

This station lies at (179m) NW of St. (2) at latitude (32º 28.' 847" N) and longitude (043º 46.' 858" E), within Dibdibba Formation, (Figure 1-2, Plate 3-3). The slope at this station consists of general slope (the first slope) which is (9m) high, (9m) long parallel to its trend , and its inclination is (380/74º-OH). This slope changes to the right side forming right side slope (R.S the second slope) which is (1.20m) high, (7m) long along its trend , and its inclination is (110/4º - OH). The bedding plane is faint , (Figure 3-3). Below the main rock slope, there is a flat area.

The rock mass layers consist of (1.30m) thick layer which is exposed. The rocks are light pinkish orange , medium grained , thickly bedded, widely jointed, slightly - moderately weathered, SANDSTONE, moderately strong.

Plate (3-3) The slope of station No. (3) (a) Front view showing general slope , detached rock block& discontinuities , photo direction is NE (b) side view showing side slope and, discontinuities . Photo direction is SE.

The sandstone layers are cut by two sets of subvertical joints in (S1&S2), (Figure 3-3). The average dip of S1 is (200/88 º) , and that of S2 is (100/88 º) .The spacing of joints in (S1) ranges between (1-2 m), their persistence reaches (1.30m) on the slope, they are almost tight . The spacing of joints in (S2) ranges between (0.5-1.0m), their persistence reaches (1.30m) on the slope and they are open about (0.04m) .

Failure may occurr in the future by secondary toppling , due to undercutting accompanied by differential erosion in the lower parts of the slope 2 (left slope).During toppling and rock fall , in the general slope (slope1), joints in (S2) acted as back release surfaces (BRS), and joints in (S1) acted as lateral release surfaces (LRS), in the side slope (slope2), joints in (S2) acted as lateral release surfaces (LRS) while joints in (S1) acted as Back release surfaces (BRS) .

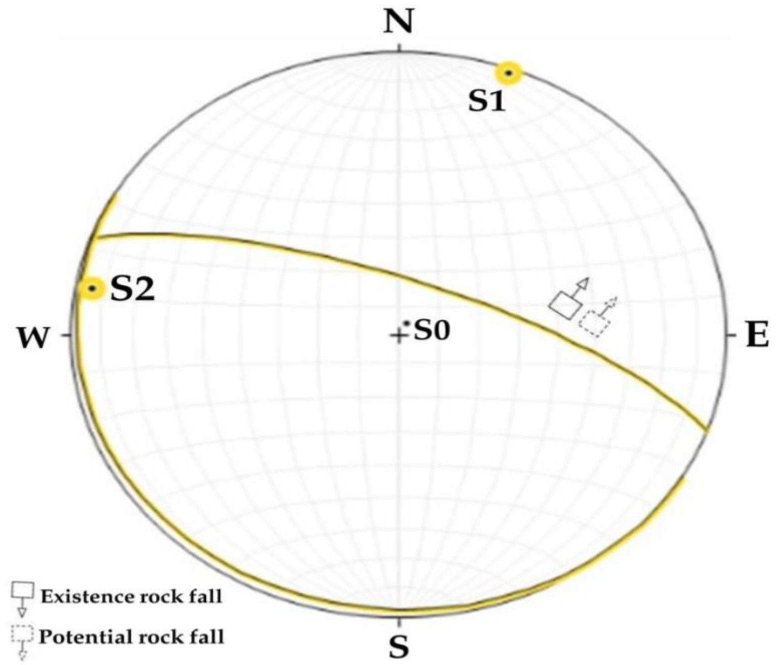


Figure (3-3) Stereographic projection of discontinuities, slope and type of failure for station No. (3) in Tar Alsayyed area .

4-Conclusions and Recommendations

4-1 Conclusions:-

1. Since Tar Al-sayyed is an arid area with high temperature in the summer and low temperature in winter , with low annual rainfall almost restricted to winter ,high annual evaporation ,and increasing wind speed in the summer ,it can be concluded that the climatic

conditions partially help in slope stability in the study area as follows :-

a) The wind is the principal agent of erosion (specially in summer) and helps in differential erosion and forms overhanging unstable slopes .
b) Seasonal and daily changes in temperature help in rock disintegration into blocks and fragments liable to easy detachment .
c) The low amount of annual rainfall helps partially instability ,specially in winter .

2. Lithology in the study area is an important factor in forming unstable and overhanging slopes due to variation in rock types and in their resistance to erosion.
3. In addition to the basic field observations , the stereographic projection is the most effective tool in slope stability assessment , specially in the determination of the role of the discontinuities in different types of failures .
4. Field observation reveals the presence of different types of slope failure in Tar Al-sayyed where Injana and Dibdibba Formations are exposed . These (from most to least abundant) are : secondary toppling (of different mechanisms) , rock fall ,disintegration.
5. Low- moderate angle soil slopes at the toe of most cliffs help in the rolling of the detached blocks from the main steep slopes .

4-2 Recommendations:-

Detailed studied and analyses of all slopes ,discontinuities ,lithology , and failures in Tar Al-sayyed area lead to the following recommendations :

1-Removal of blocks that failed or likely to fail in the future .

1. Using warning signs along the edge of the plateau close to the cliffs of Tar Al-sayyed in the graveyard and in the areas adjacent to the cliffs to draw the attention of people to failure hazards of the cliffs .
2. To build a suitable fence at a considerable distance from the cliff edge on the highlands to prevent people from reaching the unstable slopes and tension cracks for their safety.

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