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گۆڤاری زانكۆی سلیمانی- بەشی A

# Landslide Hazard of Rock Slopes Around Shaqlawa City, Kurdistan Region, NE Iraq, with Modified Classification of Hazards on Roads and proposing remedial measures

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Abstract:

**The results of rock slopes analyses around Shaqlawa area showed that Landslide Possibility Index (LPI) values range between Low (LPI) for rock slopes of Tanjero, Kolosh and (marl and siltstone) of Gercus Formations, Moderate (LPI) for rock slopes of Shiranish, Gercus (sandstone and dolomitic limestone) and Pila Spi Formations, and High (LPI) for rock slopes of the dolomitic limestone of Pila Spi Formation at the gorge north of Shaqlawa city (at the west side of Shaqlawa - Harir main road). Two landslide hazard maps have been prepared for Shaqlawa area:**

**A- The first Hazard map (based on LPI values) shows three hazard areas; (1) Area of Low Hazards (for Tanjero and Kolosh Formations). (2) Areas of Moderate Hazards (for Shiranish, Gercus and Pila Spi Formations) and (3) Area of High Hazard (for the dolomitic limestone beds of Pila Spi Formation) west of Shaqlawa - Harir main road.**

**B- The second Hazard map (based on the effect of landslide on the roads), also shows three hazard areas but different from the first map. It shows; (1) Area of Very Low Hazard (it includes slopes of Tanjero, Kolosh and Gercus Formations) because of the wide distance between the failing slopes and the road, (2) Area of Moderate Hazard (in the slopes of Shiranish Formation) because of closeness from the road and poor protection works, and (3) Area of High Hazard (at Pila Spi dolomitic limestone slopes at the west side of Shaqlawa-Harir main road) due to its high slope angle and height, and closeness to the road in addition to poor protection works.**

**A modification on the classification of landslide hazard on roads is suggested, and some measures of landslides treatment are suggested, for slope stabilization and road protection.**

*Keywords:* Landslides, Shaqlawa area, Rock slopes, Hazard, Safin, Gird Sur, Shiranish.

## INTRODUCTION

### Location

The study area comprises rock slopes of Shiranish, Tanjero, Kolosh, Gercus and Pila Spi Formations around Shaqlawa summer resort. Shaqlawa area is located in Kurdistan region northeast Iraq and about 45 km northeast of Arbil city, Fig (1). It lies between Longitudes; 44° 18′ 00′′ and 44° 21′ 00′′ East, and Latitudes; 36° 23′ 22′′ and 36° 25′ 00′′ North.

Shaqlawa city occupies a depression between two mountainous ridges; Safin Mountain to the Southwest and Gird Sur Mountain to the Northeast, which make Shaqlawa city surrounded by rock slopes subjected to landslide hazards due to natural and manmade factors that threaten lives and properties.

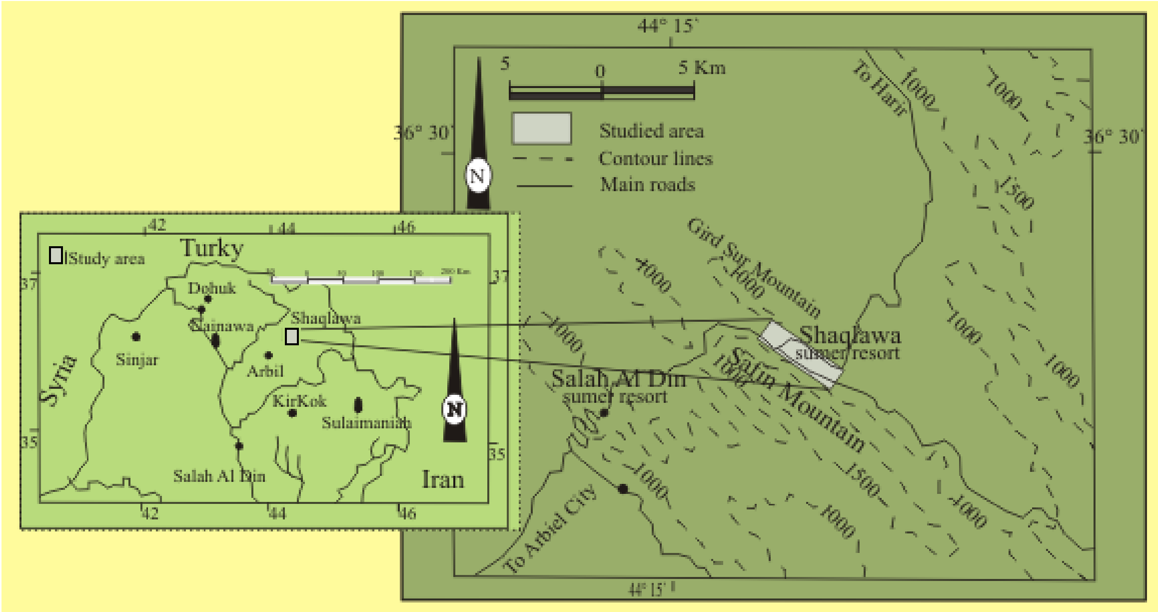


Fig (1): Location map of the studied area,(Modified after Al-Shaikh *et. al*., 1975)

## Objectives

The main objectives of this study are:

1- Landslide Possibility Index (LPI) calculations.

2- Failure hazard assessment by preparation of two landslide hazard maps;

A- The first map is based on (LPI) values of Bejerman (1998)method.

B- The second map is based on the landslide effects on roads using Barison and Conteduca (1998) classification (in Barahim, 2004).

3- Suggestion of some remedial measures for slope stabilization and road protection.

## Previous works

Most of the previous studies on Shaqlawa area are found on different geological subjects (Stratigraphic, sedimentological, structural, geophysical, hydrological and geotechnical subjects):

There is an engineering geological Master thesis on the area (Al- Obaidi, 2005) from which the basic data are derived in this paper, and one slope stability study also derived from this thesis focused on modes of failures in the area (Yousif and Al-Saadi, 2010). This paper has come up with largely revised and different conclusions from Al-Obaidi (2005) thesis.

## Methodology

In order to evaluate Shaqlawa rock slope hazards according to the risk upon life and property, data which were collected during the field works of rock slope stability study around Shaqlawa area by (Al-Obaidi,2005), are used here.

The Landslide Possibility Index (LPI) was calculated at many sites according to Bejerman (1994) method by filling sheets that consider (10) ten factors.

Two landslide hazard maps have been prepared in this study, the first map based on (LPI) values according to Bejerman (1994 and1998) classification of slope failure hazards. The second failure hazard map is based on the influence of failures on roads according to Barison and Conteduca, (1998) classification of hazards on roads (in Barahim, 2004).

## Seismic and climatic conditions

Although Shaqlawa area is close to the common seismic Torus - Zagros Zone, but it has low seismic records (Al-Kadhimi *et al.,*1996). Shaqlawa area can be classified as Savanna area according to climatic regions classification of Peltier, (1950 in Fookes *et al*., 1971) because its mean annual rainfall is 650 mm and mean annual temperature 18 C° and the mean annual snowfall is less than 5.5 day/year, (I.M.O., 1990). If the climate changes from season to another in Shaqlawa area are considered, the area seams semiarid in the general sense, because the climate is almost wet for some (7) months (October to April), and dry in other (5) months (May to September).

## Geological setting

The exposed rock Formations within Shaqlawa area range in age from Late Cretaceous to Late Eocene (Sissakian and Youkhana, 1979), Fig (2). The oldest accessible Formation is Shiranish Formation of (Early Maastrichtian) which is exposed as strip along the foot of the northeastern slopes of Safin Mountain. Shiranish Formation consists of well bedded, smooth surfaces, bluish grey clayey or marly limestone and limestone with unconfined compressive strength (uniaxial comp. str.) range between (72 – 120) MPa for the intact rock, while the joints friction angle (Ø) ranges between 26°-28°, measured by the portable shear box.

Shiranish Formation is gradationally overlain by Tanjero Formation (Late Maastrichtian) which is exposed as windows in the central part of Shaqlawa area and consists of yellowish and olive green clastics of sandstone, claystone, marl and conglomerate. The upper contact with the overlying Kolosh Formation (Early Eocene) is unconformable and occasionally taken either with the presence of conglomerate or at the color variation to dark green clastics, (Sissakian and Youkhana, 1979).

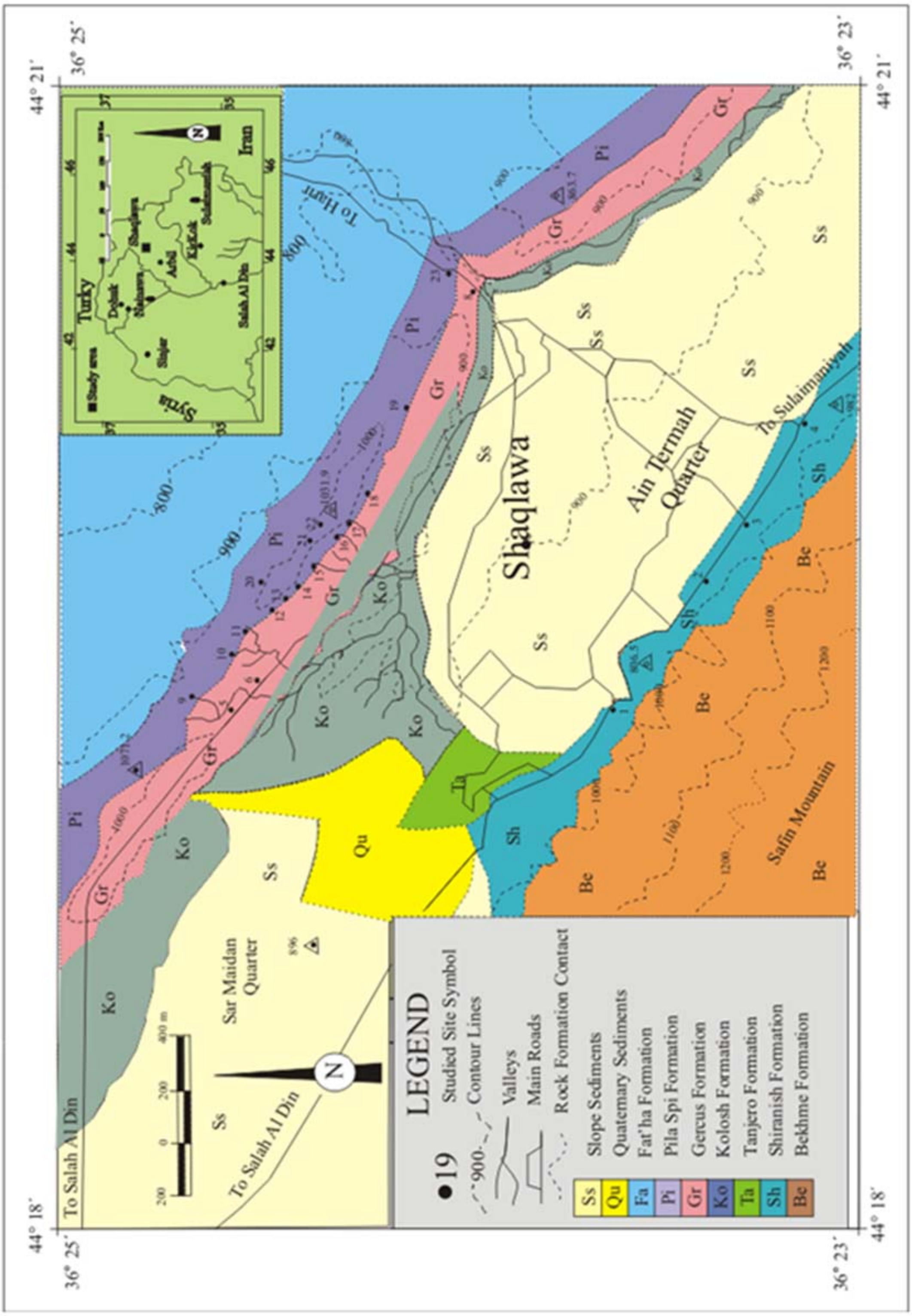


Fig (2): Geological map of Shaqlawa area,(After Sissakian and Youkhana, 1979).

Kolosh and Tanjero formations occupy the depression between Safin and Gird Sur mountains. Kolosh Formation is exposed in the central and western parts of Shaqlawa area. Kolosh Formation is prevailed by dark green shale and more of sandstone, marl and conglomerate. Kolosh Formation is overlain by Gercus red beds Formation with a probable unconformity (Bellen *et al*., 1957).

Gercus Formation in Shaqlawa area is exposed as a belt that occupies most of the southwestern slopes of Gird Sur Mountain North of Shaqlawa area. It consists of 80% marl and siltstone, 17% sandstone and 3% dolomite, with cyclic nature, fining upwards (Al-Rawi, 1980). The upper contact of Gercus Formation with the overlying Pila Spi Formation is unconformable and taken at the base of thick basal conglomerate beds (3-12 m in Shaqlawa area), Fig (3). Tamar-Agha believes that the thick conglomerate beds between Gercus and Pila Spi formation are not basal erosional because the two formations have the same age and are interlonguing in many places (Tamar-Agha, 2012, Personal Communication).

Pila Spi Formation in this area is exposed as a strip ridge extending from southeast to northwest and occupies the upper parts and the crests of Gird Sur Mountain. Pila Spi Formation essentially consists of recrystallized limestone and clayey or dolomitic limestone occasionally chalky, white to creamy, light grey and yellowish white. It is well bedded, consisting of (0.2 - 2.0 m) thick beds. The conglomeratic beds at the base of Pila Spi Formation are of considerable importance due to their large thickness, high strength, and resistant to erosion that make them forming overhanging slopes and cliffs along the southwestern slopes of Gird Sur Mountain, Fig (3).

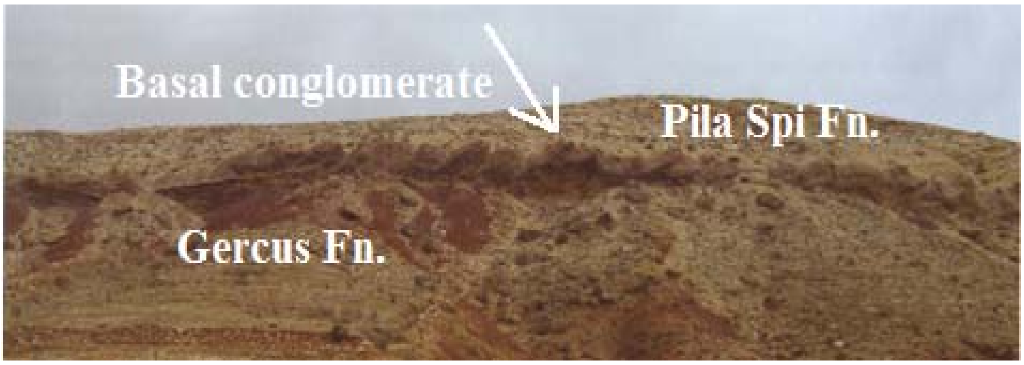


Fig (3): Overhanging slopes and cliffs along the basal conglomerate between Gercus and Pila Spi Formations due to differential erosion.

Tectonically, Shaqlawa area lies within the High Folded Zone of the Unstable Shelf of the Arabian Platform, (Buday and Jassim, 1984 and 1987).

Structurally, the studied area consists of homoclinal structure because it is a part of the northeastern limb of Safin Anticline. This anticline is NW - SE trending, asymmetrical, double plunging, with steep southwestern limb and gentle northeastern limb, (Sissakian and Youkhana, 1979).

Geomorphologically, the studied area is represented by two mountainous ridges separated by relatively wide subsequent valley through Tanjero and Kolosh Formations, and occupied by Shaqlawa summer resort.

The southwestern ridge is Safin Mountain which is the highest crest in the studied area (1975 m a.s.l.) and the northeastern ridge is Gird Sur Mountain, which is 1031 m a.s.l.

The dendritic drainage system is the prevailing pattern of valleys specially, in Tanjero, Kolosh and Gercus Formations due to the homogeneity and weakness of these clastic rocks, they all drained into Shaqlawa valley from different directions and then moving southeastward.

## Detailed Analyses of Landslide Hazards in the Study Area

23 rock slope stations,were studied in details in addition to Tanjero and Kolosh rock slopes. The current paper focuses on landslide possibility index system, by Bejerman, (1994) to estimate the possibility of sliding and hazards of the studied rock slopes and then according to Barison and Conteduca, (1998) to assess and draw the rock failure hazard on roads.

### 1- Landslide Possibility Index (LPI) of the study area:

The Landslide Possibility Index (LPI) classification of Bejerman (1994) is applied here to all of the studied stations in Shaqlawa area. The (LPI) values are calculated by adding the estimations of attributes 1-10 (Table 1). The Possibilities of landslides are classified in (Table 1) into six groups:(I) Small (LPI=0-5), (II) Very Low (LPI=6-10), (III) Low (LPI=11-15),(IV) Moderate (LPI=16-20), (V) High (LPI=21-25), and (VI) Very High (LPI > 25). Accordingly, the studied rock slopes of Shaqlawa area are as follows;

Kolosh, Tanjero and Station no. 4 in the Shiranish slopes and Station no.5 in the Gercus slopes have Very Low to Low (LPI) values, (Table 2A and B) because no previous landslides were observed on their slopes, which were orthogonal to the strike of their bedding planes, that make them in more stable situation in the case of no unfavorable discontinuities, (Hoek and Bray, 1981). The slope at Station no.4 in the Shiranish Formation are stable because; the slope and the bedding planes dip with equal angles (favorable orientation) that make the blocks sustained by the slope itself and there are no previous landslides and the rocks were moderately fractured. Also station no.5 in the Gercus slopes (marl and siltstone) has Low(LPI) value due to the favorable orientation and there are no previous landslides.

The other rock slopes at stations (except station no.23) have Moderate (LPI) values because; they are relatively high, unfavorable orientation and high slope angles (overhanging slopes) especially in the Pila Spi (conglomerate and dolomitic limestone) slopes.

Only the station no.23 has High (LPI) value, because of the high and steep slope and unfavorable orientation of discontinuities. Table 2 (A and B), demonstrates the calculated values of LPI for all the studied stations and formations in the Shaqlawa area (A) and their (LPI) categories (B).

Table (1): Landslide Possibility Index Calculation.
(Bejerman, 1994)

<table>
<tr><th colspan="6">LANDSLIDE POSSIBILITY INDEX</th></tr>
<tr>
<td colspan="2">1-Slope Height Estimation<br>(1 – 8 ) m 1<br>(9 – 15) m 2<br>(16 – 25) m 3<br>(26 – 35) m 4<br>> 35 m 5</td>
<td colspan="2">2-SlopeAngle Estimation<br>< 15° 0<br>(15 – 30)° 1<br>(30 – 45)° 2<br>(45 – 60)° 3<br>> 60° 4</td>
<td colspan="2">3- Grade of Fracture Estimation<br>Sound 0<br>Moderately Fracture 1<br>Highly Fractured 2<br>Completely Fractured 3</td>
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<tr>
<td colspan="2">4-Gradeof Weathering Estimation<br>Fresh 0<br>Slight 1<br>Moderate 2<br>High 3<br>Complete 4<br>Residual soil 5</td>
<td colspan="2">5-Gradient of the Discontinuities Estimation<br><15° 0<br>(15 – 30 )° 1<br>(30 – 45 )° 2<br>(45 – 60 )° 3<br>>60° 4</td>
<td colspan="2">6- Spacing of the Discontinuities Estimation<br>> 3 m 0<br>(1– 3) m 1<br>(0.3 – 1) m 2<br>(0.05– 0.3) m 3<br>< 0.05 m 4</td>
</tr>
<tr>
<td colspan="3">7- Orientation of the Discontinuities Estimation<br>Favorable 0<br>Unfavorable 4</td>
<td colspan="3">8- Vegetation Cover Estimation<br>Void < 20% 0<br>Scarce ( 20 – 60) % 1<br>Abundant > 60% 2</td>
</tr>
<tr>
<td colspan="3">9- Water Infiltration Estimation<br>Inexistent 0<br>Scarce 1<br>Abundant :<br>Permanent 2<br>Seasonal 3</td>
<td colspan="3">10- Previous Landslides Estimation<br>Not Registered 0<br>Registered (small volume) 1<br>Registered (high volume) 2</td>
</tr>
<tr><td colspan="6">1 + 2 + 3 + 4 ± 5 + 6 + 7 + 8 + 9 + 10= ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐</td></tr>
<tr>
<td colspan="2">I (small) (0 – 5)<br>II (very low) (6 – 10)</td>
<td colspan="2">III (low) (11 – 15)<br>IV (moderate) (16 – 20)</td>
<td colspan="2">V (high) (21 – 25)<br>VI (very high) (>25)</td>
</tr>
<tr><td colspan="6">The LPI value is obtained by adding the estimation of attributes 1 – 10. If the orientation of the discontinuities is Favorable, <u>subtract</u> the estimation of gradient.</td></tr>
</table>

Table (2): A- The calculated (LPI)values for the studied rock slopes in Shaqlawa area.

| Formation | Shiranish Formation | | | | Gercus Formation | | | | Pila Spi Formation | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| (LPI) values | 18 | 19 | 19 | 9 | 13 | 18 | 18 | 19 | 16 | 16 | 16 | 16 | 16 | 20 | 20 | 16 | 20 | 16 | 16 | 16 | 16 | 16 | 23 |
| LPI category | M | M | M | V.L | L | M | M | M | M | M | M | M | M | M | M | M | M | M | M | M | M | M | H |

B- (LPI) Categories for all the studied stations and rock slopes of Shaqlawa area

| **No. of stations** | **(LPI) category** |
|---|---|
| ------------------------------ | Small (LPI = 0-5) |
| 4 in Shiranish and 5 in Gercus (marl and siltstone) in addition to Tanjero, Kolosh rock slopes | Very Low (LPI = 6 - 10) and<br>Low III (LPI = 11-15) |
| 1, 2, 3 in rock slopes of Shiranish Fn.<br>6, 7, 8 in rock slopes of Gercus Fn.<br>9, 10,..............., and 19 in conglomerate bed of Pila Spi rock slopes.<br>20, 21, 22 in dolomite beds of Pila Spi rock slopes. | Moderate IV (LPI = 16-20) |
| 23 in the dolomitic limestone bed of Pila Spi rock slopes. | High V (LPI = 21-25) |
| -------------------------------- | Very High ( LPI > 25) |

## 2- Failure Hazard Categories according to (LPI) values:

Table (3) shows failure hazard rating according to (LPI) values of Bejerman (1994 and1998). It shows three hazard categories;

(i)- Low Hazard Category that corresponds to two (LPI) categories;

(I) Small (LPI=0-5), and (II) Very low (LPI=6-10).

(ii)- Moderate Hazard Categories that corresponds to two (LPI) categories;

(III) Low (LPI=11-15), and (IV) Moderate (LPI=16-20).

(iii)- High Hazard Category that corresponds to two (LPI) categories;

(V) High (LPI=21-25), and (VI) Very high (LPI > 25).

Table (3): Landslide Hazard Categories, according to (LPI) categories (after Bejerman, 1998).

| LPI Category | Hazard Category |
|---|---|
| I -- II (1-10) | Low |
| III -- IV (11-20) | Moderate |
| V -- VI >21 | High |

## 3- Failure Hazard Assessment of the Study Area according to (LPI) Values:

Field assessments of (LPI) in the slopes of Tanjero and Kolosh Formations and station no.4 at the Shiranish Formation indicate (Small - Very low) LPI values and therefore these slopes have Low Hazards (Table 4).

The slopes; Stations nos. 1,2 and 3 of Shiranish Formation, stations nos. 5, 6, 7 and, 8 of Gercus Formation and stations nos. 9, 10,..., and 19 (in the conglomerate beds) and stations nos. 20, 21 and22 (in the dolomitic limestone) of the Pila Spi Formation have Low to Moderate (LPI) values which indicate Moderate Hazard rating, Table 4.

Only the Station no.23 in the dolomitic limestone beds of Pila Spi Formation has High (LPI) value and therefore it has High Hazard rating, Table (4). The data in the Table (4) help to draw landslide hazard map at scale 1:10 000 for Shaqlawa area, Fig (4).

Table (4): Landslide Hazard Rating of the study area according to (LPI) values

| Stations No. | Hazard Category | (LPI) Category |
|---|---|---|
| Tanjero, Kolosh and Station 4 in Shiranish rock slopes | Low Hazard | 0 - 10 |
| 5, 6, 7, and 8 of Gercus Formation rock slopes.<br>9, 10, ........,and 19 in the conglomerate beds and 20, 21, and 22 in the dolomitic limestone beds of Pila Spi rock slopes. | Moderate Hazard | 11 - 20 |
| 23 in the dolomitic limestone of Pila Spi Formation rock slope. | High Hazard | > 21 |

**4- Failure Hazard Assessment According to Landslide Influence on Roads:**

Barison and Conteduca, (1998, in Barahim, 2004) introduced an effective factors in landslide hazard assessment on roads. These factors; are shown in the Table (5):

1- Volume of fallen rock blocks reaching the road.
2- Distance from the road to the nearest slope toe.
3- Protection works.

It can be noted that the factors of (1) fallen block sizes and their possibility to reach the road, (2) distance from the slope toe to the road and (3) the stabilization or protection methods applied to the rock slopes, are not involved in Bejerman (1994 and 1998) classification.

In fact it is well known that the blocks of large sizes have more hazardous effect than the smaller blocks, and the hazard effects are reduced when the distance between the slope toe and the road is increased. Thus, it is so obvious on the thick conglomerate slopes on the southwestern side of Gird Sur mountain where the very large detached conglomerate blocks have decreasing hazards along the distance to the road due to impact damages and fragmentation of large blocks to smaller blocks when they roll down slope, and may be blocked and rest before reaching the road.

Table (5): Classification of landslide hazard on roads and influencingfactors, (Barison and Conteduca,1998, in Barahim, 2004).

| **Contributory Factor** | **Category** | | | **Rating** |
|---|---|---|---|---|
| Rock Fall Reaching The Road . ( >3 $m^3$/ year) | Don't Reaching The Road | | | 0 |
| | Reaching The Road | Seasonal | Small Blocks ( D < 0.05 m) | 1 |
| | | | Large Blocks ( D ≥ 0.05 m ) | 2 |
| | | Permanent | Small Blocks ( D < 0.05 m) | 3 |
| | | | Large Blocks ( D ≥ 0.05 m ) | 4 |
| The Distance from the Road to the nearest Slope Toe (m) | > 10.0 m | | | 0 |
| | 0.5 -- 10.0 m | | | 2 |
| | < 0.5 m | | | 4 |
| Protection Works | Presence With | | More useful | 0 |
| | | | Less useful | 1 |
| | Absence | | Not required | 0 |
| | | | Required | 2 |
| | | | Extremely required | 3 |
| 1 + 2 + 3 = | I – Very Low (0-2) III – Moderate (5-6) V – Very High (>8)<br>II – Low (3 – 4) IV – High ( 7- 8) | | | |

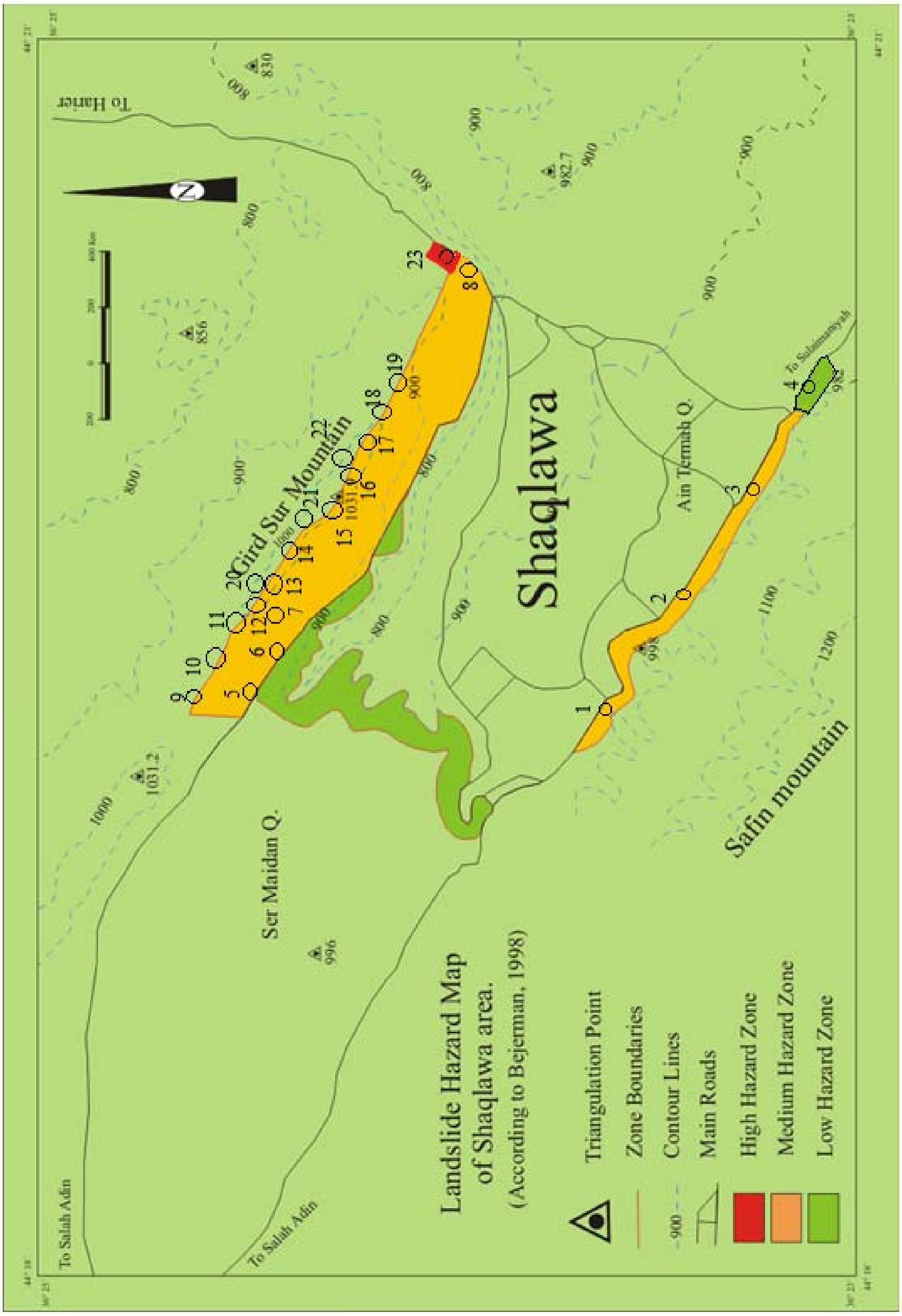


Fig (4): Landslide Hazard Map of Shaqlawa area according to (LPI) values.

These factors could be used in failure hazard assessment for the rock slopes around roads of Shaqlawa area. Consequently, this classification could contribute and give the following results, Table (6).

Table (6): Failure hazard zoning of the studied area due to their effect on roads, according to Barison and Conteduca, (1998, in Barahim, 2004) classification.

| Site No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rockfall Reach the Road | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Distance from the road to the slope toe | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
| Protection works | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total value | 5 | 5 | 5 | 2 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
| Hazard Category | M | M | M | V.L | V.L | V.L | V.L | V.L | V.L | V.L | V.L | V.L |

Continue – Table (6).

| Site No. | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rockfall Reach the Road | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Distance from the road to the slope toe | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| Protection works | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Total value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| Hazard Category | V.L | V.L | V.L | V.L | V.L | V.L | V.L | V.L | V.L | V.L | H |

These results show that; rock slopes along Safin mountain main road (sites nos.1, 2 and 3), except site no.4, have Moderate Hazards categories because the fallen rocks reach the road seasonally with large blocks (> 0.05 m) and their present protection works are less useful, while site no.4 has very low hazard category because it is stable and no rockfall reach the road and its present protection is more useful. All of the rock slopes overlook Salah Adin – Harir main road (except site no.23) have very low hazard categories because; their rock fall didn't reach the road, wide distances separating them from the road and they need no protection works. Only site no.23 of these rock slopes has High hazard category because; it's fallen rock reach the road seasonally with large blocks, the narrow distance (<0.5m) between the slope toe and the road and with less useful present protection works.

Accordingly, these results helped in drawing another rock slope failure hazard map due to their effects on main roads for Shaqlawa area, according to these three factors of Barison and Conteduca, (1998) Fig (5), this map can contribute in the preliminary urban planning and design to avoid the hazardous zones or to protect and minimize slope failure hazards.

**Modification of Barison and Conteduca, (1998) classification:**

The classification of Barison and Conteduca, (1998, in Barahim, 2004) of rock slope stability and road risk evaluation is modified here (Table 7) by:

1- Dividing Category (1) of very low hazard with (0-2) rating value into two divisions (subcategories); (1) Ia of No Hazard with (0) hazard rating value, and (2) Ib of Very Low Hazard with (1-2) hazard rating values.

2- If the detached block does not reach the road, the hazard rating is zero (0), so that other contributing factors to hazard are cancelled.

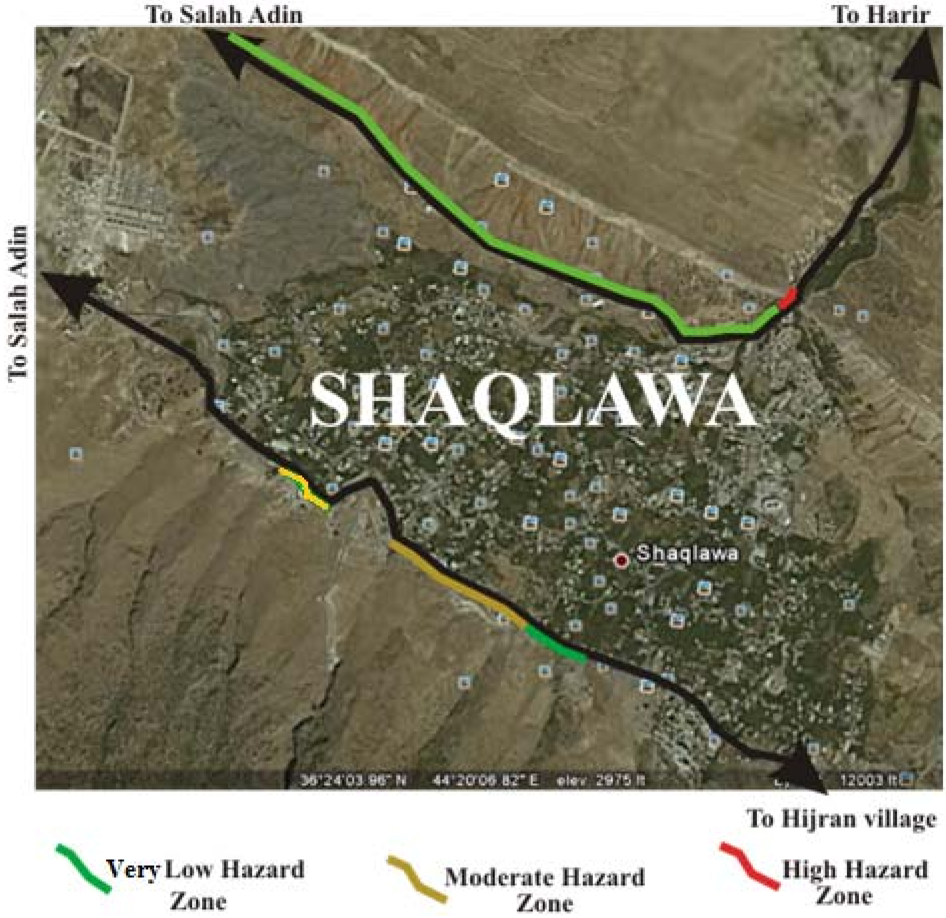


Fig (5): Landslide Hazards on Roads Map for Shaqlawa city.

**Assessment of Landslide Hazard effectson the Roads according to the modified classification for the Study Area:**

Table (8) shows three hazard categories which affect the roads based on the modified classification of the Barison and Conteduca, (1998) in Table (7). The three categories are;

1- No hazard category that include slopes of Tanjero, Kolosh, Gercus and Pila Spi slopes in Gird Sur Mountain (except in station 23) because in all these slopes, the detached blocks do not reach the Salah Adin - Shaqlawa - Harir main road due the wide distance between the failure site and the road, as in Gercus and Pila Spi slopes or because this road is higher than Tanjero and Kolosh slopes.

Table (7): Modified classification of landslide hazards on roads.

| Contributory Factors | Conditions of Contributory Factors | | | Rating |
|---|---|---|---|---|
| (1) Possibility of rockfall to reach the road | Do not Reaching the Road | | | 0 |
| | Reaching the Road | Seasonal | Small Blocks (D < 0.05m) | 1 |
| | | | Large Blocks (D ≥ 0.05m) | 2 |
| | | Permanent | Small Blocks (D <0.05m) | 3 |
| | | | Large Blocks (D ≥ 0.05m) | 4 |
| (2) Distance from the road to the nearest slope toe (m). | > 10 m | | | 0 |
| | 0.5 - 10 m | | | 2 |
| | < 0.5 m | | | 4 |
| (3) Protection Works | Present | Effective | | 0 |
| | | Not effective | | 1 |
| | Absent | Not required | | 0 |
| | | Required | | 2 |
| | | Extremely required | | 3 |
| Hazard Categories by adding 1+2+3 | Ia No Hazard (0) | | III Moderate Hazard (5 - 6) | |
| | Ib Very Low Hazard (1 - 2) | | IV High Hazard (7 - 8) | |
| | II Low Hazard (3-4) | | V Very High Hazard (> 8) | |

Note: If the detached rock blocks do not reach the road or other civil structure, the hazard rating is (0)zero, i.e., cancel all other factors contributory to landslide hazard on roads.

2- In Shiranish slopes, station no.4, although it is close to the road, it has No Hazard because it is supported by the retaining wall, but stations nos. 1, 2 and 3 of Shiranish slopes have Moderate Hazards on roads because of their closeness from the road and have not effective protection works.

Table (8): The results of landslide hazard effects on the roads hazard assessment of the studied area according to the modified classification.

| Stations No. | Hazard Rating | Hazard Category |
|---|---|---|
| 1- Tanjero and Kolosh rock slopes.<br>2- Station- 4 in Shiranish rock slopes.<br>3- Stations 5, 6, 7 and 8 of Gercus slopes.<br>4- Stations 9,10,..., and19 in the conglomerate beds and 20, 21 and 22 in the dolomitic limestone beds of Pila Spi rock slopes | 0 | No Hazard |
| Stations 1,2 and 3 in Shiranish rock slopes | 5 - 6 | Moderate Hazard |
| Station - 23 in the dolomitic limestone of Pila Spi rock slopes | 7 - 8 | High Hazard |

3- Only one area in the dolomitic limestone of Pila Spi slopes (at the gorge that is located to the north of Shaqlawa city) to the west side of Shaqlawa - Harir main road (station no. 23) has High Hazard on road because of its high and steep slope, closeness from the road and has not effective protection works.

## Comparison between the General Hazard Map and the Hazard Map on Roads:-

The new results of the modified classification, which made all the rock slopes that previously assessed as "Very Low Hazard landslides on roads" according to the landslide hazard effects on roads (by Barison and Conteduca, 1988), currently assessed as "No Hazards on roads" as shown in Table (8). From the authors point of view and according to their experience and field observations; these new results are considered as more reasonable and feasible situation and need no worry because the fallen rock is not likely to reach and affect the highway traffic.

## Landslides hazard prevention and treatment

Damages resulting from landslides include both property damage and loss of life.

Many efforts have been used to prevent, and/or treat landslides hazards. These methods vary with slope variations and purposes for either prevention or protection works with quick and low costs depending on amount and volume of landslide and the distance to the nearest public structure. Almost the treatment works can include the following categories (Ali *et. al.*, 1990):

1- Change the slope geometry to reduce excess loads or to increase resistance strength.

2- Control the underground and surface water effects.

3- Sustaining and reinforcing the slope material to increase resisting forces.

Shaqlawa area rock slopes with its rugged, heights and hazards does no need for such requirements, where all of the rock slopes (except one site) have medium hazard (according to Bejerman, 1998) which needs protection works only, such as retaining walls, trenches or ditches and fences to prevent failed rock blocks from reaching the road or any other structure.

## Prevention landslides of Shiranish Formation rock slopes

All the rock slopes of Shiranish Formation are characterized by plane sliding along bedding planes dipping less than the slope angle that made them (bedding planes) daylight at the slope face and slides as small blocks (5x20x20) cm. This sliding happened in the upper part of station no.2 (6 m high) during winter 2004 although the slope in this site had been sustained with retaining wall (2 m high). Because the slope in Site no.1 is so close (about 1.5 m) to the road, it needs to construct reinforced retaining wall in site no. 1 and continuous maintenance and increase the height of the current retaining wall in sites nos. 2 and 3 for further 0.5 m.

## Prevention landslides of Tanjero and Kolosh Formations rock slopes

Tanjero and Kolosh Formations consist mainly of clastic materials (relatively with some variations in sandy versus clayey materials), very thinly bedded and highly fractured that make them disintegrate (due to weathering) by raveling and rolling to the slope toe as small rock fragments that do not exceed more than 5 cm in diameter, in addition to the strike of their bedding planes which are orthogonal to their slopes in the central part of Shaqlawa area which make them less unstable, (Hoek and Bray, 1981) and do not require quick and steady remedy. Cultivate these slopes with grass mat or to make small benches with (60-90) cm height and (60-90) cm width on the slope face, these are quite enough for grasses to grow and prevent rolling fragments to reach the road.

**Prevention landslides of Gercus Formation rock slopes**

Gercus Formation is exposed along the southwestern slopes of Gird Sur Mountain and occupies the northeastern part of the studied area. The bedding planes of the Gercus Formation are discordantly dipping against the slope that make it favorable for stability.

Marl and siltstone beds have no unfavorable discontinuities for stability and suffering from granular disintegration (because of weathering) by raveling and rolling due to gravity down slope as small lumps of about (3-5) cm in size. So they are similar to Tanjero and Kolosh rock slopes.

The construction of rocky stages (benches like) from the fallen rock blocks and fragments at the Gercus slopes may hinder and restrain the rolled rocks and prevent them from reaching the slope toe. Fig (6) explains the construction of such rocky stages in the rill erosion valleys along the soft rocks of the Gercus Formation.

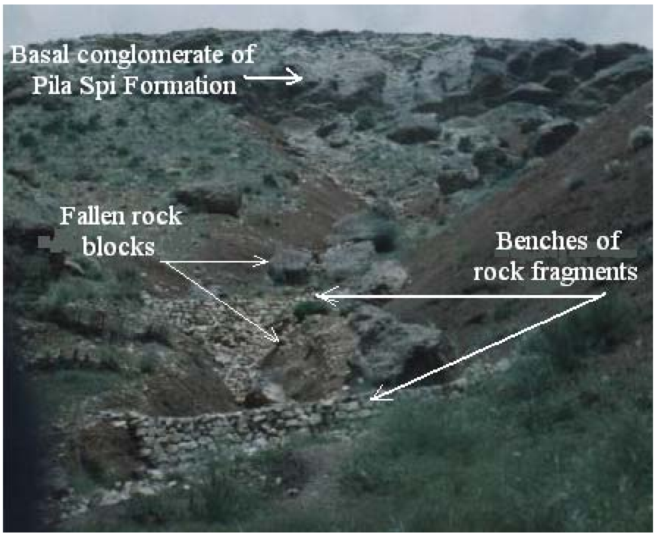


Fig (6): Rocky stages and benches to restrain and prevent the fallen rocks from reaching the slope's toe.

Also, ditches along the slope toe (parallel to slope strike) with (0.5-1.0) m distance, will drain and contain the fallen rocks and fragments and prevent them to reach the road.

Ritchie, (1963) showed that a ditch of 7.5 m width and 1.8 m depth will be sufficient for a slope with 30 m height. These dimensions can be reduced by a thick carpet of gravels on the base of that ditch to dissipate energy of the impact, Fig (7), Hoek and Bray (1981).

Another method to prevent such hazards is the construction of stages cultivated with trees to block the fallen rocks and prevent them rolling along the Gercus slopes, Fig (8).

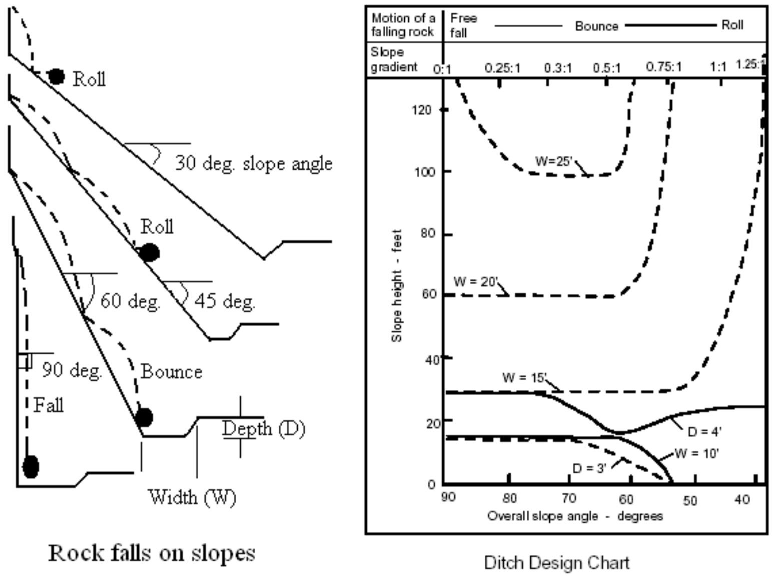


Fig (7): A method to prevent rock fall, Ritchie, (1963).

Fig (8): Cultivated stages along the Gercus slopes to block the rolled fallen rocks.

**Prevention landslides of Pila Spi Formation rock slopes**

Pila Spi Formation with both of conglomerate and carbonate rocks crop out at the crests and the high parts of Gird Sur Mountain northeast of Shaqlawa city. These rocks are characterized by their hardness, high to very high compressive strength and thickly bedded with widely spaced joints. These physical properties made Pila Spi rocks detached as moderate to large blocks of high hazards especially on Salah Adin – Harir main road, hotels and restaurants constructed along this main road.

Pila Spi rocks occupy the high parts and the crests of Gird Sur slopes with about 100 m height above the main road, so the mitigation works include preventing the slides from reaching the road by; cultivated stages, rock benches especially at the rill erosion valleys and areas of active landslides, in addition to construct a steel fence to catch the rolled rocks.

A special case located at the station no 23, to the west of the beginning of Shaqlawa – Harir road. In this case,the slope is more than 20 m high and less than 1.5 m away from the paved road which is suddenly turning that makes it of high hazard and requires an urgent mitigation works including the installation of wire mesh at the face of the slope, Fig (9) to contain the slides between the slope and the wire mesh. Also this case requires installing a reinforced retaining wall along the slope toe to hinder the landslide from reaching the road.

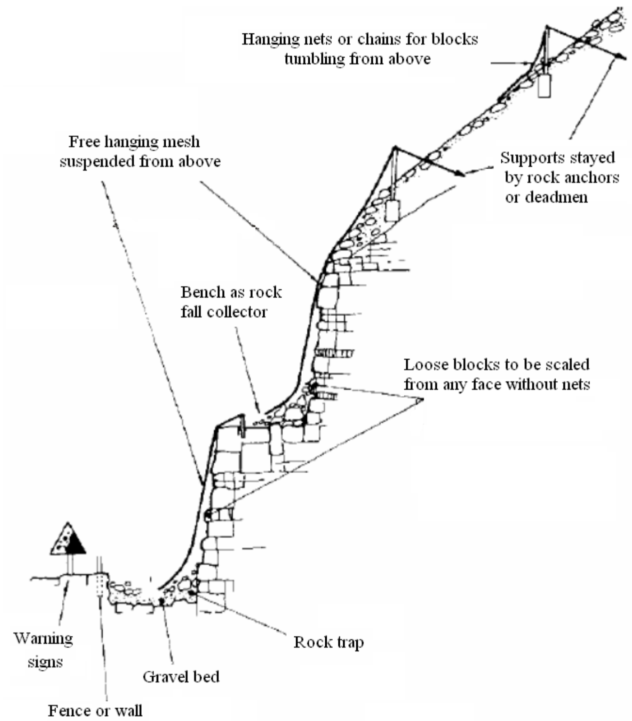


Fig (9): rock fall control, (after Fooks and Sweeny, 1976).

## Conclusions

Field observations showed that all of the Pila Spi Formation rock slopes, especially the conglomerate layers have high hazard due to the following:

- The large detached blocks from, which may exceed 1 $m^3$ in size.
- These rocks are hard and have high strength.
- They have steep slopes which due to the differential erosion they become overhanging slopes.
- They are cut by more than one set of joints.

But these hazards are mitigated and reduced to low hazard due to:

* The relatively wide distance that separates these slopes from the road. The large blocks are broken down to smaller than half of their sizes during the impact and rolling along the Gercus Formation slopes. That is also what happened to the carbonate rock blocks of the Pila Spi Formation in sites nos.20, 21 and 22 at the crests of Gird Sur Mountain, which are reduced to less than 1/4 of their original sizes because they are of relatively lesser strength than the conglomerate beds.

* The rill erosion valleys grooved along and normal to the strike of the Gercus slopes behave as collector channels and restrain the fallen blocks.
* The relatively low angle slopes along the Gercus Formation which consists mainly of weak materials (marl, siltstone and sandstone) that absorb the impact energy of the fallen blocks.

All of these effects contribute to the protection works to mitigate these hazards to No Hazard Category, according to the currently modified classification by Al-Saadi and Yousif.

Rock slopes along Shiranish Formation have Moderate hazard because; they are so close to the road and non-active protection works have been done due to the low and weak existing retaining wall.

Only station no 23 within the carbonate rocks of Pila Spi Formation has high hazard, due to the following:

- Relatively high and very steep slope.
- Very close (less than 1.5 m) to the main road.
- Rock blocks reaching the road exceed 0.05 m.
- A set of joint and bedding planes offer back release and lateral release surfaces respectively.
- Non active protection works, due to low and weak masonry retaining wall.

## Recommendations

Shiranish rock slopes subjected to plane sliding along the bedding planes, as small slabs (10x20x20 cm), during rainy season. These rock slopes are so close (about 1.5 m) to the road and supported with 2.0 m high retaining wall. This wall is insufficient to prevent the plane sliding to took place, which happened during winter 2004 in sites nos.1, 2 and 3. Hence, Station no 1 requires reconstruction of new reinforced retaining wall. In stations 2 and 3 the upper layers which were suffered from plane sliding require adding an excess of 0.5 m to the current wall to block the rock slabs from reaching the road. Also, these rock slopes need warning signals installed at a distance 50m ahead to warn the drivers from rocfalls.

- Tanjero, Kolosh and Gercus Formations characterized by; gentle slopes, mostly they consist of clastic materials, layers are in opposite direction to slope face and have no unfavorable discontinuities for stability, so there are no landslide signs on these slopes. But due to weathering, they suffered from raveling and granular disintegration to small lumps that do not exceed 0.05m in size, rolled down slope. These raveling rocks have low hazards, and require no quick and urgent mitigations, although they need to reduce weathering effects by cultivation with trees and grass, in addition to construct trenches or ditches at the slope toe to drain the slope and to contain the rolled down rock lumps.
- Pila Spi rock slopes (except station no 23) occupy the upper parts and crests of Gird Sur Mountain with 100 m distance away from the west side of Salah Adin – Harir main road that made these slopes of moderate hazards. Accordingly, they require construction of benches cultivated with trees along Gercus slopes to block and prevent sliding and falling blocks from Pila Spi rock slopes. For more efficiency, a fence of steel mesh installed at 1.0 – 1.5 m away from and parallel to the slope toe.

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