Slope Stability Assessment of Korre Village Landslide, SW of Shaqlawa Town, the Kurdistan Region

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ABSTRACT

Potentially unstable slopes present hazards and pose risks to the traveling public, to the transportation infrastructures, to local economies, and to the environment. The main aim of this study was to evaluate the landslide hazards along Permam–Shaqlawa main road employing the landslide possibility index (LPI) proposed by Bejerman (1994; 1998). The LPI values along with the hazard category were applied to three stations along the above-mentioned main road at Korri village. The raw data for determining the LPI and hazard category were obtained from field observations and measurements. The obtained data involved the study of 10 main characteristic features encompassing geological, structural, hydrological, and geomorphologic conditions of the area under study. Further, soil samples were obtained from the study area for conducting some selected geotechnical properties for interpretation of the obtained results. With no exceptions, all road cut slopes have adverse factors that contribute to create potentially unsafe ground above the main road. The results also indicated that the possibility of failures is high at each station. The causal factors for a landslide in the study area were also presented. In addition, the remedial measures for study slope locations are suggested based on the degree of possibility of failure and field observations.

Keywords: Atterberg limits, Landslide possibility index, Landslide, Retaining wall

1. INTRODUCTION

The Korre road is one of the important links between the Erbil city and tourism sites at the mountainous area within Erbil Governorate. Over this road, landslides pose a recurrent hazard to human life and livelihood. Landslide is the movement downslope of a mass of rock, debris, earth, or soil (soil being a mixture of earth and debris). Landslides occur when gravitational and other types of shear stresses within a slope exceed the shear strength (resistance to shearing) of the materials that form the slope. The hazard from landslides can be reduced by avoiding construction on steep slopes and existing landslides, or by stabilizing the slopes. Stability increases when groundwater is prevented from rising in the landslide mass by: (1) Covering the landslide with an impermeable membrane, (2) directing surface water away from the landslide, (3) draining groundwater away from the landslide, and (4) minimizing surface irrigation. Slope stability is also increased when a retaining structure and/or the weight of a soil/rock berm are placed at the toe of the landslide or when mass is removed from the top of the slope.

The methods that were adopted for the evaluation of slope stability against landslide hazards encompass the determination of geological strength index, introduced by Hoek (1994) and modified by Hoek et al. (1998); Hoek and Brown (1997), Hoek and Marinos (2007), and landslide possibility index (LPI) system suggested by Bejerman (1994). These two systems/indices are basically based on simple field

observations of the rock mass. It is worth mentioning that we have adopted the latter method.

The study area represents a hilly area with a gradient of about 15%; however, the gradient of the road cut reaches 18%. The majority of the area is covered by clayey soil which is derived from the weathering of the underlying limestone beds of the Pila Spi Formation. The weather in the study area is semi-arid to wet with average precipitation of 61–10 mm in Autumn and Winter, and almost dry in many months [Table 1]. During December–April, very heavy rain showers often occur in the study area. Such heavy rain showers will increase the water content in the clayey soil; consequently, will increase the failure possibility due to high water pore pressure.

Studies concerning the slope stability of the region did not exist; however, some relevant studies in other areas are mentioned below. Hamasour (1991) studied the unstable slopes (M.Sc. thesis) and presented the main unstable parts of the road. Jassim et al. (2013) studied the unstable slopes and considered the landslides and rock falls are the main mass movements' phenomenon present in the study area. They presented their work through 14 studied stations and concluded that the possibility of sliding is high. Sidiq et al. (2016) studied a landslide that had happened on November 11, 2015 and documented the details and causes of the landslides; they also gave recommendations for stabilizing the concerned area. Jassim and Tokmachy (2015) studied the rock Mass Units of the Abandoned Koya Tunnel and recorded different geotechnical properties. Ibrahim (2017) reported about the unstable slopes along the road crossing. She conducted 18 studied stations and gave proposals to keep the road cuts stable.

The aim of this research work is to indicate the reason for the happened slope failure in the road cut and to recommend relevant methods for stabilizing the unstable slope.

2. MATERIALS AND METHODS

Site investigations were carried out on exposures along the main road connecting Permam to Shaqlawa town. The study area was described at three stations [Figure 1] with reference to the geological setting and slope characteristics. The elements of field investigation were topographic and geologic maps of different scales besides satellite images. In addition, five soil samples were obtained from the depth of 0.5 m for performing some selected geotechnical properties such as particle size distribution and indices properties. The stability of the slope at each station was investigated using LPI (Bejerman, 1994; 1998). The determination of LPI was based on 10 characteristic features derived from geological, structural, hydrological, and geomorphologic conditions of the given area. Estimated values of 10 parameters are added to determine the LPI. The degree of the hazard of the slopes was determined based on the obtained values of the LPI.

For slope measurements, we have used the Brinton compass, and those for discontinuities, we have used normal measuring tape. The soil samples were tested in Salahaddin University, College of Engineering.

2.1. Geological Setting
The geological setting of the studied area is shortly briefed; using the best available data. The geological setting includes geomorphology, tectonics, and structural geology, and stratigraphy.

2.2. Geomorphology
The studied area represents an erosional slope with a slope of 12°, formed due to the presence of many valleys draining the slope area [Figure 2]. The valleys flow from SE to NW, some of them flow over the barren, exposed rocks of the

Month	Average maximum temperature (°C)	Average minimum temperature (°C)	Average precipitation per month (mm)
January	12	2	61–100
February	15	3	61–100
March	19	7	61–100
April	25	11	61–100
May	32	16	31–60
June	39	21	0–5
July	43	25	0–5
August	42	24	0–5
September	38	19	0–5
October	29	14	6–30
November	21	8	31–60
December	14	4	61–100

Table 1: Some climatic parameters in Erbil Governorate (http://www.whatstheweatherlike.org/iraq/erbil.htm)
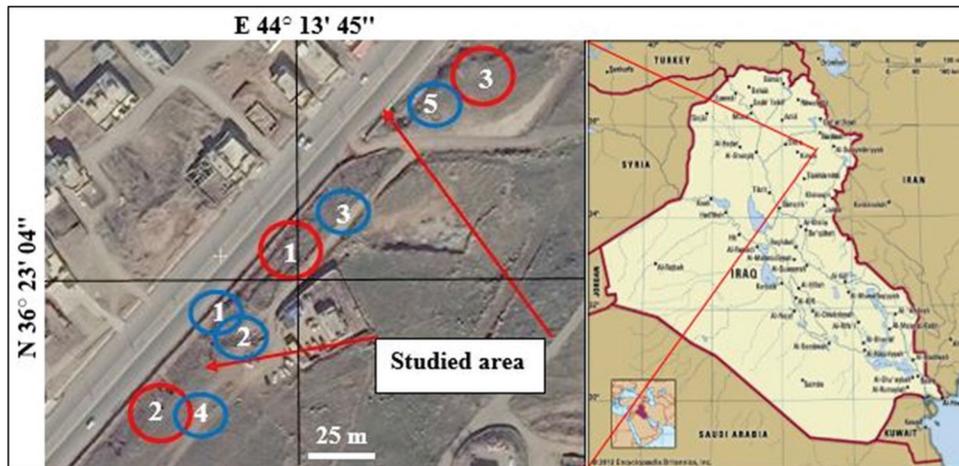
Figure 1. Zoom earth image of the studied area showing the three studied stations for landslide possibility index (encircled in red) and the location of soil samples (encircled in blue)
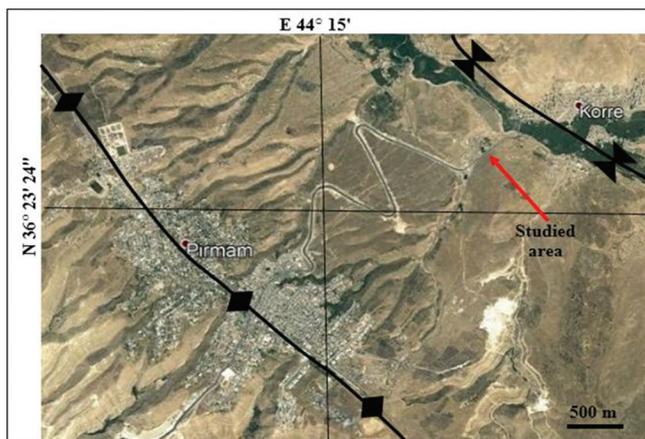
Figure 2. Satellite image of the study area and surrounding. Note the hilly terrain of the study area and the presence of Permam anticline and neighboring syncline
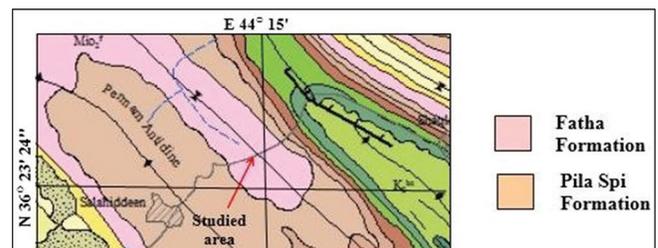
Figure 3. Geological map of the studied area and surroundings, only the concerned geological formations are shown in the legend (After Sissakian and Fouad, 2014)

2.4. Stratigraphy

The exposed formation in the studied area is the Fatha Formation (Sissakian, 1979 Sissakian and Fouad, 2012) [Figure 3]. The Fatha Formation in the study area consists of thick reddish brown and soft claystone with very thin limestone and gypsum beds in cyclic nature. The thickness of the formation is about 130 m. The Fatha Formation is underlain unconformably by the Pila Spi Formation; it consists of well-bedded dolomitic limestone, dolostone, and rare marl (Sissakian and Al-Jiburi, 2014).

2.5. Characters of the Unstable Slope

The studied area represents a road cut along the main paved road between Salahaddin and Shaqlawa towns. The length of the unstable slope is 180 m. The height difference between the road level and the highest unstable part of the slope is 30 m. The slide type is of soil sliding accompanied with a flow that had overflown on the constructed retaining wall [Figure 4 a, b and d]. The main slid mass is in the central part of the unstable slope with a scarp of 1.5 m [Figure 4c], length of 12.40 m and slope of 12°, with many crescent-shaped cracks in the, slid mass [Figure 4f].

Pila Spi Formation; whereas others flow within the clastics of the Fatha formation and the covered thick residual soil. The latter facilitates infiltration of the rainwater; consequently, increasing the pore pressure. Apart from the existing studied slope failure, no such event was recorded in the studied area and near surroundings.

2.3. Tectonics and Structural Geology

The studied area is located in the High Folded Zone of the Outer Platform within the Arabian Plate; it also belongs to the Zagros Thrust–Fold Belt (Fouad, 2012). Permam anticline is NW–SE trending symmetrical anticline. Toward north is a syncline between Permam and Safeen anticlines. In the trough of the SE-ward plunging syncline, the studied area is located [Figure 2].

2.6. LPI

To check the stability of the studied area, we applied the Bejerman (1994) Method, which can be applied on both natural slopes and road cuts. We have used the special form for the three studied locations [Figure 1]: One in the unstable part of the slope and two others on both sides of the unstable slope, within stable parts. The raw field data are presented in Table 2 with the scored results of the LPI. By applying the total scored marks [Table 2] at each of the three studied stations, the category of LPI was obtained; following the given classification [Table 3] by Bejerman (1994 and 1998). The results are shown in Table 4. The LPI allows assessing the landslide possibility for rock slopes cut in mountainous roads (Bejerman, 1994), as well in natural slopes, as we have applied. The estimated values for each of the three studied stations [Table 2] are compared with the failure possibility classification (Bejerman, 1994; 1998), which consists of six classes; as shown in Table 3. Accordingly, the failure possibility is indicated at each of the four studied stations. The results are shown in Table 4.

2.7. Laboratory Work

To indicate the type of the soil in the studied area, five samples were collected from different locations [Figure 1]. The collected samples were subjected to geotechnical tests. The details are mentioned hereinafter.

2.8. Geotechnical Tests

The five collected disturbed samples were subjected to grain size analysis and Atterberg limits test. Both tests were run following ASTM Nos. D 422 and D 4318, respectively. The

Figure 4. (a) Side view (looking northwards), (b) side view (looking northwards), (c) the develop scarp in the crown area, (d) the destroyed retaining wall, (e) longitudinal cracks, (f) crescent-shaped cracks developed in the slid mass

Table 2. Raw field data for the three studied stations and their scored marks according to Bejerman (1994)

Station No.	Numbers of aspects used in LPI Form										Total
	1	2	3	4	5	6	7	8	9	10	
	Slope		Grade		Gradient (°)	Discontinuities		Vegetation cover (%)	water Infiltration (%)	Previous land slide volume	
	Height (m)	Angle(°)	Of fracture	Of weathering		Spacing (m)	Orientation				
1	30	23	Sound	Residual soil	31	<0.05	Unfav.	Void	Abun. Seasonal	Small	
	4	1	0	5	2	4	4	0	3	1	24
2	36	26	Sound	Residual soil	32	<0.05	Unfav.	Void	Abun. Seasonal	Not Register.	
	4	1	0	5	2	4	4	0	3	1	23
3	29	24	Sound	Residual soil	49	<0.05	Unfav.	Void	Abun. Seasonal	Not register.	
	4	1	0	5	3	4	4	0	3	0	24

results of the tests are presented in Table 5. The cumulative curves of the grain size analyze and those of the Atterberg limits are shown in Figure 5. According to the Unified Soil Classification System (USCS), the five samples are classified as low plasticity clay "CL." By imposing the acquired geotechnical data [Table 5 and Figure 5] on the USCS chart, we have found that the soil type in the studied area is of the CL type. It means lean clay with low plasticity index, which will not behave as plastic when loaded and unloaded again.

2.9. Geochemical Data

To indicate the clay minerals in the collected soil samples, we used the acquired data by Mirza and Faraj (2017) from applying the XRD test on the claystone of the Fatha Formation. They did not find any dominant clay mineral in the tested samples; therefore, none of them will have a significant effect on the soil; as the clay mineralogy is considered. The found main clay minerals of the tested samples are chlorite, smectite, mixed layer illite, and kaolinite. Accordingly, we considered the mentioned types of clay minerals to be the same in the soil without any significant importance as the stability of the road cut is concerned.

3. RESULTS

A slope along a road cut covered by residual clayey - silty soil originated from the weathering of the clastic rocks of the Fatha Formation at the northeastern limb of Permam anticline suffers from slope instability. A landslide had occurred; most probably of the rotational type associated with mudflow, which had over toppled and damaged the retaining wall [Figure 4b, d, and f]. We have thoroughly inspected the slope to indicate the reasons for the landslide; moreover, we collected five soil samples and subjected to the geotechnical test. We have found that the main reasons for the landslide are:

3.1. Oversaturation of the Soil

The clayey soil (lean clay) is oversaturated after heavy rain showers. The presence of limestone quarries [Figure 6a] in the upper part of the slope, facilitate the infiltration of the rainwater into the clayey soil, which is of CL type clay [Table 5] that contain 39 – 42 % clay, 40–43% silt, and 17 – 19 % sand. The Plasticity Index values range from

Table 3. Landslides hazard categories (After Bejerman, 1994; 1998)

Landslide possibility index				Hazard Zone	LPI category	Failure possibility
Grade	Category	Estimation				
VI	Very high	25	>25	High hazard	VI	Very high
V	High	21–25			V	High
IV	Moderate	16–20	(11–24)	Moderate	IV	Moderate
III	Low	11–15		hazard	III	Low
II	Very low	6–10	<10	Low hazard	II	Very low
I	Small	0–5			I	Small

LPI: Landslide possibility index

Table 4. LPI scored marks and hazard zones at the three studied stations

Station No.	Scored mark	Landslide possibility index		Hazard zone	LPI category	Failure possibility
		Grade	Category			
1	24	V	High	Moderate	V	High
2	23	V	High	Moderate	V	High
3	24	V	High	Moderate	V	High

LPI: Landslide possibility index

Table 5. The results of Grain Size analysis and Atterberg Limits of the studied sample

Sample No.	Grain size analysis (%)			Atterberg limits			USCS symbol
	Clay	Silt	Sand	L. L.	P. L.	P. I.	
1	40	41	19	41	22	19	CL
2	39	43	18	42	17	25	CL
3	40	42	18	39	19	20	CL
4	40	43	17	35	22	13	CL
5	42	40	18	35	22	17	CL
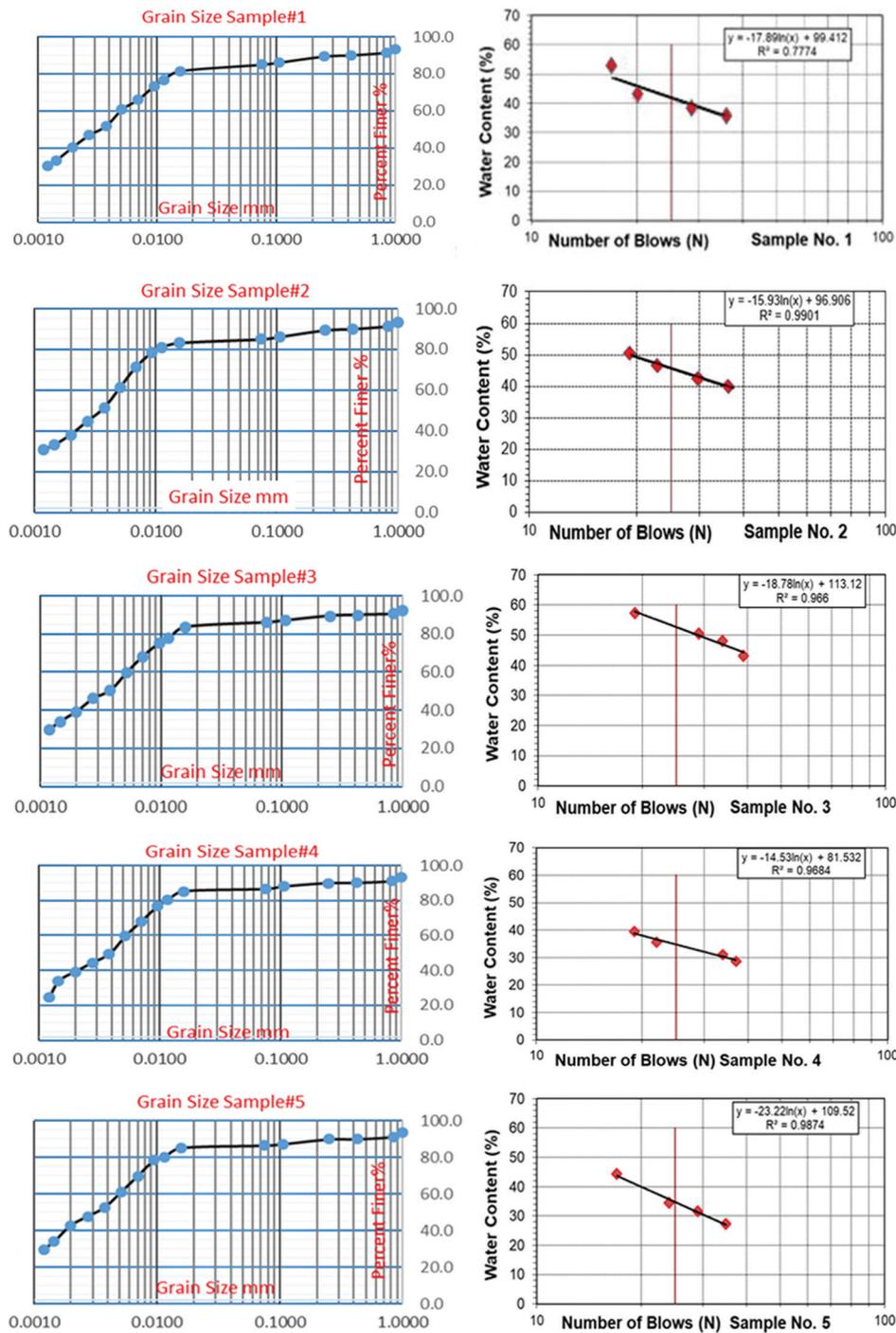
Figure 5. Geotechnical data of the studied samples (Left) Cumulative grain size curves and (Right) Atterberg curves

13 to 25. As the water saturation increases, the pore water pressure increases; consequently, the internal friction angle decreases (Terzaghi et al., 1996) and the slope fails.

3.2. Bad Drainage System
To decrease the pore water pressure in the soil, a good drainage system should be adopted, especially in the retaining

walls (Terzaghi, 1934; Ambrose, 1991; and FAO, 2017). The installed draining pipes in the retaining wall were not sufficient and were not designed properly; therefore, they were blocked by washed fine-grained soil [Figure 6b].

3.3. Improper Retaining Wall

The designed retaining wall is improper; as the height, construction materials, and thickness are concerned [Figures 7a, b and 8a]. The height of the wall is <½ of the slope height [Figure 7b]. Therefore, the wall could not resist the pressure exerted by the sliding of the clayey soil; accordingly, it was collapsed down and damaged, and locally, over toppled [Figure 7a and 8a]. To the left side of the main slid mass [Figure 7b], the retaining wall is already pushed off; it will collapse down in the next rainy season, if not proper precautions are considered in the reconstruction of the damaged retaining wall.

3.4. Overweighting the Slope

The local people have used large limestone blocks (LB) in their houses for leveling purposes. The size of the blocks ranges between 0. 25 and 0.5 m^3, which means the weight of each block range between 0.625 and 1.25 tons per block. At least, 40 blocks are used in one single house [Figure 8b]; it means about 37 tons. The used rock blocks are within the effective zone of the slope because the slope is about 24° and the height of the retaining wall is 1.5 m [Figures 7 and 8a]; therefore, the exerted weight of the LB [Figure 8b] will be within the effective zone. Accordingly, the weight of the LB have caused overweighting of the slope, which facilitates the soil failure; such cases are well explained by Terzaghi (1943).

Figure 6. (a) Small rock quarry in the upper part of the failed slope, it facilitates the infiltration of the rainwater in the soil; consequently, accelerates the failure and (b) A blocked draining pipe

Figurer 7. (a) Toppled soil over the retaining wall, note the poorly designed drainage system in the retaining wall, almost no draining pipes are installed and (b) Note the height of the retaining wall (About 1.65 m) and compare it with the height of the slope

Figure 8. (a) The damaged retaining wall, note the height, thickness and used construction materials; all are improper, (b) Large limestone blocks used in the leveling of the ground below the house; consequently, causing overweight of the slope and its failure

Figure 9. (a) Erosional rills along the slope, they can be lined with impervious material and used as draining ditches and (b) a retaining wall in the opposite side of the concerned landslide, note the excellent system of draining outlets (Some are encircled by red color)

Figure 10. (a and b) The excavated materials from the toe are dumped on the already failed slope, this will increase the weight of the soil on the slope and damage the natural drainage. Accordingly, will increase the shear stress

Figure 11. The toe area of the landslide is not cleaned properly. Parts of the damaged retaining wall are mixed with the slid mass, and the road's draining ditch is destroyed and dumped

Figure 12. (a) A heavily constructed house on the slope and (b) haphazardly constructed houses and unpaved roads. This will increase the infiltration of the rainwater in the soil and will increase the failure possibility

4. DISCUSSION AND RECOMMENDATIONS

The main reasons for the slope failure in the studied area are discussed hereinafter, and relevant recommendations are given.

4.1. Drainage, Retaining Wall, and Oversaturation of the Clayey Soil

The road cut slope is covered by a clayey soil [Table 5]. To avoid oversaturation of the soil, which increases the pore water pressure and decreases the internal friction angle (Terzaghi, 1934; 1945; and Terzaghi et al. 1996), the following should be performed:

a. Preventing of quarrying LB from the existing small quarries in the upper part of the slope [Figure 6a].
b. Construction of many ditches from the uppermost part of the slope downward to the road and lining the ditches with relevant impervious material to reduce infiltration of the rainwater in the soil. The already existing vertical erosional rills [Figure 9a] can be used as draining ditches; after being lined with impervious relevant material.
c. Construction of a relevant retaining wall, with acceptable height and width, using reinforced concrete.
d. Providing the retaining wall with proper draining pipes to avoid oversaturation of the soil behind the wall. On the opposite side of the landslide, a proper retaining wall is constructed with the excellent draining system. The slope is higher than the failed slope, but is still stable [Figure 9b].

4.2. Over Weighting of the Slope, Slope Modification, and Reinforcement

The used LB in the leveling of the houses [Figure 8] has increased the applied external stresses over the slope. To reduce the applied stress and increase the shear strength of soil, which will stabilize the slope, the following should be performed.

4.3. Excavation of Undesired Materials

It creates a reduction in soil weight and can be accomplished by (i) removal of the soil mass at the top of the potential slide, (ii) flattening of the cut slopes above the road, and (iii) benching of cut slopes. Unfortunately, the excavated materials from the toe area were dumped on the slope. This also has increased the weight of the slope [Figure 10] and damaged the natural drainage.

4.4. Excavation and Filling Techniques

This should include: (1) Excavating the toe area of the landslide [Figure 11], (2) removing and replacing failed materials with lighter and more stable materials, or re-compacted debris, and (3) excavating to unload upper portions of a mass failure, and filling to load the lower portions of a mass failure.

4.5. Preventing Overweighting the Failed Slope

Using large LB [Figure 8b and 12 a] in the construction of houses on the slope should be prevented as well as using heavy fences and benches that will overweight the slope. Moreover, the haphazardly constructed houses and unpaved roads [Figure 12b] should also be re-planned; the unpaved roads should be paved with proper draining ditches, to prevent infiltration of the rainwater in the soil.

5. CONCLUSIONS

A slope along the road cut between Salahaddin and Shaqlawa towns suffers from instability, and the road cut was failed and blocked the road. Since the details of the failed slope damage during the removal of the failed materials; therefore, it is difficult to recognize the type of the failure. However, most probably it is of rotational type. The slope is covered by residual clayey - silty soil of CL type, which is lean clay with low plasticity index. The results of the LPI showed that the failure possibility of the road cut is high.

The whole slope will fail, and the nearby constructed houses most probably will be affected too, because they are within the effective zone of the failed slope if the slope is not treated relevantly.

6. ACKNOWLEDGMENT

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