On the Landslide of Daigala Slope-Kurdistan-Iraq

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***Abstract*— The strategic two-lane road (Erbil – Koya) is the main link between Erbil and Suleymaniya governorates. It passes through Daigala bridge whose edge from Koya side is adjacent to a curved section which experienced a slope failure (Fig. 1) in the form of rotational sliding which progressed into a slump failure through the mechanism of "progressive failure" after the overburden soil and sediments were fully saturated with water due to some heavy rain storms which happened at the end of January 2013 leading to the loss of cohesive force and triggering that failure which was developed into a progressive failure by the action of additional loading which was imposed by the heavy traffic of big oil tankers which were running on the adjacent paved road.**

The research team tried to study and analyze this failure by collecting some soil samples (both disturbed and disturbed) from the study area and performing different laboratory tests in addition to some in-situ field tests by using the "Inspection Vane Tester, H – 60" for the purpose of enabling this study and analysis.

The location of the study area was described and illustrated by providing a location map and the geological settings were explained.

As a theoretical background, the different modes of soil slopes failures and their conditions were presented.

At the end, some conclusions of this study were outlined and few recommendations for future remedial measures were eventually made.

Keywords*— Rotational sliding, slump failure, landslide, slope stability, cohesion, angle of internal friction, progressive failure, factor of safety, Atterberg limits.

1. Introduction

Land slopes are usually subjected to different modes of failures depending on the prevailing geological settings, geotechnical conditions and environmental circumstances which will govern the mode or type of failure or landslide which occurs.

Daigala Bridge is an important element of the strategic Erbil – Koya road connecting Erbil and Suleymaniya governorates, as illustrated in the topographic map shown on Fig. 1 below.

2. Location of the Study Area:

The study area is located south of Daigala Area on the west side of (Daigala-Koisanjaq) road, northern Iraq, between latitude ($36^0$10.612") North and longitudes ($45^0$23.440") East at an elevation about (705 m), Fig. 1.The region is semi-arid with humid period of seven months (October – May) and mean annual rainfall of 763 mm (Al- Saed, 2006).

Fig. 1: Location and topographic map of the Daigala area.

3. Geological Setting:

Tectonically, the study area belongs to Chamchamal-Erbil subzone in the Foot hill Zone for Unstable Shelf Area and close to its northeastern border with the High Folded Zone, according to (Al-Kadhimi et al., 1996) classification. The area forms part of the southwestern limb of a NW-SE trending Bana-Bawi anticline, It is dominated by 10-15m strike ridges and valleys trending NW-SE with southwestern gentle slope and northeastern steep slope (Fig's. 1 & 2).

Geological Formation is the most effective factor in slope stability, in most regions (Pezham, et al, 1998), because slope stability is a function of the material properties and geometry of the slope. In the core of (Bana- Bawi) anticline Bekhme Formation is exposed and overlain by Tanjero, Kolosh, Gercus, PilaSpi, Lower Fars, Upper Fars, and Lower Bakhtiari Formations respectively. The study area lies within the exposures of the Fat'ha (Lower Fars) Formation which belongs to (Middle Miocene) age (Bellen, et al., 1959). This formation is extremely variable in lithology, it consists of clastic sediments interbedded with thin beds of limestone containing the alternation of the following rocks: Conglomerate (in lower part), Gypsum, Anhydrite, Salt rock, green Marls, Limestone, Sandstone, and Red Claystone (in upper part). The main constituents of the Formation are reddish brown claystone and shale which make more than half of the thickness of the Formation but toward the upper part the coarser clastics of siltstone become dominant.

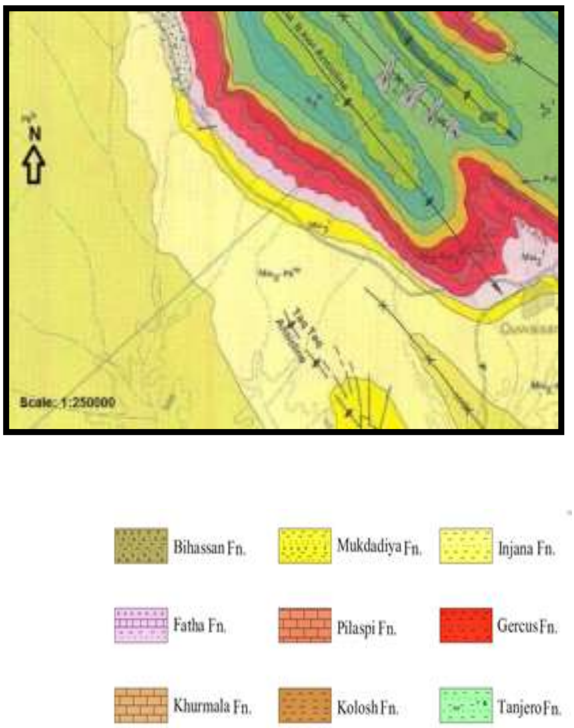


Fig. 2: Geological Map of Daigala area.

4. Description and Development of Slope Failure:

The curved road immediately on the Koya side of the bridge end consists of a land slope covered at the curved part by sedimented mixture of sand, gravel and some clay which resulted from the precipitation of continuous and successive eroded sediments from neighboring hill sides during the rainy seasons over many years. The very heavy rain storms which happened on the 27th, 28th and 29th of January 2013 caused a landslide on this curved part of the hill side beside the paved road in the form of rotational sliding which developed later into a slump failure due to the mechanism of progressive failure. This affected this land slope approaching, step by step the edge of the paved road putting it at the risk of failure and collapse due to the added load imposed on it by the heavy traffic of big oil tankers which were travelling on the road, if it weren't for the immediate actions which were taken to try and hinder the continuation of the progressive failure.

The research team had intervened at the traffic police authorities who were present at the site by giving an advice of closing the lane of the road closer to the landslide and doing some remedial actions to stop and freeze this progressive failure. The effect of this failure on the paved road is clear in the development of tension crack at the edge of the paved road [see white arrows in the following picture], (Fig. 3) and also (Fig. 4), taken on 3.2.2013) which illustrates the later effect of the slope failure on the foundation of the electricity post standing adjacent to the failed slope in the form of a crack progressing in the direction of the slope (white arrows):

Fig. 3: The Start of crack development on edge of paved road due to progressive failure.

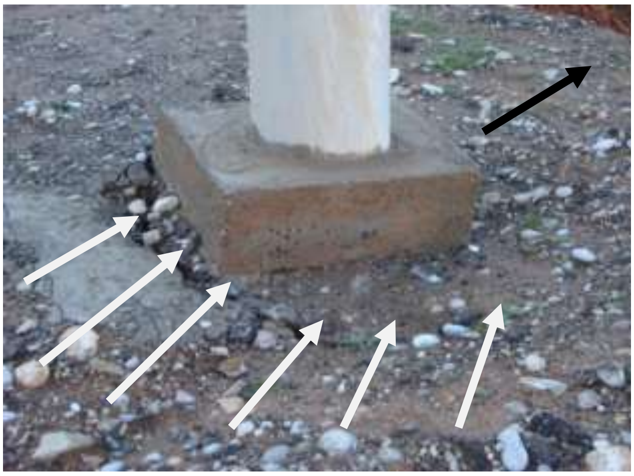


Fig. 4: The development of a crack at the foundation of electricity post due to progressive failure.

The slump failure resulted in a downward movement of the curved saturated block of sediments pushing and cutting, on its way, the lower emergency paved road leading to a considerable partial displacement to a section of this lower road making it inaccessible as shown in the following Fig. 5, as marked by the white arrows:

Fig. 5: A view of the failure and the damaged lower road (white arrows).

The location of the study area was described, providing a location and topographic map of the study area, (Fig. 1). The geological settings of the area were also outlined (Fig. 2).

Different soil samples (both disturbed and undisturbed) were collected from the study area by the research team and different laboratory tests were performed in order to study and analyze the failure which happened. Some in-situ field tests were also done by using the "Inspection Vane Tester, H – 60" to add to the information needed for the intended study and analysis.

5. Theoretical Background about Modes of Failure:

Rotational Sliding:

Rotational sliding involves sliding of materials on a single discontinuity surface curved concavely upward, which will tend to follow a circular failure path Fig. 5. It is formed in a soil or in highly fractured and weathered rocks as well as rocks with closely spaced, randomly oriented discontinuities (Hoek & Bray, 1981) [10]. The shape of the slip surface in rocks is influenced by the discontinuity pattern of the material involved.

Slumping Failure:

Slumping failure is one of the modes of failure that is in common classified with rotational sliding (Nelson, 2002) [5]. The slumping involves the relative movement of rock units and/ or soils, where there are some unconsolidated or weak rock layers that travel as a unit to the down slope along a curved, concave upward failure surface, like a spoon, as shown in Fig. 6. They **o**ccur where erosion has under-cut the slopes. Heavy rains and earthquakes can trigger slumps.

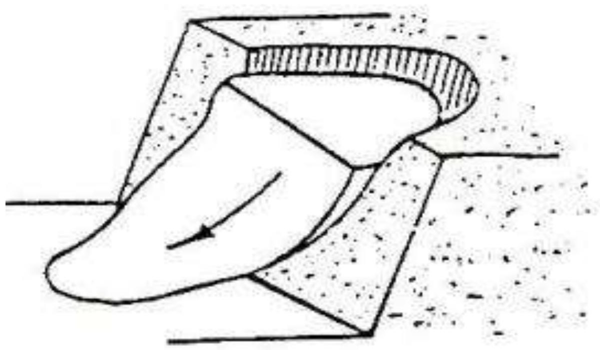


Fig. 6: Rotational sliding which occurs with no identifiable structural pattern (Hoek and Bray, 1981), [10].

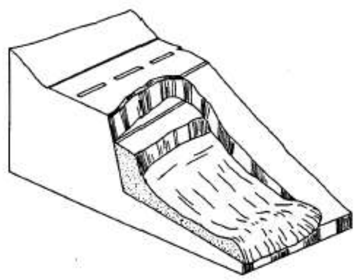


Fig. 7: Sketch showing idealized Slump failure.

Plane Failure:

As shown in Fig. 8, plane failure occurs when a geological discontinuity, such as a bedding plane, strikes parallel to the slope face and dips into the excavation at an angle greater than the angle of friction (Hoek and Bray, 1981) [10].

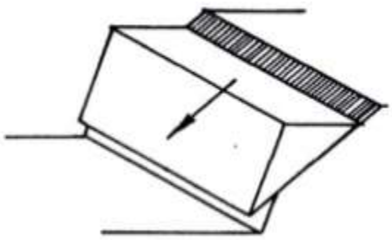


Fig. 8: Illustration of a plane failure, [10].

Wedge Failure:

This failure happens when two discontinuities strike obliquely across the slope face and their line of intersection daylights in the slope face, the wedge of rock resting on these discontinuities will slide down the line of intersection, provided that the inclination of this line is significantly greater than the angle of friction (Hoek and Bray, 1981) [10]. This mode of failure is illustrated in Fig. 9 below:

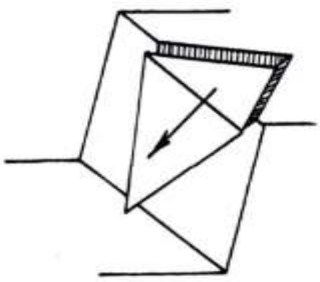


Fig. 9: Illustration of a wedge failure, [10].

The following graph helps for slope stability design and presents the relationships between the critical slope height and slope angle in the form of different graphs for various materials, (Hoek and Bray, 1981) [10].

Critical Slope Height versus Slope Angle Relationships:

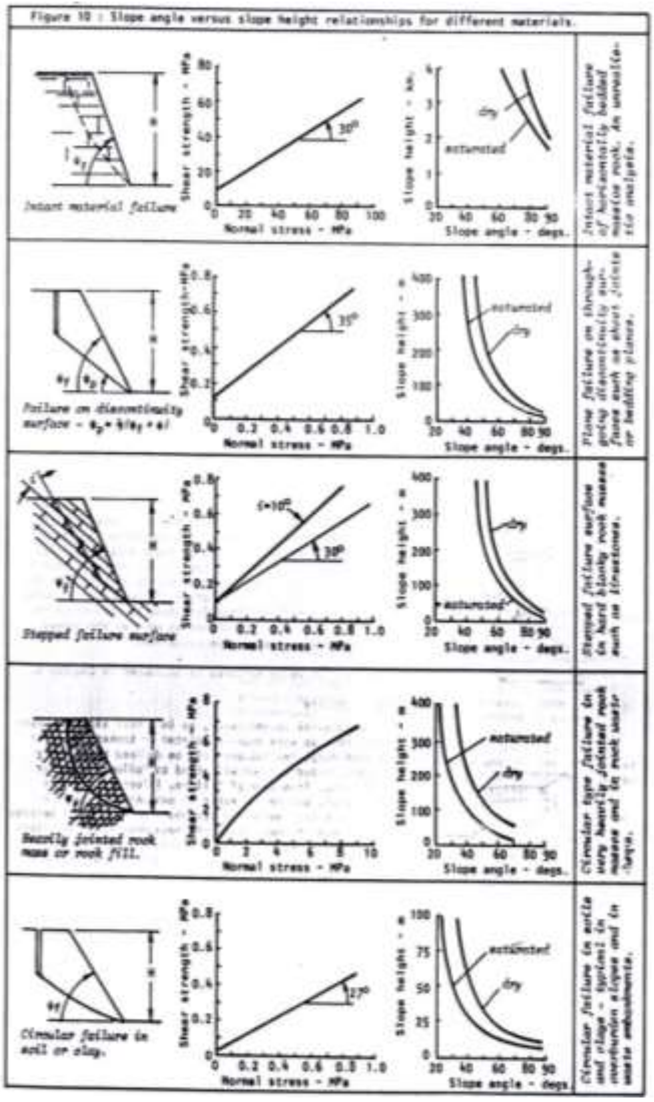


Fig. 10: The Relations between Slope Height and Slope Angle, [10].

6. SOIL TESTING AND DISCUSSION OF RESULTS:

The following laboratory tests were done on soil samples which were taken from Daigala site:

Unit Weight: The unit weight was found in the soil mechanics laboratory having an average value of 19.55 kN/m^3.

Unconfined Compressive Strength (Undrained Shear Strength) of soil based on Vane-Shear tests has been found in the field by taking several measurements which gave an average value of about 59.7 kPa.

Indirect Shear Tests: Soil samples were tested at the soil laboratories of the University of Salahaddin by using the indirect shear testing machine which lead to the results below:

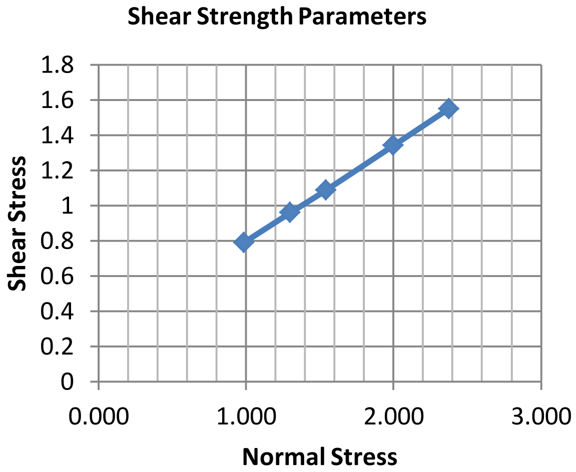


Fig. 11: Plot of indirect shear test results.

When Normal Stress = 0.00 ➔ Shear Stress, C = 24.8 kPa

The Slope of the line, $\phi = 28.8\,^{o}$

Atterberg Limits: Soil samples were tested to find the Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI), as shown below:

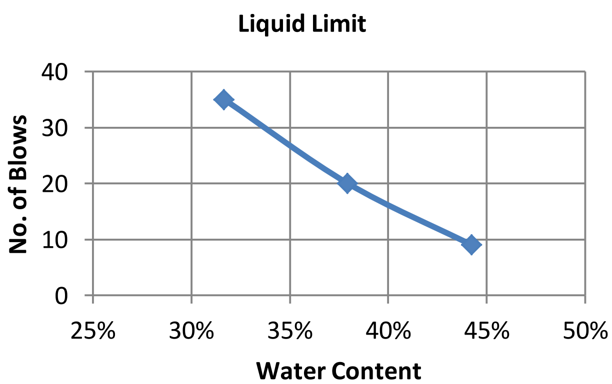


Fig. 12: Plot of liquid limits data.

At 25 blows ➔ LL = 36%

Plastic Limit ➔ PL = 19.4%

Plasticity index = LL – PL = 36 – 19.4 = 16.6%

7. SIEVING ANALYSIS - WET PROCESS:

A soil sample of (555) gm. weight was wet sieved and the results are represented below:

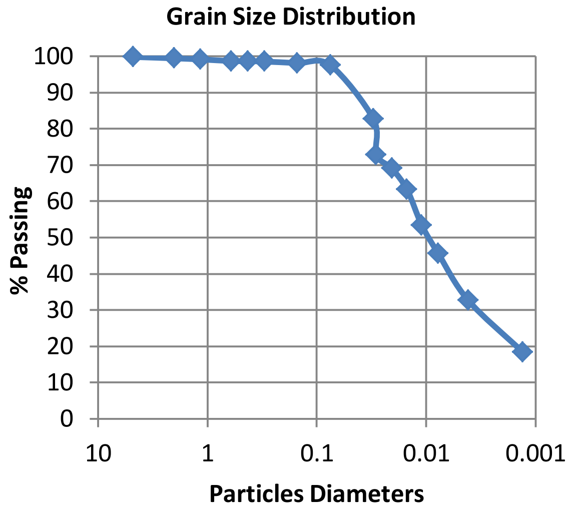


Fig. 13: Sieving analysis plot.

8. QUICK DESCRIPTION:

The soil is classed as fine soil because 97.53 % (clay and silt) pass through sieve no 200.

Soil Classification According to the Plasticity Chart:

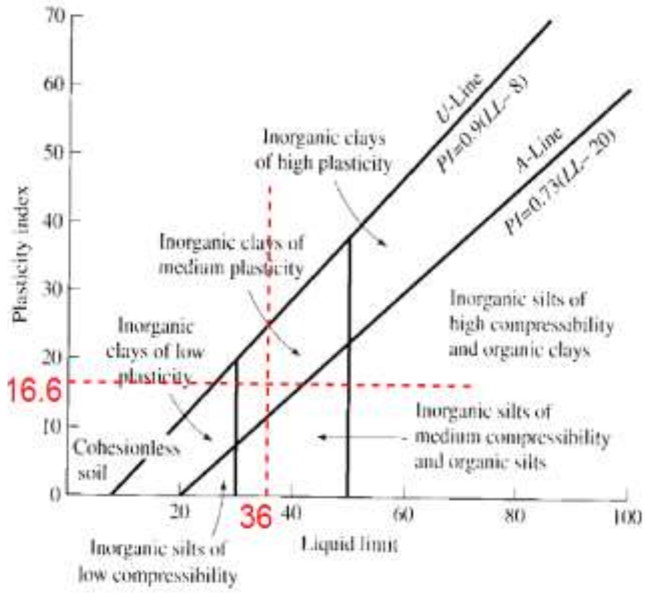


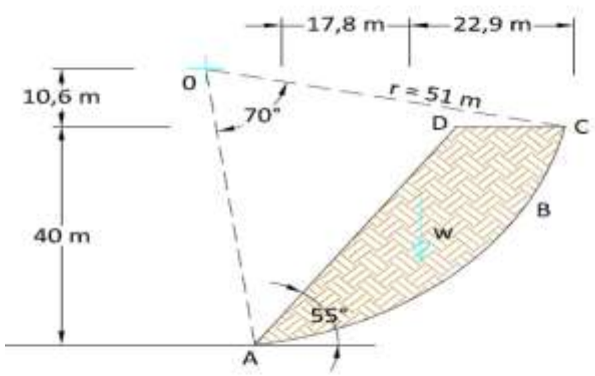
Fig. 14: Plasticity Chart.

Based on unified soil classification system and visual inspection, percent passing from sieve #200 is greater than 50%, so by using plasticity chart (Fig. 14) to classify the soil:

Plasticity index = LL – PL = 36 – 19.4 = 16.6%
The soil is ***brown reddish medium plasticity clay***.

9. Analysis of Slope Failure and Calculation of Safety Factor (F):

Our Case: From the geometrical measurements which were taken at the site (illustrated in the figure below) and the necessary values from laboratory tests (illustrated in the table below), the following procedure has been used to analyse the slope failure and to calculate the slope factor of safety (F):



Cross-sectional area ABCD is 673 m^2.
Weight of soil mass = 673 × 19.55 = 13,157.2 kN/m

The centroid of ABCD is 17.8 m from O. The angle AOC is 70.0° and radius OC is 51.0 m. The arc length ABC is calculated as 62.6 m. The factor of safety is given by:

$$F = \frac{C_u\, L_a\, r}{W\, d} = \frac{59.7 \times 62.6 \times 51}{13157.2 \times 17.8} = 0.813$$

This is the factor of safety for the failure surface selected and is not necessarily the minimum factor of safety.

Based on the principle of geometric similarity by Taylor, [11], he published stability coefficient for the analysis of homogenous slopes in terms of total stress. For a slope of height H, the stability coefficient (N_s) for the failure surface along which the factor of safety is minimum can be calculated as;

$$N_s = \frac{C_u}{F\,\gamma\,H} = \frac{59.7}{0.813 \times 19.55 \times 40} = 0.094$$

The minimum factor of safety can be estimated by using the below Equation, and the value of N_s ;

Then;

$$F_{min} = \frac{C_u}{N_s\,\gamma\,H} = \frac{59.7}{0.094 \times 19.55 \times 40} = 0.81$$

10. CONCLUSIONS:

This research has lead to the following conclusions:

1- The type of failure which occurred at the Daigala slope was a rotational sliding which progressed later into a slumping failure due to water saturation, very low cohesion and continuous disturbance.

2- The mechanism of progressive failure was noticeable which lead to the development of tension cracks towards the paved road, endangering its stability.

3- The calculated minimum factor of safety of the slope was calculated, based on the existing geometrical parameters and material properties and characteristics and found to be 0.81 which explains the failure which happened and its development.

4- The continuous loading due to the travel of heavy oil tankers and the vibrations accompanied with their travel have contributed to the development of progressive failure and the creation of new tension cracks before these vehicles were stopped and the closure of the road lane nearer to the valley was accomplished which reduced the danger of continuation of progressive failure.

11. RECOMMENDATIONS:

The research team can make the following recommendations:

1- The disturbed blocks have to be removed and different measures of slope stabilization have to be made.

2- The water infiltration rate has to be reduced by installing horizontal drainage pipes at different locations across the slope face. These drainage pipes have to be of various lengths to cover most of the slope section and the perforated part at the far ends of the pipes have to be long enough to secure efficient drainage.

3- The toe parts of the slope have to be supported by installing some form of key structure to act as retaining element.

4- Application of soil nailing at the most critical locations of the slope in order to prevent the horizontal sliding of the slope.

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