LANDSLIDES IN THE WHITE MOUNTAIN (GEOTECHNICAL STUDIES AND ENGINEERING TESTS)

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Abstract: *The White Mountain area in the city of Nablus, Palestine, had severe landslides in the year 1997. Necessary studies to find out the causes and to overcome this problem were carried out. This included surveying of the area, geotechnical studies (digging out five boreholes, taking necessary samples, and conducting laboratory tests), and slope stability analysis. The factor of safety was found to be more than one (between 1.4 and 1.8), and this indicated factors other than the natural slope caused the sliding in the White Mountain. It was found that the main causes of landslides were the cuts in the lower part of the area. After the causes for*

INTRODUCTION

Landslides occur in many places around the world, especially the mountainous areas. They cause great danger to structures and people close to them. They occur when the component of gravity is large enough so that the driving force overcomes the resistance form the shear strength of the soil along the rupture surface. The stability of the slope in not an easy task (1), it depends on soil stratification, shear strength parameters of soil, seepage through the slope, and the choice of a potential slip surface. The most likely rupture surface is the critical plane that has the minimum factor of safety. Secondary causes may trigger and activate landslides, especially in areas that had old landslides (2).

Historically, the site that had landslides in the City of Nablus, Palestine, is known as Al-Maajeen, the site is shown in Figure 1. This name indicates clearly how danger is this site, the name means that the soil becomes like flour paste when water infiltrates it. This is because the soil in the site is Marl Soil (silty clay). In addition, the people in that area called this mountain the slippery mountain (3).

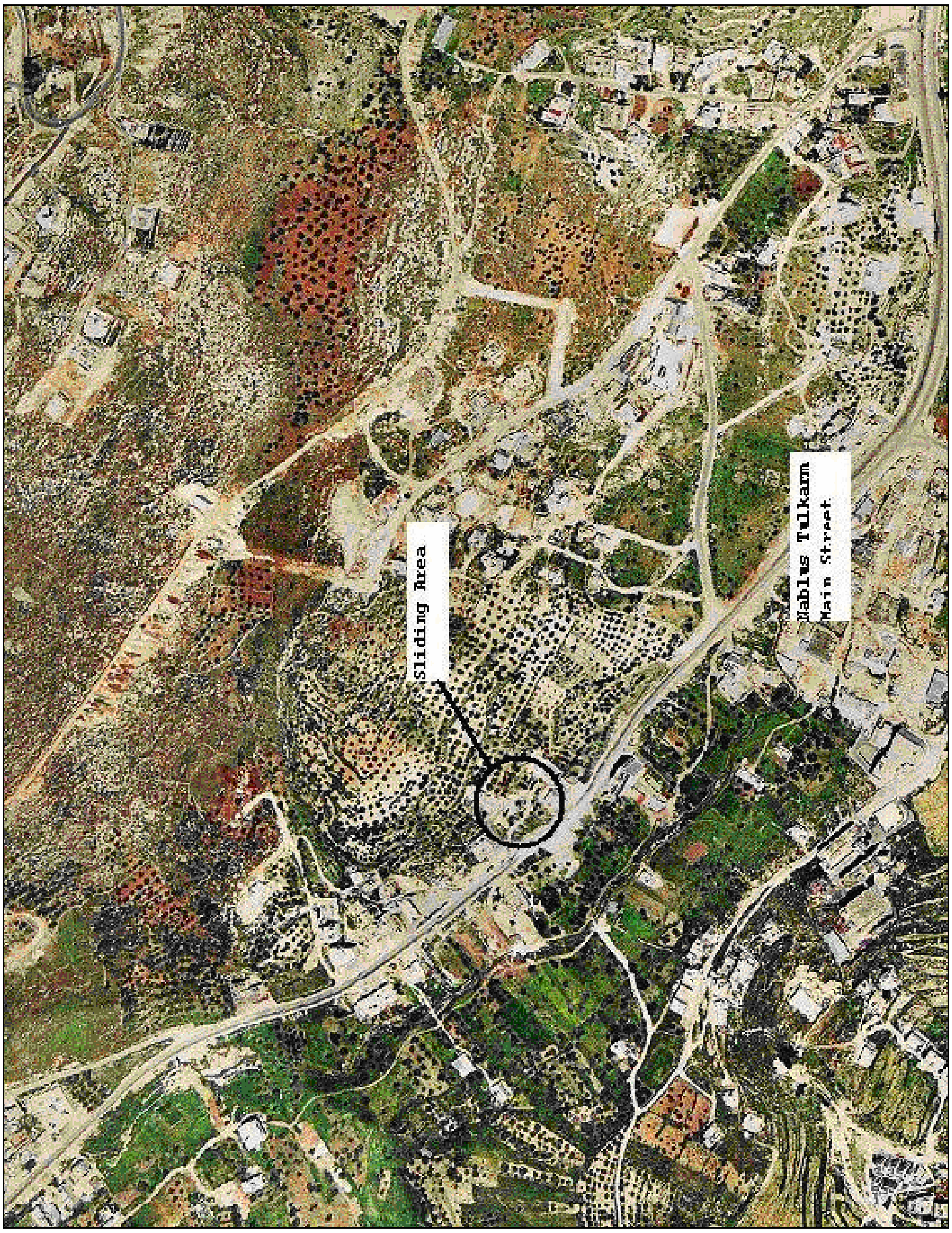

Figure (1): An Arial map of North Western part of Nablus City showing the sliding area.

This study presents description of the landslides that occurred at the White Mountain and necessary studies to find out the causes of landslides and how to overcome problems caused by them. This included surveying of the area subjected to landslides and geotechnical studies (digging out five boreholes, taking necessary samples, and conducting laboratory tests). In addition, slope stability analysis was done using specialized software called PCTANI (4) for different cross-sections across the sliding area.

The factor of safety for the natural ground conditions was found to be more than one (between 1.4 and 1.8), and this indicated that factors other than the natural slope caused the sliding in the White Mountain. It was found out that the main causes of landslides were the cuts in the lower part of the area, the increased loads in the upper part due to construction of a house, and the earthquakes that occurred in February and March of the year 1997. Although, earthquakes effect was considered minor, however, they acted as a trigger for landslides in that area.

After the causes for landslides were determined, engineering solutions to overcome landslides were suggested. The solutions included reducing the slope, supporting the area by a series of bored cast in-situ reinforced concrete piles to form a sheet pile, installing drainage system all-over the area including the upper and lower parts, and rehabilitation of the road in the lower part of the area using selected backfill materials.

DESCRIPTION OF THE LANDSLIDES CASE

The White Mountain in the city of Nablus suffered large landslides; this area is shown in Figure 1. The landslides case can be described as follows:

- Landslides in the soil are due to loosing cohesion between the soil strata, since the soil in the area is marl soil (silty clay). This caused large surface cracks and settlements in the soil at the upper part of sliding area as shown in Figure 2, which led to several levels in the soil surface.
- A house subjected to sliding and thus moving horizontally causing the house completely failure, as shown in Figure 3.
- The main street between Nablus and Tulkarm at the bottom of the landslide area subjected to uplift and horizontal forces and that led to uplift and horizontal movements, as shown in the bottom of Figure 4.
- Collapse of a barracks of steel structures in the landslide area. This structure subjected to horizontal movement, as shown in Figure 5.
- Another building at the bottom of the landslide subjected to horizontal and uplift movements. This caused cracks in the walls of the building and uplift movements in the ground floor.

- Main utility lines were subjected to horizontal forces that caused damages to them and led to horizontal displacement from their original place.

Figure (2): Cracks and settlements in the sliding site.

Figure (3): A Photograph shows the Landslides and the damaged house in the White Mountain

Figure (4): A Photograph shows the bottom of Landslides and Nablus – Tulkarm damaged main street in the White Mountain

Figure (5): A Photograph shows the damaged Barracks in the White Mountain

GEOTECHNICAL STUDIES

Purposes of Geotechnical Studies:

The purposes of the geotechnical studies are to assist in finding out the causes of landslides and hence suggesting solutions to this problem. The purposes included describing the subsurface soil strata and drawing geological sections of the area that subjected to the landslides, determining the necessary geotechnical parameters for geotechnical analysis, and running slope stability analysis for different cross-sections across the sliding area. Slope stability analysis is used to determine the location of rupture surface, which the sliding surface that has minimum factor of safety.

Methodology to Achieve the Purposes:

Five boreholes were dug out in the site under the supervision of the authors. These boreholes are shown in Figure 6. These boreholes gave the opportunities for eye exam of the soil and the soil strata, and taking needed samples for laboratory tests. Laboratory soil tests were carried out at soil mechanics lab at An-Najah National University, to determine the soil properties and parameters, such as unit weight, natural moisture content, liquid limit, plastic limit, plasticity index, and unconfined compressive strength.

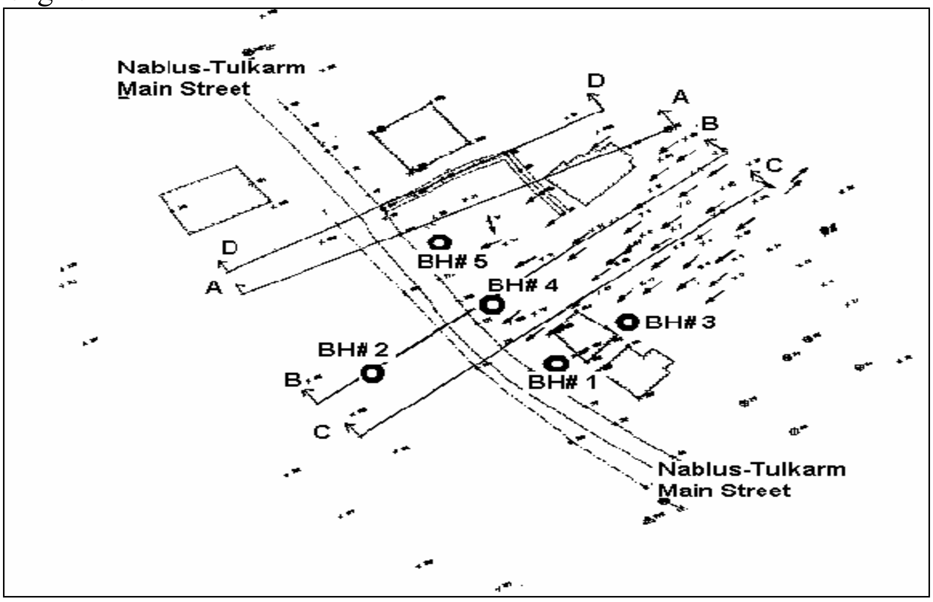

Figure (6): Location of the boreholes and cross-sections for slope stability analysis

Geological Description of the Site:

From borehole logs, geological sections (typical geological section is shown in Figure 7), and excavation in the site, the top soil of the site may be described as fill material which is mainly dumped soil from various sources, the depth of this layer ranges between 0.5 to 1.0 m. The soil below the fill material is white silty clay of low to medium plasticity (Marl Soil), mixed with aggregate of varying sizes, classified according to Unified Soil Classification System (USCS) as CL-ML. The thickness of this layer ranges form 8 to 16 m below the elevation of the main street. The soil below the marl soil is weathered fragmented and disintegrated marlstone of weak to medium strength.

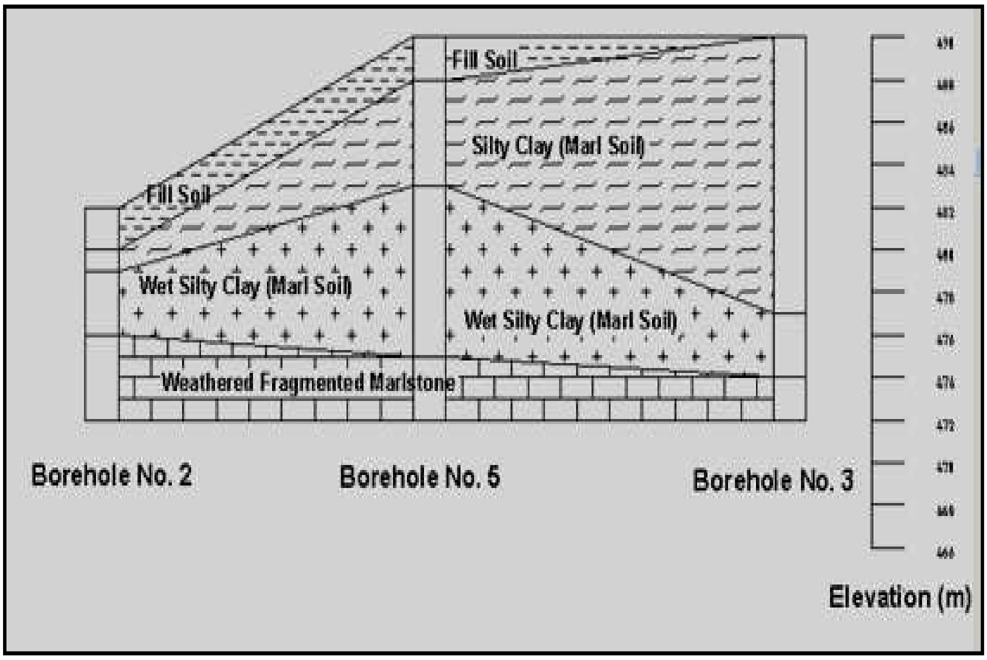

Figure (7): Typical geological section in the sliding area

Natural moisture content of the soil was found to be high and varying form elevation to elevation and from borehole to borehole. This indicated that the moisture was mainly from rainfall water that penetrated the soil layer through cracks resulted form sliding.

Results of Laboratory Tests:

Several laboratory tests were carried out at An-Najah National University, Soil Mechanics Laboratory, to classify the soil at the site such as sieve analysis (5), natural moisture content (6), liquid limit, and plastic limit(7), and to determine shear strength parameters such as unconfined compressive strength (8). Table 1 summarizes soil mechanics laboratory tests results.

Table (1): Summary of the laboratory tests results

Borehole No.	Sample No.	Depth M	Natural Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index	Undrain Cohesion kN/m^2
1	1	0.0 – 5.5	16				90
	2	5.5 – 8.5	21	39	27	12	
	3	8.5 – 10.5	18	50	29	21	215
	4	10.5 – 12.5	16				
2	1	0.0 – 2.5	12	40	29	11	130
	2	2.5 – 3.5	12				
	3	3.5 – 4.5	14	35	26	9	145
	4	4.5 – 6.0	12				
	5	6.0 – 7.5	12				
3	1	0.0 – 6.5	19	44	29	15	95
	2	6.5 – 9.0	18	40	30	10	100
	3	9.0 – 13.0	15	42	25	17	
	4	13.0 – 16.0	14				110
4	1	0.0 – 1.5	12				
	2	1.5 – 6.0	13	36	25	11	125
	3	6.0 – 7.0	12				
	4	7.0 – 8.5	12				
5	1	0.0 – 1,5	12				47
	2	1.5 – 3.5	15	35	21	14	120
	3	3.5 – 8.5	17				90
	4	8.5 – 14.0	14	43	24	19	110
	5	14.0 – 15.0	14				

The following is the summary of the ranges of these results:

Natural moisture content (N.M.C):	12% to 25%
Liquid Limit (L.L.):	35% to 50%
Plastic Limit (P.L.):	21% to 30%
Plasticity Index (P.I.):	9 % to 21%
Undrained Cohesion (Cu):	47 to 130 kN/m^2
Wet Unit Weight:	17 to 19.5 kN/m^3
Dry Unit Weight:	1.36 to 1.7 kN/m^3

Geotechnical Situation (Slope Stability Analysis):

Slope stability analysis was done for several cross-sections across the site (sections A, B, C, and D as shown in Figure 6). The aim of this analysis is to locate the critical rupture surface (surface of minimum factor of safety). This analysis was done using numerical integration by a computer program called PCTANI (Hector, 1983). PCTANI is an interactive program that computes the factor of safety of slopes using Bishop's Modified Method. The program accepts data from a FILE as well as from the KEYBOARD. Data must be entered in the following order describing the slope geometry, soil properties, type of units used, soil data, and piezometric data. The program, also finds the coordinates of center and radius of the circle that have the least factor of safety.

The analysis was carried out for two cases for the above-mentioned four sections. The first case, soil strata of the site was assumed of homogeneous soil, which is Marl soil (Silty Clay). The second case, soil strata has a bedrock layer at a depth of about 15 meters form the main street level. The first case considered as the critical condition while the second condition considered as the common strata types of the sliding site.

Results of the Geotechnical Studies:

Geotechnical studies, especially the slope stability analysis using computer program PCTANI for the four sections through the site showed that section B is the critical section and has the lowest values of factor of safety. For the first case, one layer of homogenous Marl soil, slope stability analysis showed that the minimum factor of safety is 1.4, and the surface rupture existed at a depth of about 40 meters below the main street level. However, slope stability analysis showed that, the minimum factor of safety is 2.3, and the surface rupture occurred on top of the bedrock layer, when introducing Marlstone bedrock layer in the second case.

From the above analysis, one can conclude that the sliding (surface rupture) may occur on the top of the bedrock layer, which is about 15 meters below the main street level as the maximum depth. On the other hand, sliding may occur at a depth less than the depth of the bedrock layer and this was found in the field in one of the borehole, which was about 3 meters below the main street level.

In general, the analysis showed that the site with type of soil and slope available is safe against sliding and this indicated that there are external factors that led to sliding.

REASONS FOR THE LANDSLIDES IN THE WHITE MOUNTAIN

The first sign of an imminent landslide is the appearance of surface cracks in the upper part of the slope perpendicular to the direction of the movement. These cracks may gradually fill with water, which weakens the soil and increases the horizontal force that initiates the slide.

The main reason for sliding was the large man-made cut at the site, which was lack of engineering design and supervision. This led to cracks all over the site that filled with rainfall water and penetrated the soil layers, thus weakened the shear strength parameter (cohesion) and caused horizontal pressure. Other reason is the type of soil available at the site, which silty clay soil (Marl soil) that loses its strength (cohesion) when water penetrates it. In addition to the earthquakes, those have secondary causes by triggering and activating landslides, which hit the area (Palestine) in February and March of 1997.

SUMMARY OF REMEDY MEASUREMENTS

Many methods can be used to correct landslides (WinterKorn and Fang, 1975). The commonly used correction methods can be divided into the following three main groups. The first one is geometrical methods, which involve the change of the geometrical conditions of a slope. The stability of a slope can be increased by one or more of the following: flattening of the slope, removal of the soil or other loads at the top of the slope, and placing pressure berms at the toe of the slope. Second method is hydrological methods, such as a lowering of the ground water table or a reduction of the water content of the soil or rock. This can be accomplished, for example, by surface drains, or drainage galleries, or sand drains. The third method is mechanical and chemical methods, which increase the average shear strength of the soil. This method can be done by various techniques, such as, compaction, grouting, freezing, rock bolts, piles and sheet piles, and retaining walls.

Remedy measurements suggested to overcome the sliding problems in the White Mountain area are drainage of the rainfall water for both surface water and water that penetrated the soil layers, and installing an overall drainage system for the whole site including the top and bottom of the slope. Flattening the slope, recommended slope for this case is 1 vertical to 3 horizontal. Strengthening the bottom of the slope by introducing a row of bored cast in-situ reinforced concrete piles, to form reinforced concrete sheet pile. Planting the site with suitable type of trees to increase the strength of the soil and reducing soil moisture. Finally rehabilitation of the road in the lower part of the area using selected backfill materials.

In addition to suggestion of precaution measurements, such as, implementing land use policy in our country based on engineering decisions, enforcing site investigation program for new structures, and designing and supervising excavations by experienced engineers. Figure 8 shows part of remedy measurements that took place in the site.

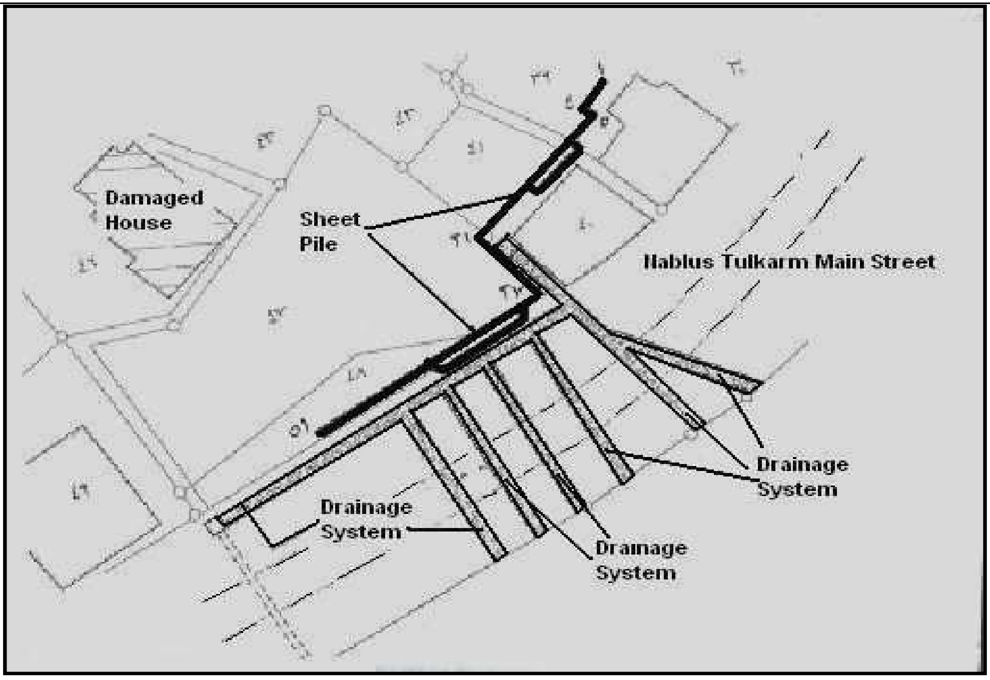

Figure (8): Part of remedy measurements that took place in the sliding site

CONCLUSIONS AND RECOMMENDATIONS

Slope stability analysis using computer program PCTANI showed that minimum factor of safety is greater than one for two cases of strata considered for the study area to analyze causes of sliding. This indicated that there are external factors that led to sliding. One of the main reasons for sliding was the large man-made cut at the site, which was lack of engineering design and supervision. This led to cracks all over the site that filled with rainfall water and penetrated the soil layers, thus weakened the shear strength parameter (cohesion) and caused horizontal pressure.

Therefore, it is recommended to have experienced designer and supervisor for designing and constructing excavations. In addition to implementing land-use policy by zones according to their suitability for uses, and enforcing site investigation through specialized geotechnical engineers for new structures.

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