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Site Investigations, Treatments, and Construction Regulations in Landslide-Prone Areas in Jordan

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Abstract

Most of the landslides that occurred in Jordan in the last few decades at the sites of major engineering projects could have been averted had adequate site investigations been conducted.[1] The causes and the prevailing geological and geotechnical conditions at some of these landslides areas are discussed with the correction and mitigation measures being considered or carried out. The paper discusses the different options for dealing with the landslide hazards and suggests construction regulations for the newly developed areas based on the hazard intensity, cost of treatment, and the resilience of the community. The paper emphasizes the important role of landslide hazard zoning maps, monitoring and warning systems, and the preparedness measures in avoiding or alleviating the consequences of landslides hazards. Risk analysis and guidelines regarding the reconstruction works of the areas affected or under the threat of potential landslides as well as their impact on people and environment are discussed. The proper selection of the team (engineers, geologists, planners. …etc.) commissioned to carry out these works is emphasized.

Introduction:

Landslides pose serious threats to life, traffic, engineering structures, facilities, and environment. Landslides sometimes result in serious inconvenience to the economic and social activities of people. Many factors contribute to the occurrence of landslides and rock falls that commonly include geological, physical, chemical, hydrological, seismic, and biological ones as well as human activities. Prevention of landslides and mitigation measures heavily depend on the data provided by site investigations, laboratory testing, visual inspection, and instrumentation measurements.

SITE INVESTIGATIONS

Proper site investigations should provide data that are adequate in quantity and quality to establish design criteria and construction procedures for safe and economic engineering works.

Proper site investigations should also consider the palegeological history of the project site and should also provide information about the possible changes in the physical, chemical, hydrological and geological conditions of the project area due to natural factors or human activities that may impact the stability of the site. Fluctuation in ground water table, rise in artesian pressure, deep scour erosion, dissolution of salts, development of sinkholes, and seismic activity are just few examples of the factors that may affect the stability of any engineering project especially when associated with deep cuts or high fills. Inadequate site investigations might lead to the design or construction of unsafe or uneconomic engineering projects. The main aspects of inadequacy of site investigations are: Deficiency in the type, scope, volume, and distribution of investigation works, poor sampling and testing of samples, and inaccurate interpretation of the field and laboratory testing data as well as improper consideration of the geological, hydrological, and geomorphological characteristics of the project site.

It is a common practice among many consulting engineering offices to carry out only the minimum required site investigations before embarking on the preliminary design of any project in order to keep their expenses at their lowest possible level.

Site investigations, in such cases, are often limited to the excavation of some test pits and the drilling of few boreholes and carrying out some routine field and laboratory tests. Such an approach proved to be unsatisfactory and doesn't guarantee safe economic design of engineering projects in areas with complicated geologic and hydrogeologic conditions.

Many large slides occurred due to shallow cuts that resulted in the daylighting of weak plastic layers of clay or marl, or due to dumping of material on the crown of old landslides[2]. Careful examination of aerial photographs along the proposed routes of highways by competent photogeologists could help in producing accurate engineering geological maps that show the locations where the slopes exist in a critical stability condition. Monitoring of slopes and installation of inclinometers may be needed in some cases to detect creep movement and to define the location of potential sliding surfaces. Installation of piezometers to measure fluctuations in pore water pressure is necessary for defining ground water conditions and for conducting accurate slope stability analyses in areas with subsurface seepage.

The following are some examples of engineering works that suffered from slope failures due to inadequate site investigations or improper evaluation of the data gathered from these investigations. These are manifested by the oversimplication of the geological section in the areas affected by tectonic disturbance and old landslides. The use of peak shear strength parameters along pre-existing slip surfaces and the assumption of adequate drainage conditions in the stability analysis often lead to false and unsafe conclusions concerning the stability of cut slopes. This is quite clear in the following examples of slope failures.

EXAMPLES OF SLOPE FAILURES

Wadi Es Sir Sewage Treatment Plant (WESTP)

The Wadi Es-Sir Sewage Treatment Plant (WESTP) is located about 10 kms to the south west of Wadi Es-Sir town and about 20 kms to the east of the Jordan Dead Sea Rift. The site of the project was affected by a major landslide in September 1993.

The investigation works that were carried out in February, 1994[3]showed that the sliding surface passed through a weak layer of loose colluvium and that the slopes were cut at angles that were too steep for such a weak layer particularly under the conditions of high saturation. Reports issued after further investigations recommended the cancellation of some lagoons, shifting of some lagoons further down the slope, flattening the slopes, and the provision of effective drainage system. Although some of the lagoons were shifted to other locations and the slopes were flattened to 4H: 1V many landslides occurred in the period from September, 1993 till February, 1997 as shown in Figure (1).

The foundation materials at the sites of the lagoons are dominated by weak colluvial deposits and wet plastic marls.

The geological and geomorphological features of the area clearly indicate that it suffered from many old landslides. The poor surface and subsurface drainage conditions had further contributed to the instability of cut slopes. Figures (2, 3) show the consequences of the last landslide resulting in the partial failure and displacement of the gabion wall at the toe of the slope and the breaking down of the gabion on the northwestern side of the cut slope. Had adequate site investigations been carried out the site would have been deemed inappropriate for the construction of the plant.

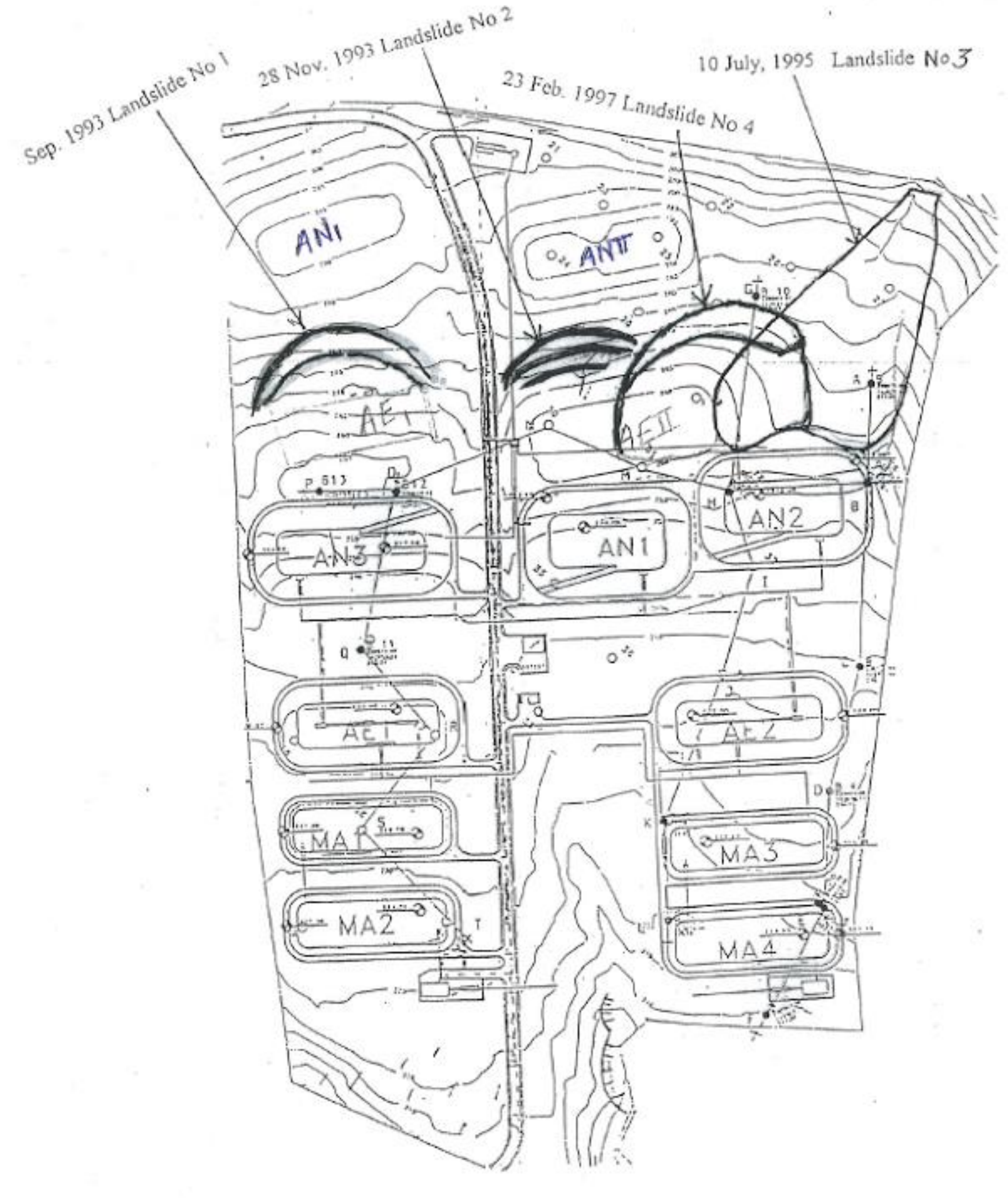

Figure (1). Approximate locations of the four landslides (WESTP)

(A)

(B)

Figures 2, 3 show the breaking down of the side gabion wall (top) and the tilting displacement of part of the gabion wall at the toe of the cut slope (bottom) at WESTP

Amman – Naur – Dead Sea (AND) Highway: Landslide No. 4

The Amman-Naur-Dead Sea highway was constructed in 1956. Section 3 of this highway crosses what was designated later as landslide No. 4. Several embankment failures (Figure 4) occurred between 1956 and 1964 in this area. It was open to traffic from 1958 to 1964, but was abandoned after the 1964 slide. After many phases of site investigations the Ministry of Public Works decided to pass the highway through a route at a higher elevation which was later designated as the "Upper Alignment" without carrying out adequate site investigations along this new alignment [4]. Many landslides occurred along this new route due to the presence of plastic clayey marls and perched water at different levels. This resulted in a substantial increase in the cost of construction and in a considerable delay in the completion of the works.

The extensive investigation works carried out at the "Lower Alignment" indicated that the strata were inclined favorably into the slope. During the construction of the highway along the adopted "Upper Alignment" the dip of the strata changed in the further stations in the unfavorable orientation out of the slope which further contributed to the instability of the cut slopes.

Irbid- Jerash – Amman (IJA) Highway:

This 57 km highway suffered during its construction as well as after its completion from many cut slope and embankment failures.

The investigation works that were carried out at the locations of 7 major slides as well as along the route of the highway have indicated that the main causes of slope failures were:[5]

1. The presence of intercalations of weak and water-sensitive plastic layers within the slope materials like the shale beds within the Kurnub Sandstone Formation (L. Cretaceous) and clayey marls within the lower Ajloun Group (U. Cretaceous).

2. The poor surface and subsurface drainage conditions that led to the deep percolation of rain water within the slope materials and the softening of the argillaceous beds of shale and marl.

3. The daylighting of the wet shale and marl beds with unfavorable dip orientation during the excavation at the toe of slopes that were in a precarious state of stability (Figure 5).

4. The placements of high embankment fill on colluvial deposits that were existing in a critical stability condition.

It is worth mentioning in this respect that no single borehole or any engineering geological mapping or any sort of geotechnical investigation was carried out in the 7 major slide areas prior to the occurrence of these slides.

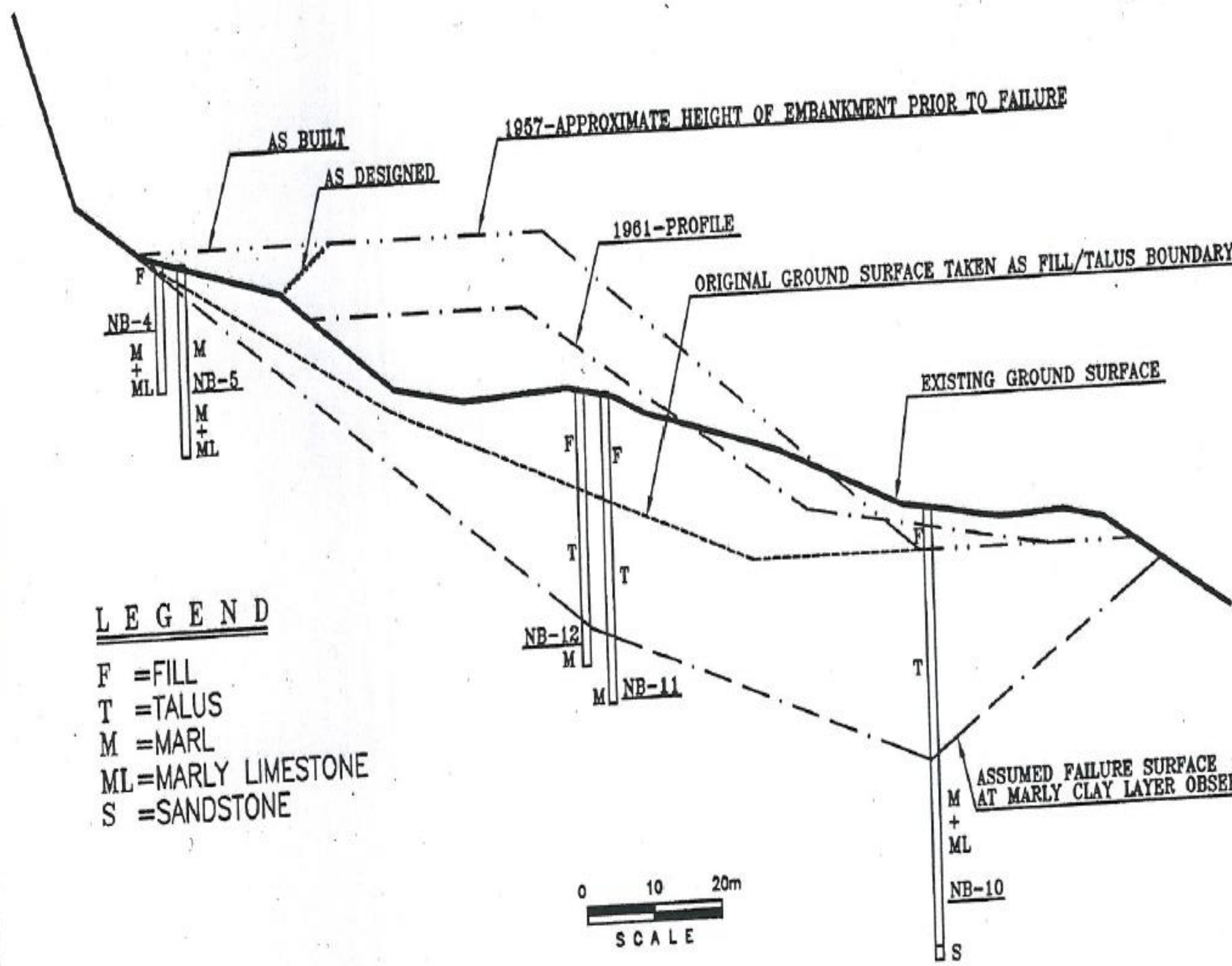

Figure 4. CROSS SECTION OF LANDSLIDE No.4
ST. 10+300
(REF. 4)

Figure 5. Failures along Jerash- Irbid highway due to daylighting of wet plastic marls.

Left Abutment of Mujib Dam:

During the excavation at the left abutment of the roller compacted concrete Mujib Dam an unexpected landslide occurred that prompted the designer to shift the axis of the dam downstream of its original position. The landslide was due to the daylighting of a moderately thick (about 1.0m) wet plastic mudstone layer overlain by loose colluvium that allowed percolation of rainwater towards the mud layer that was dipping unfavorably out of the cut slope forming a slip surface for the landslide (Figure 6).

Tafila Retaining Walls

Retaining walls were constructed on the western side of a major street passing through Tafila town near Wadi Zeid. During the first winter season after their construction the retaining walls failed by tilting and excessive displacement down the slope. Post-failure investigations indicated that the failure was due to the low bearing capacity of the wet plastic clayey marls on which the retaining walls were founded and to the poor drainage condition and the poor quality of the backfill materials behind the retaining walls.(Figure 7).

Jordan Street

After constructing the Jordan Street at a zone few kilometers before the link with Sweileh- Jerash highway creep movement resulted in the subsidence and cracking of the asphalt surface of the highway. Investigations indicated that the creep movement was due to the placement of high fill on a pre-existing slip surface passing through moist plastic marl in an area that suffered from an old landslide.

The geomorphological features and the inverse dip of strata on the eastern side of the road from that on its western side across the nearby wadi clearly indicate that the area suffered from an old landslide.

This creep movement promted the designer to shift the alignment of the road to a more stable area on the east (Figure 8).

Kufranja Dam Spillway Chute:

A landslide occurred in the spillway chute of Kufranja Dam on March 17, 2012. Post – failure investigations indicated that the slide was initiated in plastic clayey marl near the middle of the spillway chute that was recently excavated due to the absorption of moisture from the preceding rainy months. The percolated water through the jointed rock mass near the top of the spillway excavation affected the colluvial deposits in the lower zone of the spillway chute. The colluvium was much thicker than what was assumed in the design and the geologic conditions were also worse than the expected ones. Figure 9 shows the spillway chute excavated area after the landslide which resulted in an increase in the cost of the project and delay of its construction.

Most of the failures mentioned above could have been averted had adequate site investigations been carried out and proper interpretation and conclusions of the gathered data been utilized in the design and construction of the above engineering projects.

(A)

(B)

Figure 6: A Landslide on the left of abutment of Al – Mujib dam.
A) The escarpment of the slide in the talus material.
B) The slickenslide surface in the underlying mud layer.

(a)

(b)

Figure 7. (a)The displacement and overturning of retainig wall on wadi Zied in Tafila
(b) The displacement of slope material beyond the failed wall.

Figure 8. The shifted section of Jordan Street highway

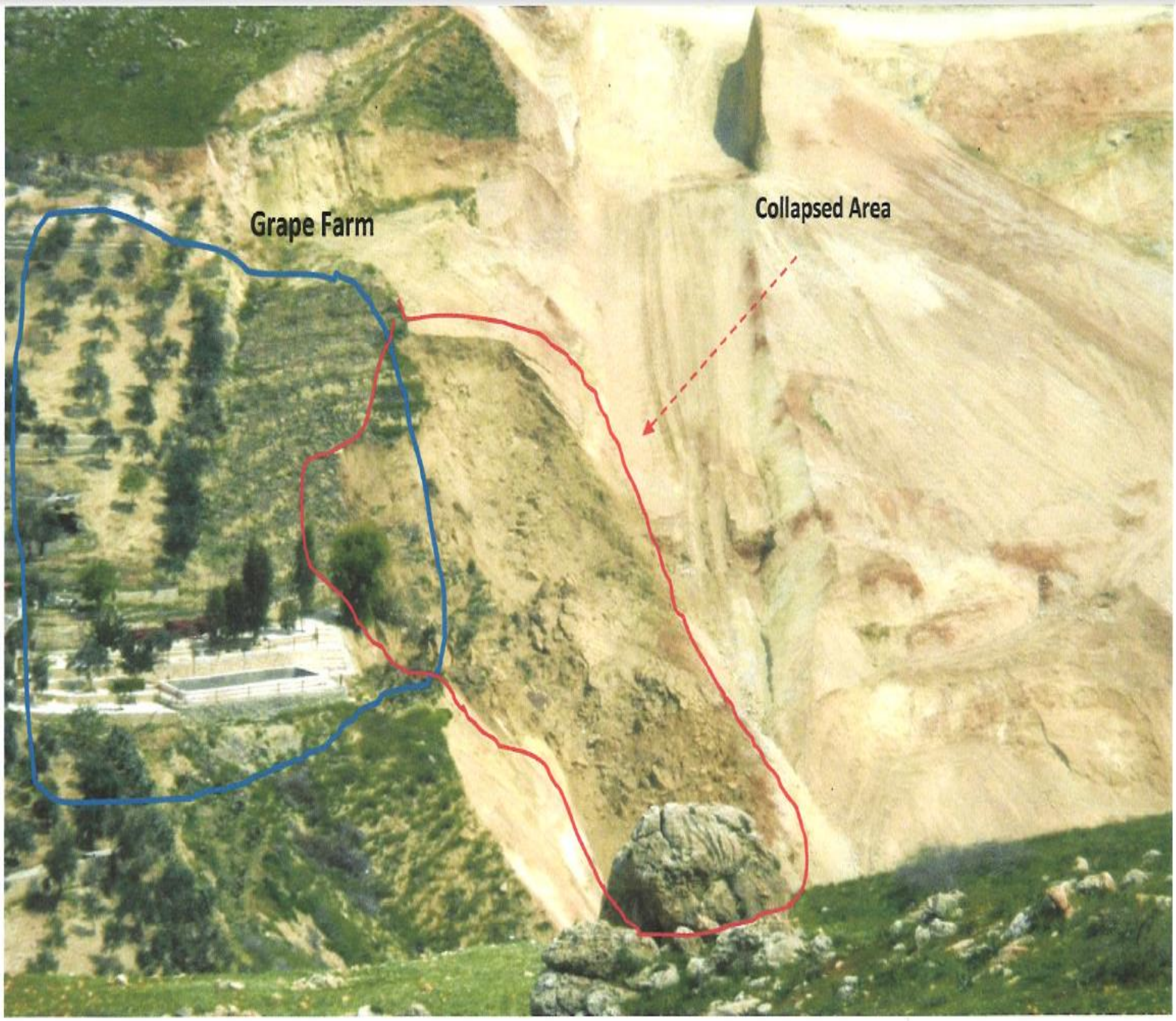

Figure 9 . Excavation of Spillway, Chute and Flip Bucket (31/03/2012)

(Kufranja Dam)

OBSERVATION AND MONITORING

It is of a paramount importance to observe and record any unusual features that may affect the cut slopes in the project area. Such features may be detected at an early stage by field inspection, periodic survey measurements, or by the examination of aerial photographs taken at different periods of time.

Among the features that may give an early indication of instability are:

1- Emergence of springs or wet spots that didn't exist before.
2- Tilting of objects like trunks of trees, electric or telephone poles, or metallic fences.
3- Development of tension cracks on the slope face or near its crest.
4- Cracking of any civil engineering structures like buildings, box culvers, concrete retaining walls,…etc on or near the cut slope.
5- Sudden loss of liquids in septic tanks, pits, or pools on or near the cut slope.
6- Any distortion in the surface or alignment of roads passing within or close to the project site.
7- Any unexplained change in the alignment of water pipelines or leakage form these pipelines within the project area.
8- Any displacement of retaining structures within the site manifested by, for example, tilting of the walls and widening of their expansion joints, or the bulging of gabions and the breaking down of their wire meshes.

MAIN FEATURFES OF LANDSLIDE AREAS

It could be concluded from the study of 46 landslides that occurred in the last 5 decades in Jordan that most of them belong to Ajlun Group of the Upper Cretaceous (mainly Naur Formatin A1-2, and Fuheis Formation A3) and to the Kurnub Sandstone Formation of the Lower Cretaceous (Figure 10)[6]. The dominating material in the landslide areas are marls and shales calssified as clays of low and high plasticity (Figures 11 and 12)[7].

It is also interesting to note that most of the landslides occurred in the years of high annual rainfalls particularly in the winter season of the years 1991 and 1992 when the total annual rainfall exceeded 900 mm in the highlands of the north and west Jordan (Figure 13).

It is also interesting to note that most of the marls and shales in the landslide areas are air-slaking materials that readily disintegrate when subjected to cycles of wetting and drying. The highly plastic clayey marls have high water absorption characteristics and under intense rainfalls their water contents may well exceed their liquid limits[2] transforming them to viscous fluids upon remolding and thus contributing to the frequent mudflows that occurred along Amman- Dead Sea highway during its construction.

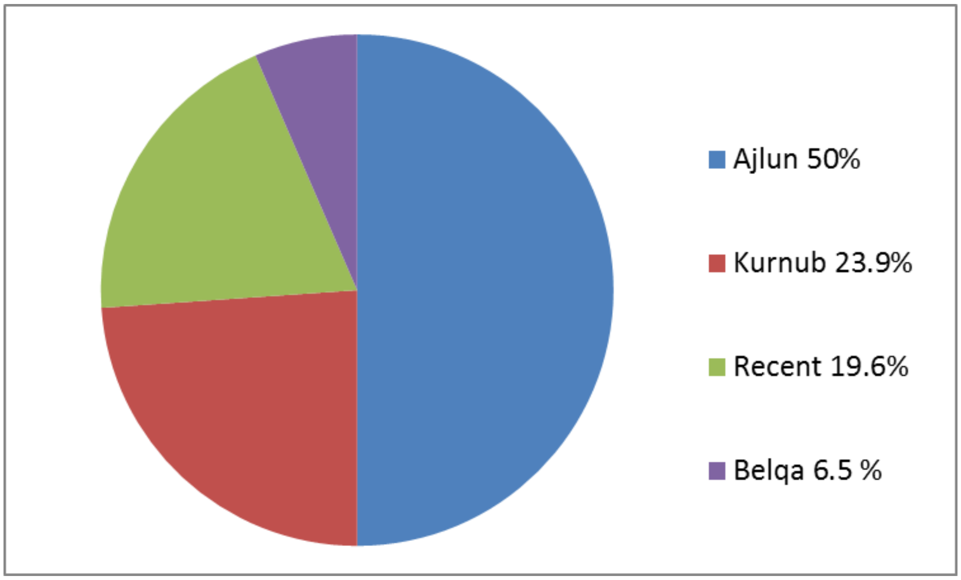

Figure (10) Frequency distribution of the geological formations in 46 landslide areas.

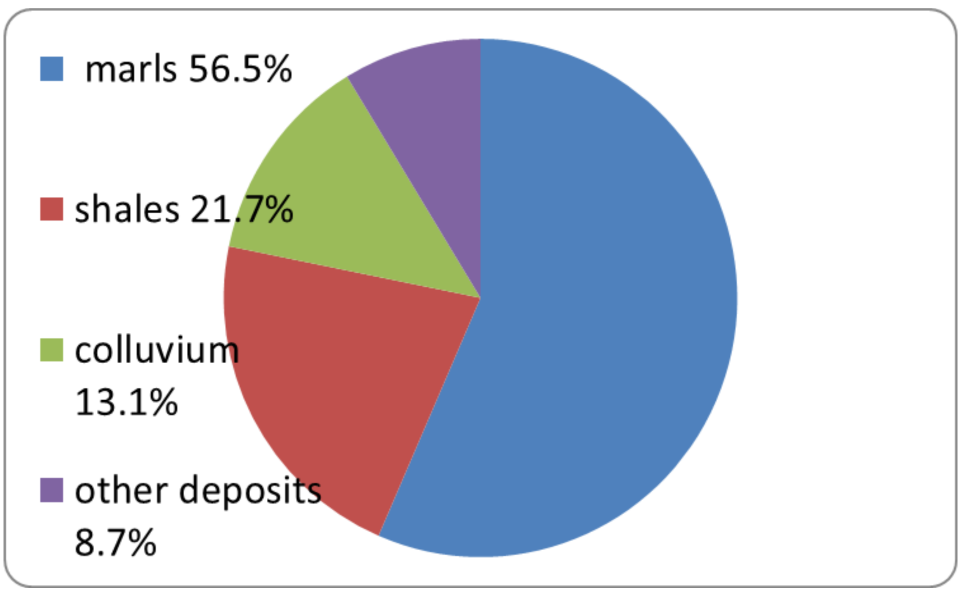

Figure (11). Frequency distribution of the dominating materials in 46 landslide areas.

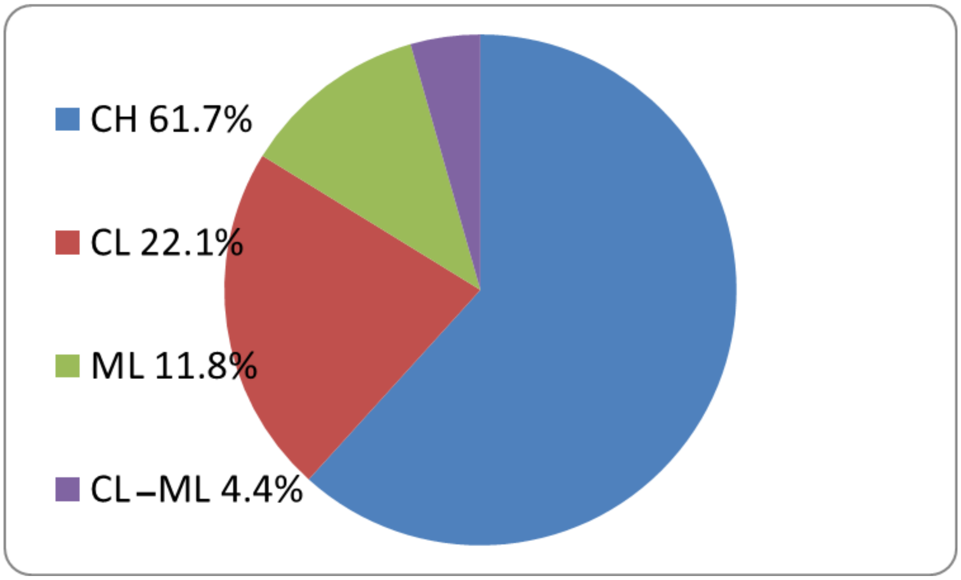

Figure (12) Frequency distribution of 68 samples from the landslide areas according to the Unified Soil Classification System.

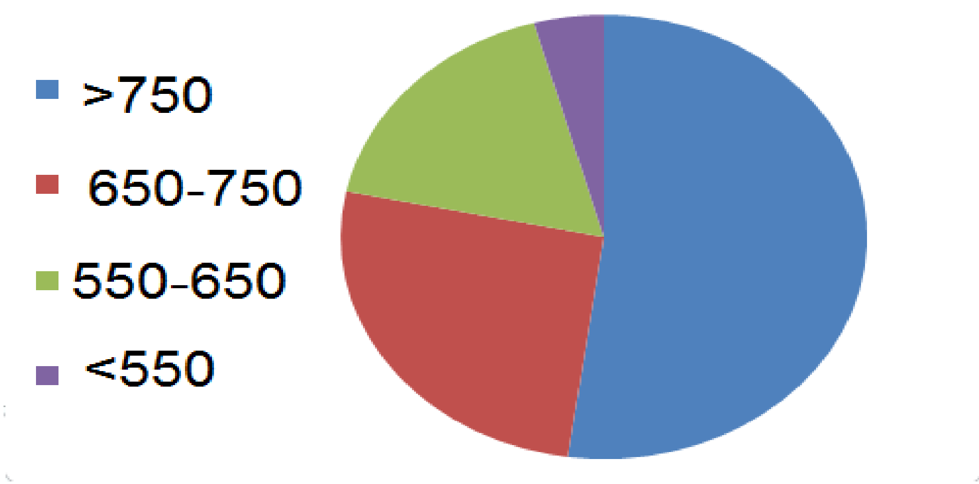

Figure (13). Frequency distribution of 46 landslides according to the total annual rainfall (mm) in the years of their occurrence.

Landslide Risk Management

Qualified teams of engineering geologists, geomorphologists, geotechnical engineers, surveyors, and photogeologists should be commissioned with the task of identifying the landslide – prone areas as well as the mode, volume, velocity of displacement, and the probability of occurrence of the potential landslides and their impact on people, structures, and facilities. Based on their frequent visual inspection visits to the landslide – prone areas, particularly during and after intense rainfalls or the occurrence of earthquakes with regular reading and analysis of the instrumentation measurements, they can recommend measures to be taken depending on the level of risk, the consequences of the potential landslides, and the resilience of the community. In assessing the relative stability of any slope and to maintain the same level of safety the targeted factor of safety should be higher at the sites of erratic ground conditions with higher uncertainty about their characteristics and engineering behavior under variable ground water and loading conditions.

Treatment Options

The common options for dealing with landslides and risk acceptance when the abandonment of the site to avoid landslide hazards is practically not feasible, or when the preventive measures of a potential landslide entail prohibitive costs, then the option is to reduce risk by some mitigation measures that mainly include:

1- Changes in the geometry of the slope by flattening, benching, unloading (excavation at top of slope), or placing buttress fill at the toe of the slope to increase the resisting forces.

2- Surface and subsurface drainage measures to divert water away from the slope, reduce water percolation into the slope material, and lower the ground water table.
3- Increasing the shear resistance of the slope material by chemical or mechanical means depending on the type of slope material and geometry, and cost of treatment. Anchoring, soil nailing, piles, reinforced earth are some of the common means used to increase the factor of safety against sliding.
4- Protection of the cut slope face from weathering and erosion by the use of geomats and grassing of slopes, geogrids, wire meshes and shotcreting. Rock- trap ditches with or without fences are used to protect traffic from rockfalls.

In case of highway embankments resting on weak foundation and suffering from subsidence and creep movement partial shifting of the highway alignment to a more stable ground could be the option as was the case in many sections along Amman- Jerash- Irbid highway, Amman- Naur-Dead Sea highway, and Jordan Street highway[5].

When the treatment measures to increase the factor of safety of a slope against sliding are technically or economically not feasible and the site cannot practically be abandoned then the monitor collapse policy could be adopted as was the case with many areas that were deemed to be at marginal stability along Amman – Jerash – Irbid highway[5]. In such cases proper preparedness measures reinforced with effective monitoring and warning systems should be provided. In general, landslide hazard intensity decreases with the provision of effective monitoring and warning systems and mitigation measures as could be visualized in Figure 14 which also shows that the hazard intensity is generally lower in uniform ground than in ground with erratic conditions.

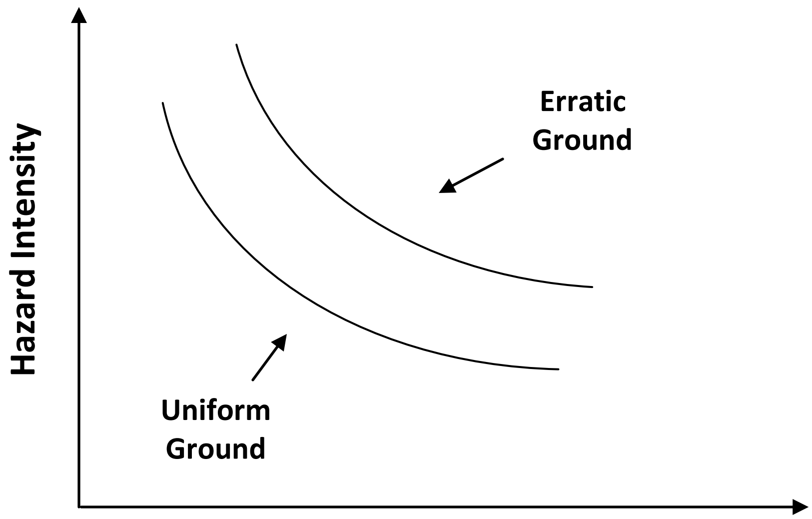

Fig. 14 Cost of Monitoring and Mitigation Measures

The risk is accepted if deemed to be within the tolerable zone as could be visualized in Figure 15.

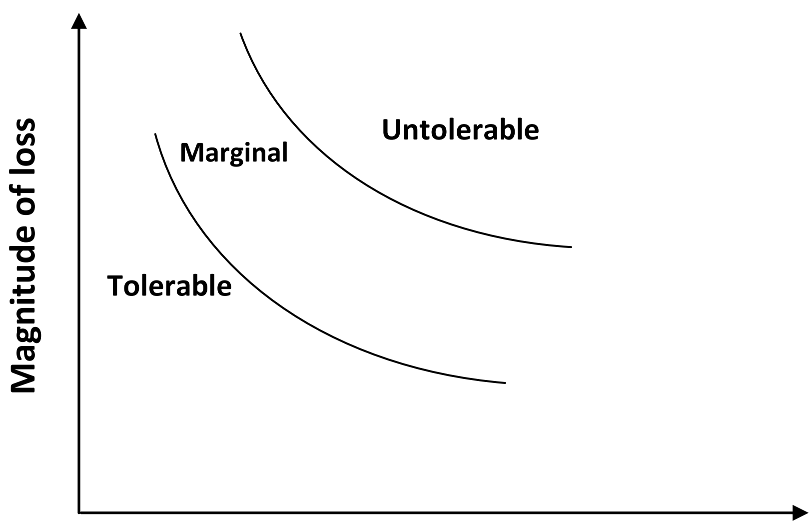

Fig. 15 Probability of Sliding

Construction Regulations

Reconstruction of damaged structures and facilities requires proper estimation of the costs and assessment of the potential hazards, natural or otherwise, to which these structures and facilities might ever be subjected in their entire design life. Reconstruction of these structures and facilities at other safer sites is an alternative that should be carefully considered. The reconstruction process provides opportunities to construct structures and facilities better than the damaged ones .Yet, the reconstruction process could have adverse impact on the environment and people and could seriously interfere with their economic and social activities especially if these structures and facilities are constructed at sites far from their original ones. The decision concerning the development activities in the new areas mainly depends on three factors, namely: the hazard intensity, cost of treatment, and the resilience of the community. Landslides hazard intensity mainly depends on the probability of their occurrence, their volume, speed of displacement, and their consequences. The resilience of the community depends on its capacity of self management and recovery and the quality of the preparedness measures. Based on the level of the above three factors rated as L (Low), M (Moderate), and H (High) the new areas considered for development and construction activities could be classified into the following four groups (Table1):

1- Prohibitive areas where no construction activities are allowed.
2- Restricted areas where construction activities are only allowed under the condition of extreme necessity and after intensive investigations and proper precautionary measures.

3- Regulated areas where construction activities are allowed after conducting adequate investigations and taking defensive measures against the potential landslide hazards.
4- Allowed areas where construction activities are allowed without restrictions due to the high level of safety against landslide hazards.

Table 1. Classification of the newly developed areas

	Hazard Intensity	Cost of Treatment	Resilience of Community
Prohibitive	H	M TO H	L
Restricted	M TO H	M	L TO M
Regulated	L TO M	M	M TO H
Allowed	L	L	H

The above classification is a subjective one and greatly depends on judgment, experience, and proper consideration of the local and national interests which could vary from one country to another and from one district to another in the same country.

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