PORTAL LANDSLIDE ANALYSIS OF THE NEW HAIBAT SULTAN TUNNELS IN KOYA, KURDISTAN REGION, IRAQ

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ABSTRACT: The road connecting Koya town to Dukan town is the primary conveyance for vehicles between these two municipalities. Numerous rock falls or slope failures occur annually along various segments of this road on Haibat Sultan Mountain. These slope failures can potentially, kill passengers and block the road for several days and sometimes weeks. In order to mitigate this problem, the Ministry of Construction & Architecture has enacted to build a double tube tunnel, referred to here as New Haibat Sultan Mountain Tunnel. This tunnel was under construction for several months, but lack of funding prevented their completion. The portals of the tunnel and approximately 60 meters of each tube were completed. Shotcrete had been applied to the area above the portals. After construction were terminated, a massive slope failure occurred above each tunnel portal. It would appear that the efforts to stabilize the slope above the tunnel were insufficient. This document proposes to investigate the area above the tunnel portals to determine the cause of the slope failure and provide recommendations.

The detailed geological setting of the relevant Haibat Sultan Mountain series was described and the necessary maps were presented. The relevant previous works have been inspected and studied. All field inspection data collection and visual inspection activities were fully undergone and possible analysis tasks have been performed. An analysis software program (named Prokon, of Prokon Software Consultants (Pty) Ltd.) was applied and the results and conclusions were discussed.

The landslide data geometry was drawn depending on measured and observed field data and the results of analysis applying the mentioned software were presented in the form of landslide geometry. The factor of safety of slope failure was found to be about 1.04 for dry conditions and 0.69 for wet conditions. The necessary recommendations were made to control the portal sliding.

Keywords: Factor of Safety, Landslide Analysis, Landslide Geometry, Slope Failure, Shotcrete, Tunnel Portal.

1. INTRODUCTION

1.1 The study area is concerned with the newly planned double-tube tunnel which is designed to cross the Haibat Sultan Mountain series in Koya town and was under construction since 2014, (Fig. 1).

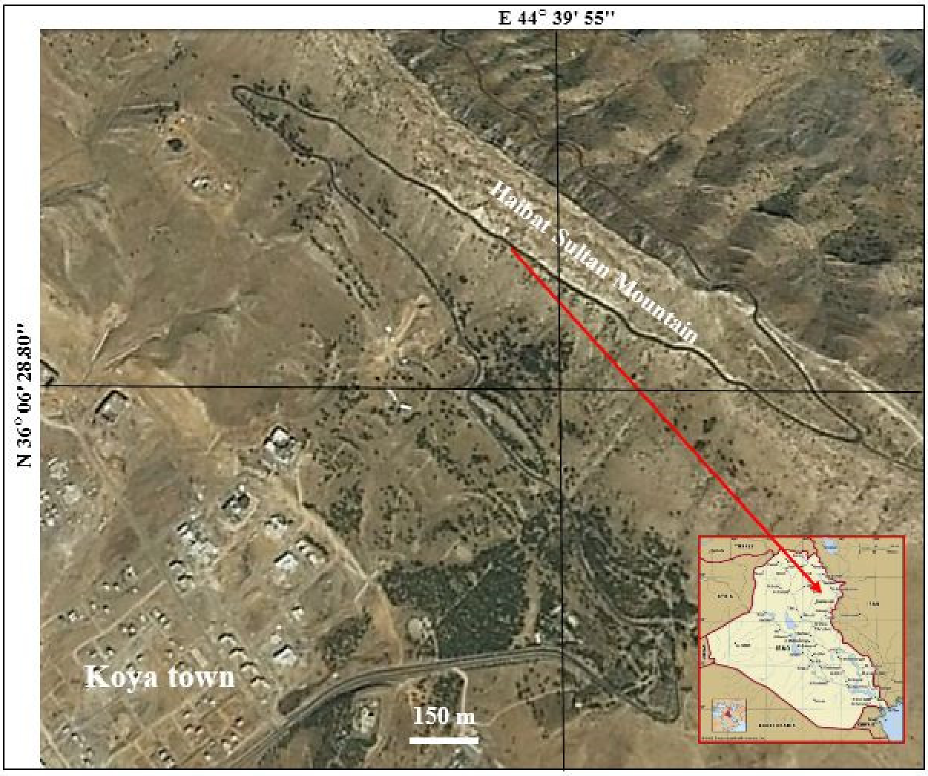


Figure 1: Satellite image showing the study area and the road across Haibat Sultan Mountain.

The road connecting Koya Town to Dukan Town and Sulaimaniya City is the primary conveyance for vehicles between these municipalities. It is one of the most dangerous roads due to its zigzag nature with multiple sharp turns, in addition to the neighbouring down-looking mountain slopes on one flank of the road and steep valleys on the other flank (Fig. 1).

Numerous rock falls and landslides and/ or slope failures occur annually along various segments of this road on Haibat Sultan Mountain, especially during heavy rains in winter. These slope failures (Fig. 2) can potentially kill passengers and block the road for several days and sometimes weeks.

Figure 2: Slope failure at Haibat Sultan Road: **Left)** on 14.12.2013, **Right**) on 8/5/ 2016.

In order to mitigate this problem, the Ministry of Construction & Architecture in Kurdistan Region has planned to build double tube tunnel which is referred to here as New Haibat Sultan Mountain Tunnel. The objectives of constructing this tunnel are to shorten, considerably, the crossing distance of this mountain series (from an existing length of 9 km to around 2 km) on one hand and to secure safe and economical driving for the traffic along the tunnel on the other hand.

This tunnel was under construction for several months, but lack of funding prevented its completion in mid. 2016 as it was planned. The portals of the tunnel and approximately 60 meters of each tube were completed. Shotcrete had been applied to the area above the portals. After construction was terminated, a massive slope failure occurred above the portals after heavy rains in March 2015 (Fig. 3). It would appear that the efforts to stabilize the slope above the tunnel were insufficient. Figure (3) provides comparative illustration of the status of tunnel portals before and after the portal slide failure.

Figure 3: **Left)** The status of the tunnel portals before the failure (pictured on 17.12.2014), **Right)** The tunnel after tunnel portals sliding in March 2015 (pictured on 25/11/2017).

2. PREVIOUS WORKS

Some of the previous works on land slide and slope stability are reviewed below:

Zamani (2008) studied the joint trace length which he considered to be discontinuous across the potential surface of failure as it happens in nature. This assumption is satisfied and the shear strength characteristics of intact rock have played part in the analysis. Abood et al. (2013) have studied slope stability of all types of failures in Hamrin Anticline outcrops. The slopes in the area were classified based on the direction of strike slopes and strike of beds into Parallel, Oblique, Lateral and Orthogonal slopes. Abood et al. (2017) have studied rock slopes stability in north-eastern limb of Boor anticline (Fatha, Injana and Mukdadiya formations). They identified the main different modes of failure involved and pinpointed the main reasons for failures as due to differential weathering which gives rise to overhanging slopes by undercutting in addition to the discontinuities in rock masses. Jassim et al. (2013) have made some assessment of the slope stability through examining 14 stations along Haibat Sultan Road, Koya. They tried to assess the stability of slopes and evaluate the existing dangers at these stations through photographic documentation, personal inspections and onsite observations. Some remedies and solutions to these problems and risks were also suggested. Jassim et al. (2014) have studied, analytically, a slope failure which happened on a curved section of the road near to Daigala Bridge, SW of Koya town. The research team tried to study and analyze this failure by collecting some soil samples (both disturbed and undisturbed) 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. At the end, some conclusions of this study were outlined and few recommendations for future remedial measures were eventually made. Hamasour (1991) studied the unstable slopes in an M.Sc. thesis and presented and discussed the unstable parts of the road.

Ibrahim and Jassim (2017) presented a report about the unstable slopes along the road crossing. They identified 18 study stations and recommended proposals to keep the road stable. Sidiq et al. (2015) studied a landslide that had occurred on 11//11/ 2015 and documented the details and causes of the landslide; they also gave recommendations for stabilizing the concerned area. Sissakian et al. (2019) did an assessment of Haibat Sultan Crossing Road, North of Koya, whereby they performed a comparative study using kinematic analyses and qualitative field method in 11 stations along that road.

3. GEOLOGICAL SETTING

The available geological data concerning the studied area are briefly reviewed including geomorphology, tectonics and structural geology, and stratigraphy based on Sissakian and Fouad (2014).

3.1 GEOMORPHOLOGY

The main geomorphological feature in the site is the outstanding long and continuous anticlinal ridge that forms the bulk of Haibat Sultan Mountain. The ridge is characterized by giant flatirons with heights ranging between (25 – 150) m and width of (15 – 55) m, (Fig. 5). The southern slope of the main ridge is the manifestation of the dip of the bedding planes of thickly, well bedded limestone, which exhibits many landslide cases. The presence of rock fans in the valleys and both depositional and erosional pediments, (Fig. 4) are good indication of the disintegration ability of the exposed rocks within different formations. However, normal alluvial fans exist along the slope in the form of coalescing fans forming Bajadas. These fans are another indication of the high intensity of erosion by means of rain water, besides the well bedding nature and intensely jointed rocks of the Pila Spi Formation. Another common geomorphological feature is the hogbacks and cuestas (Fig. 4), both are formed in the Fatha and Injana formation due to the alternation of hard rocks (sandstone beds) and soft rocks (claystone beds).

Another outstanding geomorphic feature is the main landslide, (Fig. 5 Left) which had happened along the contact between the Pila Spi and Fatha formations. The former includes many tension cracks of few meters' length and up to one meter in depth with spacing of (0.5 – 1.5) m (Fig. 5 Right), which is filled with small disintegrated limestone fragments and clayey soil. These cracks will be filled by water during rainy seasons and will decrease the cohesion and friction angle of the rocks; accordingly, will accelerate and facilitate failure of the slope.

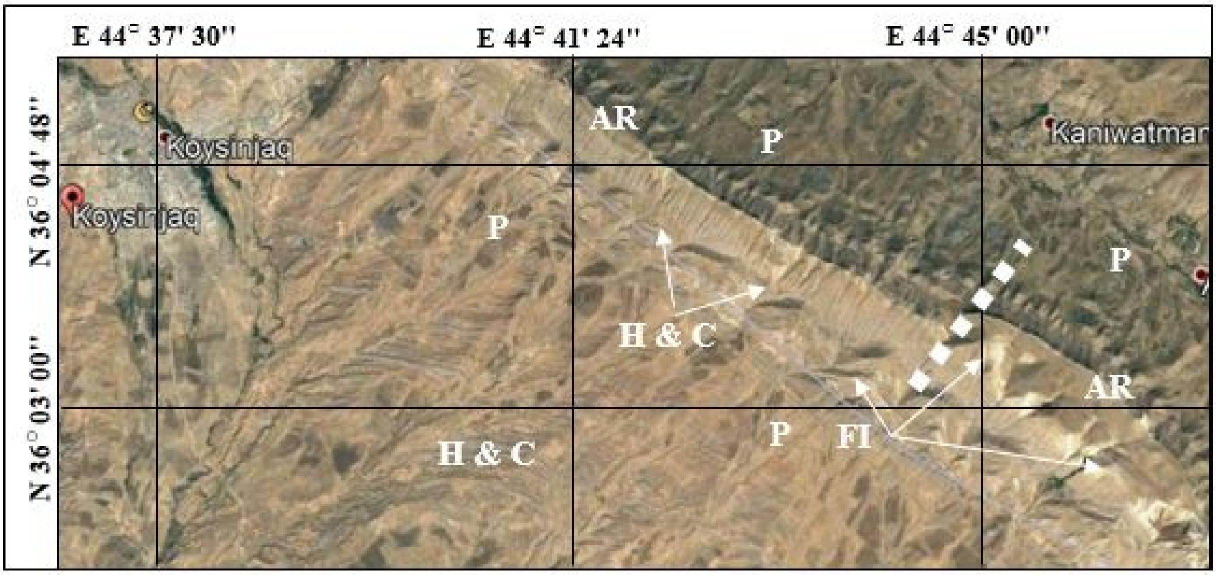


Figure 4: Satellite image of the tunnel site and surrounding. Note the flat irons (FI), anticlinal ridges (AR), hog backs and cuestas (H & C), and pediments (P). The dashed white line is the approximate location and extension of the tunnel

Figure 5: **Left)** General view of the landslide with the two portals, **Right)** A large tension crack, note its length, depth and opening.

3.2 STRATIGRAPHY

The stratigraphic sequence of the exposed rocks at the studied area is briefly described, based on Sissakian and Al-Jiburi (2014). The geological map is presented in Fig. (6). The geological formations are briefly described from the oldest to the youngest:

- **Khurmala Formation** (Eocene): The formation is exposed on the northeastern facing slope of the ridge. The formation consists of greyish and light brown, thinly bedded and hard limestone. The northeastern portal (Ranya side) will be within this formation.
- **Gercus Formation** (Eocene): The formation is exposed on the northeastern facing slope of the ridge and very locally in some deeply cut valleys. The formation consists of reddish brown thinly bedded fine clastics; mainly claystone and sandstone. Very locally, very thin beds (3 – 8 cm) of limestone occur too
- **Pila Spi Formation** (Upper Eocene): The formation forms the bulk of the ridge within which the portal of the tunnel is located in Koya side. The formation consists of white to greyish white, well bedded (1 – 12) m limestone and dolostone with some thin beds of yellowish white marly limestone in the lowermost part.
- **Fatha Formation** (Middle Miocene): The formation is exposed along the foothills of the main ridge in form of continuous low ridges and valleys forming hogbacks and cuestas. The formation consists of cyclic sediments. Each cycle consists of alternation of thick reddish brown soft claystone, white, bedded and hard limestone, and very rarely hard greyish white gypsum beds.

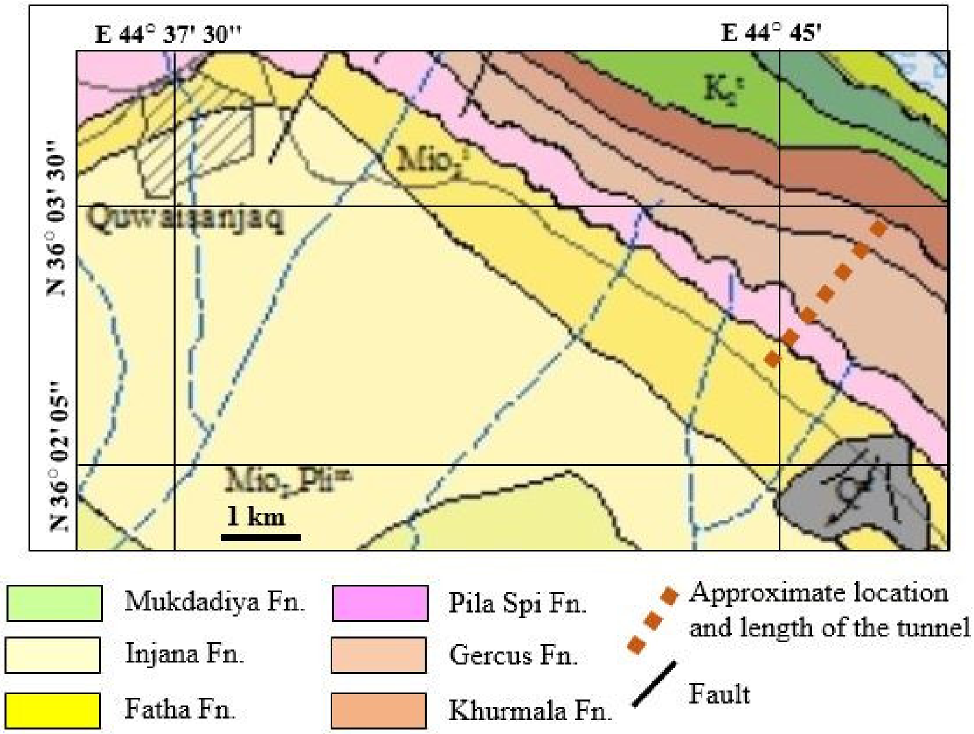


Figure 6: Geological map of the site and surrounding (after Sissakian and Fouad, 2012).

3.3 TECTONICS AND STRUCTURAL GEOLOGY

The main ridge in the site area represents the contact between the Low Folded Zone (in the south) and the High Folded Zone (in the north); both zones are within the Outer Platform of the Arabian Plate as they are part of the Zagros Thrust – Fold Belt (Fouad, 2012). The ridge that forms Haibat Sultan Mountain is the south western limb of a small anticline called Bustana and continues eastwards to form the south western limb of a very wide anticline called Khalikan anticline. It is NW – SE trending (Figs. 4 and 6). The dip amount of the exposed rocks ranges between (30 – 55)° SW. The exposed rocks along the ridge are very intensely jointed as tension and shear joints. The spacing between the joints varies from (3 – 150) cm; however, locally they are very closely spaced (not more than 15 cm), especially in the Pila Spi Formation. The joints are of open type; filled by small rock fragments and clayey soil. The former is derived from the disintegration of the carbonate rocks of the Pila Spi Formation, whereas later is derived from the weathering of the carbonate rocks of the Pila Spi Formation and very locally from the Gercus Formation too. These characters of the joints decrease the rock mass strength and accelerate any mass movement phenomena like landslide, bedding slide, rock fall and toppling.

4. PORTAL LANDSLIDE AND ITS ANALYSIS

As it is clear from the Figures (3 and 5), a major portal landslide happened in March 2015 after heavy rains which took place in the area. The comparison is clear between the status of the tunnel portals before and after the sliding (Fig. 3). This landslide is described, discussed and analyzed in the following section, whereby the technical reasons for it have been addressed.

4.1 FORM OF THE PORTAL LANDSLIDE

The portal landslide is one of the planar sliding type which happened to the weak claystone layers of the Fatha Formation resting on the limestone layers of the Pila Spi Formation (Fig. 7 Left) with a clear nature of progressive failure; as it is clear in Figure (7, Right).

Figure 7: **Left**) The contact between the claystone and limestone layers along which the failure happened, **Right**) Illustration of the progressive failure nature of the portal landslide.

5. METHODOLOGY

The detailed methodology for analyzing the portal landside is discussed below.

5.1 KINEMATIC ANALYSIS OF THE PORTAL LANDSLIDE

Computer software using the programme Prokon Software (Pty) Ltd., (Planar failure in Rock Slopes, ROCKPF) was applied to analyze this landslide. The programme ROCKPF determines the factor of safety (FOS) of a planar failure in rock by using simulation techniques.

5.2 METHODOLOGY OF PERFORMING KINEMATIC ANALYSIS

The necessary geometrical measurements were made using total station. These geometrical parameters, in addition to the shear parameters of the claystone for both dry and wet conditions were used in the mentioned software to calculate the factor of safety. The shear parameters were based on a relevant work by Jassim et al. (2015).

The use of total station is characterized by its flexibility, high speed, high efficiency, automatic data saving and accuracy. The measured points were chosen according to the failure shape and hazard areas. Final survey results acquired from the data measured directly and the indirect data analysis (using excel and Survey Software) are illustrated in Figure (8).

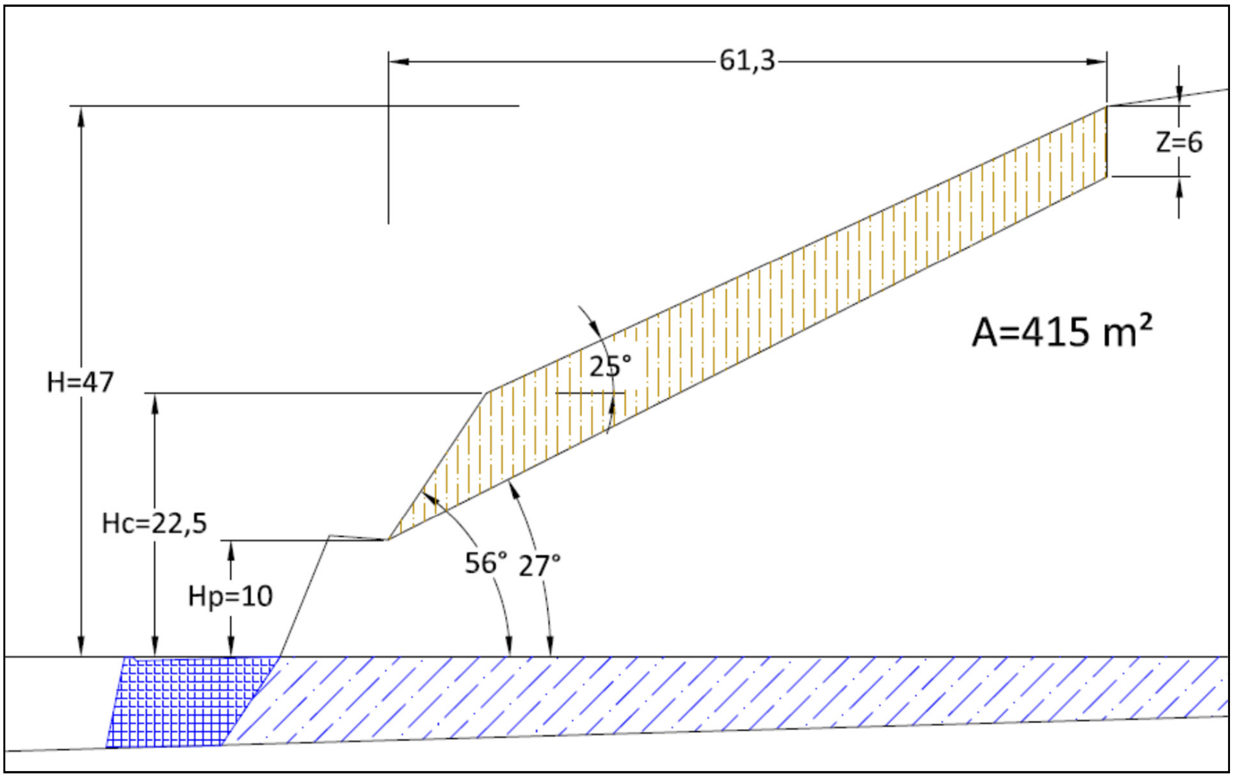


Figure 8: Landslide geometry.

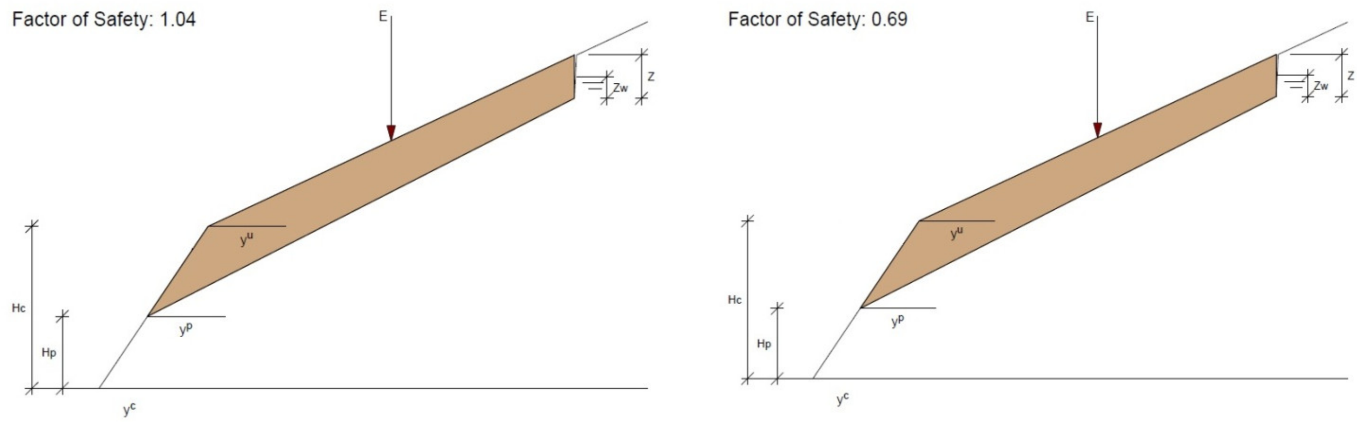
5.3 ROCK SHEAR PARAMETERS IN DRY AND SATURATED CONDITIONS

Sheng and Reddish (2005) in their works showed that the cohesive strength reduction rates are 27% and 16% for the coarse grain sandstone and silty sandstone, respectively. The initial cohesive strength drops down to zero no matter whether dry or wet, while the friction angle of the silty sandstone has decreased about 25.5%; once the intact silty sandstone sample is saturated. For the coarse grained sandstone, no reduction happens on this parameter. Cherblanc et al. (2016) showed that the mechanical characteristics of various sedimentary stones depend on the water content, where 70% loss of their mechanical strengths can be observed when saturated by water. Mohamad et al. (2011) studied the effect of moisture in alluvium, they showed that the moisture content has great influence on the reduction of the shear strength (τ), friction angle (Ø) and cohesion (C). When the moisture content of older alluvium is increased, the shear strength will reduce to 22.3% and 75.3% at wet and saturated condition, respectively in comparison to the magnitude of shear strength at dry condition. Similarly, the friction angle is reduced to 18.6% and 66.9% at wet condition and saturated condition, respectively. The results showed also that the magnitude of cohesion increased to 12.7% at wet condition and decreased to 54.6% at saturated condition in comparison to the magnitude at dry condition. Yadav and Hagan, (2017) showed that reduction in uniaxial compressive strength when saturated was about 17% for limestone, and 64% for sandstone, while the reduction in tensile strength was 14% and 76% for limestone and sandstone, respectively.

Based on the above works which are related to the reduction in shear parameters as a result of saturation, 45% reduction factor for the friction angle, and 40% for the cohesion are proposed in the current study and the results are illustrated in Table (1) and Figure (10).

Table 1: Shear parameters of claystone in dry and saturated conditions

Condition	Dry	Saturated
Cohesion	22	13.2
Angle of friction	20	11
Factor of Safety, FOS	1.04	0.69



(a) dry condition (b) saturated condition

Figure 9: ROCKPF Program outputs

6. DISCUSSION

The discussion of the portal landslide is outlined in the following paragraphs:

It appears that tension cracks exist ahead above the tunnel portals (Fig. 5, Right) and as are shown in Fig. (10). These tension cracks were filled with small disintegrated limestone fragments and clayey soil followed by water during rain falls in March 2015. This decreased cohesion and friction angle of the rocks adding to the downward pressure due to the pore water pressure and the volume expansion on freezing of water filling the tension cracks in winter. These reasons have triggered the failure. As the materials and beds above the portal have increased in saturation, the progressive nature of the failure developed gradually with time. The effect of stress redistribution on transferring from the primary stress field to the secondary stress field as a result of tunnel construction may have added to the triggering of the portal landslide. The results of the analysis have given a drop in the overall factor of safety from 1.04 for the dry condition to 0.69 for the saturated condition. This is considered as low leading to the landslide which had occurred.

Figure 10: Tensions cracks: **Left**) Perpendicular on the slope within the claystone
Right) A tension crack above the tunnel portal.

7. CONCLUSIONS

This study has led to the following conclusions:

- Under the dry conditions the slope was intact with no signs of landslide.
- The kinematic analysis which was performed under dry conditions has led to a factor of safety which is equal to 1.04, indicating high stability, whereby no potential failure is about to occur.
- Under wet conditions, during rainy seasons, the landslide occurred, whereby the relevant calculations have led to a value of the factor of safety equaling 0.69.
- Tunneling activities have, most probably, contributed to the triggering of the portal landslide.

- The progressive nature of the landslide was clearly indicated after personal field inspection and photo documentation.

8. RECOMMENDATIONS FOR LANDSLIDE REMEDIES

The following recommendations can be made as a result of this research work:

- Detailed inspection of existing tension cracks further ahead along the tunnel portal and securing their filling with suitable filling material to ensure that no water percolation will happen inside the formation structure during future rain falls.
- Increasing the stability of the slope face by constructing shotcrete and rock bolting support further ahead along the tunnel portal within the limestone beds.
- Construction of benches further ahead along the tunnel portal with extra shotcreting and rock bolting.
- If tunneling restarts, then the slopes along the orientation of the tunnel should be monitored and checked continuously in order to indicate any new tensional cracks and/ or increase in the size of already existing cracks.
- Access to the work site needs to be restricted with fencing and warning signs at the entrance to the portals and on the slope above the portal. Fencing and warning signs should be located approximately 150 meters from the tunnel entrance and approximately 50 meters from the edge of the escarpments formed on both sides of the slope, above the tunnel portals.
- Horizontal drains and sub-horizontal drains need to be installed into the slope of the mountain and behind any shotcrete to reduce the build-up of pore water pressure.

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