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SLOPE STABILITY ANALYSIS AND MITIGATION ALONG CPEC ROUTE (KKH) BY USING ROCSCIENCE SLIDE MODELING;(A CASE STUDY OF LANDSLIDE AT HUMARRI, PAKISTAN

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ABSTRACT

Northern Pakistan is one of the most active and dangerous geological zones on the planet. As a result, several huge landslides have occurred in the area throughout history, destroying infrastructure, blocking the Hunza River, and seriously damaging the Karakoram highway. Due to the difficult logistics and wide distances involved, despite the high frequency of large-magnitude landslides and the subsequent destruction, the whole area remains understudied. Using the Limit Equilibrium Method, this study explores the slope failure along the Hunza River (HR), Village Humarri Nagar District Upper Hunza Gilgit Baltistan, Pakistan (LEM). Using Slide Rocscience programmer, the slope was fully studied for geological conditions, slope geometry, soil strength parameters, and FOS determination. Soil samples from the slope were gathered for analysis of geotechnical properties, and the slope's geometry was also analysed during the excursion. Moisture content (w) 1%, specific gravity (Gs) 2.64, unit weight (r) 19kN/m3, angle of internal friction (AIF) 30 and cohesion (c) 69 kPa are the strength parameters of the soil sample. The Humarri active landslide soil was classed as sandy silt with the group sign ML by the Unified Classification System (UCS). In Slide Rocscience programme, the FOS of the slope was calculated using LEM with the assumption of ordinary (O), Janbu (J), and Bishop (B) techniques. A set of instances were used to calculate the influence of Pore Water Pressure (PWP), Unit Weight, Cohesion, Angle of Internal Friction, and Overburden on FOS. FOS increases when cohesiveness and angle of internal friction rise; yet, FOS increases as unit weight and overburden of overlying materials grow. Furthermore, while PWP has some good effects, increasing it causes a significant decline in FOS. Because every FOS is larger than 1, the Humarri active landslide is judged to be stable in its current form based on available strength metrics and simulated slide rocscience results.

Key Words: Factor of Safety, Slope Stability, Janbu Approach, Bishop Approach, Cohesion, Liquid Limit, Plasticity Index, Specific Gravity

1 INTRODUCTION

Humarri Village, in the District Hunza Nagar in Gilgit Baltistan, was chosen as a case study for landslide research. Due to its active tectonics, fragile geology, and dynamic geomorphology, Gilgit–Baltistan is one of the world's most hazardprone regions. Pakistan's northern regions are seismically active, with numerous major earthquakes in recent years. The Hunza River undercuts landslide toes below the rock/debris fall upslope, which is one of the greatest dangers in these areas. Other factors, such as active tectonics, make these areas vulnerable to geo-hazards.

Ancient landslide craters along high-gradient channels in the Hunza River basin, as well as associated layers of very fine-grained late debris of varying thicknesses, bore evidence to the river's past disasters. Deeply cut valleys and rough rocks characterize the scenery in the Hunza-Nagar region, which rises from 1746 meters to 7315 meters above sea level. This region's topography has a significant impact on the climate. (Shamsa Kanwal, 24 Aug 2016)

As a result, the humarri village landslide was chosen as a case study because a large potential landslide, similar to Atta bad, could be expected, emphasizing the need for a better understanding of the many types of landslides, their mechanisms of manifestation, material strength, impacts, and mitigation methods. The major focus of the research is on the geological characterization of human slopes, as well as assessing the risk of slope instability at Humarri and modelling the Humarri slope using Slide software.

1.1 Background and history

The study area is in the strategic Hunza-Nagar Districts of northern Pakistan. A portion of the Karakorum Highway (KKH) connecting Pakistan and China via the small Hunza Nagar valley could be obstructive in the event of a catastrophic landslide. This region contains some of Pakistan's highest peaks and most abundant glaciers. The overall structural tendency of the Karakoram mountains beside the Hunza-Nagar valley is NW-SE. The research region extends between latitudes of N 36°16'29.88" and longitudes of E 74°42'45.23" (Fig:2) (Fig:2). The Humarri landslide is located at the MKT's hanging wall in district Nagar, to the southwest of Humarri village. Hunza is around 20-25 kilometers from Humarri settlement. The research location is 652 kilometres from Peshawar and may be reached by two routes: road 1 from Mansehra and road 2 from the Swat Valley. Two roads link Peshawar with the research location, which is 675 kilometers distant. Hasan Abdal, Havelian, Haripur, Abbottabad, Bttagram, Besham, Sazin, Dassu, Chillas, Jaglot, Gilgit, Nomal, Nilt, Alliabad, and Humarri Nagar are all connected by the first route. Travelers can also take the Peshawar-Besham Road via the Shangla Pass before returning to Nagar by the same route, passing through Batkhela, Mingora, and Khwazakhela.

1.2 Aim and Objectives

The goal of this thesis is to conduct a slope stability study of the Humarri landslide in order to determine the possibility of a slope failure and the causes for it. The following are the primary goals of the study:

- Calculate the slope's geometry and comprehend the underlying circumstances (lithology, thickness and shear strength of the soil).
- Conduct stability assessments and identify safety variables to assess the effects of geotechnical parameters on landslide activity.
- To get a better knowledge of the failure processes and the effects of natural and man-made factors on landslide triggering.

1.3 Literature review

Geologic hazards are a part of existence for millions of people all around the planet. Huge earthquakes, volcanic eruptions, landslides, and other natural disasters make the news every year, but the harm they inflict is often forgotten. Residents of high-risk areas cannot afford to lose sight of what is going on. They are always aware of the impending peril that comes with living in a hazardous location, and they are constantly exposed to the risk of disaster.

Falls, topples, slides, spread, flows, and complicated landslides were divided into six categories by Varnes (1978) based on the materials utilized and how they moved. Several researchers (Hunger, Evans, Bovis, and Hutchinson) proposed categories that were comparable. Based on their activity, (Varnes,

1978) and UNESCO (WP/WLI) (1993.1993a.1995) classified landslides as active, inactive, reactivated, abandoned, suspended, relict, or stable. Landslides were classified into three groups based on their ages: current, earliest, and fossil.

A natural catastrophe happens when the materials that make up a slope lose their strength and fall as a result of gravity's pull. These materials can be a mix of soils, rocks, or artificial fill, or a mix of all three (Lundgren, 1999). The rate of flow of the specific components might vary greatly, culminating in catastrophic catastrophes. (Varnes & Cruden, 1996) Slope failure occurs when the disturbing force exceeds the resisting force due to a change in shear strength. (Das, 2010).

The time-based link analysis between landslide movement and precipitation was investigated using a time-series analysis. Irrigation is one of the factors that might trigger a landslide by boosting groundwater levels and causing a landslide (Derbyshire, Fort, & Owen, 2001). In north Pakistan, irrigation canals are diverted from glaciers at a much higher height, then cross for kilometers at a higher elevation until they reach the target population cluster while retaining a reasonable slope. In the upper reaches of the Humarri landslide, near the new escarpments, two irrigation canals provide water for agricultural uses. These channels emerge from the east glacier valley and appear to be active since vegetation was discovered alongside them. In the forecasted landslide location, the irrigation system may leak a significant amount of melt water, causing the slope to degrade. The springs on the hillside suggest a saturated soil in the terrace area. The Humarri landslide's toe is being eroded by the River of Hispar, which contributes to the slope's instability. If the soil near the toe dissolves, plunges, or vaporises, the collapse of large chunks of direct toe support can be devastating, as in the case of landslides. (Derbyshire, Fort, & Owen, 2001).

1.4 Climatic Conditions

The Hunza and Nagar districts examined are very cold in the winter, with a harsh climate, but pleasant in the spring and summer. Most of the precipitation falls as snow in January and February, the coldest months of the year with temperatures as low as 10°C, followed by a wet monsoon season that averaged 72.3mm rainfall in 2013. Several natural occurrences, such as mudslides, rock falls, and avalanches, occur as a result of snow melting (Searle, Khan, Fraser, Gough, & Jan, 1999). For both natives and visitors, the months of March and April are the most dangerous.

1.5 Outcome and Importance

The Humarri Valley Slope Stability Analysis will aid in determining the triggering mechanism and probability in a key geological material in the research region. The information will also emphasize the environmental and economic consequences of a landslide in the area. Researchers will be able to acquire a better knowledge of the nature, extent, and frequency of possible slope concerns across the country as a result of this study.

Table 15: Soil Parameters	
SOIL	SILTY SAND
C`	69
Φ	300
γ	18.6
G_S	2.64

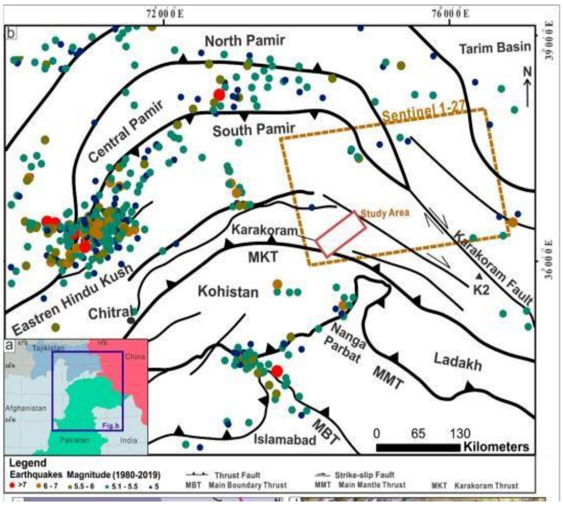


Fig-1: Study Area

2 MODELING OF HUMARRI SLOPE USING SLIDE (ROC SCIENCE)

Slide (ROCSCIENCE) Software

Researchers were able to gain a greater understanding of the physical structure of landslide-prone areas, as well as the material characteristics and distribution of such attributes, thanks to the field campaign and laboratory testing. Based on this data, Slide v6.011 was used to create a 2-D slope stability model of the landslide. (Rocscience 2011).

2.1 Slope Stability Evaluations

Humarri slopes, a case study, was researched with LE methods and Slide Rocscience computer programmer. The study's purpose was to investigate into the environmental elements that might impact the slope's stability in the future, as well as analyses the slope's stability. In addition, the study included several LE techniques that are often utilized in practice. In this study, the impact of GWT modifications was explored in both dry and wet scenarios.

2.2 Selected Methods (Analysis)

The most powerful and practical approaches, such as Janbu generalized (JG), Bishop's simplified (B), and Ordinary (O) procedures, were employed for analyses and computing stability parameters.

2.3 Input Parameters

3 Humarri Slope (Dimensions)

The size of the humarri landslide varies over its length. To calculate the height, the Hunza River, which runs at the bottom of the hill, is utilized as a reference point. As illustrated in the image, Surfer 10 was used to build a 3D map of the current landslide in Humarri (Fig:2).

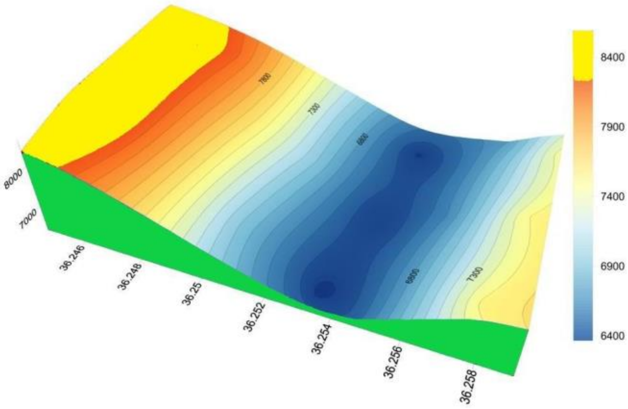


Fig-2: Contour Map (Humarri Landslide)

3.1 Landslide Modeling

In the Slide programmer, the boundaries between different soils were identified using a simple technique. As a result, the entire slope was separated into two layers, with the upper strata made up mostly of Silty sandy produced by bedrock disintegration and glacial deposits, while the bottom strata made up primarily of metamorphic bedrock.

The groundwater table (GWT) at that location is constantly shifting due to extreme weather conditions. The fluctuation of GWT is expected in different seasons, according to data supplied by Pakistan Meteorological Department (PMD).

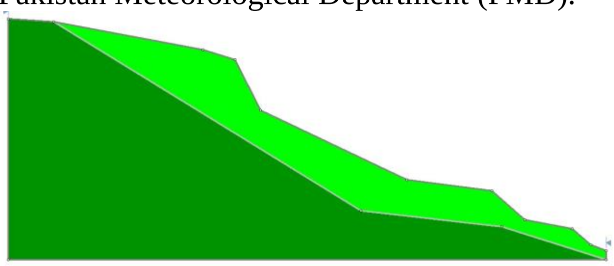


Fig-3: Showing Humarri Model

3.2 Different cases for stability evaluation

This study focuses on the impact of groundwater variations on the development of pore water pressure. To characterize the influence of the groundwater table on the slope when the research area's climatic circumstances vary, the slope is investigated for the groundwater table using dry and wet season assumptions. In the investigations, the thickness of the overlaying components is also considered.

4 Analyses of Humarri Landslide

4.1 Dry condition

With a sandy silty surface and a dry season, the top layer's thickness was estimated to be 200 meters. Slide programmer is used to simulate the FOS created for this situation by applying the above-mentioned parameters to it. The Slide program's critical slips surface (CSS) and FOS simulation results are displayed in (Fig: 4), (Fig: 5), and (Fig: 6). (Fig:6). According to the study, the slope is stable in its current condition with existing strength parameters because the FOS of all techniques is greater than 1. To demonstrate the difference between a factor of safties, many methods have been utilized. Janbu Simplified, Bishop Simplified, and others are examples of these techniques.

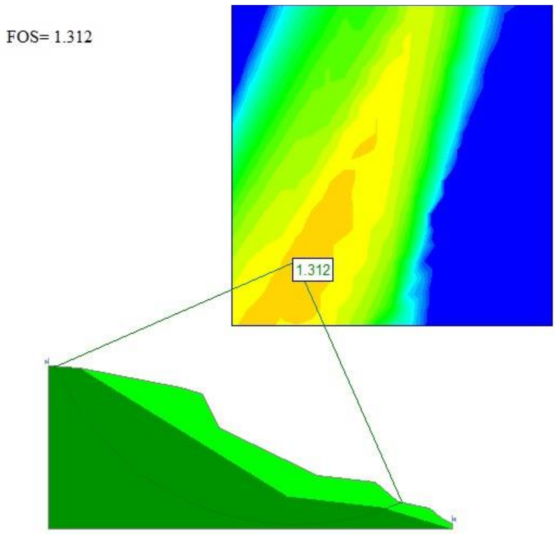


Fig-4: Bishop Simplified

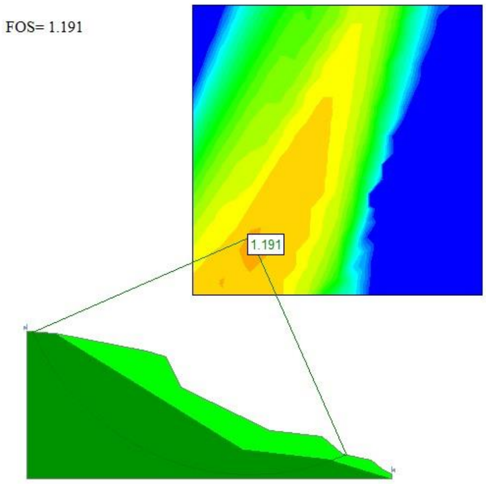


Fig-5: Janbu Simplified

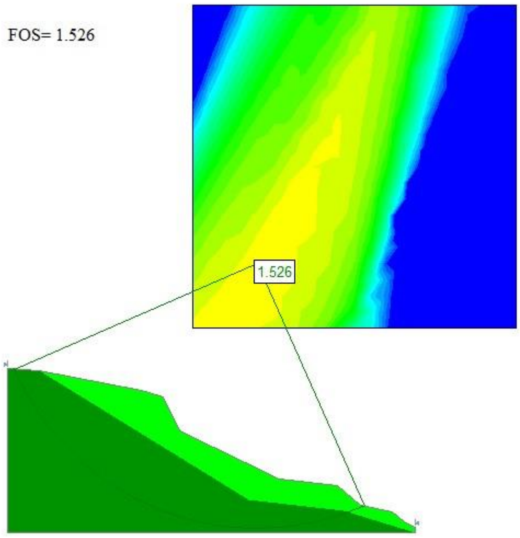


Fig-6: Ordinary Method

4.2 Wet Condition

And it was assumed that the situation is wet (due to rain during monsoon season) and that GWT is improved by maintaining soil thickness constant, resulting in an increase in PWP. By activating the Piezometric line in the Slide programmer, the pore pressure distribution is determined. The Slide software's findings are displayed in (Fig:6), (Fig:7), and (Fig:8) (Fig:9). Because all approaches have a factor of safety that is clearly more than 1, the slope is stable in the current scenario.

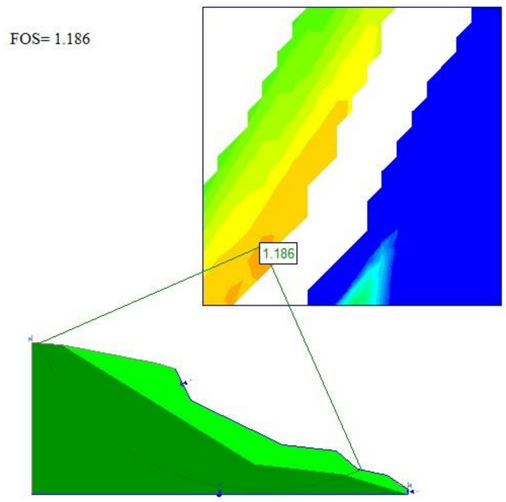


Fig-6: Janbu Simplified

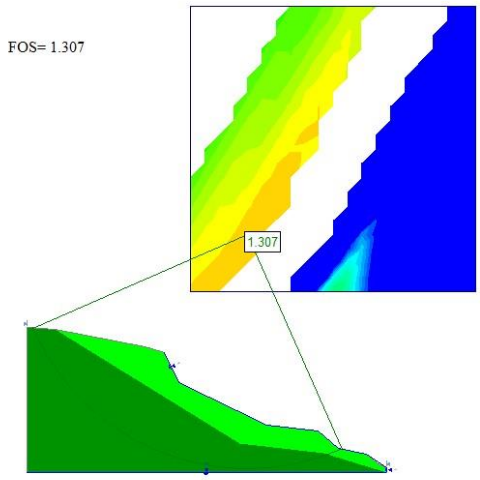


Fig-7: Bishop Simplified

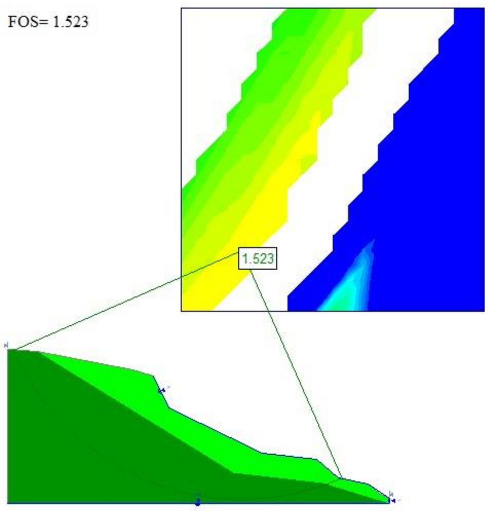


Fig-8: OMS

4.3 FOS via Probability (Dry Condition)

The chance of failure is defined as "the probability that the factor of safety is less than 1.0, as well as the possibilities of failure of an exact slope with the supplied input parameters." The input parameters are always susceptible to some degree of uncertainty while solving slope stability problems. Slides are used to account for this type of uncertainty in the study. Rocscience has been used to estimate the probability distribution function for probabilistic analysis in various types of studies by doing a Monte Carlo probabilistic analysis for each input parameter given a standard deviation value. The standard deviation of a parameter represents the degree of uncertainty associated with that value. In probabilistic analysis, the dependability index, probability distribution, and likelihood of failure are all employed. (Reale, Gavin, Prendergast, & Xue, 2016).

To assess the stability of the results, the likelihood of the Humarri slope is calculated using three different unit weights: 11, 12, and 13. This implies that the weight of the soil unit varies over its width owing to weathering. Metamorphism rates in metamorphic rocks vary. The probabilistic analysis for the Humarri slope modelled with given data demonstrates that the slope is stable with FOS, as shown in (Fig: 9). (1.287). The dependability index for the slope in Fig-8 is (5.611), suggesting that it is reliable in its current state.

The relative frequency Via FOS is given in the Histogram plot (Fig:10). The relative frequency is compared with unit weight, cohesion and angle of internal friction in the below-given Histogram plots ((Fig (11,12,13)).

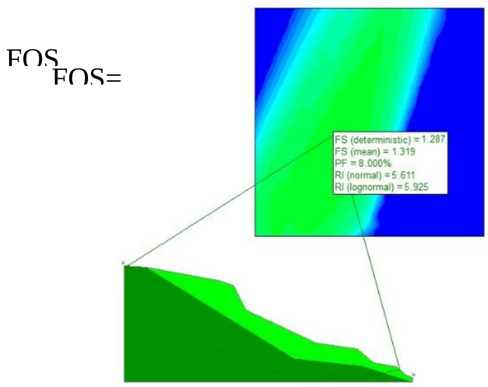


Fig-9: Factor of Safety

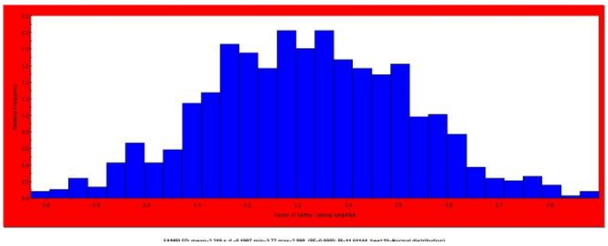


Fig-10: FOS vs Relative Frequency

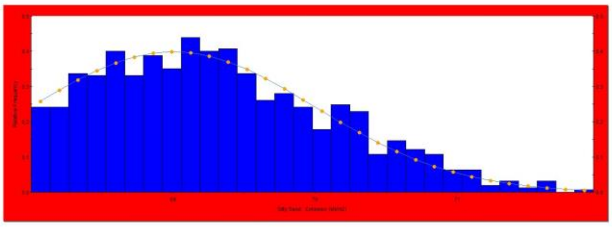


Fig-11: Cohesion vs relative frequency

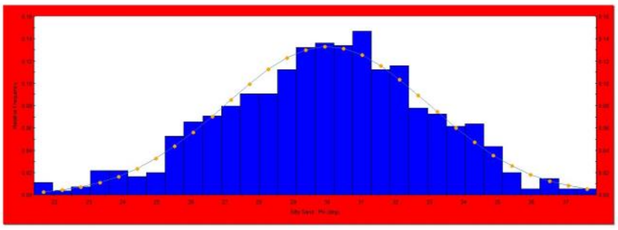


Fig-12: Phi vs relative frequency

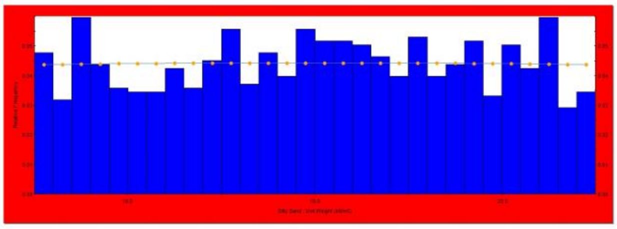


Fig-13: Unit weight vs relative frequency

4.4 FOS via Probability (Wet Condition)

The wet season's probability function is generated, and its impacts on stability are explored using three distinct unit weights of 11, 12, and 13 to determine the stability outcomes. Slide Rocscience examination of the current situation reveals that the slope is stable, with FOS 1.307. (Fig: 14). The slope has a reliability index of 5.461, indicating that it is still dependable in its current state (Fig: 26). In a histogram plot, the relative frequency via FOS is shown (Fig: 15).

The relative frequency is compared with unit weight, cohesion, and angle of internal friction in the below-given Histogram plots ((Fig:16,17,18)).

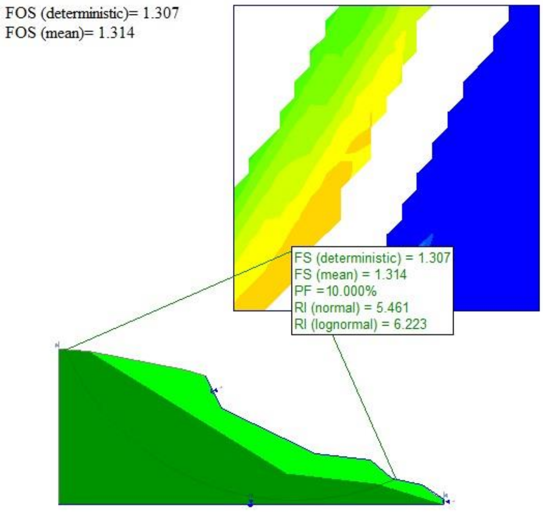


Fig-14: Factor of Safety

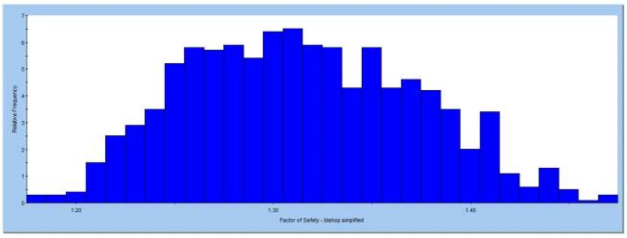


Fig-15: Relative Frequency vs FOS

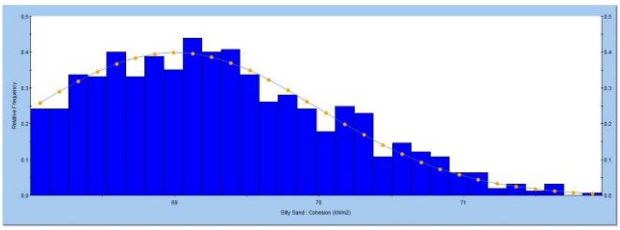
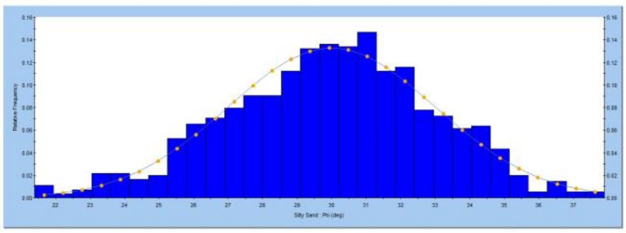


Fig-16: Relative Frequency vs Cohesion



Fg-17: Relative Frequency vs PHI

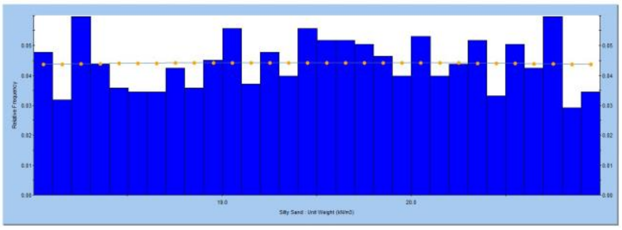


Fig-18: Relative frequency vs unit weight

4.5 Sensitivity of Slope(Dry Condition)

The sensitivity analysis, which involves the input of several stability parameters to compute for FOS, is completed on this slide. In a sensitivity analysis, several strength parameters such as unit weight, cohesiveness, and angle of internal friction are considered. The influence of various stability factors on stability and FOS is examined in sensitivity analysis. The sensitivity analysis standard deviation is computed by multiplying the unit weight standard deviation by 1.0, the angle of internal friction standard deviation by 2, and the cohesiveness standard deviation by 10. The FOS is computed assuming either a dry slope with no PWP development or a steep slope with no PWP development (Fig: 19). The following is a sensitivity chart for various strength settings (Fig:20).Janbu simplified FOS and sensitivity plot in Figure (21 & 22) respectively.

FOS= 1.312

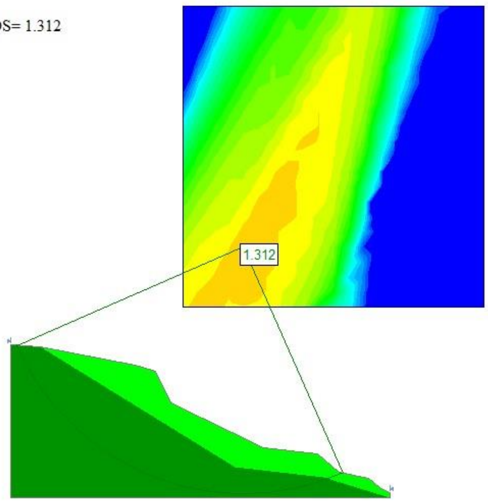


Fig-19: Factor of Safety (Bishop Simplified)

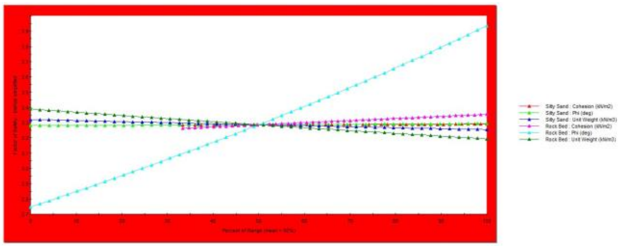


Fig-20: Sensitivity Plot dry condition)

FOS= 1.186

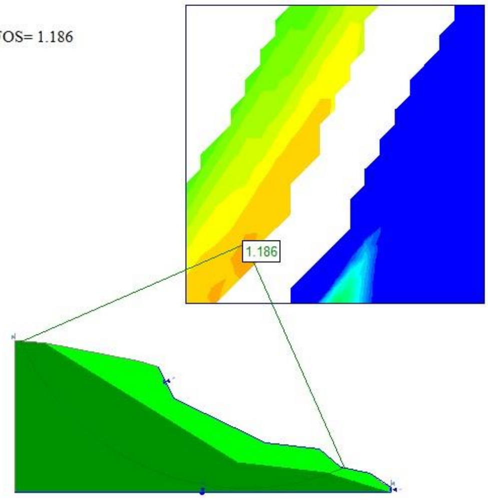


Fig-21: Factor of Safety (Janbu Simplified)

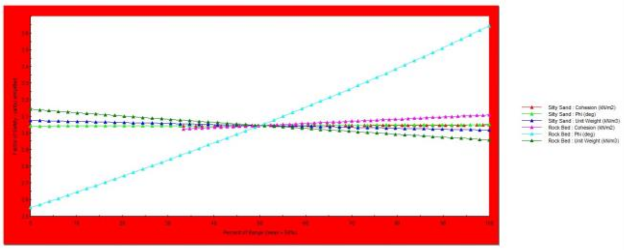


Fig-22: Sensitivity Plot dry condition

4.6 Sensitivity of slope (Wet Condition)

The same situation as in case 5, but the PWP is changed and the effect on stability is calculated, resulting in three distinct unit weights. A small change in pore water pressure causes a small change in the FOS, according to the findings.

The findings show that minor changes in soil factors like unit weight, friction, and cohesiveness have a minor impact on FOS in the case of PWP (Fig:23). Internal friction, according to the sensitivity chart, varies more rapidly than other parameters, making it critical to stability analysis (Fig: 24). The simplified FOS and sensitivity plots of Bishop are shown in Figures 25 and 26.

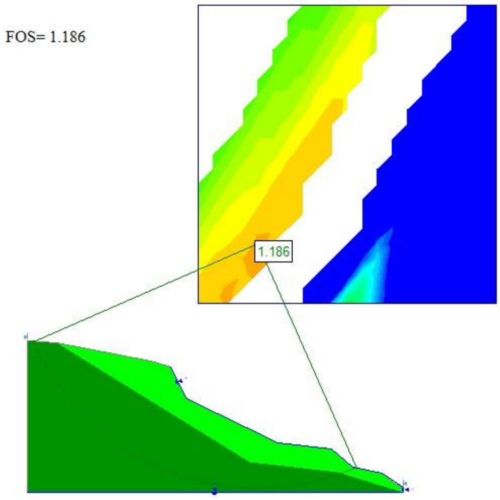


Fig-23: Factor of Safety (JANBU SIMPLIFIED)

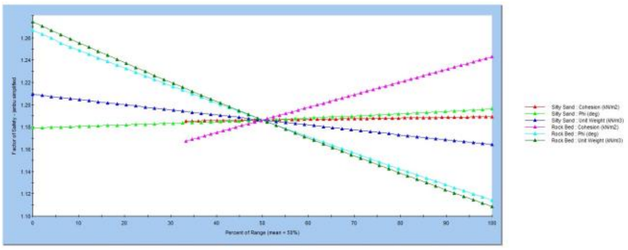


Fig-24: Sensitivity Plot Wet condition)

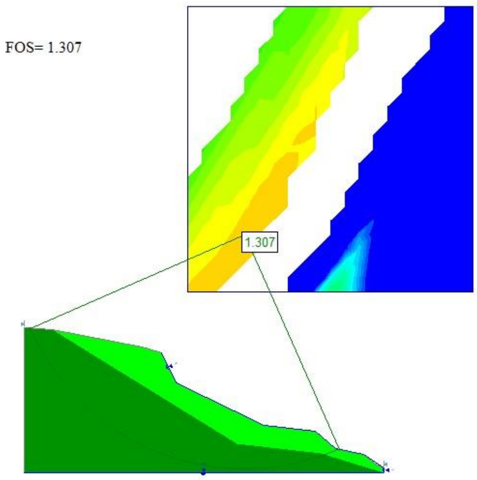


Fig-25: Bishop Simplified

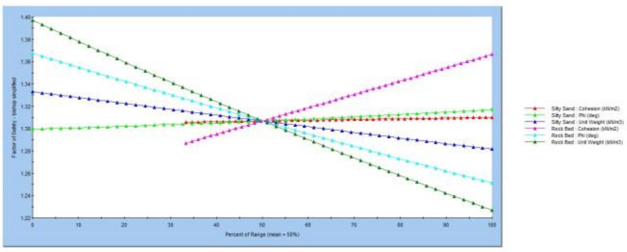


Fig-26: Sensitivity Plot Wet condition

5 Conclusion

• The Humarri active landslide, according to Slide Rocscience, is geotechnically stable in its current form, with FOS better than 1 for all methodologies.

•

The Humarri active landslide appears to be moving, as seen by the Humarri soil fissures.

• Even though geological processes are slow, they are consistent, and thus have a big impact on slope stability.

• The area's natural and man-made features all contribute to slope failure and land sliding. Road cutting, water penetration through bathroom septic tanks, and excessive irrigation water use all contribute to slope collapse and may hasten the mass migration process. Furthermore, rain-induced surface runoff exacerbates the situation.

• Because of the geology, material composition, and geomorphology of the valley, the impact of the Atta bad Landslide cannot be compared to the anticipated Humarri landslide. Its repercussions might be even more serious than the landslides in Atta.

• Advanced/partial slope failure has a larger chance of occurring than complete slope collapse. The presence of an outlier in the downhill section keeps the slope from collapsing entirely.

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