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Assessment of Slope Stability of Glacial Rocks of Malana Valley Using ESRI ArcGIS & Geo-Studio

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Abstract
In the study performed here, we have considered the study area to be "Malana Valley" situated in Himachal Pradesh. The main reason to consider this area is that, the area is in the prime location of route describing region. In near future, it is predicted that the slope analysis is going to be required in the area. Digital Elevation Model is used for capturing the elevation profile of the surface. ArcGIS is the software, the product of ESRI, helps in creating and finding the ground profiles and sketching maps. The slope stability is measured by the Geo-Studio's SLOPE/W facility. Further, four strata under the ground is suspected namely, Mixed Glacial Soil, Silty Sand, Decomposed Rocks and Bedrocks. The study is composed by the Mohr-Columb Method which is most convenient method to calculate the stability of slope. Pore water pressure and slip surfaces are the two forces considered externally for the solution part. The entry and exit points are considered on the basis of saturated soil condition which is the worst condition for the construction of any type of civil work.
From the analysis, we can conclude that the ground profiles in the region North-West, are highly unstable. For the construction in this risk prone area, Factor of safety is near about 20.272 which is very high and leads to high cost of construction. But the maximum activating force is 12.062841 kN in the upward direction leads to the stability of ground.
Keywords: *Slope Stability, GeoStudio, ArcGIS and Digital Elevation Model*

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I. INTRODUCTION

1.1 Slope Stability

A slope is a naturally or intentionally sloped ground surface. The ability of an inclined slope to bear its own weight while being shifted by external factors is referred to as "slope stability." To maintain slope stability, ground mechanics, geosciences, and construction geography are applied. If the conditions for stability are not met, the slope's soil or rocky structure may undergo a slow or sudden downhill movement. This phenomenon is referred to as slope collapse or landslides. A landslide can be caused by an earthquake, strong storms that exceed hydraulic conductivity, or degradation of the ground's mechanical properties. Slope collapses wreak havoc on prospects for regular addressing, resulting in a huge number of incidents and casualties.

The Culmann Method, Bishop Method of Slices, and Ordinary Method of Slices are three typical approaches for analyzing the stability of a slope. Except for the Culmann approach, which assumes a flat surface of failure across the toe of the slope, these methods are based on the premise that the plane of failure is a circular arc. The method for the determination of slope stability is needed for various engineering activities, including the layout of hydraulic structures and earthworks, the interpretation of instinctual slope stability, the assessment of excavated rock slopes, and the investigation of groundwork and securing wall depth failure.

Slope Failure can be classified into several forms. Circular slips are associated with isotropic, homogeneous soil conditions. Non-circular slides occur under non-homogeneous soil properties. Translational failure occurs when the shape of the fault plane is influenced by the occurrence of an adjacent stratum of variable strength, and the adjoining stratum is relatively shallow. Compound Failure happens when the essence of a subsequent stratum of progressive enhancement affects the morphology of the slip surface, and the adjacent stratum is substantially profound. In the examination of slope stability, many safety variables are considered. For example, safety variables such as strength, cohesion, friction, and height. The former is more common.

1.2 Glacial Rocks

Rock glaciers have a higher proportion of rock than winter weather in their composition. When sluggish glacial ice is buried by debris, rocky crampons might emerge. They're common in valleys with sloping cliffs, where rocks and silt tumble first from hillsides out onto the glaciers. As freezing topsoil spreads downslope, rock terraces could arise. Permafrost can also be countless generations old or dozens of millennia-old, making it useful for climatology. Researchers may drill and retrieve ice core samples in mountain glaciers for uncovering a lengthy environmental change. Scientists look at a variety of core components, including trapped air bubbles, which disclose historical atmospheric composition, temperature fluctuations, and plant varieties.

Glaciers are dynamic, and a variety of factors influence their learning and advancement. Snow accumulates at the accumulation region, which is normally the glacier's highest height, increasing the glacier's tonnage. Also, as snow melts and hardens to ice, overall weight of the glacier increases, causing its ice to distort, driving the glacier will flow downstream. The exfoliation site is situated farther beneath the iceberg, typically at a reasonable level, and is where the majority of the draining and evaporation originates. A equilibrium is created between these regions, with snowstorm equaling discharge, and the mountain is in balance. When this orderly process breaks down, whether through excessive precipitation or excessive runoff, the glacier accelerates or recede at a greater rate than usual.

Glaciers not only convey material, but they also sculpt and slice away at the earth under them as they travel. The weight of a glacier, paired with its slow movement, may modify the terrain dramatically over hundreds or even thousands of years. Ice erodes the ground surface and transports fractured rocks and soil debris far from their original locations, creating some unique glacial landforms. Glacial valleys are the most prominent glacial landform and are found all over the planet. They are trough-shaped, similar to fjords, and typically have steep near-vertical cliffs where glacial action swept whole mountainsides. Yosemite National Park, where glaciers physically swept away mountain sides, producing deep valleys with sheer walls, is one of the most stunning instances of glaciated valleys.

II. LITERATURE REVIEW

Rainfall-induced landslides occur on Kitaotao's national route every year, causing important goods and services to be transported. To develop an accurate landslide hazard map, analytical methodologies based on soil mechanics and notions of soil plasticity, landslide susceptibility, and other elements are necessary. The slope angle and the soil thickness are intertwined. The safety factor is calculated for two types of groundwater: semi-saturated and completely saturated. The landslide danger map is divided into six categories, ranging from severely unstable to extremely stable. Validation of these conclusions is based on actual field outcomes. (Arca et al., 2018)

The researchers also used a colonial rivalry optimization technique a perceptron for the issue of slope stability construction plots. Limit equilibrium estimates had typically been the clearest accountability for civil engineers. It is a hazard for occupied gradients that have been cut, wooded, or man-made. Quantitative analysis may not always be achievable or recommended related to time and economic restraints, notably in difficult issues. Both for the ANN and ICA–ANN forecasting algorithms, significant findings of layout design diagrams are obtained. The conclusions of both the numerical simulation boundary value problems were compared to the predicted exit point out from learned systems. (Dyson et al., 2019)

In the canyon of the Ms6.9 earthquake, about 700 landslides and a quarter-dozen dam lakes were generated. The size and geological characteristics of the area determine the location and scale of geohazards. Satellite pictures acquired before and after the earthquake were used to investigate the mechanisms that caused the Tsangpo Gorge to be triggered. The dangers of glacial debris flow and material losses caused by earthquakes are also mentioned. (Zhang et al., 2019)

Slope, climatic, topographic, and ice-thermal variables all influence the collapse of glaciers owing to gravity. This can cause ice-mass flow, which can lead to large avalanches. For the following several months or years, the second phase will consist of high flow speeds because to glacial portions. Such catastrophic instabilities are caused by climate and meteorological influences, tensions, and friction factors. Due to the unclear nature of some triggering elements at the time, long-term prediction of such enormous collapses is not conceivable, but evidence of earlier prospective collapses can be explored for their lithology and geomorphic conditions. (Kääb et al., 2018)

Slope failures are produced by a number of causes, including geological, topographical, and hydrological properties, as well as slope surface cover and climate. Slope collapses in Korea likely to happen at the intersection of a shallow weathered residual soil layer and an underlying rock layer. (Kang et al., 2020)

Seepage failure and slope collapse of an earth dam are two of the most prevalent forms of earth dam failures. Dam safety is a critical aspect of preserving national investment. The upstream and downstream slopes of the dam were analyzed using three different amounts of water and six different limit equilibrium slope stability methods. (Malik et al., 2020)

The landslide threat on NH31A prevents products and services from being transported. Natural factors such as heavy rainfall and seismic activity, as well as manmade factors such as deforestation as well as road cutting, are primarily responsible for these landslides. Hazard detection can lead to premature mitigation and preventative measures. This study created a landslide susceptibility map by overlaying aggregation models in ArcGIS 9.1 and categorizing regions into high, moderate, considerable, and insignificant risk categories. (Ogila & W. A. M., 2021)

III. STUDY AREA

For this research purpose, the study area considered is "MALANA VALLEY". It is situated above Kasol ridge line shown in the image below. The valley is enclosed in the red polygon and the coordinates are as follows:

Coordinates: 32˚ 06' 18.85" N 77˚ 19' 19.33" E

Elevation: 3124 m above MSL

Figure 1 Study Area - Malana Valley

IV. TOOLS AND METHODOLOGY

4.1 Tools Used

4.1.1 ESRI ArcGIS – Arc Maps

ArcGIS Online is a mapping and analytic tool that runs in the cloud. Make visualizations, gather information, and collaborate and share with that as well. Connects directly to document management applications, mapping and statistics from around the globe, and paddock tools. ArcGIS provides all you need to remove the background and spatial information data and retrieve answers. It provides with image processing and analysis abilities as well as exposure to the largest global images library.

4.1.2 Geo-Studio – SLOPE/W

The premier slope stability tool both soil and rock slopes is SLOPE/W. For a multitude of slip surface shapes, pore-water fluid pressure, soil characteristics, and loading circumstances, SLOPE/W can accurately assess both basic and complicated situations. SLOPE/W may be used to study practically every slope instability you'll meet across that in any topographical, structural, or extraction projects due to its vast range of attributes.

4.2 Data Collection

For the authenticity of the work, all the data used for the analysis are received from the global sources. The lists of data raised during the study are as follows:

1. DEM Dataset – TanDEM-X captured on 02/01/2021.
2. DEM Dataset – ASTER GDEM captured on 10/5/2005.
3. Soil Data released by Indian Meteorological Department.

4.3 Methodology

To achieve the prime objectives mentioned earlier, the certain mathematical models were created by the researchers. According to the study area and ground conditions, the specific steps are followed to attain the milestones.

1. Preparing the data to be used in the study

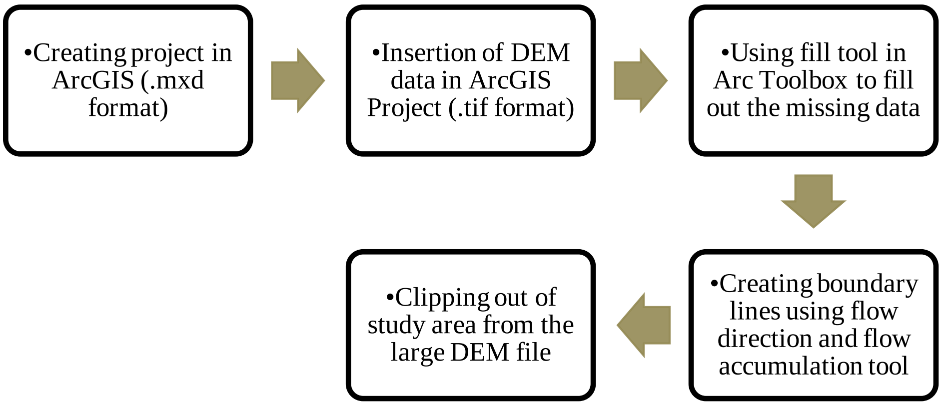

Figure 2 Preparing the data to be used in the study

2. Extracting the study ready data in a concise format

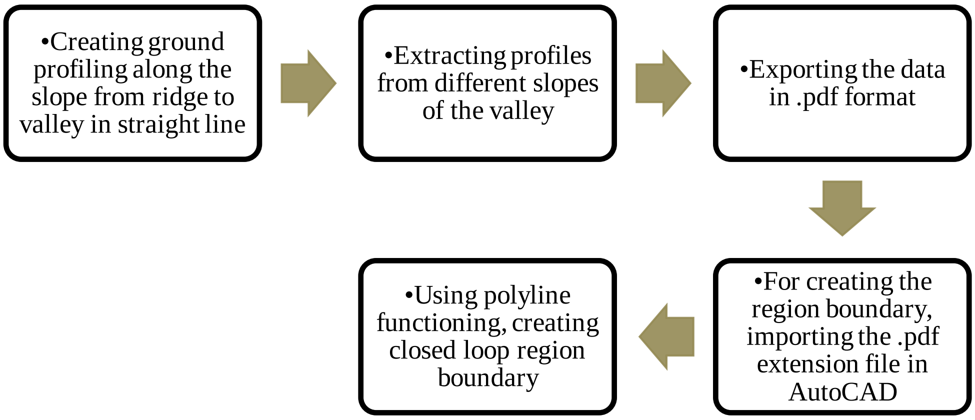

Figure 3 Extracting the study ready data in a concise format

3. Assigning the material Properties

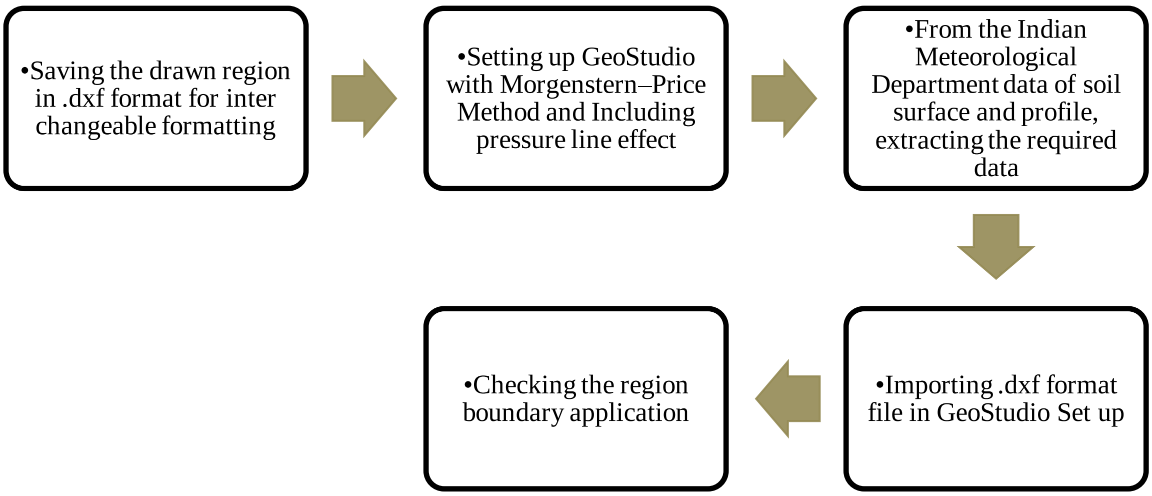

Figure 4 Assigning the material properties

4. Completing the analysis and solving for the final result

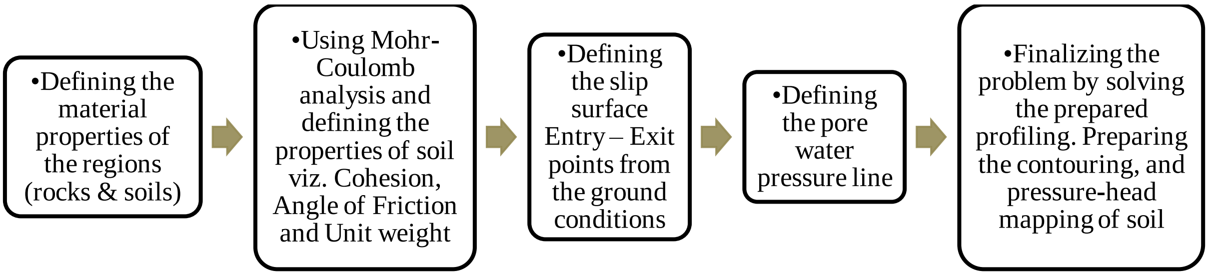

Figure 5 Completing the analysis and solving for the final results

5. Comparing the Analysis of two distinguished datasets

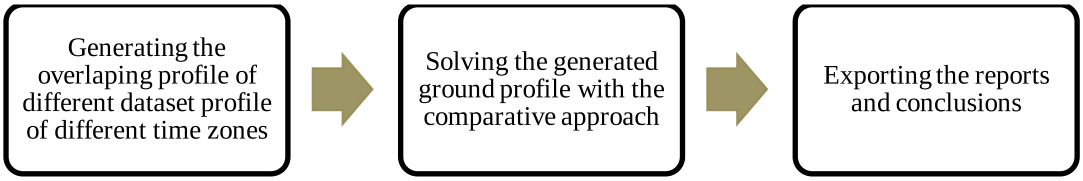

Figure 6 Comparing the Analysis of two distinguished data sets

V. RESULTS AND DISCUSSIONS

5.1 Analysis Settings - Slope Stability

- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions from: Piezometric Line
    - Apply Phreatic Correction: No
    - Use Staged Rapid Drawdown: No
  - Unit Weight of Water: 9.807 kN/m³
- Slip Surface
  - Direction of movement: Left to Right
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit
  - Critical slip surfaces saved: 1
  - Optimize Critical Slip Surface Location: No
  - Tension Crack Option: (none)
- Distribution
  - F of S Calculation Option: Constant
- Advanced
  - Geometry Settings
    - Minimum Slip Surface Depth: 0.1 m
    - Number of Slices: 30
  - Factor of Safety Convergence Settings
    - Maximum Number of Iterations: 100
    - Tolerable difference in F of S: 0.001
  - Solution Settings
    - Search Method: Root Finder
    - Tolerable difference between starting and converged F of S: 3
    - Maximum iterations to calculate converged lambda: 20
    - Max Absolute Lambda: 2

5.2 Materials

5.2.1 Mixed Glacial Soil

Model	:	Mohr-Coulomb
Unit Weight	:	20 kN/m³
Cohesion'	:	10 kPa
Phi'	:	44 °

5.2.2 Silty Soil

Model	:	Mohr-Coulomb
Unit Weight	:	22 kN/m³
Cohesion'	:	50 kPa
Phi'	:	33 °

5.2.3 Decomposed Rock

Model	:	Mohr-Coulomb
Unit Weight	:	26 kN/m³
Cohesion'	:	100 kPa
Phi'	:	45 °

5.2.4 Bedrock

Model	:	Mohr-Coulomb
Unit Weight	:	28 kN/m³
Cohesion'	:	1000 kPa
Phi'	:	44 °

5.3 Slip Surface Values

5.3.1 Slip Surface Entry and Exit

Left Type	:	Range
Left-Zone Left Coordinate	:	(20.525469, 24.994943) m
Left-Zone Right Coordinate	:	(21.594718, 24) m
Left-Zone Increment	:	8
Right Type	:	Range
Right-Zone Left Coordinate	:	(38, 18.563813) m
Right-Zone Right Coordinate	:	(38.541905, 18.17923) m
Right-Zone Increment	:	8
Radius Increments	:	4

5.3.2 Slip Surface Limits

Left Coordinate: (20.16667, 25.97353) m
Right Coordinate: (39.15278, 18.25131) m

5.4 Piezometric Line

Table 1 Piezometric Line Coordinates

	X	Y
Coordinate 1	20.12 m	17.98 m
Coordinate 2	24.67 m	18.16 m
Coordinate 3	30.45 m	18.08 m
Coordinate 4	34.72 m	17.98 m
Coordinate 5	39.15 m	18.06 m

Slip Surfaces Analyzed: 123 of 405 converged

5.5 Current Slip Surface

Slip Surface	:	38
Factor of Safety	:	4.409
Volume	:	47.129227 m^3
Weight	:	944.32486 kN
Resisting Moment	:	18,780.867 kN·m
Activating Moment	:	4,259.4455 kN·m
Resisting Force	:	1,088.7031 kN
Activating Force	:	246.91865 kN
Exit	:	(38.380517, 17.876408) m
Entry	:	(20.525469, 24.994943) m
Radius	:	15.836281 m
Center	:	(34.114224, 33.127197) m

5.6 Results and Discussion

5.6.1 Definition of Surface

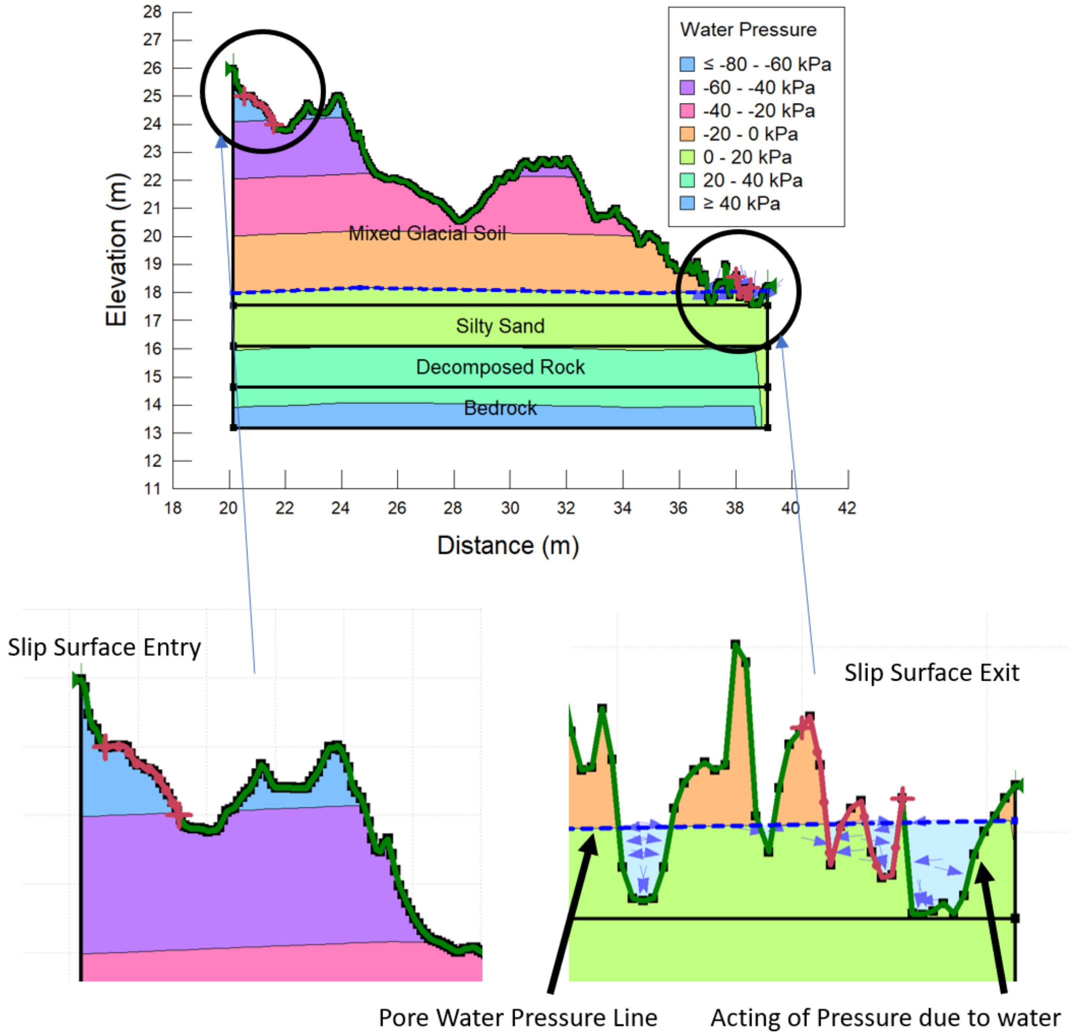

Figure 7 Definition Diagram of profile

5.6.2 Results Obtained

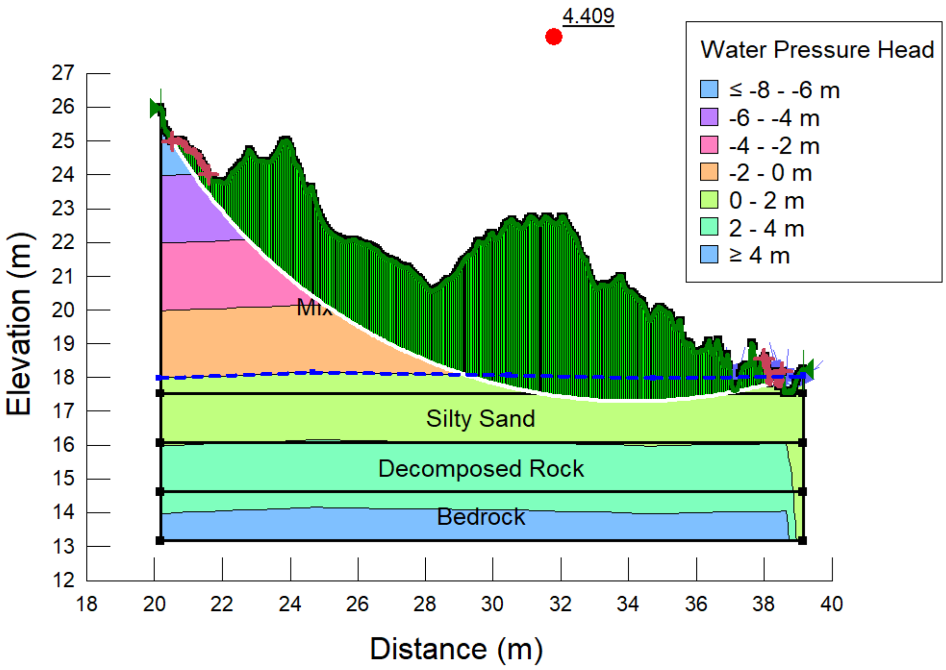

Figure 8 Result obtained by solving the definition

VI. CONCLUSION

From the analysis, we can conclude that the ground profiles in the region North-West, are highly unstable. For the construction in this risk prone area, Factor of safety is near about **20.272** which is very high and leads to high cost of construction. But the maximum activating force is **12.062841 kN** in the upward direction leads to the stability of ground.

STUDY MAP

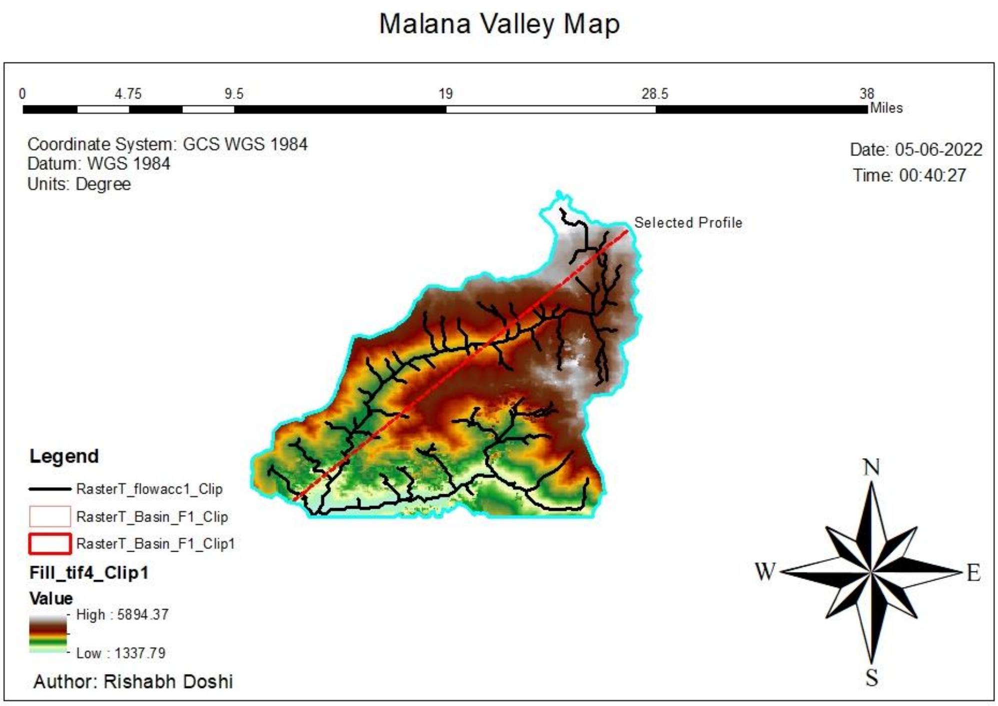

Figure 9 Study Map - Malana Valley

The mapping is created in ArcGIS software – ArcMaps 10.7.1 using the TanDEM-X dataset captured in January, 2022 extracted from the https://geoservice.dlr.de/

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