VIVA-TECH INTERNATIONAL JOURNAL FOR RESEARCH AND INNOVATION
ANNUAL RESEARCH JOURNAL
ISSN(ONLINE): 2581-7280

REAL CASE STUDY OF LANDSLIDE

Nikita Tiwari[1], Piyush Tiwari[2], Arathy Menon[3]
[1]*(Civil Department, Viva Institute of Technology, India)*
[2]*(Civil Department, Viva Institute of Technology, India)*
[3]*(Civil Department, Viva Institute of Technology, India)*

Abstract - *Landslides represent a significant geological hazard that can have devastating impacts on communities, infrastructure, and the environment. This Report presents areal case study of the 2014 so landslide in Malin State, Maharashtra, India which tragically claimed the of 151 people are died and resulted in extensive property damage. The study examines the geological, hydrological, and anthropogenic factors that contributed to the slide, highlighting the role of prolonged rainfall and the inherent instability of the slope due to past logging activities. A detailed analysis of pre- and post-event satellite imagery and geological surveys provides insights into the landslide mechanism, including the failure of a shallow landslide that transformed into a more extensive debris flow. The study emphasizes the importance of comprehensive hazard assessments and monitoring systems in identifying and mitigating landslide risks in vulnerable areas. By analyzing community response and recovery efforts, this paper underscores the need for effective land-use planning and public awareness campaigns to enhance resilience against future landslides. The lessons learned from the Malin landslide contribute to a growing body of knowledge aimed at improving landslide risk management strategies globally, ultimately aiming to reduce the loss of life and property associated with such catastrophic events.*

Keywords - *Heavy Rainfall, Deforestation, Slope instability, Mudflow, Mass Wasting.*

I. INTRODUCTION

Landslides, also known as landslips or slope failures, refer to the movement of rock, debris, or soil down a slope due to gravitational forces. This phenomenon occurs when the forces acting on a slope, primarily gravity, exceed the slope's resistance to movement. Landslides can happen suddenly, triggered by natural events such as heavy rainfall, earthquakes, volcanic activity, or even human actions such as deforestation and construction activities. The rate of movement can vary from a slow creep to a rapid, catastrophic collapse that may result in significant damage to life and property.

Landslides are part of a broader category of mass-wasting events, which describe the downward movement of soil and rock under the influence of gravity. They differ from other geological hazards, such as earthquakes and floods, because their occurrence is largely dependent on local topography, soil composition, and other environmental factors. While gravity is the primary force behind landslides, many additional factors contribute to their frequency, magnitude, and destructiveness.

II. LITERATURE REVIEW

2.1 Petley, D.N., et al. (2006)

Title: "The global occurrence of fatal landslides in 2003–2006"

Journal: Geophysical Research Letters

Petley, D.N., et al.'s 2006 article titled "The global occurrence of fatal landslides in 2003–2006" in Geophysical Research Letters provides a comprehensive analysis of landslide events that resulted in fatalities during the stated period. The study identifies landslides as a major natural hazard, often underestimated compared to other natural disasters like earthquakes or floods. The authors compile data from multiple sources, including reports and databases, to examine the distribution, frequency, and triggers of fatal landslides across the globe.

2.2 Guzzetti, F., et al. (1999)

Title: "Landslide hazard evaluation: A review of current techniques and their application in a multi-scale study, Central Italy" Journal: Geomorphology.

Guzzetti, F., et al.'s 1999 article titled "Landslide hazard evaluation: A review of current techniques and their application in a multi-scale study, Central Italy" in Geomorphology provides an extensive review of the methodologies used to evaluate landslide hazards. The study focuses on assessing landslide risks at different spatial scales, from local to regional, with a case study in Central Italy, a region prone to frequent landslides due to its complex terrain and climatic conditions.

2.3 Glade, T., et al. (2005)

Title: "Linking debris-flow hazard assessments with geomorphology, rainfall, and climate change"

Journal: Natural Hazards.

Glade, T., et al.'s 2005 article titled "Linking debris-flow hazard assessments with geomorphology, rainfall, and climate change" in Natural Hazards explores the relationship between debris-flow hazards and various environmental factors. The study emphasizes the importance of understanding the geomorphological characteristics of landscapes in assessing the potential for debris flows. The authors link these hazards with rainfall patterns, noting that intense or prolonged precipitation is often a trigger for debris flows.

III. METHODOLOGY

3.1 Introduction

Landslide assessment methodologies typically involve a multi-disciplinary approach that includes the integration of geological, hydrological, and geotechnical data to analyse and predict landslide susceptibility, hazard, and risk. A systematic methodology is crucial for understanding the factors that trigger landslides and for developing effective mitigation strategies.

Selection of site:

Date: 30 July 2014

Location: Malin Ambegaon, Taluka – Pune, District - Maharashtra, India

Co-Ordinates: 19°9′40″N 73°41′18″E

Cause: Landslide due to heavy rain

Deaths: 151

About the Malin Pune landslide

The landslides were caused by heavy rainfall that had begun the previous day, with the village receiving 108 mm (4 in) of rain on 29 July and continuing throughout the following day. The environmental destruction that resulted in the landslide is believed to have had several causes. The major cause was the negligence of geological factors before any developmental processes. Another key contributor was deforestation in the area, which removed not only trees but also the root structures that held the soil together. As a result, the surrounding soil was loosened, and experts argue that deforestation was the primary anthropogenic cause of the landslide.

3.2. Laboratory Test-:

3.2.1. Triaxial test:

A triaxial test is a widely used laboratory testing method in geotechnical engineering to determine the mechanical properties of soil, rock, or other granular materials under controlled pressure conditions. The test simulates the stress conditions that a material experiences in the ground and provides crucial information about its strength, deformation, and stability characteristics.

Applications:

- Soil Shear Strength: To determine how much stress soil can bear before failing, which is crucial for foundation design and slope stability analysis.
- Permeability Testing: Triaxial tests can also be used to assess how easily water moves through soil under varying pressure conditions.
- Rock and Material Testing: Used to evaluate the strength and deformation characteristics of rocks, especially for projects involving tunnels, slopes, and excavation.

3.2.2. Direct Shear Test:

The Direct Shear Test is a common laboratory testing method used in geotechnical engineering to determine the shear strength parameters of soil or other materials. It is designed to simulate the conditions under which soil or rock might experience shear failure in the field, such as along a slip surface in a slope or under a foundation.

Applications:

- Slope Stability Analysis: To determine the potential for a landslide or slope failure by measuring the shear strength of the soil.
- Foundation Design: Used to assess the bearing capacity of soil beneath foundations and predict potential settlement or failure under loading.
- Retaining Wall Design: To determine the forces acting on retaining walls from the surrounding soil and design for adequate stability.

3.2.3. Constant Head:

The Constant Head Test is a laboratory testing method used in geotechnical engineering to determine the permeability (also called hydraulic conductivity) of granular soils, such as sands and gravels, where water can flow easily. Permeability is a measure of a soil's ability to allow water to pass through its pores.

Applications:

- Groundwater Flow Analysis: To determine how easily water can move through subsurface soils, which is critical for assessing groundwater flow and contamination spread.
- Design of Drainage Systems: In civil engineering, knowing the permeability of soil is essential for designing drainage systems, earth dams, and retaining walls.
- Seepage in Dams and Embankments: Permeability is important in predicting the rate of seepage in dam foundations or embankments.

3.2.4. California Bearing Ratio:

The California Bearing Ratio (CBR) test is a penetration test developed by the California Division of Highways to evaluate the strength of subgrade soil, sub-base, and base materials used in the construction of pavements, especially for roads and airstrips. The test measures the resistance of a material to penetration under controlled conditions and compares it to the resistance of a standard crushed stone material.

 Volume 1, Issue 8 (2025)
PP 01-13

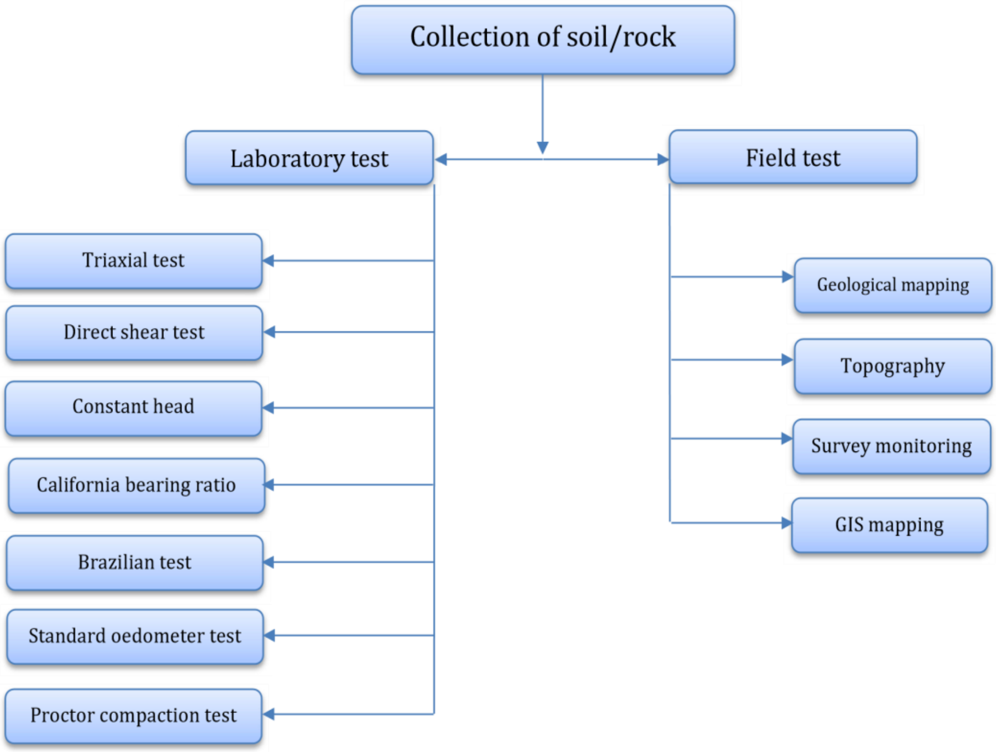
Applications:

- Pavement Design: CBR is crucial for designing flexible pavements. Based on the CBR value of the subgrade, engineers determine the thickness of different pavement layers (sub-base, base, and surface courses) required to adequately support traffic loads.
- Airfields: In airfield pavement design, the CBR value helps assess how well the soil or subgrade can support the load of aircraft.
- Railways and Embankments: CBR is also used to determine the suitability of subgrade materials under embankments or railway tracks.

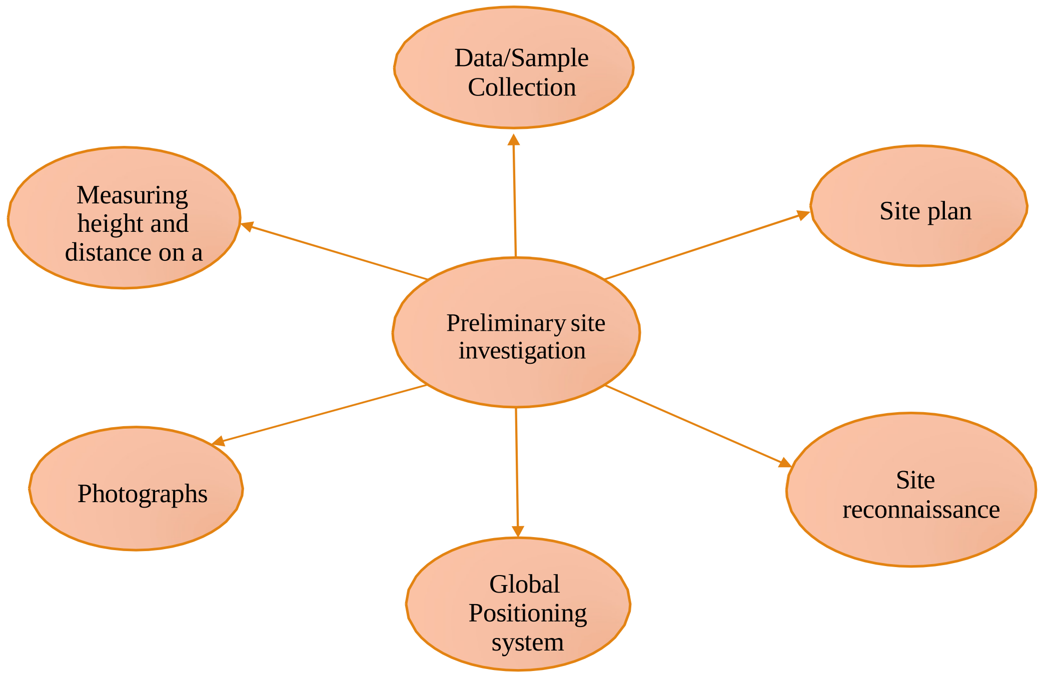
IV. FIGURES AND TABLES

Malin Pune before landslide.

Malin Pune after landslide view



Flow chart



Flow chart about Preliminary site investigation

Section	1st Zone		2nd Zone		3rd Zone		4th Zone		
A-A’	20°		10°	25°	30°		18°	25°	50°
B-B’	10°	28°	10°	25°	30°	20°	25°	30°	40°

Table 1: Slope angles at different slope zones along sections AA’ and BB’

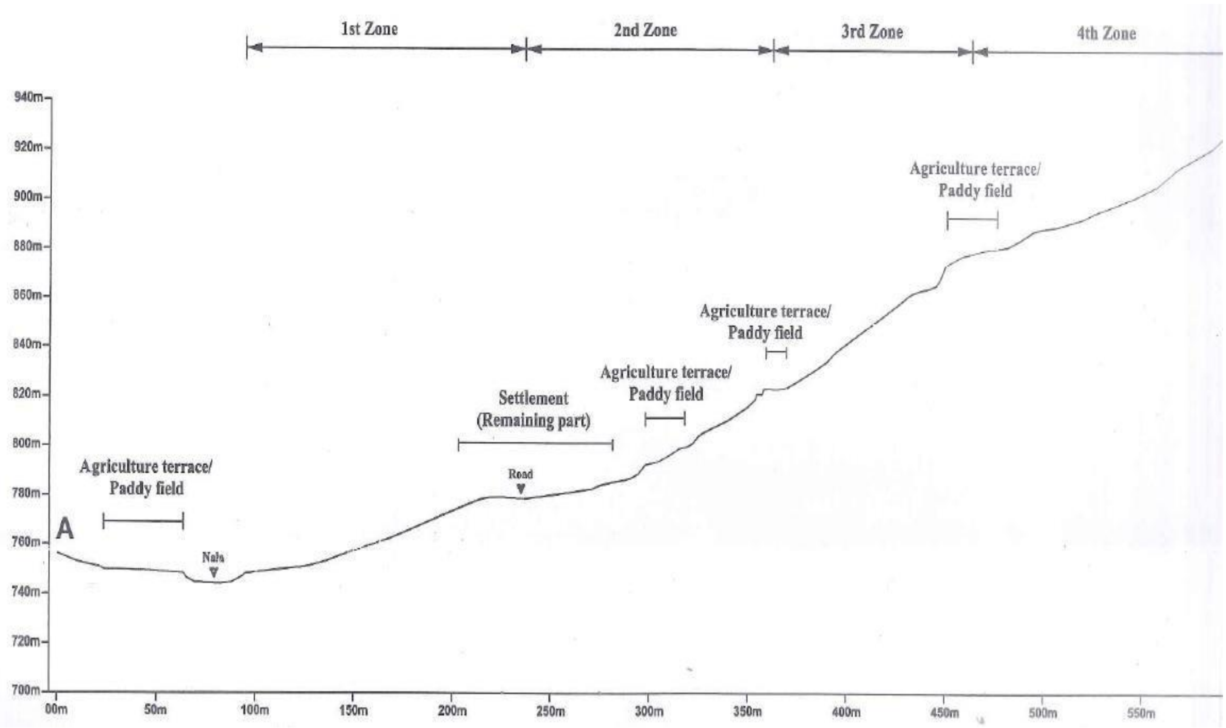


Figure 2: Longitudinal topographical section along A-A’

Features of the Malin Landslide

The Malin Landslide covered a significant area, with an estimated height of approximately 190 meters. The width of the landslide varied between 45 meters and 134 meters, while the total length, from the crown to the toe, was measured at 514 meters. In total, the landslide affected an area of approximately 44,245 square meters.

Zones and Extent of Damage

- The crown of the landslide was located at an elevation of 936 meters, marking the top of the 4th zone.
- The width of the landslide within this zone ranged from 45 meters to 134 meters.
- The landslide depleted (removed) part of the 4th zone, the entire 3rd zone, and most of the 2nd zone.
- The lowest part of the 2nd zone along with the 1st zone formed the zone of accumulation.

Impact on Malin Village

The zone of accumulation unfortunately coincided with the settlement area of Malin village, resulting in significant damage and loss of life.

Material Thickness and Rescue Operations

The maximum thickness of the sliding material could not be accurately determined because, by the time detailed mapping began, most of the failed slope material had already been removed during rescue operations. However, the thickness was roughly approximated to be around 7 meters.

Soil Sampling and Testing

Representative soil samples were collected from the Malin landslide area at three different levels within the main landslide. The geotechnical properties of these samples were tested to better understand the characteristics of the failed slope materials. The results of these tests are summarized in

Table 2. Result of geotechnical tests on soil samples

Parameter	From slided area		
Zone	2	3	4
Moisture content (%)	36.41	27.92	38.70
Dry density (g/cc)	1.32	1.36	1.24
Liquid limit (%)	53	51	46
Plastic limit (%)	31	29	28
Plasticity Index (PI)	23	23	18
Specific Gravity	2.57	2.51	2.58
Grain Size analysis (Silty clay, %)	57	78	31
Cohesion (Kg/cm^2)	0.125	0.391	0.339
Friction angle (°)	4.06	10.31	41.41

The grain size analysis indicated that the samples collected from slide area belong to silty-clay group. The plasticity index values vary from 18 to 23 %. The average bulk density of the slope material is taken as 1560 kg/m^3.

Rainfall Process

Malin village does not have its own rain gauge station; therefore, rainfall data were obtained from nearby rain gauge stations located around the village.

Figure 3 presents the recorded rainfall data for Malin village from 22nd July to 30th July.

- The data indicate that the antecedent rainfall recorded between 22nd July and 28th July was not particularly unusual.
- However, on 29th July, after a period of 168 hours, the rainfall spiked significantly to 108 mm.

This sudden and intense rainfall on 29th July is believed to have played a key role in triggering the slope instability, contributing to the Malin landslide.

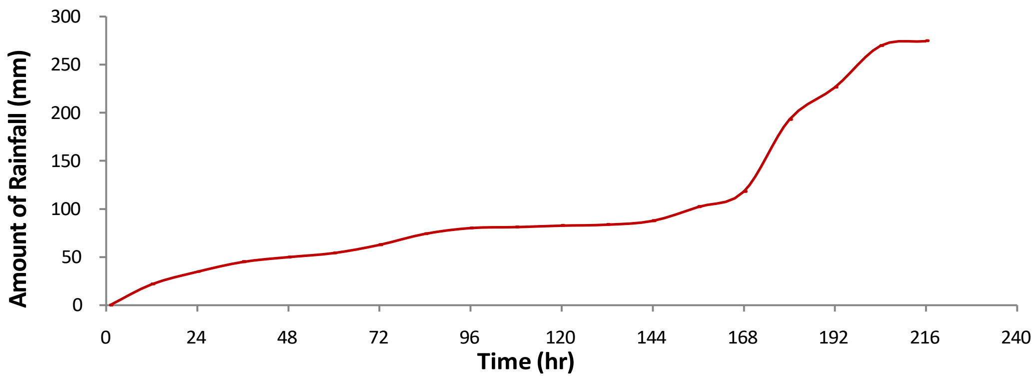


Figure 3: Rainfall data of Malin village

3. Method of Analysis

Back Analysis of the Failed Slope

Slope failure occurs when the factor of safety (FOS) reduces to unity (FOS = 1), indicating that the resisting forces are equal to the driving forces. Back analysis is a common technique used in such cases to improve understanding of slope stability parameters. These parameters include soil strength properties and pore water pressure conditions at the time of failure.

The Malin landslide offers useful information for back analysis, as the factor of safety at failure was 1 and the length of the failure surface was measured at 514 meters.

Parameters for Back Analysis

To achieve a factor of safety of 1, the shear strength parameters of the soil (cohesion c′c' and friction angle ϕ′\phi') must be back-calculated. This analysis aims to estimate the appropriate values of cohesion and friction angle that controlled failure in the original slope.

The Duncan and Stark (1992) method is applied for this purpose. This method estimates the friction angle using the plasticity index (PI), and once the friction angle is known, the cohesion parameter at the moment of failure can be back-calculated.

Known and Unknown Parameters

- Known Parameters:
  - Factor of Safety = 1
  - Length of Failure Surface = 514 m
  - Plasticity Index (PI) = 23
- Unknown Parameters:
  - Friction Angle (φ')
  - Cohesion (c')

Friction Angle Estimation

The following table (Table 3) provides typical values of friction angle (φ') for different plasticity index (PI) ranges:

Plasticity Index	Fully Softened φ' (degrees)	Residual φ' (degrees)
0-10	30-40	18-30
10-20	25-35	12-25
20-40	20-30	10-20
40-80	15-25	7-15

For the plasticity index of 23 (PI = 23), the friction angle (φ') is expected to range between 20° and 30°. Based on this, a friction angle of 22° was adopted for the slope in this study.

Analytical Model and Approach

The analysis adopts a rotational failure model, representing a circular failure surface that extends from the crown of the landslide in the 4th zone to the 2nd zone. This circular surface descends to the weathered/unweathered interface, consistent with the long, shallow failure surface observed at the site.

To evaluate the shear strength parameters at failure, Bishop's Method of Slices is applied.

- A slip circle is drawn along the failed slope.
- The soil mass above the slip circle is divided into 14 vertical slices of equal width, which allows for a more detailed analysis of forces acting within the slope.

this case. Failure length = 514 m, Radius of arc taken = 295 m, Number of slices = 14, width of each slice = 25 m.

Considering the whole length of slip surface L as 514 m, the total driving and resisting forces are:

Driving forces = ∑T; Resisting force = ∑c'L + tan υ'∑N

Hence, the factor of safety against sliding is

$$F = (c'L + \tan \upsilon' \sum N) / \sum T \qquad (1)$$

Where, N is the normal component of weight and T is the tangential component of weight. Normal force and Tangential component are calculated as$N = W*\cos \alpha$ and $T = W*\sin\alpha$.

From the analysis: $\upsilon' = 22°$, $\sum N = 86452.17$kN/m, $\sum T = 201075.1$kN/m, L = 514 m, F = 1

Since factor of safety is one, the left hand side of equation (1) equals the right hand side. Assuming the value of υ' as 22° and solving equation (1), we obtained the value of cohesion mobilized along the slip/failure surface as 10.14 kPa.

Validation Using Finite Difference Method (FLAC 2D)

To validate the results obtained from the limit equilibrium method, the slope stability of the Malin landslide was also analyzed using the finite difference program FLAC 2D (Fast Lagrangian Analysis of Continua).

Slope Geometry and Material Model

The geometry of the slope, along with the finite difference grid, is shown in Figure 4. The analysis used the Mohr-Coulomb model to represent the soil behavior. The cohesion and friction angle values used in the analysis were:

- Cohesion (c') = 10.14 kPa
- Friction Angle (φ') = 22°

Other soil properties were taken from Table 2.

Boundary Conditions

- Vertical boundaries were fixed in the x-direction.
- The bottom boundary was fixed in both x and y directions.

Grid and Mesh Considerations

FLAC organizes zones into a row and column grid, but the grid can be distorted to fit complex shapes. To maintain accuracy and stability, the following general rules were considered:

- The aspect ratio (height to width) of each zone should be close to 1.
- The area ratio between adjacent zones should not exceed 4:1.

Due to the complex geometry of the Malin slope, finer grids became distorted under gravity conditions and failed to simulate the slope accurately. As a result, coarser grids were adopted, with a gradual variation in grid size from Zone 2 to Zone 4.

- Finer grids were applied in Zone 4 to capture detailed displacement and stress values more accurately.
- The total number of zones used in the model was 830.

Analysis and Results

The analysis was performed under gravity conditions only. The slope was divided into Zones 2, 3, and 4, each having different slope inclinations as provided in Table 1.

- Each zone was depicted using different color shades.

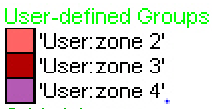
FLAC calculated the factor of safety (FOS) using the strength reduction method.

- The factor of safety was found to be 1, confirming slope failure conditions.
- The modeled slip surface closely matched the observed slip surface at the site, covering:
  - Part of Zone 4
  - All of Zone 3
  - Part of Zone 2

This modeled failure pattern is consistent with field observations at Malin.

Visual Representation

Figure 5 illustrates the Malin slope at the time of failure, showing the affected zones and the modeled slip surface.



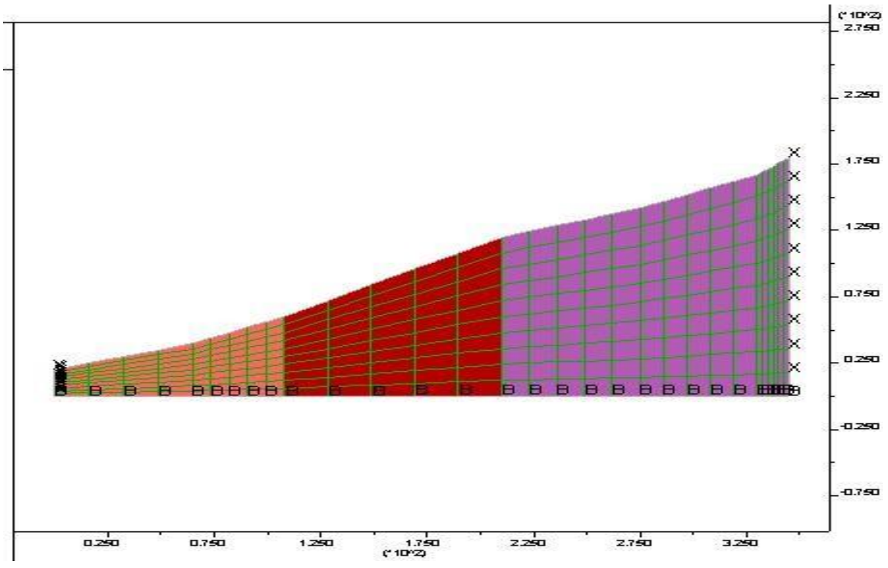


Figure 4: Finite difference grid

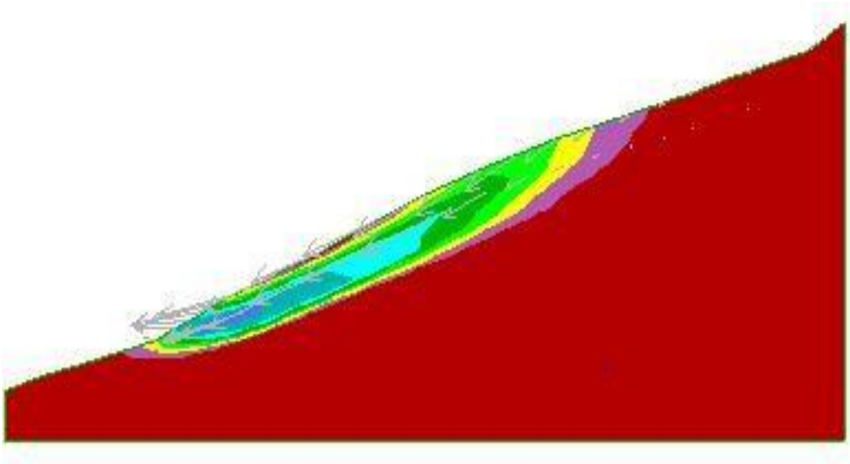


Figure 5: Malin slope at the time of failure (Factor of safety = 1.00)

Analysis performed using FLAC confirms the accuracy of back analysis performed on the failed slope. Figure 6 shows the displacement contours of the slope and it is found that the maximum thickness of slip surface is 10 m. During the site investigation, the thickness of material depleted from various zones during landslide was approximated as 7 m although the value was not measured accurately because when the detailed mapping work was carried out, most of the failed slope material was removed from the place as part of rescue efforts.

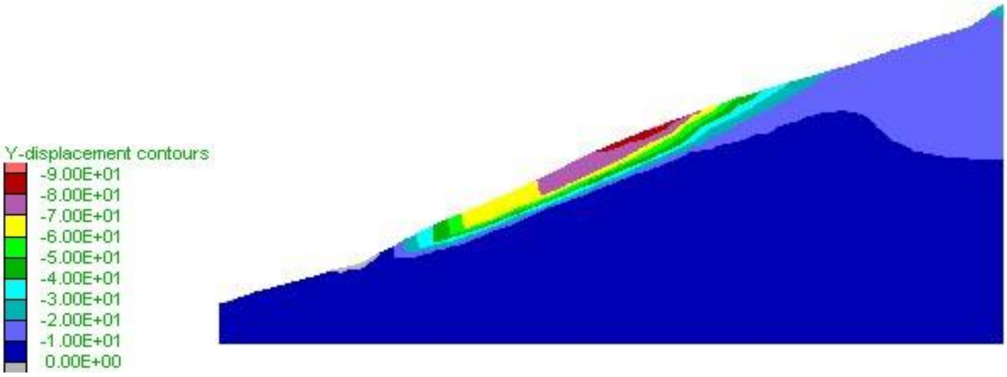


Figure 6: Displacements contours at the time of failure

Pre-Slide Shear Strength Analysis Using FLAC

Using FLAC, the pre-slide shear strength parameters of the slope were determined. For natural soil slopes, a factor of safety (FOS) of 1.5 or higher is typically considered stable.

A stability analysis was conducted using the Mohr-Coulomb model, with the same boundary conditions as the previous analysis, under gravity conditions only.

The slided slope was divided into three zones, each with different slope inclinations, shown in different color shades.

The analysis found that a cohesion of 36 kPa and a friction angle of 22° resulted in a factor of safety of 1.5, representing the pre-slide strength parameters of the slope.

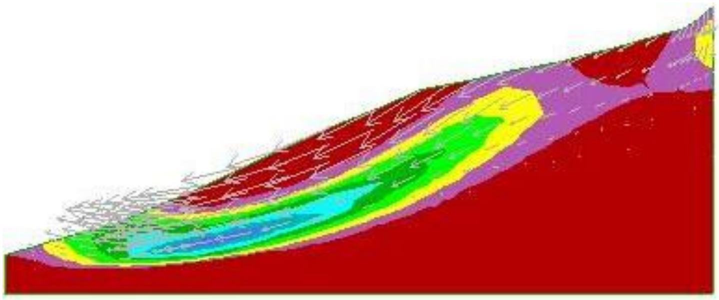


Figure 7: Pre-slide Malin slope (Factor of safety = 1.52)

Figure 7 shows that the pre-slide slope suggested deep rotational slip circle, however the rainfall infiltration into the soil profile decreased the strength parameters and caused shallow slide. Table 4 compares the strength parameters of pre-slide, failure state and post slide state of the same slope where landslide occurred. It is observed that for the same friction angle value of 22° there is a considerable decrease in the value of cohesion.

Table 4: Pre-slide and failure state strength parameters

Parameter	Pre-slide	Failure state	Post-slide
Cohesion (kPa)	36	10.14	38.3
Friction angle (°)	22	22	10.31

It is evident that there has been a decrease in strength parameters from pre-slide state due to failure of slope (parameters of post-slide are taken from Table 2). Excessive rainfall in the area for more than a week has been identified as the triggering mechanism for the failure. Chowdhury and Flentje (2002) observed that high pore water pressures that are generated after prolonged and intense rainfall trigger most cases of significant landsliding. The mobilized shear strength as low as c' = 0 kPa and υ' = 15° have been determined from back analyses and for deep-seated landslides, the shear strength parameters determined are c' = 0 and *φ'* = 9°. SivakumarBabu and Dasaka (2005) showed that decrease of matric suction with time is a time dependent process and evaluated the reliability of a typical landslide in Himalayan terrain. Zhang et al. (2009) performed back analysis of slope failure using probabilistic methods. A cut slope failed due to heavy rainstorm was back-analyzed in a probabilistic way. The mean value of strength parameters determined from the analysis were c' = 8kPa and υ' = 38°. Soon Min Ng et al. (2014) investigated the slope failure triggered by rainfall using numerical back analysis method. Back analyses were performed via finite element shear strength reduction method. The results showed that the shear strength parameters at failure were c' = 11 kPa and υ' = 20°. The slope consisted of silty soil in large amounts. Hence the results obtained by back analysis based on limit equilibrium and finite difference methods are comparable with the results from Soon Min Ng et al. (2014).

This decrease in strength parameters which resulted in failure of slope can be attributed to the loss of matric suction in the unsaturated part of the slope due to excessive rainfall infiltration. Once the rain-water starts infiltrating the vadose zone, the negative pore-water pressures will tend to dissipate due to an increase in the soil water content. This process contributes to lowering the shear strength of the soil layers close to the surface. Under normal conditions the negative pore water pressure creates suction in the vadose zone and increases the strength of the soil.

CONCLUSION

Landslides are a natural phenomenon and associated with slopes. But the human activities have increased the risk of landslides in different parts of the state. The state of Maharashtra is characterized by the undulating topography of the Western Ghats comprising the Sahyadri, Mahadeo hills, Ajanta hills and their offshoots. It receives heavy orographic rainfall between the months of June to September which is characterized by a few rainy days intermittent with long dry spells. The rate of weathering is high due to high temperature and high annual rainfall.

Any activity of humans like faulty agriculture, deforestation, stone quarrying, etc., leads to slope destabilization and may lead to more such severe events and cause massive destruction of human life and property besides being damaging to natural habitats in the region affected by the disaster

ACKNOWLEDGEMENT

We are using this opportunity to express our gratitude to everyone who has supported us throughout the completion of this project. We are thankful for their guidance, constructive criticism and friendly advice during the project work. We express our gratitude to Prof. Aarthy Menon for giving us an opportunity to carry out project on “REAL CASE STUDY OF LANDSLIDES” We would also like to thank Prof. Akshay Mistry, Head of Civil Department and Dr. Arun Kumar, the Principal for their wholehearted support.

Lastly, we express our gratitude towards all those who directly or indirectly helped us in the completion of our studies.

REFERENCES

(1) Cannon, S. H., & Gartner, J. E. (2005). Wildfire-related debris flows: The importance of soil moisture. Geophysical Research Letters, 32(14), L14401.
- This study explores the impact of wildfires on soil moisture and its subsequent effect on debris flow susceptibility.

(2) Miller, S. A., & S. M. G. (2012). Landslide risk assessment: A review of techniques. Natural Hazards, 62(3), 833-853.
- The authors review various methodologies for assessing landslide risk, highlighting strengths and limitations.

(3) Wieczorek, G. F. (1996). Landslide triggers and mechanisms. Landslides: Investigation and Mitigation, Special Report 247, Transportation Research Board, National Research Council, Washington, D.C., 17-33.
- This book chapter discusses various triggers and mechanisms leading to landslides.

(4) Takahashi, T. (2007). Landslides: A review of the causes and effects. Landslide Science and Practice, 2, 1-12.
- A comprehensive review of the causes and effects of landslides, emphasizing their significance in various regions.

(5) Sidle, R. C., & Ochiai, H. (2006). Landslides: Processes, prediction, and land use. Water Resources Publications, Highlands Ranch, CO.
- This book provides an in-depth look at landslide processes, prediction techniques, and land use planning.

(6) Bishop, A. W. (1955). The use of the slip circle in the stability analysis of slopes. Geotechnique, 5(1), 7-17.
- This foundational paper introduces the slip circle method for analyzing slope stability.

(7) Hungr, O., & Evans, S. G. (2004). Rock avalanches: A review of the occurrence and causes. Geological Society of America Bulletin, 116(5-6), 653-662.
- A review of rock avalanches, examining their characteristics and underlying causes.

(8) Fritz, C., & Wu, M. (2011). Assessment of rainfall-induced landslide hazard in the Greater Vancouver region. Landslides, 8(1), 87-101.
- This paper evaluates the landslide hazard associated with rainfall events in the Vancouver area.

(9) Guzzetti, F., et al. (2006). Landslide hazard assessment: A review of the state of the art. Journal of Earth Science, 17(1), 65-75.

- The authors review the latest advancements in landslide hazard assessment techniques.

(10) Sassa, K., & Nakano, M. (2004). Geohazards and landslide risk assessment in Japan. Landslides, 1(1), 1-12.
- This article discusses the geohazards and landslide risks in Japan, providing insights into local geological conditions.

(11) Keefer, D. K. (1984). The importance of earthquakes in landslide activity. Landslides: Investigation and Mitigation, Special Report 247, Transportation Research Board, National Research Council, Washington, D.C., 19-31.

(12) howdhury, R.N. and Flentje, P. (2002). "Uncertainties in rainfall-induced landslide hazard", *Quarterly Journal of Engineering Geology and Hydrogeology*,***35**, 61–70*