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Limit Equilibrium Method Based Slope Stability Analysis of One of the Most Highly Landslide Susceptible Region of Guwahati

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Abstract: Guwahati, situated in a hilly region, faces the constant threat of landslides due to its susceptibility to high rainfall. The city has a history of several instances of landslides, causing substantial loss of life and property. The Assam State Disaster Management Authority (ASDMA) has identified at least 366 locations within the city as highly seismic-prone areas. In response to this, a comprehensive analysis of slope vulnerability has been initiated. One of the targeted sites, recently affected by landslides, is undergoing thorough examination using the Limit Equilibrium Method (LEM). To achieve this, a detailed survey of the slope profile has been conducted, including the collection of geological data and soil samples. The geotechnical parameters are being meticulously analysed based on the obtained soil test reports, considering factors such as drainage conditions and historical rainfall intensity data. This crucial information serves as input for a LEM-based software, which is commonly available for slope stability analysis. The software utilizes sophisticated algorithms to assess the vulnerability of the slope under varying rainfall intensities, offering valuable insights into potential landslide risks. By combining field surveys, geotechnical testing, and advanced software analysis, this comprehensive approach aims to provide a holistic understanding of slope stability, aiding in the formulation of effective strategies for landslide mitigation in the identified vulnerable regions of Guwahati. This initiative aligns with the broader goal of enhancing disaster preparedness and resilience in the face of natural hazards in the region.

Keywords**: Landslide, Pore water pressure, Slope stability, Limit Equilibrium Method,* *Unconfined Compressive Strength Test**.

I. INTRODUCTION

A landslide is a geological occurrence shaped by the gravitational movement of rock, debris, or soil down a slope or hill. This category encompasses diverse forms of soil and rock motion initiated by gravitational forces. Landslides manifest in five principal modes – falls, topples, slides, spreads, and flows – each linked to distinct geological materials like bedrock, debris, or earth. Instances of landslides include debris flows, often termed mudflows or mudslides, and rock falls, frequently observed in hilly and mountainous terrains. According to the International Disaster Databases (EM-DAT), landslides account for 5% of total natural disasters globally over the last two decades, the fifth highest after floods, storms, earthquakes, and extreme temperatures (Mizutori & Guha-Sapir, 2020). In Guwahati, high demand on the scarce habitable land inside the city has forced a section of population, mostly those belonging to the low-income group, occupy these hills. The extent of human activity in these hill areas has reached such a stage that Guwahati City now has to deal with loss of life and property almost every year due to landslides, the worst so far being 18 deaths in the year 2004. The month of July, 2014 has witnessed huge devastation due to landslide in the hill areas around Guwahati including 3 human casualties. The landslides of Guwahati are mostly shallow slides and are triggered by rainfall (U.K.Das, 2015).The complexity of landslide events arises from multiple contributing factors, incorporating geological, environmental, and human-induced elements. These factors range from being rainfall induced to deforestation and construction activities that destabilize slopes.

This study focuses on analysing slope stability in a rainfall-induced region by identifying landslide-susceptible areas through a comprehensive survey. The investigation centres on the meticulous collection of soil samples from designated sites, subjected to thorough analysis to understand their geotechnical properties. The critical parameter under scrutiny is the Factor of Safety (FOS), considering the influence of pore water pressure factors in the rainfall-induced region. Over the past four decades, numerical analyses have been conducted mainly through conventional LEM. These methods are statically indeterminate and require pre-assumptions to determine the factor of safety.

(Moniruzzaman et al., 2015). Calculated using the Limit Equilibrium Method (LEM), the FOS analysis aims to assess slope stability, providing valuable insights into potential landslide risks in the surveyed areas. The systematic approach, integrating surveying, soil analysis, and LEM-based slope stability assessment, contributes to the overarching objective of identifying and understanding the susceptibility of specific areas to landslides in the context of rainfall, facilitating informed decision-making for effective landslide mitigation strategies.

II. LITERATURE REVIEW

Limit Equilibrium Methods (LEM) are integral to slope stability analyses, with the Swedish slip circle method being a foundational approach, later refined by Bishop. The stability of slopes is commonly assessed through the factor of safety (FOS), indicating the ratio of resisting to driving forces. The studies of Wright et al., Spencer (1967 &1973), and Duncan (1996) indicated that the average value of FOS for those LEMs that satisfy all conditions of equilibrium are accurately near to the rigorous methods by a tolerance of ±6 percent. Morgenstern and Price (M-P) further advanced this field, particularly enhancing stability analyses against slippage along weak geosynthetic liner systems, where consideration of a planar failure surface becomes crucial. Morgenstern and Price (1965) stated that the reasons of this popularity are ability of this method to consider internal forces of the soil body, pore pressure, and multi layered slopes (Kalatehjari et al., 2013). Numerous studies exploring slope stability using traditional LEM have converged on the suitability of the M-P method for analysing planar failure surfaces. The M-P method stands out for its capacity to satisfy both force and moment equilibrium equations when calculating the factor of safety. This proficiency makes it particularly adept at evaluating stability against slippage along planar failure surfaces, underscoring its significance in geotechnical analyses.

III.STUDY AREA

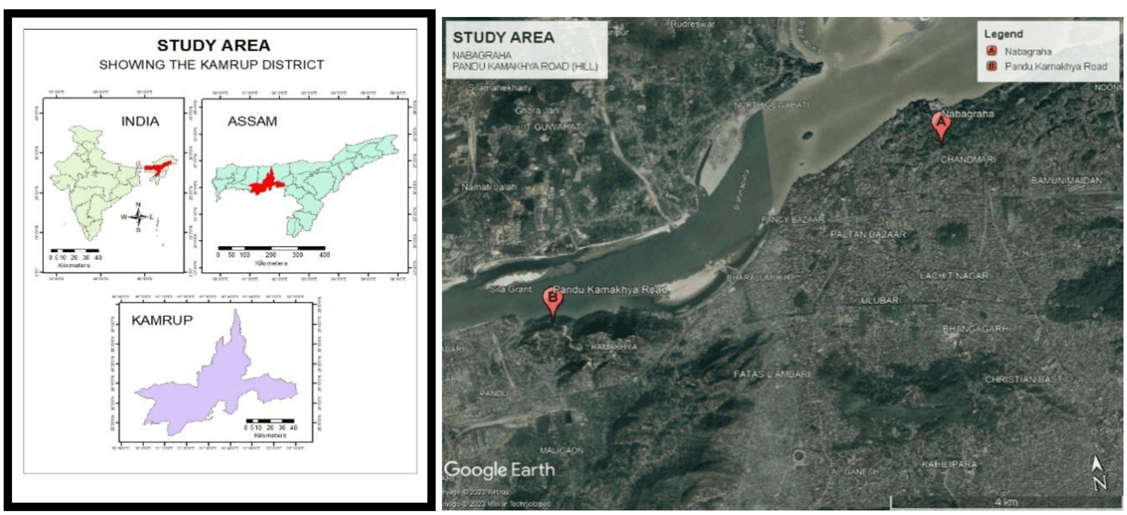

Fig. 1 Map depicting the study area, Navagraha Hill with respect to Kamakhya temple

The geo-climatic conditions in Guwahati, Assam, pose a significant challenge due to its high susceptibility to landslides. Characterized by steep slopes and geological features, the region becomes inherently prone to landslides, especially when compounded by heavy monsoon rainfall. The magnitude of destruction depends on the location of the landslide area. In the context of Guwahati, it is a painful truth that most, if not all, the areas susceptible to landslide hazards are inhabited by the economically weaker section of the 2 population who have neither the resources nor the expertise to organize rehabilitation measures out of their own (ASDMA, 2014). This lack of a thorough understanding hinders the formulation of effective mitigation and management plans. The chosen site for our research project is the Navagraha Hill, located in the Silpukhuri area of Guwahati. This hill is one of the 20 identified hills in the city prone to landslides. The area is characterized by hilly terrain and has experienced recurrent landslides, encompassing soil creep, mudslides, debris flow, and rockfall. These landslides annually result in substantial property damage and unfortunate loss of human lives. The specific coordinates of our study area are 26°11’32.35” N latitude and 91°46’03.80” E longitude, situated at an elevation of 170 meters above sea level. This site details the geographical and topographical features of the Navagraha Hill, highlighting its susceptibility to landslides and emphasizing the importance of in-depth research for effective mitigation strategies.

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IV. HISTORY OF LANDSLIDE OCCURANCE

Nestled amidst the captivating landscapes of northeastern India, Guwahati has been shaped by its distinctive terrain, characterized by verdant hills, valleys nestled between mountains, and the imposing Brahmaputra River. Against this picturesque backdrop, landslides have emerged as a recurring natural phenomenon, leaving a profound impact on the city's narrative. Exploring the historical account of landslides is crucial for grasping the city's vulnerability and devising effective strategies for risk mitigation. By delving into documented records of landslides in Guwahati, and leveraging data from NASA's extensive landslide inventory, which meticulously logs instances of such events, our investigation seeks to uncover the historical intricacies influencing the city's susceptibility to these geological occurrences. This retrospective analysis not only sheds light on the natural processes contributing to landslides but also underscores the human elements that may exacerbate the risk. As we embark on this research journey, a comprehensive understanding of Guwahati's past landslide occurrences becomes fundamental for our contemporary efforts in mapping landslide susceptibility. This knowledge serves as the foundation for crafting proactive measures to safeguard the city's inhabitants and infrastructure from the persistent challenges posed by landslides.

TABLE I
THE COMPILATION of LANDSLIDES OCCURRING WITHIN GUWAHATI CITY from 2007 to 2017

Sl. No	Date	Source	Place	Trig Factor
1	7/19/2007	Saharas Samay	Guwahati	Rain
2	9/13/2007	Saharas Samay	Guwahati	Rain
3	4/20/2010	Assam Tribune	Raj Bhavan Guwahati, Assam	Downpour
4	4/20/2010	Assam Tribune	Kharghuli, Guwahati, Assam	Downpour
5	9/23/2011	Nbtvlive	Maighuli, Guwahati, Meghalaya	Downpour
6	6/2/2012	Ibnlive.in	Guwahati , Assam	Downpour
7	6/20/2012	twocircles.net	Lalunggaon, Guwahati, Assam	Downpour
8	6/22/2012	thesop.org	Gorchuk area	Downpour
9	5/11/2013	articles.timesofi ndia.indiatimes.c om	Sarania Hills, North Guwahati , Guwahati	Rain
10	5/11/2013	articles.timesofi ndia.indiatimes.c om	Nursery, North Guwahati, Guwahati, Assam	Rain
11	10/6/2013	articles.timesofi ndia.indiatimes.c om	Nilachal Hill, Guwahati, Assam	Downpour
12	10/6/2013	articles.timesofi ndia.indiatimes.c om	Batahguli, Guwahati, Assam	Downpour
13	6/26/2014	Two Circles	Narakasur	Continuous _ rain
14	6/26/2014	Two Circles	Bamunimaidam	Continuous _rain
15	6/27/2014	Assam Times	Bhangagarh, Assam	Rain
16	6/28/2014	Assam Times	Kharghuli Hills, Assam	Rain
17	9/22/2014	Assam Tribune	VIP Road	Rain
18	9/22/2014	Assam Tribune	Dakhingaon	Rain
19	9/22/2014	Assam Tribune	Noonmati	Rain

20	9/22/2014	Assam Tribune	Dhirenpara	Rain
21	9/22/2014	Assam Tribune	Batahghuli	Rain
22	9/22/2014	Assam Tribune	Lalmati	Rain
23	2/14/2015	Telegraph	Kailashpur Hill	Mining
24	9/23/2015	Assam Times	Kamakhya Temple	Continuous_rain
25	6/22/2016	NYOOOZ	Piyali Phukan Nagar	Downpour
26	7/14/2016	Indian Express	Pub sarania hill, South Sarania, Guwahati, Assam, India	Monsoon
27	7/14/2016	Indian Express	Noonmati Nijarapar area of the city, Guwahati, Assam, India	Monsoon
28	7/20/2016	Times of India	Noonmati, Guwahati, Assam,India	Rain
29	12/15/2016	NBC Daily	Landslide at Pub Sarania Hill	Unknown
30	12/15/2016	NBC Daily	Landslide at Noonmati Nijarapar	Unknown
31	7/6/2017	DY365	Landslide crushes house	Continuous_rain
32	7/10/2017	The Assam Tribune	Landslide damages house	Continuous_rain
33	7/10/2017	The Assam Tribune	Landslide in Chandmari	Continuous _rain

V. METHODOLOGY

Our project methodology is integral to achieving a comprehensive understanding of the subject at hand, employing specialized procedures for information identification, selection, processing, and analysis. This approach equips readers with the tools needed to critically evaluate the study's robustness, serving as a theoretical framework guiding the selection of methods to effectively address research questions. To obtain a detailed view of the study area, we conducted a survey using total station instrument. This involved the process of data collection and slope profile determination, enabling a detailed examination of the terrain. Soil tests were then performed to gather crucial information on geological composition and properties, providing valuable insights into ground conditions.

The analysis of slope stability was a focal point in our methodology. Utilizing a Limit Equilibrium Method (LEM) based software, we assessed slope vulnerability under varying conditions, with a specific focus on factors like rainfall intensity. This advanced software facilitated a comprehensive evaluation, allowing us to draw meaningful conclusions about potential risks and contributing factors influencing slope stability. In brief, our methodology seamlessly integrates these key methods to yield a thorough and well-rounded understanding of the subject. This ensures the reliability and relevance of our study by addressing the complexities of the terrain and geological composition. Through the combined effort of total station surveys, soil testing, and advanced slope stability analysis, our approach provides a stern foundation for drawing meaningful insights and conclusions from the collected data.

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VI. RESULTS AND DISCUSSION

Landslide susceptibility mapping is a process of identifying areas that are more likely to experience landslides. It is a crucial tool for hazard mitigation and risk reduction, as it helps communities and authorities prepare for and avoid potential disasters.

Geographic Information Systems (GIS) play a vital role in landslide susceptibility mapping, particularly in determining slope and aspect, two crucial factors in assessing landslide risk. Here's how GIS functions are utilized in this process:

A. Thematic Mapping

1) Slope

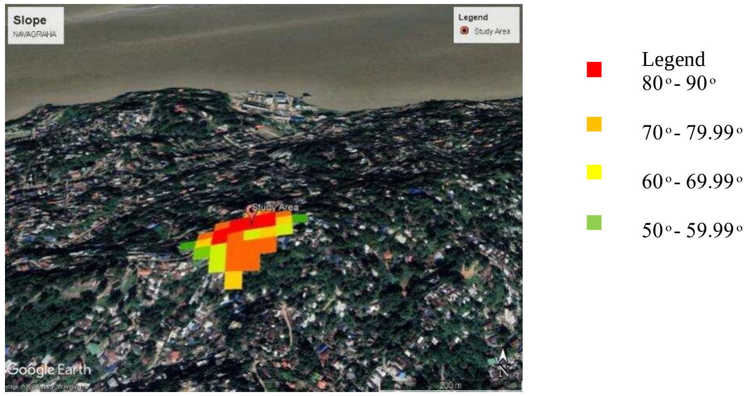

Fig. 2 Slope Mapping of Navagraha hill in GIS

Slope Gradient: GIS software utilizes the "Slope" function within the "Surface" or "Spatial Analyst" toolset. This function analyses the Digital Elevation Model (DEM) to calculate the rate of change in elevation across each cell, generating a slope gradient map.

Reclassification: Slope gradient maps require reclassification into meaningful categories for landslide susceptibility analysis. Common methods include equal interval, quantile, or natural breaks classifications, depending on the specific study area and landslide characteristics.

2) Aspect

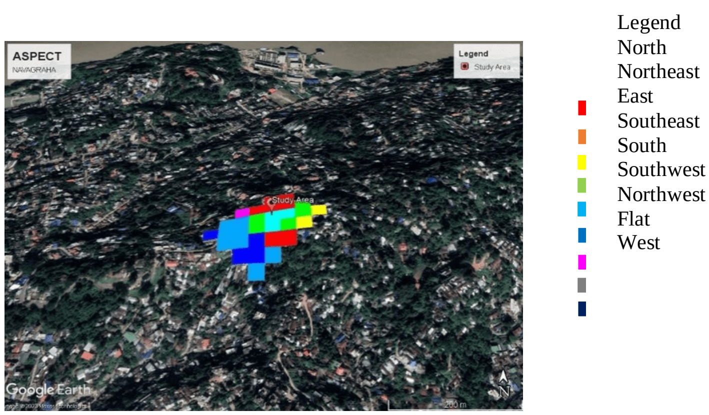

Fig. 3 Aspect Mapping of Navagraha hill in GIS

Aspect Calculation: Like slope, the "Aspect" function within the "Surface" or "Spatial Analyst" toolset is used. This function analyses the DEM to determine the compass direction of the maximum slope for each cell, producing an aspect map.

Aspect Categorization: Aspect maps are categorized into specific aspect classes based on their compass direction. This facilitates analysis of the relationship between landslide occurrence and aspect, identifying areas with higher susceptibility.

B. Soil Tests

To classify the soil samples, a series of tests were conducted in accordance with established standards. These tests included:

1) Liquid limit test (IS 2720{Part 5}-1985)

The Cone Penetration Method was adopted. This method utilizes a standardized cone penetrometer with a specific angle and weight. Liquid Limit is the moisture content at which the groove, formed by a standard tool into the sample of soil taken in the standard cup, closes for 10 mm on being given 25 blows in a standard manner.

2) Plastic limit test (IS 2720{Part 5}-1985)

Plastic limit is the arbitrary limit between semi-solid and plastic stages of consistencies of soil, as defined by Atterberg. Experimentally, Plastic Limit (PL) is determined by rolling out a thread of the fine portion of a soil on a flat, non-porous surface. The plastic limit is defined as the moisture content where the thread attains a diameter of 3 mm (about 1/8 inch) and simultaneously Moisture content (%) = (W_w/W_s) No. of blows surface cracks appear on it, without the thread being broken or buckled. A soil is considered non-plastic if a thread cannot be rolled out down to 3 mm at any moisture content.

3) Core Cutter test (IS 2720{Part 29} -1975)

The core cutter method is employed to assess the in-situ density of cohesive or clayey soils utilized as fill in the field.

4) Unconfined Compressive Strength Test (IS 2720 {Part 10} - 1973 Methods of test for soils

This test is done to determine the unconfined compressive strength (UCS) of cohesive soil.

C. Test Results

TABLE 2
SOIL TEST RESULTS

Liquid Limit (LL)	28.76%
Plastic Limit (PL)	9.01%
Plasticity Index (I_p)	19.75%
I_p for A Line (IS 1498{1970}) (0.73*(LL-20))	6.40%

TABLE 3
SOIL PROPERTIES

Property	**Value**
Density (ϒ in kN/m^3)	15.90
Cohesion (C in kPa)	17.73
Angle of internal friction (ϕ in degree)	0.00

The soil is low plasticity clay. A plot is made between stress and strain. The maximum stress from the curve gives the values of the unconfined compressive strength q_u.

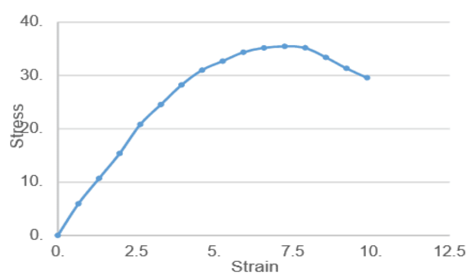

Fig. 4 Stress Strain Curve for intact soil

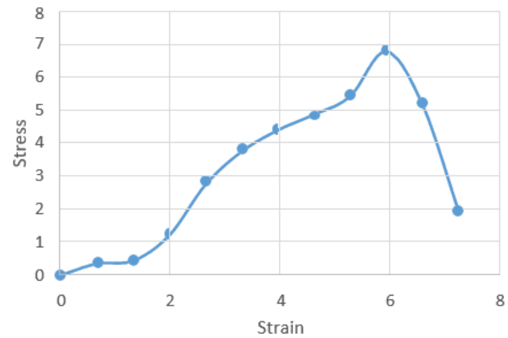

Fig. 5 Stress Strain Curve for failed soil

D. Slope Stability Analysis

Slope stability analysis was conducted to gain a better understanding of the landslip problem and behaviour of the soil under varying conditions for a particular site. This process was carried out independently for each of the six reference lines established in the earlier stages. Each reference line served as a unique point, contributing to the creation of a distinct slope profile specific to its orientation and the points surrounding it. Consequently, this approach resulted in the generation of six separate slope profiles, each encapsulating the nuanced variations and characteristics of the studied area. The pore water pressure head (Ru) values were changed to check the variation in Factor of safety (FOS) values. The subsequent Ru values were then compared to the rainfall intensity variations. Following are the FOS values obtained for one slope.

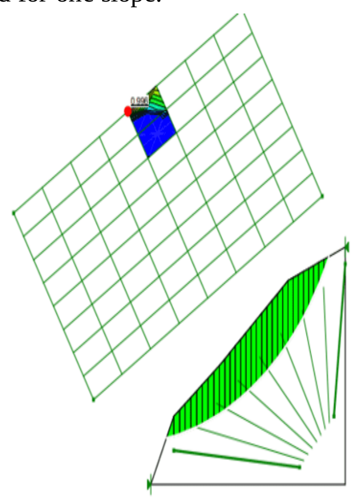

Fig. 6 2D slope analysis of first cross section for Ru=0.5

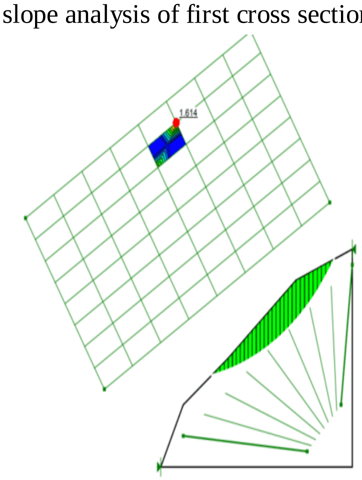

Fig. 7 2D slope analysis of first cross section for Ru=1.5

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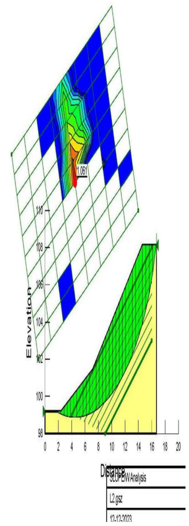

Fig. 8 2D slope analysis of second cross section for Ru=0.5

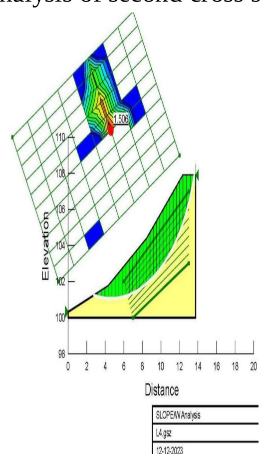

Fig. 9 2D slope analysis of second cross section for Ru=1.5

VII. CONCLUSION

The factor of safety of a structure is influenced by pore water pressure head through its effects on soil shear strength, effective stress, and the overall stability of the structure, particularly in saturated or partially saturated soil conditions. Higher pore water pressure heads typically correspond to lower effective stresses, resulting in reduced stability and lower factors of safety. For the specific issue examined in the research beyond a pore water pressure head (Ru) value of 1, the stability of the landfill decreases. Nevertheless, the Ru value does not significantly impact stability against slippage along the liner systems. The increase in pore water pressure during rainfall can reduce the factor of safety of slopes and embankments. If the pore water pressure exceeds the so it's shear strength, it can trigger slope failures or landslides.

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