A Review on Slope Stability Analysis

Mrittika Chakraborty and Prince Rathod

October 1, 2020

A Review on Slope Stability Analysis

Mrittika Chakraborty
Department of Civil Engineering
Parul Institute of Technology Vadodara, India
190305215001@paruluniversity.ac.in

Prince Rathod
Department of Civil Engineering
Parul Institute of Engineering and Technology
Vadodara, India
prince.rathod@paruluniversity.ac.in

***Abstract-*— Slope stability analysis is a rapid developing area of study in geotechnical engineering as it has gained its importance after some major slope failure catastrophe. To provide a slope which is economic and safe is a great concern in construction industry. A slope is considered stable if the forces available to resist the movement are greater than the force driving the movement. A number of slope failures in the recent year calls for the slope analysis and possible preventive measures. The aim of the paper is to provide an overview of the research work which has been carried out which focus on the factors affecting the slope stability like sudden seepage pressure, erosion, tectonic activities etc. mechanism of the slope failure, numerical analysis. Also the paper aims to review the common methods to mitigate the failure.**

Keywords—Slope Stability, Slope failure, Preventive measures

I. INTRODUCTION

A surface inclined at some angle from the horizontal which may be a rise or fall is called slope. There are two types of slope (1) Infinite and (2) Finite slope. In nature only finite slope exists. These finite slope are further divided into two: (1) natural (2) man-made. The man-made slopes are generally gentler and are constructed with respect to the time, cost and quality. Whereas the natural slopes are steeper, the failure of these natural slope are major concern of geotechnical engineers as they cause fatality and economic losses. The failure of the slope is primarily due to increase in the shear stress or decrease in the shear strength. There are various methods of slope stability analysis like, Limit Equilibrium Method (LEM), Finite Element Method (FEM) and Numerical method of modelling (NMM). The LEM or the analytical techniques have been in practice for long, but to analyze these natural slope failures calls for an integrated analysis of analytical techniques and FEM or NMM.

II. REVIEW OF PREVIOUS WORK DONE

This section comprises some of the literatures used for studying the slope stability analysis.

A. Stability Analysis of a Recurring Slope Failure along the NH-5, Himachal Himalaya, India.

(Singh et al., 2018) in their paper "Stability Analysis of a Recurring Slope Failure along The NH-5, Himachal Himalaya, India." They conducted an extensive study of the repetitive soil slope failure along the National Highway (NH)-5 in Jhakri region of Himachal Pradesh. Absence of any previous stability investigation of this recurring slope failure calls for an integrated geotechnical and numerical approach in order to understand the instability factors.

A slope failure study in this region is important because a wide range of slope movement keep pacing and there is strong relationship between the tectonic movement and erosional activity. The region of Himalayas shows a wide range of complex landslide, which about 30% of landslide in world which are potent of causing huge fatality and economic losses. (Li 1990; Dahal et al. 2009) Human activities like deforestation, poor design construction, hydropower projects etc. have added up the landslide event. (Haigh et al. 1989). The area of the Rampur- Jhakri of Shimla district is zone where the landslides are predominantly shallow is mostly initiated by the rainfall and is caused by the major debris depositions which has a glacio-fluvial origin. The constant Jhakri slope failure during every monsoon causes transport disruption and communication loss for long time. (Himachal Pradesh State Disaster Management Authority (HPSDMA) 2012). Therefore, the researchers have studied the mechanism of the slope failure and investigated the causes through field and geotechnical investigation. Using the Limit Equilibrium Method (LEM), Slide v7.0, an analysis of a pre-failure and post failure slope is carried out demonstrate the failure surface and deduce the most probable critical failure surface for both conditions respectively. From the geotechnical investigation parameters like particle size (silt= 19.07% to 37.93%; sand= 15.21% to 19.07%; clay=1.6% to 4.86%), Atterberg Limit (LL=24% to 29%; PL= 18%to 21%; PI=7%), cohesion (9.81 kPa), angle of internal friction (32°), coefficient of permeability (0.0026m/h), natural moisture content (12.80%), Unit weight (13.30 kN/m^3), bulk density (1420 kg/m^3), saturated unit weight (17.14 kN/m^3) and their values were deduced. A Scanning

Electron Microscope (SEM) analysis also has been carried out to understand the surface morphology of the soil sediments. An Energy-dispersive X-ray spectroscopy (EDS) was also carried out along with SEM. The EDS study concluded by stating that there is high Mg, Al, Fe, K, Si. There is close knit of the failure types, critical surface, gradient, height, slope geometry, pore water pressure lithology contributing to the mechanism of the landslide. (Picarelli and Abolmasov, 2014). The slope section selected for the study had a steep gradient and semi-circular failure surface. The geometry of the shallow slope is more relatable with the factors like failure type, critical failure type and amount of mass displaced. (Frattini and Crosta 2013; Chen et al. 2016). A graph plotted for the Jhakri slope (North and South section). The geometry of the failure indicates high unstable condition in the south section of the slope in both pre and post failure condition. Benching has been proposed for the southern section, exhibiting critical stability in dry condition. The northern section of the slope exhibits critical stability in dry state at a smaller height. The relation of the slope height and slope angle with the slope geometry indicates that both the section of the slope is unsafe, in dry state.

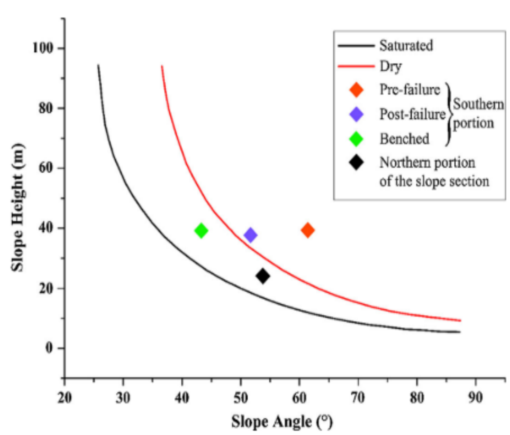

FIGURE 1. Critical slope height versus slope angle relation for soil slope geometry (after Hoek and Bray 1981)

The shallow slope failure activated by a rainfall infiltration has four phases: (a) Movement of the water to the failure zone or bedrock soil interface zone (surface flow, interflow), (b) cohesion loss or slide occurring through the layers of soil. (c) material mobilization. (d) collapse of the material. (Ellen 1988).

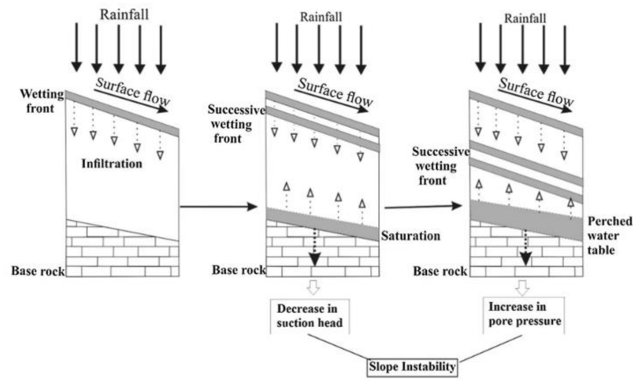

FIGURE 2. A sequential schema of shallow landslide initiation (after Malet et al. 2005; Kuriakose et al. 2009)

To define the rainfall threshold two empirical approaches based on the rainfall measurement were considered. They are (1) precipitation obtained for specific rainfall event (Guzzetti et al. 2007). (2) antecedent rainfall measurement (causing the slope to fail) (Iverson 2000; Godt et al. 2006). From the examination conducted it was concluded that the antecedent rainfall of 91mm for 30 days will cause the failure of the slope without any preventive measure and in post monsoon condition the slope will reactivate if it receives a rainfall of 110mm. For stability analysis of the slope LEM was carried out as it is an accurate and versatile method. For the FoS computation Bishop's Simplified (BS) and Morgenstern-Price (MP) methods was considered. From the analysis it was concluded that the slope is unstable even after the failure in the southern section the preventive measure of reinforced benching was proposed and it was found that the slope is stabilized.

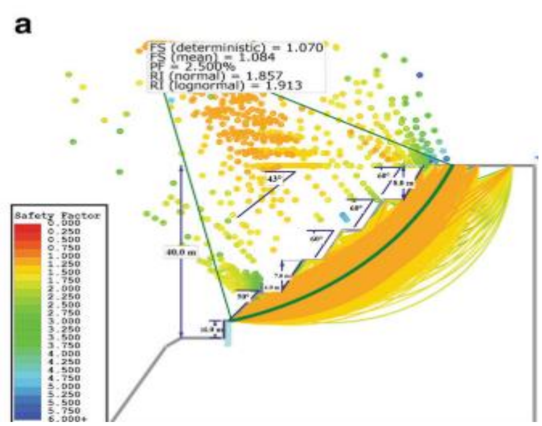

FIGURE 3. Slip surfaces from LEM result for a proposed benched slope

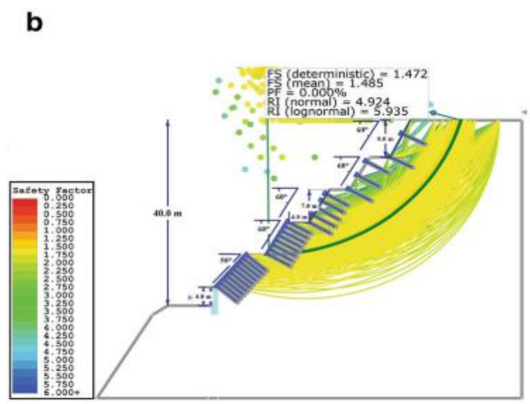

FIGURE 4. Slip surfaces from LEM result for a proposed reinforce benched slope

The angle, height and width of the bench is determined using hit and trial method. Furthermore, a sensitivity analysis is carried out know the sensitivity of the FoS. The results indicated that the Reliability Index(RI) of the pre, post failure slope is negative in both BS and MP method. Therefore, in the preventive measures uses both the benching and soil nailing to check the RI. The bench angle is kept 60° with 5 benches and overall slope is kept 43°. The soil nails used are 5 m long with a tensile capacity of 200kN tensile strength. In benched slope the RI is less than 3 in both BS and MP method which means the slope is unstable. But a reinforced slope is having a RI of 5.004 and 4.924 in both BS and MP method, respectively.

B. Rain- Triggered Slope Failure of the Railway Embankment at Malda, India.

(Raj & Sengupta, 2014) their paper "Rain-triggered slope failure of the railway embankment at Malda, India." They examined the railway embankment failure at Malda which cause the derailment of the train.

The height of the railway embankment was maximum 4.4m with the slope of 2(H):1(V). The width of the top of the slope is 6.7m and is designed to take an axial load of 25t of the train, which is a distributive load of 94.5 kPa. 30% of the sudden impact load is already included in this load which is a requirement of Indian Railways. (RDSO, 2003). The districts receive a rainfall of 2,000 to 4,000 per year, (IMD,2012). Malda on 28^{th} September 1995 received the maximum rainfall in the history of intensity 23.75 mm/h.(Khaladkar et al., 2009.)

The prime factor for the failure of this railway embankment slope was the rainfall the district received. So the researchers established a soil-water content and matric suction relationship for the embankment soil and also a numerical simulation with FE-code GEO-STUDIO (GEO-SLOPE,2007) was performed. Significant reduction in the factor of safety was indicated by numerical analysis which was found to be dependent on the intensity and duration of rainfall. The stability analysis of the slope is also carried out using the LEM methods. The Morgenstern-Price method, Janbu's method, Ordinary slice method and Bishop's simplified method.

From the Geotechnical analysis it was observed that the soil has an effective cohesion c' of 0.2 kPa and an effective angle of internal friction φ' of 29.5°. The graph shows that the soil is well graded soil.

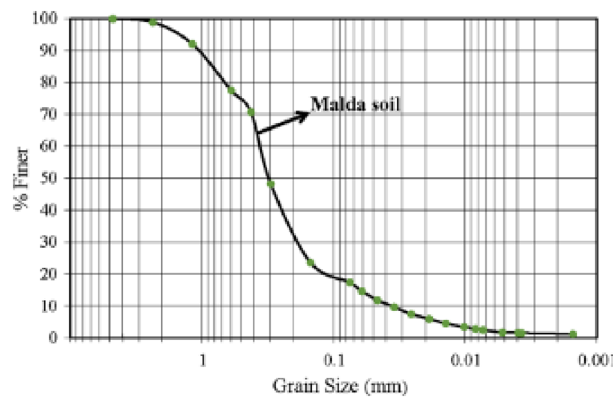

FIGURE 5. Grain size distribution of the embankment soils

Tension meters were used to determine the soil water characteristic curve using a standard method (ASTM,2004). The hydraulic conductivity with suction was found to be 8.4 x 10^{-4} cm/s. Empirically a relationship was established between the hydraulic conductivity and suction pressure using the (Genucheten, 1980).

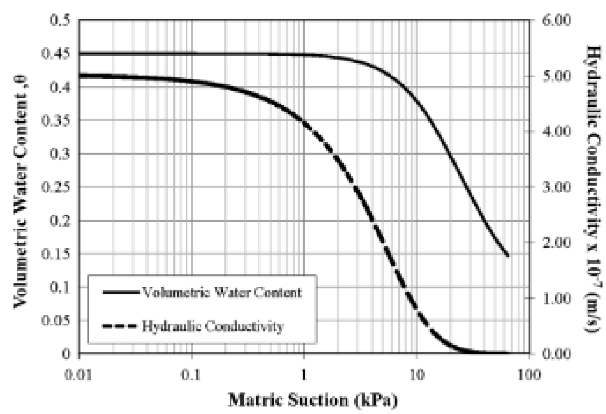

FIGURE 6. Variation of volumetric water content and hydraulic conductivity with suction pressures for the Malda soil.

From the numerical analysis it was observed, the embankment does not fail with the rainfall of 2 mm/h for 20h, but if this intensity of rainfall exceeds then the FoS drops rapidly. theoretically the embankment fails after receiving a rainfall of 4 mm/h of intensity for 8h. The slope remains stable of 3h if this intensity increases to 8 mm/h.

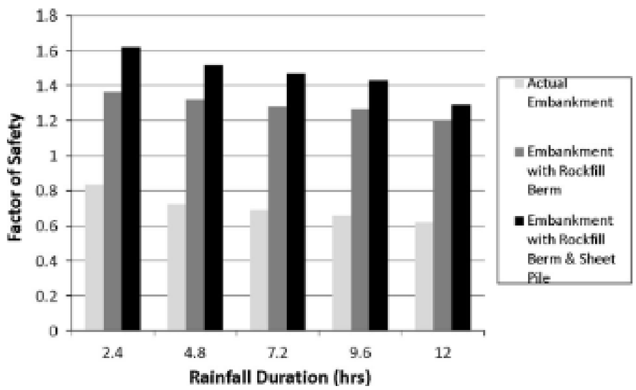

FIGURE 7. Factor of safety of the Malda embankment with proposed modifications for 25 mm/h rainfall events

The stabilization of the embankment with a 2 m wide free draining rock fill berm on top of slope can sustain a rainfall of 25 mm/h intensity for 12h to enhance this stabilization 5 m long sheet pile can be driven to protect the toe of the slope.

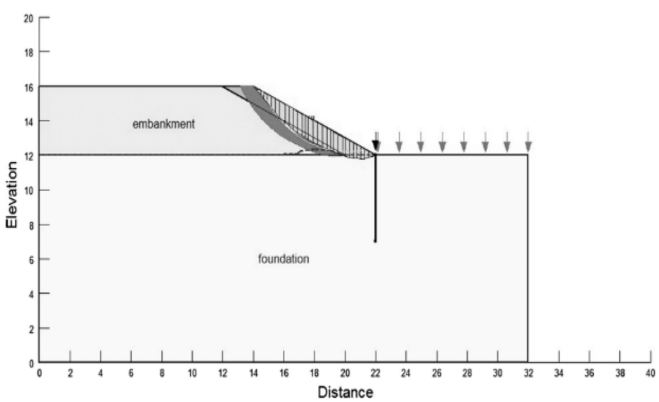

FIGURE 8. Critical sip surface within the embankment with rock fill berm and sheet piling in place

C. A hill slope failure analysis: A case study of Malingaon village, Maharashtra, India

(Shah et al., 2019) in their paper on "A hill slope failure analysis: A case study of Malingaon village, Maharashtra, India", studied and concluded that the landslide catastrophe of 30th July 2014, was triggered due the excessive rainfall and un-scientific method of agricultural practice by the dwellers. Geological composition of this slope is basaltic strata. (Singh et al., 2016). The geotechnical investigation of the soil samples from the bottom, middle and top of the slope revealed the parameters to be specific gravity (2.8-2.25), bulk density (0.62 g/cm^3), dry density (1.35g/cm^3-1.26g/cm^3), Atterberg limit (LL= 52.5%; PL= 31.75%-27.88%; PI=20.75%- 24.62%), cohesion (0.13kg/cm^2- 0.42 kg/cm^2), angle of internal friction (4.35°- 36.4°). The specific gravity of the soil samples infer that the soil has a high amount of sand particle, but with respect to the water content the soil is sandy-clayey soil. (Sathe, S. S., & Mahanta, C. 2019).

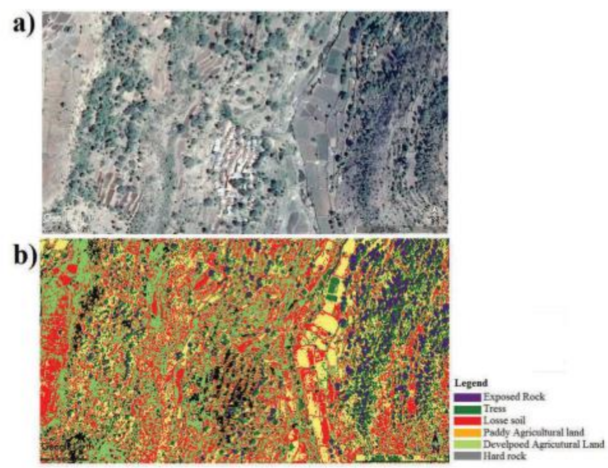

FIGURE 9. Land use land cover map of Malingaon before occurrence of landslide in year 2014 (a and b)

For the recognition of the vulnerability of the slope images from Google Earth map 2018 were introduced into ArcGIS 9.1 and analyzed, before and after the landslide. The comparison showed that the landslide was in the area where the agricultural land was developed this developed agricultural land caused a lot of loose soil in the surrounding of the hill which also contributed to the hill slope failure work includes numerical analysis, seepage analysis, geotechnical properties of soil samples from various depth of the slope.

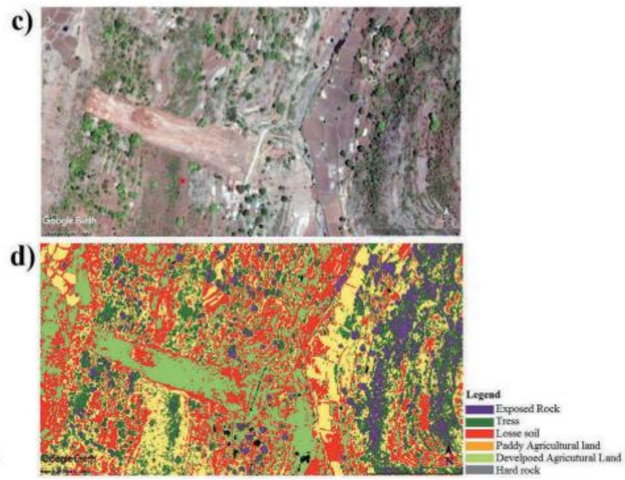

FIGURE 10. Land use land cover map of Malingaon before occurrence of landslide in year 2014 (c and d)

III. CONCLUSION

From the review of the papers a conclusion can be drawn that geotechnical parameters like- particle size, Atterberg limits, cohesion, angle of internal friction is important in determining the factor of safety of the slope. Also, in a tropical country like India, the failure of slopes is governed by the seepage of the rainwater.

REFERENCES

[1] ASTM (2004). Standard guide for measuring matric potential in the vadose zone using tensiometers. ASTM standard D3404-91. American Society of Testing materials, West Conshohoken, PA.

[2] Chen XL, Liu CG, Chang ZF, Zhou Q (2016) The relationship between the slope angle and the landslide size derived from limit equilibrium simulations. Geomorphology 253:547–550

[3] Dahal RK, Hasegawa S, Yamanaka M, Dhakal S, Bhandary NP, Yatabe R (2009) Comparative analysis of contributing parameters for rainfall-triggered landslides in the Lesser Himalaya of Nepal. Environ Geology 58(3):567–586

[4] Ellen SD (1988) Description and mechanics of soil slip/debris flows in the storm. In: Ellen SD, Wieczorek GF (eds) Proceedings of the conference on landslides, floods and marine effects of the storm of January 3–5, 1982, in the San Francisco Bay Region, California, Washington, USA, USGS professional paper 1434:03–112

[5] Frattini P, Crosta GB (2013) The role of material properties and landscape morphology on landslide size distributions. Earth Planet Sci Lett 361:310–319

[6] GEO-SLOPE Intl. Ltd. (2007). Seepage modeling with SEEP/W: an engineering methodology. 2007 edition, GEO-SLOPE Intl. Ltd, Calgary, Alberta, Canada

[7] Godt JW, Baum RL, Chleborad AF (2006) Rainfall characteristics for shallow landsliding in Seattle, Washington, USA. Earth Surf Process Landf 31:97–110

[8] Guzzetti F, Peruccacci S, Rossi M, Stark CP (2007) Rainfall thresholds for the initiation of landslides in central and southern Europe. Meteorog Atmos Phys 98:239–268

[9] Haigh MJ, Rawat JS, Bartarya SK (1989) Environmental indicators of landslide activity along the Kilbury road Nainital, Kumaun Lesser Himalaya. Mt Res Dev 9:25–33

[10] Himachal Pradesh State Disaster Management Authority-HPSDMA (2012) Activity Report (2007–2011). Government of Himachal Pradesh, Department of Revenue (Disaster Management Cell). www. hpsdma.nic.in

[11] Hoek E, Bray JW (1981) Rock slope engineering, 3rd edn. Institute of Mining and Metallurgy, London

[12] IMD (2012) Monsoon 2012: a report. IMD MET monograph no. 13/2013, Pai DS, Bhan SC (eds) National Climate Centre, Indian Meteorological Department, Government of India, Pune, India

[13] Iverson RM (2000) Landslide triggering by rain infiltration. Water Resource Res 36(7):1897–1910

[14] Khaladkar, R. M., Mahajan, P. N., & Kulkarni, J. R. (2009). *Alarming Rise in the Number and Intensity of Extreme Point Rainfall Events over the Indian Region under Climate Change Scenario Indian Institute of Tropical Meteorology*.

[15] Kuriakose SL, Sankar G, Muraleedharan C (2009) History of landslide susceptibility and a chorology of landslide-prone areas in the Western Ghats of Kerala, India. Environ Geol 57(7):1553–1568

[16] Li T (1990) Landslide management in the mountain area of China, ICIMOD Kathmandu. Occasion Paper no. 15, p 50

[17] Malet JP, Asch TWJV, Beek RV, Maquaire O (2005) Forecasting the behaviour of complex landslides with a spatially distributed hydrological model. Nat Hazards Earth Syst Sci 5(1):71–85

[18] Picarelli L, Abolmasov B (2014) Introduction: recognition and mechanics of landslides. In: Sassa K et al (eds) Landslide science for a safer geo-environment, vol 1. Springer, Switzerland, pp 295–296

[19] RDSO (2003) Guidelines for Earthwork in Railway Projects. Guidelines no. GE: G-1, Ministry of Railways, Govt. of India, Geotechnical Engineering Directorate, Research Designs and Standards Organization, Lucknow, India

[20] Sathe, S. S., & Mahanta, C. (2019). Groundwater flow and arsenic contamination transport modeling for a multi aquifer terrain: Assessment and mitigation strategies. Journal of Environmental Management, 231, 166–181.
[21] Raj, M., & Sengupta, A. (2014). *Rain-triggered slope failure of the railway embankment at Malda ,*. 789–798. https://doi.org/10.1007/s11440-014-0345-9
[22] Shah, C. R., Sathe, S. S., Bhagawati, P. B., & Mohite, S. S. (2019). A hill slope failure analysis: A case study of Malingoan village, Maharashtra, India. *Geology, Ecology, and Landscapes*, *00*(00), 1–6. https://doi.org/10.1080/24749508.2019.1695714
[23] Singh, A. K., Kundu, J., & Sarkar, K. (2018). Stability analysis of a recurring soil slope failure along NH-5, Himachal Himalaya, India. *Natural Hazards*, *90*(2), 863–885. https://doi.org/10.1007/s11069-017-3076-z