ASSESSMENT OF A TYPICAL LANDSLIDE IN UTTARAKHAND AND MITIGATION SOLUTIONS

A Dissertation

Submitted for the partial fulfilment of the

requirements for the award of the degree

of

Masters of Technology

in

DISASTER MITIGATION AND MANAGEMENT

By

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CENTRE OF EXCELLENCE IN DISASTER MITIGATION AND MANAGEMENT

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MAY, 2018

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled, **"Assessment of a Typical Landslide in Uttarakhand and Mitigation Solutions"** is presented on behalf of partial fulfilment of the requirements for the award of degree of "Master of Technology" in Disaster Mitigation and Management submitted in the **"Centre of Excellence in Disaster Mitigation and Management"** of the Indian Institute of Technology, Roorkee, is an authentic record of my work done under the guidance of **Prof. B.K Maheshwari, IIT Roorkee** and **Dr. Ravinder Singh,** Consultant (Landslide & Avalanche), NDMA.

Date: **May, 2018**

Place: **Roorkee** **(Deepak Rawat)**

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of our knowledge and belief.

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ABSTRACT

As we know landslide is a natural phenomenon as well as extremely catastrophic natural hazard. It has a potential to damage any natural landscape, road, railway track, human life, and property. India has many landslide prone states wherein with each passing day, an increase in the population of the country has become a concern for landslide. A larger part of Uttarakhand is already affected by the landslide. This makes it compulsory for us to have a proactive approach for the prevention from landslide rather than waiting for a disaster to occur (NDMA, 2009)

The Lakhwar Dam Top Landslide is located at a distance 70km from Dehradun on Dehradun-Yamnotri highway (NH-123) junction with Vikasnagar-Kalsi-Barkot in the district Dehradun, Uttarakhand, India. On the basis of field study survey, the slope has been categorized into two parts. These two categorised slopes were studied and it was found that one of them is potential rock slide and the second is potential debris slide which have been under consideration for detailed investigation. The site is visited during monsoon and after monsoon season. The available predominant materials at the site are soil and rock where soil type is well graded silty gravel and rock type is Phyllite and Sandstone.

To quantify the susceptibility of landslide, the Central Building Research Institute (CBRI), Roorkee uses Landslide Susceptibility Score (LSS), while Bureau of Indian Standards (BIS) for uses Landslide Hazard Evaluation Factor (LHEF). Once the problem of landslide is quantified, various civil engineering measures can be suggested which can vary from spot bolting to pattern bolting to erection of retaining wall and even modification of slope.

For long-term remediation of Lakhwar Dam Top Landslide, a slope stability analysis and Geotechnical studies were carried out to evaluate suitable mitigation measures. Soil nailing with short creating, Slope Modification with retaining structure, and Drainage Measure etc. are predominantly set of remedial measures designed and suggested to improve the slope and national highway.

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Chapter-1

Introduction

Landslide is a one form of ground failure, which impacts communities all across the world. Despite the advance in technology, losses increased to result in life losses, human suffering, billions of dollars of property and environmental humiliation. As day by day population is increasing and communities have become more complex, the cost of a landslide in terms of economics, societal, and ground failure is rising day by day. As a nation, it is required to understand the capabilities, identify the landslide hazards and also the strategies to apply mitigation measures. The development mechanism to provide a set of mitigation measure for a particular landslide according to its characteristics is needed. The world help in minimizing the infrastructural damage and other losses.

1.1 Definition

Landslide denotes downward and outward moment to slope forming material under the action of its own weight. It is the movement of rock, debris or the earth down the slope. They result from the failure of the material which makes up the hill slope and is driven by the gravity alone. These are also sometimes termed as a landslide or slope failure.

Table 1.1: Type of Landslide (After Varnes,1978)

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX		Combination of two or more principal types of movement		

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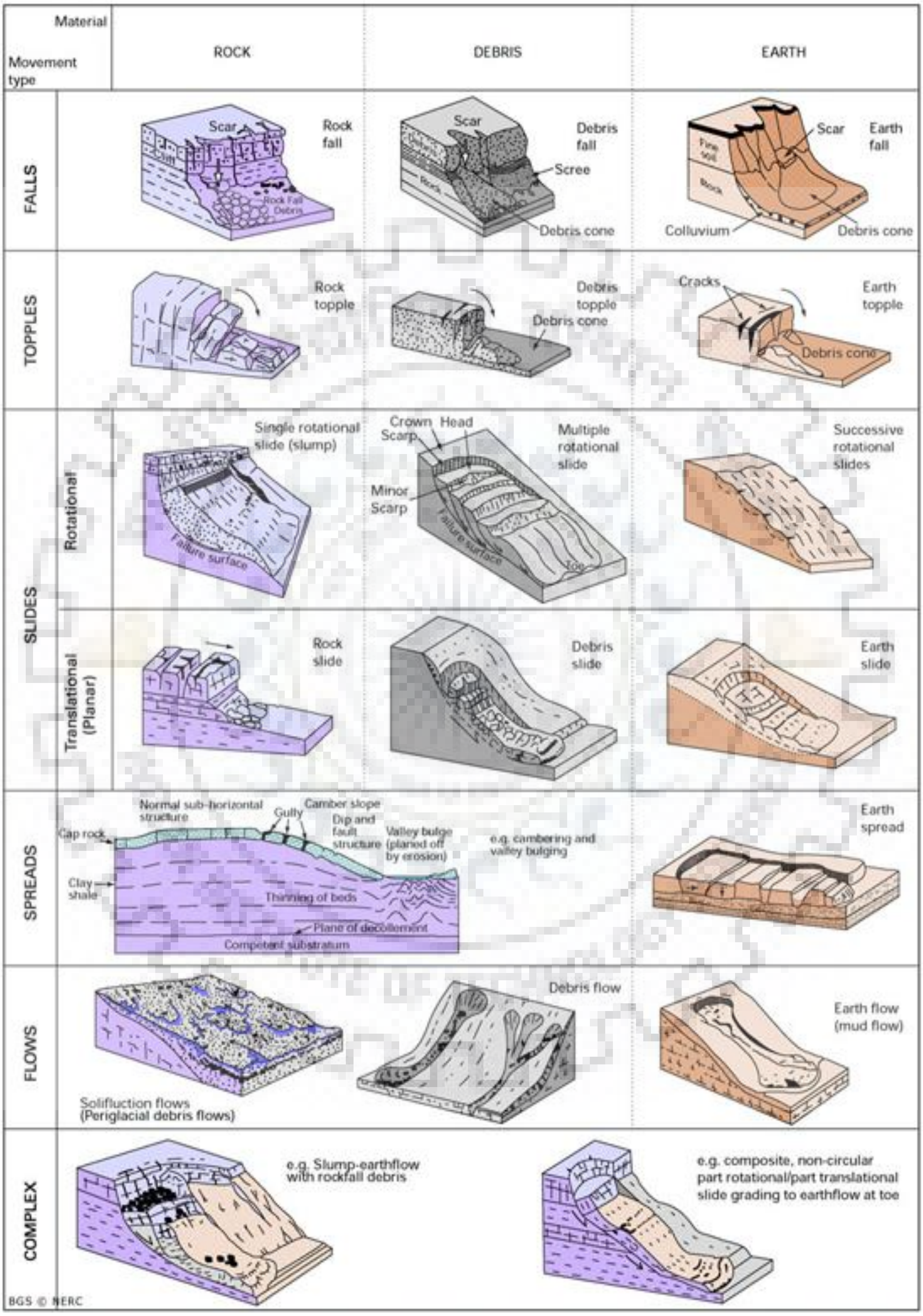
Table 1.2: Landslide moment classification (After Hungr et al., 2014)



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1.2 Causes

Landslides can be triggered by natural as well as anthropogenic

Natural cause includes:

1. Elevation of pore water pressure by saturation of slope material from intense or prolonged rainfall, and seepage,
2. Vibration caused due to the earthquake,
3. Undercutting of cliffs and banks by waves or river erosion and
4. In some case volcanic eruption too.

Anthropogenic causes include:

1. Interference with or changes to natural drainage,
2. Unsustainable cutting of trees on the slope,
3. Leaking pipes such as water and sewer reticulation,
4. Modification of slope by the construction of roads, railways, building,
5. Overloading slope,
6. Mining and quarrying activities,
7. Vibration from heavy traffic, blasting etc.
8. Excavation and displacement of rocks.

1.3 Need of the Study

Landslide is a natural hazard and it is very risky for society and if not controlled, it becomes a disaster. As a part of community of Disaster mitigation and management, our endeavours are always towards making our society disaster resilient. To pursue that motivation, a landslide affected area is chosen and it was studied to understand the causes of landslide and how to mitigate them. In that context, Lakhwar dam landslide was chosen for study.

According to the google images, the landslide started since 2004, however local findings states that it was stared in 1999 when the first rock fall detached and fall down nearer to the existing natural water outlet source. After interpreting the various years google images Figure 1.1(a) to Figure 1.1(f) showing different year images of landslide and it was observed that landslide area is increasing and widening year by year. On this basis, it can be used to investigate the reason of extended affected areas of landslide. It was observed and identified that material at the site

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is colluvial and rocks are phyllite and sandstone. In the year 2002, landslide had a very small area that was affected but later the affected area has increased due to ignorance of landslide mitigation. Earlier the problem started from middle of the landslide but later the source of the landslide was changed and now it is from the head of the landslide. The reason behind this was the construction of a new road in year 2011 where all slope cutting material were dumped at the head of the landslide and it eroded the head of the landslide as well as got accumulated between the catchment. When a catchment gets heavy rainfall, water and all accumulated colluvial material start sliding down rapidly as the slope is very steep. In the year 2010, due to heavy rainfall landslide became severe and came to attention of public work department of Uttarakhand and they applied some mitigation measures to control the landslide. Due to lack of complete understanding about the existing hydrology, geography and the root cause of the affected area, some retaining structure such as concrete block and gabion wall at the toe of landslide was constructed. As a result, the retaining structure got destroyed and became debris as show in Figure 1.2. During the monsoon season with rainfall as the landslide had a very high velocity due to steep slope.

Fig.1.1(a): Landslide affected area in 2004 **Fig.1.1(b):** Landslide affected area in 2010

Fig.1.1(c): Landslide affected area in 2011 **Fig.1.1(d):** Landslide affected area in 2013

Fig.1.1(e): Landslide affected area in 2016 **Fig.1.1(f):** Landslide affected area in 2017

Figure 1.1: Landslide affected area of Lakhwar Dam Top Landslide at various stages. (from Google Earth)

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Figure 1.2: Destroyed retaining structure at the toe of the Lakhwar Dam Top Landslide (Photo taken on 14th January,2018)

The patch where the landslide occurred was earlier free from any water source but after mass sliding from the hill it came out and water started flowing on the surface of landslide as well as on the national highway. Figure 1.3 and 1.4 showing the water source before 2004 and after the 2010 respectively.

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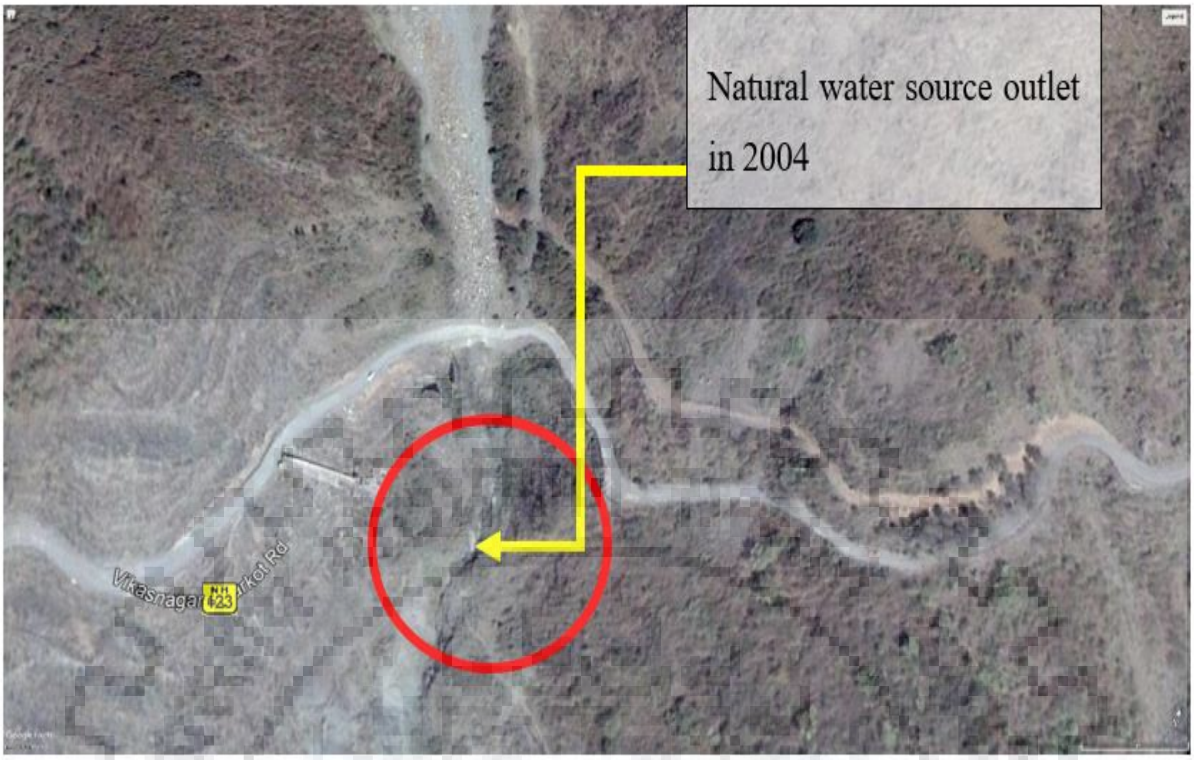

Figure 1.3: Showing water source below the road in 2004 (from Google Earth)

Figure 1.4: Drainage above the road in 2017 (Photo taken on 25th September,2017)

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As discussed above, it can be concluded that Lakhwar dam top landslide is very risky and has become more hazardous due to ignorance of mitigation. Now it has become the need of study to find the solutions on the bases of past experience, site investigation, existing material property and other geological condition on site.

1.4 Objectives

Lakhwar dam top landslide situated at Uttarakhand experiences unstable slope defect which is hazards to the adjacent national highway. To solve this issue following objectives have been taken up to reduce the risk.

1. Collection of field data.
2. Sample test and analysis.
3. Assessment of Landslide
4. Suggesting suitable measures to reduce the risk and vulnerability due to an unstable slope.

1.5 Methodology

The methodology shows in Figure 1.5 to be used in the dissertation is described in brief as under:

1. Collection and analysis of field data.
2. Visual interpretation of Google Earth image: Preparation of landslide profile for geo-morphological analysis of slope. Necessary field data and samples will be collected and analysed in the laboratory.
3. The study area will be visited during monsoon and post monsoon. The field data related to mass wasting, slope morphology, soil characteristic, and soil depth and soil texture, land use/land cover pattern and its association, lithology, landforms and structural features etc will be collected in detail. The available weather data will be collected. The field photographs of the important view of landslide and other related features will be taken during the field investigations.
4. Check Slope Stability
5. Designs & Protection Measures: The appropriate landslide mitigation / slope stabilisation measures will be designed with stability analysis and load bearing capacity of slope as per the data analysis.

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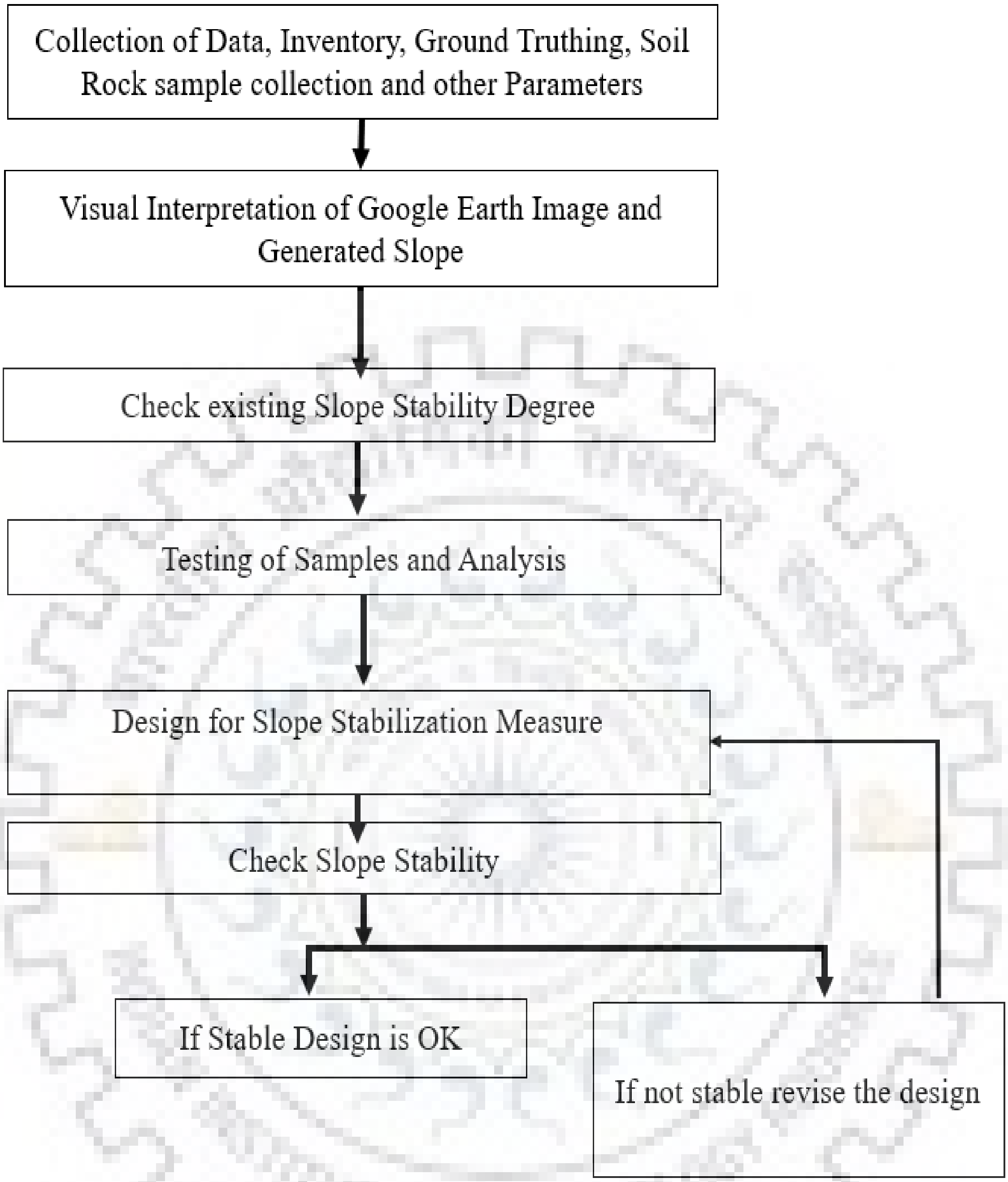

Figure 1.5: Flow Chart of Methodology

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Chapter– 2

Literature Review

A thorough understanding of the landslide phenomenon and their behavior in various terrains is needed before any study about mitigation measure is taken up. There have been various instances where landslide once triggered gets reactivated again when exposed to a triggering factor either earthquake or rain.

2.1 Background

The evaluation of slopes stability depends on various factors such as geometrical, geological, hydrological, topographical, and material characteristics that influence the stability of a particular slope. Information on these characteristics is required to reliably perform and interpret the results of both static and seismic stability analysis.

Laboratory tests are generally used for the physical characteristics of many subsurface materials to input the data into a numerical modeling of slope stability analysis. Once the information is obtained, stability analysis can be performed. Although, the focus is on the methods of slope stability analysis, which itself an important part of a complete slope stability evaluation.

Slopes usually becomes unstable when the shear stresses on a potential surface exceeds the shearing resistance of the soil. In case of slopes where stresses on the potential surface failure are high, the additional earthquake-induced stresses needed to trigger failure are low. So, in this case, seismic slope stability depends upon the static slope stability. Limit equilibrium method is commonly used for slope stability analysis whereas stress-deformation analysis, using the finite element method is performed for large problems.

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2.2 Past Studies on Landslides

More than 3000 deaths have been reported in Uttarakhand alone, according to Government of India between the years 2001 – 2012 (data.gov.in). The Kedarnath floods and landslide of June 2013 resulted in perishing of more than 5000 individuals. In 2014, rainfall and landslide caused 17 people to be buried under the debris in Kath Bangla area of Dehradun city. In 2015, incessant rainfall in monsoon caused landslides in many districts of the state obstructing the smooth running vehicles on the roads and bringing the lifelines to a standstill. The damage to infrastructure is immense and each event of landslide pushes the development process out of the way affecting the social and economic condition of inhabitants, often leaving a trauma in the minds of victims.

According to a report by National Institute of Disaster Management titled "Uttarakhand Disaster – 2013", Uttarakhand region has experienced 11 earthquakes of magnitude greater than 6 during the last century. Landslide is manly common in two zones lying in close proximity of two major tectonic discontinuities:

1) Main Boundary Thrust (MBT)
2) Main Central Thrust (MCT)

Apart from that, according to Earthquake Hazard Zonation Map of India, out of 13 district of Uttarakhand Bageshwar, Chamoli, Pithoragarh, Rudraprayag, and Uttarkashi fall under seismic zone-V. Being so much seismically active, combination with fragile slope of young Himalayas renders the major cities established in valleys of these mountains highly prone to landslide caused devastation as earthquake is one of the major triggering factors for the genesis of landslide. In the surrounding regions, snow-covered higher altitudes of holy shrines of Hemkhund Sahib, Badrinath, Kedarnath, Gangotri and Yamunotri, the hazard of avalanche also become prominent. Similar is the scenario of most of the hilly states of the country. The fragile and young slopes of Himalayas are highly prone to landslide due to instability.

According to Hasegawa and Danal (2009), the study of the natural sliding slope of large scale along the highway, the effect and cause of debris flow during monsoon period, large-scale landslide is needed to be considered during construction of highway cut slope in hills and their mitigation measures were suggested.

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Highland and Bobrowshy (2008) stated that an old land use policies cannot always reflect the best plan for land use, which is weak for landslides. Due to poor or non-underground land use policies, it reduces the probability of realistic risk or damage from Geological hazards, they are many financial complexities and complications of the communications.

Landslides are often described as local problems but their effect and costs often exceed local jurisdiction and can cause the state or provincial problems. Wherever possible, it should be consulted with professional geologist/engineers or those who have experience for the successful mitigation of unstable slope before mitigation measures are taken.

Interrelationship of landslide with other natural hazards- The multiple hazards effect

Natural hazards such as volcanic eruption, flood, earthquake, and landslide can occur simultaneously, on one or more of these threats can trigger one or more of the others. Landslide is often the result of flood, volcanic activity, rainfall, earthquake and may result in subsequent threats. This can be understood by examples as given:

1) Volcanic eruption induced earthquake or induced landslide that block the river, due to which the water is backed up behind the mass and floods in the upstream area.
2) An earthquake induced landslide can case a fatal tsunami if enough landslide material falls down into the water body in reservoir to remove large amount of water. Figure 2.2 shows multi-hazard event involving landside.

Figure 2.1: The 1999 multi-hazard event in Tanaguarena, America. (After Matthew, 2008)

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2.2.1 NDMA Guideline on Landslides

National Disaster Management Authority has taken a review on the disaster management mechanism which was done by the Government in June 2002 and the matter of disaster management was shifted from the Ministry of Agriculture to the Ministry of Home Affairs. Subsequently, the Geological Survey of India was declared the nodal agency for landslides by the Government in January 2004. The prevention of loss of life and property due to natural calamities is being viewed very seriously by the Government of India. As a part of this strategy, the Government decided to institute task forces for landslides. The work done by them is-

(a) Geological and Geotechnical Investigations: For landslide prediction, one needs to find out when and where it will occur, and how far and how fast it will move. For the design of control measures for landslide management, one needs to understand the landslide type (its classification), the different possible modes of failure, the location of the landslide boundaries, the operating shear strength characteristics of the boundary shears, and how the pore pressure varies on the landslide boundaries with time. Geotechnical investigations for mass movements like rapid motion landslides, multi-tier landslides, rock falls, debris flows and avalanches may throw up many other investigational requirements.

(b) Landslide Risk Treatment: Risk treatment is the ultimate aim of risk management which helps in mitigating the effects of a natural hazard. Once the risk has been analysed, the strategy is to identify the options and methods for treating the risk. Landslide risk can be mitigated through five approaches used individually or in combination and those are Restricting Development in Landslide Prone Areas, Codes for Excavation, Construction and Grading, Protecting Existing Developments, Monitoring, and Warning Systems.

(c) Landslide Monitoring and Forecasting: Landslide monitoring is generally not practiced in our country. Therefore, few landslides get identified for monitoring and early warning. Methods used for monitoring landslides can be Surface Measurements of Landslide Activity and Sub-Surface Measurements of Landslide Activity.

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(d) Hazard Zonation Mapping: NDMA divided the whole country in different landslides zones for the easiness of the study.

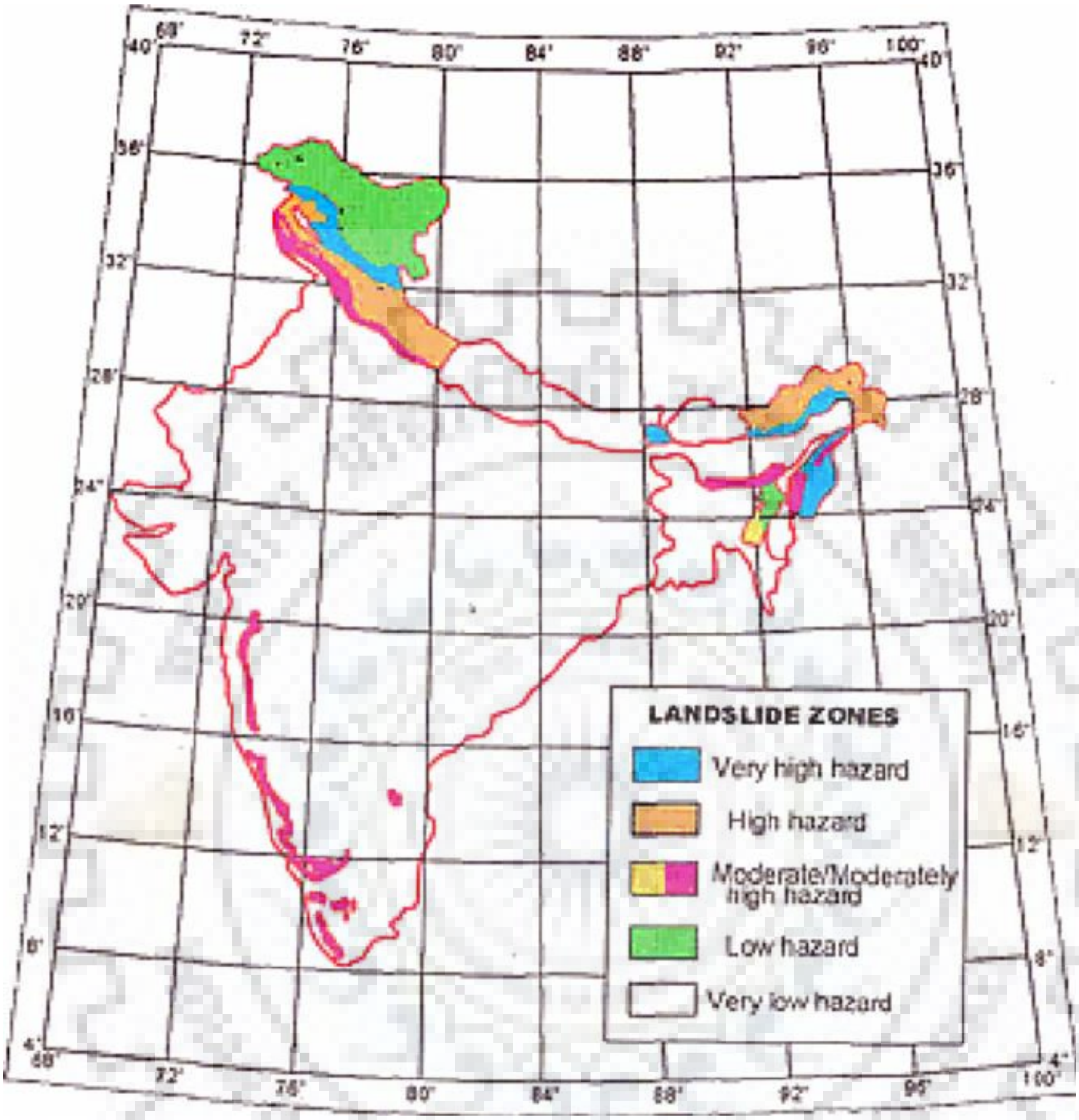

Figure 2.2: Landslide Hazard Zonation Map of India Prepared by GSI (Source: NDMA, Govt. of India)

(e) Awareness and Preparedness: The level of awareness about landslides has been quite low compared to other disasters like earthquakes, floods, and cyclones. State governments/SDMAs of landslide affected areas in collaboration with the nodal agency and other key stakeholders, are making special efforts to mobilize communities to carry out landslide mitigation efforts. Organizations and institutions like the GSI, NIDM, IITs, CDDM, and other knowledge-based institutions including some NGOs will be entrusted with the responsibility of preparing material for awareness generation campaigns pertaining to the landslide prone states in the country in a scheduled manner.

(f) Training, Documentation, Research, and Development:

The nodal ministry in consultation with the TAC and in collaboration with the MoM-GSI. The SDMAs/DDMAs, BRO, CoA, NGOs, central and state education departments, IITs, universities and other academic institutions with the help of technicians, administrators, and rescue workers who have been well trained and oriented to act during emergency situations contribute significantly in reducing the impact of disasters.

2.3 Case Study

Varunavat Landslide

Uttarkashi town, Garhwal Himalaya, India was severely affected by the Varunavat hill landslide, which occurred on 23 September 2003. The houses situated at the foot of the hill were completely destroyed; however, there were no casualties. Figure 2.3(a) and Figure 2.3(b)showing the pre and post scenario of Varunavat hill.

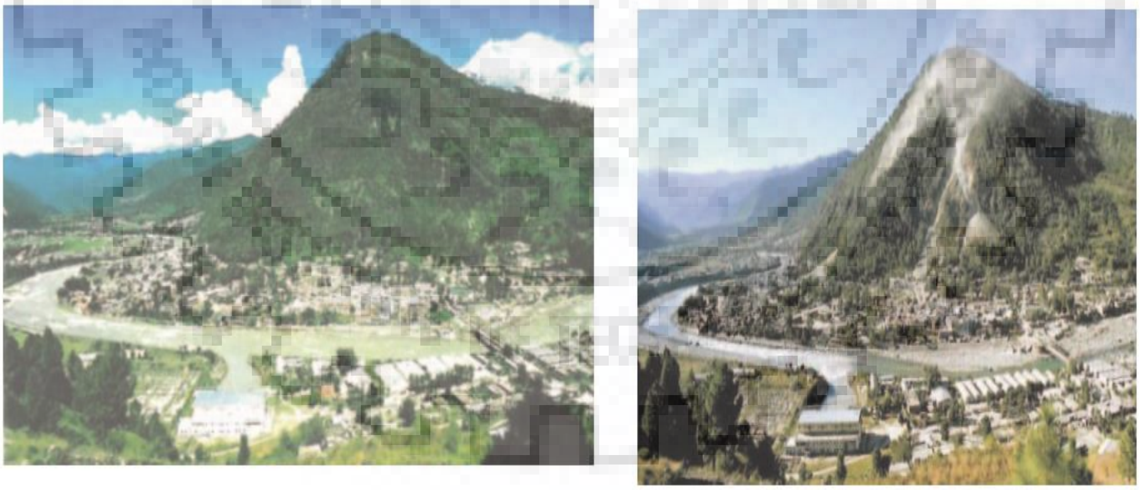

Figure 2.3 (a) Pre-landslide scenario of the Varunavat hill **Figure 2.3 (b)** post-landslide scenario of the Varunavat hill (Pande & Uniyal,2007)

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Geology

Uttarkashi town is situated at the foot of the Varunavat hill on the right bank of the river Bhagirathi in Uttarakhand State of India. The earthquake originated from slipping of segments of faults in the active zone of the Main Central Thrust (Valdiya 1991). The maximum peak ground acceleration was 0.29g at Uttarkashi. Geological map of the area. Rocks constituting the Varunavat Parvat are mainly quartzite and phyllites belonging to Damta group, dipping into the hill at 30–35 (Gupta and Bist,2004).

Slope instability and causes

The causal factor associated with the landslide initiation was the continuous rainfall that occurred for several days before the slide was triggered on 23 September 2003. The jointed and fractured rocks acted as pathways for water percolation and thereby developed high pore pressure leading to failure. From the rainfall data of 1990–2003 it was observed that the annual total rainfall in the area was about 1350 mm, with 60% of rainfall falling in the months of July–September (Gupta & Bist 2004). The average annual rainfall in the area for the year 2003 was above normal. In July and August 2003 there was continuous rainfall with a peak of 140 mm on 5 July. In September 2003 continuous rainfall fell for 13 days before the landslide was triggered but the intensity was not especially high. On 23 September, the day on which the slide was triggered, the rainfall was only 35 mm. This indicates that cumulative rainfall over a period of days was primarily responsible for triggering the landslide rather than high-intensity rainfall.

Mitigation measures

The Geological Survey of India recommended control measures to arrest the sliding activity. These are mainly slope grading, shotcreting, surface drainage and rock anchoring. To implement these measures a vehicular track was made to reach the uphill slope. The accumulated debris resting on the middle of the slope and at the road level was removed and disposed of in an adjacent valley and covered with biodegradable jute mesh to avoid erosion and debris flow. The control measures were implemented during 2008–2009. The slope has been modified and shotcreting has been applied with wire mesh reinforcement on the entire slope. Rock anchoring and rock bolting has been implemented to strengthen the weak jointed and fractured rocks. After covering the main landslide scarp at the crown portion with geo-grid, bio-measures have been adopted to protect the slope from erosion. Special grass has been

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planted to stabilize the slope through root reinforcement. Subsurface horizontal drains have been installed at various levels to drain groundwater. Surface drainage has also been constructed at various levels to drain surface runoff from the slope. At the toe, a retaining wall was constructed to provide support to the slope. At present Figure 2.4, the slide appears to be stabilized and no activity was reported after the implementation of the above control measures.

Figure 2.4: Present scenario after implementation of control measures at Varunavat Landslide (Photo taken on 31st December,2017)

Chapter -3

Study Area and Data Use

Analysis of any slope is needed to determine the properties of material, land use and land cover, lithology and seismic zone in which the slope or site exists. Hence, a detailed investigation is carried out and samples are collected from the field. In this section, the location of site, type of materials present, existing vegetation and hydrology are described in detail.

3.1 Location of the Landslide

The lesser Himalaya in Uttarakhand is well known for the frequent occurrence of landslide hazards. The study area is located at a distance 70km from district Dehradun on Dehradun – Yamunotri NH-123 junction with Vikas Nagar-Kalsi-Barkot in the Uttarakhand state of India. Lakhwar dam top landslide is situated on the NH-123 section km (37) from 2 to 4, dam top near village Lakhwar and is referred as Lakhwar Dam Top Landslide. Figure 3.1 shows the location of landslides in district Dehradun.

Geographically, the landslide is located in tile number 43N between latitude 30^{0}31’14.25” North and 30^{0}31’7.08” North and longitude 77^{0}55’7.89” East and 77^{0}56’54” East. Elevation from MSL of the landslide crown and toe of landslide respectively are 1330meter and 840 meters. At the elevation of 950 MSL on the landslide, there is a natural water outlet. It is a perennial stream water flowing on the surface which creates water seepage. This natural stream adjoins the Yamuna river at the downhill slide below the road level as shown in Figure 3.2. The total length of the landslide is 650 m Figure 3.2, showing the global existing condition on earth.

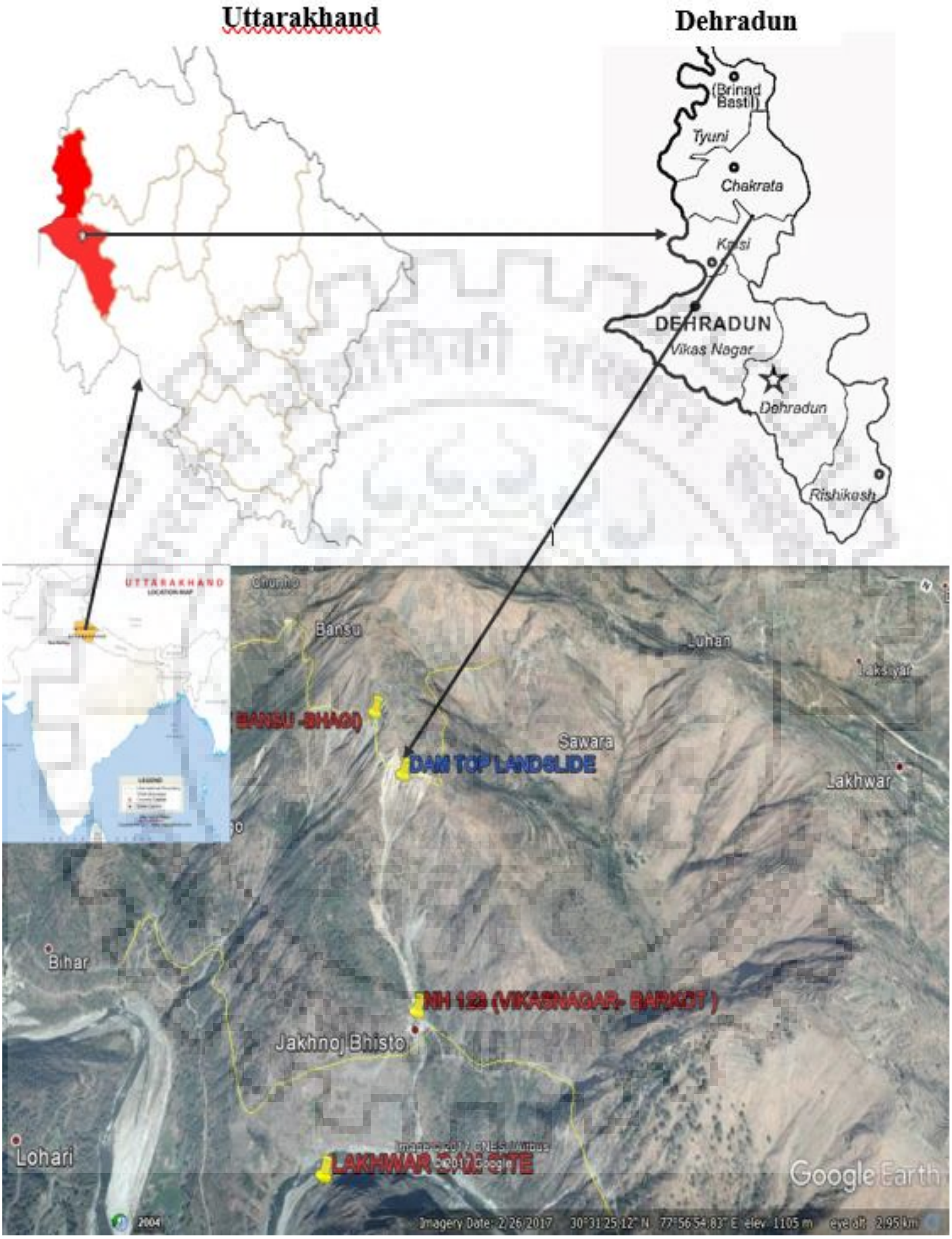

Figure 3.1: Location map of Lakhwar Dam Top landslide

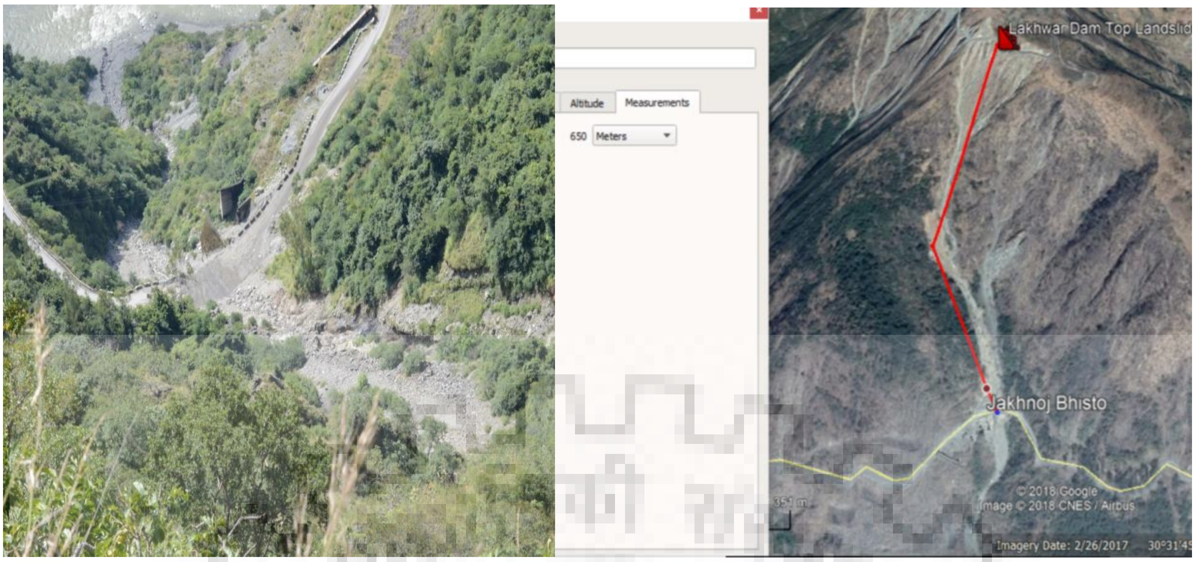

Figure 3.2: Landslide joining the river and showing existing total effected length of 650 meters on Lakhwar Dam Top

The type of landslide is complex because it has toppled slide whereas the slide is of translational type as well as the state of activity of landslide is suspended. The suspended landslide has moved within the last twelve months but not active at present. Distribution activity of landslide is retrogressive and in a retrogressive landslide, the rupture surface extends in the direction opposite to the movement of displacement.

The left flank of the landslide is quite stable as compared to the right flank. Right flank is extending towards the right corner of the landslide. For better reference, if it is to be considered that landslide head of the landslide is the source of the landslide. All loose materials and water in the rainy season are collected in the catchment and the catchment outlet is nearer to another hillslope and because the catchment outlet is nearer to another hill, the debris strikes the hill and erodes the striking portion. In every Rainy season, the same phenomenon is repeated due to which the erosion is extended, resulting in an increase in the size of a landslide at a particular location as shown in Figure 3.3.

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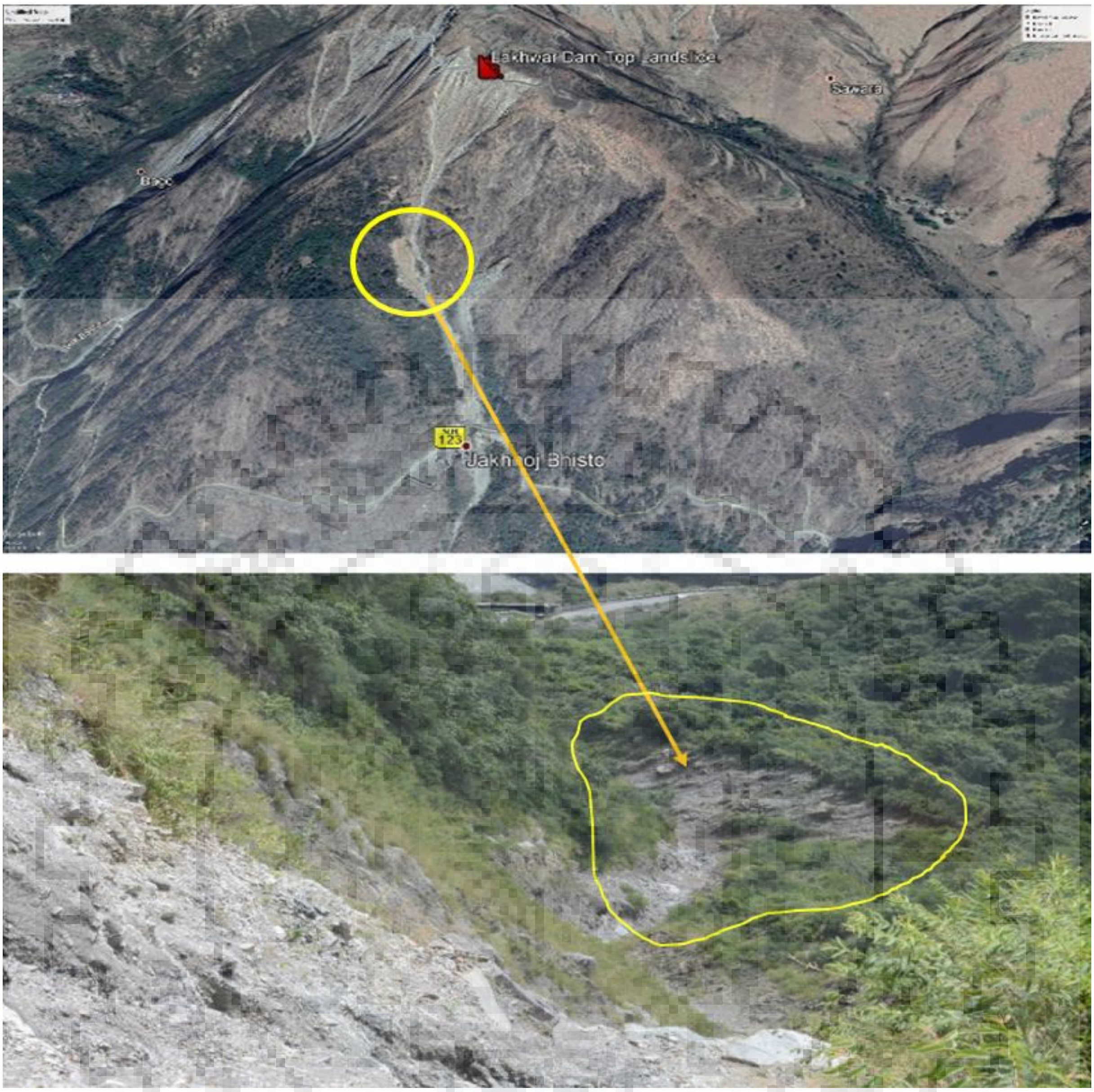

Figure 3.3: Showing the eroded area, extending the size of the landslide

The site was visited during and after the monsoon and it was observed that the landslide is more active during monsoon time, however, the risk of sliding of loose material pronounced throughout the year. It was also observed that after the monsoon, the detachment of rocks was there as shown in Figure 3.4.

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Figure 3.4: Detachment of rocks on site at the top of the landslide

The vegetation grown in the site was of varying nature in the monsoon season. After monsoon, it was observed that in the upper portion of the landslide, there was a scarce vegetation and it varies from top to bottom when compared during monsoon. It was also seen that the right flank has more vegetation than left as there is no layer of soil present and the rock is almost exposed, because of which the left flank is more stable than the right flank. The top to bottom view of right flank shows that it is lightly dense which consists largely of shrubs and small trees or it can be said that the right flank has mixed forests as shown in Figure 3.5.

Figure 3.5: Showing mix vegetation on the right flank

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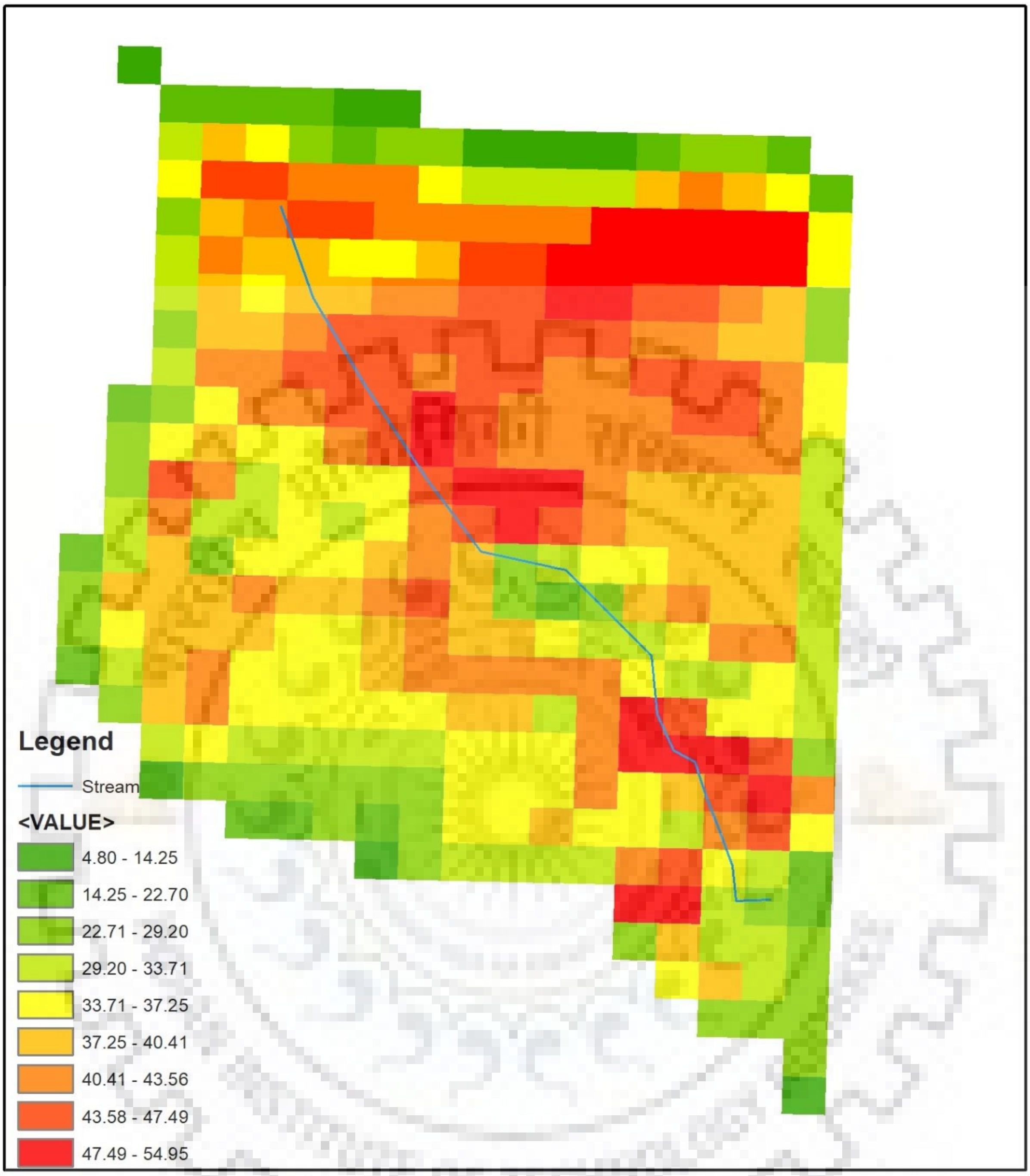

Figure 3.6: Slope map produced by ArcGIS, 2012

In a detailed investigation of the slope, the drainage pattern was studied by which the location of the catchment outlet was determined. Similarly, a slope map shown in Figure 3.6, was also developed using ArcGIS. The slope angle was found to be in the range from 45 to 55 degree which is considered a steep slope.

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3.2 Material

From soil investigation, it is seen that the material on site is colluvial or colluvium.

"Colluvium material is a general name for loose, unconsolidated sediments that have been deposited at the base of hillslope by either rain-wash, sheetwash or slow continuous downslope creep or if the variable combination of these processes".

It has been observed that the landslide slope is a colluvial slope, and it is characterized primarily by being on a steep slope. It can be seen that a rockface in this landslide is a **Phyllite** bedrock that is forming a face of the cliff. The top of this slope and as the material breaks through largely physical weathering process. this material under the influence of gravity downslope and a geological time. There built up a deposit of coarse angular fragments collectively referred as a colluvial apron. As a vegetation near the landslide can be seen. It is typical of a colluvium in areas where this colluvium process in downslope movement under the influence of gravity is more active, tend to have unvegetated episodic movement probably in the springtime of a snowmelt or rainfall. A bit of moisture moving through this slope too much movement. Therefore, the vegetation becomes established. But it can be observed that the patches of early succession vegetation, large shrubs, small trees and eventually areas which are more stable enough that will fully support the down forests and also have a mixed forest (Douglas fir and Pine) here. The parent material would like from this type of activity. It is an assemblage of angular fragments that vary in size from pebble size to some of the larger blockier sizes that are available at the site. If dug a little deeper in the material, it is found that more fine material is there wherever there is moisture moving through these slopes that roots can get down and there is a moisture supply, the establishment of the forests. In semi-arid environment, much of this colluvium slope will remain unvegetated largely because of lack of moisture but in more humid part of the province, slope is in the range of 45-60 degree. The above is a description of colluvial land formation on site.

3.3 Classification of soil

The classification of soil is done by according to Indian Standard Soil Classification System (ISSCS). The soil sample under consideration were taken from three locations on landslide i.e. Left flank, Right flank, and Top of the landslide area. Due to the lack of required equipment for the collection of undisturbed soil sample, sample collected manually and they all are disturb

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sample. Disturbed sample is collect by digging a pit of 1 feet and then sample were taken out. For soil classification total weight of one sample is 1000gm and it is oven dried sample. The taken sample were then tested in laboratory and sieve analysis was done according to (IS-2720-part-4, 1985), and the particle size distribution graph for three soil sample are drawn. According to ISSCS, if soil particle passing through 4.75 mm is more than 50% of total weight of soil that is 1000gm, then is classified as fine grain soil otherwise it is course grain soil. After that D_{10}, D_{30} and D_{60} were determined from the graph of particle size distribution. Once the value of D_{10}, D_{30} and D_{60} taken out from graph then coefficient of curvature (C_c) and coefficient of uniformity (C_U)were carried out as given below.

$$C_c = \frac{(D_{30})^2}{D_{60} * D_{10}} \quad \text{(3.a)}$$

For well-graded material, C_C value should be laid in between 1 to 3.

$$C_u = \frac{D_{60}}{D_{10}} \quad \text{(3.b)}$$

For Gravel, C_U >4 and For Sand, C_U >6.

Sample 1: Left Flank

The sample mainly having 10mm and 4.75mm particle size. Table: 3.1 showing the soil particle size percentage passing through the sieves. Sieve are using in this soil classification are stared from 80mm to .075mm. After the analysis of sieve, particle size distribution is drawn show in Figure 3.7.

After the analysis of soil sample coefficient of curvature (C_c) and coefficient of uniformity (C_U) were calculated from graph. Putting the value of (C_c) and (C_U) in the equation (3.a) and (3.b) (C_c) and (C_U) values are 1.0008 and 57.154 respectively. According to ISSCS soil fall in the group of coarse-grained soil along with more than half of coarse fraction is smaller than 4.75 mm IS Sieve size and the percentage finer from 75 microns is laying between 5 to 12 so it is classified as **well graded silty-sand**.

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Table 3.1: Particle size distribution of sample 1, collected from left flank of landslide

IS sieve size (mm)	Weight of soil Retained (N)	Cumulative Mass Retained	%Cumulative Retained	%Finer
80	0	0	100	100
10	353	353	35.3	64.7
4.75	131	484	48.4	51.6
2.36	77	561	56.1	43.9
1.18	121	682	68.2	31.8
0.425	128	810	81.0	19
0.212	68	878	87.8	12.2
0.150	16	894	89.4	10.6
0.075	53	947	94.7	5.3
PAN	53	1000	100	0
Total	1000			

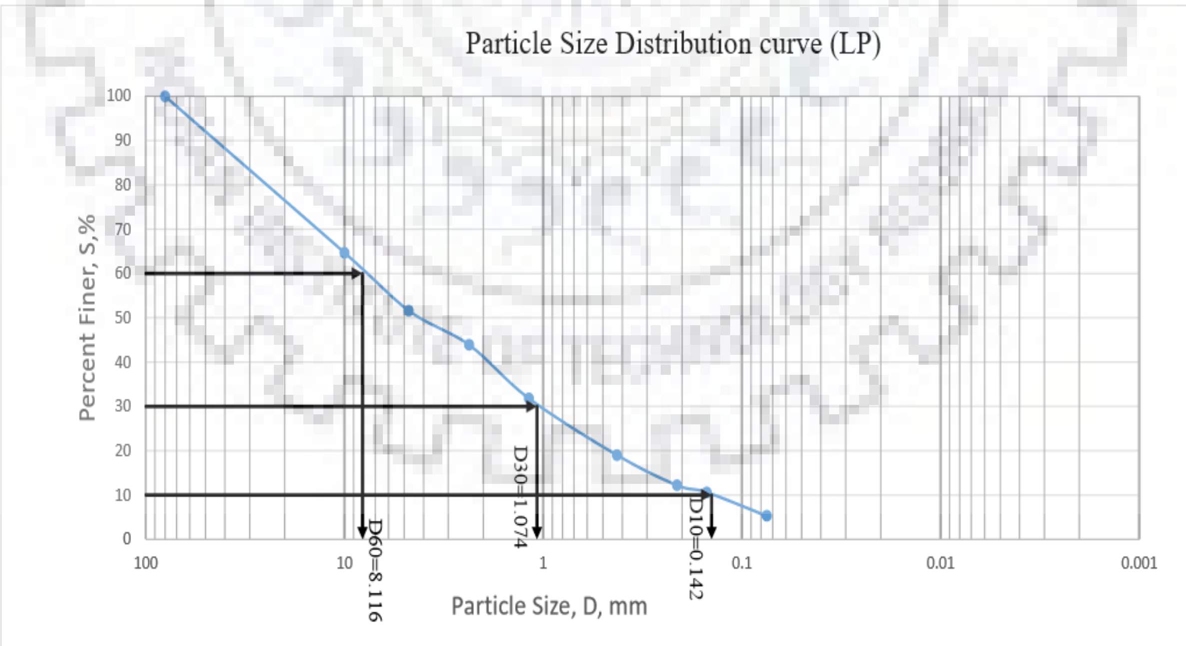

Figure 3.7: Particle size distribution curve of left flank soil sample

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Sample 2: Top of the Landslide

The sample mainly having 10mm particle size. Table: 3.2 showing the soil particle size percentage passing through the sieves. Sieve are using in this soil classification are stared from 80mm to .075mm. After the analysis of sieve, particle size distribution drawn show in Figure 3.8.

Table 3.2: Particle size distribution of sample 2, collected from top of the landslide

IS sieve size (mm)	Weight of soil Retained (N)	Cumulative Mass Retained	%Cumulative Retained	%Finer
80	0	0	0	100
10	464	464	46.4	53.6
4.75	98	562	56.2	43.8
2.36	87	649	64.9	35.1
1.18	149	798	79.8	20.2
0.425	98	896	89.6	10.4
0.212	53	949	94.9	5.1
0.150	19	968	96.8	3.2
0.075	19	987	98.7	1.3
PAN	13	1000	100	0
Total	1000			

After the analysis of soil sample coefficient of curvature (C_c) and coefficient of uniformity (C_U) were calculated from the graph. Putting the value of (C_c) and (C_U) in the equation (3.a) and (3.b) (C_c) and (C_U) values are 0.65576 and 34.7753 respectively. According to ISSCS soil fall in the group of coarse-grained soil along with more than half of coarse fraction is greater than 4.75 mm IS Sieve size and the percentage finer from 75 microns is less than 5% so it is classified as **poorly graded gravel**.

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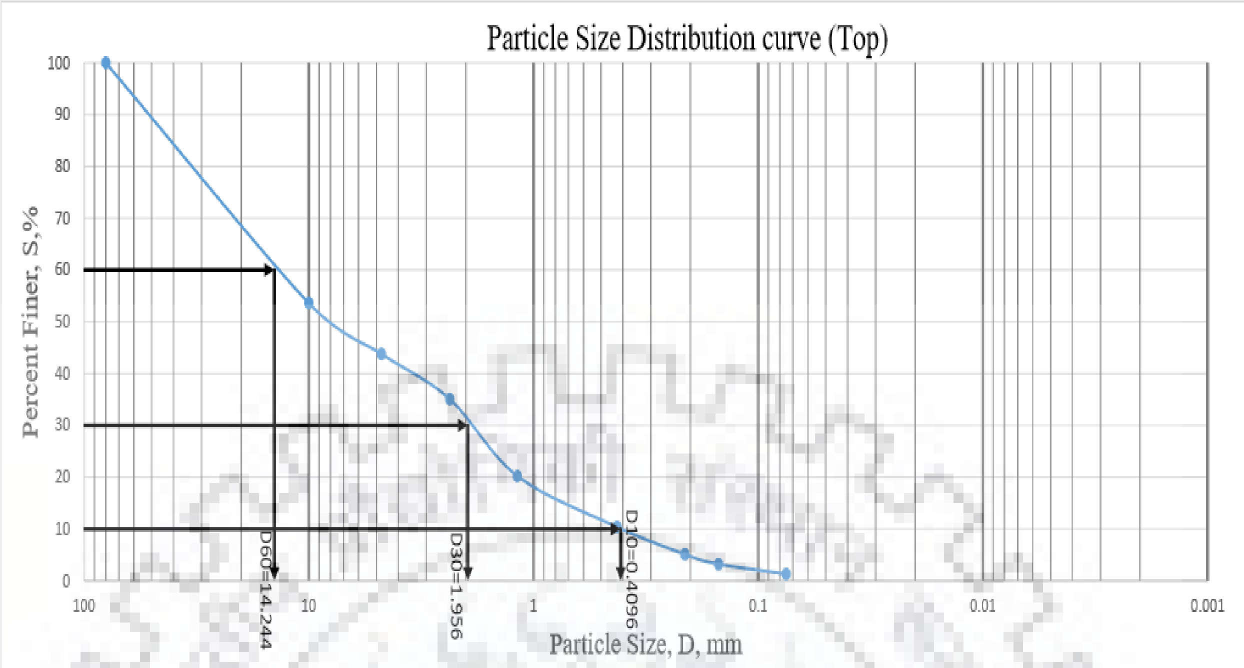

Figure 3.8: Particle size distribution curve of top of the landslide soil sample

Sample 3: Right Flank

The sample mainly having 10mm and 0.425mm particle size. Table: 3.3 showing the soil particle size percentage passing through the sieves. Sieve are using in this soil classification are stared from 80mm to .075m. After the analysis of sieve, particle size distribution is drawn show in Figure 3.9.

After the analysis of soil sample coefficient of curvature (C_c) and coefficient of uniformity (C_U) were calculated from the graph. Putting the value of (C_c) and (C_U) in the equation (3.a) and (3.b) (C_c) and (C_U) values are 1.06222 and 36.1364 respectively. According to ISSCS soil fall in the group of coarse-grained soil along with more than half of coarse fraction is smaller than 4.75 mm IS Sieve size along with more than half of coarse fraction is greater than 4.75 mm IS Sieve size and the percentage finer from 75 microns is less than 5% so it is classified as **well-graded gravel**.

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Table 3.3: Particle size distribution of sample 3, collected from right flank of the landslide

IS sieve size (mm)	Weight of soil Retained (N)(gm)	Cumulative Mass Retained	%Cumulative Retained	%Finer
80	0	0	0	100
10	468	468	46.8	53.2
4.75	45	513	51.3	48.7
2.36	67	580	58.0	42
1.18	145	725	72.5	27.5
0.425	170	895	89.5	10.5
0.212	56	951	95.1	4.9
0.150	16	967	96.7	3.3
0.075	30	997	99.7	0.3
PAN	3	1000	100	0
Total	1000			

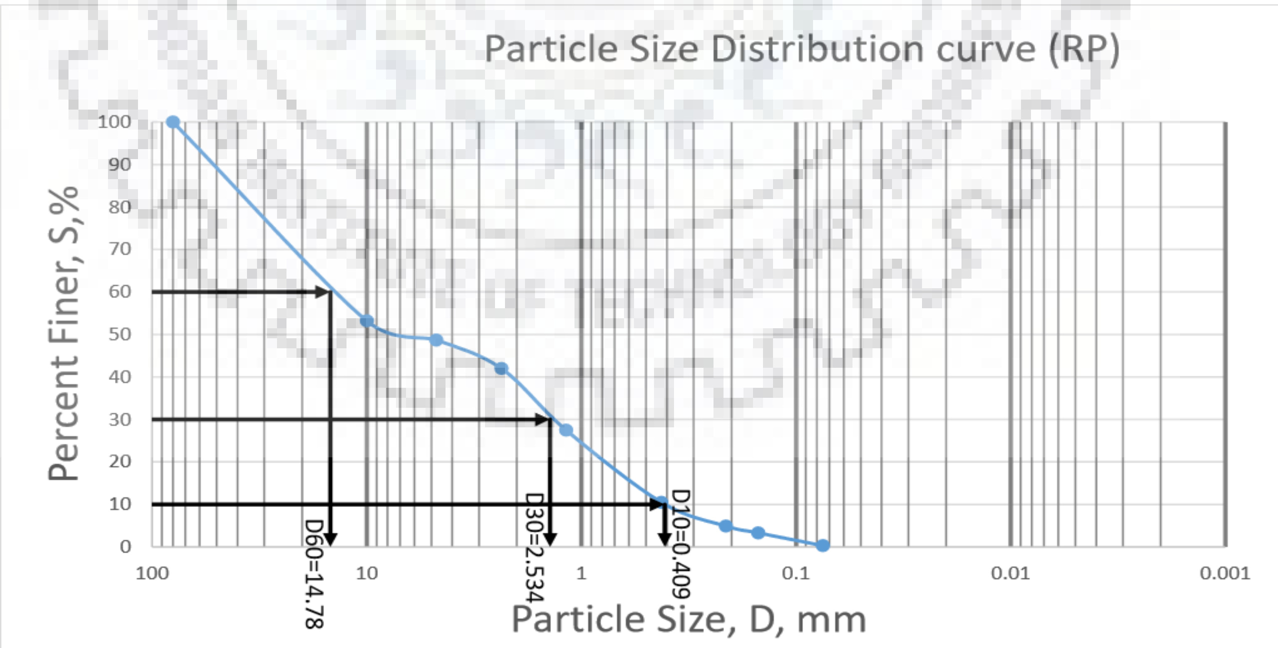

Figure 3.9: Particle size distribution curve of right flank soil sample

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As the results observed, the material at the site is colluvial and the soil classified as well graded silty gravel, poorly graded gravel, and well-graded gravel. Overall soil at the site is gravel and it has very low strength, and it is cohesionless. To keep in mind that soil sample is disturbed so that for further analysis soil properties are used from back analysis.

3.4 Rock

As it can be seen on site landslide zone consists of colluvial material underlain by phyllite and sandstone. Due to unavailability of core cutting equipment to collect the soil sample, data use for analysis taken from literature suitably.

3.4.1 Phyllite

The underlain phyllite rock is light grey, moderate to thickly foliated, low strong, medium to coarse grain and fresh to slightly weathered. Phyllite cover head of the landslide and almost cover all upper slope.

3.4.2 Sandstone

The main lithology of the area comprises of thick overburden soil. Sandstone bed rock is present at the toe area of landslide. The landslide zone are pours, due to porosity of sandstone it can be seen seepage passing through sandstone itself.

The description of the properties of the material and from where they have been taken is described in the Tables- 3.4 to 3.6.

a) **Angle of internal friction (ϕ)**

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Table 3.4: Typical values of angle of internal friction [(Geologic and Otherwise) GEOL 615]

Type of Material	**ϕ (Degree)**
Rock	30
Sand	30-40
Gravel	35
Silt	26-35
Clay	20
Colluvial	52
Loose sand	30-35
Medium sand	40
Dense sand	40-35
Gravel with some sand	34-48

b) Cohesive strength (τ_o)

Table 3.5: Typical values of cohesive strength [Some (Geologic and Otherwise) GEOL 615]

Type of Material	**τ_o (kPa)**
Rock	10000
Silt	75
Colluvial	270
Very soft clay	0-48
Medium clay	96-192
Stiff clay	192-384
Very stiff clay	384-766

c) Density (ρ)

Table 3.6: Typical values of densities (Geologic and Otherwise) GEOL 615]

Type of Material	**ρ (kg/m^3)**
Sandy soil	1800
Gravel soil	2000
Silty soil	2100
Clay soil	1900
Colluvial soil	1320
Igneous rock	2700-3000
Metamorphic rock	2700

Phyllite rock	2600

Table 3.7: Values of material properties adopted for modelling of landslide slope

UPPER SLOPE		
Material properties	Overburden (colluvial material)	Rock (Phyllite)
Cohesive strength	Not present	0 kPa
Angle of internal friction	Not present	24.30^0
Density	Not present	21.5 kN/m^3

MIDDLE SLOPE		
Material properties	Overburden (colluvial material)	Rock (Phyllite)
Cohesive strength	20 kPa	0 kPa
Angle of internal friction	30^0	24.30^0
Density	19 kN/m^3	21.5 kN/m^3

LOWER SLOPE		
Material properties	Overburden (colluvial material)	Rock (Sandstone)
Cohesive strength	20 kPa	100 kPa
Angle of internal friction	30^0	45^0
Density	19 kN/m^3	27 kN/m^3

Chapter - 4

Assessment of Landslide

Landslide assessment in terms of hazard and susceptibility is carried out. It involves consideration of several landslide explanatory variable. Although it is a very important task to determine the relative contribution of an individual parameter in landslide occurrence. To quantify the susceptibility of landslide, Central Building Research Institute (CBRI) method named as Landslide Susceptibility Score (LSS) used and Bureau of Indian Standard (BIS) method for hazard assessment named as Landslide Hazard Evaluation Factor (LHEF) used that are discussed in following section.

4.1 Landslide Susceptibility Score (LSS)

To counter this problem for minimizing the effect of landslide, we have to have a very good idea about to quantify the landslide susceptibility. To quantify the susceptibility of landslide, Landslide susceptibility score (LSS) is discussed.

In this method, there are nine parameters from the field these are, Vegetation Type, Lithology, Rock Mass, Weathering, Joint and Fractures, Slope and Discontinuity Relation, Overburden Thickness, Slope, and Hydrology. Every factor has a Rank and a number of categories with a weight. The score for each factor is calculated as s sum of products of rank and weight of all factors.

$$\text{Landslide susceptibility score (LSS)} = \sum (\text{Rank} \times \text{Weight}) \quad \ldots\ldots\ldots\ldots(4.1)$$

$$\left.\begin{array}{ll} > 300 & (\textbf{High Susceptibility}) \\ = 200 \text{ to } 300 & (\textbf{Moderate Susceptibility}) \\ < 100 & (\textbf{Low Susceptibility}) \end{array}\right\} \ldots(4.2)$$

For calculation of rank and weight, is given in table 4.1.

Table 4.1: Rank and Weight used for LSS method for the site

Factor	Rank	Category	Weight	Based of field survey: Upper slope – Category	Upper slope – Wt.	Lower slope – Category	Lower slope – Wt.
Hydrology	9	Flowing	9	Dry	1	Flowing	9
		Wet	6				
		Dry	1				
Slope (degree)	8	Flat	0	50^0	9	46^0	9
		$0 < 15^0$	2				
		$15^0 < 30^0$	5				
		$30^0 < 45^0$	7				
		$> 45^0$	9				
Overburden Thickness (meters)	7	<1	1	1.5	3	4	9
		1- 2	3				
		2-3	6				
		>3	9				
Slope and Discontinuity Relation	6	Dip Slope	9	Dip slope	9	Dip slope	9
		Oblique Slope	5				
		Opposite	1				
		Flat Slope	0				
Joint and Fractures	5	High	9	High	9	Mode-rate	4
		Moderate	4				
		Low	2				
Weathering	4	High	6	High	6	High	6
		Moderate	5				

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		Low	2				
Rock Mass	3	Soli and Bolder	9	Massive	1	Soil and Bould-er	9
		Thinly Bedded	6				
		Thick Bedded	3				
		Massive	1				
Lithology	2	Sale/Schist*/phyllite	7	Phyllite	7	Sand stone	6
		Sandstone*/Limestone*	6				
		Gneiss/Quartzite*	5				
		Basalt*/Rhyolite*	4				
		Granite*/Granulite*	3				
Vegetation Type	1	Barren	9	Barren	9	Barre-n	9
		Sparse	7				
		Moderate	5				
		Agricultural	3				
		Thick	1				
*Added by the author to make it Broad-Based and Realistic							

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Table 4.2: LSS calculation for Lakhwar dam top site

Factor	LSS FOR UPPER SLOPE (Rank × Weight)	LSS FOR LOWER SLOPE (Rank × Weight)
Hydrology	9 x 1 = 9	9 x 9 = 81
Slope (degree)	8 x 9 = 72	8 x 9 = 72
Overburden Thickness (meters)	7 x 3 = 21	7 x 9 = 63
Slope and Discontinuity Relation	6 x 9 = 54	6 x 9 = 54
Joint and Fractures	5 x 9 = 45	5 x 4 = 20
Weathering	4 x 6 = 24	4 x 6 = 24
Rock Mass	3 x 1 = 3	2 x 9 = 27
Lithology	2 x 7 = 14	2 x 6 = 12
Vegetation Type	1 x 9 = 9	1 x 9 = 9
LSS value = ∑ (Rank × Weight)	**251**	**362**

Observation and Discussions

For the Lakhwar dam top site, based on data from field and lab, for each of the factors of LSS method, applicable category, and corresponding weights is identified from Table 4.1. Finally using Table 4.1, LSS is calculated as shown in Table 4.2. It can be observed that LSS for upper slope and lower slope are 251 and 362 respectively. Thus, according to Table 4.2, these values denotes moderate susceptibility and high susceptibility, respectively.

4.2 Landslide Hazard Evaluation Factor

Bureau of Indian standards has taken ten different causative factors and given it different numbers which are given in Table 4.3, termed as Landslide Hazard Evolution Factor (LHEF). The ten-causative factors are lithology, structure, slope morphology, hydrology, land use and land cover, relative relief, rainfall, Seismic Zone landslide incidences in past and slope erosion.

Table 4.3: Landslide hazard evaluation rating scheme

Causative Factor	Maximum LHEF Ratings		Description	Ratings
1. Lithology	2	ROCK SLOPE	Basalt, Quartzite, and Massive Limestone & Dolomite	0.2
			Massive Granite, Gabbro and Dolerite	0.3
			Well-cemented terrigenous sedimentary rocks (dominantly sandstone) with minor beds of clay stone and Gneissic rocks	1
			Fresh to moderately weathered Phyllite	1.6
			Highly Weathered Shale and all other argillaceous rocks, Phyllite and Schistose rocks	2
		SOIL SLOPE	Older in-situ soil (alluvial), older well compacted fluvial fill material (alluvial)	0.8
			Clayey soil with naturally formed surface (alluvial, aeolian)	1

<table>
<tr><td rowspan="4"></td><td rowspan="4"></td><td rowspan="3"></td><td colspan="2">Sandy soil with naturally formed surface (alluvial)</td><td>1.4</td></tr>
<tr><td rowspan="2">Debris comprising mostly loose rock pieces mixed with clayey or sandy soil (colluvial)</td><td>Younger loose material</td><td>2</td></tr>
<tr><td>Older, Well compacted</td><td>1.2</td></tr>
<tr><td></td><td colspan="2">Younger, incompact residual soil (lying as thin cover on hill slopes)</td><td>2</td></tr>
<tr><td rowspan="6">2. Structure</td><td rowspan="6">2</td><td rowspan="3">ROCK SLOPE</td><td colspan="2">Parallelism between slope and discontinuity</td><td>0.5</td></tr>
<tr><td colspan="2">Relationship between slope inclination and dip of discontinuity plane/ plunge of wedge line</td><td>1</td></tr>
<tr><td colspan="2">Dip of discontinuity/ plunge of wedge line</td><td>0.5</td></tr>
<tr><td rowspan="3">SOIL SLOPE</td><td colspan="2">$36^0 – 45^0$</td><td>1</td></tr>
<tr><td colspan="2">$46^0 – 60^0$</td><td>1.5</td></tr>
<tr><td colspan="2">> 60^0</td><td>2</td></tr>
<tr><td rowspan="5">3. Hydrological Condition</td><td rowspan="5">1</td><td rowspan="5"></td><td colspan="2">Flowing</td><td>1</td></tr>
<tr><td colspan="2">Dripping</td><td>0.8</td></tr>
<tr><td colspan="2">Wet</td><td>0.5</td></tr>
<tr><td colspan="2">Damp</td><td>0.2</td></tr>
<tr><td colspan="2">Dry</td><td>0.0</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">2</td><td rowspan="2"></td><td colspan="2">Agricultural land or populated flat land (≤ 15°)</td><td>0.65</td></tr>
<tr><td colspan="2">Thickly vegetated forest area</td><td>0.80</td></tr>
</table>

4. Land use and Land Cover Type			Moderately vegetated forest area	1.20
			Sparsely vegetated area with thin grass cover	1.50
			Barren land – without anthropogenic activity	1.70
			Hill slopes experiencing active toe erosion/ toe cutting by rivers, streams or any other form of natural drainage	2.00
			Sparsely urbanized slope	1.20
5. Seismic Zone	0.5		II	0.2
			III	0.3
			IV	0.4
			V	0.5
6. Landslide Incidences	2		In Past	2
7. Slope Erosion	2			2
8. Rainfall (average, cm)	0.5		≤ 50	0.2
			51 - 100	0.3
			101 - 150	0.4
			> 150 cm or history of cloud burst	0.5

9. LHEF Rating for slope Parameter

		(a) Slope Morphometry Classes					
		A ($<15^0$)	B ($16-25^0$)	C ($26-35^0$)	D ($36-45^0$)	E ($46-65^0$)	F ($>65^0$)
	(<50m)	0.5	0.9	1.3	1.5	1.8	1.9

(b) Relative Relief Classes	(50-100m)	0.6	1	1.4	1.6	1.9	2
	(101-200m)	0.7	1.1	1.5	1.7	1.95	2
	(201-300m)	0.8	1.2	1.55	1.75	2	2
	(>300)	0.9	1.3	1.6	1.8	2	2

Table 4.4: Landslide hazard evaluation rating scheme based on site investigation

Causative factor	For Upper Slope			For Lower Slope
	Description	LHEF	Description	LHEF
1) Lithology	Fresh to moderate weathered Phyllite	1.6	Highly Weathered	2.0
2) Structure	Dip of discontinuity	0.5	46^0-60^0	1.5
3) Slope Morphology	46^0-65^0	1.95	46^0-65^0	1.95
4) Relative relief (m)	(101-200)		(101-200)	
5) Land Use and Land Cover	Sparsely vegetated area with thin grass cover	1.5	Barren land	1.70
6) Hydrology Conditions	Dry	0.0	Flowing	1.0
7) Landslide Incidences	Yes	2.0	Yes	2.0
8) Slope Erosion	Yes	2	Yes	2
9) Rainfall (cm)	21	0.2	21	0.2
10) Seismic Zone	IV	0.4	IV	0.4
Total Estimated Hazard (sum of LHEF)		**10.15**		**12.75**

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Table 4.5: Total Estimated Hazard as per (BIS 2011)

Total Estimated Hazard	Zone Category	Zone Description
< 4.90	I	Very Low Hazard
4.90 – 7	II	Low Hazard
7.10 – 8.40	III	Moderate Hazard
8.41 – 10.50	IV	High Hazard
> 10.50	V	Very High Hazard

Observation and Discussions

For the Lakhwar dam top site, based on data from field and lab, for each of the factors of LHEF method, applicable category and corresponding rating is identified Table 4.4. Finally using Table 4.3, LSS is calculated as shown in Table 4.4. It can be observed that LHEF for upper slope and lower slope are 10.15 and 12.75 respectively. Thus, according to Table 4.5, these values denotes high hazards and very high hazards, respectively.

4.3 Summary

Though landslide is the very natural process and phenomenon. Though there are aggravated by anthropogenic activities. To counter this problem for minimizing the effect of landslide there has an idea about to quantify the landslide susceptibility and hazard. As result came out from LSS and LEHF showed in Table 4.6. Susceptibility and hazard for upper slope come under the second highest category and for lower slope, it comes under the highest category. Based on the results landslide has been quantified and it is necessary to control the landslide by applying suitable mitigation measures.

Table 4.6: Results of LSS and LHEF

Slope	Upper slope	Lower slope
LSS Method	Moderate Susceptibility	High Susceptibility
LHEF Method	High Hazard	Very High hazard

Chapter - 5

Slope Stability Analysis

In stability analysis of the slope, that is known what is shear strength mobilized by the soil shear stress which is actually induced by the disturbing forces. So, the ratio of available shear strength to the shear stress mobilized is referred as Factor of Safety. If this factor of safety is adequate then it can say that the slope is stable, but if this factor of safety is inadequate then it can say that the slope is on the verge of failure.

5.1 Typical slope Considered

So as far as stability analysis of slope is a concern, check slope stability in GEO SLOPE, 2012. This is a software which is used for the analysis of slope according to different site condition.

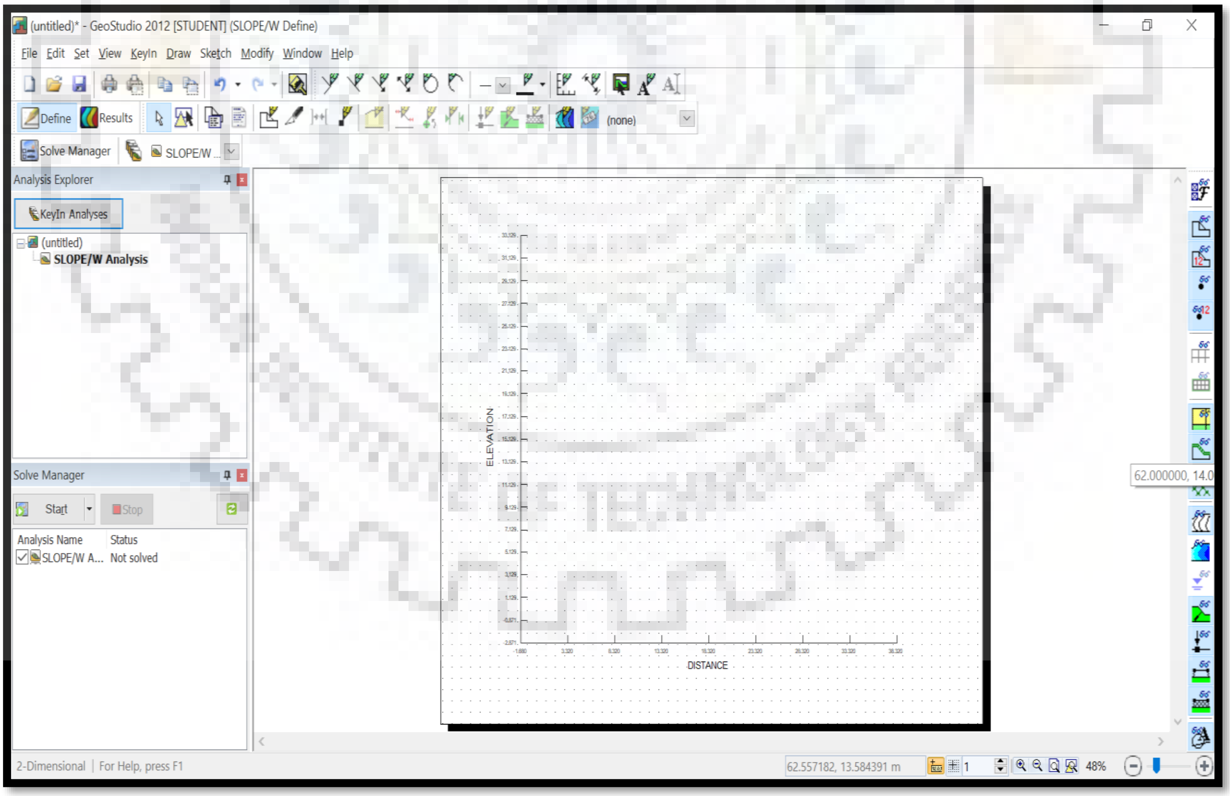

Figure 5.1: Showing interface of the Geo Slope

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The interface of this software shown in Figure.5.1. To give input soil material properties to the software for slope stability like unit weight of the material, cohesion, friction angle, piezometric condition, method to do analysis (Spencer, Morgenstern- price, Bishops, Janbu, etc.). Till here all data collect from the field and put in the software easily but the main issue come up with when profile have to draw. For creating the actual site on the software, need to collect the geometry of site, for that, use Google Earth tool. It a very useful tool for creating the slope profile like area, perimeter, length, elevation, and slope also.

As it can be seen in Figure (3.1), the total area of landslide is very huge, so it is needed to do slope stability analysis very precisely, for that slope is divided into three parts which are shown in Fig.5.2(a) name as upper slope, Figure 5.3(a) middle slope, Fig. 5.4(a) lower or end slope. Finally for these three sope profile are as given below.

Table 5.1: Slope profiling of Lakhwar dam top landslide with their coordinate

Name of Profile	Coordinate of crest	Hight of crest from the ground surface (meter)	Base length (meter)	Slanted Hight (meter)	Degree of slope
Upper Slope	30°31’29.27” N, 77°56’41.70” E	122	103.50	160	50
Middle Slope	30° 31' 26.15"N, 77° 56' 47.71"E	163	133	210	50
Lower Slope	30° 31' 19.19"N, 77° 56' 47.59"E	145	140	202	46

After getting the slope profile the range of slope 46^0 to 50^0, these slopes come under the category of a steep slope, to justify these slope results are correct, a slope map of Lakhwar dam top landslide was created as shown in Figure 3.6, on ArcGIS software. The attributes of slope angle the range between 45^0 to 59^0. So that range of slope falls under the same category i.e. very steep slope. It means both methods for slope profiling is suitable.

For stability of the slope, as mentation earlier that complete slope of the landslide is divided into three parts and slope stability analysis is carried out in each part, all the slope stability analysis as given in further sections.

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Upper Slope

Upper slope Figure. 5.2(a), has a rock bed and this bed rock is consist of Phyllite, as mentioned earlier in chapter 3, there is no overburden on the slope. Keeping the properties of rock and seismic zone category, slope study analysis is carried out, as shown in Fig. 5.2(b), the output of slope stability in unsaturated condition and Fig 5.2(c), shows the slope stability with the addition of seismic factor for zone IV.

Figure 5.2(a): Upper slope, with their elevation profile (Google Earth)

Table 5.2: Data used for upper slope stability analysis in static and dynamic case

Analysis Type	Bishop Method
Piezometric condition	Unsaturated
Seismic factor	0.24 (only for Dynamic case)
Type of material	Phyllite Rock
Depth of overburden	Not present
Cohesion (c)	0 kPa
Friction angle (ϕ)	24.3^0
Unit weight	21.5 kN/m^3
Model	Mohr-Coulomb
Slip Surface Option	Entry and Exit

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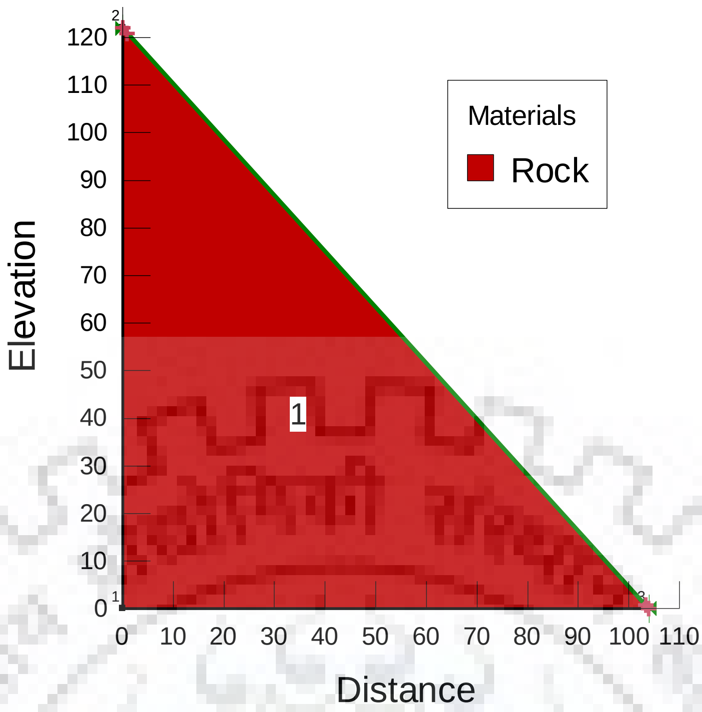

Figure 5.2(b): Upper slope profile before slope stability analysis

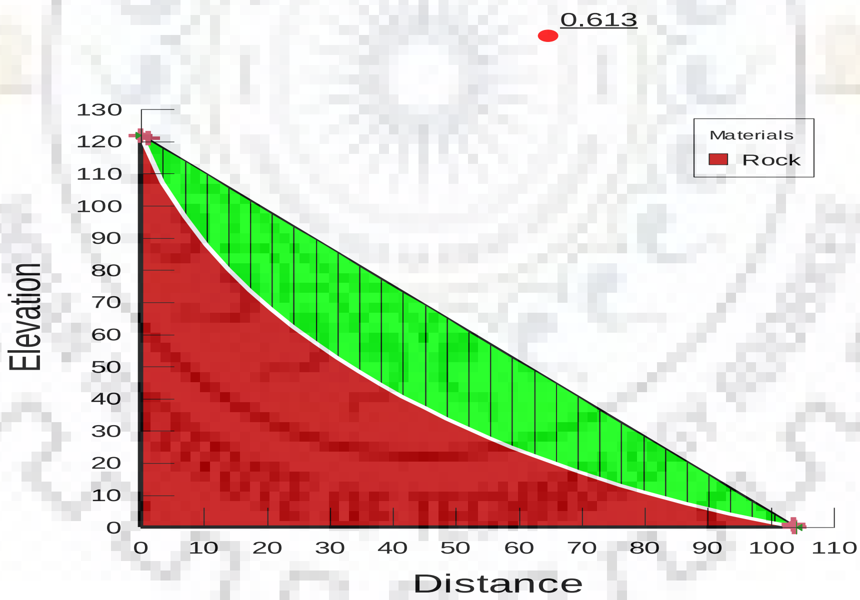

Figure 5.2(c): Slip surface for upper slope for the static case

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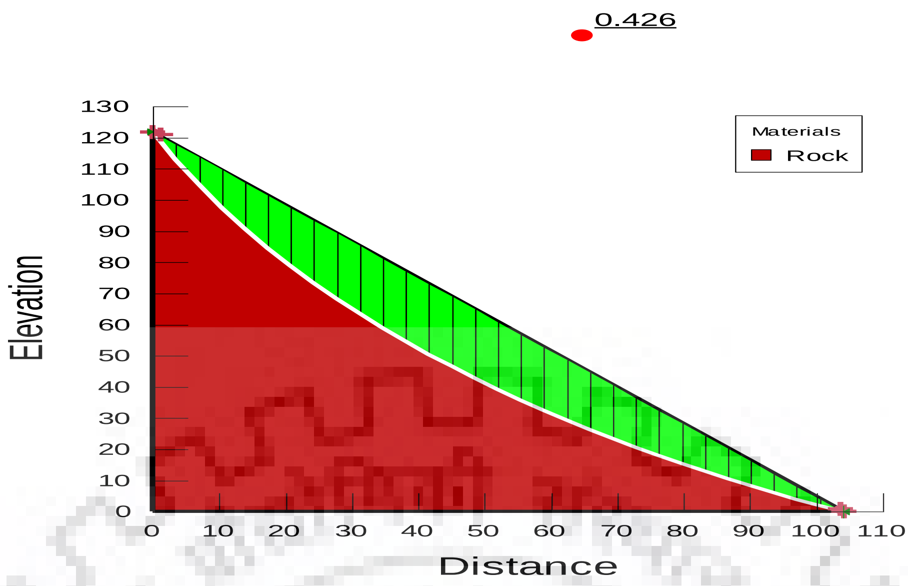

Figure 5.2(d): Slip surface for upper slope for Dynamic case

Observation and Outcome:

- The factor of safety for static and dynamic analysis is 0.613 and 0.426 respectively, which is less than 1, therefore it indicates that upper slope is unstable in both cases.
- It can be observed that factors of safety are reduced from 0.613 to 0.426 when the seismic load is considered.

Middle Slope

Middle slope Figure 5.3(a), has a rock bed and overburden material (silty-sand gravel). The bed rock is consisting of Phyllite, as mentation earlier in chapter 3, about the properties of phyllite has no significant strength. Keeping the properties (Table 5.2 and 5.3) of rock and seismic zone category slope study analysis is carried out, as in Figure 5.3(b), shows the slope stability in unsaturated condition and Figure 5.3(c), shows the slope stability with the addition of seismic factor for zone IV.

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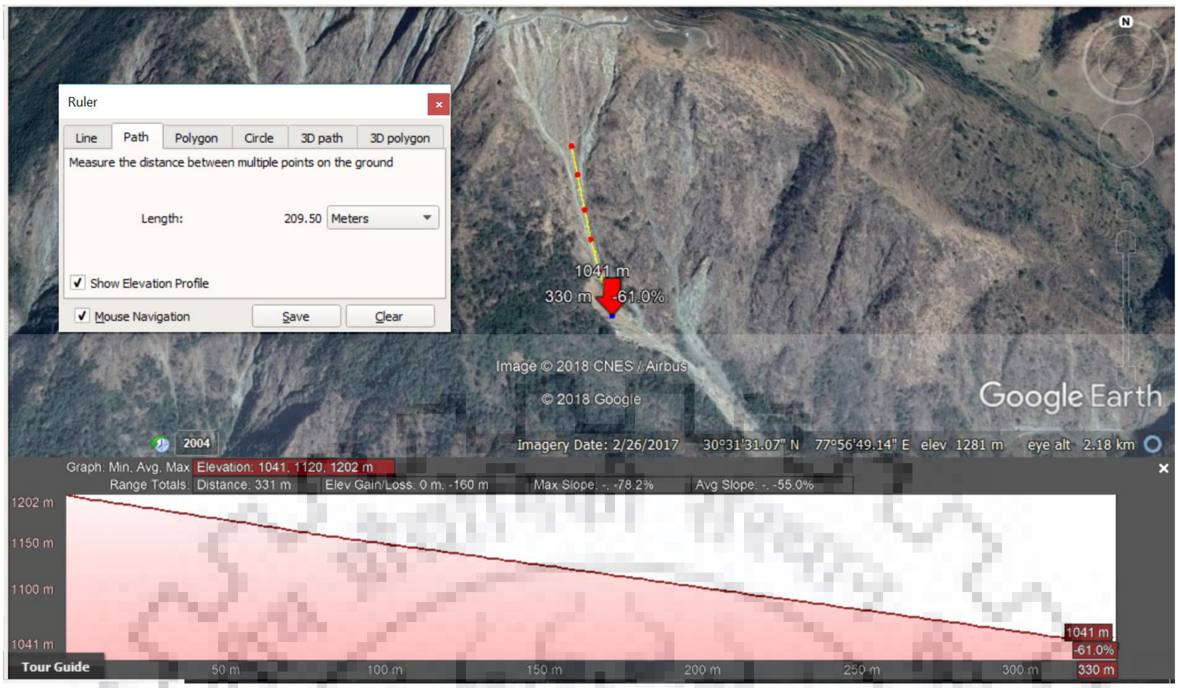

Figure 5.3(a): Middle slope with their elevation profile (Google Earth,2012)

Table 5.3: Properties used for overburden material

Overburden Material	
Type	Silty- sand gravel
Cohesion (c)	20 kPa
Friction angle (ϕ)	30^0
Unit weight	19 kN/m^3

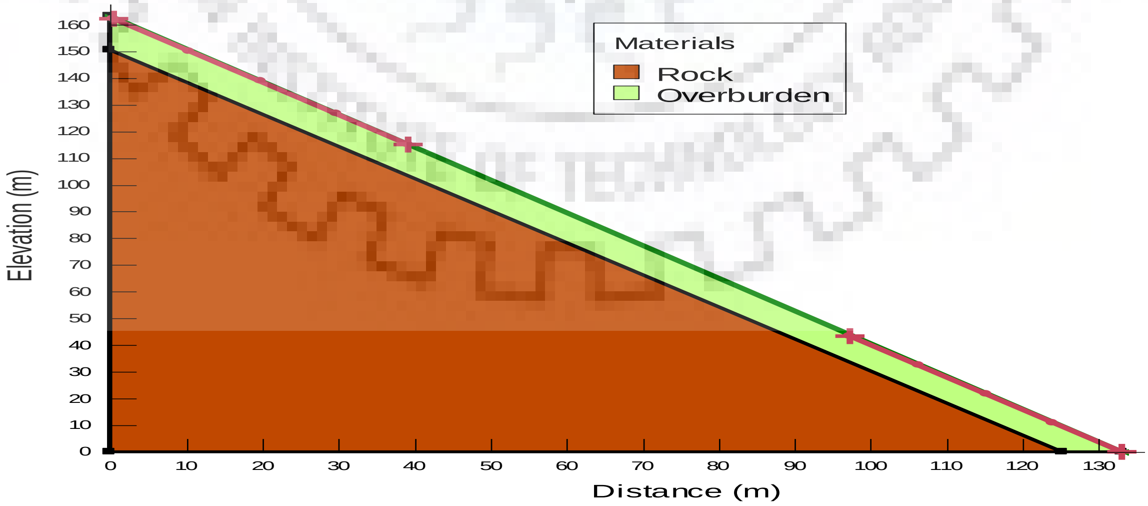

Figure 5.3(b): Middle slope profile before slope stability analysis

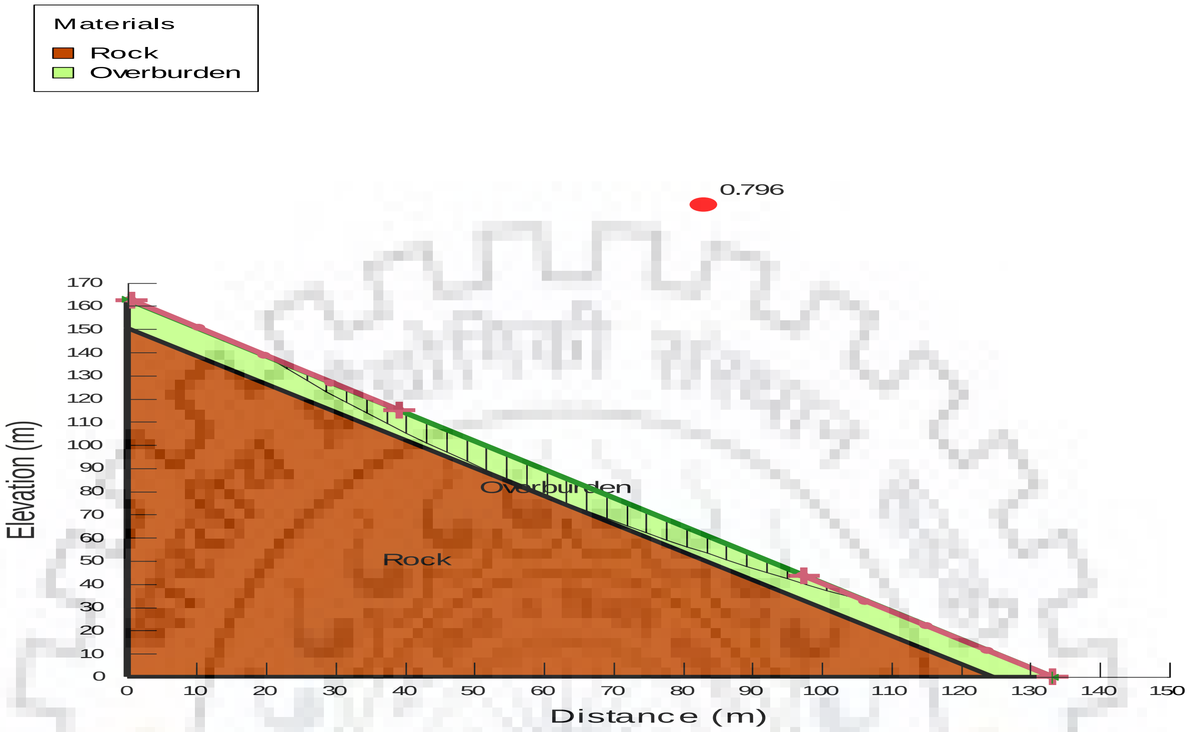

Figure 5.3(c): Slip surface for middle slope in static condition with overburden

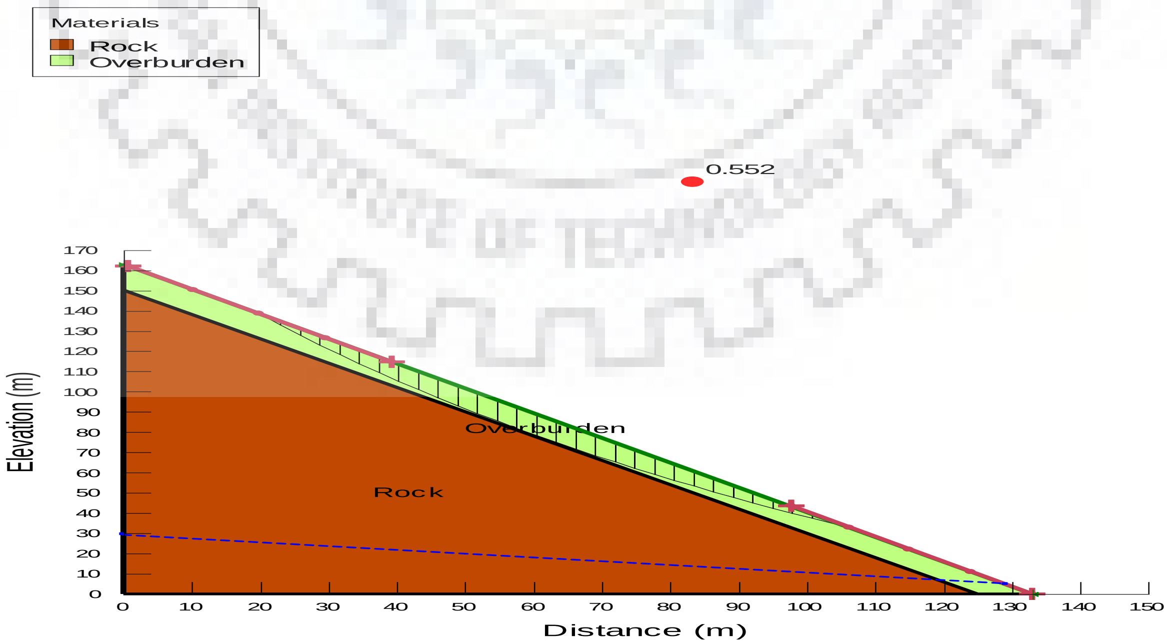

Figure 5.3(d): Slip surface for middle slope in Dynamic condition with overburden

Observation and Outcome:

- The factor of safety for static and dynamic analysis is 0.796 and 0.552 respectively, which is less than 1, therefore it indicates that middle slope is unstable in both cases.
- It can be observed that FOS is reduced from 0.769 to 0.552 when the seismic load is considered.
- Middle slope has higher FOS compare to upper slope because it has overburden which provides little stability due to its weight, even degree of slopes is same.

Lower Slope

Lower slope Figure 5.4(a), is consist of Sandstone, silty sand gravel and water flowing and throughout in this slope. This slope has an overburden with seepage water, with these characteristics this slope becomes more venerable. There is no surface drainage path or channel to drain water without seepage. For analysis, consider these all properties and get more precise results. Figure 5.4(b), in this analysis consider a hypothetical condition and FOS come out less than 1. It means slope already fail without considering the seismic effect and seepage pressure. But for understanding that how much FOS get affected other two conditions also analyzed as shown in Figure 5.4(c) and Figure 5.4(d). For analysis of lower slope using data as given in Table 5.4.

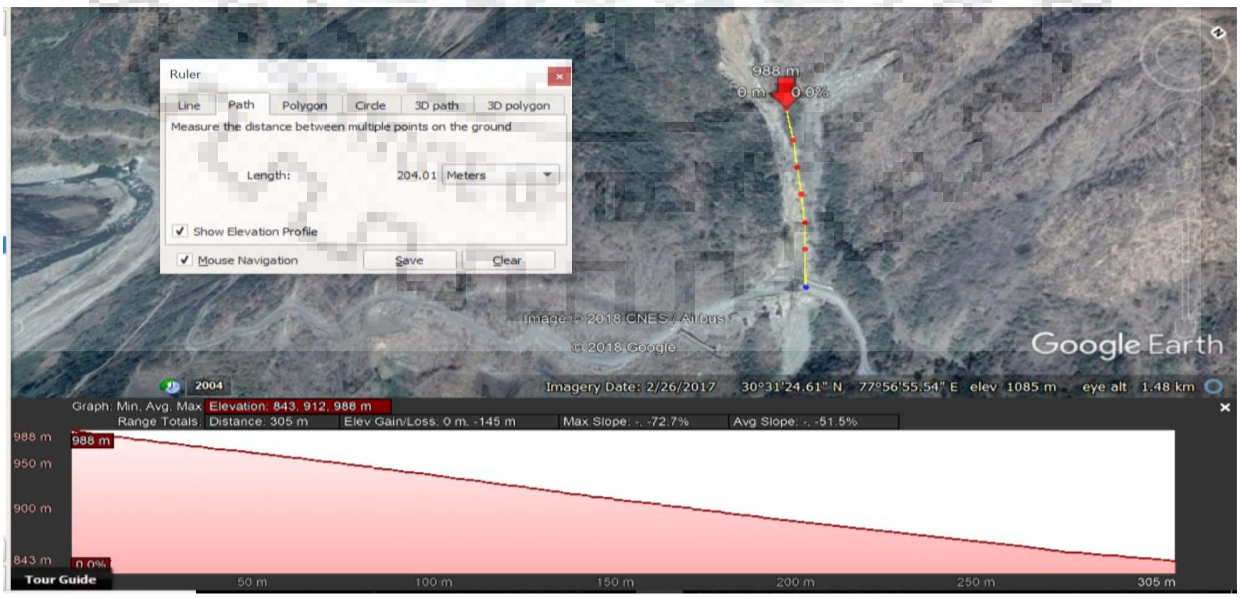

Figure 5.4(a): Lower slope with their elevation profile (source Google Earth,2012)

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Table 5.4: Data use for lower slope for stability analysis in static and dynamic condition with unsaturated and saturated conditions

Analysis Type	Bishop Method
Piezometric condition	Unsaturated, Saturated
Seismic factor	0.24 (only for dynamic case)
Type of material	Sandstone
Cohesion (c)	100 kPa
Friction angle (ϕ)	45^0
Unit weight	27 kN/m^3
Model	Mohr-Coulomb
Overburden Material	
Type	Silty-sand gravel
Cohesion (c)	20 kPa
Friction angle (ϕ)	30^0
Unit weight	19 kN/m^3

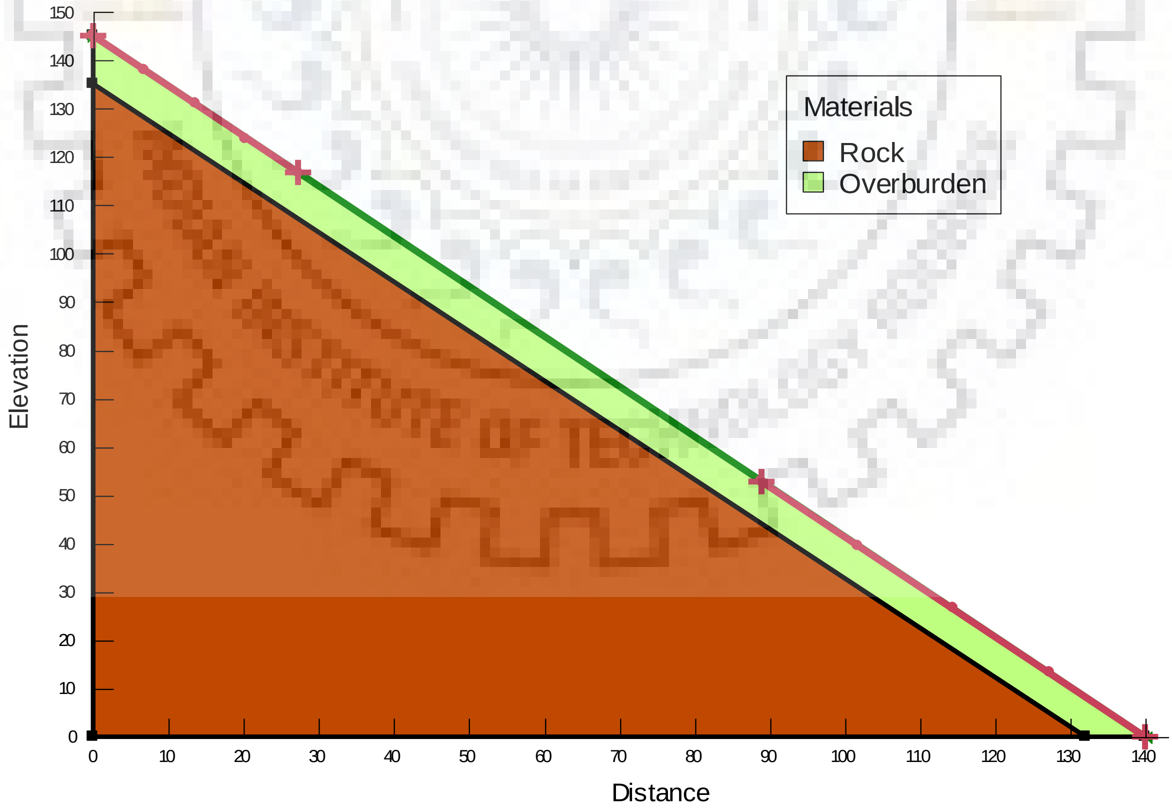

Figure 5.4(b): Lower slope profile before slope stability analysis

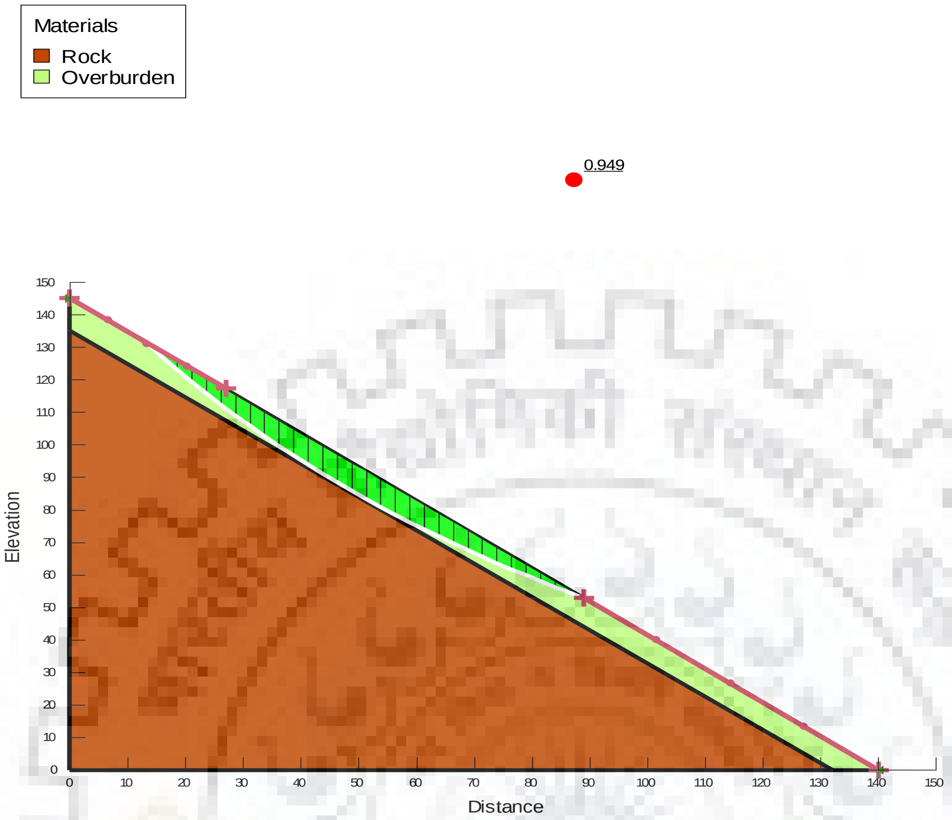

Figure 5.4(c): Slip surface for lower slope in static condition with unsaturated overburden

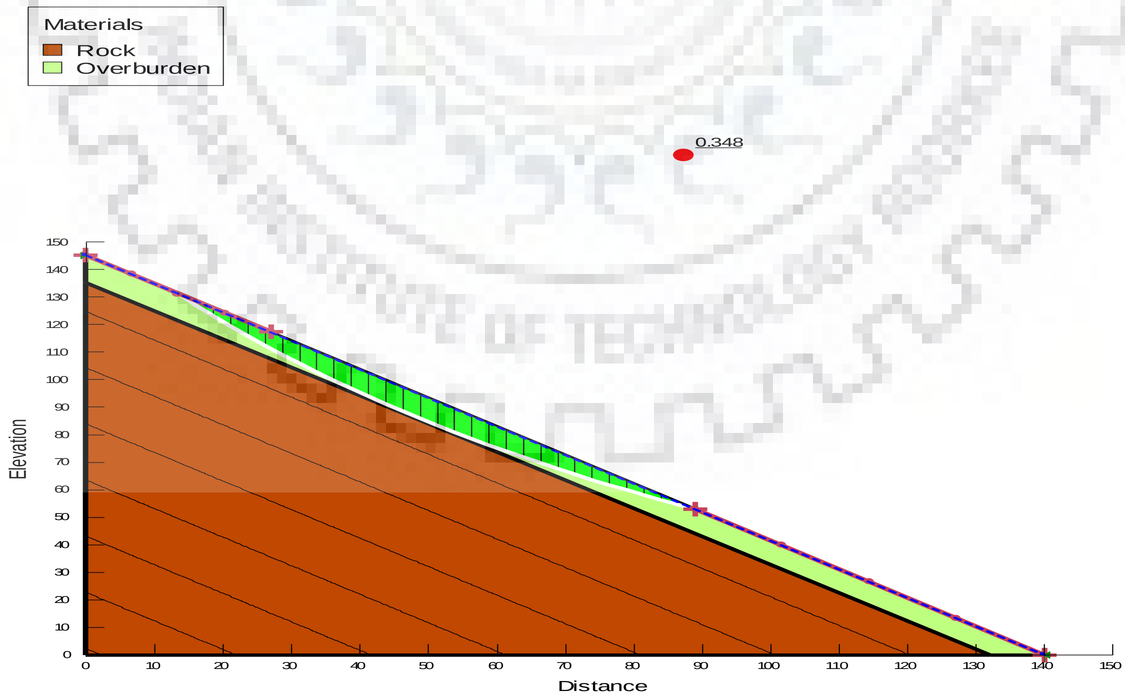

Figure 5.4(d): Slip surface for lower slope in static condition with saturated overburden

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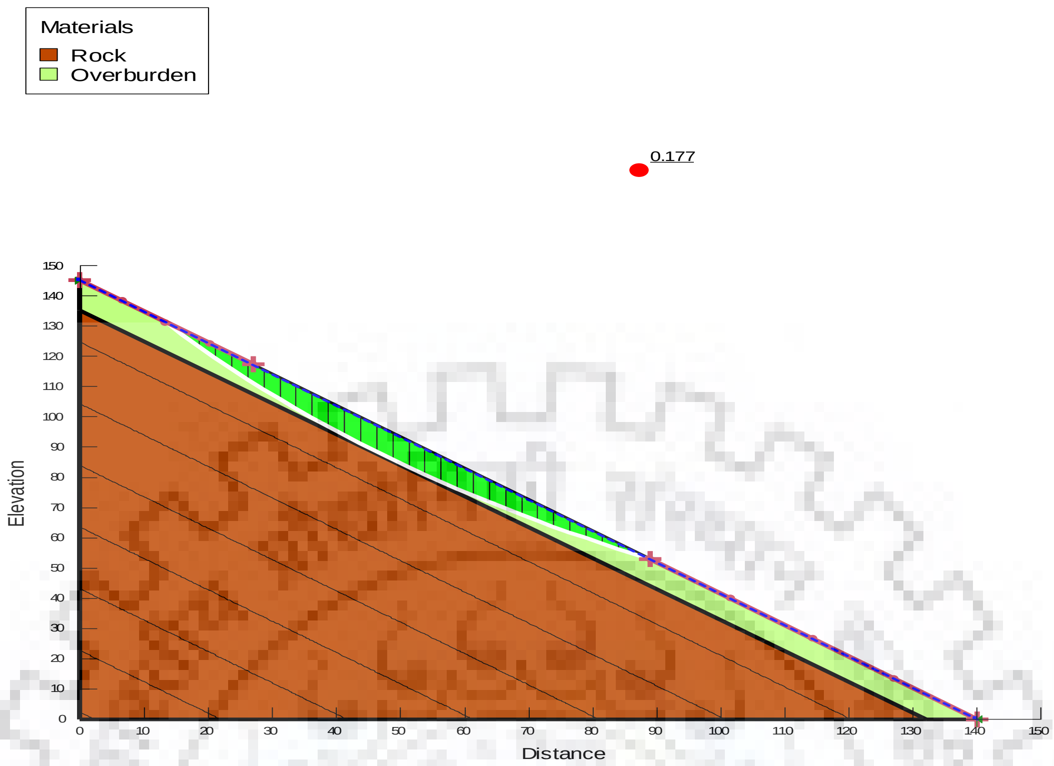

Figure:5.4(e): Slip surface for lower slope in dynamic condition with saturated overburden

In lower slope, FOS is 0.949, 0.348, and 0.177 for the static condition with unsaturated overburden static condition with saturated overburden mass dynamic condition with saturated overburden mass respectively. In all cases, FOS is less than 1, therefore lower slope also a failure slope.

Observation and Outcome:

- It can be observed that FOS is reduced from 0.949 to 0.348 when the seismic load is not considered with saturated mass. Here it can be observed that water reduce the FOS drastically. Hence water play vital role in reducing the strength of slope.
- Also, it can be observed that FOS are reduced from 0.348 to 0.177 when the seismic load is considered with saturated overburden mass or can say this case become a worse case.
- Is shows that seismic load and saturation condition reduce the almost 80% FOS of slope. That is why earthquake and rainfall are the main cause of slope failure.

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5.2 Results and Discussion

Table 5.5: Showing output of slope stability analysis in terms of a factor of safety

Slope	Analysis mode	Factor of Safety
Upper Slope	Unsaturated	0.613
	Saturated	NA
	Seismic	0.412
Middle Slope	Unsaturated	0.796
	Saturated	NA
	Seismic	0.552
Lower Slope	Unsaturated	0.949
	Saturated	0.348
	Seismic	0.177

1. As observed, according to site condition like slope angle, hydrology on site, material, and its location fall under earthquake zone IV and output of analysis shows that slope is very weak and it has very low strength to make it stable itself.

2. Second observation is about results of analysis which is very poor according to slope stability. It can be seen in all condition, slope has FOS less than 1. FOS value 1 is minimum required FOS for a stable slope.

3. After analysis, it has absorbed that in dynamic case FOS value reduces almost 30% in comparison to static case. It is a very important point to keep in mind while any mitigations design purposed because this landslide location falls under the earthquake zone IV.

4. As observed lower slope has the least FOS. It means it is very vulnerable but not just because of least FOS, also this slop is very near to national highway and a natural perennial drain flowing from the crest of this lower slope.

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Chapter – 6

Remedial Measures for Landslide Restoration

Material and their different properties have been discussed in chapter 3. A detailed analysis has been done for susceptibility and hazard, in chapter 4. Similarly, a slope stability analysis carried out under different conditions in chapter 5. In this chapter, various remedial measures used for landslide restoration are discussed.

6.1 Mitigation

After a detailed analysis, present study revealed that the present site conditions are very poor in terms of the slope, perennial flow, high rainfall in monsoon season, the site is very steep and some human interventions at the toe and head of the slope. Technically it is not correct as one factor becomes a responsible factor for triggering the landslide. It is often impossible to isolate the effect of water and identify as a single cause of failure. It is always an interaction between different factors that lead to the triggering of the landslide (Briaud and Lim, 1997). Nevertheless, it is important to evaluate the potential cause and to take into account the potential changes in time (Duncan, et al. 2014).

By regulating surface runoff, preventing soil erosion and providing slope stability measures, landslide can be effectively controlled. In this section, the main focus of remedial measures is to restore the affected slope of the landslide (Panigrahi et al. 2011). All remedial measures should be provided separately for all slopes and in the vicinity of landslide affected area. For better understanding contour map created at the 10-meter interval as well as cross-section of landslide were developed as shown in Figure 6.1.

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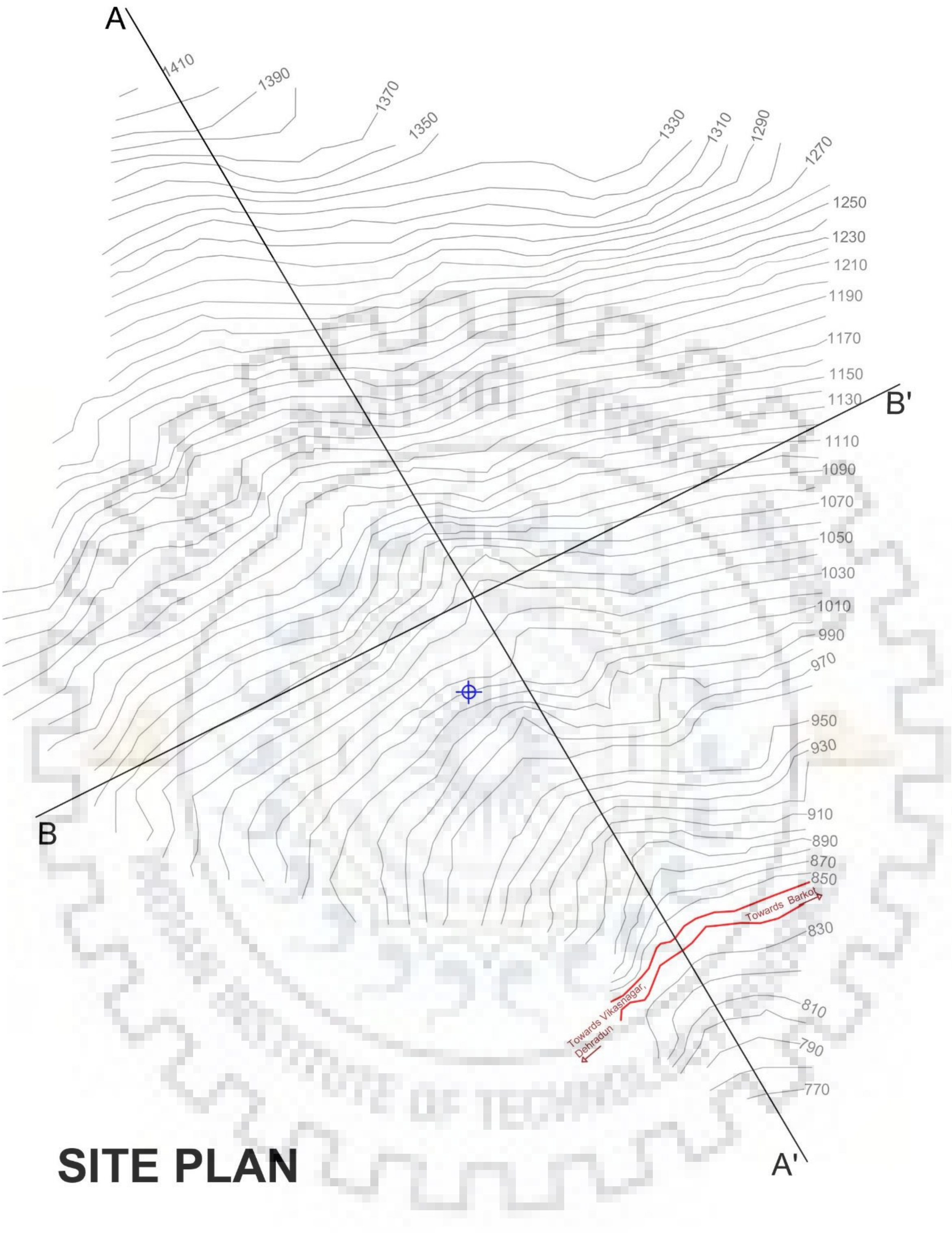

Figure 6.1: Showing contour map with cross section AA' and BB'.

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6.2 Cross Section of the Landslide

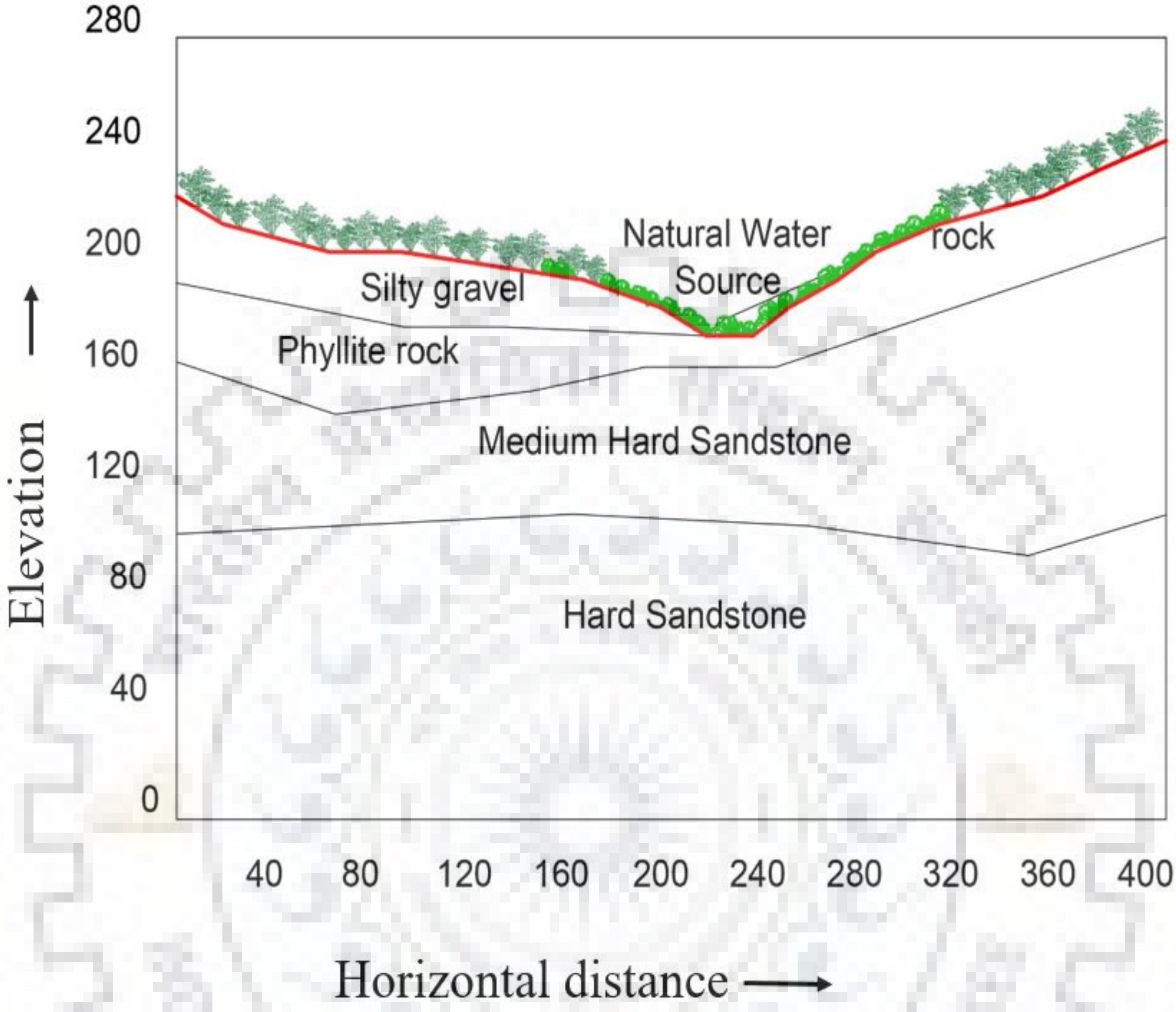

Figure 6.2: Geological cross-section of the landslide at NH123 section km (37) from 2 to 4

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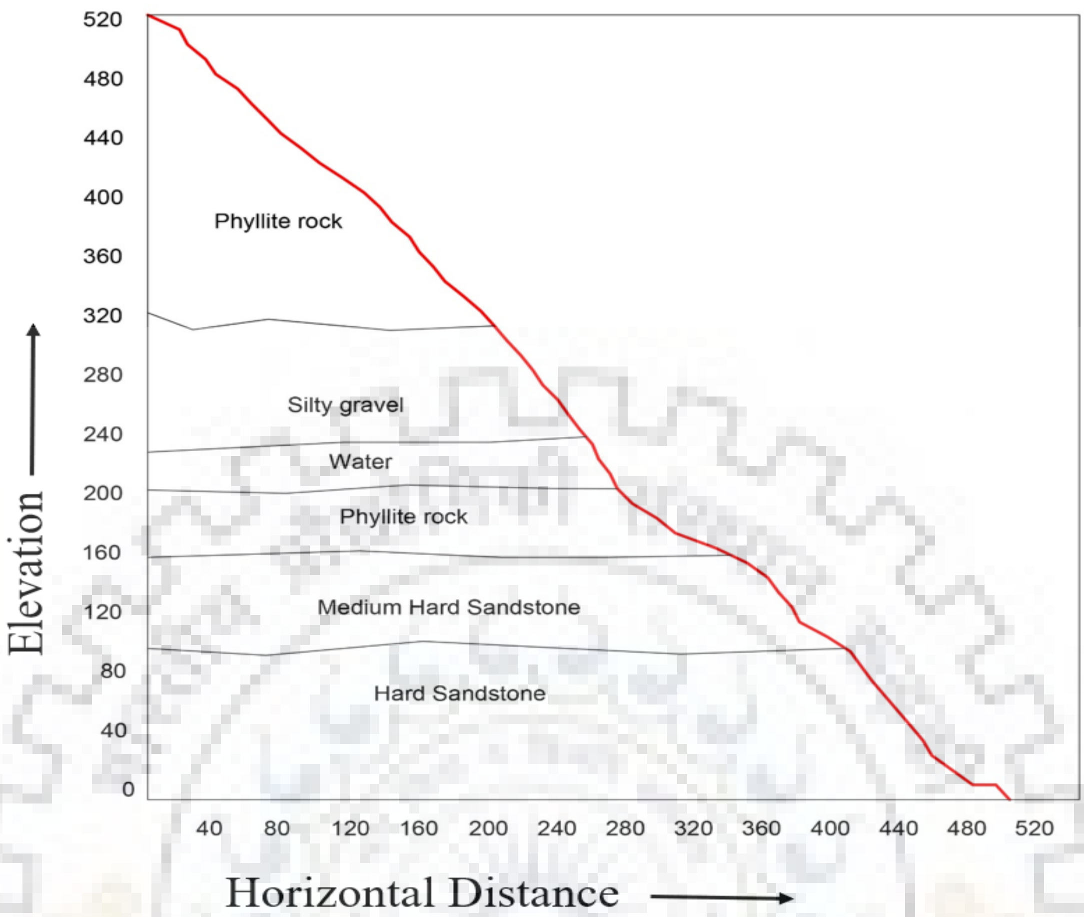

Figure 6.3: Geological cross-section of the landslide at NH123 section across the road at km (37) 2 to 4

Above the National Highway, there is a vertical overburden soil slope of about 12m depth. Below this slope, moderate weathered Phyllite strata of about 5 m thickness exist in the site. When landslide occurred, all the debris was collected on the toe of a landslide which is on the national highway. As a result, the national highway gets blocked and, in some cases, the high landslide velocity washes out the road section completely.

As observed, the vertical face of the slope is prone to landslide because of the perennial natural water source at the top of lower slope and water from rainfall infiltrate through the weathered rock strata below overburden soil. According to the above observation, restoration of hill measures is proposed to be adopted to stop the movement and to control the seepage of water into the slope. Post sliding measures are covered in this section for the protection of hill slopes like Drainage management, Earthworks, Gabion Wall, Retaining walls, Shotcrete, Soil nailing which are to be applied on landslide affected area.

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6.3 Layout plan of remedial measures

Soil nailing is proposed to upper slope because upper slope has a phyllite rock, which is very fragile and pronounced as a risk of rock fall. On the right flank of the landslide is erodible and in every monsoon season it is extending as show in Figure 3.3. due to this reason shotcrete provided on right flank portion as shown in mitigation layout plan Figure 6.4. Middle slope has a very narrow area and due to presence of overburden material which is come from upper slope and gathered in middle slope. When in rainy season rain water flow in middles slope and mixed with overburden and start flowing to down slope which is very destructive for nation highway. Due to these reasons gabion wall suggested. It allows to drain the water through it but overburden can not pass through it. That is why it is very suitable in middle slope. As found that on site there is a natural water outlet which is perennial and it is the main cause of to make lower slope failure. For that surface and sub surface drainage measures are suggested. As mention earlier lower slope is adjacent to nation highway and is has a high potential to damage the road and pronounced the risk all the time. To keep in mind these reasons retaining structure are proposed with slope modification coz slope is very steep. Details of each measures as given in section 6.3 to 6.7.

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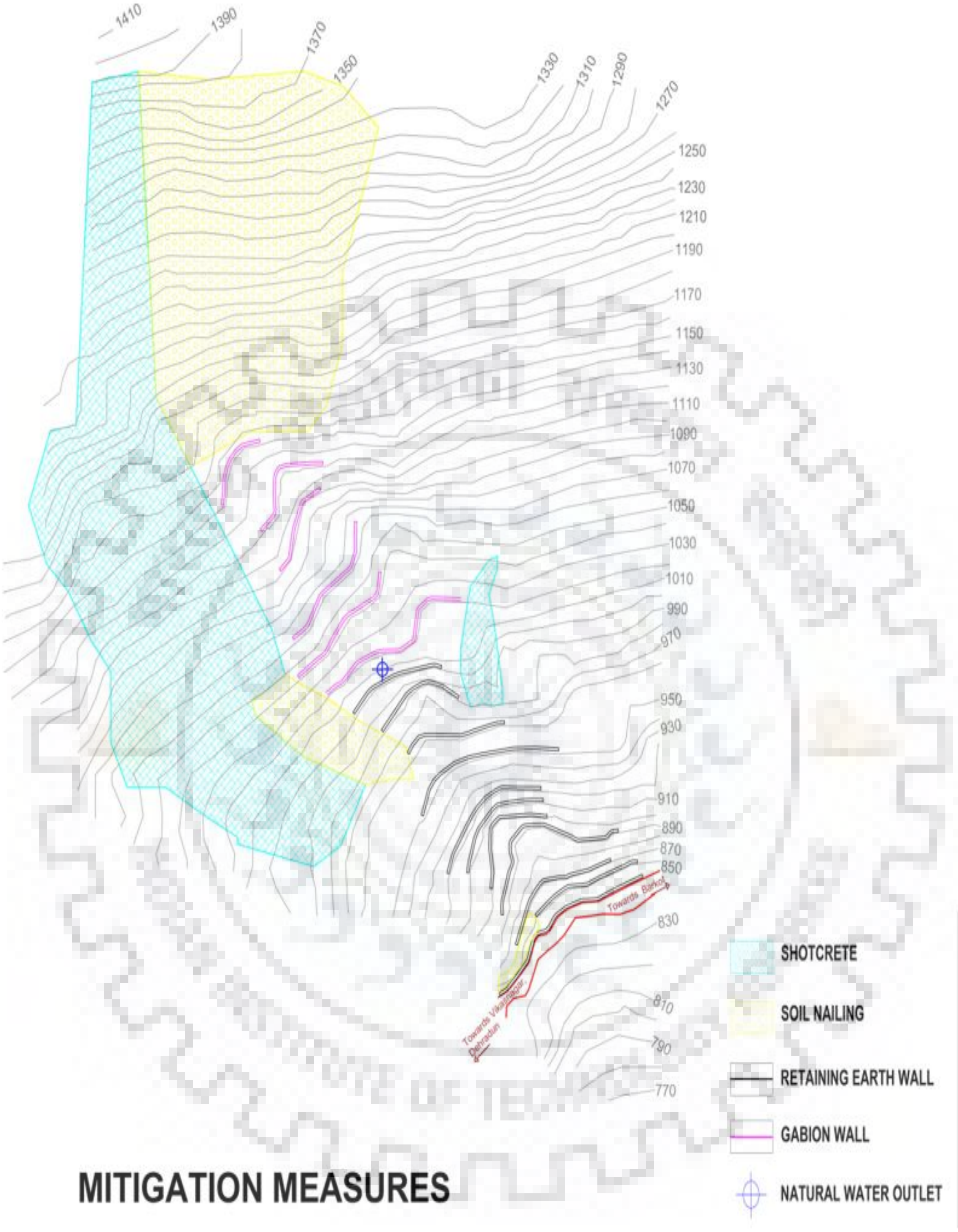

Figure 6.4: Layout plan of the mitigation measures in landslide area

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6.4 Soil Nailing

By adopting soil nailing technique, the shear strength characteristics of overburden material can be improved. This technique leads to enhanced stability of the slope. This is an elegant technique and the principal is quite simple. As in case of reinforced earth wall, a construction has a sequential construction that goes from bottom to top. Similarly, in case of soil nailing, a reinforced wall has been constructed sequentially from top to bottom.

6.3.1 Definition and Development

• Soil nailing consists of passive reinforcement of existing ground by installing closely spaced steel bars (i.e. nails), which may be subsequently encased in the grout.

• In a soil-nailed retaining wall, the properties and material behaviour of three components that are the native soil, the reinforcement nails, and the facing element and their nature interactions significantly affect the performance of the structure. (Schlosser, and Unterreiner,1990)

• As construction proceeds from the top to bottom, shotcrete or concrete is also applied to the excavation face to provide continuity or stability.

• In the US, the first Federal Highway Authority document on soil nailing was issued through FHWA's office research and development. An updated version of above FHWA soil nailing manual made public in 2003 (Lazarte and Baecher 2003).

• One of the first carried application of soil nailing was in 1972 for a railroad widening project near Versailles, France, whereas the 18m high cut slope in the sand was stabilized using soil nails. Clouterre research programme is another step (Premalatha 2009).

• In Germany, the first use of a soil nail was in 1975. The first major research program on soil nail wall was undertaken in Germany from 1975 through 1981 by the University of Karlsruhe and the construction company Bauer (FHWA 2012).

• In India use of soil nailing technology is gradually increasing and guidelines are prepared by IRC with the help of Indian Institute of Science, Bangalore.

• First publication of guideline for Soil Nailing in India is IRC – SP: 102: 2014

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6.3.2 Favourable and Unfavourable ground condition for soil nailing

• The critical excavation depth of soil is about 1m – 2m height vertical or nearly vertical cut. As it is known that excavation is needed before soil nailing so there should not be any collapse if it can stand its own for about half a meter or one meter before the nailing is done then it is absolutely fine.

• All soil nails within a cross-section are located above the groundwater table and if the soil nails are below the groundwater table, the groundwater does not adversely affect the face of the excavation, the bond strength of the interface between the grout and the surrounding ground, or the long-term integrity of the soil nails. For example, the chemical characteristics of the ground do not promote corrosion.

6.3.3 Advantages

- Requires smaller right of way.
- Construction is less disruptive to traffic.
- Causes less environmental impact.
- Relatively fast in construction and uses typically less construction material and hence, economical.

6.3.4 Limitations

Soil nail walls are not well-suited where a large amount of groundwater seep into the excavation because of the requirement to maintain a temporary unsupported excavation face.

6.3.5 Conventional Analysis and Design Methods

Here is the description of that what is presented in the Federal Highway Administration (FHWA) code so that it can be used to understand the design. FHWA has documented comprehensive information on the analysis, design, and construction of soil nail wall in highway engineering applications in its technical manual FHWA (2003) entitled "Geotechnical Engineering Circular No-7- Soil Nail Walls".

So, for designing a soil nail wall, it is important to first understand what the failure modes are, which can occur during or after construction.

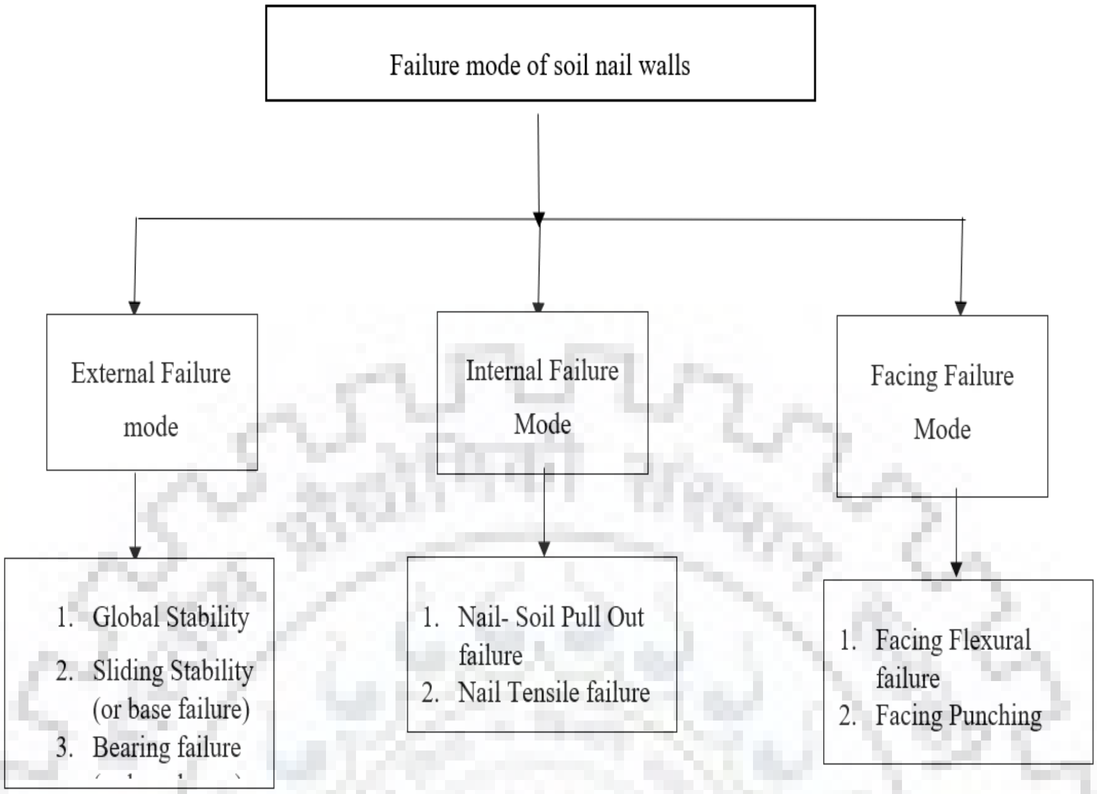

Figure 6.5: Principal failure mode of soil nail wall (FHWA,2012)

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(a) Global Stability Failure

Table 6.1: Minimum recommended factor of safety for global stability (FS_G), (FHWA 2003)

Temporary walls		Permanent walls	
Static	Seismic	Static	seismic
1.35	1.10	1.35	1.10

(b) Sliding Stability Failure

Table 6.2: Minimum recommended factor of safety for Sliding Stability (FS_S), (FHWA 2003)

Temporary walls		Permanent walls	
Static	Seismic	Static	seismic
1.30	1.10	1.50	1.10

(c) Nail Soil Pullout Failure

Table 6.3: Minimum recommended factor of safety for Nail Soil Pullout (FS_P), (FHWA 2003)

Temporary walls		Permanent walls	
Static	Seismic	Static	seismic
2	1.50	2	1.50

(d) Facing Failure Mode

Table 6.4: Minimum recommended factor of safety for Facing Failure (FS_F), (FHWA 2003)

Failure Mode	Static		Seismic	
	Temporary walls	Permanent wall	Temporary walls	Permanent wall
Facing Failure	1.35	1.50	1.10	1.10
Facing Punching Shear Failure	1.35	1.50	1.10	1.10

`

Table 6.5: Values of parameters considered for the design of soil nails

Parameter	**Value**
Internal angle of friction Overburdened Soil	30^0
Cohesion (C) of soil	10.0 kPa
Density of soil	20.00 kN/m^3
Shot Crete Thickness	0.1m
Grade of Concrete	M20
Vertical spacing of nails	1 m center to Centre
Horizontal spacing of nails	1.5m center to center
Length of nails	6 m
Diameter of nail	30mm
Bearing capacity of single nail	20kN/m
Surcharge	60 kPa

6.5 Earth Works

In Figure 3.5 showing loose material, there are loose soil and rocks at the site. For stabilization of the slope first, it is required to remove that loose material from top to the bottom of the slide because the slope of the landslide is very steep. During removal of cracked and fractured rock mass should be chiseled and gradient of the slope should be maintained to standard slope gradient.

6.6 Drainage Management

Water management plays a very important role in controlling landslide. Management of drainage network alone significantly improves the stability of the slide (Adhikari, 2001). It is the primary control measure for controlling the landslide. Drainage management consist of

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surface and sub-surface drainage which are capable to take away from the landslide zone to the natural drainage system.

6.5.1 Surface Drainage

As per the site visit and after understanding the hydrology discharge, a catch drain is proposed which should have the capacity to receive water from the natural outlet, which is in the centre of the landslide zone. Catch drain should be connected through the masonry ditch or PVC pipes, whichever are suitable considering the site condition should be used. The position of the catch drain and direction of water flow should be fixed according to the site condition and feasibility for construction of drain as there is a National Highway(NH) on the toe of landslide. So, catch drain path should pass below the NH and the end outlet of catch drain should be on the Yamuna river.

6.5.2 Sub Surface Drains

In summer and rainy seasons, usually the groundwater table rising and falling phenomenon occurs which will ultimately affect the stability of the landslide. According to site requirements, diameter of weep holes is chosen and it should be constructed in stagger pattern on the sliding area at a suitable distance, centre to centre for lowering the groundwater table and for reducing the pore water pressure acting beyond the rock mass strata.

6.7 Retaining Earth wall and Gabion Wall

At the toe of a landslide, there is a wreckage accumulation on the thumb of the vertical soil slope. Debris is in a loose position which is already broken and is highly volatile and has a tendency to slow down with the shallow surface of the sliding. Therefore, to move the slope mass and to prevent its movement, it is necessary to construct appropriate abstinence structure. Since, there is movement, the retaining structure of the type of reinforced earth has been considered.

An external permanent system (such as retaining wall) uses an external structural wall against which the stationary forces are collected. On the other hand, in an internally stable system such as reinforced earth, the strength, and expansion beyond the potential failure mass is included to ensure the consistency of the system. Like reinforced concrete, the reinforced earth is also an aggregate material that includes soil and strength. Since soil is weak in tension, tensile strength is given to take stress. Soil reinforcement provides an internal restraint against lateral distortion. The overall mass of soil and internal reinforcement acts as a coherent unit in the resistance of the outer body.

The Gabion Wall has been constructed with mountain slopes for ring protection. An additional layer of Gabion wall has been added so that it acts as an obstacle to slide the incoming material from the mounting hill slopes towards the settling basin, through NH. It retains the sliding content until its open space is filled. This foundation is built in the back-step type with the batters (inner inclination) in front of anchor 1:8, where the base has to face the base.

For proper drainage system, a weep hole in the Gabion wall is built on its base. To prevent the transport of fine particles with water, geomembranes are placed on the basis of the drain, backward side, and the Gabion wall. According to the IS 14458-1 (1998): Guidelines for retaining wall for hill area, Part 1, the Gabion wall have to be constructed.

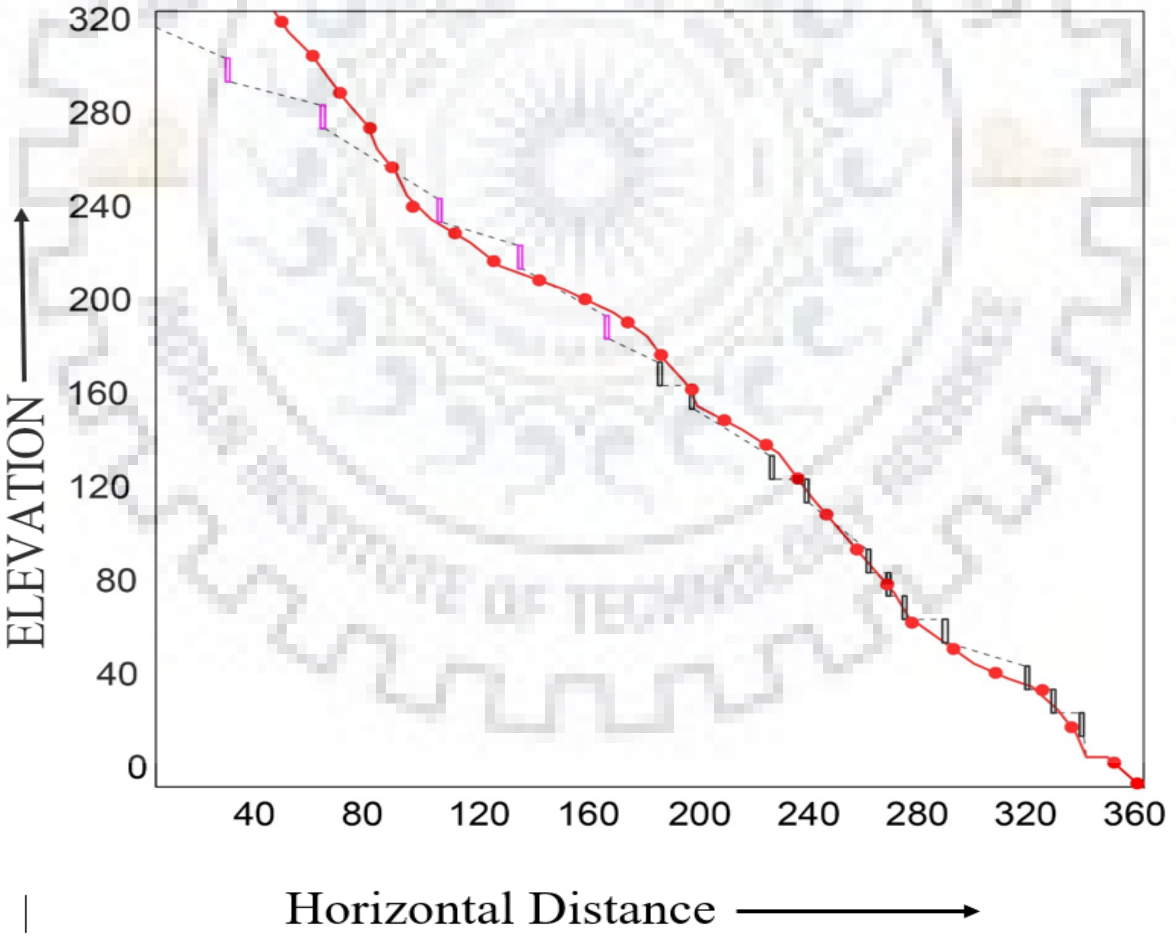

Figure 6.6: Cross section of retaining earth wall 10 meters proposed at landslide affected area

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6.8 Shotcrete

Shotcrete can be applied by two different application techniques, dry mixing process and wet mixing process. The decision to use dry or wet mix shotcrete processes is usually done on a site-by-site basis. Due to the accessibility of the site to transportation and equipment available on site, the dry mixing system will be adopted. The rock mass of the slide area is not so good, it is very loose, it is open jointed so the mash reinforced shotcrete should be adopted to stabilize the slopes. Weld mesh should be minimum made of 4 mm diameter wire welded in 100 mm x 100mm grid would be used. Since it is quite strong and there is enough light to handle the sheets. The weld trap will have pinned tight against the face and will have an anchor with rock bolt. Prior to applying a shotcrete to the surface, the work area should be sprayed with air-water jets to remove loose rock and dust, and afterward, a plain shotcrete will be applied.

6.9 Check Slope Stability

1. Upper Slope

As the results come out in Figure 5.2(b)and 5.2(c), upper slope FOS is less than 1. After applying mitigation measures on the slope stability was checked again and the factor of safety increase and now it is more than 1 (Figure 6.7), therefore slope is stable and our purpose to increase slope stability get fulfilled.

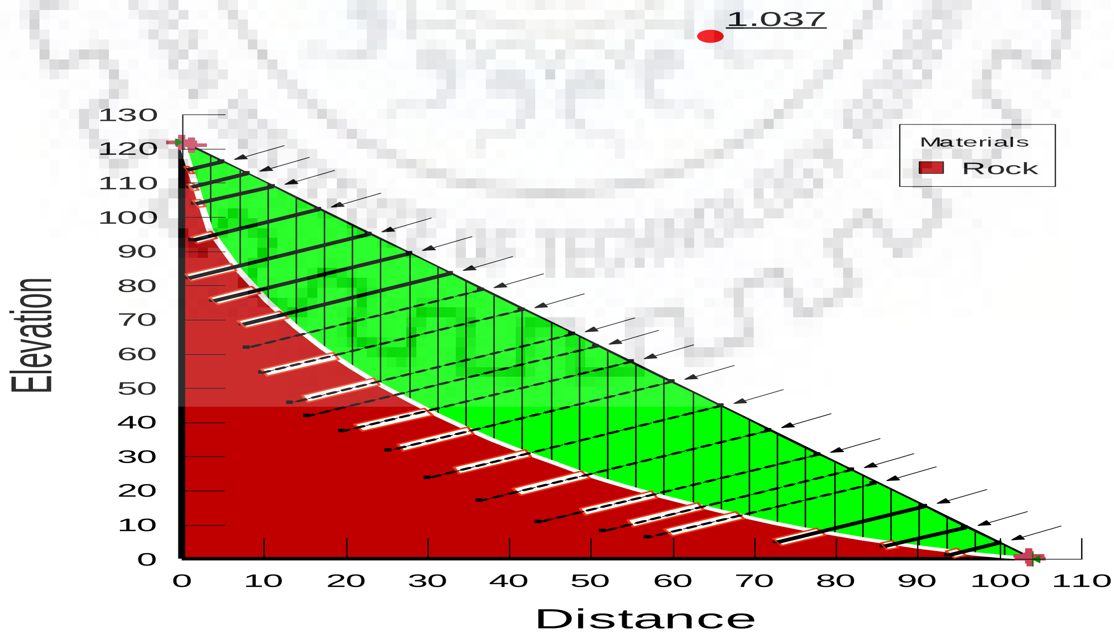

Figure 6.7: Upper slope slip surface after application of soil nailing

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2. Middle Slope

As the results come out in Figure 5.3(b)and 5.3(c), middle slope FOS is less than 1. After applying mitigation measures on the slope stability was checked again and the factor of safety increase and now it is more than 1 (Figure 6.8), therefore slope is stable and our purpose to increase slope stability get fulfilled.

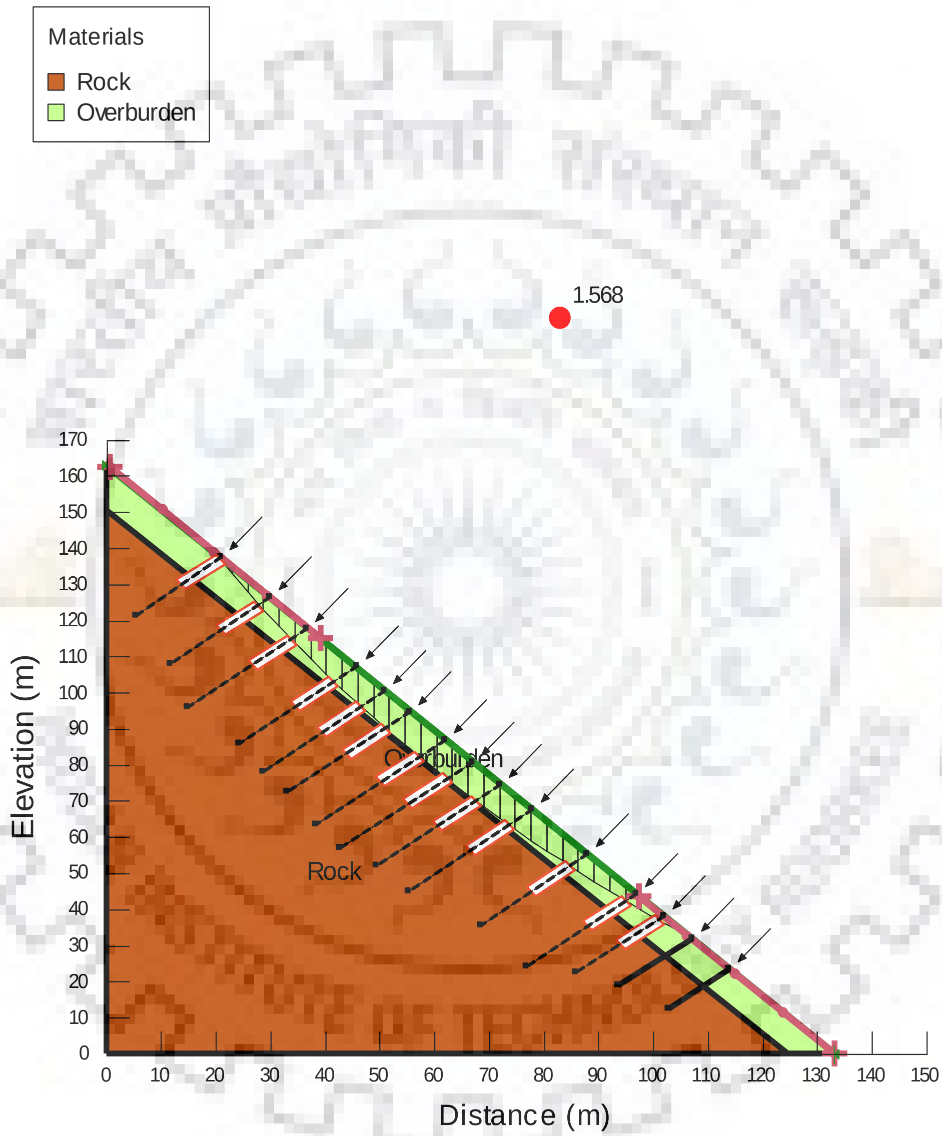

Figure 6.8: Middle slope slip surface after application of retaining structure

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3. Lower Slope

As the results come out in Figure 5.4(b), 5.4(c), and 5.4(d) lower slope FOS is less than 1. After applying mitigation measures on the slope stability was checked again and the factor of safety increase and now it is more than 1 (Figure 6.9), therefore slope is stable and our purpose to increase slope stability get fulfilled.

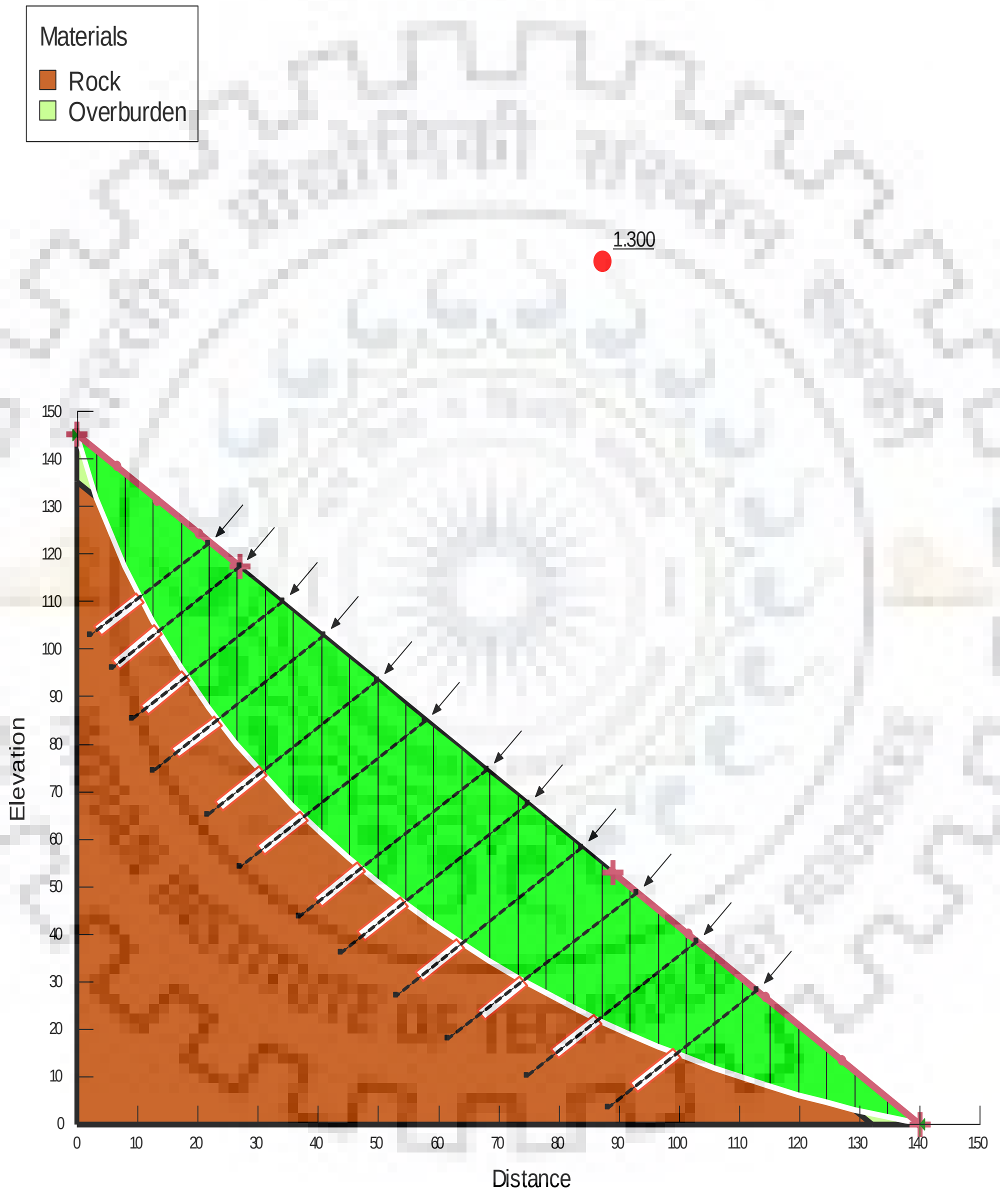

Figure 6.9: Lower slope slip surface after application of mitigation measure.

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6.10 Observation and Outcome

As an existing condition on site, the toe of the landslide was protected by concrete blockes and gabion wall, but it is insufficient for the protection of hill slope. After the landslide occurred, it destroyed the all retaining structure and effect can be seen on the national highway as it got blocked for several hours for many days.

Since this chapter focuses on the protection work of hillslope stability and suggestions are concluded accordingly. Stabilization measures adopted for the protection of the slide slope with conventional type do not always yield successful results. Leading solutions should be applied for landslide stabilization, such as the soil nailing, drainage management, shotcrete, retaining structure as it is highly effective in controlling the landslide. Table 6.6 showing how much effective all measure which are suggested.

Table 6.6: Comparison of Factor of Safety before and after application of mitigation

Slope	Before mitigation FOS	After mitigation FOS
Upper slope	0.412	1.037
Middle Slope	0.552	1.568
Lower Slope	0.177	1.300

Chapter-7

Summary and Conclusions

7.1 Summary

In this work, a particular landslide prone area was selected to provide suitable measures to minimise the risk of landslide in the area. It was observed that limited work has been done which was not sufficient to make it disaster free and therefore an attempt is made to give some better solution to the problem. A literature review is done in order to understand its geographical condition, drainage system and vegetation. Data was collected in terms of soil type and rock type. After collecting the data, landslide was assessed on the basis of two methods, Landslide Susceptibility Score (LSS) and Landslide Hazard Evaluation Factor (LHEF). Existing slope stability was checked for which google earth was used. After getting slope profile, a software for checking the slope stability i.e. Geo-slope was used, through which different conditions were tested on the same slope. Keeping in mind the above results, various mitigation measures to prevent landslide were designed from contour maps and the cross-section of the site.

These measures were then applied on the same slope and then checked with the help of geo slope and the strength was examined too. The results of which are given in conclusions.

7.2 Conclusions

1. Through visual interpretations and the localities present, it was found that the landslide started long before but due to the absence of proper measures, the area in consideration was expanding.

2. It was observed that the site consists of phyllite and sandstone and the phyllite possess low strength and is present at the source of the landslide because of which it slides every now and keep continue sliding.

3. Slope was determined by Arc-GIS and the slope map profile was found to be similar.

4. Assessment of landslide was done in two steps i.e. Susceptibility and Hazard.

5. Various methods to prevent landslide were examined for studying the landslide area. After the remedial measures slope profile was checked for its stability which is now on the safer side.

7.3 Future Scope of Work

It can be concluded that most of the information can be locally accessed and various mitigation measures with innovative technologies can be given.

- The monitoring of the high hazard landslide areas should be done.
- An estimate of the contributing factors for the failure of landslide slope should be taken into consideration, the economic and durable measures should be proposed as well.

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