Landslide Analysis & A Case Study on Recent Landslides in Solan, Shamti

A

Major Project Report

Submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision

of

Dr. Sugandha Singh

(Assistant Professor)

&

Dr. Tanmay Gupta

(Assistant Professor)

by

Pranjal Srivastava (201627)

Mohit Thakur (201642)

to

DEPARTMENT OF CIVIL ENGINEERING

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY, WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH

MAY – 2024

STUDENT'S DECLARATION

We confirm that the project report titled " **Landslide analysis & A Case Study on recent landslides in Solan, Shamti**" submitted as part of the requirements for the **Bachelor of Technology** degree in **Civil Engineering at Jaypee University of Information Technology, Waknaghat**, is our original creation. This project was carried out under the guidance of **Dr. Sugandha Singh and Dr. Tanmay Gupta**, and this project has not been submitted elsewhere for the fulfilment of any other degree or diploma.

We take full accountability for the content of our project report and verify its authenticity.

Signature of Student	Signature of Student
Pranjal Srivastava (201627)	Mohit Thakur (201642)
Department of Civil Engineering	Department of Civil Engineering
JUIT Waknaghat, India	JUIT Waknaghat, India
Date:	Date:

CERTIFICATE

This certifies that the project report titled **" Landslide analysis & A Case Study on recent landslides in Solan, Shamti"** submitted to the **Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat**, for the partial fulfilment of the requirements for the degree of **Bachelor of Technology in Civil Engineering**, is an authentic record of the work carried out by **Pranjal Srivastava** (201627) & **Mohit Thakur** (201642) from August 2023 to May 2024. The project was conducted under the supervision of **Dr. Sugandha Singh and Dr. Tanmay Gupta** from the **Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.**

The above statement made is correct to the best of our knowledge.

Date:

Signature of HOD

Name:- Prof. Dr. Ashish Kumar

Professor & HOD

Department of Civil Engineering

JUIT, Waknaghat

Signature of Supervisor

Name: - Dr. Sugandha Singh
Assistant Professor
Department of Civil Engineering
JUIT, Waknaghat

Signature of Supervisor

Name: - Dr. Tanmay Gupta
Assistant Professor
Department of Civil Engineering
JUIT, Waknaghat

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ABSTRACT

Shamti experienced landslides in the early morning of 10 of July 2023 around 4:00am (as per the locals), After continuous rainfall in Solan and other major districts of Himachal Pradesh. Many areas of Solan were affected along with Shamti. The catastrophe was this big that it affected 108 families,30 houses (collapsed), 50 houses (partially damaged) in Shamti. This report presents the findings from soil testing conducted in response to a recent landslide event in This report is completely dedicated in investigation and providing mitigation. Measures for giving a sustainable infrastructure in favor of development. Or the people of Shamti, solan.

Himachal Pradesh, India. The landslide, which occurred in Shamti, led to significant disruption and posed a threat to infrastructure and local communities. The objectives of this study were to investigate the soil properties contributing to the landslide, assess the geotechnical characteristics of the affected area, and provide recommendations for mitigating future landslide risks.The project is totally dedicated to, (a) understand the cause of landslides and structure failure, (b) providing mitigation measures to prevent Shamti from future calamities. This is to be done by performing different types of soil test and surveying the geological data for the given site. For these 2 major sites has been selected:

(1) The fisheries office: Office building which drowned away with the debris flow after the land slide.

(2) A residential building: A 2-storey building which faced pan cake failure as the water broke out in the foundation of building as the weep holes in the retaining walls were blocked with the improper construction.

Field investigations and laboratory testing were conducted to analyse the soil samples collected from the landslide site. the findings from this soil testing report shed light on the geotechnical aspects of the recent landslide in Himachal Pradesh. The results emphasize the importance of understanding soil behaviour and implementing appropriate measures to mitigate landslide risks in similar geological settings

Keywords: *Analysis, geological survey Failure, catastrophe, disruption, mitigation measures.*

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OMC	OPTIMUM MOISTURE CONTENT
SBC	STRENGTH BEARING CAPACITY
W	MOISTURE CONTENT OF SOIL
OMC	OPTIMUM MOISTURE CONTENT
Ht	HEIGHT
Ka	COEEFICIENT OF ACTIVE EARTH PRESSURE
Kp	COEFFICIENT OF PASSIVE EARTH PRESSURE
(σ_n)	NORMAL EFFECTIVE STRESS
(φ)	FRICTIONAL ANGLE
(c)	COHESION

CHAPTER – 1

INTRODUCTION

All continents experience landslides, which are essential to the changing of landscapes. Additionally, they pose a significant risk in many parts of the world. In spite of their significance, we calculate that fewer than 1% of the landmasses' slopes are covered by landslide maps, and comprehensive data on the kinds, numbers, and distribution of landslides are scarce.

Shamti experienced landslides in the early morning of 10 of July 2023 around 4:00am (as per the locals), After continuous rainfall in Solan and other major districts of Himachal Pradesh. Many areas of Solan Were affected along with Shamti. The catastrophe was this big that it affected 108 families,30 houses (collapsed), 50 houses (partially damaged) in Shamti. According to the old geological, geotechnical investigations it is seen that the water table of the location is significantly increasing every year which was not being noticed by the officials which finally resulted in landslides. In this work, we first outline the principles for landslide mapping, and we review the conventional methods for the preparation of landslide maps, including geomorphological event, seasonal, and multi-temporal inventories and through these study we try to give the landslides monitoring importance and also give different types of remedies which can be used to counter landslides in future. Next I show how to determine landslide risk at different scales using a variety of approaches, including probabilistic methods and heuristic geomorphological investigations.

There are 2 major sites in Shamti on which the report has been made and its mitigation measure need to be provided in construction of any structure in Shamti to prevent damages from landslides.

1.1.1 Basic land Slide Types

A landslide may be defined as a downward movement of rock, soil, or both on the surface of a rupture, which can be flat (translational slide) or curved (rotational slide). Most of the material in a landslide flows in a coherent or semi-coherent mass with minimal internal deformation. It should be mentioned that, occasionally, additional forms of movement may also be involved in landslides, either at the beginning of the collapse or afterwards if the characteristics change as the displaced material down the slope.

1.1.2 Topple

The forward movement of a mass of soil or rock out of a slope around a point or axis below the displaced mass's centre of gravity is known as a topple. Occasionally, the weight of the material upslope from the displaced mass exerts gravity, which causes toppling (see fig 1.1). Ice or water seeping through huge fissures can occasionally cause toppling. Rock, debris (coarse material), or earth materials (fine-grained material) can make up topples. Complex and composite topples are possible.

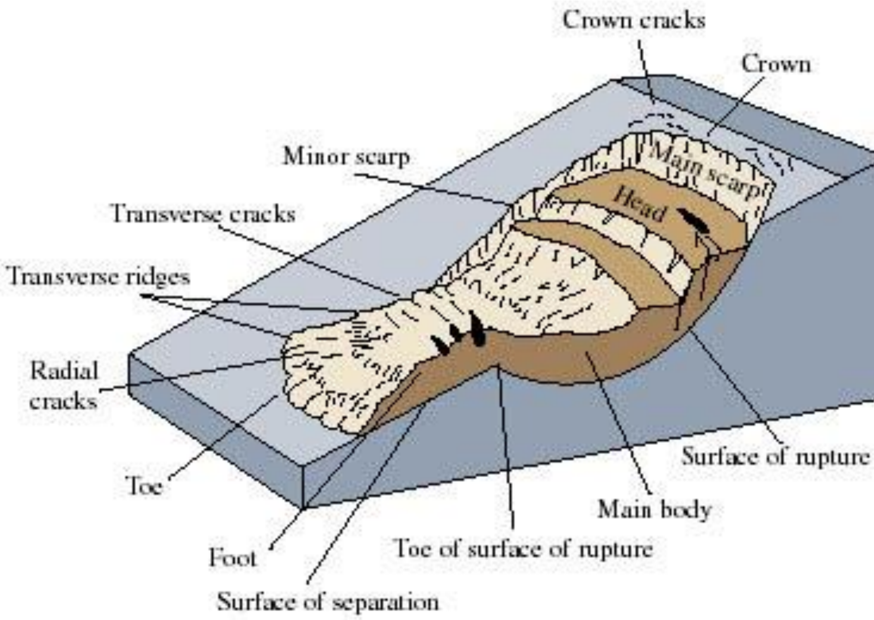


Fig1.1- Image Showing Topple landslide

1.1.3 Slides

A slide is the downslope movement of a mass of rock or soil that happens on relatively narrow zones of extreme shear strain or on surfaces that are rupturing. The volume of material that is being displaced expands from a region of local failure; movement does not initially occur concurrently over the whole area that will later become the surface of rupture.

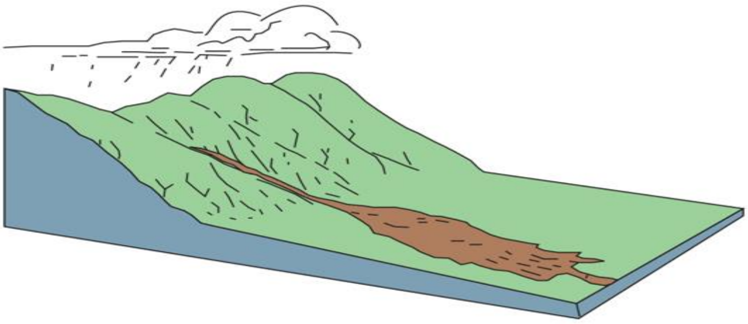


Fig -1.2 Slides Type landslide

1.1.4 Translational Landslides

With minimal rotating movement or tilting backward, the mass in a translational landslide flows outward, or down and outward, down a comparatively flat surface. Rotational slides tend to return the slide equilibrium; however this kind of slide can go significant distances if the surface of rupture is steep enough. There might be large slabs of rock, loose, unconsolidated soils, or both in the slide. Along tectonic discontinuities like faults, joints, bedding surfaces, or the interface between rock and soil, translational slides frequently collapse. In areas with permafrost, the slide may also go down it.

Fig- 1.3 Translational Landslide

1.1.5 Spreads

An expansion of cohesive rock or soil mass together with a general collapse of the cohesive material's fragmented bulk into softer subsurface material. The softer underlying material may liquefy or flow (and extrude), causing spreads. Block spreads, liquefaction spreads, and lateral spreads are examples of spread types.

Fig – 1.4 Spreads

1.1.6 Flow

A stream is a temporally perpetual motion where the shear surfaces are typically not maintained, have short lifetimes, and are closely spaced. The component velocities in a viscous liquid are similar to those in the displacing mass of a flow. The transition from slides to flows is frequently graded, based on the water material, accessibility, and movement's progression.

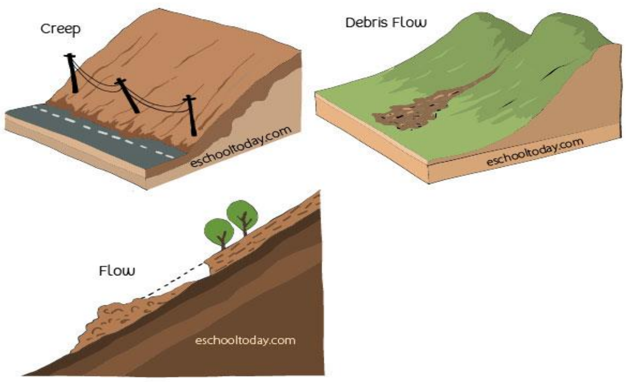


Fig – 1.5 Flow

1.1.7 Laharas (Volcanic Debris Flow)

The term "lahar" originates from Indonesia. Another name for lahars is volcanic mudflows. These are debris flows that have their source on the slopes of volcanoes. The loose piles of tephra—the solids that erupted from the volcano—and other debris are mobilized by a lahar.

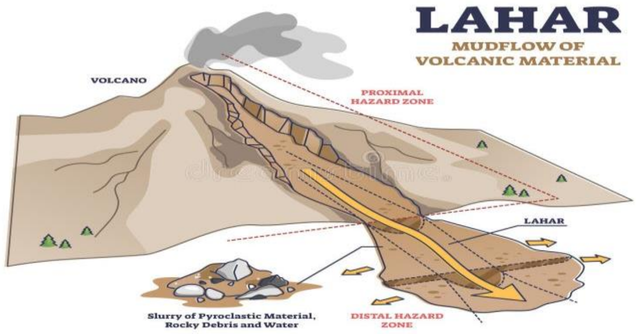


Fig – 1.6 Lahar

1.1.8 Earthflow

Earthflows can happen on mild to moderate slopes, usually in silty or clay-rich fine-grained soil, but they can also happen in extremely worn bedrock that contains clay. Within an earthflow, the mass travels as a viscous or plastic flow with significant internal deformation. When disturbed, susceptible marine clay, also known as fast clay, is extremely brittle and can rapidly liquefy, losing all shear strength in response to a change in its natural moisture content. This could possibly cause massive destruction and cause the clay to flow over several kilometres. The usual process of head scarp retrogression leads to size increases. Earthflows can also develop downslope from slides or lateral spreads.

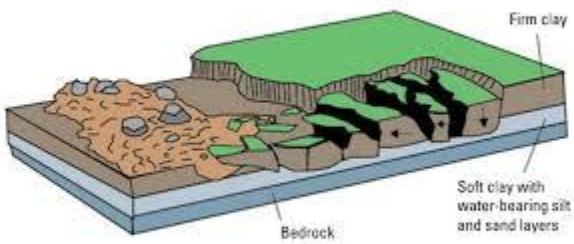


Fig – 1.7 Earth Flow landslide

1.2 Brief Profile Of District Solan

The district centre of Solan, which was established on September 1, 1972, is located in the state of Himachal Pradesh. Situated 46 kilometres south of Shimla, the state capital of Himachal Pradesh, is the biggest Municipal Council in the state. at a mean altitude of 5,200 feet (1,600 meters). The location has the name Shoolini Devi, a Hindu deity. A three-day mela at Thodo Ground is part of an annual event honoring the goddess that takes place in June. The capital of the former princely state of Baghat was Solan. Because of the extensive mushroom growing in the region and the Directorate of Mushroom Research (DMR), which is located in Chambaghat, it is referred to as the "Mushroom city of India".

Since Solan produces a large amount of tomatoes, it is known as the "City of Red Gold." The town is located on the Kalka-Shimla National Highway, which runs between Chandigarh and Shimla. Solan is crossed by the British-built Kalka-Shimla small gauge heritage railway line, which is designated as a World Heritage site.

Solan's climate is defined by mild to moderate weather conditions. Summertime precipitation is significantly higher than wintertime precipitation. The average yearly temperature in Solan is 17.5 °C/63.5 °F. There is 1262 mm, or 49.7 inches, of rainfall annually. The location that is provided is in the northern hemisphere. The location in question is in the planet's upper regions. End of June marks the start of summer, ends in September .

Key Points

A) Geographic Information

(i). Longitude location: 30°5´ and 31°15

(ii). Latitude location: 76°42¨ and 77°20´

(iii). Area Geographic: 1936 Sq. Km

1.3 Geology of State

1.3.1Topography

Its terrain is profoundly carved, its geological structure is complicated, and its temperate flora is rich in subtropical latitudes. The State is separated into five physiographic zones: wet sub-temperate zone (i), humid sub-temperate zone (ii), dry temperate-alpine high lands (iii), humid sub-tropical zone (iv), and sub-humid sub-tropical zone (v). The districts of Kullu and Shimla, as well as portions of Mandi, Solan, Chamba, Kangra, and Sirmour, are included in the humid subtemperate zone. The wet subtemperate zone includes Palampur and Dharamshala of Kangra district, Jogindernagar region of Mandi district, and Dalhousie area of Chamba district. Major portions of Lahaul-Spiti, Pangi, and Kinnaur are located in the dry temperate Alpine Highlands. The humid sub-tropical zone is made up of Bilaspur, the Bhattiyat valley in District Chamba, the Nalagarh area in District Solan, the Dehragopipur and Nurpur sections in District Kangra, and Nurpur areas of district Kangra and sub-humid tropical zone comprises of District Una, Paonta-Sahib area of District Sirmaour, and Indora area of District Kangra. The mountain environment's intricate physiography, demography, and developmental activities are vulnerable to natural disasters such intense snowfall, flooding, landslides, land subsidence, plant loss, and soil erosion. An estimate states that severe soil erosion affects 583.6% of the land, the most of which is in the Himalayas. The degree of erosion is indicated by an estimate of the sedimentation rate of the area's main river systems. Landslides can occur in a hilly region of Himachal Pradesh as a result of geological, climatic, and human causes. Over the past ten years, Himachal Pradesh has seen several terrible landslides. Landslides are more likely in Himachal Pradesh due to the hydro-meteorological conditions and the brittle structural makeup of the region's geological layers.

A significant amount of the contribution is also made by anthropogenic causes, such as the loss of plant cover and debris overloading of slopes. The issue has been made worse by development initiatives like building highways, tunnels, and excavation for hydroelectric projects.

1.3.2 Hydrological Statement

1.3.2.1 Climate

Due to height variations, Himachal Pradesh has a widely diverse climate (450 – 6500m). This region generally has a different climate than the Punjab plains because of the shorter, milder summers, greater precipitation, and longer, colder winters. The seasonal pattern of the weather and vertical zoning are the two primary climatic features of the area. In the southern low tracts, the climate is hot and humid tropical, but in the northern and eastern high ranges, it is temperate, cold, and glacial. The year is commonly split into three seasons. These three seasons are the summer (March to May), winter (October to February), and monsoon (June to September). Due to variations in elevation, the climate of Himachal Pradesh is very diverse (450-6,500m msl). The several climate zones often span from moderate temperate to subtropical (450–900 msl).

1.3.2.2 Rainfall

Solan, situated at a height of 0 feet or None meters above sea level, experiences a dry, humid winter climate (classification: Cwa). The district experiences 19.29ºC (66.72ºF) annually, which is -6.68% colder than the average for India. 43.18 rainy days (11.83% of the total) and 53.16 millimeters (2.09 inches) of precipitation fall on Solan per year.

1.3.3 Tectonic Settings

In Solan, Himachal Pradesh, India, several tectonic settings can trigger landslides due to the region's geological characteristics. These settings include:

Himalayan Tectonic Activity: Solan lies in the vicinity of the Himalayan mountain range, which is geologically active due to ongoing tectonic plate movements. The collision of the Indian Plate with the Eurasian Plate has led to intense folding, faulting, and uplift, creating steep slopes prone to landslides.

Seismicity: The Himalayan region experiences frequent seismic activity due to tectonic forces, including earthquakes. Seismic events can induce landslides by destabilizing slopes, altering ground conditions, and triggering slope failures, especially in areas with weak geological formations or steep topography.

Weathering and Erosion: Solan's geology is characterized by diverse rock types, including sedimentary, metamorphic, and igneous formations. Weathering and erosion processes, exacerbated by factors such as rainfall, freeze-thaw cycles, and vegetation cover, can weaken slope materials and increase susceptibility to landslides.

River Erosion and Valley Dynamics: River valleys and channels in Solan are subject to erosion and sediment transport, which can alter slope stability and trigger landslides. Fluvial processes, combined with tectonic uplift and seismic activity, contribute to the dynamic landscape and landslide potential in the region.

Anthropogenic Factors: Human activities such as deforestation, urbanization, road construction, and mining can exacerbate landslide hazards in Solan. Alterations to natural drainage patterns, excavation of slopes, and poor land management practices can increase the vulnerability of slopes to failure, leading to landslides.

In summary, the tectonic settings influencing landslide occurrence in Solan, Himachal Pradesh, include Himalayan tectonic activity, seismicity, weathering and erosion processes, river dynamics, and anthropogenic factors. Understanding these geological and environmental factors is crucial for assessing landslide risk, implementing mitigation measures, and promoting sustainable land use practices in the region.

1.4 Major Causes Of land Slide In District

According to surveys and various authors, landslides typically stem from three primary causes:

- Earthquake causing landslide.
- Rainfall causing landslide.
- Morphologically causing landslide.

1.4.1 Earth Quake Causing Landslide

As District Shimla , Solan lies on zone IV of earthquakes zones and a no. of earthquakes were witnessed in the state from past years like Chamba Kangra earthquake in 1905 of magnitude 8.1 on Ritcher's scale and Chamba earthquake 1995 of 4.9 magnitude on Ritcher's scale. So, earthquakes are one of a major cause of landslide. Landslides occur when masses of rock, earth material, or debris flows move down a slope due to gravity.

In general, there are two main categories of failures connected to landslides caused by earthquakes. These are (1) Coseismic landslides, which happen when there is an earthquake. These might be recently caused landslides or landslides that have already occurred or are old. (2) Post-seismic landslides: they happen after an earthquake has occurred but are caused by fractures, cracks, and deformations brought on by the earthquake.

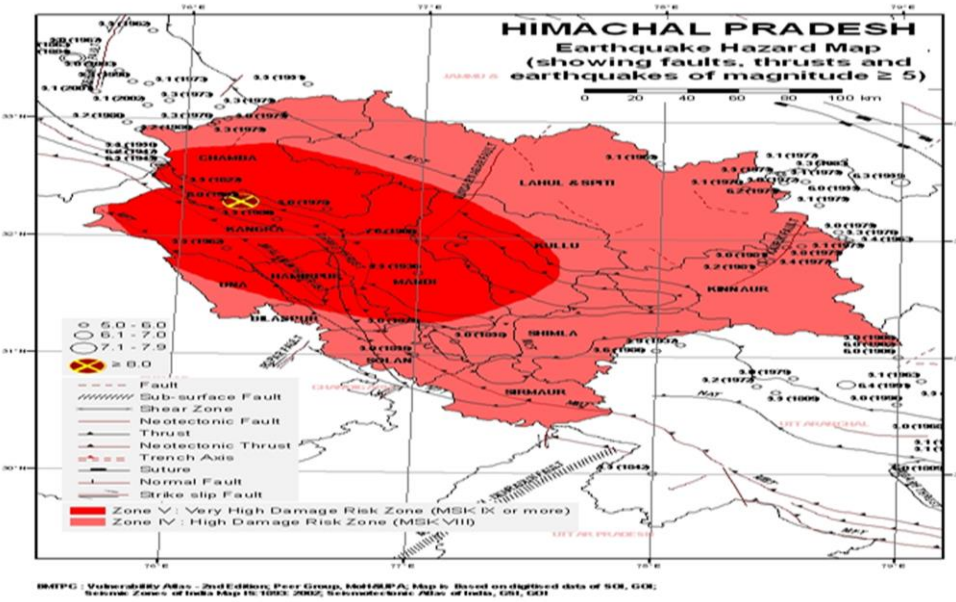


Fig-1.8 Earthquake Hazard Map of Himachal Pradesh

1.4.2 Rainfall Causing Landslide: -

Rainfall cause landslides in Himachal Pradesh through a process known as **saturation**. When intense or prolonged rain occurs, the water infiltrates the soil, increasing its weight and reducing its strength. This can lead to a **loss of friction** between soil particles, making slopes unstable. In Himachal Pradesh, which has steep terrain and fragile geological structures, this process is particularly dangerous.

Here’s a brief overview of how rainfall causes landslides in Himachal Pradesh:

Heavy Rainfall: The region receives intense monsoon rains, which saturate the soil.

Soil Saturation: As the soil becomes saturated, its weight increases, and its strength decreases.

Reduced Friction: The loss of friction between soil particles makes the slopes unstable.

Steep Terrain: The steep and complex terrain of Himachal Pradesh exacerbates the risk.

Geological Structure: The fragile geological structure of the region is prone to landslides.

Human Impact: Deforestation, road construction, and other human activities can also contribute to the instability of slopes.

It’s important for the authorities and the public to be vigilant during the monsoon season and to follow safety guidelines to minimize the risk of landslides and their devastating effects.

Fig-1.9 Rainfall Causing Landslide

1.5.3 Morphological Causes of landslide

The geological and geographical features of the area are probably a factor in the morphological causes of landslides in Solan, Himachal Pradesh. The following are a few possible morphological reasons:
Steep Slopes: Solan has steep terrain, which can lead to slope instability, just like many other parts of Himachal Pradesh. The stability of the ground is significantly influenced by the slope angle.

Geological Structure: The vulnerability of a region to landslides can be influenced by its underlying geological composition, which includes rock types, fault lines, and the existence of weak or cracked rock formations.

Weathering and Erosion: Over time, natural processes like weathering and erosion erode a slope's stability. Rainfall, snowmelt, and freeze-thaw cycles—all of which are frequent in the area—can hasten these processes.

Vegetation Cover: The stability of a slope can be impacted by the presence or lack of vegetation. By preventing surface erosion and strengthening the soil via root systems, vegetation stabilizes slopes. By eliminating this stabilizing element, deforestation or changes in land use may raise the danger of landslides.

Water Saturation: Too much rain, especially in the monsoon season, can cause the soil to become saturated and raise the pore water pressure on the slope. As a result, the slope materials experience less effective stress, which increases the likelihood of collapse.

Human Activities: The construction of roads, excavation, mining, and inappropriate land use are examples of anthropogenic influences that can change the natural environment and cause slope instability. The danger of landslides might be increased by poorly designed infrastructure projects or insufficient slope stabilizing techniques.

CHAPTER -2

LITERATURE SUMMARY

Reichenbach, Paola, et al.[1] A significant variability in the landslide and theme data types and sizes, the modelling methodologies, and the criteria used to evaluate the model performance was shown by the critical literature review using the wide literature database as evidence. Logistic regression, neural network analysis, data overlay, index-based, and weight of evidence analyses were the most often used statistical classification techniques for determining susceptibility, with a shift in favour of machine learning techniques in recent years. While some techniques outperformed others, no single technique emerged as the best under all circumstances. We find that the investigators' expertise and experience with a particular categorization technique matters more than the method itself, and we support the use of numerous approaches to acquire varying susceptibilities.

Dikshit, A., Sarkar, R., Pradhan, B., Segoni, S., & Alamri, A. M. (2020).[2] The present article aims to provide an understanding of the research being done in the Indian Himalayan area, which accounts for about 15% of all landslides caused by rainfall worldwide. Since this is the only type of landslide activity that can be controlled by early warning systems and forecasting models, and since it accounts for a large fraction of landslides in the Indian Himalaya, the article primarily discusses landslide activity that was caused by rainfall. Significant improvement is needed in a number of areas, according to the assessment, particularly when it comes to climate change, the utilization of high spatial and temporal resolution data, and novel techniques including computational and physical methods..

Joshi, V., Kumar, K.[3] It is commonly recognized that the Himalaya is prone to several kinds of mass movements because of its greater height, immature geology, river activity, heavy rainfall, seismicity, and growing anthropogenic activities. Research conducted across the Himalayan area shows that there is a rise in the frequency of intense rainfall events, which is one of the primary causes of landslides. Future loss of life and property may be more likely in certain locations due to the rise in these occurrences and population growth. In the Himalayan area, there are at least four or five such occurrences of significant severe events per year, along with downstream effects. There are instances when the impacted areas' rainfall data is unavailable. Severe rains, thrush have the potential to initiate landslides and prolong their recurrence.

Gupta, V., Ram, B.K., Kumar, S. et al.[4]In addition to the area's precipitation pattern, the catchment's geomorphological and hydrological features affect flash floods. Several flash floods have occurred in the Himalaya in the past, mostly in July and August during the monsoon season when there is an average daily precipitation of about 200 mm . Furthermore, depending on the stream's carrying capacity, human action directly increases the impact of flash floods. The Himalaya during recent years has received variable precipitation in the form of extreme rainfall, at times cloudbursts, (IPCC 2021) leading to higher incidences of landslides.

Popielski, P., Bednarz, B., Majewski, T. and Niedostatkiewicz, M., 2023.[5]Monitoring the water level in the subsurface is crucial for the safety of buildings because it can reveal the onset of seepage-induced deformations. Inaccurate application and inadequate description of the ongoing subsurface phenomenon of seepage occurrence criteria can result in mistakes in design, particularly when working related to bolstering already-existing structures, especially venerable religious buildings. In terms of HYD, the Ultimate Limit State (ULS), which pertains to failure caused as a result of water passing through a soil medium, must be considered when assessing the structural integrity of historic structures located in groundwater areas flows.

Popescu, M. E., & Sasahara, K. (2009).[6] Every engineer has to be familiar with the fundamentals of slope analysis and studies. This study aids in preventing structural deterioration and future problems. This might lessen the expense, budget, and cost of the slope construction and assist avoid unintentional damages such abrupt slope collapses. Slope stabilization must be determined in order to ensure the safety of designed structures and to stop further losses.

Kumar, A., Sharma, R. K., & Mehta, B. S. (2020).[7] Generally speaking, slopes are assessed in relation to the FOS against slipping. The topography and material qualities over the whole length of NH-205 vary greatly, contributing to the slope conditions. The material's shear strength varies when its physical-chemical characteristics, moisture content, and environmental factors vary. More emphasis is being paid to the requirement for an accurate model for the mitigation of various types and dimensions of exposed and/or predicted future landslides due to the distribution of diverse types of material with inherent heterogeneity in physical qualities. The current study deduced that the primary physical characteristics of the slope-forming material, such as its shear strength capacity, slope geometry, and structural features that significantly lower its effective shear strength, are NH-205's components are the source of instability.

Singh, S. P., & Roy, A. K. (2022).[8]Due to its complex topography, current natural conditions, and human influence and intervention, the Himalayan mountain range is prone to slope instability in many places. This construction takes into consideration National Highway-05. Slope stability is assessed at the Rampur, Shimla, Himachal Pradesh, region that is the subject of the inquiry. Maintaining the stability of the slope is the major goal of this operation in order to safeguard NH-05 and the nearby three-sided residential buildings. After the site inspection, laboratory testing and borehole geotechnical studies are carried out. Slope stability analysis is started when the geotechnical research report has been interpreted.. Numerical modelling approaches are used to compute the mitigation design parameters for the area and the circular slide failure, taking into consideration the geotechnical features of the designated study zone. The safety factor is calculated by the software in both static and dynamic scenarios. Consequently, some changes and preventative actions are recommended.

Kansal, M.L. and Singh, S., 2022.[9] The majority of Indians reside in the Indian Himalayan Regions, which serve as a vital hub for food, energy, and water for society, biodiversity, and life. Nevertheless, these regions are frequently hit by devastating natural catastrophes, particularly floods. The research emphasizes how development, deforestation, and tourism are examples of artificial causes that have exacerbated the catastrophic flood conditions, as well as natural factors like topography and harsh climate. The research also lists the difficulties in managing floods, including complicated geography, inadequate governance and policy, a lack of sufficient data and infrastructure, and the requirement for integrating flood management with climate change. In order to evaluate multi-institutional land use planning, mitigation policy implementation, and mitigation techniques, the research recommends implementing an efficient flood risk management strategy

Kahlon, S., Chandel, V. B., & Brar, K. K. (2014).[10] The research paper examines the frequency and impact of landslides in Himachal Pradesh, India, particularly focusing on Shimla, Solan, Kinnaur, and Mandi districts. Over the past four decades, there has been a noticeable increase in landslide occurrences, with high-intensity rainfall during monsoons being a primary triggering factor. This increase in landslides has resulted in significant loss of life, disruption of transport and communication infrastructure, and damage to settlements, agricultural land, and natural vegetation.

The study highlights a rising trend in landslide-related fatalities, especially during the 1900s and 2000s, coinciding with periods of intensified rainfall, cloudbursts, and flash floods. Kullu and Shimla districts are identified as the most affected areas, together accounting for nearly half of the total deaths caused by landslides.

Moammen E. Abd EI Raouf.[11]As per the author retaining wall can be classified

based on mechanism of load support, method of construction system rigidity and etc. Forces

acting on retaining wall are lateral earth pressure, self-weight of retaining wall, weight of soil

above base slab, surcharge and soil reaction below base slab.

To confirmation to check the stability of retaining wall are: i) check for sliding ii) check for

returning iii) check for bearing capacity failure and iv) check for base shear failure. The

minimum factor of safety for the stability of the wall is:

1) Factor of safety against sliding= 1.5

2) Factor of safety against overturning= 2.0

3) Factor of safety against bearing capacity failure= 3.0

2.2 Summary Of Literature Review

The literature review categorizes landslides based on their kind, speed, and material flow. Landslides are both natural and man-made. Natural factors include earthquakes, gravity, and rainfall. Landslides are mostly caused by human activity, such as excavation for construction projects that disrupt soil stability.

There are several approaches to stabilize landslide-prone slopes. Common ways for retaining walls include nailing, installing drainage systems, and employing recomposites. Retaining walls are a popular, cost-effective, and simple method for stabilizing slopes. Retaining walls are classified based on slope height and utilized accordingly.

2.3 Need & scope of Study

The alarming frequency of fatalities due to infrastructure failures raises concerns about civil engineering effectiveness. The recent tragedy in Shamti, Solan, where a 3-story building collapsed, underscores the importance of proper soil stabilization, especially on rainy days. Before construction commences, thorough soil testing, both in labs and on-site, is imperative to understand soil composition and its load-bearing capacity. Basic sieving determines soil type—silt, clay, or sand—while additional tests like moisture content and direct shear testing unveil crucial soil characteristics. Implementing these measures ensures safer construction practices, averting catastrophic consequences.

2.4 Research Gap

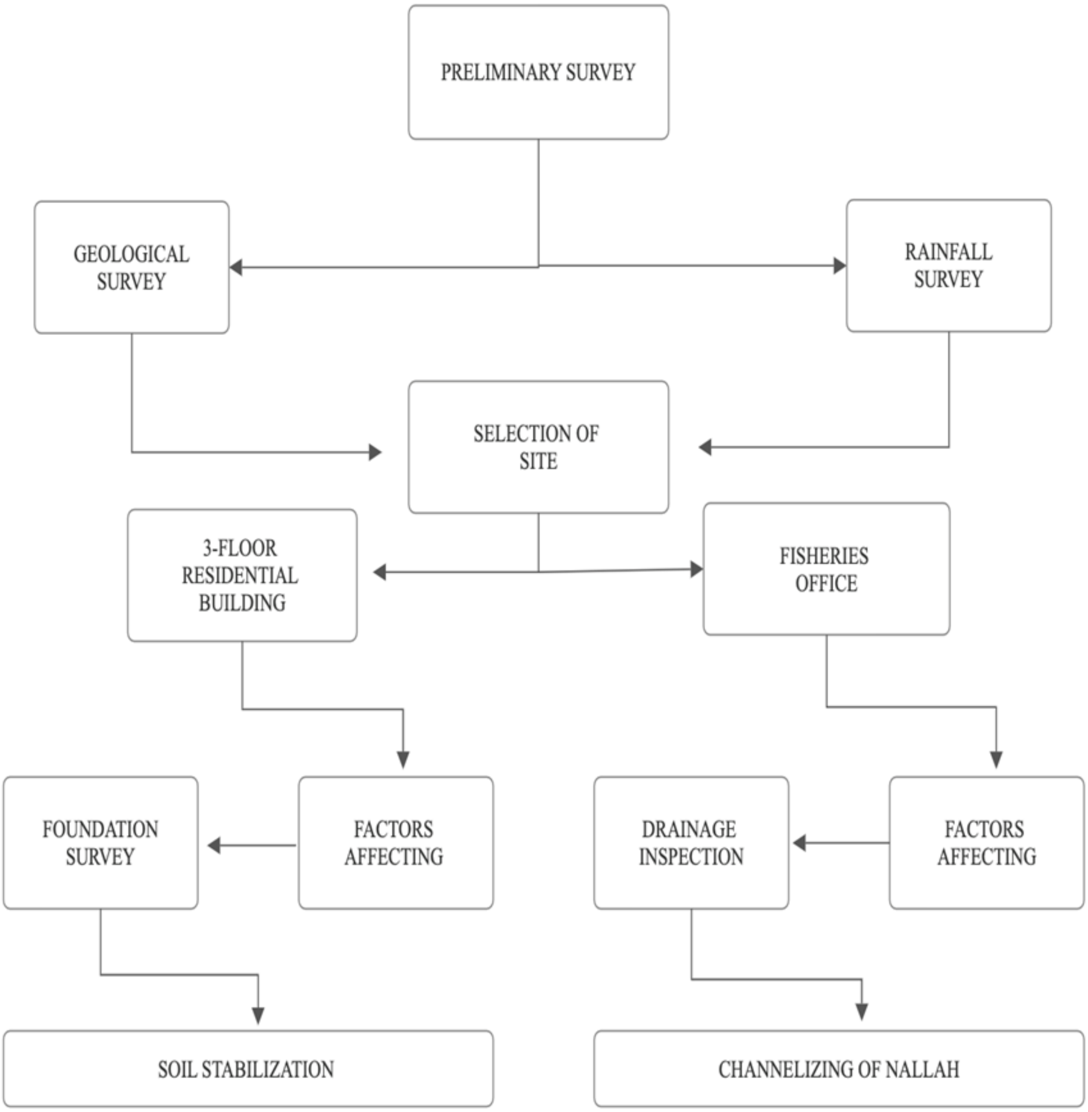
The research gap in landslide mitigation includes exploring innovative early warning systems, assessing the effectiveness of different stabilization techniques, understanding the socio-economic impacts of landslides, and developing sustainable land-use planning strategies to minimize vulnerability in at-risk areas. Additionally, there's a need for more studies on the integration of technology, such as remote sensing and artificial intelligence, to enhance landslide prediction and mitigation efforts.

2.5 Objectives

- To conduct preliminary analysis of the landslide and rainfall data to understand the cause of landslide.
- Analysis of soil for the understanding of geology of the sites.
- To provide mitigation measures for the sites of study.
    1. The Fisheries office.
    2. 3-storey residential building.

CHAPTER 3

METHODOLOGY



CHAPTER – 4

SITES STUDY

4.1 General

In this chapter we have discussed about the major causes of the landslide at the site of study. The major issues and factors which affected our sites

- The Fisheries office
- 3-storey residential building

4.2 Fisheries office

The fisheries office was located between a temple and a school from 2007 ,and also there was a flowing water channel which started from the hills, it flows down from behind the school and lastly it flows down to the road from between the temple and the fisheries, as this location is in step wise formation which was one of the basic reason of complete drowning of the Office in debris flow Shown in Fig 4.1.The main reason of this landslide was due to improper development in the school premises, few years back the school was under development and the channel flowing from behind the school was a big threat to the foundation of the school so the school authorities decided to divert the route of channel. The route change was done by cutting off the trees in the forest behind the school which left the soil loose, as we know the roots of the trees helps in the tightening of the soil and once this was done the channel route got changed and started erosion In the soil which kept on increasing gradually as the years passed and on 9th of July 2023 when the rain was on its peak the soil got failed and debris flow started critically and on the 10th of July early morning this uncertainty took place which completely drowned the fisheries office.

(a) (b)

Fig - 4.1Fisheries Office Shamti Solan

4.2.1 Cause discussion

This type of landslide is a classic example of debris flow landslide which mostly happens due to the fast-moving, gravity-driven mixtures of sediment and water with a wide range of grain sizes, often including gravel and boulders, mixed vertically. The occurrence of shallow landslides and debris flows (collectively referred to as 'debris flows' hereafter) is significant in the fields of hydro-geomorphology and natural hazard science due to their prominence among natural disasters.

4.2.2 Characteristics of Debris Flow

Debris and mud flows consist of rapidly moving water mixed with large volumes of sediment and debris, resembling pancake batter. They can occur suddenly, like flash floods, with little warning. When the flow reaches a gentler slope, it spreads out and slows down, forming debris fans or mud flow deposits. In steep channels, erosion dominates as the flow gathers more solid material. A drainage channel might experience multiple mud flows in a year or none for decades. These events are common in solan's steep terrain, varying in size and destructiveness, often triggered by cloudbursts that provide the necessary water.

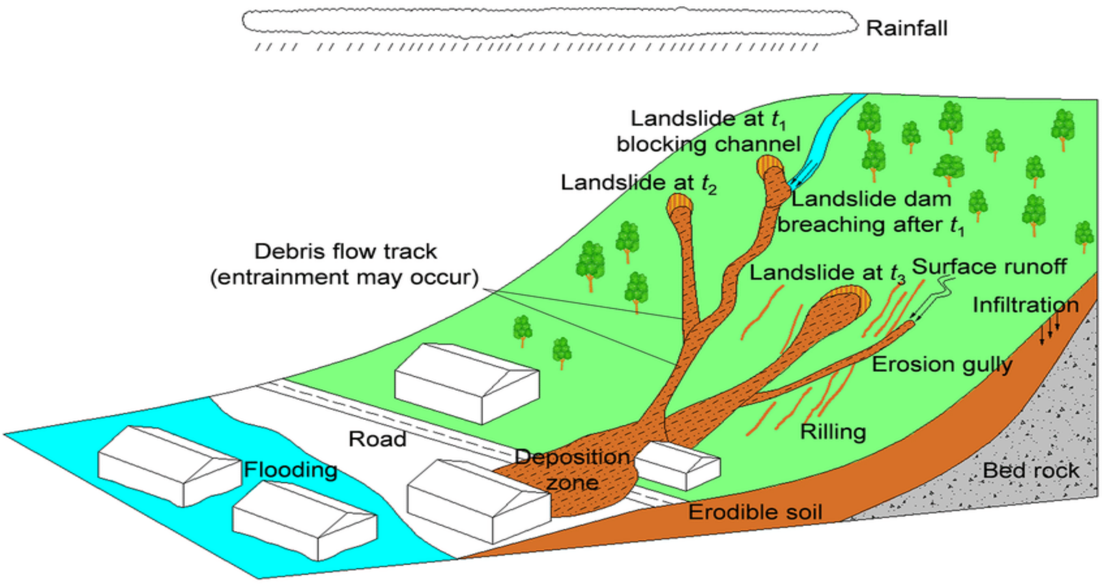


Fig:4.2 Diagrammatic explanation of debris flow landslide

4.3 Storey Residential Building

As shown in the figure the building was completely covered from both the sides and the structure also covers a retaining wall blocking its weep holes. As the weep holes of the retaining walls were covered there was no place left for the water to pass and the water started draining in the foundation of the building and the foundation of the building was inappropriate as the SBC of the mentioned structure was not accordingly designed as per the requirements of the building . The water in the foundation got collected resulting in the lateral thrust which finally resulted in pan -cake type of failure in the structure. This type of phenomenon is of particular concern since progressive collapse or pan cake collapse is often disproportionate, i.e. the collapse is out of proportion to the event that triggers it. Thus in structures susceptible to progressive collapse, small event can have catastrophic consequences.

Fig - 4.3 3-Storey Residential Building

4.3.1 Major Cause

The major cause of this type of foundation failure is excessive rainfall in this area which was more than the usual rainfall Shamti experiences. Blockage in the weep holes of retaining walls.

4.3.2 Climate analysis

In Himachal Pradesh, the climate varies widely due to elevation differences ranging from 450 to 6,500 meters. Unlike the Punjab plains, Himachal Pradesh experiences shorter, milder summers, higher precipitation, and colder, extended winters. The region's climate is marked by seasonal weather patterns and vertical zoning. Climatic conditions range from hot sub-humid tropical in the southern lowlands to temperate, cold alpine, and glacial in the northern and eastern highlands. Lahaul and Spiti are notably drier due to being shielded by high mountain ranges. The year is typically divided into three seasons: the monsoon (June-September), winter (October-February), and summer (March-May).

4.3.3 Rainfall data analysis

As we know Himachal Pradesh is water surplus state so the water table is relatively high in compared to other states. Rainfall generally increases from south to north in Himachal Pradesh, but decreases beyond Kulu due to the rain-shadow effect impacting Lahaul, Spiti, and Kinnaur, with Spiti being the driest (less than 50 cm). Around 70% of the annual rainfall occurs from June to September, 20% from October to March, and 10% from April to May. In Lahaul and Spiti, winter and spring precipitation exceeds that of summer and autumn. Pre-monsoon showers happen in June and post-monsoon showers extend into early October, though both are minimal. The highest monthly rainfall typically occurs in July or August, with Dharamsala receiving the most in July (1055.3mm) and Dalhousie in August (620mm). Dharamsala has the highest annual rainfall (3200mm). Regions like Shimla and Nurpur receive 1500-2000mm, while Dalhousie, Dharamsala, Kangra, Palampur, and Jogindernagar exceed 2000mm, tapering off towards Mandi, Rampur, Kulu, Kalpa, and Keylong. Lahaul and Spiti get less than 500mm annually, with rainy days ranging from 48 in Keylong to 99 in Dharamsala. Snowfall above 3000m averages 4m, lasting over four months. The below mentioned table provides complete data of water table of Solan for 2022.

Depth to Water Table

Distribution of Percentage of Observation Wells

2023/Jan

State : Himachal Pradesh

District	No. of Wells Analysed	Depth to Water Table (mbgl)		No. / Percentage of Wells Showing Depth to Water Table (mbgl) in the Range of					
		Min	Max	0.0 - 2.0	2.0 - 5.0	5.0 - 10.0	10.0 - 20.0	20.0 - 40.0	> 40.0
HAMIRPUR	6	2.31	16.41	0	2 33.33%	3 50.00%	1 16.67 %	0	0
KANGRA	33	0.73	14.85	9 27.27%	16 48.48%	4 12.12%	4 12.12 %	0	0
KULLU	1	10.00	10.00	0	0	1 100.00%	0	0	0
MANDI	8	0.29	12.00	3 37.50%	4 50.00%	0	1 12.50 %	0	0
SIRMAUR	13	1.56	38.21	1 7.69%	1 7.69%	3 23.08%	6 46.15 %	2 15.38%	0
SOLAN	11	5.73	29.81	0	0	3 27.27%	6 54.55 %	2 18.18%	0
UNA	32	1.08	29.58	3 9.38%	11 34.38%	11 34.38%	5 15.63 %	2 6.25%	0
Total	104	0.29	38.21	16	34	25	23	6	0

Fig: 4.4 Water Table of Solan (Jan 2023)

This table explains the depth of water table of Solan before landslide of January 2023. In January 2023, water levels in Himachal Pradesh ranged from 0.29m in Mandi District to 38.21m below ground level (bgl) in Sirmour District. Of the 104 monitored stations, most (98 stations, 94.23%) had water levels between 2-20m bgl, 16 stations (15.38%) recorded levels less than 2m bgl, and 6 stations (5.77%) had levels over 20m bgl. The DTW map indicates shallow water levels primarily in the southern Kangra Palampur valley, northern Balh valley, and Kullu Valley. Water levels of 2-5m and 5-10m bgl are common across all valleys, while 10-20m bgl levels are found in Nalagarh, Kangra-Palampur Valley, and Una Valley. Deeper levels over 20m bgl are mainly in southern Nalagarh and parts of Una Valley.

The water table of Solan has raised, the data indicates that of the 140 monitored stations, 39 experienced an increase in water levels. These rises ranged from a minimal 0.01 meters to a significant 3.31 meters, with both extremes occurring in Solan District. This variation highlights localized changes in groundwater levels, suggesting factors such as regional precipitation, groundwater recharge, or extraction rates may influence these fluctuations. The recorded increases demonstrate the dynamic nature of groundwater levels across different stations.

4.4 Previous Precipitation data of Solan

This table is presented to comprehend the whole rainfall data from the date of January 1st, 2017 to October 31st, 2021. The source of this data is the MET Centre. Shimla This chart also assists in understanding the precipitation in the solan district in order to comprehend the change in water table.

Graph:

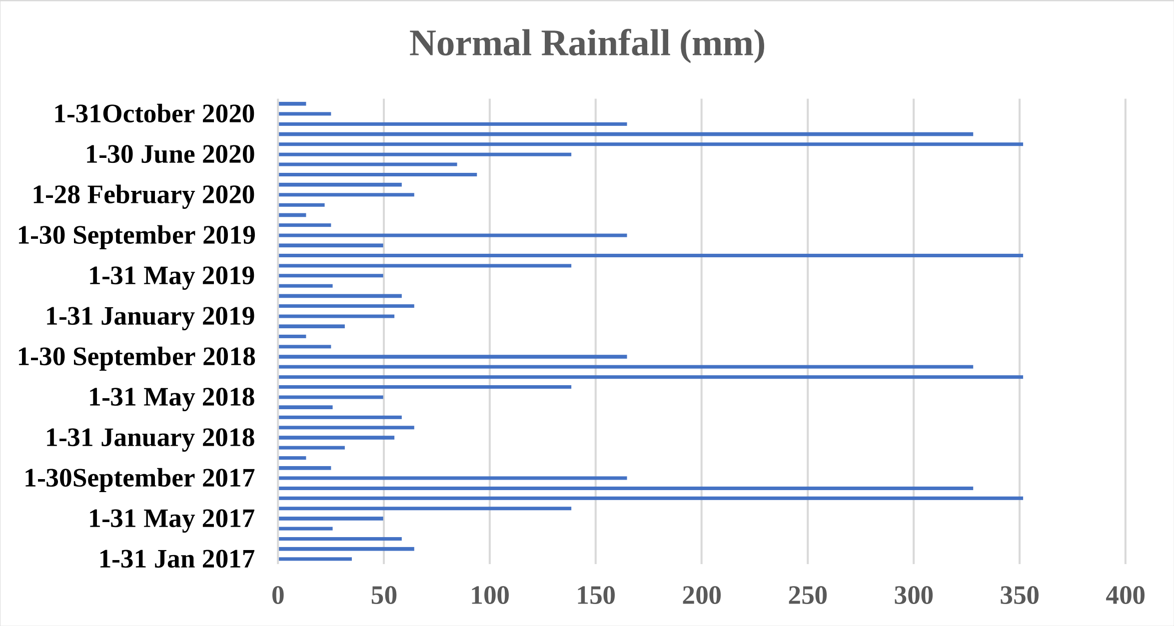


Fig: 4.5 Normal Rainfall Data In (mm)

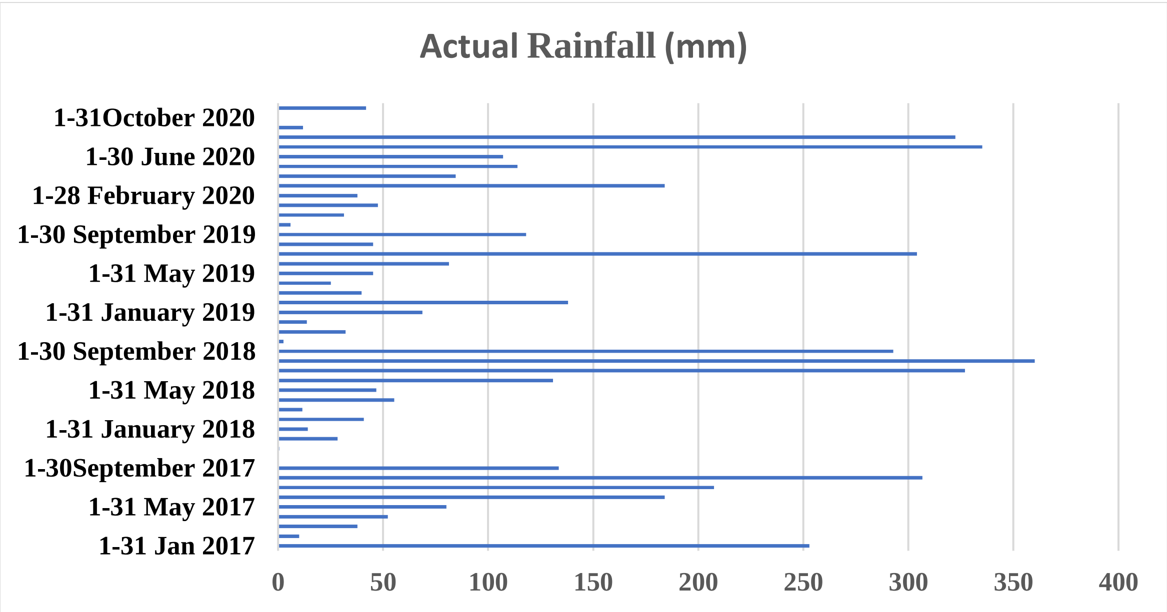


Fig:4.6 Actual Rainfall Data (mm)

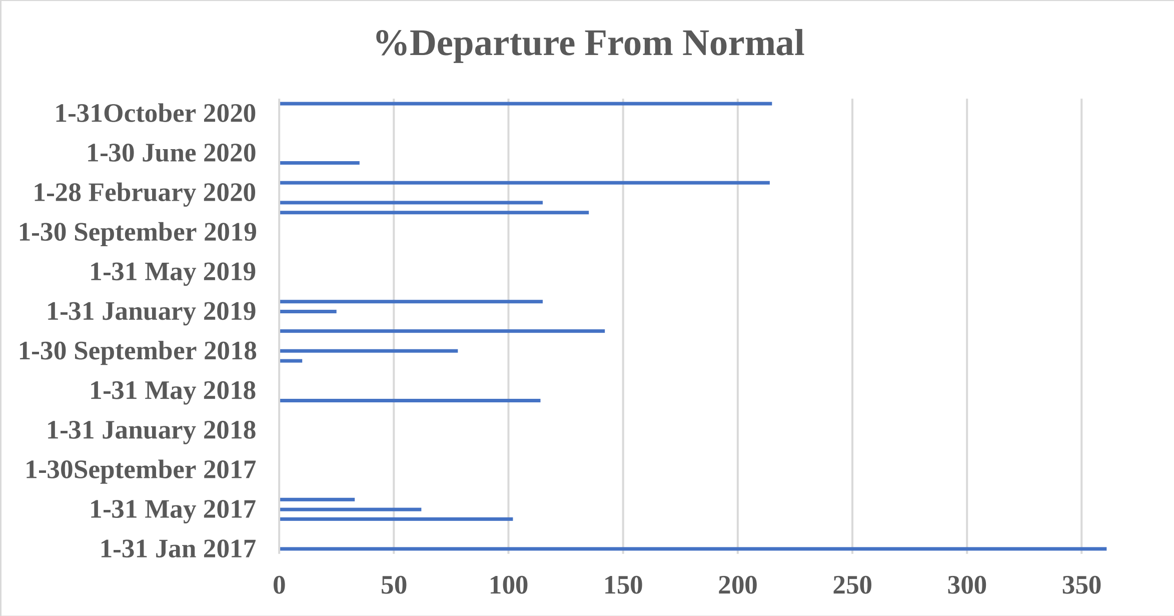


Fig: 4.7 % Departure From Normal

4.5 Graph of the Rainfall Over Solan in the Month of July 2023

The date of the landslide was July 9, 2023. To comprehend the total precipitation in the Solan area in July, we must examine all past data for the month of July in order to identify the day on which Solan experiences rainfall, which falls between July 7th and July 13th. According to the statistics, the 9th of July is the peak rainfall day for solan.

The major problem that caused the landslide was the blockage of the water channel from upstream to downstream, which was caused by a flash flood that brought debris with it, causing the blockage in the water channel and resulting in the seepage of water, which eventually started loosening of the soil, causing the landslide.

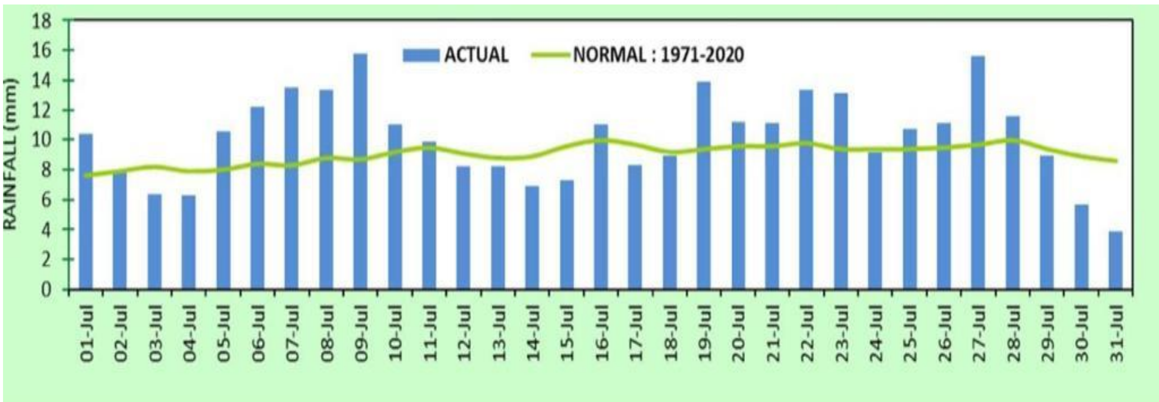


Fig - 4.8 Graph of the Rainfall in July 2023

4.6 Previous Data of Landslide in Solan & nearby Areas

This data has been provided to understand the landslide prone areas in solan. Analyzing the landslide data of solan district provides valuable insights into the frequency, severity, and potential causes of landslide in solan by examine the data we can identify high risk zones access the impact on infrastructure and communities and develop strategies for mitigation and disaster preparedness for solan.

In essence landslide data will also help to understand the patterns and dynamics of landslide experienced by solan enabling informed decision making and proactive measures to minimize risks and protect lives and property of the locals. According to the study of The Economic Times of India there has been drastic landslides occurrence in past 2 years. Solan has experienced 44 times landslides till 2022.

Fig 4.9- Landslide Site

CHAPTER - 5

TESTS CONDUCTION ON THE SOIL & DISCUSSIONS

5.1Direct Shear Test

To ascertain the shear strength of soil materials, an experimental process known as the Direct Shear Test is used in geotechnical engineering practice and research.

The strongest resistance a material can bear when sheared is known as its shear strength. The Direct Shear Test, which may be used on undisturbed or remoulded samples, is typically regarded as one of the most popular and straightforward methods for determining a soil's strength.

In soil mechanics, the Mohr-Coulomb (M-C) Failure Criterion is used to assess the shear strength. According to the M-C Criterion, the shear strength is dependent upon three variables:

The normal effective stress (σ_n)

The friction angle of the material (φ)

The cohesion of the material (c)

The qualitative correlation of those components is expressed as:

$$t = c + \sigma_n \tan \Phi \quad (1)$$

Sand soils are often seen as lacking cohesiveness. Conversely, when clayey soils are over-consolidated, they become cohesive. Figures show typical failure envelopes for over-consolidated clays and sand.

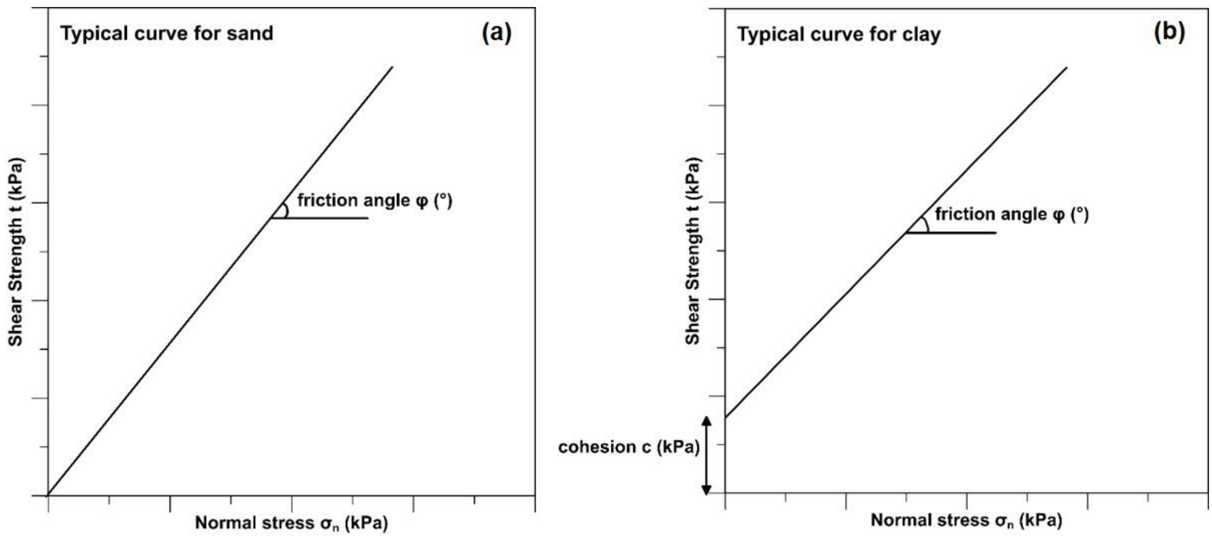


Fig-5.1 Graph of Normal Stress to Shear stress for Clavey and Sandy soil

To determine the shear strength of soil materials by Direct Shear Test

Procedure

1. Measure the soil sampler's inside dimensions and assemble the shear box's components.
2. Determine the sampler's volume and weigh it as well.
3. Three even, smooth layers of dirt should be added to the sampler. If a dense sample is needed, level the soil in each layer by giving it an equal number of blows to achieve the necessary density.
4. Level the top layer when the three levels are complete, then fill the soil sampler with dirt. To determine whether the necessary density has been reached, weigh the moist soil and compute the soil's density.
5. After positioning the base plate in the shear box, cover it with the perforated grid plate (if submerged) such that the grid plate's serrations run perpendicular to the direction of shear. After that, cover the soil specimen with the filter paper.

6. Using locking screws, secure the shear box's upper and bottom halves. Place the perforated grid plate, loading pad, porous stone, and upper filter paper on top of the soil in that order after locking.
7. Using spacing screws, make a little opening of around 1 mm between the two shear box components.
8. After placing the loading yoke on top of the loading pad, place the entire assembly within the loading frame's box.
9. After the specimen setup, return the dial gauges and proving ring to the zero position. After adding water (if soaking condition) to the top of the direct shear box setup and applying the necessary normal stress, say 0.5 kg/cm2, wait at least 20 minutes to achieve saturation (until the reading in the vertical dial gauge becomes constant), and then remove the locking screws.
10. The steps from 1 to 13 have to be repeated for another two normal stresses (1.0 kg/cm^2 and 1.5 kg/cm^2).

Observation

Cross sectional area A =360mm^2

Normal Stress(σ)= Normal Load /A

Shear Stress(τ)= Shear Load/A

Table – 5.1 Normal Stress/Shear Stress

Normal Load (N)	Shear Load(N)	Normal Stress(Kpa)	Shear Stress (Kpa)
4.9	27	50	29.67
9.8	48	100	56.667
14.7	70	200	105

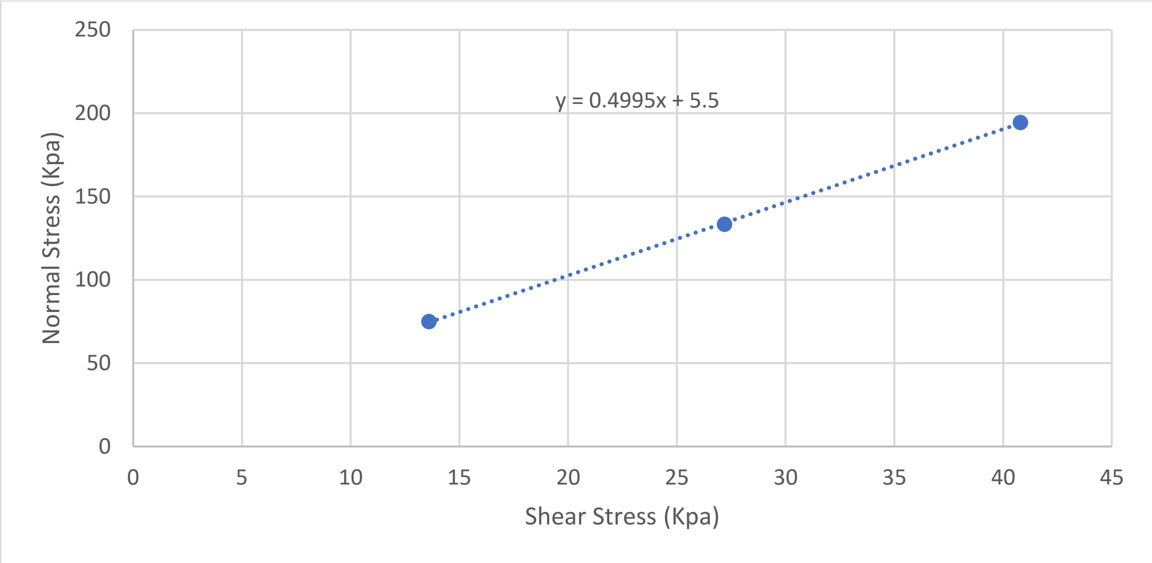


Fig- 5.2 Graph Showing Normal stress / shear stress

Y= 0.4995x + 5.5

Cohesion (c) = 5.5 =6

Angle of Friction φ= tan-1(0.4995)= 26.54˚

Result:

$\tau = 6+\sigma n \tan 26.54°$

The soil Sample has very high friction angle and cohesion , which indicates very strong resistance.

5.2 Compaction Testing of Soil

The process of subjecting soil to mechanical stress and densification is called compaction. Solid particles and spaces that are either filled with air or water make up soil. The idea of soil as a three-phase system provides a more thorough explanation of the three-phase nature of soils. Stress leads to densification, as well as a decrease in the void volume and the movement of soil particles inside the soil mass. Kneading is one way to apply mechanical stress; other ways include static and dynamic approaches. The measurement of the change in the dry unit weight of the soil, γd, may be used to determine the compaction level.

Compaction is especially helpful in engineering applications since it produces:

- An increase in strength of soils
- A decrease in compressibility of soils
- A decrease in permeability of soils

For engineering applications and projects including embankments, earth dams, pavement support, and foundation support, these components are necessary.

The type and amount of energy provided by the compaction process, the soil's water content, and the soil's physical properties all influence how compacted the soil is. For each type of soil, there is a maximum amount of moisture at which compression may occur. Put another way, a soil is reaching its maximum dry unit weight (γd,max) with a certain compactive effort at an ideal water content level (wopt).

The Proctor compaction test is the most widely used laboratory test for soil compaction.

To determine the soil's maximum dry density and ideal moisture content.

Procedure

- Weighing the 1000 cc capacity mould with the base plate connected must be done to the closest 1 g. The damp dirt is to be crushed into the mould by placing it on a strong basis, such as a concrete floor.
- Take 2.5 kg of dirt, mix it thoroughly, and add 10% of water.

- Approximately three equal-mass layers, each receiving 25 hits from a 2.6 kg
- rammer lowered from a height of 310 mm above the ground.
- The extension must be taken out, and using a straight edge, the compacted dirt must be gently smoothed off to the top of the mould.
- The compacted soil sample has to be taken out of the mould and positioned above the mixing pan.
- It is necessary to weigh the soil and mould.
- Add 2% more water until the dirt and mould start to weigh less.

Fig-5.3 Experimental setup

Specimen Taken

Weight of soil taken = 2202 g

Weight of Cylinder used excluding the collar = 3650 g

Height of cylinder = 12.7 cm

Internal Diameter of the cylinder = 10cm

Radius of cylinder = 5 cm

Volume of cylinder = $\pi r2h$

Weight of rammer = 2.6 kg

Number of layers = 3

Number of blows per layer = 25

Table-5.2 Calculation of Optimum moisture content and moisture content

Particulars of Items	1	2	3
Volume (V) (cc)	1000	1000	1000
Mass of the mould (ml) (g)	3650	3650	3650
Mass of soil + mass of the mould (m2) (g)	5852	5870	5801
Mass of wet soil (g) Ms = m2-ml	2202	2220	2151
Bulk Density =Ms/V	2.2	2.2	2.1
Weight of the container (wl) in g	29.6	27.3	27.2
Weight of container+ moist soil	55.5	69.1	67.4

(w2) in g			
Weight of container+ dry soil (w3) mg	52.4	63.7	61.4
Moisture content w = xlO0 (%)	13.5	14.8	17.5
Dry dens1.ty Bulk density (g*I* cc) 1 +w	1.51	1.39	1.11

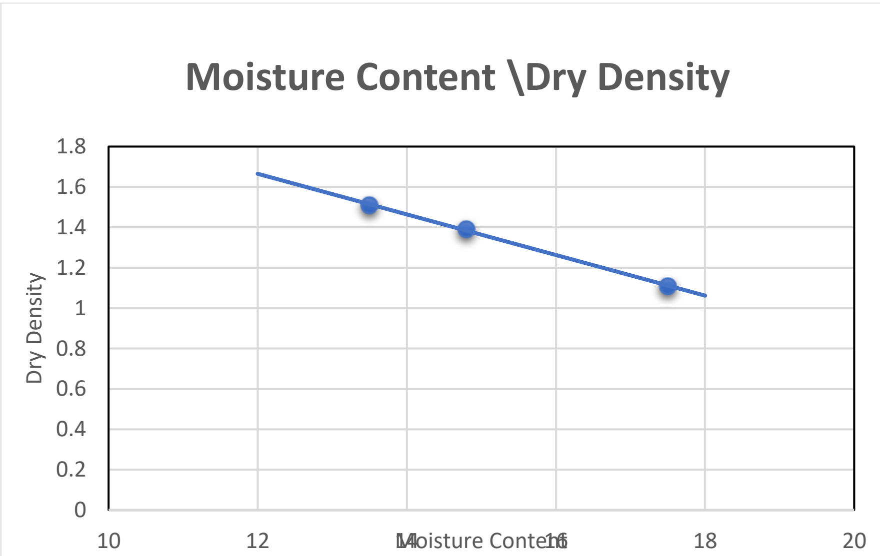


Fig - 5.4 Relation between OMC and Moisture Content

Result :

The maximum dry density of the soil is 1.51g/cc at the moisture content of 13.5 %.

CHAPTER – 6

MITIGATION MEASURES

6.1 General

In this chapter we have provided the mitigation techniques which could be incorporated in future constructions to counter the landslide and to avoid the loss which landslide would trigger.

1.For this we propose a plan of channelizing a nallah or a drainage system over the fisheries office which will help in proper flowing of the rainwater to the downstream.

2.In account with collapse of the 3-storey building we provide a plan to construct a retaining wall which could deviate the flow of water as the major problem of the structure was the failure of foundation that got triggered by the lateral thrust of the water that seeped through the retaining wall.

6.2 Channelization of Nallah

To provide a proper drainage system for the water to drain out and to provide a safe passage for the flash flood which comes from top to bottom in case of excess rainfall we propose an idea of constructing a nallah from upstream to downstream.

Constructing a drainage channel in hilly areas involves careful planning, design, and implementation to effectively manage stormwater runoff and prevent erosion.

According to the topographical survey conducted we got to know that the depth of nallah should be between 0.9m -1.2m.

And the basic problem which needed to be solved was of preventing the debris to flow with the runoff for that we are using retaining walls as the outer walls of the nallah because it will also help in tightening of the soil in the passage of nallah.

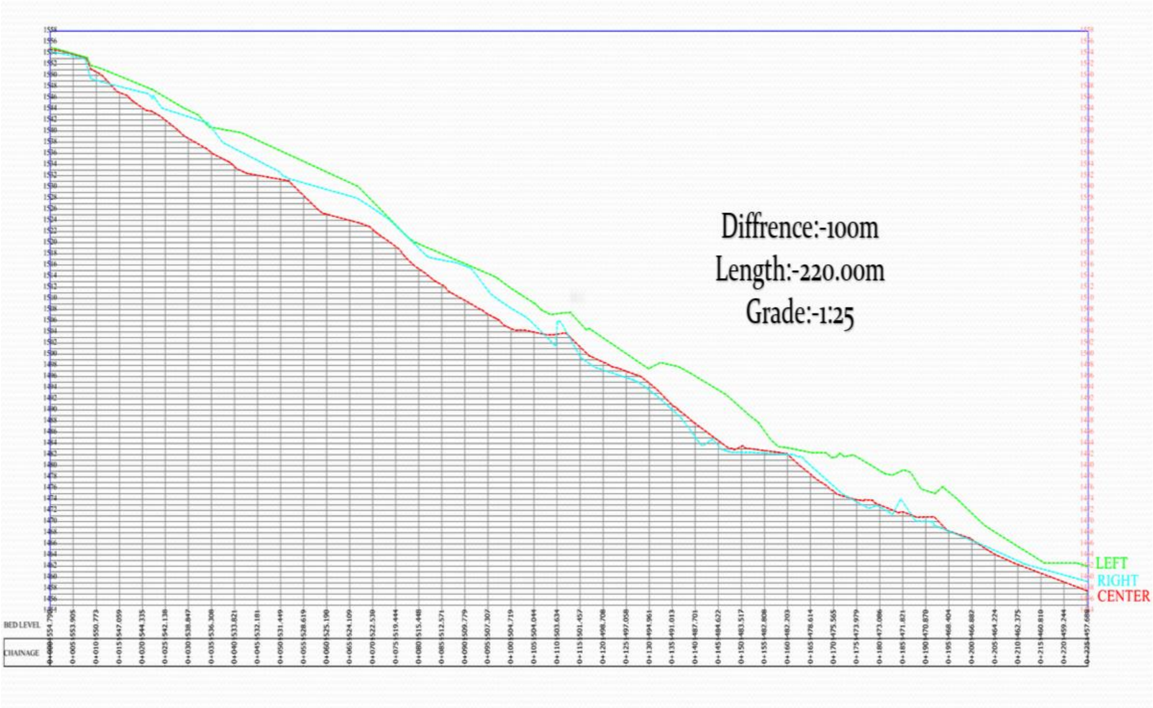


Fig- 6.1 L-Section of Nala

Fig - 6.2 Plan View & Satellite Image of Nala

6.2.1 Proposed Rectangular Nallah Design

Unit weight of soil = 18KN/m^3

Angle of internal friction of 35°

The allowable bearing pressure of the soil is 150KN/m^3

The coefficient of friction is 0.5.

The unit weight of reinforced concrete is 25KN/m^3

The drain has been provided to cater to a flow of 1.8m depth.

The unit weight of water should be taken as 9.81KN/m^3

Fck=15N/mm^2 ,fy = 415N/mm^2, cover to reinforcement =40mm

Diameter f reinforcement = 10mm

Thickness of walls = 450mm and base = 200mm

Geotechnical Design

Wall pressure calculation

Ka= (1sinϕ)/(1+ sinϕ)

Ka= (1sin35̊)/(1sin35̊) = 0.27099

Wall 1

Active pressure at the top of the drain wall = 0

Active pressure at the base of the drain wall (kaγz) = 0.27099*18*2 = 9.7556KN/m^3

Passive pressure at the top of the drain wall = 0

Passive pressure at the base of the drain wall (γ_wz) = 9.81*1.80 = 17.658KN/m^3

Net pressure at the base of the wall = 17.658 – 9.7556 = 8.102 KN/m^3

Wall 2

Active pressure at the top of the drain wall = 0

Active pressure at the base of the drain wall ($ka\gamma z$) = 0.27099*18*2 = 9.7556KN/m^3

Passive pressure at the top of the drain wall = 0

Passive pressure at the base of the drain wall ($\gamma_w z$) = 9.81*1.80 = 17.658KN/m^3

Net pressure at the base of the wall = 17.658 – 9.7556 = 8.102 KN/m^3

Total Vertical Load (N)

Walls (w_{ws}) = 2*0.45*1.8*25 =40.5KN/m

Base (W_d) = 580.2*25 = 25KN/m

Water (w_w) = 4.1*1.8*9.81 =72.39KN/m

Total vertical load = 137.89KN/m

Horizontal Force on Drain Walls due to backfill and water.

Wall 1 = $0.5ka\gamma z^2$ - $0.5\gamma_w z^2$ – 9.7556 – 15.8922 -6.1366KN/m

Wall 2 = $0.5ka\gamma z^2$ - $0.5\gamma_w z^2$ – 9.7556 – 15.8922 -6.1366KN/m

Total Horizontal Load (P_a) = 286.1366 = 12.1232 KN/m

Stability Check

1. Resistance to Sliding

Frictional force (F_l) - μN= 0.5*137.89 = 68.945 KN/m

Factor of safety = 5.75

The factor of safety 2.134 is greater then 1.5 therefore , the drain is very safe from sliding.

2. Resistance to Overturning

Taking moment about wall 1;

Sum of overturning moment (MD) = 12.1232*2/3 = 8.08KN/m

Sum of restoring moment (MR) = (920.25* 0.225) + (20.25*4.775) – (25*2.25) + (72.39*2.25) = 248.70875 KN/m

F.O.S = MR/MO = 248.70875/8.08 = 30

The factor of safety 30 is greater than 2. Therefore, the drain is very safe from overturning.

3 Bearing Capacity Check

$\bar{X}$= MR/N = 248.70875/137.89 = 1.8036

Eccentricity (e) = 2.5 – 1.8036 = 0.696

Check e greater than B/6 = 0.696 greater than 0.833, there is no tension in the drain base

Maximum pressure is the drain base.

Q max = P/B(1+6e/B) m = 137.89/5{1+ (6*0.696)/5} =50.611KN/m^2

Minimum pressure in the drain base

Q min = P/B (1- 6e/B) m = 137.89/5{1- (6*0.696)/5} = 4.544KN/m^2

Since Q min and Q max are lower than the allowable bearing pressure of the soil (150KN/m^2)

Bearing capacity check is satisfied.

3.Structural Design of the Wall

Centroid (x)= 2/3 = 0.667

Taking moment at the bottom of the drain wall due to the active force

M = 6.1366*0.667 = 4.093KNm/m

At ultimate limit state

Designed moment, M = 1.5*4.093 = 6.139 KNm/m

Design of the Base

The pressure distribution of the base at serviceability limit state is shown below.

Qmin = 7.061KN/m^2

Qmax = 15.005KN/m^2

On investigating the maximum design moment at wall 1&2.

8.102*2/3 = 5.40133KNm/m

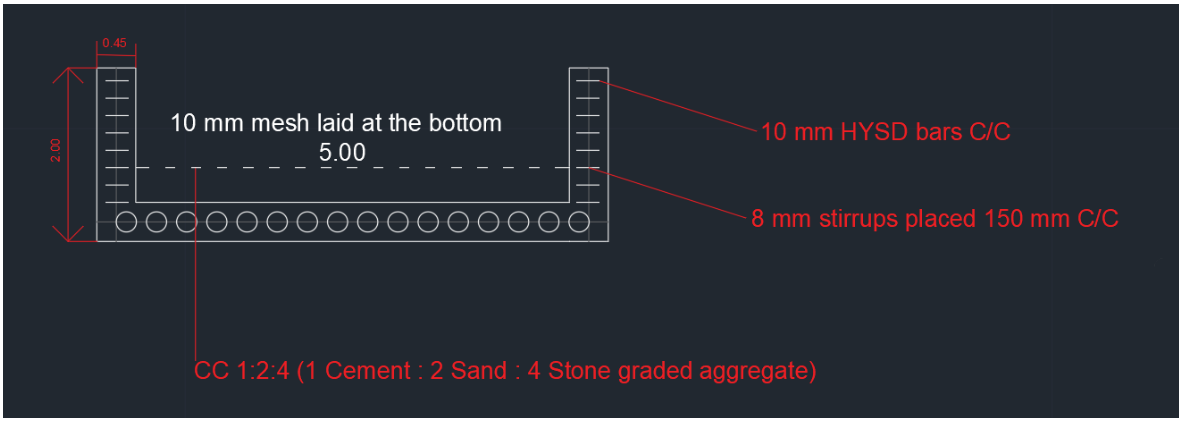


Fig – 6.3 cross Section of nallah at Shamti Solan

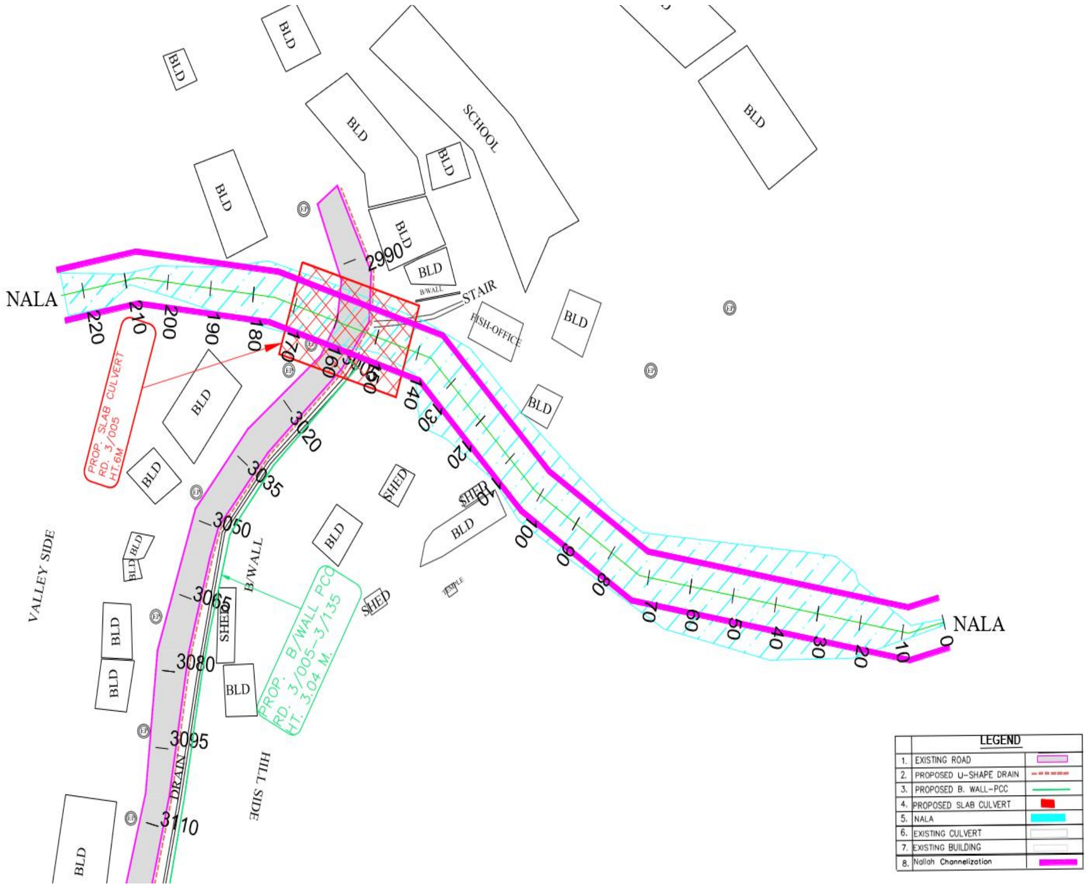


Fig- 6.4 Plan View Of Nallah Design

6.3 Retaining walls Designing

Retaining walls are crucial for highway construction and maintenance, requiring quick and accurate analysis. Computer programs significantly save time and ensure detailed analysis. This dissertation presents a user-friendly program, 'Analysis and Design of Retaining Wall for Hilly Region,' developed for personal computers. The interactive program efficiently considers various soil and loading conditions and performs pseudo-dynamic analysis for seismic effects using IS: 1893-1984 standards. It also adjusts for water table variations and designs elements according to IS: 456-1978 requirements. A parametric study comparing Gravity and T-shaped walls shows T-shaped walls are more economical beyond approximately 3 meters in height, based on construction costs.

Back Fill Type	Particulars	Cement Masonry															Dry Stone Masonry								
		Ht 3M			Ht 6M			Ht 8M			Ht 10M			Ht 3M			Ht 6M			Ht 8M			Ht 10M		
Good Back-fill	Top width in m	0.65	0.70	—	0.75	1.00	1.00	0.80	1.00	1.00	0.90	1.00	—	0.70	—	—	0.75	0.95	1.00	0.85	1.00	1.00	0.90	1.00	—
Full Drainage	Base width in m	1.91	2.01	—	3.92	4.78	8.41	5.23	8.10	10.96	6.64	13.57	—	2.01	—	—	3.92	4.32	8.50	5.33	6.89	11.81	6.64	14.58	—
GW, GP SW, SP	Foundation pressure in t/m^2	14.00	13.00	—	25.0	20.00	13.00	33.00	20.00	17.00	40.00	21.00	—	11.00	—	—	22.00	20.00	17.00	29.00	20.00	13.00	36.00	16.00	—
Fair Back-fill	Top width in m	0.60	0.75	—	0.90	1.00	1.00	0.95	1.00	1.00	1.00	1.00	1.00	0.75	—	—	0.85	1.00	—	1.00	1.00	1.00	1.00	1.00	1.00
Low pore Water pressure	Base width in m	1.81	2.11	—	4.12	4.47	4.88	5.53	6.59	8.14	6.94	9.90	14.03	2.11	—	—	4.12	4.42	—	5.63	6.49	6.94	6.94	8.50	10.26
GM, SM SM, SC	Foundation pressure in t/m^2	15.00	13.00	—	25.00	22.00	20.00	32.00	25.00	20.00	39.00	25.00	11.00	11.00	—	—	22.00	20.00	—	28.00	22.00	20.00	34.00	25.00	20.00
Poor Back-fill	Top width in m	—	—	—	—	—	—	—	1.00	1.00	1.00	1.00	1.00	—	—	—	—	—	—	1.00	1.00	1.00	1.00	1.00	1.00
High pore Water pressure	Base width in m	—	—	—	—	—	—	—	6.49	7.89	8.50	7.79	11.01	—	—	—	—	—	—	6.54	8.65	8.70	7.84	10.11	11.97
GC, SC ML	Foundation pressure in t/m^2	—	—	—	—	—	—	—	22.00	20.00	19.00	29.00	23.00	—	—	—	—	—	—	22.00	20.00	16.00	25.00	20.00	18.00

NOTES

1 Wall Geometry : Front face vertical back, face inclined, base inclined with hill.

2 Back Fill Top : Horizontal with surcharge 1.5 t/m^2.

3 Select wall dimensions such that allowable bearing capacity is greater than the foundation pressure.

4 The base width for dry stone masonry wall is slightly less for cement masonry wall because wall friction angle is likely to be equal to angle of internal friction of back fill in the case of dry stone masonry.

FIG. 6.5 Standard Design Of Cement And Dry Stone Masonary Retaining Walls (**IS CODE : 144458.2: 1907**)

6.3.1 Design of Retaining Wall of 4.88m Height

Unit Weight of PCC (1:4:8)	24KN/m^3
Unit Weight of Backfill	18KN/m^3
Angle of internal friction	35°
Coefficient of sliding Friction	0.5
Angle of backfill	0°
Height of Retaining wall	4.88m
Length of base till rectangular portion	1.63m
Depth of triangular portion	0.36m
Bottom base of Stem	2.23m
Top of stem	0.6m
Coefficient of active earth pressure	0.27

Ka=cos(α)cos(α)–cos2(α)–cos2(ϕ′)√cos(α)+cos2(α)–cos2(ϕ′)

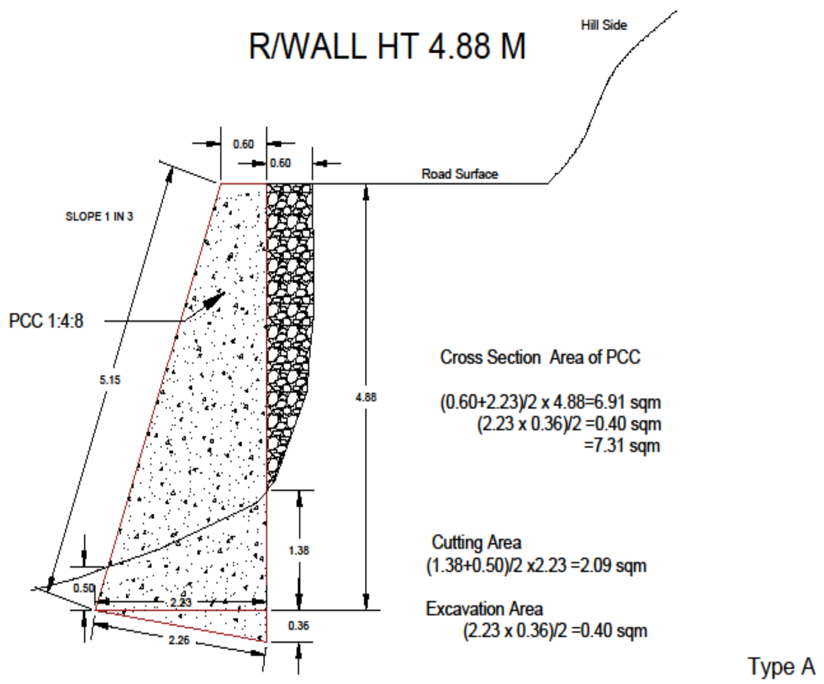


Fig – 6.6 Retaining wall of 4.88m

6.3.2 Design of Retaining Wall of 6.09m Height

Unit Weight of PCC(1:4:8)	24KN/m^3
Unit Weight of Backfill	18KN/m^3
Angle of internal friction	35°
Coefficient of sliding Friction	0.5
Angle of backfill	0°
Height of Retaining wall	6.09m
Length of base till rectangular portion	1.93m
Depth of triangular portion	0.42m
Bottom base of Stem	2.53m
Top of stem	0.6m
Coefficient of active earth pressure	0.270

Ka=cos(α)cos(α)–cos2(α)–cos2(ϕ′)√cos(α)+cos2(α)–cos2(ϕ′)

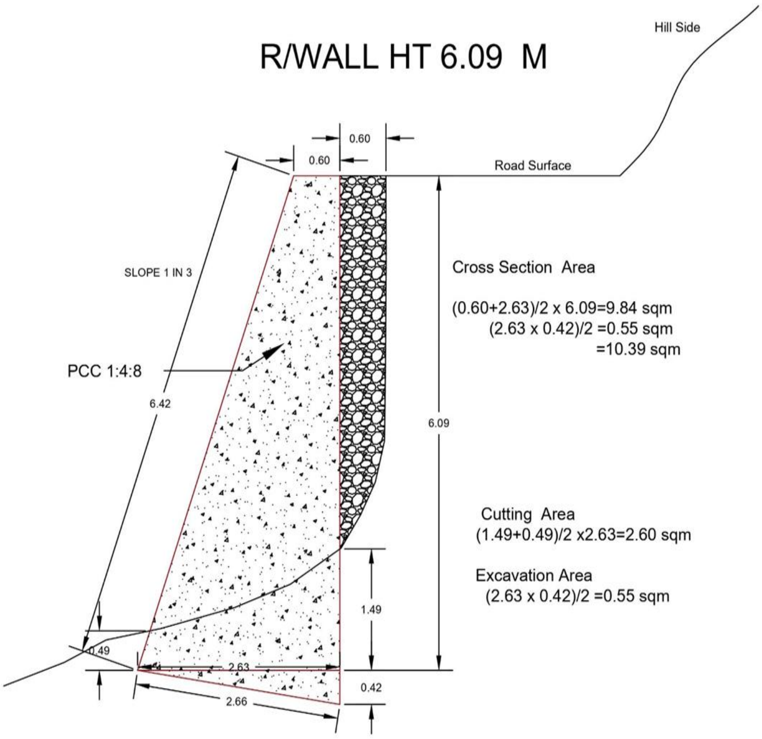


Fig – 6.7 Retaining wall of 6.09m

6.3.2 Importance Of Weep Holes

To allow stored water to move through walls, weep holes are placed in masonry walls, retaining walls, underpasses, wing walls, and other ground-draining structures. The purpose of weep holes is to allow water to escape the wall through leaks, capillary action, or penetrations into the wall's backfill. In addition to acting as a ventilator by allowing air to pass behind walls to prevent moisture, dry rot, and mildew, which can negatively impact a building's lifespan and performance, weep holes in brick masonry also serve this purpose. Commonly seen in the outside brickwork of hollow walls are weep holes.

They may also be found above the walls of cavities. They are maintained at regular intervals to let the water go out. 45 cm is the recommended distance between weep holes. Weep holes decrease the water pressure or hydrostatic pressure on retaining walls from an engineering perspective. This results in a reduction of the thickness and reinforcing needs, which lowers the structural design demand of the water and earth pressure. Weep holes do this by reducing the buoyancy and uplift on the structure, allowing lighter structures to be built without raising concerns about stability.

6.3.3 Installation of Weep holes As per IS 14458 Part -2 : 1997

Weep holes shall be provided in cement stone masonry walls at spacing of about 1.5m centre-to-centre in neither direction. The size of weep holes shall be 100 mm to 150 mm PVC (flexible) pipes and shall be embedded at 10” down from the horizontal towards valley side to effectively drain the water from ground.

Weep holes 15*15 cm size at 1-2 m c/c 50 cm rubble backing for storage. In cement masonry type of retaining walls.

CHAPTER - 7

CONCLUSIONS

7.1 General

In this chapter conclusions are drawn according to the experiment performed and the mitigation measures had been provided on the profound studies made.

7.2 Conclusion Drawn

From the study conducted, the soil at the study site is:

- Well graded soils (reddish soil)
- specific gravity of 2.7
- Slope of 28.8 degree
- it has low optimum moisture content i.e. only 13.5%

The soil if experiences a heavy rainfall it can easily get saturated and flow down the slope leading to slope failure which eventually results in landslide. Thus, stabilizing the soil on the slope before the construction of a building is inevitable, which will prevent landslide.

The soil is stabilised by constructing a cantilever retaining wall behind the house . Using a cantilever retaining wall to stabilize the slope is not just convenient but also very economical with compare to other retaining wall as cantilever retaining wall has shorter width at top and broader width towards the foundation.

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