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**Original Research Article**

# Geotechnical analysis of landslide-affected regions in Himachal Pradesh, India

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**ABSTRACT**
A common geological danger in mountainous areas across the world, including Himachal Pradesh, India, is landslides. The Solan district is the subject of this investigation because landslides there seriously endanger both human life and infrastructure. The study examines landslide-prone regions along National Highway-707, focusing on the soil's geotechnical characteristics. The risk of landslides is increased by elements like heavy rainfall, seismic activity, and human activity. To evaluate ground surface movement, soil strength loss, the effect of falling boulders, and surface collapse, soil samples are subjected to sieve analysis, liquid limit testing, and the standard proctor test. In order to increase infrastructure resilience and lower the risk of landslides, this research aims to improve soil stabilization and road construction procedures. To guarantee long-term safety and resilience in the area, the study will pinpoint efficient mitigation techniques, including as early warning systems and sustainable land use practices.

## 1. Introduction

A landslide occurs when slope-forming materials, such as rocks, soil, and man-made fills, slide, flow, or fall downward and outward along surfaces of separation. A landslide movement known as "falling" happens when rock or soil separates from a cliff or steep slope and plunges through the air. Infrastructure could sustain serious damage as a result of this abrupt and quick descent. In places like Himachal Pradesh, where steep topography leaves areas vulnerable to landslides, such occurrences are especially significant. Although they are frequently associated with hilly areas, human activity such as building, roadway, and open-pit mining excavations can also cause landslides [1]. These gravity-driven motions include spreads, slides, topples, and falls. The equilibrium between shear stress and shear strength is the main factor influencing slope failure. Slope instability can be caused by geologically unstable material, which is frequently caused by the structure and composition of rock or soil. Landslides are frequently caused by excessive rainfall, particularly during storms, and slope erosion, especially in mountainous areas during periods of heavy snowmelt [2]. In a variety of geographical and geological contexts, earthquakes have also been observed to trigger landslides that result in rock falls, soil slides, and rockslides. Furthermore, volcanic ash on hillsides can hasten erosion, leading to frequent flows of mud or debris, particularly following periods of intense precipitation [3]. Environmental conditions, hydrology, terrain, and geology are some of the elements that affect the likelihood of landslides in Himachal Pradesh, India [4]. Due to intense and constant rainfall, which frequently creates flood-like conditions, the area frequently encounters devastating landslides, particularly during the monsoon season. Heavy rains was the primary cause of a large landslide that killed over 50 people in Solan, Himachal Pradesh, on August 14, 2023 [5]. Because of its geological features—weak lithology, considerable weathering in some rock types, and complex structural discontinuities—the Himalayan region is especially susceptible to landslides [6]. Therefore, it makes sense that Himachal Pradesh experiences a high frequency of recurring geohazard landslides.These landslides result in significant property damage as well as fatalities. Examples include harm to exposed road cut slopes, highways, towns, and agricultural land. The study area has been chosen for this purpose in a section of Solan, which is prone to landslides. It is located along the NH-707 road corridor from Solan Bus Stand to Kumarghatti in Himachal Pradesh, India. The paper goes into additional depth about the methods used to identify the geotechnical parameters for the soil samples that were taken from the study area. To comprehend ground surface movement, loss of soil strength from shaking, falling rocks from slopes, and surface collapse involved in failure occurrences, geotechnical parameters are assessed.

## 2. Study area

The Solan bus stand and Kumarhatti landslide soil were the sites of the study, which was carried out at coordinates 30.9042°N, 30.8450°N, and 77.0964©E, 77.0814©E. On August 14, 2023, landslides were caused by a cloudburst of torrential rainfall in the Solan district of Himachal Pradesh (Figure 1).

## 3. Methods and experimental methodology

The landslide is located in Kasauli Tehsil, Solan district, Himachal Pradesh, roughly 10 kilometers from Kumarhatti and Solan Bus Stand on National Highway-707. The impacted region is situated on a curved ridge and is about 10 km (6.2 miles) long. The study area's geographic coordinates are between 30.9088°N and 30.8835°N and 77.0960°E and 77.0405°E.

**Figure 1:** Floods and landslides in Solan district of Himachal Pradesh.

This region include both Kumarhatti and the Solan Bus Stand. Six sites were used to gather soil samples: three close to Kumarhatti and three near the Solan Bus Stand. Salogra, Thodo Ground, Chambaghat, Bhalku, Dharot, and the Solan Bypass were the locations of further samples. The influence of the region's intense summer monsoon rainfall, which raises soil moisture, erosion, and slope instability, was evaluated by analyzing these samples. With maximum temperatures between 28 and 30°C (82 and 86°F) and lowest temperatures between 18 and 20°C (64 and 68°F), the area has a moderate mean yearly temperature. To ascertain the characteristics of the soil, a number of engineering tests were carried out, such as the Standard Proctor Test, Liquid Limit Test, and Sieve Analysis. These tests are essential for enhancing soil stability, landslide risk assessment, building foundation design, road construction, and maintenance. Steep slopes, intense rains, and soil erosion are characteristics of landslide-prone regions, such as Thodo Ground, Kumarhatti, and Solan Bypass. Effective solutions, including as early warning systems, soil stabilization methods, and evacuation plans, are crucial to reducing the negative effects of landslides on the environment, infrastructure, and human settlements.

## 4. Results and discussion

The results of laboratory tests performed to examine soil samples taken from the research locations are shown in the section that follows. The conventional Proctor test, liquid limit test, and sieve analysis were among the fundamental tests. Because of the area's high slopes, where loose material is more prone to failure, rock falls may happen [8]. Following thorough mixing and preparation, a variety of geotechnical tests were conducted on the soil samples due to the significant landslide susceptibility in the area, increasing rainfall, deforestation, and continuous road construction operations all contribute to the increasing landslide susceptibility in the studied locations, particularly the Solan Bus Stand and Kumarhatti, which are situated in a humid sub-temperate zone. Given the importance of the route and the lack of prior research, a geotechnical evaluation was conducted [7].

### *4.1 Sieve analysis*

The laboratory performs sieve analysis on soil samples that contain the key soil categories of gravel, sand, silt, and clay. The grain sizes of the gravel are more than 4.75 mm, the sand is 0.075 micron, and the silt or clay is 0.002. According to sieve analysis, course-grained soil is separated into two parts: wet and dry sieves. 1000g of samples are placed in a dry sieve set, and the soil sample is added to a bottom pan that is manually mechanically sieved at 75µm, 150µm, 300µm, 600µm, 2.36mm, 1.18mm, and 4.75mm. When measuring sieving, the number of particles of various sizes in the soil sample is ascertained using the particle size analysis method. Soils with coarse grains are subjected to sieve analysis. The soil sample is made up of a mixture of silt, clay, sand, and gravel particles, according to the sieve analysis results. The coarse percentage of soil retained on a sieve is depicted in Figure 2, which also shows the separated gravel-sized particles following the sifting operation.

**Figure 2:** Soil samples and set of IS sieves.

**Table1:** Particle size distribution

| % Weight Retained | % Finer |
|---|---|
| 10.0 | 90.0 |
| 20.0 | 70.0 |
| 15.0 | 55.0 |
| 16.0 | 39.0 |
| 12.0 | 27.0 |
| 6.0 | 21.0 |
| 8.0 | 13.0 |

With the highest percentage retained at 1.18 mm and a gradual decline as the particle size decreases from 600 µm to 50 µm, Table 1 displays the particle size distribution of the following sequence along with the variation in retained mass percentages and corresponding cumulative percentages for different particle sizes in Sample 1. The size of the sieve apertures is determined by the diameter of the particles, which is shown in millimeters in Figure 3.

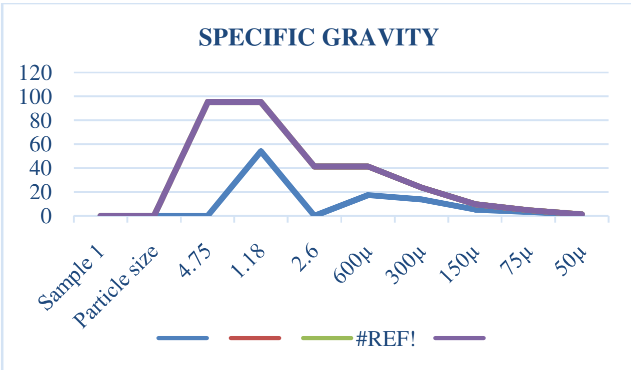


**Figure 3:** Sample of well-graded sieve analysis for sample (specific gravity).

**Figure 4:** Pycnometer to test specific gravity Consistency's Limit Test.

The ratio of a material's density to that of a reference substance is known as specific gravity. The reference for liquids is usually water at its densest temperature of 4°C, and the standard for gases is room temperature air at 21°C. The mass of the substance divided by the mass of the reference substance for the same volume is another way to represent this ratio. The reference and the sample must be measured under identical conditions or adjusted to a standard temperature and pressure because specific gravity depends on both. In water, a material having a specific gravity of one is neutrally buoyant. Because they are denser than water, substances having a specific gravity greater than one will sink, whereas substances with a specific gravity less than one will float. One technique for determining specific gravity is to use a pycnometer, which is a customized bottle that can be filled exactly to a given (or may be unknown) amount. In Table 2, the particle size distribution shows that the proportion of finer particles falls as cumulative mass rises at particle sizes and in Figure 4. By measuring the mass of soil maintained in the jar, sand density cones are used in field testing to ascertain the in-situ density of soil.

**Table 2:** Mix proportion of different particle sizes

| Sample 1 | | |
|---|---|---|
| Particle size | % Weight retained | % Finer |
| 4.75 mm | 4.8% | 95.2 |
| 1.18 mm | 54.1% | 41.1 |
| 2.6 mm | 0% | 41.1 |
| 600 µm | 17.4% | 23.7 |
| 300 µm | 13.8% | 9.9 |
| 150 µm | 5.2% | 4.7 |
| 75µm | 3.3% | 1.4 |
| 50 µm | 1.3% | 0 |

| Sample 2 | | | | | |
|---|---|---|---|---|---|
| Particle size | Retained Mass | Cumulative Mass | % Finer | Particle size | Retained Mass |
| 4.75 | 0 | 0 | 100 | 4.75 | 0 |
| 2.36 | 0.19 | 0.19 | 80 | 2.36 | 0.19 |
| 2 | 0.052 | 0.242 | 75 | 2 | 0.052 |
| 1.18 | 0.16 | 0.402 | 59.3 | 1.18 | 0.16 |
| 0.6 | 0.296 | 0.698 | 29.4 | 0.6 | 0.296 |
| 0.3 | 0.158 | 0.856 | 13.5 | 0.3 | 0.158 |
| 0.15 | 0.053 | 0.909 | 8.1 | 0.15 | 0.053 |
| 0.09 | 0.034 | 0.943 | 4.7 | 0.09 | 0.034 |
| 0.075 | 0.003 | 0.946 | 4.4 | 0.075 | 0.003 |
| <0.075 | 0.044 | 0.99 | 0 | <0.075 | 0.044 |

## *4.2 Liquid limit test*

The moisture level, stated as a percentage of the weight of oven-dried soil, at which 25 to 35 blows are needed to close a groove in the soil is known as the liquid limit of a soil. Soil that weighs 150 to 200 grams and passes through a No. 40 sieve is prepared for the test, and its water content is adjusted appropriately. A horizontal surface is created by smoothing the prepared soil in the liquid limit cup. Next, a groove is made using a grooving tool that is kept perpendicular to the surface. The 25 to 35 blows are used to test the soil until the groove closes. Following the test, the mass of the soil and the container are measured after a slice of soil is taken out. A semi-logarithmic graph is used to exhibit the data, and the flow curve is shown as a straight line that passes through four or more plotted points. The liquid limit of the soil is the moisture content equal to 25 blows, rounded to the closest whole number. Figure 5 depicts the moisture content at which soil transitions from a plastic to a liquid condition. Table 4 illustrates the link between the number of blows and the corresponding moisture level, with fewer blows often indicating higher moisture content. This is crucial for determining the consistency of the soil.

**Table 3:** Liquid limit test

| No. of Blows | Moisture Content |
|---|---|
| 36 | 30 |
| 34 | 30.769 |
| 27 | 40 |
| 15 | 42 |
| 20 | 40.8 |
| 28 | 39.1 |

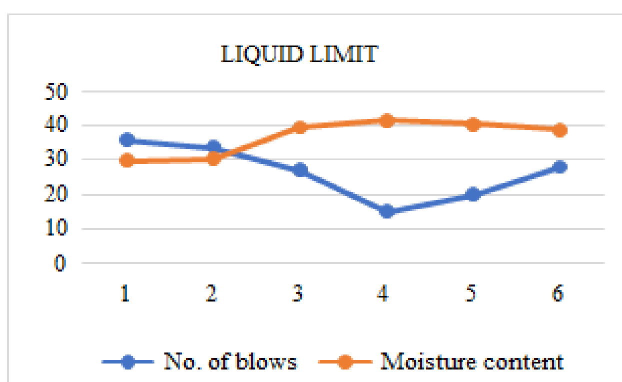


**Figure 5:** Graph showing the liquid limit test result.

### 4.3 Standard Proctor test

A correlation between dry density and water content is determined by the Standard Proctor Test, which measures the dry density of soil for specific completion efforts.

Soil to proctor: The laboratory test uses a standard mold with an internal diameter of 4 and an effective height of 4.58. Its standard volume is 1×30 cubic feet, and it also has a detachable base plate. A specified amount of comp active effort is applied to a constant volume of soil mass for the test.About 15 to 20 kg of soil are collected from the field, and either 5 kg of the sample is crushed or the soil is allowed to air dry and any organic material is removed. When a homogenous soil sample is run through a 20 mm sieve, the water content drops to roughly 4% for coarse-grained soil and 8% for fine-grained soil. During the maturation stage, the soil is allowed to absorb moisture uniformly after being properly mixed and covered with wet clothing for 15 to 30 minutes. The weight of water can be measured as the water content. One compaction test is represented by each depicted point on this graph (Figure 6). Compaction is used to determine the soil's maximum dry density and ideal moisture content. Values for various mix proportions are shown in Table 4, together with the accompanying volume, moisture content, and dry unit weight—all of which are essential for determining the stability and compaction of the soil.

**Figure 6:** Standard proctor test mould and soil sample.

**Table 4:** Values of various mix proportion volume, moisture content and dry unit weight.

| Moist unit weight | Dry unit weight |
|---|---|
| 97.8 | 90.221 |
| 124.5 | 12.976 |
| 140.1 | 124.755 |
| 120.6 | 105.236 |
| 108.9 | 93.236 |

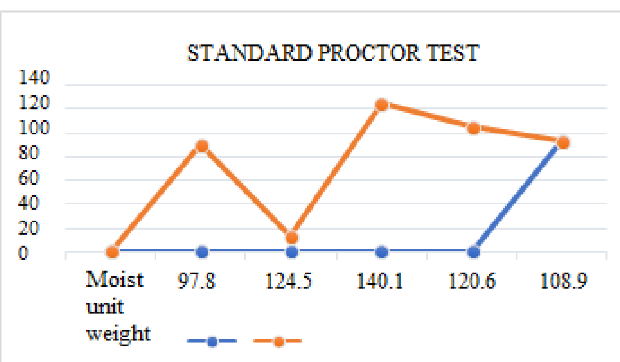


**Figure 7:** Standard Proctor Test.

Figure 7 shows the volume over time the line slopes upwards as you move from left to right on the graph it indicates an increase volume over time.

## 5 Conclusions

According to this study, landslides are a common and pervasive phenomenon in Himachal Pradesh, especially in the Solan area near the National Highway -707. The landslide that happened between the Solan Bus Stand and the Kumarhatti neighborhood is the specific subject of this article, which was published in the context of Solan. The investigation focuses on a number of factors that are probably responsible for landslides, such as lineaments, hydro-meteorological conditions, soil moisture, geology, and seismic activity. Intense rainfall, seismic activity, unstable soil moisture levels, complicated geological formations, the existence of large lineaments, and the removal of more trees are some of the factors contributing to landslides. All of these factors combined to cause the slopes that led to the avalanche to become unstable. This is the reason for regions with steep slopes, particularly when paired with elements like intense rainfall or seismic activity. The soil structure may then be weakened and rendered more vulnerable to landslides by excessive soil moisture brought on by severe rainfall, inadequate drainage, or water infiltration areas where a lot of human activity occurs, such building roads, mining, and construction. These have the potential to worsen slope instability and raise the danger of landslides. Poor engineering techniques and inappropriate land use frequently exacerbate these issues. However, because there are fewer landslides, it affects places that have been improved with flat or mild slopes because there is less gravity pulling on the slope. Soil stability is maintained by natural drainage and appropriate water management in areas with well-drained soils and moderate moisture levels. Because sustainable development and the use of these rigorous planning techniques assist protect slope stability, areas with little human interference or well-managed land use practices are less likely to undergo landslides. It has been discovered that the sieve analysis, liquid limit test, and standard proctor test improve stability and safety. Heavy rainfall, erosion, road durability, and overall infrastructure resilience were all improved by the soil's increased compressive strength.

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