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GEOTECHNICAL INVESTIGATION OF FAILED SLOPE: SOIL PROPERTIES AND CAUSES OF FAILURE

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Abstract: *Slope failure is a common geotechnical problem in hilly regions where soil instability, water infiltration, and steep slope geometry contribute to mass movement. This study investigates a failed slope located in Karfectar, South Sikkim. Laboratory and field investigations were conducted using disturbed and undisturbed soil samples collected from the crest and toe portions of the slope. The tests included Atterberg limits, grain size analysis, specific gravity, and moisture content determination. The results showed that the soil is coarse-grained, non-plastic, and primarily composed of sand and gravel with very low fines content. According to IS:1498 and USCS classification systems, the soil was classified as GW and GP-SP respectively. The main cause of slope failure was identified as water infiltration into loose colluvial soil on a steep slope, reducing shear strength and stability. Suitable remedial measures such as drainage systems, retaining structures, soil reinforcement, and vegetation are recommended.*

Index Terms: *Slope failure, Geotechnical investigation, Colluvial soil, Soil classification, USCS, IS:1498, Water infiltration, Soil stability.*

I. INTRODUCTION

Slope failure occurs when soil or rock masses lose stability and move downward under the influence of gravity. The causes of slope failure include heavy rainfall, seepage, weak soil type, external loading, and steep slope geometry. In mountainous regions such as Sikkim, landslides and slope failures are frequent due to intense rainfall and fragile geological conditions. This research focuses on the investigation of a failed slope composed mainly of colluvial soil. The study aims to identify soil properties, classify the soil using standard systems, analyze the causes of failure, and recommend suitable remedial measures.

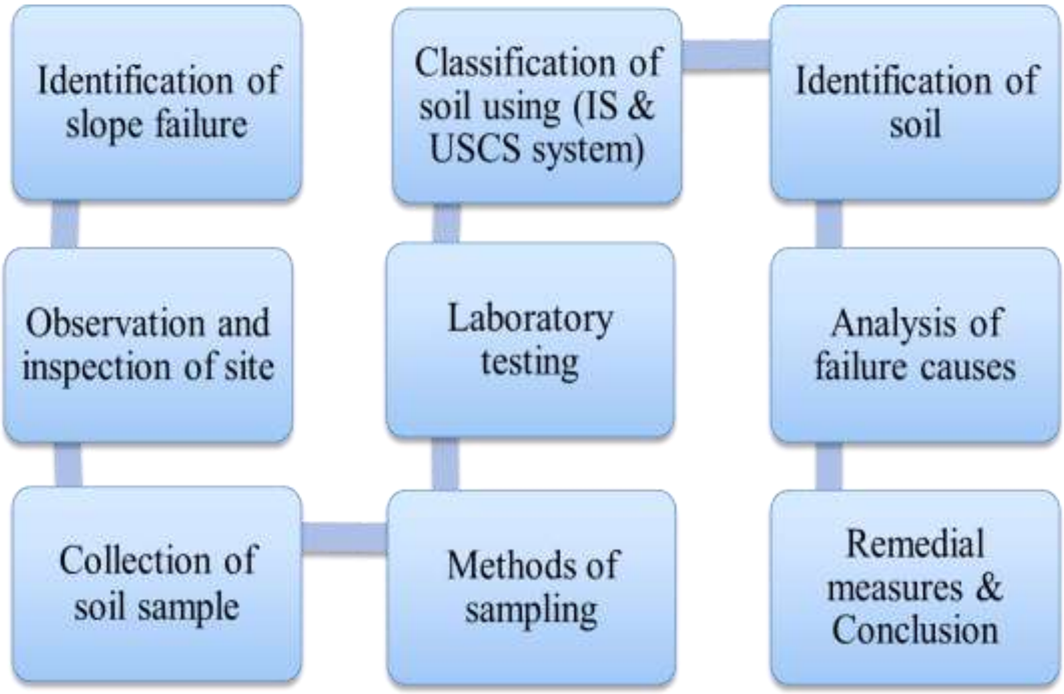
II. OBJECTIVES

1. To investigate the geotechnical properties of soil collected from the failed slope at Karfectar, South Sikkim. (Principle of Geotechnical Engineering pp.1-25)
2. To determine the physical characteristics of the soil through laboratory tests such as Atterberg limits, grain size analysis, specific gravity, and moisture content tests (Manual of soil laboratory pp.45-160)
3. To classify the soil using standard soil classification systems including IS:1498 and the Unified Soil Classification System (USCS) (Classification and identification of soil for general engineering purposes pp.4-15)).
4. To identify the major factors responsible for slope failure, particularly the effects of water infiltration, slope geometry, and soil composition. (Soil mechanics pp.115-130)
5. To evaluate the engineering behaviour of colluvial soil in relation to slope stability (Basic and Applied Soil Mechanics pp.220-255)
6. To recommend suitable remedial and stabilization measures such as drainage systems, retaining structures, soil reinforcement, and vegetation techniques for preventing future slope failure. (Geotechnical engineering: principles & practices pp.110-125)
7. To provide a foundation for further geotechnical studies involving Optimum Moisture Content (OMC), Maximum Dry Density (MDD), and Triaxial shear strength tests for detailed stability assessment. (Measurement of soil properties in triaxial test pp.15-120)

III. SITE DESCRIPTION

The study area is located in Karfectar, South Sikkim. The site consists of a very steep slope where instability and failure were observed. Soil samples were collected from both the toe and crest portions of the slope. Disturbed samples were collected using hand tools, while undisturbed samples were collected using Shelby tubes and core cutters. The soil was identified as colluvial soil with gravel and sand composition.

IV. METHODOLOGY



V. LABORATORY TESTS AND RESULTS

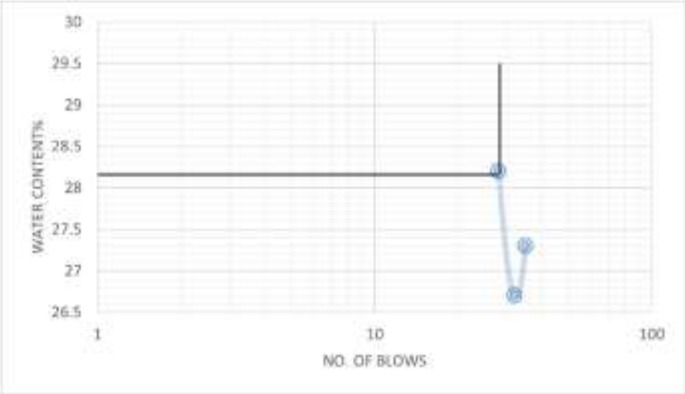
5.1 Atterberg Limits

Liquid Limit values were 25.9% and 20% for the toe and crest portions respectively. The low values indicate low plasticity and low water-holding capacity.

Formula: W = (Wt. of water / Wt. of dry soil) × 100

Table 1: Atterberg Limits – Liquid Limit Test Data

Description	Sample 1	Sample 2	Sample 3
Container No.	1	2	3
Wt. of Container, W1 (gms)	14	14	14
Wt. of Container + Wet Soil, W2 (gms)	22.21	23.91	24.85
Wt. of Container + Dry Soil, W3 (gms)	20.5	21.75	22.54
Wt. of Water, Ww (gms) W2–W3	1.71	2.16	2.31
Wt. of Solid (gms) Ws = W3–W1	6.4	7.65	8.44
Moisture Content V = Ww/Ws × 100	26.71%	28.23%	27.36%



5.2 Plastic Limit Test

Plastic Limit values were around 31%, showing the soil to be non-plastic to slightly plastic with negligible clay content.

Formula: w (%) = Ww/Ws × 100

Where: Ww = Weight of water, Ws = Weight of dry soil

Table 2: Plastic Limit Test Data

Description	**Sample 1**	**Sample 2**	**Sample 3**
Container No.	1	2	3
Wt. of Container, W (gms)	14	14	14
Wt. of Container + Wet Soil, W1 (gms)	18	20	21
Wt. of Container + Dry Soil, W2 (gms)	17	19	19
Wt. of Water, Ww (gms)	1	1	2
Wt. of Dry Soil (gms) Ws = W1–W	4	6	7
Water Content, Ww/Ws × 100	25	16.6	28.57
Plastic Limit (%)	25	16.6	28.57

5.3 Moisture Content Test

Moisture content values were 11.5% and 8.48% respectively, showing moderate moisture conditions.

Formula: w (%) = Ww/Ws × 100

Where: Ww = Weight of water, Ws = Weight of dry soil (solid)

Table 3: Moisture Content Test Data

Description	**Sample 1**	**Sample 2**	**Sample 3**
Container No.	1	2	3
Wt. of Container, W1 (gms)	14	14	14
Wt. of Container + Wet Soil, W2 (gms)	55	51	52
Wt. of Container + Dry Soil, W3 (gms)	52	49	50
Wt. of Water, Ww (gms) W2–W3	3	2	2
Wt. of Solid (gms) Ws = W3–W1	38	35	36
Moisture Content W = Ww/Ws × 100	7.89%	5.71%	5.5%

5.4 Grain Size Analysis

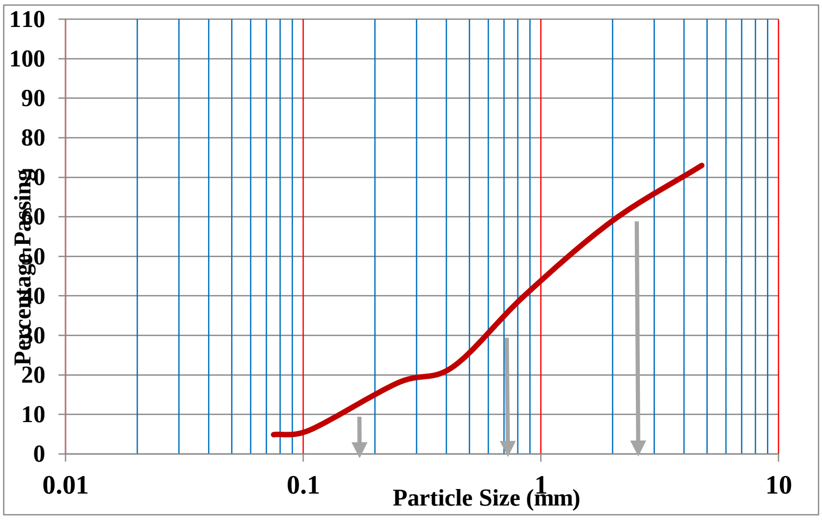
The soil composition consisted of 49% gravel, 49% sand, and only 2% fines, indicating a coarse-grained clean soil. Calculation for Cc and Cu:

Formula used for Cu = D60/D10

Formula used for Cc = $(D30^2)/(D60 \times D10)$

Table 4: Grain Size Analysis – Sieve Test Data

Sieve Opening (mm)	Wt. Retained (gm)	% Retained (%)	Cumulative % Retained (%)	% Finer (%)
4.75	270	27	27	73
2	140	14	41	59
0.85	190	19	60	40
0.425	180	18	78	22
0.25	40	4	82	18
0.106	120	12	94	6
0.075	11	1.1	95.1	5



Graph for sieve analysis

5.5 Specific Gravity Test [Principle of geotechnical engineering (8th Ed. pp. 18-20]

Specific gravity values ranged between 2.5 and 2.6, indicating inorganic quartz-based soil.

Formula: G = (W2–W1) / [(W4–W1) – (W3–W2)]

Table 5: Specific Gravity Test Data

Description	Sample 1	Sample 2	Sample 3	Avg.
Temperature in Celsius	27°C	27°C	27°C	27°C
Weight of Bottle W1 (gm)	660	660	660	660
Weight of Bottle + Dry Soil W2	1200	1100	1180	1160
Weight of Bottle + Soil + Water W3	1860	1850	1800	1836.6
Weight of Bottle + Water W4	1530	1530	1530	1530

5.6 Undisturbed Soil Tests

5.6.1 Compaction Test

Optimum Moisture Content (OMC) = 12%–15%

Bulk Density Formula: $\gamma b = (W2–W1) / V$

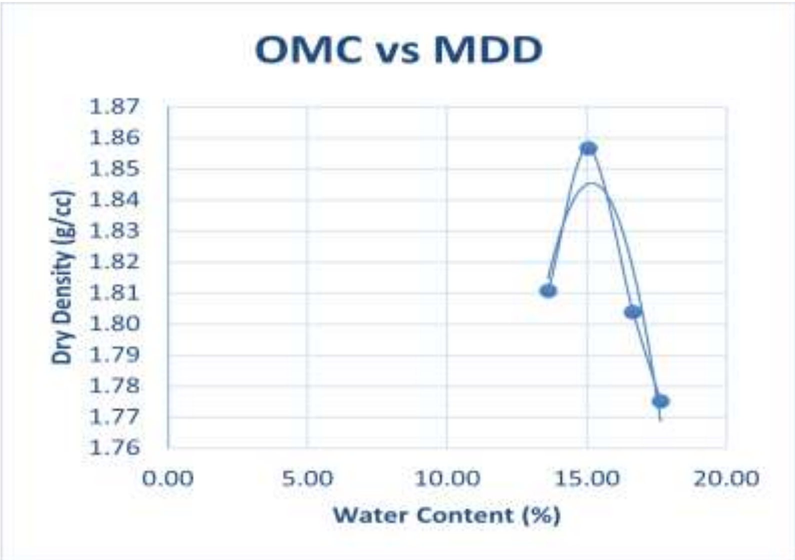
Water Content Formula: $w = [(W4–W5) / (W5–W3)] \times 100$

Maximum Dry Density (MDD) = 1.85 g/cc – 2.0 g/cc

Dry Density Formula: $\gamma d = \gamma b / (1 + w/100)$

Table 6: Compaction Test Data (Proctor Test)

Determination	**1**	**2**	**3**	**4**
Wt. of Mould + Compacted Soil, W2 (gm)	3976.9	4055.4	4023.7	4007.7
Bulk Density, γb (g/cc)	2.06	2.14	2.10	2.09
Dry Density, γd (g/cc)	1.81	1.86	1.80	1.78
Container No.	SK-5	SK-11	SK-14	SK-19
Water Content (%)	13.62	15.06	16.65	17.64
OMC (%)	15.06			
MDD (g/cc)	1.86			



Graph for OMC & MDD

5.6.2 Triaxial Test

Unconfined compression triaxial test was conducted to determine the shear strength parameters of the undisturbed soil sample.

Initial Cross-Sectional Area: $Ao = \pi d^2/4$

Corrected Area: $Ac = Ao / (1 – \varepsilon)$

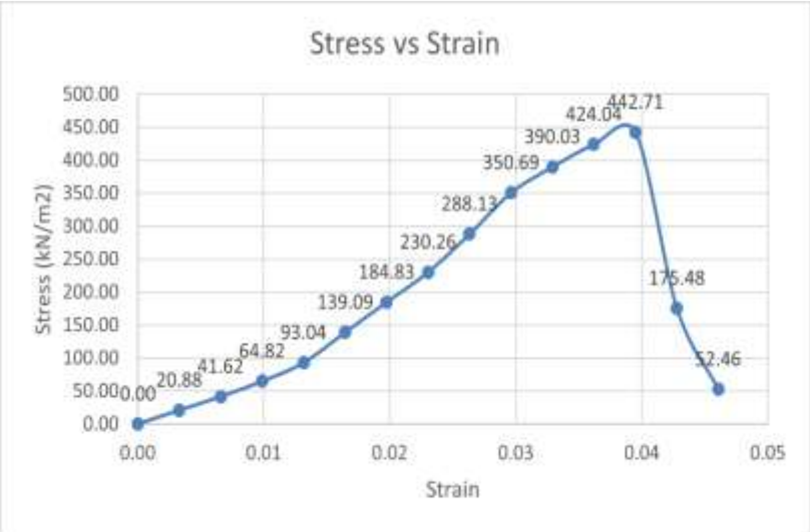
Load (proving ring): $W = B \times 2.97$

Compressive Stress: $\tau = (W / Ac) \times 10^3$ (KN/m²)

Peak Stress (Failure Point): Maximum stress = 442.71 KN/m², Corresponding strain ≈ 0.05

Table 7: Triaxial Test – Observation Table

Dial Gauge Reading (A)	Displacement δ=A×0.01 (mm)	Strain ε=δ/H	Corrected Area Ac=Ao/(1-ε) (mm²)	Proving Ring Reading (B)	Load W=B×2.97 (N)	Compressive Stress τ=(W/Ac)×10³ (KN/m²)
0	0.00	0.00	1134.11	0	0.00	0.00
25	0.25	0.00	1137.86	8	23.76	20.88
50	0.50	0.01	1141.63	16	47.52	41.62
75	0.75	0.01	1145.42	25	74.25	64.82
100	1.00	0.01	1149.24	36	106.92	93.04
125	1.25	0.02	1153.08	54	160.38	139.09
150	1.50	0.02	1156.95	72	213.84	184.83
175	1.75	0.02	1160.84	90	267.30	230.26
200	2.00	0.03	1164.77	113	335.61	288.13
225	2.25	0.03	1168.72	138	409.86	350.69
250	2.50	0.03	1172.69	154	457.38	390.03
275	2.75	0.04	1176.69	168	498.96	424.04
300	3.00	0.04	1180.72	176	522.72	442.71 (Peak)
325	3.25	0.04	1184.78	70	207.90	175.48
350	3.50	0.05	1188.87	21	62.37	52.46



Graph for Triaxial Test

VI. SOIL CLASSIFICATION

Based on grain size distribution and Atterberg limit results, the soil was classified using IS:1498 and the Unified Soil Classification System (USCS). The soil contained less than 5% fines, which categorized it as a clean coarse-grained soil. According to IS:1498, the soil was classified as GW (Well-Graded Gravel with Sand), while under USCS it was classified as GP-SP (Poorly Graded Gravel-Sand Mixture).

VII. ENGINEERING PROPERTIES OF SOIL

Advantages:

- High bearing capacity
- Good drainage characteristics
- No shrink-swell behaviour
- Suitable for foundations and road construction

Disadvantages:

- Low cohesion
- Easily erodible on steep slopes
- Difficult compaction if poorly graded

VIII. CAUSES OF SLOPE FAILURE

The primary cause of slope failure was identified as water infiltration into loose colluvial soil on a steep slope. Water reduced the shear strength of the soil and increased instability. The low cohesion and loose arrangement of gravel and sand particles further contributed to failure.

IX. REMEDIAL MEASURES

- Installation of proper drainage systems
- Construction of retaining structures
- Soil reinforcement techniques
- Vegetation and bioengineering methods

X. FUTURE SCOPE OF WORK

Further studies including Optimum Moisture Content (OMC), Maximum Dry Density (MDD), and Triaxial tests are required to determine detailed shear strength parameters and confirm the stability characteristics of the slope.

XI. CONCLUSION

The comprehensive geotechnical investigation conclusively determined that the slope failure was primarily triggered by water infiltration into the loose, coarse-grained colluvial soil, predominantly composed of sand and gravel, on a steep slope. This infiltration led to a substantial reduction in shear strength and overall stability of the slope. The key factors that significantly contributed to the failure mechanism include inadequate drainage, the steep geometry of the slope, and the inherent lack of cohesion in the soil matrix. Despite the soil exhibiting good bearing capacity and acceptable drainage characteristics under dry conditions, its loose structure rendered it highly susceptible to erosion and mass movement when subjected to saturation. The study effectively highlights and underscores the critical importance of thorough geotechnical investigation in understanding complex slope behaviour, identifying potential failure mechanisms, and determining appropriate stabilization measures, particularly in vulnerable hilly terrains prone to heavy rainfall and erosion. The findings emphasize the need for careful consideration of soil properties, drainage conditions, and slope geometry in slope stability assessments

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