LABORATORY INVESTIGATIONS TO ASSESS THE GEOTECHNICAL CHARACTERISTICS OF SOILS FROM SIKKIM HILL-SLOPES

Shiv Shankar Kumar¹, Dawa T. Tamang², Rabin Timsina³, Arindam Dey⁴

ABSTRACT

Laboratory tests of soils provide the data necessary to classify the soil and develop the correlations between index properties and engineering properties of the soil which help to understand the behavior of soil pertaining to the field conditions. Preliminary laboratory investigations are extremely necessary for later stages of design of structures resting on similar strata on the field. Moreover, the determined parameters provide the tools to understand the sustaining capacity and stability characteristics of the soil site. Sites comprising of different size of soil particles behaves differently and affects the strength due to interaction of solid, air and water in its three-phase system. Thus, the proper evaluation of the soil properties, such as geotechnical, physical and engineering properties, by means of laboratory and in-situ testing are very much essential instead of direct use of purely empirical correlations. In addition to this, it has been seen that the soil collected from the same place do not give the exactly similar results due to non-homogeneity of the soil structure, confinement, stress history, voids present in the soil, presence of organic contents, pore water pressure, test methodology, perfection during tests and many more. Hence, the inherent non-homogeneity and anisotropicity renders the soil to exhibit varying engineering characteristics over space and time, which further necessitates the requirement of proper and detailed laboratory investigation and interpretation.

This paper reports the results of the detailed laboratory investigations carried out on two different types of soil, which has been collected from the landslide prone area of Sikkim state, near Sikkim Manipal University, India. Laboratory tests have been performed to find out the parameters such as particle size distribution (PSD), specific gravity, Atterberg’s limits, maximum dry density (MDD) using standard proctor compaction tests, shear strength parameters, infiltration characteristics and one-dimensional consolidation. The soil samples collected from the site were peculiar in nature due to the fact that visually the soil looked to be very fine clayey type, while the PSD revealed a significant composition of fine sands

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(Fig. 1). One of the sites even revealed the presence of whitish calcite in the soil. In order to ensure the reliability of test results, several repetitions of the tests had been carried out as per necessity. It has been seen that the both soil having more or less similar PSD, although the engineering properties were notably different. The understanding gained from the present investigations would be further used to assess the slope stability and landslide susceptibility characteristics of the hill-sites from where the soils were collected.

![Particle size distribution](image)

**Fig. 1** Particle size distribution of (a) Tumin site soil and (b) Sirwani site soil

**Keywords:** Laboratory investigations, Geotechnical characterization, PSD, Atterberg limits, Shear strength parameter, Consolidation, Compaction, Infiltration,
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ABSTRACT: Laboratory tests have been performed on two soils, collected from landslide prone areas, to find out their geotechnical characteristics such as particle size distribution (PSD), specific gravity, Atterberg’s limits, maximum dry density (MDD), shear strength parameters, infiltration characteristics and one-dimensional consolidation characteristics. The soil samples were peculiar in nature as although visually they represented fine-clayey soil, the PSD revealed a significant composition of silt and sands. It was also observed that both soils possessed similar PSD; however, the engineering properties were notably different. The detailed characterization would help to enable further studies on slope instability and landslide mechanisms in the area.

INTRODUCTION
The terrains of Sikkim region, marred with slopes having steep vertical angles, become a disaster prone area due to landslide during rainy season and on event of earthquakes. Moreover, Sikkim falls in zone IV [1], which always alarms the engineers involved in designing and construction of structure and responsible for the safety of life and property. Every civil engineering structure requires a proper foundation for its stability, which depend on the type of bearing soil. For proper evaluation of the suitability of the soil and its better performance as a foundation material, it is utterly necessary to characterize the soil in terms of its geotechnical properties along with the physical and engineering behavior. Several studies have been carried out to characterize the soil based on particle size distribution (PSD) and to find out different physical and engineering behavior of soils. Several researchers [2-7] have performed laboratory tests to find out physical and engineering properties of soils and soil mixtures and concluded that the laboratory tests of the soils provide data necessary to classify the soil and also to develop the correlations among index properties and engineering properties, which can be very useful for design of foundation.

This paper reports the results of the detailed laboratory investigations carried out on two different types of soil, collected from the landslide prone area of Sikkim state, near Sikkim Manipal University, India.

MATERIALS AND METHODOLOGY
In the present investigation, two different types of soils have been thoroughly investigated for their engineering and geotechnical properties. The soils are collected from two different locations; ~15.0 km apart from each other located near Sikkim Manipal University, India., which are named as Tumin (27°20’11”N and 88°29’52”E) and Sirwani (27°15’N and 88°28’E). Following the Indian Standards, laboratory investigations of the physical and engineering properties of the soils have been conducted, namely specific gravity (G), grain size analysis, Atterberg’s limits [i.e., liquid limit (LL), plastic limit (PL)], free swell index, standard proctor compaction characteristics [i.e., optimum moisture content (OMC) and maximum dry density (MDD)], consolidation characteristics [i.e., compression index (Cc), variation of coefficient of consolidation, coefficient of compressibility, coefficient of volume compressibility, and coefficient of permeability], infiltration characteristics...
characteristics and shear strength characteristics (i.e., cohesion and angle of internal friction).

RESULTS AND DISCUSSIONS

Laboratory tests have been performed on the both soils to find out the physical and engineering properties of soil.

Physical Properties

Water Content

The water content of a soil is defined as the amount of water present within the pore spaces of the soil grains. From Table 1, it can be observed that there is a significant loss in the natural moisture content of both soils within the duration of 15 days from the day of sampling i.e. ~20% in case of Sirwani site soil (S) and ~36% in Tumin site soil (T) respectively. This observation reflects that measurement of in-situ water content is extremely important for the sites affected by instability or landslides, and that estimation of the same in the laboratory after a specific time lapse fails to provide the correct information. As observed, the reduction of water content by significant percentages after specific period of time might provide a wrong information about the natural strength of soil in-situ, as a reduced water content would erroneously suggest for higher effective strength of soil. If modeled with such information, the slopes can even show stability which might not match with the observed phenomenon at site.

Visual Characterization

Photographs 1 and 2 provide the visual identification of the two soils collected from Tumin and Sirwani sites respectively. It can be observed that although the sites were only ~15 km apart, the soils show significantly different visual characteristics. Tumin soil is grey in colour, while Sirwani soil is more whitish. Upon touching, the Sirwani soil was felt to be more slippery, supposedly indicating for calcite content, which imparts the white colour to the soil. Moreover, it was observed that the Sirwani soil possessed significantly higher large-sized gravel content, mostly comprising of smooth particles. Hence, it can be understood that although nearby, soils can vary significantly in their characteristics and impart different mechanisms of landslide and slope failures in the site.

### Table 1 Water content of soil [8]

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>State of water content determination</th>
<th>Water content (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sirwani</td>
<td>Tumin</td>
</tr>
<tr>
<td>1</td>
<td>Just after in-situ sample collection</td>
<td>11.07</td>
<td>7.2</td>
</tr>
<tr>
<td>2</td>
<td>After 15 days</td>
<td>8.8</td>
<td>4.63</td>
</tr>
</tbody>
</table>

Specific Gravity

The specific gravity [9] of soils has been found to be 2.746 and 2.793 for Sirwani site and Tumin site soils respectively. Specific gravity (\(G\)) is the ratio of the mass of dry particles to the mass of water they displace. It has been reported that the \(G\)-value for most of the soils generally lies between 2.60-2.80 [10].
Particle Size Distribution

Soil consists of an assemblage of discrete particles of various shapes and sizes. The characterization of those particle sizes is very useful in engineering properties of soils. The graphical representation of sieve analysis called as the particle size distribution which shows the percentage finer against the particle size on a logarithmic scale. Particle size distribution (PSD) is used to classify the particles into different sizes such as coarse (gravel and sand) and fine (silt and clay) particles. Before finding out the engineering properties, PSD [11] of both soils have been carried out.

Initially, dry sieving, the simplest method for crude estimation of PSD, was performed and it has been observed that the Tumin site soil contains ~18% fines whereas Sirwani site soil contains ~8% fines. It is specified in the code [11] that if the soil contains significant percentage of fines, we should adopt, although the quantification for the significant percentage is not provided. Nevertheless, it is well understood that for soils containing finer fractions, there is every possibility of sticking and lumping of the finer fractions over and above the coarser fractions, which when classified through dry-sieve analysis, would provide wrong information about the PSD. Hence, for in-situ soils revealing finer fractions, it is imperative to conduct wet-sieving which has been adopted in the present study, which can be deemed necessary based on the visual classification of the soils as revealed in Photographs 1 and 2. Wet sieving results indicate that both Tumin and Sirwani sites contain ~40% fine content, which is significantly different from that concluded from dry sieve analysis. Hence, it can be stated that the wet sieving procedure can give better insight into the PSD of a soil sample, which is also mentioned in [10]. Table 2a enumerates the soil composition as obtained through sieve analysis.

Hydrometer analysis has also been done as per [11], for the particle size smaller than 75μm, to observe the silt and clay percentage present in the soil. Fig. 1 reveals the combined PSD, which reflects that both the site contains significant quantity of gravel, sand and silt, and can be considered to well-graded soil with significant fine content.

Table 2a Soil composition through sieve analysis

<table>
<thead>
<tr>
<th>Parameters (%)</th>
<th>Tumin Site</th>
<th>Sirwani site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel &gt; 4.75 mm</td>
<td>27</td>
<td>22</td>
</tr>
<tr>
<td>Sand (4.75-0.075 mm)</td>
<td>56</td>
<td>38</td>
</tr>
<tr>
<td>Fines (&lt; 0.075mm)</td>
<td>17</td>
<td>40</td>
</tr>
</tbody>
</table>

Fig. 1a Combined PSD of Tumin soil

Fig. 1b Combined PSD of Sirwani soil

Based on the combined PSD for both the sites,
Table 2b enlists the particle characteristics for both the soils considering both dry- and wet-sieving. It can be observed that the mean diameter ($D_{50}$) of the Sirwani soil is higher than that of Tumin soil. As per [11], a soil is designated to be well graded if the coefficient of uniformity $C_u > 4$ and the coefficient of curvature $C_c = 1-3$. Based on the magnitudes of the coefficients estimated as shown in Table 2b, whereas a gravel is well graded if $C_u > 4$ and $C_c = 1-3$. From the grain size distribution results in Table 2, it can be stated that both the Tumin and Sirwani soils are well-graded, and presents nearly identical gradations as understood from the composition shown in Table 2a.

### Table 2b Parameters from particle size analysis

<table>
<thead>
<tr>
<th>Descriptions</th>
<th>Tumin Site</th>
<th>Sirwani site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>Dry sieve</td>
<td>Wet sieve</td>
</tr>
<tr>
<td>$D_{10}$ (mm)</td>
<td>0.015</td>
<td>0.006</td>
</tr>
<tr>
<td>$D_{30}$ (mm)</td>
<td>0.15</td>
<td>0.025</td>
</tr>
<tr>
<td>$D_{50}$ (mm)</td>
<td>0.65</td>
<td>0.11</td>
</tr>
<tr>
<td>$D_{60}$ (mm)</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>$C_u$</td>
<td>100.00</td>
<td>66.67</td>
</tr>
<tr>
<td>$C_c$</td>
<td>1.00</td>
<td>0.26</td>
</tr>
</tbody>
</table>

**Atterberg’s Limits**

The Atterberg limit defines the boundaries between different states of fine grained soils. The different states of the soil (clay) are solid, semi-solid plastic and the liquid state. The liquid limit was attempted to be determined by the conventional Cassagrande apparatus [12], however, due to presence of silt content proper grooving was not achieved, and hence the cone penetration method has been used for the present student to determine the liquid limit of the soil. The average liquid limit (LL) from several trials of cone penetration method was found to be ~39% and ~33% for Tumin and Sirwani soil respectively (Fig. 2). Plastic limit (PL) has also been evaluated [12] and found to be ~21% for both soils. Plasticity index (PI) calculated based on the LL and PL revealed that the both soils can be considered to be clay with low or intermediate plasticity (CL-CI) as per the plasticity chart of Indian Standard Soil Classification System (ISSCS) (Fig. 2c). The free swell tests conducted on the soils revealed then to be non-swelling type.

**Engineering Properties**

**Compaction tests**

Soil is generally used as a fill material for construction. To achieve satisfactory engineering properties for design and construction, it is
necessary to compact the soils to a dense state because loose soil may not give satisfactory results. Compaction of soil can be done by mechanical means such as rolling, ramming and vibrating to packing the soil particles more closely and hence the dry density of soil increases. The moisture content at which the highest value of dry density achieved for the given amount of compaction is the optimum moisture content (OMC), and the corresponding dry density is the maximum dry density (MDD).

In this study, the standard proctor tests [14] have been performed to find out the maximum dry density (MDD) of both soils. Several trials have been made to evaluate the MDD and OMC (Fig. 3). The average values for MDD and OMC of Tumin soil were found to be 1.797 g/cc and 14.5% respectively, while the same for Sirwani sites were found to be 1.96 g/cc and 10.6% respectively. The results state that the Sirwani soil has more strength under the OMC-MDD condition.

**Shear strength parameters**
Each structure on the earth imposes a load on the soil which supports the foundations resulting development of stress. The development of stresses causes deformation (due to elastic deformation, volume change and slippage of the particles) of soil. In this study, direct shear tests (DST) have been used to evaluate the stress-strain behaviour (Fig. 4) of the both soils which give an idea about their resistance to failure. The soil specimens for DST have been prepared at OMC and MDD condition. The stress-strain behaviour of the DST samples have been obtained under three different normal stresses, namely 50, 100 and 150 kPa respectively.
Based on the peak shear stress, the Mohr-coulomb failure envelope of the soil samples have been established which have been used to estimate the shear strength parameter of the soils in terms of their angle of internal friction (Fig. 5) [15]. The shear strength of the soil depends upon the friction and interlocking nature of particle [16]. It can be observed that the angle of internal friction of the soil obtained from Sirwani is higher than that of the Tumin soil, and as a consequence would conventionally impart more resistance to failure. The observation also corresponds to the findings of the Proctor compaction test.

Figure 6 represents the volume change during shearing which depicts the dilative behaviour of soil specimen prepared at MDD. It can also be seen that higher normal stress reflects high dilative behaviour. The obtained results from DST can be applicable for stability analysis of foundations, slopes and retaining structures.

**Seepage characteristics**

The seepage characteristics of the soils have been determined in their natural disturbed state. The infiltration curve presented in Fig. 7 depicts the variation of cumulative infiltration depth with square root of elapsed time. The values of infiltration permeability determined indirectly by
Zang method [17] have been found to be 2.7×10⁻⁵ m/sec and 3.0×10⁻⁶ m/sec for Tumin and Sirwani site soil respectively. The low infiltration permeability of Sirwani site soil is attributed due to the presence of calcite content.

**Consolidation tests**

The consolidation tests [18] have been conducted on the specimens prepared at MDD, to evaluate the compressibility of soil using oedometer test. The obtained results such as compression index ($c_c$), swelling index ($c_s$), coefficient of consolidation ($c_v$) and hydraulic conductivity ($k$) of the soils are presented in Table 3.

![Fig. 8a e-log p curve for Tumin soil](image)

**Fig. 8a e-log p curve for Tumin soil**

![Fig. 8 e-log p curve for Sirwani soil](image)

**Fig. 8 e-log p curve for Sirwani soil**

Fig. 8 represents the loading and unloading plot related to the consolidation of both the soils, which reflects that the void ratio decreases with the increase of effective stress during compression, whereas increases with the decrease of effective stress during swelling. The preconsolidation stresses for the Tumin and Sirwani soils were found to be 39 kPa and 100.5 kPa respectively, which is higher than the overburden pressure of the soil as when collected at a depth of 1m from the ground surface at the site. Hence, both the soils can be considered to overconsolidated soils, with Sirwani soil showing a higher overconsolidation ratio (OCR). Table 3 illustrates the compression and swelling index for both the soils, which indicates that soil collected from Sirwani site has higher compression and swelling indices, which renders the soil to be more affected by the presence and absence of water. It is also observed that the Sirwani soil has comparatively higher average coefficient of consolidation, while the permeability is lesser, which indicates that the Sirwani soil is more compressible. It is worth mentioning that although $C_v$ and $k$ are mentioned in their average form in Table 3, these parameters along with the coefficient of volume compressibility ($m_v$) and coefficient of compressibility ($a_v$) are functions of applied pressure and needs to expressed likewise. The variation of the above parameters is depicted in Figs. 9-13 for a stress of 50-800 kPa. It can be easily recognised from the set of curves that even though the overall gradation of the particles are nearly the same, still the consolidation characteristics are notably different.
Fig. 9b $C_v - p$ curve for Sirwani soil

Fig. 10a $k - p$ curve for Tumin soil

Fig. 10b $k - p$ curve for Sirwani soil

Fig. 11a $a_{v} - p$ curve for Tumin soil

Fig. 11b $a_{v} - p$ curve for Sirwani soil

Fig. 12a $m_v - p$ curve for Tumin soil
The evaluated consolidation test parameters can be used in engineering design to evaluate the settlement of foundation and to calculate the effect of seepage. The permeability calculated from consolidation test is lesser than the infiltration tests because of the state of the soil during test which is subjected to continually increasing pressure.

**Table 3** Summary of oedometer test

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Tumin site</th>
<th>Sirwani Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>(c')</td>
<td>~0.098</td>
<td>~0.1033</td>
</tr>
<tr>
<td>(c_s)</td>
<td>~0.0206</td>
<td>~0.0264</td>
</tr>
<tr>
<td>(c_v) (m/s)</td>
<td>~3.22×10^{-7}</td>
<td>~4.71×10^{-7}</td>
</tr>
<tr>
<td>(k) (m/s)</td>
<td>~6.21×10^{-10}</td>
<td>~3.53×10^{-10}</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

Two types of soil from two nearby sites have been studied to evaluate their physical and engineering properties and the following conclusion has been drawn.

- A significant loss in the natural moisture content occurs with elapsed time which renders the laboratory determine moisture content of the soil different from its natural in-situ condition.
- Specific gravity for both the soils are obtained to be similar.
- Wet sieve analysis purports the better PSD characterization of soils because the fine particles such as silt and clay cannot be easily separated during dry sieve analysis, which renders improper PSDs.
- It was observed that even if the soils from both the sites were of similar gradation, their engineering characteristics were significantly different. Hence, PSD cannot be used as a sole descriptor for the engineering and geotechnical characteristics of soils.
- Based on the estimated Atterberg limits, as per ISSCS, both the soils are classified as CL-CI, i.e. both the soils show low-to-medium compressibility.
- The compaction characteristics state that soil from Sirwani site comparatively has more strength than the Tumin soil, which is manifested by higher MDD and lower OMC obtained from a standard Proctor compaction test.
- The high peak shear stress obtained from DST of Sirwani site soil reveal the high angle of internal friction and strength at MDD, indicating that the Sirwani soil would more resistance towards instability.
- Sirwani soil shows a lower cumulative infiltration owing to lesser permeability in its natural state.
- Consolidation test reveals that the Sirwani soil is more compressible, however, will take more time to consolidate as revealed by its lower permeability at all levels of stress.
- The permeability calculated from consolidation test is lesser than the infiltration tests because of the state of the soil sample during the test where it is subjected to continually increasing stress.

Based on the observations and conclusions, it can be stated that although the sites are not located far away from each other, and even though some of the engineering and geotechnical characteristics for both the soil are same, still noticeable difference exists between the two soil sites in their geotechnical manifestations. It is to be noted that both the sites are landslide prone, and these differences in their geotechnical characteristics lead to the variability in mechanisms of failure and
should be properly estimated to determine proper mitigation procedures and techniques.

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