

# Geotechnical Characterization and Mineralogical Evaluation of Soils in Srinagar City, Jammu and Kashmir

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**Abstract.** Srinagar city in the Kashmir valley of Jammu and Kashmir state has been studied to understand the types of soils present in the city. Disturbed and undisturbed samples were collected from 30 locations at a depth of 1m in the main city. Index properties and engineering properties were evaluated from the geotechnical laboratory tests. X-ray Diffraction technique was used to determine the mineralogical composition. Results indicate that soils at this depth in Srinagar city are predominantly fine grained. The proportion of clay size in the soils ranges from 7% to high values of about 42% in Batpora and Hawal. The soils have been classified as silty or clayey soils having intermediate to high plasticity according to the Indian Standard and Unified soil classification systems. Low swelling potential and low activity was observed during laboratory tests. This behavior is supported by mineralogical analysis which revealed presence of Quartz and Illite minerals in the soils. Absence of high swelling minerals makes the soil less problematic. Shear strength parameters ( $c$  and  $\phi$ ) were found to be low to medium except in few areas like Hariparbat, Harwan, Cheshmashahi and a few areas in the central portion of the city. This suggests that bearing capacity of the soils is less and thus needs attention before starting any engineering work.

**Keywords:** Srinagar· Jammu and Kashmir· Geotechnical Characterization· X-Ray Diffraction.

## 1 Introduction

Soil is the most basic and easily available natural material and is encountered in all civil engineering works. Civil engineering structures are constructed either of the earth, on the earth or within the earth. Types of soils which are present in any area depend on the mode of their origin through varied geological processes that the region

has undergone in the past. Characteristics and behavior of soils are further influenced and continuously modified by climatic conditions and other environmental factors which are prevalent in the region. The environmental factors govern the nature and extent of weathering to which rocks and soils are subjected. This makes their behavior highly unpredictable and therefore the safety and stability of any engineering structure constructed of soil or on soil is entirely dependent on a proper investigation of its geotechnical properties. It becomes an essential task to distinguish amongst the various kinds of soils in order to reduce or avoid hazards while dealing with soils [1].

The aim of this paper is to characterize soils in Srinagar city and create a database of information of the geotechnical properties. For this purpose, disturbed and undisturbed soil samples were collected at a depth of about 1m from 30 locations within the city. Laboratory tests were conducted on all soil samples to determine the index properties and the engineering properties. Index properties including in-situ water content, in-situ density, specific gravity, grain size distribution and Atterberg limits; and engineering properties including shear strength and compaction characteristics have been determined directly from the tests. The database will help to understand the general variation of soil properties in the study area and will serve as a source of valuable information to determine the types of soils present in the region. The engineering suitability of soils within Srinagar city may be investigated by utilizing this data.

### **1.1 Study Area**

Srinagar is one of the most densely populated districts in Jammu and Kashmir. It is the summer capital of the state and is situated in the Kashmir division. Kashmir is a NW-SE oriented oval shaped valley within the Himalayan region. The North eastern margin of the basin is delineated by Zaskar range and the South eastern margin by Pir Panjal range. Himalayan region is highly active tectonically due to the presence of a large number of faults which are mainly thrusts.

Kashmir valley basin has been filled by about 1300m of sedimentary deposits over a period of 4 million years, resulting from the uplifting of the Pir Panjal range as a result of tectonic movements within the thrusts in the region [2]. Srinagar city lies in the center of the Kashmir valley and is therefore, mostly plain. Figure 1 shows a map of Srinagar city superimposed by the topographic layer for the region and elevation contours at 100m intervals. However, topography varies due to the presence of a few isolated hills like Hari Parbat and Shankaracharya hill within the city, and Zabarwan hills which form a part of the mountain range on the eastern end. The general elevation in the central portion of the city is 1585 m above mean sea level and varies gradually to about 1620 m in some of the peripheral areas. The hills stand up to an elevation of 200–300 m above the level of the city. Dal lake, Anchar lake, a few wetlands and the river Jhelum form a system of water bodies within the region, being originally depressions created during the formation of the valley filled with water in the past history. Jhelum flows through the middle of the study region in the NE-SW direction. Presence of lakes, rivers and hills within the city creates a depositional environment. The surficial soils in the study area are thus younger sediments deposited from the lakes, flooding of rivers and sediments brought down by gravity from hills and moun-

tain ranges. There are hence, mostly loose, unconsolidated fluvial sediments around the water bodies.

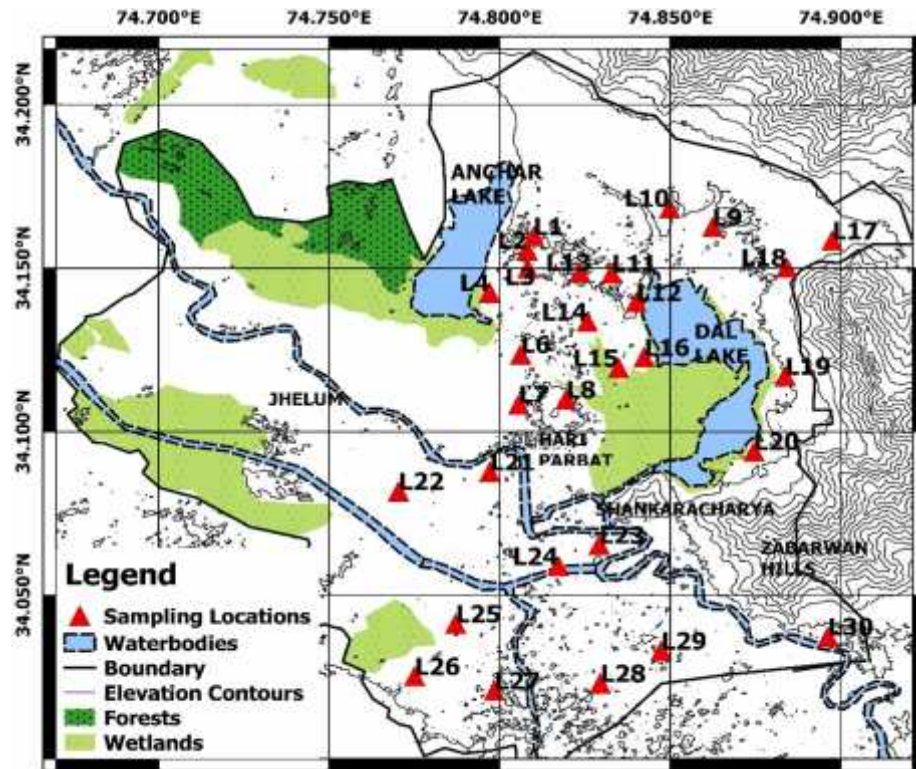


Fig. 1. Map of Srinagar city showing selected locations for sample collection.

## 2 Testing and Methodology

### 2.1 Collection of samples in the field

Disturbed and undisturbed soil samples were collected from 30 locations within the Srinagar city (Fig. 1). Sample collection was done from April to May of the year 2019. Top layer was first removed and a trench then dug up to a depth of 1m using basic digging tools. Undisturbed samples were collected using core cutters, sealed properly and taken to the laboratory in order to avoid change in structure and moisture content of the soil. Disturbed samples were also collected at the same depth from all locations.

## 2.2 Laboratory Soil Testing

The samples were taken to the geotechnical engineering laboratory in NIT Srinagar and all basic tests for characterization of soils were performed for each site. Indian Standards (IS): 2720 'Methods of Tests for Soils' outlines in separate parts the standardized procedures to be followed to conduct various geotechnical laboratory tests on soils. For this study, geotechnical laboratory tests have been performed in compliance with IS: 2720 (1973) and subsequent revised versions [3]. Index properties including in-situ water content, in-situ density, specific gravity, grain size distribution and Atterberg limits; and engineering properties including shear strength and compaction characteristics have been determined directly from the tests. Mineralogical analysis of the soils has been performed using X-Ray Diffraction technique conducted in the XRD facility in the TEQIP section of NIT Srinagar. Using this data, the soils were classified based on Unified Soil Classification and Indian Soil Classification systems. Important parameters and properties of the soils were derived from the results of the analyses. Compression index, which is required for the calculation of settlements of fine grained soils, has been calculated indirectly using an empirical equation given by Skempton involving liquid limit.

## 3 Results and Discussion

Detailed quantitative information has been obtained for soils in Srinagar from the results of laboratory tests. Further, properties of soils obtained at discrete locations have been plotted in a GIS platform and then interpolated in order to get a spatial distribution of the respective parameters over the whole study region. This helps to visualize the general variation of any parameter over the city and to get a better understanding of properties and behavior of soils in the region. However, it must be noted that in-situ moisture content is not constant, and hence geotechnical properties also may vary.

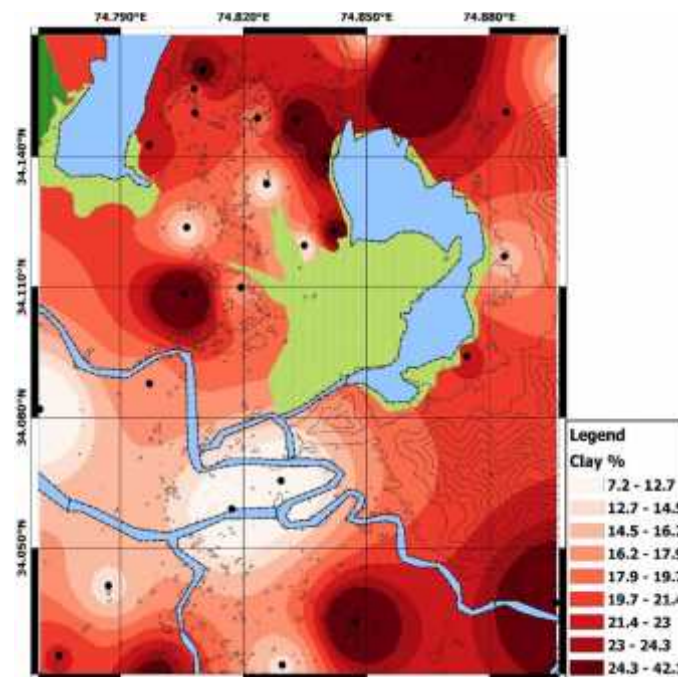
### 3.1 Index Properties

**In-situ Tests.** The in-situ water content of the samples varied between a minimum of 13.76% in Hariparbat and a maximum of 46.2% in Nowgam area. High values were obtained in the belt which extends through Rajbagh, Rawalpora, Nowgam and Sempora in the southern part of the region, which was also clearly observed during the sampling procedure. Dry density was found to be in the range 1.32 – 2.02 g/cc, with maximum values observed in the northern portion of the city.

**Specific Gravity (G).** G values of soils in the city lie between 2.409 and 2.688. Most of the sites have G greater than 2.6 except for a few areas like Ahmednagar, Malbagh, Habak, NIT and Cheshmashahi and low values (2.4) in the belt to the south of Jhelum

which includes locations like Hyderpora, Peerbagh, Rawalpura, Nowgam and Sempora (L25–L30).

**Grain Size Distribution.** Sieve analysis revealed that the percentage of particles passing through the  $75\mu$  sieve is greater than 50% for soils at all the sites. Thus, they are classified as fine grained soils according to Indian Standard soil classification system. The fines content is more than 90% for most of the locations except Hawal, Hariparbat, Nishat, SKUAST (Shalimar) and Harwan, which have some proportion of gravel as well which is probably due to their proximity to hills and mountain ranges. Hydrometer test on the portion of soil passing  $75\mu$  sieve gives percentages of silt and clay sizes present in soils. Silt size is predominant in all the sites. Percentage of clay size ranges from very low (7 – 8%) in Bemina, Rajbagh and Jawaharnagar, to high (30 – 42.1%) in Soura, Hawal and Batpora (Fig. 2). The variation of percentage of silt size over the region follows a pattern opposite to that of clay size, as the soils are predominantly fine grained.



**Fig. 2.** Spatial distribution of percentage of Clay size in soils in the Srinagar city.

**Atterberg Limits.** Since the soils are fine grained, Atterberg limits are significant for further classification using Unified soil classification and Indian soil classification systems. From Casagrande liquid limit test it has been determined that liquid limit ( $w_L$ ) for soils in the region varies between 31.3% and 60.8%. The spatial distribution

of liquid limit over the region is shown in Figure 3. Liquid limit for the soils is mostly low for the whole region, reaching up to slightly higher values in areas like Peerbagh, Nowgam and Hawal. Plastic limit ( $w_p$ ) was also determined and the results obtained indicated a range of 17.8 – 40.4%. Plasticity Index ( $I_p$ ) gives the degree of plasticity of a fine grained soil and is calculated from the Atterberg limits. The obtained values range from 8% to 27.9%, which means that the soils have intermediate to slightly high plasticity characteristics. Subsequently, points were plotted on the plasticity chart to classify the soils as silts and clays on the basis of their behavior (Fig. 4).

It was observed that soils around the Jhelum river behave as silts, whereas in areas in the northern part of the study region the behavior is clayey. This might be due to the deposition of silt by the river during floods. As is indicated by the plasticity chart, soils of Hawal, Cheshmashahi, Rawalpura and Nowgam show high compressibility ( $w_L > 50\%$ ) while others are categorized as low compressibility soils as per the USCS, and low and intermediate compressibility soils as per the ISSCS. Moreover, as the points are nearer to the A-line, it can be deduced that the clay mineral present in the soils is either Illite or Kaolinite, depending on whether the points lie above or below the A line respectively. This suggests that the soils have low swelling and shrinkage potential. A number of parameters can be evaluated once the Atterberg limits are known.

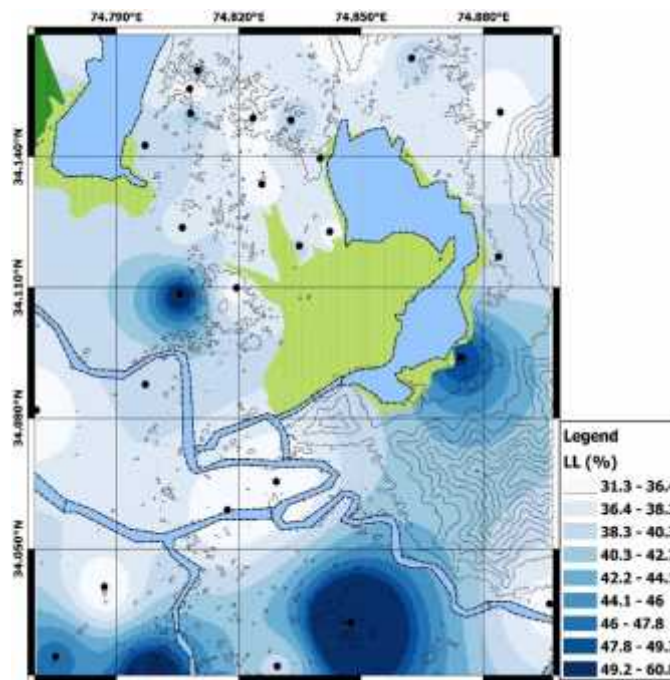


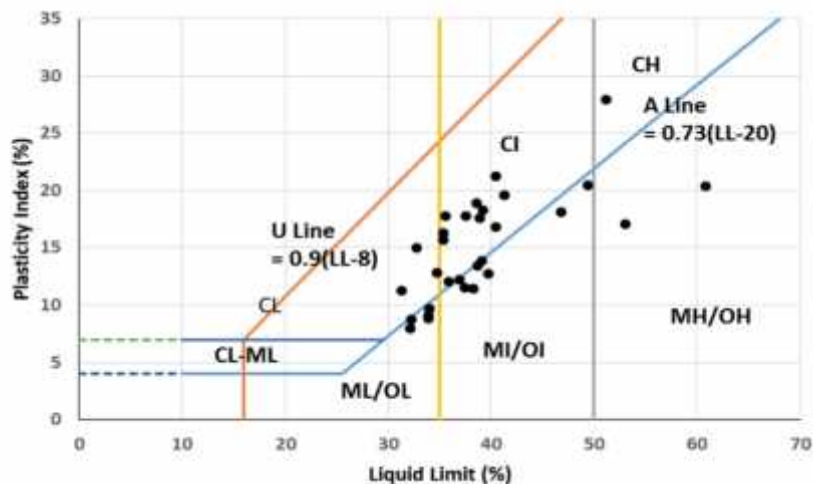
Fig. 3. Map showing variation of liquid limit of soils over the area in Srinagar city.

Activity is another parameter derived from plasticity index  $I_P$  and percentage of clay fraction (F) in the soils defined by Skempton in 1953. Activity corresponds to plastic behavior over a large range of water content which means high shrinkage and swelling characteristics. The range of Activity obtained for soils in Srinagar city was 0.43–1.5. It was observed that the soils are mostly Inactive (A less than 0.75) and Normal (A between 0.75 and 1.25), except for Bemina, Anchar, Lalbazar and Nigeen which are slightly active (A greater than 1.25). Low values indicate presence of Kaolinite and Illite as clay minerals. Values nearer to 1.5 may indicate presence of Montmorillonite which must be verified by mineralogical analysis through XRD.

Flow Index ( $I_F$ ) signifies the rate of loss of shear strength of a soil with increase in water content. The values of flow index ( $I_F$ ) for soils tested for the study region fall between 0.543 and 5.038. Higher values signify lower shear strength of soils. Toughness index ( $I_T$ ) is a measure of shear strength of soils at plastic limit. The values obtained are greater than 1 for all locations which indicates good shear strength at plastic limit.

The in-situ behavior of a soil deposit at its natural water content ( $w_n$ ) is studied by using two indices: Liquidity Index ( $I_L$ ) and Consistency Index ( $I_C$ ). Liquidity Index gives nearness of the natural water content to the liquid limit of a soil, whereas, Consistency Index gives nearness of the natural water content to the plastic limit of a soil.

From the results obtained from the analyses, most of the locations which lie in the northern portion of the city, have low  $I_L$  (less than 0.5) and high  $I_C$  (greater than 0.5), suggesting that they are stiff and thus good as foundation materials in their natural state of water content. A few locations like Bemina, Rajbagh and Nowgam near river Jhelum have values nearer to 1, signifying that they have soft consistency, and thereby construction of foundation at the in-situ water content may not be feasible. However, these indices are subject to change in natural water content which varies drastically with weather conditions.



**Fig. 4.** Plasticity chart with points (represented as dots) plotted for the 30 selected locations.

### 3.2 Engineering Properties

**Compression Index.** Compression index is an important parameter with the help of which settlement can be calculated in a soil deposit under a loading. Compression index has been determined for the whole study area indirectly by using an empirical equation given by Skempton in 1944 [4]. The obtained values for the region range between 0.149 and 0.355. This equation signifies that compressibility is high in soils of high liquid limit. Thereby, a similar variation is observed for  $C_c$  for the region as  $w_L$ . Higher compression index means a larger amount of settlement in the soils may be expected under loading, which thus needs to be taken care of in the design of engineering structures.

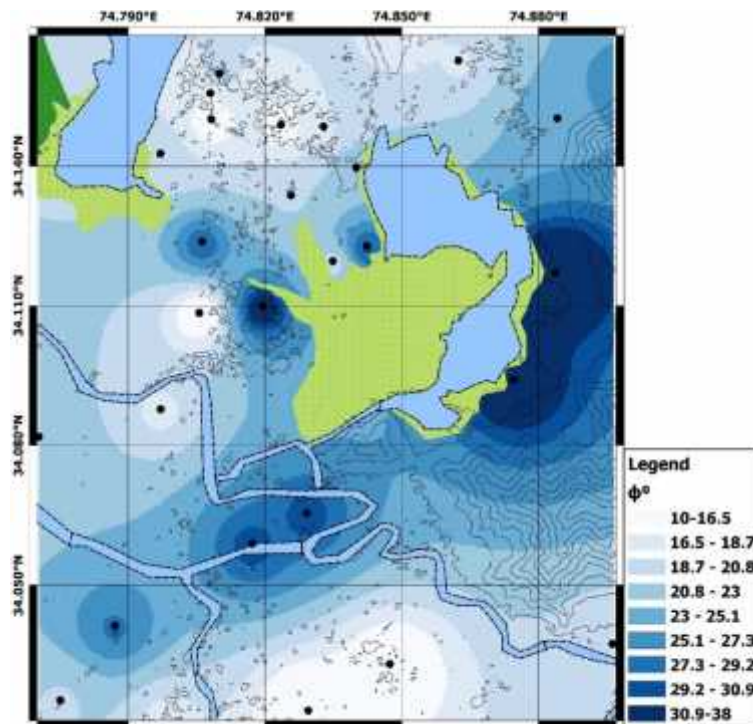
**Compaction Characteristics.** Proctor compaction test has been performed on all the samples to obtain the compaction characteristics for the region. The compaction curves were plotted for all soils and values of MDD and OMC were extracted. The range of MDD is 1.37–1.77 g/cc and that of OMC is 16.3 – 31.2 % for the region. The results conform to the values generally anticipated for silty clays and clayey silts. MDD values are low for Nowgam, Rawalpura, Peerbagh, Hawal, Cheshmashahi and Nowshera. It has been noticed that the variation in OMC and MDD is for most of the parts consistent with the distribution of clay, silt and sand content. The areas with higher content of clay size and/or lower proportion of sand, have higher OMC and lower MDD values and vice versa.

**Shear Strength Parameters.** Direct shear tests have been conducted on samples compacted at corresponding MDD and OMC to find out the shear strength parameters ( $c$  and  $\phi$ ). Spatial distribution of friction parameter for the region is shown in Figure 5. Higher shear strength parameters ( $c$  and  $\phi$ ) were obtained for soils of Cheshmashahi, Harwan and Hariparbat. It is worth mentioning that the high angle of internal friction in these locations might be due to the greater proportion of silt and/or sand contents as a consequence of their proximity to the hilly areas. These areas may thus be expected to possess higher bearing capacities. Areas in the northern part of the city have comparatively lower values of both  $c$  and  $\phi$  which suggests that they may have low bearing capacities. Care must be taken in the geotechnical design of structures in these areas. Locations in the belt around Jhelum, except Sempora, have been found to have medium to high values of cohesion and low to medium values of angle of internal friction. There is an apparent similarity of properties in this belt perhaps due to the similar fluvial deposition from rivers. For the whole region, the angle of internal friction varies between 10.6 – 37.7 and cohesion parameter varies between 11.4 – 64.6 kN/m<sup>2</sup>. These results fall in the general range generally obtained for clayey silts and silty clays. Unconfined compressions tests have been conducted on samples which revealed a good agreement with the results of DST.

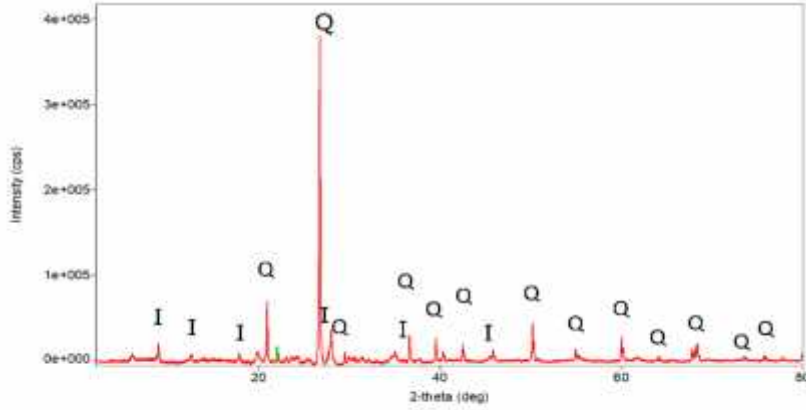


### 3.3 Mineralogical investigation

X-ray diffraction facility accessed in NIT Srinagar uses a  $Cu K$  filter. Analysis of the data revealed peaks at  $2\theta$  angles corresponding to d-spacing of Quartz and Illite minerals (Fig. 6). In the analysis of the data of soils at all the sites, presence of Quartz was established as the primary mineral and that of Illite as the clay mineral. Illite has low swelling potential, low activity and shows low liquid limit as compared to minerals like Montmorillonite and Smectite [5]. Therefore, swelling potential need not be considered during the design of structures in Srinagar. These soils do not pose any serious concern related to volume changes due to change in moisture content. Results of XRD verify the behavior of the soils captured through Atterberg limits.



**Fig. 6.** Spatial variation of angle of internal friction for soils in Srinagar city.



**Fig. 5.** X-Ray Diffraction spectrum of <75 $\mu$  of sample from location L9. Q = Quartz, I = Illite

#### 4 Conclusion

Tables 1, 2 and 3 present the summary of various calculated and derived properties of soils from the results of laboratory tests collected at 1m depth in Srinagar city.

**Table 1.** Index properties of soils at all locations.

Locations	Labels	$W_n$ (%)	$d$ (g/cc)	Silt (%)	Clay (%)	G
Ahmednagar	L1	21.15	2.006	72.40	26.04	2.531
Buchpora	L2	24.09	1.972	78.16	20.40	2.688
90 Feet Road	L3	32.05	1.697	76.43	20.53	2.590
Anchar	L4	20.45	1.937	85.05	14.33	2.659
Soura	L5	16.98	2.023	67.30	30.16	2.590
Nowshera	L6	24.20	1.688	78.30	13.53	2.570
Hawal	L7	20.77	1.977	54.43	32.27	2.617
Hariparbat	L8	13.76	1.770	71.44	17.05	2.653
Batapora	L9	18.99	1.898	57.34	42.10	2.655
Tailbal	L10	16.45	1.605	76.26	15.10	2.634
Zukura	L11	23.11	1.898	72.07	27.32	2.625
Habak	L12	25.12	1.721	68.24	26.66	2.532
Malbagh	L13	24.10	1.982	80.08	18.20	2.500
Lalbazar	L14	23.20	1.867	86.40	12.89	2.604
Nigeen	L15	25.85	1.687	85.40	12.56	2.657
NIT Hazratbal	L16	28.03	1.794	67.9	26.29	2.557

Harwan	L17	28.10	1.941	71.66	15.10	2.680
Skuast	L18	24.42	1.937	66.67	21.51	2.590
Nishat	L19	21.61	1.798	75.06	15.50	2.655
Cheshmashahi	L20	42.61	1.747	78.15	21.71	2.486
Karannagar	L21	28.71	1.944	77.26	16.47	2.673
Bemina	L22	31.22	1.318	85.70	07.20	2.640
Rajbagh	L23	32.77	1.765	89.50	07.74	2.688
Jawaharnagar	L24	26.73	1.809	92.00	08.00	2.663
Hyderpora	L25	26.57	1.702	78.76	13.71	2.544
Peerbagh	L26	34.47	1.799	78.76	21.68	2.457
Rawalpora	L27	36.01	1.772	71.45	25.52	2.450
CUK Nowgam	L28	36.88	1.819	78.76	14.06	2.463
Nowgam Railway	L29	46.20	1.658	69.94	28.65	2.409
Sempora	L30	20.33	1.756	71.56	28.03	2.525

An attempt has been made to extract maximum useful information about the behavior and nature of the soils from the results. This database may be used as a preliminary guide while planning and design of constructions in the city.

**Table 2.** Results from soil classification tests.

Labels	W <sub>n</sub> (%)	W <sub>L</sub> (%)	W <sub>P</sub> (%)	I <sub>P</sub> (%)	I <sub>C</sub> (%)	I <sub>L</sub> (%)	I <sub>F</sub>	A	ISCS	USCS
L1	21.15	38.90	21.34	17.56	1.01	-0.01	3.17	0.6	CL	CI
L2	24.09	32.80	17.80	15.00	0.58	0.419	5.02	0.7	CL	CI
L3	32.05	41.33	21.70	19.63	0.47	0.527	8.41	0.9	CL	CI
L4	20.45	40.49	19.26	21.23	0.94	0.056	4.43	1.4	CL	CI
L5	16.98	38.66	25.31	13.35	1.62	-0.62	1.25	0.4	ML	MI
L6	24.20	37.40	25.9	11.50	1.14	-0.15	4.22	0.8	ML	MI
L7	20.77	51.25	23.34	27.91	1.09	-0.09	5.67	0.8	CH	CI
L8	13.76	35.44	19.70	15.74	1.37	-0.38	1.35	0.9	CL	CI
L9	18.99	39.20	34.79	04.41	4.58	-3.58	10.41	0.1	CL	CI
L10	16.45	32.25	24.28	07.97	1.82	-0.98	6.77	0.5	ML	ML
L11	28.03	40.46	23.73	16.73	1.03	0.257	4.73	0.6	CL	CI
L12	25.12	37.59	19.82	17.77	0.71	0.298	1.84	0.6	CL	CI
L13	24.10	31.33	20.01	11.32	0.63	0.361	4.44	0.6	CL	CL
L14	23.20	35.37	19.19	16.18	0.75	0.248	4.21	1.2	CL	CI
L15	25.85	38.64	19.67	18.97	0.67	0.326	4.06	1.1	CL	CI
L16	28.03	35.97	23.94	12.03	0.66	0.340	6.35	0.4	CL	CI

L17	28.10	36.95	24.70	12.25	0.72	0.278	6.93	0.8	ML	MI
L18	24.42	34.74	21.88	12.86	0.80	0.198	2.05	0.5	CL	CL
L19	21.61	39.19	25.24	13.95	1.26	-0.26	7.40	0.9	ML	MI
L20	42.61	49.43	28.91	20.52	0.33	0.668	8.28	0.9	ML	MI
L21	28.71	38.31	26.90	11.41	0.84	0.159	8.45	0.6	CL	CL
L22	31.22	33.86	24.80	9.06	0.29	0.709	10.79	1.2	ML	ML
L23	32.77	32.26	23.60	8.66	-0.06	1.059	2.96	1.1	ML	ML
L24	26.73	33.97	25.16	8.81	0.82	0.178	4.05	1.1	ML	MI
L25	26.57	34.00	24.30	9.70	0.77	0.234	6.15	0.7	ML	ML
L26	34.47	46.87	28.70	18.17	0.68	0.318	7.08	0.8	ML	MI
L27	36.01	53.01	35.91	17.01	0.99	0.006	5.58	0.6	MH	MH
L28	36.88	39.73	27.06	12.67	0.22	0.775	6.88	0.9	ML	MI
L29	46.20	60.8	40.40	20.40	0.71	0.284	11.6	0.7	MH	MH
L30	34.47	35.63	17.75	17.88	0.85	0.935	5.43	0.6	CL	CI

**Table 3.** Engineering properties of soils at each location.

Loca- tions	Compaction		DST		UCS	
	MDD (g/cc)	OMC (%)	c (kPa)	(°)	C <sub>u</sub> (kPa)	C <sub>c</sub>
L1	1.643	19.76	26.98	19.92	40.37	0.20
L2	1.736	17.68	64.57	16.25	68.83	0.16
L3	1.648	18.23	37.12	14.00	31.19	0.22
L4	1.657	19.81	18.39	21.99	17.40	0.21
L5	1.667	20.30	11.74	17.56	20.77	0.20
L6	1.552	23.97	37.64	29.16	34.9	0.19
L7	1.560	24.00	35.21	12.78	39.58	0.29
L8	1.706	17.50	42.90	33.34	19.82	0.18
L9	1.671	20.20	19.65	18.42	14.98	0.20
L10	1.775	17.58	35.87	16.69	31.14	0.16
L11	1.687	18.62	13.68	18.42	18.00	0.21
L12	1.667	20.05	15.47	22.20	21.49	0.19
L13	1.716	18.40	33.25	14.03	41.98	0.15
L14	1.667	21.07	37.67	20.54	41.69	0.18
L15	1.648	20.50	40.44	19.92	42.07	0.20
L16	1.719	17.73	53.63	29.52	42.28	0.18
L17	1.712	19.44	50.96	26.17	30.93	0.19

L18	1.728	18.52	12.14	24.61	18.98	0.17
L19	1.557	20.00	13.49	37.76	15.78	0.20
L20	1.562	21.27	54.82	35.29	58.64	0.28
L21	1.643	21.00	27.96	18.00	35.6	0.19
L22	1.663	17.50	44.00	21.8	46.00	0.17
L23	1.716	17.74	30.84	30.24	34.6	0.16
L24	1.697	18.00	56.78	30.24	51.2	0.17
L25	1.736	16.30	34.05	27.69	31.5	0.17
L26	1.512	22.48	30.18	20.55	32.58	0.26
L27	1.491	25.64	49.32	17.56	29.32	0.30
L28	1.600	21.86	35.89	10.61	40.32	0.21
L29	1.370	31.20	39.35	12.44	33.16	0.36
L30	1.702	18.03	11.46	19.28	16.20	0.18

More tests need to be conducted at various depths and also borehole data might be collected to get an extensive and complete knowledge of the soils in Srinagar.

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