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Geotechnical Facets of Active Sediments and its Bearing on Natural Hazards and Mitigation Measures: An Approach on Sediments of the Nubra Valley (Ladakh), Trans-Himalaya, India

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ABSTRACT

The paper highlights the geotechnical attributes of Quaternary stratified sediments in Trans-Himalayan zone around the Nubra Valley (Ladakh), India for classifying the sediment's sequences and characterizing their participation in natural hazards susceptibility and mitigation measures. The study is based on the experimental works performed on collected samples of sediments at different sites and depths (1.5 to 5.5 m) of sequences for determination of grain size sensitive parameters and geotechnical characteristics as per American Society for Testing and Materials standard and with help of empirical relationships. The results reveal that the majority of sediments are bimodal distributed with wide variation in uniformity coefficients (1.84-5.0), low variation in coefficient of curvatures (0.5-0.61) and sorting coefficient (1.12-1.69) exhibit wide range of shear strengths (25 kPa to 130 kPa), cohesions (0.02-0.13 kg/cm^2) and angles of internal frictions (36°-45°) which may be due to distinct differences in their densities, void ratios, liquid and plastic limits. Based on geotechnical values, the sediments strata can be categorized as foot-hill debris zone, normal sediment (soil) zone and active sediment (soil) zone. The foot-hill debris zone is found more prone to mass-wasting due to influence of gravity and their low binding habits. The active sediment (soil) zone exhibits lower shear strengths and cohesions in comparison to normal sediments due to higher liquid and plastic limits of sediments exposed to freezing and thawing actions. This zone is found more susceptible to slope instabilities and differential settlements hazards, hence requires specific care during engineering establishments and mitigation measures in the valley.

INTRODUCTION

The Himalayan mountain chain is seismo-tectonically and climatically most active and fluctuating regions of the world. It has deformed and fragile rocks/rock masses and soil strata of structurally complex natures. The interaction of climate and tectonics in the high altitude provinces of Himalaya imparts a vigorous role in erosions, transportation and deposition of the sediments, melting of glaciers, severe floods, mas wasting, land instabilities, sinking, etc. (Kumar et al., 2014). The stumpy thermal lethargy of the soil makes the area cool and heating fast in high daytime variations. In addition to these, the climatic impact in this area is existed in form of the least fertile sandy-soils with very low water retaining capacity, delicate plant density, humidity (<30%), strong solar radiation, low oxygen content, low atmospheric pressure, high wind velocity and uneven topography. These are often causing severe instability hazards such as landslides, and subsidence. In view of these problems, such kinds of areas need the pertinent understanding of geotechnical properties of the sediments (soils) of the region which are essential for a preliminary evaluation of strata for further field investigations. Johnston (1981) and Moh (1984) have given several geotechnical aspects and methods for field studies in such kinds of mountainous terrains (Dietze et al., 2014).

The Trans-Himalayan region includes a part of vast Tibetan Plateau within the main Himalayan arch under the 'rain shadow zone' (Dar and Dubey, 2013). This part is extended over approximately 186,000 square kilometers. The region is traversed by Indus river and it's principal tributaries namely the Shyok river and the Nubra river (Rodgers et al., 2000) (Fig.1). These two rivers flow along major fault lines in NW-SE direction (Saini, 2013). The Quaternary deposits scattered in the river valley and hill slopes of the Nubra region (Ladakh) show the loose to semi-consolidated alluvium, glacial and fluvio-glacial sediments, lacustrine sediments and debris. These sediments occur as terraces, alluvial fans, moraines, debris and mud flows in the region. The intricate and delicate dynamic climatic conditions exhibit the abrupt and arbitrary sediment influx and variation in their physical characteristics. The features preserved in sediment's layers show heterogeneous stratigraphic successions may be due to superposition of sedimentary environments along with glacial loading and unloading processes.

Geotechnically, these sediments of variable and composite origins appear to be complex and erratic in nature in comparison to sediments of southern temperate climatic regions, may be due to the potential freeze-thaw actions and salinity changes (Johnston, 1981; Moh, 1984). The dissimilarity in values of specific gravity and dry density in this kind of setting portrays mixed type of sediment facies (Al-Imam et al., 2013). The geotechnical investigations in such kinds of mountainous regions are typically of tedious and critical in natures due to steep and rugged topography of strata confluence by changing climatic conditions. However, very limited systematic work on geotechnical attributes of the sediments are available which are going to affect both safety, expansion and development of the region. Therefore, the present study elucidates the various important geotechnical evaluations of sediment's sequences in such delicate climatic variable zones for their future applications in resolving problems related to natural hazards susceptibility and expansion program of development by performing an experimental approach on sediment's sequences of a high altitude area in and around the Nubra Valley (Ladakh), India.

Geological Setting

The Nubra River Valley (Ladakh) is a part of Trans-Himalayan batholith system that outlines the southern boundary of the Tibetan plateau (Fig.2). The area is comprised of some of the important geographical features and vast valleys such as Suru, Changthang, Zanskar, Leh and Nubra (Murugan et al., 2010). The study area lies between the Indus Suture Zone (ISZ) in the south and Shyok Suture Zone (SSZ) limited by Karakoram to its north and northeast. These

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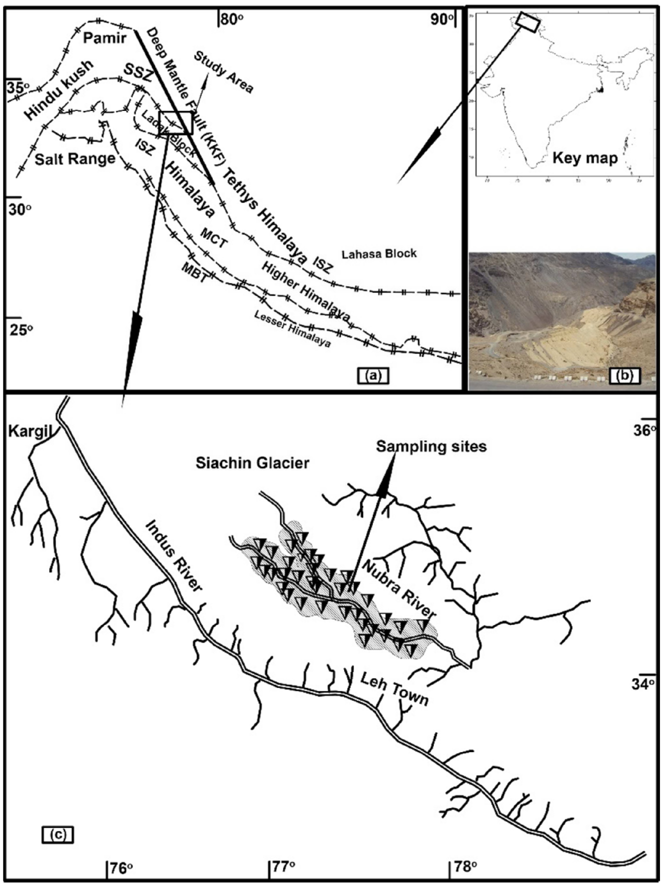

Fig.1. Map showing **(a)** overview of the Himalaya **(b)** outcrop of sediment sequence **(c)** location of the study area and sites of sampling.

junctures spot the closing of diverse branches of the Tethys Ocean and the last collision of India with Eurasia in 60–50 Ma ago (Upadhyay et al., 1999). The Ladakh block inhabits an intermediate position between the Indian Plate in the south and the Karakoram terrain to the north. It is parted from the Kohistan complex by the Nanga Parbat–Haramosh syntaxis, in the west, and from the Lhasa block in the east by the deep mantle fault (Karakoram fault) (Klemperer et al., 2013). In the southeastern side of the Ladakh Batholith, the high relief, deformed Tertiary sediments of the Zanskar Zone form the southern margin of the Indus Valley. The Indus valley imparts succession of sediments encompasses of limestone, mudstones and conglomerates of Eocene to Miocene age (Searle et al., 1990). The SSZ towards the north is inferred as an oceanic suture representing rocks of back-arc basin (Gansser, 1977; Upadhyay, 1999; Thakur and Mishra, 1984). The Shyok-Nubra rivers valleys and the adjoining part of the Karakoram terrain are tectonically active (Sinha and Upadhyay, 1997). The active slices are made up of sedimentary, metamorphic and magmatic rocks and considered as the remnants of an accretionary complex (Sinha and Upadhyay, 1997). The Quaternary deposits in Shyok-Nubra river valleys overlies the basement granitic and volcanic rocks and comprises of loose to semi-consolidated alluvium, glacial and fluvio-glacial sediments, lacustrine sediments and debris in the form of terraces, alluvial fans, and moraines (Pant et al., 2005).

Sampling

Samples of sediments were collected from vertical sections of three open natural trenches from the Nubra Valley (Shyok-Nubra rivers valleys) at different depths ranging from 1.5-5 m from local ground surface and at approximate interval of 1 meter during late summer season (Aug 3rd to Sept 3rd) to avoid the freezing conditions for smooth sampling (Fig.3). The collected samples were sealed in plastic bags and designed Polyvinyl Chloride (PVC) pipes for laboratory studies. The established vertical litho-structural successions from each trenches were designated as NS1, NS2 and NS3 for the Nubra valley (Fig.3). Based on size, three types of litho-facies namely the periglacial (mixed type) sediments (67.54%), silty-clays (21.34%) and medium sands (11.12%) have been identified in the Nubra valley.

Laboratory Work and Computation

The laboratory work was carried out to analyze various parameters such as water content, particle size distribution, liquid and plastic limits, density, specific gravity, void ratio, porosity and shear strength properties of the sediment's samples.

The water content estimate in this dynamic and high altitude region is a vital module in geotechnical investigation due to partially frozen sediments (soils) which are pronouncedly prompting the geotechnical properties such as thaw consolidations (settlements), creep strengths, and thermal properties. The sands show the minimum water content of 10-12%, while silt 5-10% and silty-clays 15-25% water contents during the late summer measurements (Table 1). The soils with less than 16% moisture content have good property for construction and some of the sediments (soils) with more than 16% natural moisture content in this areas is assumed to be a saturated sediment (soil) and are not good for construction purpose (Mallo and Akuboh, 2012). The water contents may be more in early to mid-summer periods in the region due to glacial melts. Therefore, the proper assessment of sediment's (soil) water content in this type of area provides the data about runoff potential, flood control, soil erosion and slope of failures during crowning climatic unstable periods (Lukanu and Savage, 2006).

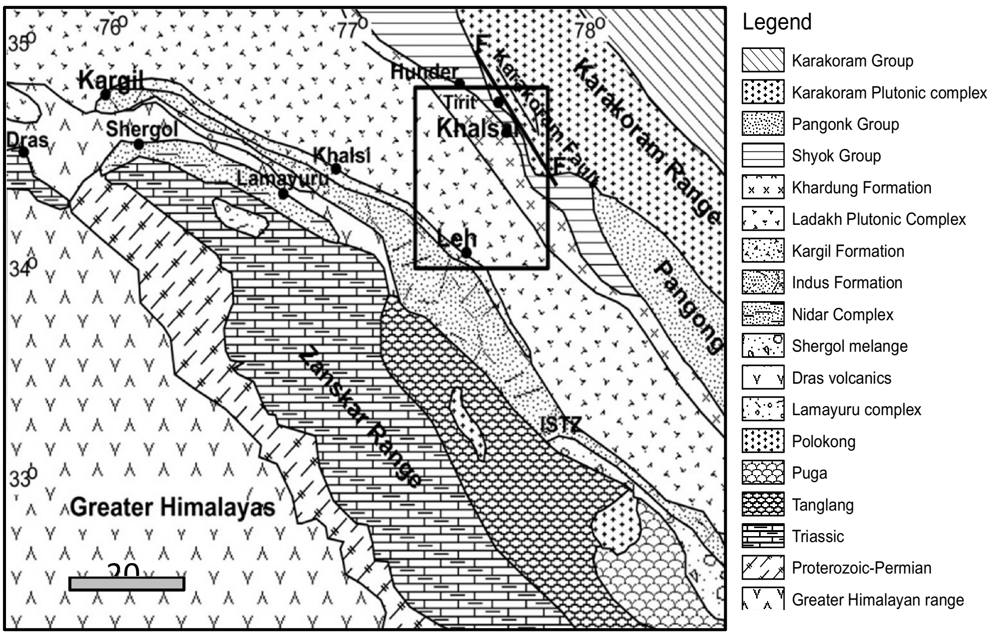

Fig.2. Geological map of the area (modified after Phartiyal et al., 2010).

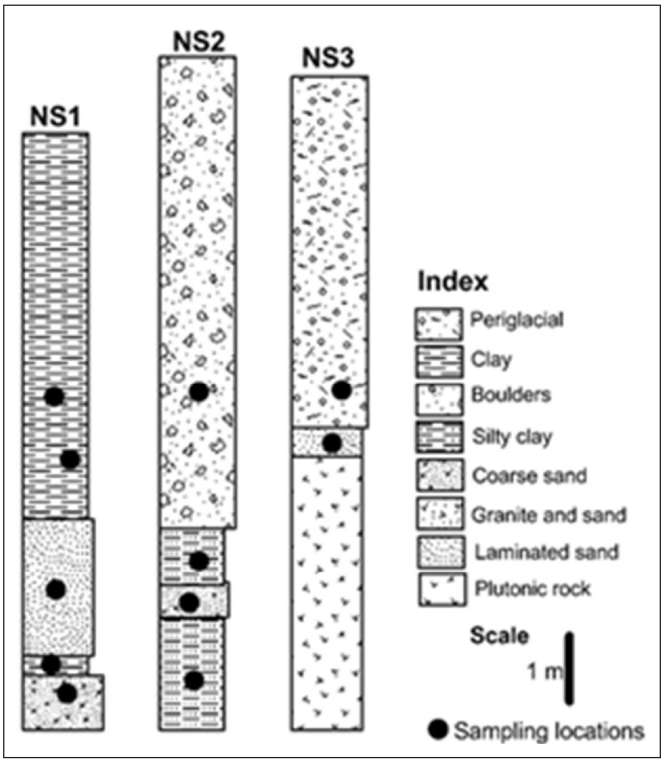

Fig.3. Lithological succession and sampling sites ((NS1, NS2, NS3) and levels of sediments in the Nubra Valley (Ladakh), India.

Table.1. Summary of different geotechnical properties of sediments of Nubra Valley (Ladakh) (where SC=silty clay, CS=Coarse sand, FS=Fine sand, MS=Medium sand and SL= Silt). DescriptionSediment's Samples

Sample number	L7	L8	L9a	L9b	L10	L11	L12a	L12b	L14
Bulk density (g/cc)	1.78	1.67	1.67	1.78	1.78	1.67	1.67	1.78	1.67
Dry density (g/cc)	1.59	1.59	1.59	1.55	1.59	1.58	1.52	1.59	1.57
Degree of saturation (%)	56.25	21.74	19.26	60.76	22.70	21.65	38.46	78.02	21.08
100% saturation	21.33	23	25.96	24.69	22.03	22	26	15.38	23
Void ratio	0.51	0.58	0.70	0.62	0.59	0.56	0.65	0.32	0.57
Porosity (%)	33.86	36.51	41.21	38.16	37.29	35.71	39.39	24.41	35.81
Specimen length (cm)	6	6	6	6	6	6	6	6	6
Specimen width (cm)	6	6	6	6	6	6	6	6	6
Specimen thickness (cm)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Specimen area (sq.cm)	36	36	36	36	36	36	36	36	36
Specimen volume (cc)	90	90	90	90	90	90	90	90	90
Specimen weight (g)	160	150	150	160	160	150	150	160	150
Water content (%)	16	5	5	15	5	5	10	17	5
Specific gravity	2.64	2.67	2.7	2.61	2.62	2.62	2.66	2.68	2.6
Sigma n (kg/sq.cm)	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Unconfined compressive strength (kg/cm^2)	0.97	0.74	0.72	0.96	0.82	0.74	0.64	1.00	0.73
Sediment (soil) type	SC	CS	CS	SC	CS	CS	FS	SC	CS

The water content of the sediments of the field is determined by weighing the samples before and after drying the samples for 48 hours in an electric oven:

$$\text{Water content } (W\ \%) = (W_2\text{-}W_3/W_3\text{-}W_1)*100 \quad (1)$$

where, W_1 is the mass of the can, W_2 is mass of can plus moist soil and W_3 is mass of can plus dry soil).

Grain size dispersals in the collected sediments were computed to presume their size characteristics and physical properties. The grain size distribution study of the sediments was carried out by sieving according to ASTM-D2487 Standards. Mechanical sieve shaker was used with set of sieves (3.35mm, 2mm, 1.2mm, 0.6mm, 0.42mm, 0.3mm, 0.25mm, 0.15mm, 0.09mm, 0.06mm). The grain size distribution curves were prepared by plotting the grain size (mm) versus % finer (Fig.4).

The effective grain sizes (D_{10} and D_{50}) and other important percentiles of the sediments were calculated (Fig.5a). The uniformity coefficient (C_u), coefficient of curvatures (C_c) and sorting coefficients (S_o) were determined from the particle size distribution curves (PSD) by using equations:

$$\text{Coefficient of uniformity } (C_u) = D_{60}/D_{10} \quad (2)$$

$$\text{Coefficient of curvature } (C_c) = D_{30}{}^2/D_{10}*D_{60} \quad (3)$$

$$\text{Sorting coefficient } (S_o) = (D_{75}/D_{25})^{1/2} \quad (4)$$

where, D_{10}, D_{25}, D_{30}, D_{60}, and D_{75} signifies the percent finer than 10%, 25%, 30% , 60% and 75% respectively. Besides this the compositional analysis was presented in terms of gravel, sand, silt and clay (Fig.5b). In support to the above grain size parameters the petrographic study of the sediments' samples has also been performed under the optical microscope with 10X resolution (Fig.6a). The different mineralogical constituents were presented in ternary diagrams for understanding the sources of the sediments and weathering status (Fig.6b)

In spite of size analysis, the estimation of liquid and plastic limits (Atterberg's limits) of the sediments from such high mountainous regions is a significant parameter to evaluate the stability of the sediments (soils) sequences at different slopes. The more plastic a soil shows the higher compressibility and shrinkage-swell potential, and the lower permeability (Abramson, 1996). The frontier between each state (solid, liquid and plastic) is defined in view of change in the sediment's (soil) behavior. The sediments with high values of the plasticity index are triggering more engineering problems associated with the sediment (soil) such as foundation support for residential building and road sub-grades (Bowles, 1992). The plasticity of the sediments (soils) collected from the valley was computed in accordance to Unified Soil Classification System (USCS). The Atterberg's limits of the silty and silty-clays sediments from Nubra Valleys were determined by using standard Casagrande apparatus (as per IS: 2720 and ASTM-D4318 Standards). The liquid limit (LL) was calculated by counting the number

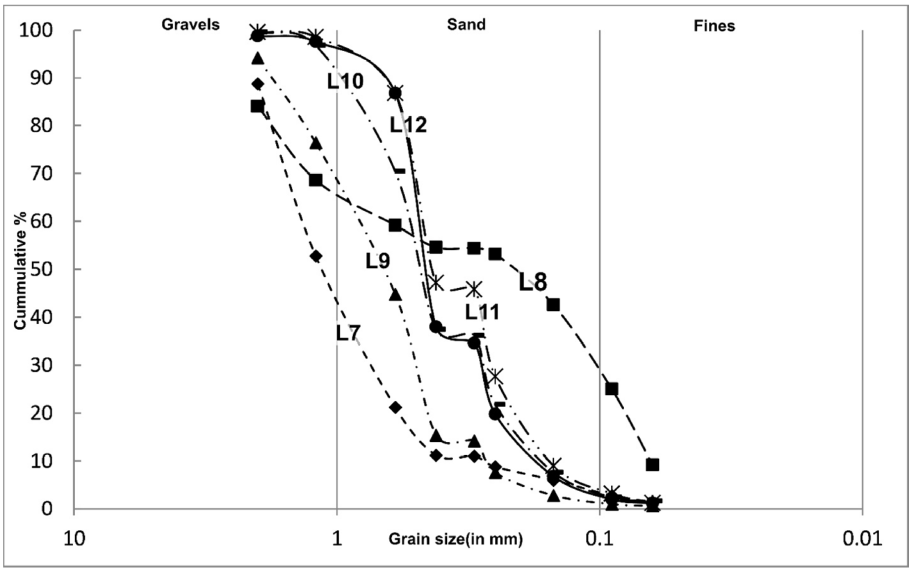

Fig.4. Particle size distribution curves (PSD) of sediments (L7, L8 of NS1; L9, L10 of NS2 and L11, L12 of NS3 showing bimodal pattern.

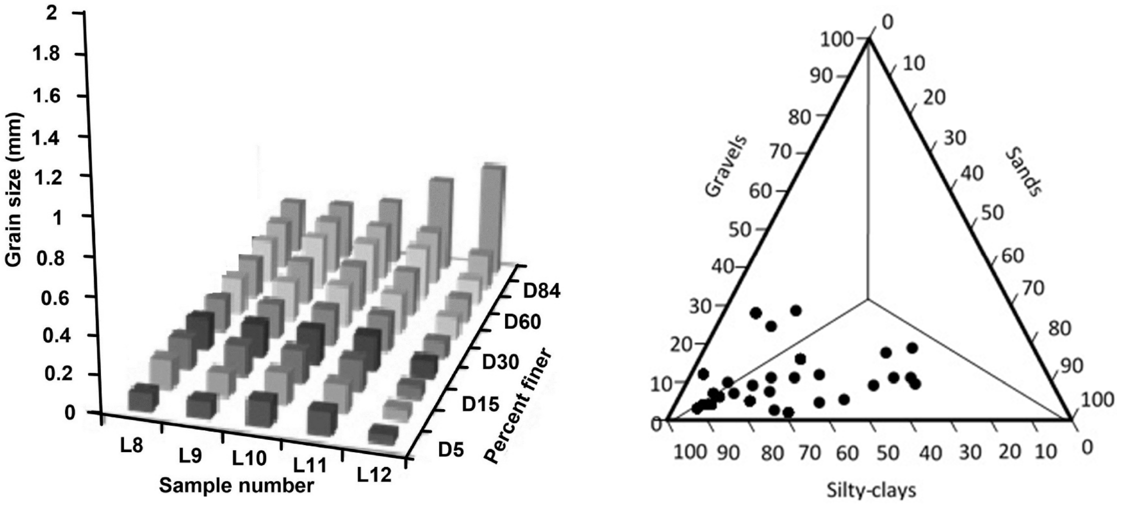

Fig.5. (a) Effective grain size plot of sediments from the Nubra Valley (Ladakh). **(b)** Distribution of sediments in GSSc ternary diagram.

of blows (N) to close the 0.5 inch groove at different water contents (%) by using Casagrande standard apparatus (Fig.7).

The plastic limit (PL) of the sediments samples was calculated by rolling the silty-clays into ~3mm diameter thread until the thread failed by crumbling (Equation 5):

$$\text{Plastic Limit, PL} = (W_2\text{-}W_3/W_3\text{-}W_1)*100 \quad (5)$$

where, W_1 is the mass of the can, W_2 is mass of can plus moist sediment (soil) and W_3 is mass of can plus dry sediment (soil).

Similarly, the plasticity index (PI) and Liquidity Index (LI) were determined by using Equations 6 &7:

$$\text{Plasticity Index (PI)} = \text{LL-PL} \quad (6)$$

$$\text{Liquidity Index (LI)} = (\text{W-PL})/(\text{LL-PL}) \quad (7)$$

where, W is the water (%).

The specific gravity of the sediments shows their relative density as compared to water. The specific gravity (G_S) was determined in 50 ml density bottle as per Equation 8:

$$G_S = W_2\text{-}W_1/(W_4\text{-}W_1) - (W_3\text{-}W_2) \quad (8)$$

where, W_1 is the weight of the empty bottle in g, W_2 is the weight of bottle plus dry sediment (soil) in g, W_3 is the weight of bottle plus sediment (soil) plus water in g and W_4 is the weight of the bottle plus water in g(gram).

The average specific gravity of the samples ranges between 2.6-2.82 (coarse sands-silty clays) (Fig.8). The slight decrease in specific gravity is also observed in the sediments of the Nubra Valley may be due to the presence of clasts.

The void ratios (0.32-0.81), porosities (24.41-44.89%), bulk densities (1.67-1.78 g/cc) and dry densities (1.52-1.59 g/cc) of the sediments were determined by using standard apparatus.

Besides these, the shear strength of sediments (soils) of mixed facies settings is an important parameter that lead to the classification of the condition of a sediment (soil) entity that assist the engineers in drawing critical inferences about the overall soil mechanics and sedimentations (Coduto, 2001). The shear strength properties of the samples were assessed by using direct shear apparatus and software by HEICO hydraulic and engineering (as per IS 2720 part XIII).

The total loading capacity of the instrumental system is 8 kg/cm^2 provided with standard 60 mm shear box assembly. The set of weights to give a normal stress up to 3 kg/cm^2 on the sample through lever is provided as standard. The three-channel microprocessor based signal conditioning unit is the three-function system. The functions are load, horizontal displacement and vertical displacement directly indicated in their particular engineering units. The system receives the output signal from the sensors i.e. load-cell and displacement sensors. It contains of the power supply, signal conditioning cards and processing card. The signal conditioning card amplifies the signal of each sensor

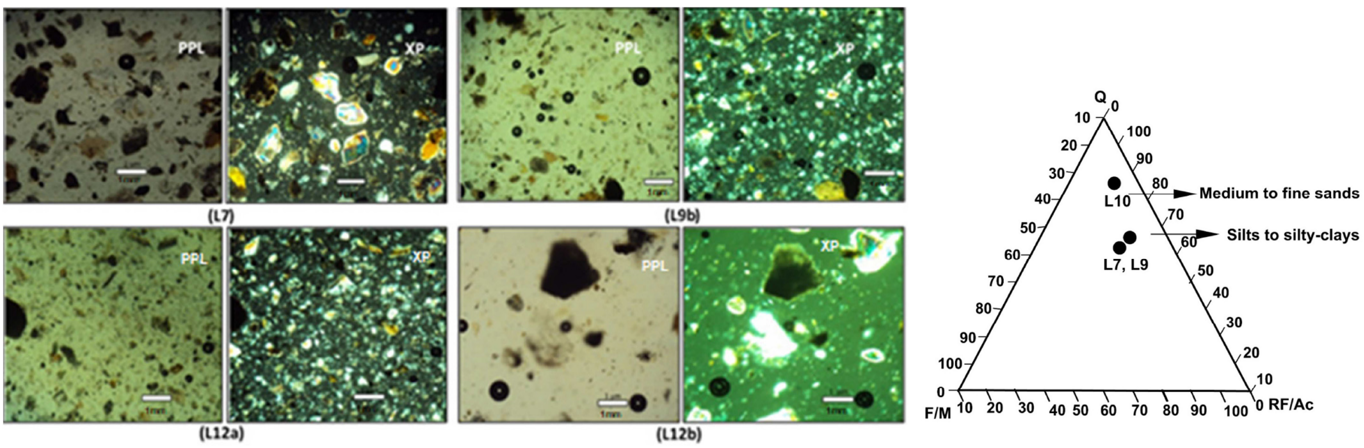

Fig.6. (a) Photomicrographs show epiclastic (L7, L9b (NS1), L12a, L12b (NS2)) texture of sediments collected from the Nubra Valley (Where, PPL is in plane polarized light and XP is in cross-polar view). **(b)** Representative compositional plot showing the dominance of Quartz in thin sections followed by Feldspar-Micas and Rock fragments/Accessories (where Q = Quartz, F/M is Feldspar/Micas and RF/Ac is Rock fragments and Accessories).

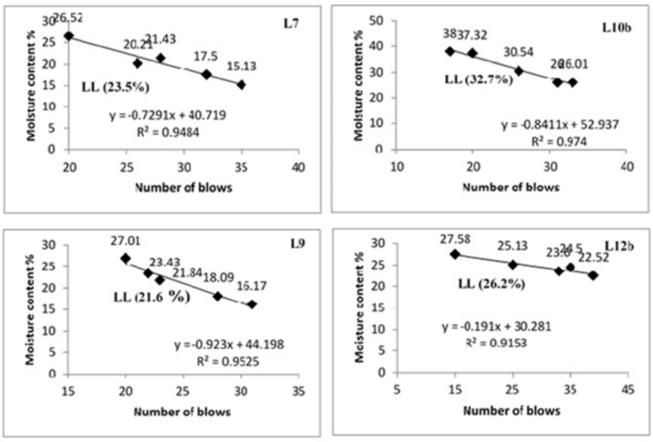

Fig.7. Liquid limits of silts and silty-clay samples (L7, L9, L10b, and L12b L14) of the Nubra Valleys (Ladakh).

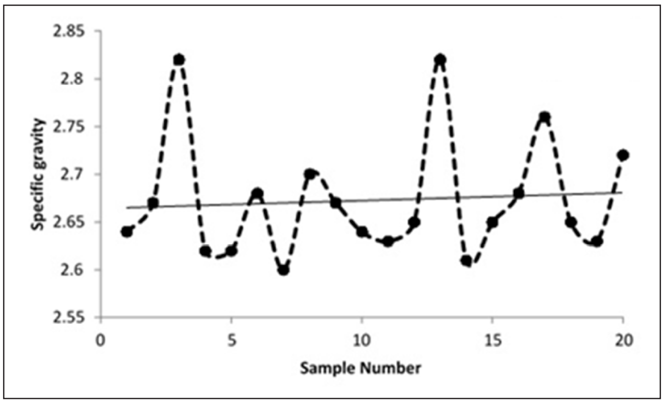

Fig.8. Specific gravity (G_S) plots of sediments of the valley.

and transfers it to processing card. The processing card consists of a micro-controller that stores the reading of each sensor and finally allocate it to computer. Direct shear experimentations were performed by using three different normal loads of 0.65, 1.15, 1.65 kg/sq.cm to determine the shear force. The shear-displacement curves for were drawn for each samples. The majority of samples (loose sandy type) attained the peak values before failure and some samples (dense silty type) exhibited instantaneous failure in shear box (Fig.9 a & b). The medium to coarse sand samples showed the higher undrained shear strength (110-130 kPa), while as silty-clay show the lower strength (25-50 kPa) and silts show the intermediate strength (50-85 kPa) when converting the shear values from kg/sq.cm to kPa. Further, the C (cohesion) and φ (angle of internal friction/obliquity) values were calculated to understand the shear deformation behaviour of sediments (Fig.10).

In addition to experimental deformation, Mohr's principle elemental analysis was chosen for determination of magnitude of stresses and strains on specific planes that leads to failure of the sample using MDSolids 4.0 software. These computations have been accomplished by using stress and strain transformation equations by approving Mohr's circle (Roylance, 2011; Hooke and Hansen, 2013). The principal stresses/strains and maximum in-plane shear stress/shear strains along their orientations were plotted for each samples with calculations of their plain stress/plain strain parameters (Fig.11). The center and radius of the circle in terms of stress was determined by locating the average normal stress using the equations 9&10:

$$C= (\sigma x + \sigma y) / 2 \tag{9}$$

$$R = \sqrt{\left\{\frac{\sigma_x - \sigma_y}{2}\right\}^2 + \tau_{xy}^2} \tag{10}$$

where, C is the center of the circle and R is the radius.

In case of strain transformation the equations are written in terms of e and g. The primary difference in a Mohr's circle for strain is that the vertical axis is the scaled as the shear strain divided by 2. Mohr's circle is made in terms of e axis (in the horizontal direction or abscissa) and g/2 axis (in the vertical direction or ordinate) rather than the normal x and y directions. Therefore, the 'C' and 'R' in terms of shear stress calculated by using the following equations 11 & 12.

$$C = (\varepsilon_x + \varepsilon_y) / 2 \tag{11}$$

$$R = \sqrt{\left\{\frac{\epsilon_x - \epsilon_y}{2}\right\}^2 + \left\{\frac{\gamma_{xy}}{2}\right\}^2} \tag{12}$$

In Mohr's circle the shear stress (τ) above the σ axis rotates the stress element in clockwise direction and plot 'τ' below the 'σ' axis rotates the stress element anticlockwise. Hence, the Mohr's circle is constructed in terms of σ and τ axis. The angles measured in the Mohr's circle are twice as large as the corresponding angles in the x-y coordinate. The principal stress (σp_1) is the most positive normal stress, and (σp_2) is the most negative normal stress and the principal

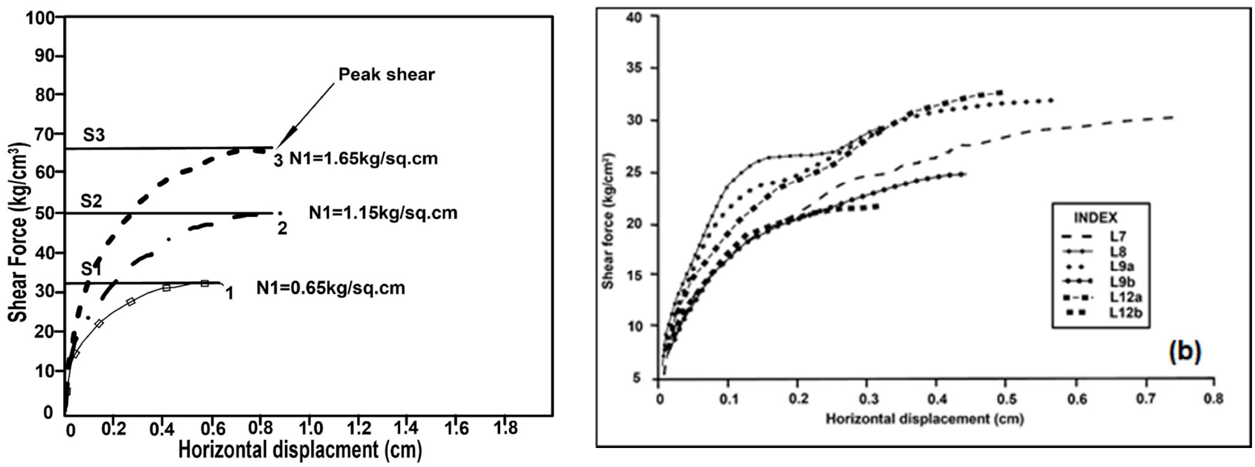

Fig.9. (a) showing shear-displacement curves of one of the ideal sample at three different normal loads. **(b)** Shear-displacement curves of various samples at N1, where the maximum samples (loose sandy type) attain the peak values before failure while other samples (silty-clayey type) show uniform behavior.

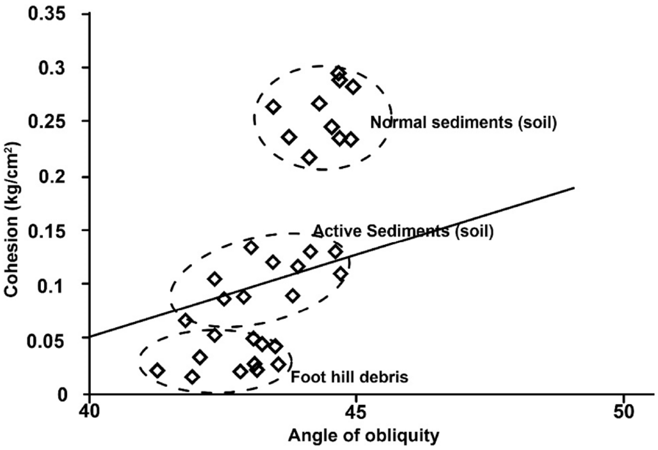

Fig.10. Cohesion values distribution and angle of obliquity of three kinds of sediments of the Nubra Valley (Ladakh), India.

strain (εp_1) is the most positive normal strain, and (εp_2) is the most negative normal strain (Table 2). From inspection, the extreme normal and shear stresses arise at the two points where the circle crosses the σ and ε axis as per Equations 13-14:

$\sigma p_1 = C + R$ (In terms of stress) (13a)

$\sigma p_2 = C - R$ (13b)

$\varepsilon p_1 = C + R$ (In terms of strain) (14a)

$\varepsilon p_2 = C - R$ (14b)

RESULTS AND DISCUSSION

The grain size of sediments of the Nubra Valley ranges between 0.06 to 3.90 micro-meter (i.e., silts-gravels) (Fig.4). The grain size distribution curves show the gap gradations or bimodal distributions (L6, L7, L8 (NS1), L9, L10 (NS2) and L11, L12 (NS3) (Fig.4). The sediments exhibit the mean grain size of 0.6 mm, with standard deviation of 0.94 (poorly sorted), Kurtosis of 5.60 (leptokurtic) and Skewness of 2.31 (very coarse skewed). The effective grain sizes range between 0.15-0.4 mm (D_{10}) and 0.42-1.2 mm (D_{50}) (Fig.5a). The uniformity coefficients range between 1.84-5.0 with coefficient of curvatures of 0.5-0.61 and sorting coefficient of 1.12-1.69 and 1.12-1.69 (moderately sorted). The ternary plot of sediments of the Nubra Valley indicates the domination of silty-sand and silty gravel which is valid for the reverse situation also (Fig.5b).

The microscopic views of sediments show epiclastic nature with sub-angular to sub-rounded textures (L7, L8 (NS1), L9, L10 (NS2)) (Fig.6a). The proportion of quartz and clay minerals (allogenic type) constitute about 70-80% in polygenetic types with less abundance of feldspar, mica with higher matrix while in epigenetic types quartz makes about 90-95% with 10% of biotite and feldspars (Fig.6b). The sediments show the possible evidences of the processes involved in evolution and tentative chronology of the periglacially disturbed sequences in the Nubra Valley.

The strata associated with the base of the litho-successions (section NS2) of the Nubra Valley (Fig.3) strongly support the deposition of sediments in low-energy glacio-lacustrine environment. The deposition of lacustrine sediments is followed by the emplacement of coarser material, including sand and pebbles that show the evidences for a more proximal environment of deposition regarding the ice sheet or a new source of coarser sediments and clasts. In such mountainous region where the rain runoff and erosion rate are recognized as very high the rock fragments/clasts of various sizes may accumulate with sand and silts/clay (soil) in the lower regions in the form of alluvial fans (NS2, NS3) (Fig.3). Based on these observations it is inferred that the

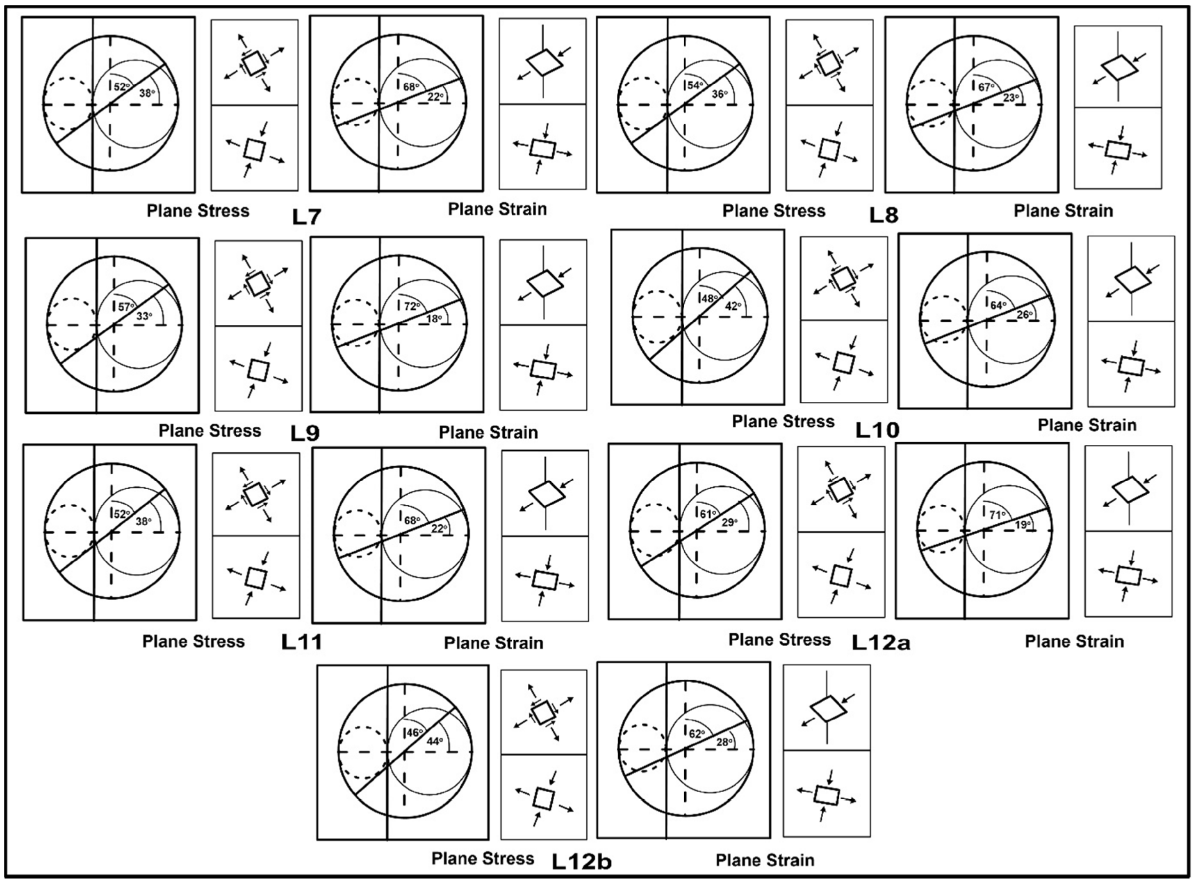

Fig.11. Stress and strain estimations by Mohr's element empirical relation for the sediments of the Nubra River Valley (Ladakh), India.

Table 2. Plain stress-strain values of sediment samples (L7, L8, L9, L10, L11, L12a and L12b) of the Nubra Valley (Ladakh), India (Note : tension is denoted in terms of stress and elongation in terms of strain)

Sample	Plain stress Parameters	Plain strain Parameters
L7	σ_n = 18.0 kPa Tension (+) σ_t = 18.8 kPa Tension (+) τ_{nt} = 68.5 kPa CW on n face (-)	ε_n = 18.223090 mm/mm Elongation (+) ε_t = 18.566910 mm/mm Elongation (+) γ_{nt} = 117.557157 rad CW from n axis (-)
L8	σ_n = 16.7 kPa Tension (+) σ_t = 16.1 kPa Tension (+) τ_{nt} = 63.2 kPa CW on n face (-)	ε_n = 16.559298 mm/mm Elongation (+) ε_t = 16.300702 mm/mm Elongation (+) γ_{nt} = 106.217475 rad CW from n axis (-)
L9	σ_n = 16.1 kPa Tension (+) σ_t = 16.8 kPa Tension (+) τ_{nt} = 62.0 kPa CW on n face (-)	ε_n = 16.537976 mm/mm Elongation (+) ε_t = 16.322024 mm/mm Elongation (+) γ_{nt} = 105.510577 rad CW from n axis (-)
L10	σ_n = 17.4 kPa Tension (+) σ_t = 16.9 kPa Tension (+) τ_{nt} = 62.7 kPa CW on n face (-)	ε_n = 17.047898 mm/mm Elongation (+) ε_t = 17.282102 mm/mm Elongation (+) γ_{nt} = 109.004997 rad CW from n axis (-)
L11	σ_n = 16.2 kPa Tension (+) σ_t = 17.2 kPa Tension (+) τ_{nt} = 65.7 kPa CW on n face (-)	ε_n = 16.596161 mm/mm Elongation (+) ε_t = 16.753839 mm/mm Elongation (+) γ_{nt} = 108.757286 rad CW from n axis (-)
L12a	σ_n = 17.2 kPa Tension (+) σ_t = 16.2 kPa Tension (+) τ_{nt} = 59.3 kPa CW on n face (-)	ε_n = 16.959468 mm/mm Elongation (+) ε_t = 16.390532 mm/mm Elongation (+) γ_{nt} = 105.013937 rad CW from n axis (-)
L12b	σ_n = 16.8 kPa Tension (+) σ_t = 18.0 kPa Tension (+) τ_{nt} = 69.7 kPa CW on n face (-)	ε_n = 17.562556 mm/mm Elongation (+) ε_t = 17.267444 mm/mm Elongation (+) γ_{nt} = 114.225260 rad CW from n axis (-)

Quaternary sediments of this region were derived from multiple sources with contrary geomechanical and geotechnical properties. The sorting characteristics of the sediments pronouncedly affect the catastrophic conditions in this kind of high altitude region such as floods, cyclones and mass flows. The presence of clay-sized and silt-sized particles in spaces between coarse components covering them with coatings (Gefuric distribution pattern) is due to the fine particles travelling with the help of water after thawing of the ground ice. The fine particle coatings on the sand-sized components (L9b, L12b of NS2 and NS3) show the possible evidence of mass movement in these areas. The similar evidences have also been reported by Harris and Ellis (1980).

The liquid limit (LL) of sediments (L7 (NS1), L9, L10b (NS2), L12b and L14 (NS3) shows the LL in range of 21.6-38.4% (Fig.7). The 'LL' values show the average values ranging between 17-40% and falls in the transitional boundary of silts (M) and clays (C) on the plasticity chart (Fig.12).

In general, the sediments (soils) have been classified in 'ML' and 'CL' type as per USCS (inorganic silts and clays of low to medium plasticity with low compressibility and quick dilatancy). The plastic limit (PL) of sediments ranges from 14.21% to 21.73% with plasticity index (PI) of 3.68% to 21.17% (low to medium plasticity) and liquidity index (LI) of 0.16-0.94%. (Fig.12). Similar type of sediment (soil)

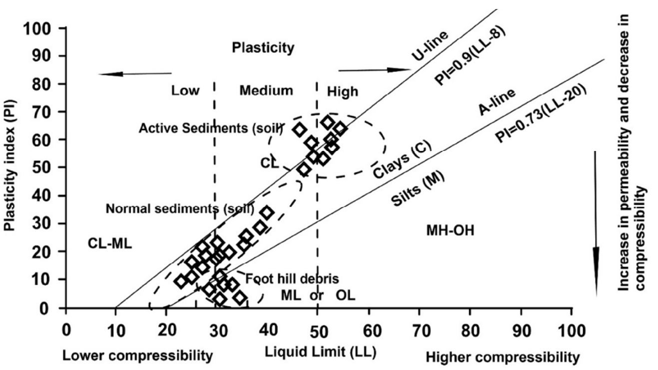

Fig.12. Plasticity chart (where most of the samples fall in three fields which shows low to medium plasticity side with lower compressibility).

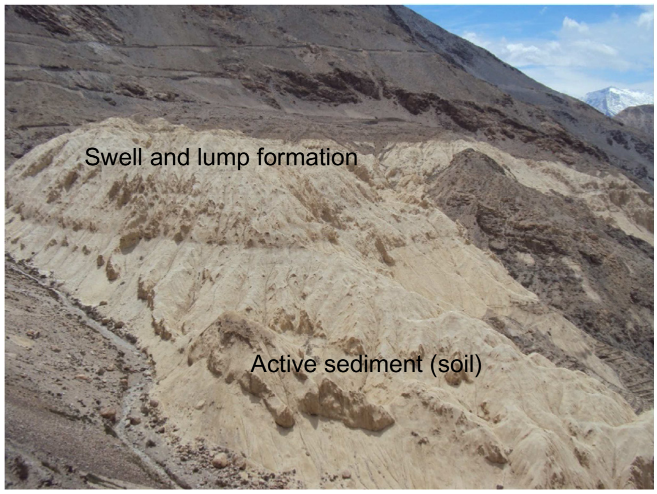

Fig.13. Shows normally active sediments (soils) observed in the upper sections of the Nubra Valley (Section-NS1) with higher potential of swell and lump formation (not feasible for engineering purposes).

properties is also observed for the sediments (soils) of the Venezuela which belongs to the Kaolin Group (Nassima, 2005). The sediment's samples of some locations of the valley (NS1) have also exhibited the higher LL (41%) and plastic limit (29.3%) values which reveal the higher potential of swell and lump formation and are considered as active sediment (0.75-1.0 activity) with swelling potential of 3-5% (Figs.12-13). The number of field evidences of swell and lump are in support of the experimental outcome (Fig. 13)

The majority of the sediment's samples (medium to course sands) show very low cohesion values (0.02-0.1 kg/sq.cm) with higher internal friction angle (46^0-49^0) (may be due to angularity of the grains) (Zelasko, et al., 1975) and recognized as foot-hill debris while as the medium to fine sands with silts show low cohesion of 0.1-0.15 kg/sq.cm with slightly lower internal friction angles (42^0-45^0) and recognized as active sediment (soil). The silty-clays show the maximum cohesion values of 0.22-0.3 kg/sq.cm with low internal friction angles of 36^0-43^0 and designated as normal sediments (soils) (Fig.10).

The increase in fine content of the samples results in the decrease of angle of internal friction and increase in shear strength (Teuten, 2012). The modulus of elasticity of the samples shows the coarse sands with silts attaining the peak shear at 120-125 kg with instantaneous failure (elastic behavior) due to filling of silts gains in voids formed by sand grains compaction, and fine sands and silts fail at greater stress values of 80-130 kg (elasto-plastic behavior) and in silty-clays the sample fails gradually at 75-110 kg after attaining the ultimate strength (plastic behavior) (Fig.9b). These observations are partially deviates from the general rules related to strength of the materials, however, in the case of the other factors such as liquid limit and plastic limits along with strength of constituents grains and their arrangements may responsible for such kinds of experimental observations. In view of the peculiarities of results related to strengths in association with other geotechnical parameters such as LL, PL, and PI etc. suggest that the overall geotechnical response of sediments may be a function of index properties and rheology of the sediments (soils) of the area.

From Mohr's principle element assumptions, the determined maximum tensile stress (σ_1) in case of the sediment's samples of the Nubra Valley (L7, L8, L9, L10, L11, L12a and L12b) ranges from 76.0 to 87.1 kPa with minimum tensile stress (σ_2) of -42.7 to -52.3 kPa. The maximum principle strain (ε_1) of the samples vary between 69.18 to 77.17 mm/mm with minimum principle strain (ε_2) of -35.83 to -40.38 mm/mm. The angles of the stress (from x to σp_1, 2θ) vary approximately from 32^0 to 44^0 and angle of strain approximately varies

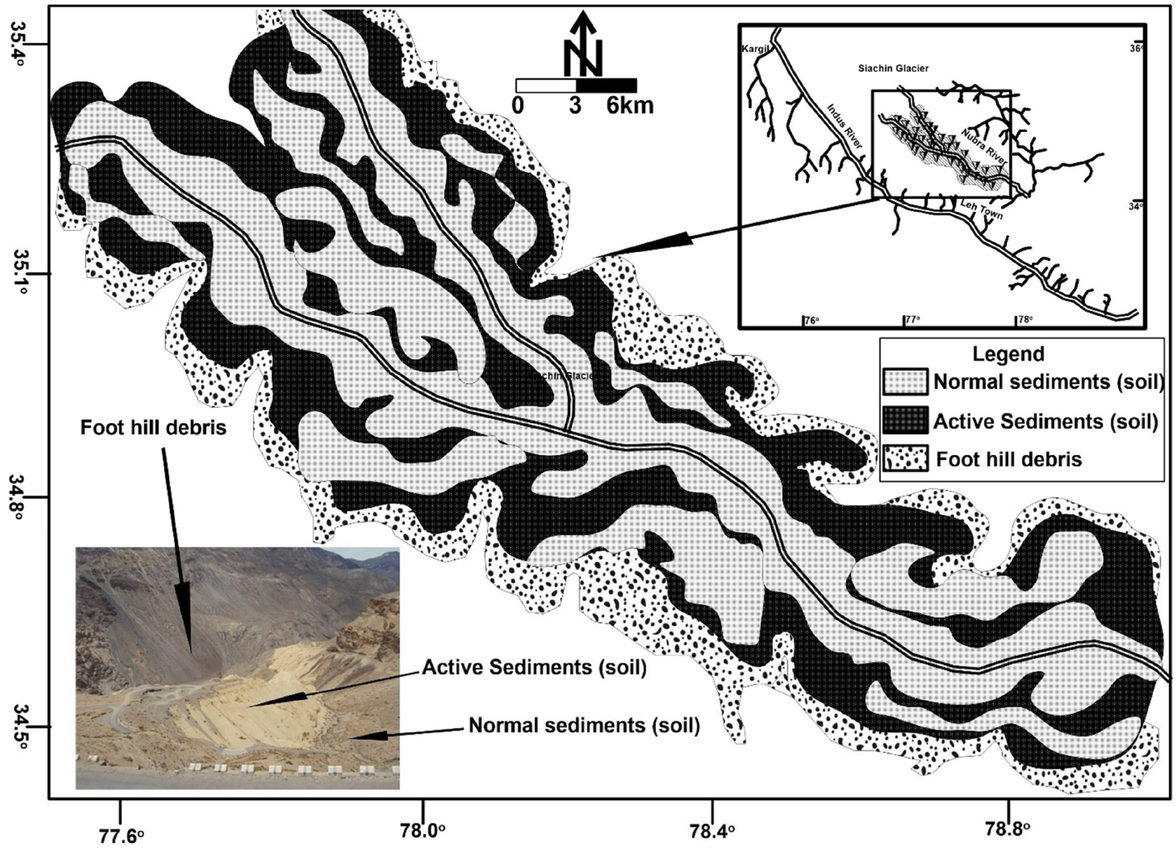

Fig.14. The distribution of foot-hill debris, normal sediment (soil) and active sediment (soil).

from 19^0 to 28^0. The angle of maximum shear element (τ_{max}) (from x to $\tau_{Abs\ max}$) varies from 62^0-72^0 (Fig.11) (Table 2).

The sediments of the valley show poorly graded nature and variable shear strengths. Mohr's principle element computations also supports the results by showing the higher values of maximum and minimum principle stresses, principle strains, angle of stresses and strains in this case of sediment sequences.

In view above results, the sediments (soils) of the area are categorized in normal and active and foot-hill debris zones (Fig. 14). The normal sediments (soils) sequences are more than the sequences made up active sediments. It is mainly distributed along and close to the rivers channel valley and contributed to the area approximately 58% of the total area exposed and appears to formed by dominantly river and running water (Fig14). The sequences containing active sediment are lying just at the extremities of sequences of normal sediment but in irregular and erratic patterns. The textural attributes, LL, PL and cohesions of such sediments suggest that the sequences of active sediments are formed by fluvio-glacial agencies. The constituents present in this type of sediments are more sensitive to freezing and thawing actions. The sequences of the active sediments are contributing approximately 27% of the area. The strata of active sediments are found more prone to swelling and lump forming activities and show problems of slides, subsidence and foundation settlements active sediments. The layers of sediments deposited near the foot of hills by the gravitational forces are having move voids and heterogeneous in natures and is designated as foot-hill debris. This kind of sequence of sediments is more prone to mass wasting. This debris is contributing approximately 15% of the total area and laying away from river channel after active sediment's sequences.

CONCLUSION

The Quaternary sediment's sequences in the Nubra Valley (Shyoke-Nubra Rivers valleys), Ladakh (high altitude region of Himalaya) are dissected by gullies, swelled strata and lumps and slope-slide and mass wasting and erosional features thus more susceptible to natural instability hazards and formation of cold desert and wasteland. The geotechnical characterization of such sediments showed the distinct change in their physical and mechanical properties due to dissimilarities in their constituents and surrounding conditions (related to pronounced fluctuations in temperature conditions). In view of physical and geotechnical evaluation of results, the sediments sequences of the valley are classified into three zones namely normal sediments (soil) sequences, foot-hill debris and active sediments (soil). The sequences consisting of foot-hill debris and active sediments (soils) seem to be more susceptible to the future natural hazards due to higher voids ratio, higher values of LL and PL, and lower shear strengths, cohesion and other strength related parameters as compared to other kinds of sediments zones (normal sediments-soils) of the valley. The wide temperature fluctuations induced freezing and thawing action on some silt and sand dominating sequences (as active sediments) are the principle cause recognized for intricate and delicate instability and desertification hazards. Therefore, based on these derived assumptions the presented geotechnical database may be helpful in assisting the engineers and planners for future development in the high altitude mountainous regions of Nubra Valley (Ladakh), Inadia as well as similar regions.

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References

Abramson, L.W., Lee, J.S., Sharma, S., Boyce, G.M. (1996) Slope Stability and Stabilization Methods. John Wiley and Sons, Inc., New York, pp.620-629.

Al-Imam, O.A.O., Elzien, S.M., Mohammed, A.A., Hussein, A.A., Kheiralla, K.M. and Mustafa, A.A. (2013) Geotechnical Properties of Mixed Marine Sediments on Continental Shelf, Port Sudan, Red Sea, Sudan. Amer. Jour. Engg. Res., v.3, pp.68-79.

Bowles, J.E. (1992) Engineering properties of soils and their measurement", 4th ed., McGraw-Hill, Inc., USA. pp.241-256.

Coduto, D.P. (2001) Foundation Design: Principles and Practices, Second Edition. Prentice-Hall, Inc. pp.79-96.

Dar, J.A., Dubey, R.K. (2013) Desertification of Trans-Himalayan Glacial Valleys- An Indicator of Climatic Fluctuation and Instability. Proc of environ imp and manag in mining and mineral based industries. IIT-BHU, India. pp.41-50.

Dietze, E., Maussion, F., Ahlborn, M., Diekmann, B., Hartmann, K., Henkel, K., Kasper, T., Lockot, G., Opitz, S. and Haberzettl, T. (2014) Sediment transport processes across the Tibetan Plateau inferred from robust grain-size end members in lake sediments. Climate of the Past, v.10, pp.91–106.

Gansser, A. (1977) The great suture zone between Himalaya and Tibet, a preliminary account. Sc de la Terre Him, CNRS. v.268, pp.181–192.

Harris, C. and Ellis, S. (1980) Micromorphology of soil in soliflucted materials, Okstindan, Northern Norway. Geoderma, v.23, pp.11-29.

Hooke, R. and Hansen, J.B. (2013) Notes on the Stress Analysis, Strain Analysis, and Shearing of Soils in the Engineering of Foundations. Dan Geotec Inst. Bull, 28, Copenhagen. pp.113-176.

Johnston, G.H. (1981) Permafrost, engineering design and construction. Nat Res Coun of Canada, John Wiley & Sons, pp.483-498.

Klemperer, S.L., Kennedy, B.M., Sastry, S.R., Makovsky, Y., Harinarayana, T., Leech, M.L. (2013) Mantle fluids in the Karakoram fault: Helium isotope evidence. Earth Planet. Sci. Lett., v.366, pp.59–70.

Kumar, A., Verma, A., Dobhal, D.P., Mehta, M., Kesarwani, K. (2014) Climatic control on extreme sediment transfer from Dokriani Glacier during monsoon, Garhwal Himalaya (India). Jour Earth Sys Sci. v.123, pp.109–120.

Lukanu, G. and Savage, M.I. (2006) Performance of the theta probe ML2 in the presence of non-uniform soil water profiles. HighLand 2006: Land Degradation and Soil and Water Conservation in Tropical Highlands, Mekelle, Ethiopia. pp.14-36.

Mallo, S.J., Akuboh, I.N. (2012) Geotechnical Investigation of soils: A Case Study of Gombe Town (Sheet 152NW), North Eastern Nigeria. Internat. Jour. Mod. Engg. Res., v.2, pp.4280-4286.

Moh, Z.C. (1984) Site investigation, a paper presented in seminar on Design and construction of roads in mountainous terrain in Malaysia, Jabatan Kerja Raya. Penin Malaysia. v.1, pp.233-236.

Murugan, M.P., Raj, J.X., Kumar, P.G., Gupta, S., Sigh, S.B. (2010) Phytofoods of Nubra valley, Ladakh- The cold desert. Indian Jour. Trad. Knowledge, v.9, pp.303-308.

Nassima, A. (2005) Development of pull apart basins and associated structures by the Riedel shear mechanism: insight from scaled clay analogue models. Ph.D. Thesis submitted to the Ruhr-university of Bochum, Germany. pp.17-29.

Pant, R.K., Phadtare, N.R., Chamyal, L.S., Juyal, N. (2005) Quaternary deposits in Ladakh and Karakoram Himalaya: A treasure trove of the palaeoclimate records. Curr. Sci., v.88, pp.1789-1798.

Phartiyal, B., Sharma, A., Nautiyal, C.M. (2010) Interpretation of the Apparent Ages in the Ladakh and Lahaul Spiti Quaternary Lacustrine Sediments. Geol. Proces. Climate Change, v.18, pp.1-10.

Rodgers, W.A., Panwar, H.S., Mathur, V.B. (2000) Wildlife Protected Area Network in India: A Review (Executive Summary). Wildlife Institute of India, Dehradun. pp.45-56.

Roylance, D. (2011) Notes on Transformation of Stresses and Strains. Department of Material Scicne and Engineering, Massachusetts Inst. of Tech Cambridge, MA 02139. pp.1-15.

Saini, H.S. (2013) An outline of the Late Quaternary Stratigraphy and Paleoclimate of Ladakh Region. J Geol Soc India. v.82, pp. 202.

Searle, M.P., Pickering, K.T., Cooper, D.J.W. (1990) Restoration and evolution of the intermontane Indus Molasse basin, Ladakh Himalaya, India. Tectonophys., v.174, pp.301-314.

Sinha, A.K., Upadhyay, R. (1997) Tectonics and sedimentation in the passive margin, trench, forearc and backarc areas of the Indus suture zone in Ladakh and Karakoram: a review. Geod .Acta. v.10, pp.1–12.

Teuten, J.M. (2012) Shear Characteristics of Soils with Varying Silt/Clay Fractions. 1st Civil and Environmental Engineering Student Conference, Imperial College London. v.25-26, pp.63-78.

Thakur, V.C., Mishra, D.K. (1984) Tectonic framework of the Indus and Shyok suture zones in eastern Ladakh, northwest Himalaya. Tectonophys. v.101, pp.207–220.

Upadhyay, R., Sinha, A.K., Chandra, R., Rai, H. (1999) Tectonic and magmatic evolution of the eastern Karakoram, India. Geod. Acta. v.12, pp.341-358.

Zelasko, J., Krizek, R.J., Edil, T.B. (1975) Shear Behavior of Sands as a Function of Grain Characteristics, Proceedings of the Istanbul Conference on Soil Mechanics and Foundation Engineering, Istanbul, Turkey, v.1, pp.55-64.

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