Understanding the Engineering Behavior of Soil from an Impact Crater, India

Channabasavaraj.W

Abstract— **Lonar crater is an impact crater created by a meteor impact during the Pleistocene Epoch. Due to this, a lake called Lonar Lake, was formed, which lies in a basalt impact structure and is both saline and alkaline in nature. Geologists, ecologists, archaeologists, naturalists, and astronomers have reported several studies on various aspects associated with the Crater Lake ecosystem. Studies in the past are mainly focused on understanding the magnetic and gravitational effect of the crater. In addition, few attempts have been made by researchers to understand the characteristics (viz., chemical and morphological) of these soils. The current study focuses on complete characterization of the soils includes Physical, Chemical, Mineralogical and Morphological characteristics which is quite prudent in comprehending the geological history and external effects (viz., magnetic and gravitational effect of meteor impact) on these soils. It has been observed that the soil from the Lonar Crater is non-plastic to slightly plastic with high rate of swelling; also there is a presence of a variety of heavy metals and minerals in the soil usually absent on the earth's surface.**

Keyword: Crater, Meteorite, Terrestrial analogue, Lonar lake, Characterization.

I. INTRODUCTION

Meteor impact craters like Barringer Crater in Arizona United States   and the Lonar Crater in Buldhana District of Maharashtra, India (refer to fig.1) are rare on Earth's surface [1], [2]. Approximately 52,000 years ago, a huge meteorite struck Lonar resulting in the formation one of the largest meteorite craters of about 1830 m in diameter and 150 m deep in the Basalt formation, which eventually created a lake that is both saline and alkaline in nature. A dense forest formed on the steep slopes of the crater. The two slopes within the crater are 15^0 to18^0 and 30^0 with respect to horizontal. The gentle slope (15^0 to$18^{0)}$ has a notch through which the Meteor first hit the ground. The opposite side of the slope is increased due to the pressure created by the Meteor and the notch was enveloped by the meteor debris [3]. The Lonar crater has been proved to be caused by an Aerolite Meteor (contains mainly rocky material) because no metal fragments have been found strewn around the crater.

The rocks at the depths of the lake have undergone shock metamorphism because of the impact. This in turn also produced high temperature and pressure as a result of which certain new minerals and glassy materials (due to molten rocks) are formed. It has been reported by researchers that, before the impact the meteor got fragmented in three

Channabasavaraj.W, Department of Civil Engineering, Don Bosco Institute of Technology (Affilated to VTU Belagavi), Bangalore, India,

pieces which has led to the formation of three lakes known as Lonar Lake, Ganesh Lake and Amber Lake. Incidentally, the Ganesh Lake and Amber Lake have dried up now.

Terrestrial analogue sites are places on earth with one or more geological or environmental conditions similar to those found on the Moon, Mars, or any other extraterrestrial body [4], [5a]. However, [6] explained that by studying the Moon, one could learn about the origins of all of the planets, including Earth, and of their moons. Many astronomers and geologists in early 20th century concluded that lunar craters are volcanic in origin and are not due to meteorite or comet impacts. More detailed comparative studies began to reinforce the idea that lunar craters, as well as many on Earth, were the result of meteorite or comet impacts [7], [6], [8].

However, later in the 20th century, many researchers have opined that the craters are formed impact of meteorite which travels through the atmosphere at a velocity (impact velocity) in the range of 11 km/s – 72 km/s [9]. Impact of such meteors can produce shock waves in solid materials and both impacter as well as material impacted gets compressed to high density and upon de-pressurization it explodes violently to produce the impact crater. The presence of rock that has undergone shock metamorphic effects such as shatter- cones, melted rocks and crystal deformations [10]. Shock metamorphic effects include a layer of shattered or breciated rocks under the floor of the crater [11]. Another mark of an impact crater is the presence of some elements like Ni, Pt, Ir, and Co which are not usually found in the Earth's interior [9]. The presence of Maskelnite i.e, glassy type material at the impact site is also one of the distinctive features of an impact crater.

II. EXPERIMENTAL INVESTIGATIONS

Sampling of Lonar crater was done all across the lake and three samples (disturbed samples) were collected from different location of lake (viz., LC-A, LC-B and LC-C). Details of various tests conducted on these soil samples, for establishing physical, chemical, mineralogical, morphological, thermal and geotechnical characteristics, are presented in the following sections.

Fig.1. Satellite image of the lonar lake.

III. PHYSICAL CHARACTERIZATION

A. Specific gravity

The specific gravity, Gs, of the sample was determined by using an Ultra Pycnometer, (Quantachrome, USA) which utilizes helium gas as the displacing fluid (as per the guidelines provided by [12]). For the sake of accuracy, the average specific gravity was obtained by conducting three tests. It was observed from the test results that the value of G lies between 2.7 to 3.0. Since the value of specific gravity is high it is assumed that there may be presence of heavy metals in the soil.

B. Gradational Characteristics

The particle-size distribution characteristics of the sample were determined by conducting the sieve analysis, as per [13], and results are presented in Fig.2 It was observed that the soils LC-A, LC-B and LC-C contain less amount of clay (varies between 1% to 15%) and these soils predominantly contain silt and sand, they are mostly classified as sandy silt to silty sand.
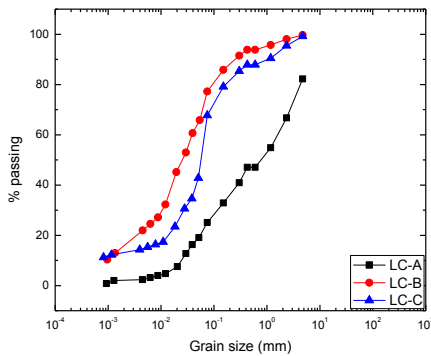

Fig.2. The particle size distribution characteristics of different samples.

C. Consistency Limit

Consistency limits (Liquid limit, WL, Plastic limit, WP) of the soils were determined according to the guidelines of [14]. It is observed that LC-A and LC-C soils are non-plastic in nature has these sample contains very less percentage of clay and LC-B exhibits higher percentage of clay and silt compared to LC-A and LC-C, the soil is plastic in nature.

Based on the consistency limits and the gradational characteristics the soils were classified as per the guidelines of Unified Classification System [15].

D. Specific Surface Area

The specific surface area, SSA, of the soils LC-A, LC-B and LC-C was determined by employing Ethylene Glycol Monoethyl Ether, EGME, method which has been recognized has a most appropriate method for determining the SSA [16] – [18] As per the guidelines, 2 g of air-dried soil sample was spread uniformly on the bottom of a glass Petri dish, which is 40mm in internal diameter, 2 mm thick and 20 mm height, and covered with a perforated watch-glass. Six such dishes (two for each sample), with soil samples in them, were placed in a vacuum desiccators, which contains 250 g of P_2O_5 for maintaining a constant vapour pressure. The sample was evacuated by applying vacuum (0.03 mbar) for 2 h, weighed and replaced in the desiccators, subsequently. This process was repeated several times until three consecutive weights of the dish were found to be almost same. Later, 6 ml of analytical grade EGME solution was added to the sample of each dish and mixture was swirled, gently, till it becomes slurry. The dishes were then placed in the desiccator over a desiccant (mixture of 100 g $CaCl_2$ and 20 ml EGME) for 12 h, which helps in maintaining constant conditions that are just sufficient to form a monolayer of EGME on soil surface. Subsequently, the slurry along with the glass dish was weighed using a precision balance and the dish was again replaced in the desiccator for evacuation under vacuum. The glass dishes were taken out of the desiccator, weighed and replaced in it at regular intervals, until the weight becomes steady in consecutive attempts. The amount of EGME (Wa, in g) that gets absorbed on per gram of the sample (Ws, in g), corresponding to this constant weight condition, was computed by subtracting the dry weight of the sample from the final weight of the EGME mixed sample. Consequently, by employing 'Eq. 1', SSA of the sample (in m2/g) was determined and the results are presented in Table 1. Since clay content is very less in these soils, SSA also found to be less and hence activity of these soils will be less (Inactive soils).

$$SSA = Wa (0.000286. Ws)-1 \qquad (1)$$

E. Free Swell Index

Free swell index, FSI, of the soils were determined according to guidelines of [20]. Where two 10 grams soil specimens were taken which is oven dry passing through 425-micron IS sieve. Each soil specimen shall be poured in each of the two glass graduated cylinders of 100ml capacity. One cylinder shall then be filled with kerosene oil and the other with distilled water up to the 100ml mark. After removal of entrapped air the soils in both the cylinders shall be allowed to settle. Sufficient time (not less than 24 hours) shall be allowed for the soil sample to attain equilibrium state of volume without any further change in the volume of the soils. The final volume of soils in each of the cylinders shall be read out. By employing 'Eq. 2', FSI of the sample (in m2/g) was determined and the results are presented in Table 1. It has been observed that the FSI for soils LC-A and LC-C are zero has these soils contains very less amount of fines (clay percentage) and soil LC-B exhibts Very high FSI has the soil particles are in suspension even after 24 hours.

Table :1. Physical Characterization

Designation	% Fraction			G	OC (%)	Atterberg Limits (%)			USCS	FSI	γ_d (kN/m3)	OMC (%)	SSA (m^2/g)
	Sand	Silt	Clay			LL	PL	PI					
LC-A	75	24	1	2.73	4.6	Non-plastic			Sandy silt	0	20.7	11.48	4.5
LC-B	23	63	14	2.50	7.8	46	17	29	Silty sand	492*	19.54	13.95	8.6
LC-C	32	56	12	2.98	8.9	Non-plastic			Silty sand	0	20.7	12.5	7.9

$$\text{Free swell index, percent} = \frac{V_d - V_k}{V_k} \times 100 \qquad (2)$$

Where: Vd is the final volume of soil in distilled water a nd Vk is the final volume of soil in kerosene

F. Compaction Characteristics

The compaction characteristics of the three soil samples (viz., LC-A, LC-B & LC-C) were established by employing a miniature compaction device developed by[19]. The apparatus consists of a cylindrical slit mould of 38 mm internal diameter, 76 mm in height and a plunger attached with a spring. With the help of this compactor, a compaction energy which is equivalent to that of standard compaction energy can be achieved. The results obtained from the compaction test (viz., optimum moisture content and maximum dry density) are listed in the Table.1. Also compaction curve for different soils are presented in fig. 3. It is observed from the results that the three soils exhibits very good range of MDD and OMC with respect to backfill material (for highways and any reclamation activities) and hence these soils are best suited for backfill purpose as for as strength criterian.
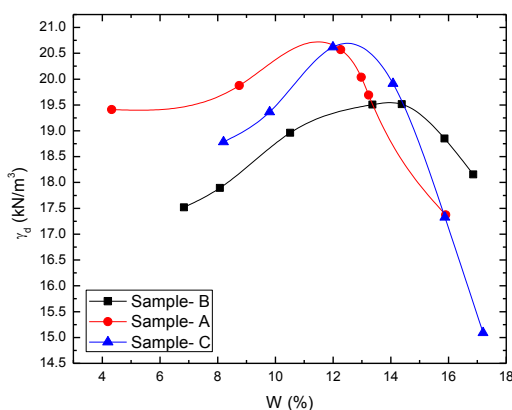

Fig.3. The compaction curve of different soils

IV. Chemical Characterization

A. X-ray fluorescence (XRF) analysis

Chemical composition of the sample, in its oxide form, was determined by employing an X-ray fluorescence instrument (Philips 1410, Holland). The sample was prepared by mixing thoroughly 4 g of the finely grounded soil and 1.0 g microcrystalline cellulose with isopropyl alcohol. The mixture was then kept below an infrared lamp for slow drying. A small aluminum dish (inner diameter 33mm and height 12mm) was taken and the two-third of the dish was filled with the mixture of 70% methyl-cellulose, the remaining with the dried sample. The sample thus obtained was subsequently compressed with the help of a hydraulic jack (by applying a 15 ton load) to form a pallet. Afterwards, the sample was mounted on the monochromatic sample holder of the XRF setup for determining its chemical composition and results are presented in Table.2. It is observed that in all the three soils silica content is predominating followed by aluminum and iron. However, earlier researchers, have reported that there is a presence of different kinds of heavy metals which are not usualy present in the soils on earth's surface. Hence, detailed qualitative analyses have been done on these samples using XRF and the following elements have been identified Ba, Rb, Sr, Pb, La, Pr, Ce, Nd, Sm, Gd, Ho, Tm, Y, Hf, Nb, Eu, Tb, Er, Yb, Lu, Th, U, Zr, Ta, Sc and V

B. pH, electrical conductivity and total dissolved solids

The pH of the sample was determined as per IS:2720 (Part XXVI)-1987, by using a digital pH meter (Elico Private Ltd. Make, Model L1-120). The pH was established corresponding to liquid to solid ratio, L/S, varying between 2 and 20. The pH meter was calibrated by using different standard buffer solutions (pH=4, 7 and 9.2) prior to each measurement. 30 g sample was mixed with distilled water and the resultant suspension was stirred thoroughly. The solution was allowed to stand for 1 hour and the stirring was done intermittently. The pH value of the solution was recorded corresponding to 20 °C at regular time intervals. The same instrument, with automatic temperature compensator (corresponding to 25 °C) was employed for measuring the electrical conductivity, EC, of the soil solution and total dissolved solids, TDS. The measured values can be considered as the background values of the sample. The results of pH, EC and TDS with different liquid to solid ratios (L/S), for different sediments, are presented in Table 3A. When the results of pH are plotted as depicted in Fig. 4, it can be noted that soil LC-B and LC-C are highly basic in nature (pH is more than 10) and variation of pH with L/S is minimum. However, the overall variation of pH with L/S is observed to be random. Furthermore, EC and TDS values of the soils LC-A, LC-B and LC-C are found to decrease with an increase with L/S, as depicted in Figs. 5 and fig. 6, respectively.

Table 2. Chemical composition of different soil samples by XRF

Designation	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	TiO_2	MgO	P_2O_5	K_2O	V_2O_5	MnO
LC-A	42.5	19.4	13.8	14.1	4.4	2.2	1.7	0.9	0.6	0.1	0.1
LC-B	41.0	17.2	14.3	10.6	10.5	2.4	2.0	0.7	0.8	0.1	0.1
LC-C	19.2	12.0	14.5	11.2	36.5	2.3	2.3	1.0	0.8	0.1	0.1

Table 3A.Chemical properties of the lonar soils

| Parameter	Designa-tion	L/S										
		2	3	4	5	6	7	8	9	10	15	20
pH	LC-A	7.87	7.62	7.45	7.41	7.74	7.6	7.56	7.53	7.43	7.4	8.2
	LC-B	10.42	10.64	10.61	10.42	10.67	10.73	10.55	10.45	10.49	10.47	9.8
	LC-C	10.34	10.45	10.53	10.54	10.59	10.66	10.67	10.74	10.77	10.81	10.7
σ (mS/cm)	LC-A	0.55	0.49	0.33	0.32	0.30	0.25	0.28	0.20	0.20	0.14	0.13
	LC-B	11.51	12.56	8.76	8.58	6.78	5.28	5.24	3.92	3.72	3.510	1.23
	LC-C	74.49	54.12	35.08	28.83	24.23	21.34	21.14	17.0	16.65	12.32	9.72
TDS (ppt)	LC-A	0.28	0.24	0.16	0.16	0.15	0.12	0.14	0.10	0.10	0.07	0.07
	LC-B	5.89	6.4	4.38	4.3	3.38	2.64	2.62	1.96	1.86	1.76	1.02
	LC-C	30.02	21.79	17.53	14.43	12.1	10.68	10.56	8.51	8.32	6.16	4.86
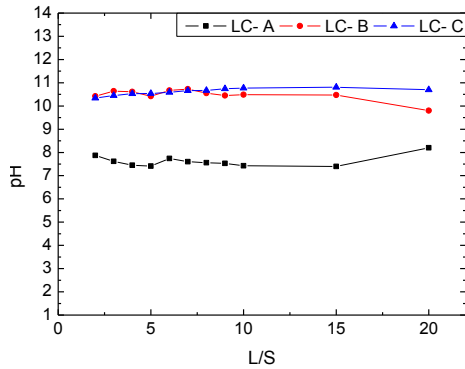
Fig.4. The variation of pH with liquid to solid ratio for different soils

Fig. 5. The variation of electrical conductivity with liquid to solid ratio for different soil
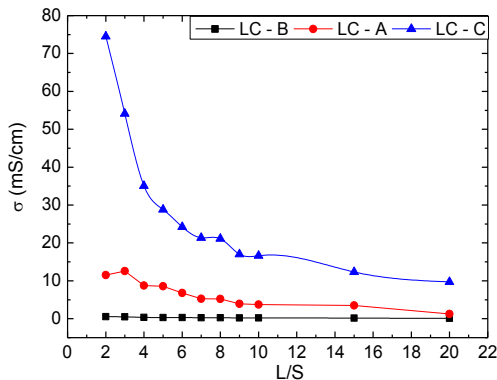

Fig.6. The variation of total dissolved solids with liquid to solid ratio for different soil

C. Lime reactivity

The affinity of a material towards Calcium, which indicates its activity, is called as lime reactivity, LR. Methods such as electrical conductivity, empirical equation on soluble silica are used to obtain the lime reactivity of any soil samples, as suggested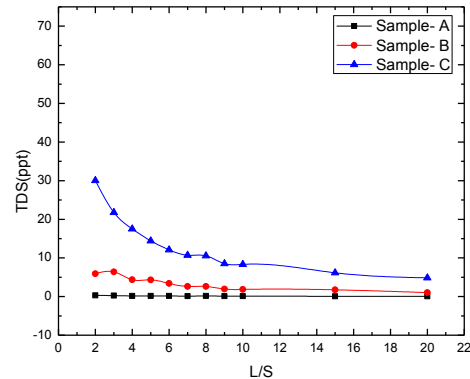 by the earlier researchers. As such, 125 mg Calcium hydroxide and 100 ml distilled water were mixed to make a solution and its electrical conductivity was obtained immediately (designated as EC1). Subsequently, a solution of L/S=50 was prepared by mixing the soil sample with the Calcium hydroxide solution, stirred for 30 minutes and the final electrical conductivity of the decanted solution (designated as EC2) was recorded. The difference between the two EC values (= ΔEC) when substituted in the following relationship, would yield the LR and the results are presented in Table. 3. It is known that higher the value of LR more will be the reactivity of the soils. From the results it is observed that all the three soils are exhibiting less values of LR has these soils contains very less amount of clay and also lower value SSA. Off the three soils LC-B has higher value of LR.

$$LR = 0.25 \cdot \left(\frac{\Delta EC}{EC_1}\right) - 2.5 \qquad (3)$$

Table. 3B Chemical properties of the lonar soils

Designation	CEC meq./ 100g	LR	Chloride (ppm)	Total Alkalinity (in ppm) as CaCO3	Total Hardness as CaCO3 (in ppm)	Calcium Hardness as CaCO3 (in ppm)	Nitrate (ppm)
LC-A	60	15	30	50	30	24	Nil
LC-B	76	27.5	100	60	25	14	20
LC-C	60	10	1000	600	45	34	100

The LR of the sample can also be obtained by employing the empirical relationship proposed by earlier resercher.wherein the amount of soluble silica, S can be obtained by using the procedure suggested by earlier resercher.

$$LR = \left(\frac{s}{1000}\right)^{0.85} \cdot \xi^{0.8} \tag{4}$$

where, S is the specific surface area and ξ is the percentage soluble silica.

D. Cation-exchange capacity

The capacity of a soil to hold cations is defined as cation exchange capacity (CEC). The ability of a soil to hold cations which cannot be removed even after leaching process is called cation exchange capacity. The test procedure is according to EPA 9081 guidelines. 1g of sample is taken in a plastic tube, of capacity 15 ml and mixed with 9 ml of sodium acetate solution and placed in a mechanical shaker for 15 minutes. Subsequently, this mixture was centrifuged at 4000 rpm and the supernatant is decanted. Fresh sodium acetate is added to the residues and the above mentioned procedure was repeated twice. Furthermore, 9 ml Isopropyl alcohol is added to the residues and the procedure of mixing and centrifuging is repeated for three times. Subsequently, 9 ml Ammonium acetate solution was added to the residues from the above steps and the mixture was centrifuged. This procedure is repeated twice and the decanted solution is collected in all the three trials. The solution from the three trials was mixed and analyzed by using a inductively coupled plasma (ICP-AES) unit for detection of the cations present. The CEC was obtained by employing the following relationship and the results are presented in Table.3B. It is well known that, clay content, SSA and CEC are directly related and for these soils Clay content and SSA are observed to be very less and hence CEC is also less

$$CEC = \left(\frac{\text{Concentration of } Ca^{2+}\left(\frac{\mu g}{ml}\right) \times 100 \times \text{Vol. of extract(ml)}}{\text{Equivalent weight of cation} \times 1000 \times \text{wt. of sample}}\right) \tag{5}$$

E. Fourier Transform Spectrometer (FTIR)

For the identification of the chemical bonds present in the soil samples, FTIR studies found to be quite useful. Spectrograph of the soils were captured by employing a Fourier Transform Infrared Spectrometer (Nicrom Instruments corporation, USA; Model: MAGNA 550; Range 500 cm-1 to 4000cm-1). A small quantity of sample in powder form (weighing 2 mg) mixed uniformly with KBr and

pallatised into a transparent disk by applying 3 T loading. Subsequently, the pallets were irradiated with the IR beam for complete range of wavenumbers, mentioned above, and the intensity of the IR radiation that has been absorbed and/or transmitted was recorded. The obtained spectra of the soils are presented in Fig. 7. It is observed from the spectra that the presence of silica bonding are more predominant in all the soils.
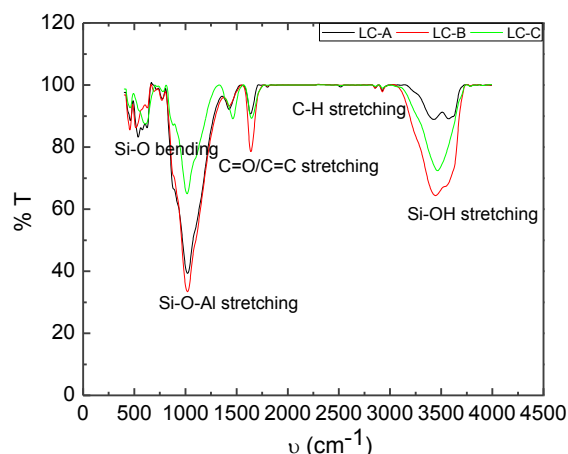

Fig. 7 FTIR spectra of the soils samples

V. MINERALOGICAL CHARACTERIZATION

A. X-ray diffraction (XRD) analysis

The mineralogical composition of the soil samples LC-A, LC-B and LC-C was determined by employing an X-ray diffraction (XRD) spectrometer (Philips 2404, Holland)which utilizes a graphite monochromator and Cu-Kαradiation. The samples were scanned from2θ ranging from5° to 120°. The presence of various minerals in the samples was identified with the help of the data files developed by the JCPDS (Joint Committee on Powder Diffraction Standards, 1994). It is observed from the X-ray diffractogram (refer to Fig.8.) that, there is a formation of certain new minerals such as D- Diopside (Calcium magnesium Aluminum Silicate); A- Anorthite, (Calcium Aluminium Silicate); L- Lemmerite (Copper Arsenate); H- Hardystonite (Calcium Zinc Silicate). The formatrion of new minerals may be resulted due to the high pressure and temperature induced during meteorite impact, rock get melted and turned into glassy minerals.

Fig. 8. X-ray diffractograms of different soil samples

VI. Morphological Characterization

In order to categorize the various surface features of the grains, scanning electron micrographs of the three different samples were obtained by employing Quanta make 200 ESEM. Observations were carried out on a representative sample of grains placed in a sample holder, coated with platinum to avoid charge effects and the images were captured at various magnifications, as shown in Fig. 9. It is observed from the images that the shape of the soil particles are irregular and these soil particles are found to have more porous in their structure. This may be due to meteorite has impacted the earth at very high velocity which build up the pressure and which made soil particles in different shapes. However, because of high pressure induced during impact the temperature has increased tremendously which has made the soil particle to more porous.

Fig. 9A. Scanning electron micrographs of the sample LC-A

Fig. 9B. Scanning electron micrographs of the sample LC-A

Fig. 9C. Scanning electron micrographs of the sample LC-B

Fig. 9D. Scanning electron micrographs of the sample LC-B

Fig. 9E. Scanning electron micrographs of the sample LC-C

Fig. 9F. Scanning electron micrographs of the sample LC-C

VII. CONCLUSIONS

The following conclusions are drawn from present study

- It has been observed that because of the meteorite impact the parent soil properties has got changed because of extensive pressure and temperature which has been produced during impact.
- The physical Characteristic of soil shows that these soils are predominantly sand and silt very less organic content and having good engineering properties (OMC and MDD). Hence these soils can be used for engineering applications (as backfill material).
- The chemical characterization of soil reviles that these soil contains heavy metals which are usually absent on the earth surface. Because of this reason if these soils are used for some engineering applications there may be long term durability problems.
- To justify the presence of heavy metals in the soil, mineralogical analysis has been carried out to know the mineral constituent in the soil. It has been observed that there is a presence of wide variety of minerals in the soil, which are not usually present in the soil.
- Also, Morphological analysis shows that these soils are having larger cavities inside the soil particle; this may be due to the impact of crater which induced high temperature and pressure.

VIII. REFERENCES

[1]. Hoyt W. G.: 1987, in Coon Mountain Controversies: Metor Crater and the. Development of impact theory, University of Arizona press.
[2]. Shoemaker, E. M., Middlehurst, B., and Kuiper, G.P., (1963). The solar System: The Moon, Meteorites, and Comets, Universe Chicago press, Chicago, vol.4, p, 3.
[3]. Naseer Iqbal, M.N Vahia, Tabasum Masood and Ajaz Ahmad (2008) A Probable Meteor Impact Crater in Kashmir Valley (India).
[4]. Osinski, G. R., Le´veille´, R., Berinstain, A., Lebeuf, M.,Bamsey, M. (2006).Terrestrial analogues to Mars and the moon: Canada'srole.Geoscience Canada 33(4), 175–188.
[5a].Le´veille´, R. J. (2010).Validation of astrobiology technologies and instrument operations interrestrial analogue environments. Comptes Rendus Palevol.
[5b].Le´veille´ Richard (2010) "A half-century of terrestrial analog studies: From craters on the Moon to searching for life on Mars". Planetary and space science, vol(58). 631-638.
[6]. Urey, H.C., (1952). The Planets, Their Origin and Development. Yale University Press, New Haven, CT, 245p.
[7]. Baldwin, R.B., (1949). The Face of the Moon. University of Chicago Press, Chicago, IL, 239p.
[8]. Kuiper, G.P., (1954). On the origin of the lunar surface features. Proceedings of the National Academy of Sciences 40 (12), 1096–1112.
[9]. Melosh,H. J,1989,impact catering:A geological process:New York, Oxford University Press,245p
[10]. Charles, A. (1978) Wood and Leif Anderson, New Morphometric data for Lunar Raters, , proceding 9th Lunar and Planet.
[11]. Bond J.W., (1981).The development of central peaks in lunar craters., Moon and Planets, vol.25.
[12]. ASTM D 5550-00 (2000), "Test method for specific gravity of soil solids by gas pycnometer", Annual Book of ASTM Standards, Vol. 04.08, ASTM International, West Conshohocken, PA, USA.
[13]. ASTM D 422-63 (1994), "Standard test method for particle size analysis of soils", Annual Book of ASTM Standards, Vol. 04.08, ASTM International, West Conshohocken, PA, USA.
[14]. ASTM D 4318-93 (1994), "Standard test method for liquid limit, plastic limit and plasticity index of soils", Annual Book of ASTM Standards, Vol. 04.08, ASTM International, West Conshohocken, PA, USA.
[15]. ASTM D 2487-93 (1994), "Standard classification of soils for engineering purposes (Unified Soil Classification System)", Annual Book of ASTM Standards, Vol. 04.08, ASTM International, West Conshohocken, PA, USA.
[16]. Carter, D.L., Mortland, M.M, and Kemper, W.D. (1986). "Specific Surface", Methods of Soil Analysis, American Society of Agronomy, USA.
[17]. Cerato A.B. and Lutenegger A.J. (2002). "Determination of surface area of fine grained soils by the ethylene glycol mono-ethyl ether (EGME) method", Geotechnical Testing Journal, ASTM, Vol. 25, No.3, pp: 1-7.
[18]. Arnepalli, S. Santhakumar, B. Hanumantharao and D.N. Singh (2008). "Comparison of methods for determining specific surface area of fine-grained soils", Geotechnical and Geological Engineering, Vol. 26, pp: 121-132.
[19]. Kolay, P.K. and Singh, D.N. (2001). "Physical, chemical, mineralogical and thermal properties of cenospheres from an ash lagoon", Cement and Concrete Research, Vol. 31, pp: 539-542.
[20]. IS: 2720. Part XXVI (1987). "Determination of pH value of soil samples", Indian Standards, methods of tests for soils.
[21]. JCPDS - Powder Diffraction File 44 7354 -CD ROM(1994). International Centre for Diffraction Data, Pennsylvania, USA.

Channabasavaraj.W

Education
UG: BE in Civil Engineering
PG: Master of Engg in Geotechnical Engg

- Published an international journal paper in "Applied Clay Science" (2014) titled: Simulation of fabric in sedimented clays, (article in press).

- An international journal paper has been submitted to "Engineering Geology", titled: Characterization of samples from Lonar Crater, India, (Under review).

- Presented a technical paper in an international conference (Seventh international conference on case history in Geotechnical Engineering) at university of Illinois, Chicago, USA. Title: "Influence of Relative Position of the Tunnels, A Numerical Study on Twin Tunnels", by varied soil parameters and design conditions.

- Presented a technical paper in International level Conference (Indian Geotechnical Conference) at IIT Delhi (2012). Title: Influence of Relative Position of the Tunnels - Numerical Analysis on Interaction between Twin Tunnels.

- Presented a technical paper in a International level Conference (Indian Geotechnical Conference) at JNTU Kakinada (2014). Title: Characterization of Dredged Sediments.