Pakistan Journal of Science (Vol. 65 No. 3 September, 2013)

IMPACT OF SAND MIXING ON SETTLEMENT ANALYSIS: A CASE STUDY OF KALA SHAH KAKU (KSK), LAHORE, PAKISTAN

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ABSTRACT: Settlement of subsoil is the main cause of structural damages which requires costly and cumbersome remedial measures. Among available stabilization techniques, mixing of sand is one of the viable option to control the settlement of problematic soil.In this paper, settlement analysis is performed by stabilizing clayey soil of KSK, Lahore, Pakistan and observed the effect of mixing various percentages of sands on samples 2, 3, 4, and 5 feet depth. Basic soil classification was carried out with consolidation tests which were performed on undisturbed and disturbed samples at 2, 3, 4, and 5 feet depth. Effect of mixing sand on consolidation characteristics and its impact on settlement of KSK soil was analyzed. Results were compiled in a spreadsheet using the consolidation parameters determined above. It was found that compressibility characteristics, i.e., compression index 'C_c', coefficient of compressibility 'a_v', coefficient of volume compressibility 'm_v', decrease 12% to 30% as the %age of sand increases from 5% to 25%. The coefficient of primary consolidation 'C_v' decreases 15% to 38% with sand content varying from 5% to 25%. Consolidation settlement reduces between 11% to 64% for sand content varying from 5% to 25%..

Key words: Settlement analysis, Impact of sand mixing, Structural damages, Kala Shah Kaku (KSK), Compressibility characteristics, Consolidation parameters

INTRODUCTION

Settlement of the subsoil causes severe damages to the structures and its stability (Emad, 2006). The more accurate the settlement predictions are made the more effective planning and designing of the construction sites will be possible and the minimum destruction due to settlement problems. As a result, the cost of projects will be reduced. The consideration of compressible strata as the major contributing factor to the settlement is inevitable during settlement analysis, however, in some cases, such as that embankment on soft soils, creep dominates to such an extent that settlement due to consolidation is masked and confused (Leonards and Altschaefel, 1964). The settlement analysis in the classical way uses one dimensional consolidation theory of Terzaghi (1942). According to this theory, the consolidation characteristics of the foundation soil can be determined in the laboratory and the results can be extrapolated for application in the field.

Following objectives were considered to establish consolidation characteristics of cohesive soil of Kala Shah Kaku (KSK), Lahore, to assess the settlement problems.

1. To establish a stress-strain relationship (e-logσ_v curve) of KSK, Lahore, Pakistan.
2. To determine the compressibility characteristics of local soil and its comparison with soil mixed with various amounts of local sand.
3. To determine the settlement for various foundation loads based on consolidation characteristics for natural local soil and those of sand mixed soils.

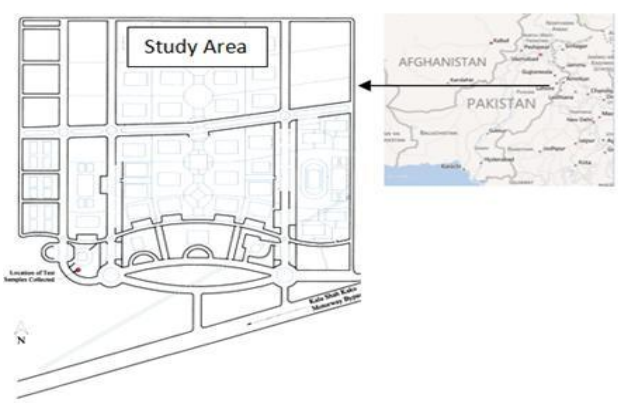


Figure 1: Location map of study area:

METHODOLOGY

Undisturbed block samples at 2ft, 3ft, 4ft and 5ft depths and local sand from KSK, Lahore for mixing with the clay were collected, sealed, marked and stored until the time of testing from the location area as shown in Figure 1. Basic soil classification and Oedometer tests were performed on both undisturbed and disturbed samples. All tests for basic soil properties (liquid limit, plastic limit, sieve analysis and hydrometer) were performed in the civil Engineering Department, UET, Lahore according to ASTM standard.

RESULTS AND DISCUSSION

Basic soil properties: The determination of index properties is an important criteria to consolidation test. Various tests such as specific gravity (Gs), atterberg limits, sieve analysis and hydrometer for particle size distribution were performed on both undisturbed and disturbed samples for assessing the consolidation characteristics. Basic soil classification is shown in Table 1 which demonstrates that the top layer is cohesive soil consisting of silty clay/silt (CL-ML) and clay content varies from about three feet (3 ft) to twenty feet (20 ft)

Table 1 shows the soil classification parameters with basic soil properties. LL, PL, PI, and LI indicate Liquid Limit, Plastic Limit, Plasticity Index and Liquidity Index.

Sample	Depth	Natural M.C	Sp. Gravity	Grain Size Analysis			Atterberg Limits				Soil C'fication	Initial Void Ratio	Initial Bulk Density	Initial Degree of Saturation
				Gravel	Sand	Silt & Clay	LL	PL	PI	LI				
	[ft (m)]	%	Gs	%	%	%	%	%		%			[kN/m^3]	%
1	2 (0.6)	1.01	2.69	0	3	97	27	20	7	-2.7	CL-ML	0.91	14	3.02
2	3 (0.9)	1.28	2.68	0	5	95	28	22	6	-3.5	CL-ML	0.71	15.6	4.83
3	4 (1.2)	1.4	2.69	0	7	93	34	23	11	-1.9	CL	0.76	15.2	4.93
4	5 (1.5)	16	2.69	1	5	94	29	21	8	-0.6	CL	0.94	15.8	46.12

Analysis of consolidation data: The results of consolidation tests are plotted from Figure 2 to 7 which are discussed below. The symbols used for 2, 3, 4 and 5 feet depth samples are given below

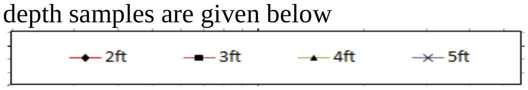


Figure 2 indicates the stress-strain behavior from KSK for both disturbed and un-disturbed samples, Lahore. Analysis shows that the void ratio range from 0.37 to 0.76 for 4ft undisturbed sample and for

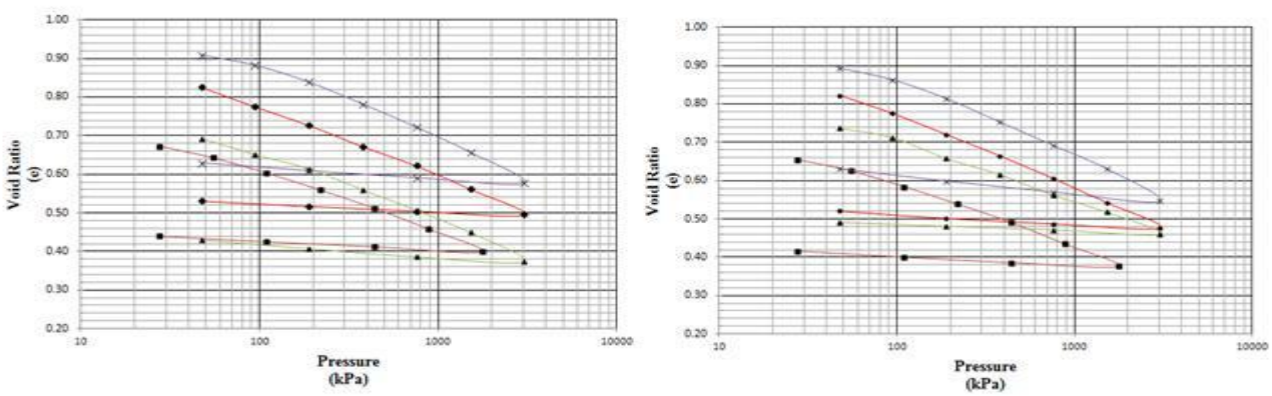


Fig. 2: Void Ratio- log Pressure Curves for Un-disturbed (Left) and Disturbed (Right) Samples

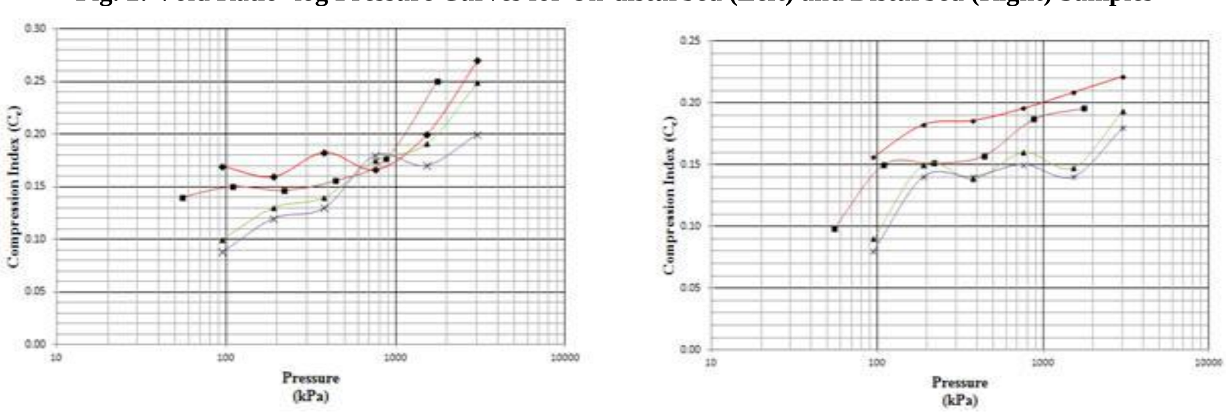


Fig. 3: Compression Index-log Pressure Relationship for Un-disturbed (Left) and Disturbe (Right) Samples

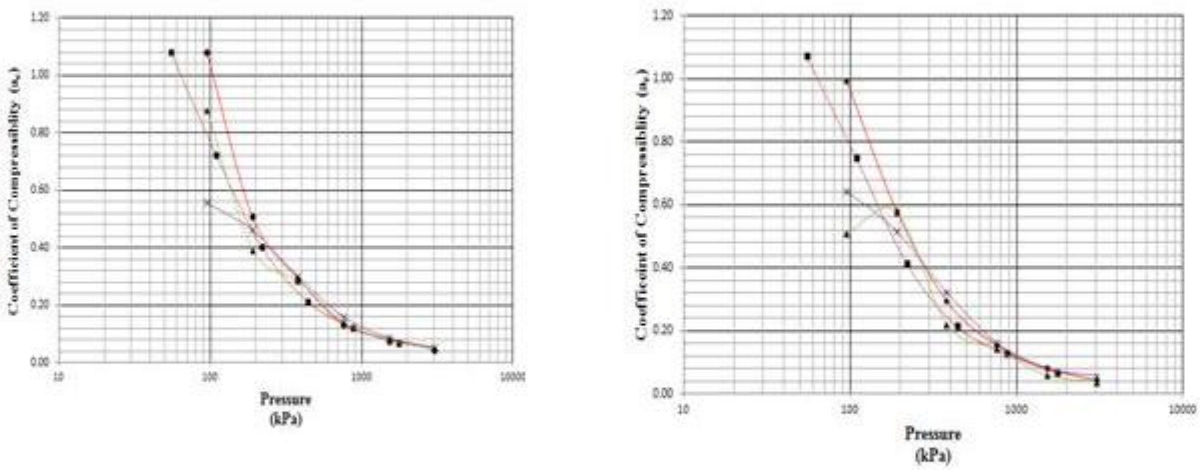


Fig. 4: The curves of coefficient of compressibility (a_v) with pressure for Un-disturbed and Disturbed Samples

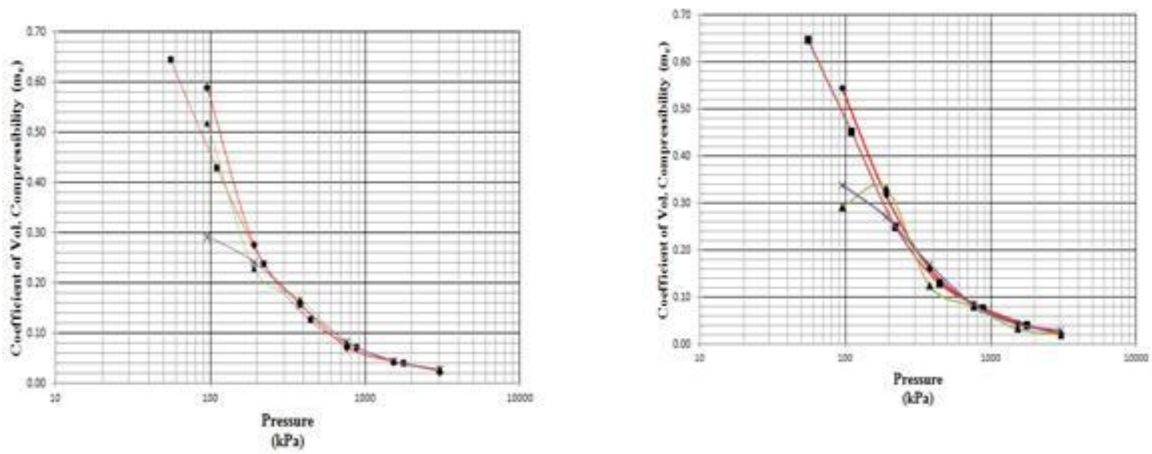


Fig. 5: The relationship of coefficient of volume compressibility (m_v) with pressure

disturbed sample, the range is from 0.46 to 0.76. Initial void ratio for the 5ft undisturbed sample is the highest value compared with other samples which 0.936.

Figure 3 indicates the relationship between the variation of compression index (C_c) with log pressure for un-disturbed and disturbed samples. This shows that C_c value generally increases when the pressure increases on samples of same depth. Similar findings have been reported by Teves (1968), Bergado (1992), Reinmanorom (1974) and Thumaprudti (1974). It is further noted that Cc values decrease with depth which indicates less potential for settlement with increase in depth.

Figure 4 shows the curves of coefficient of compressibility (a_v) with pressure for both un-disturbed and disturbed samples. It is noted that the value of a_v decreases with increase in applied pressure on samples of same depth. The values of a_v are in scattered formation at initial pressures and converge closer to each other as the applied pressure increases. This indicates that all soil samples have been compacted to a similar stiff structure and would behave in the same way under higher load. It is also observed that value of a_v decreases with depth. Figure 5 shows the relationship of coefficient of volume compressibility (m_v) with pressure. The discussion on the results is the same as stated for coefficient of compressibility above (Wong Leong Sing, et al. 2008).

Figure 6 and 7 indicate the variation of the coefficient of primary and secondary consolidation with pressure on log scale for un-disturbed and disturbed samples. For un-disturbed samples it is seen that the values of C_v decreases with increase in applied pressure and tends to be more or less constant at higher pressure. No definite conclusions can be drawn about the variation of C_α with depth, however, the values of C_α tend to increase and decrease with increase in pressure. Similar results have been reported by Teves (1968) Reinmanorom (1974) and Nanegrungsunk (1976).

Effect of sand mixing: The effect of sand mixing with various percentages (5, 10, 15, 20 and 25% by weight) on local soil of KSK and its impact on consolidation characteristics is discussed here. Samples from 2, 3 and 4 feet depth were prepared at 6% moisture content while 5ft sample was prepared at 16% moisture content.

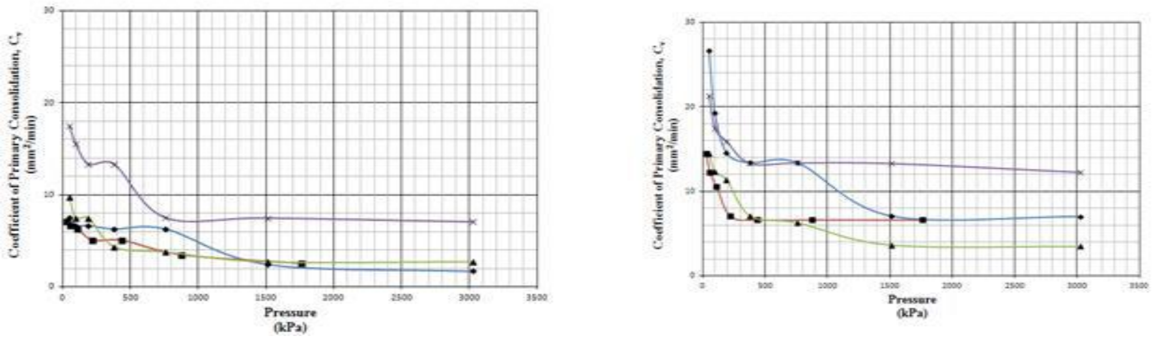


Fig. 6: Variation of the coefficient of primary consolidation with pressure on log scale

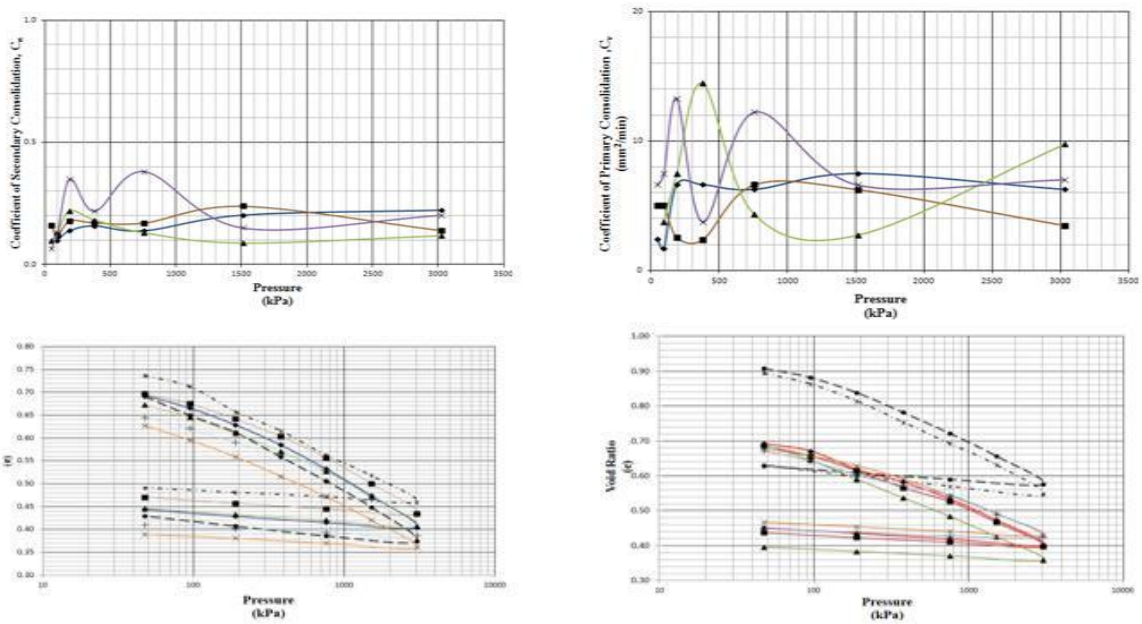


Fig. 7 is indicating the relationship between Coefficient of Secondary Consolidation

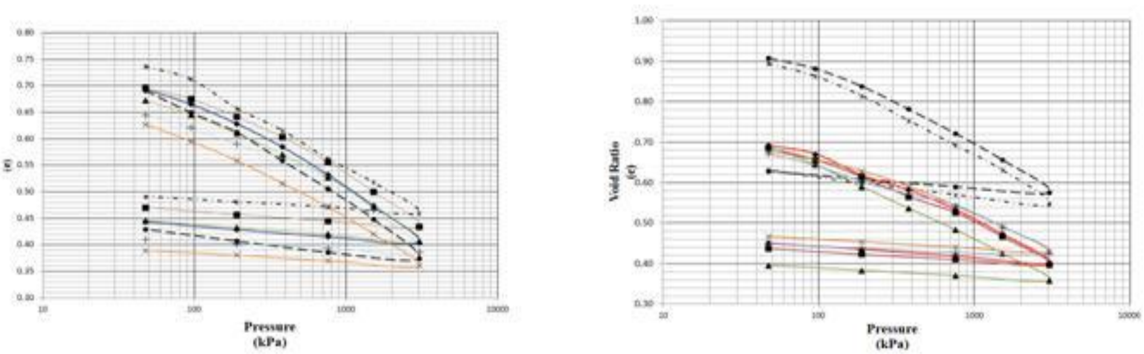
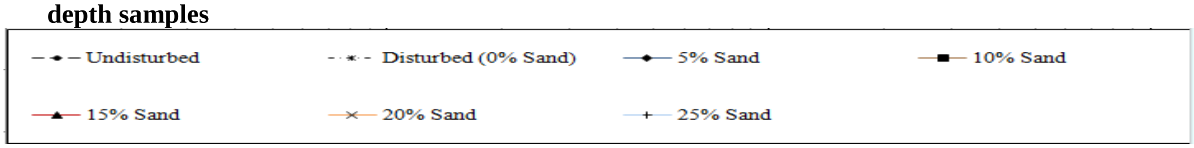


Fig 8: Void Ratio-log Pressure Relationship for 2 (top left), 3 (top right), 4 (bottom left) and 5 feet (bottom right) depth samples



All samples were prepared at original density on which conventional consolidation tests were performed. Symbols used in this paper for sand mixing effect are shown below.

On Void Ratio: The values of void ratio (e) for for 2, 3, 4, and 5 feet samples computed of all soil samples at each pressure increment as shown in Figure 8. This Figure shows that high percentage of sand gives low values of void ratio, so lower most curves is attaining of e vs log P.

Compressibility Characteristics: The effect of sand mixing on compression index is shown in Figures 9 for 2, 3, 4 and 5 feet depth samples. The value of C_c decreases as the percentage of sand increases. Undisturbed soil samples give more value of C_c but as percentage of sand increases value of C_c decreases. Similar results were reported by Nanegrungsunk (1976), Seah and Koslanant (2002) and Emad (2006) Symbols used for disturbed and undisturbed samples in the following graphs are shown in Figure 2.

Figures 10 and 11 indicate the effect of sand mixing on coefficient of compressibility a_v and coefficient of volume compressibility for 2, 3, 4 and 5 feet depth samples. It is noted that values of a_v decreases with increase in percentage of sand. At beyond 500 kPa curves come closer to each other. The discussion of the results of coefficient of volume compressibility is same as stated above for coefficient of compressibility.

Effect of sand mixing on coefficients of primary (C_v) and secondary (C_α) consolidation are shown in Figure 12 and 13 for 2, 3, 4 and 5 feet depth samples. It is observed that the value of C_v decreases as percentage of sand increases. Similar findings were found by Teves (1968), Thumaprudti (1974), Towan(1976), Wong Leong Sing et al. (2008)

No definite conclusions can be drawn about the variation of C_α with pressure. The results indicate that the value of C_α reduces as the %age of sand increases. Similar findings have been found by Teves and Moh (1968), Thumapruditi (1974) and Nanegrungsunk (1976).

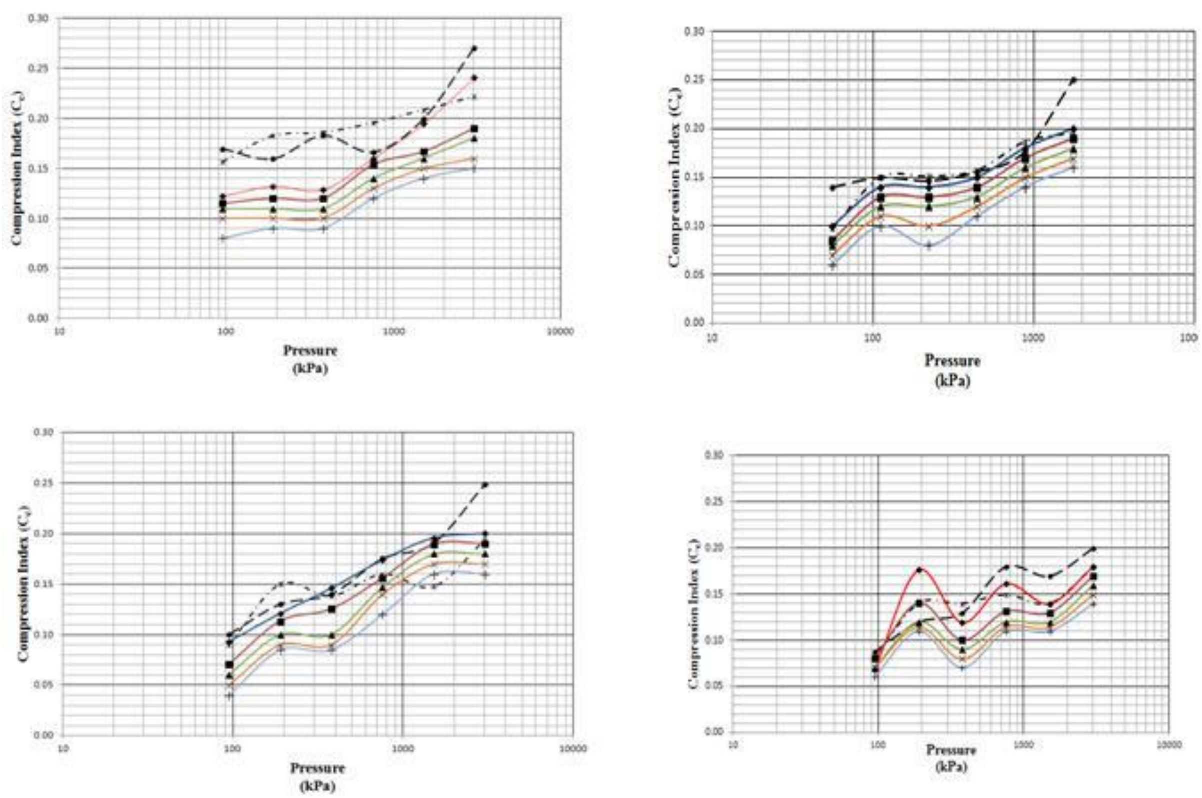


Fig 9: Compression Index-log Pressure Relationship for 2 (top left), 3 (top right), 4 (bottom left) and 5 feet (bottom right) depth samples

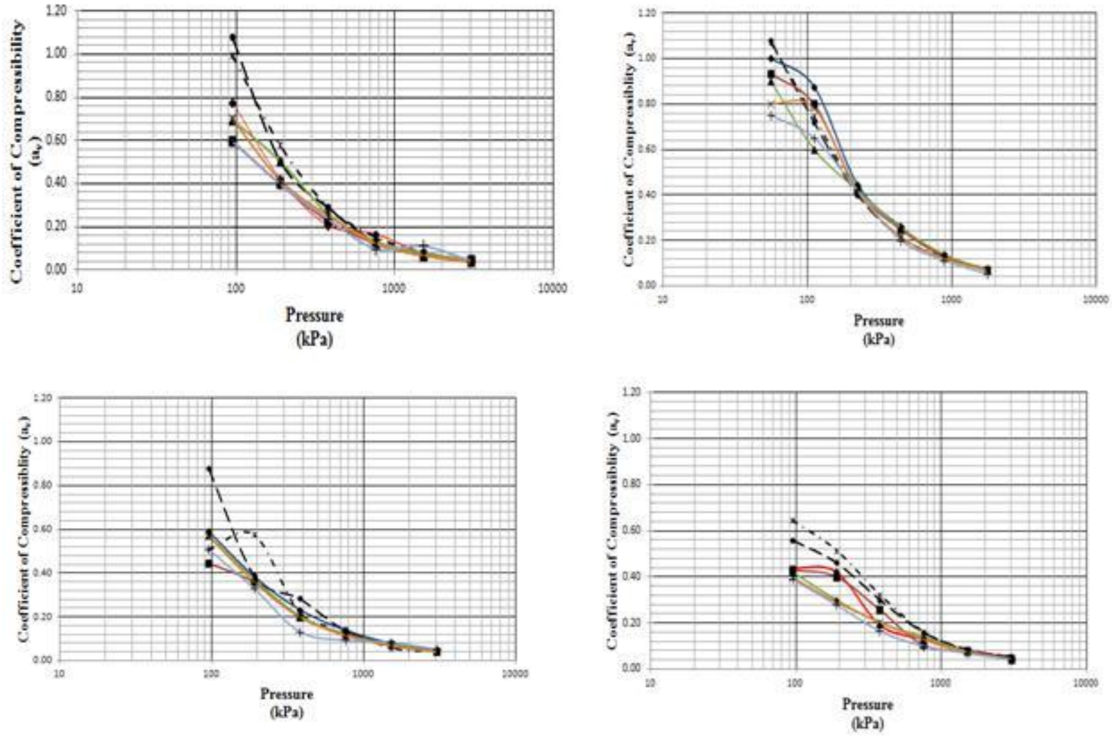


Fig 10: Coefficient of Compressbility-log Pressure Relationship for 2 (top left), 3 (top right), 4 (bottom left) and 5 feet (bottom right) depth samples

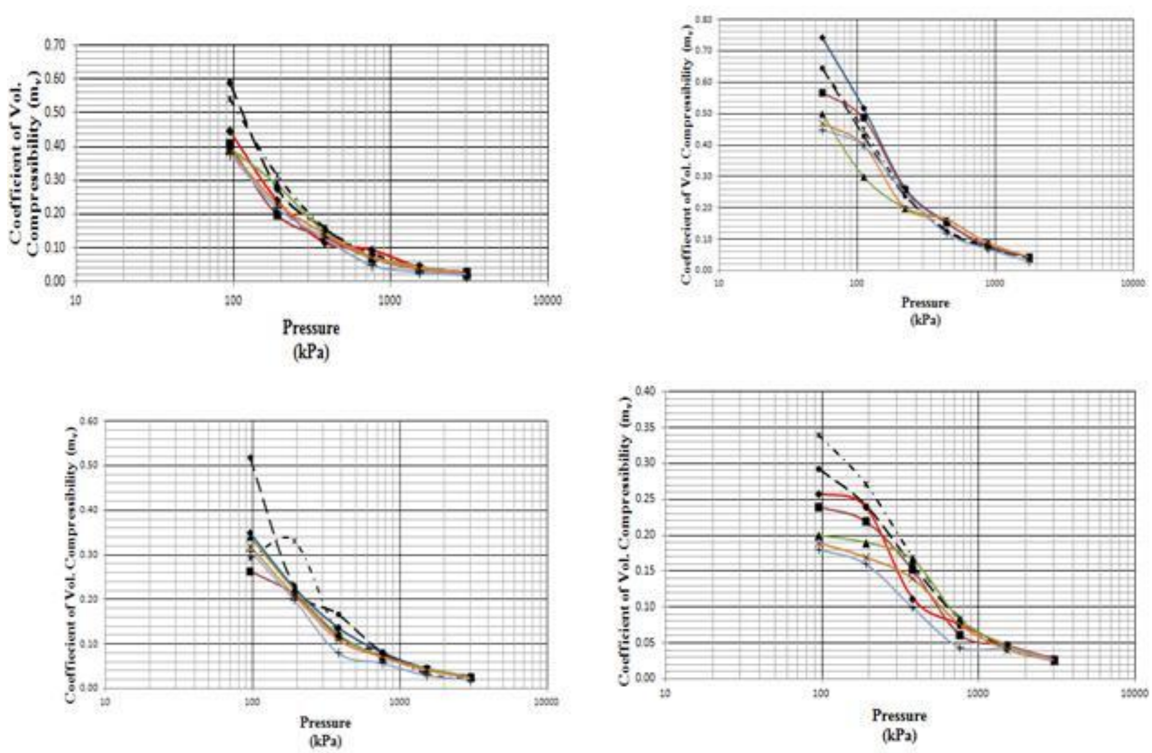


Fig 11: Relationship between Coefficient of Volume Compressbility and log Pressure for 2 (top left), 3 (top right), 4 (bottom left) and 5 feet (bottom right) depth samples

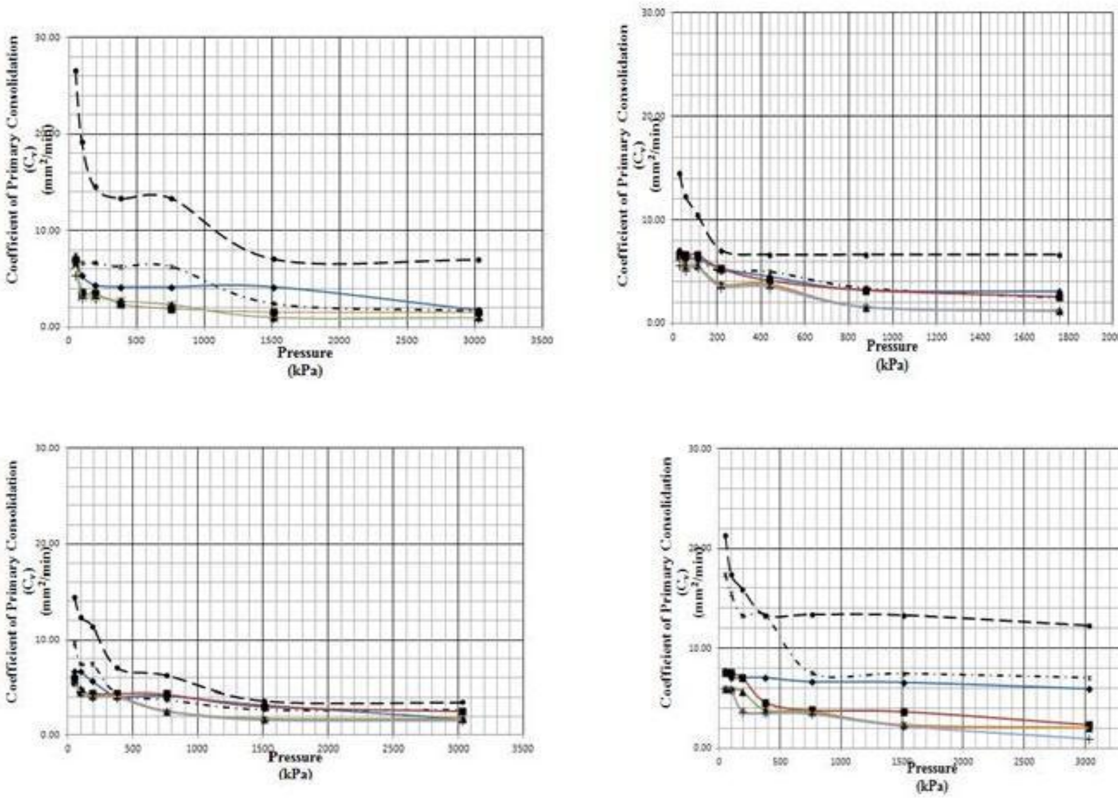


Fig 12: the relationships shows the variation of Coefficient of Primary Consolidation with Pressure for 2 (top left), 3 (top right), 4 (bottom left) and 5 feet (bottom right) depth samples

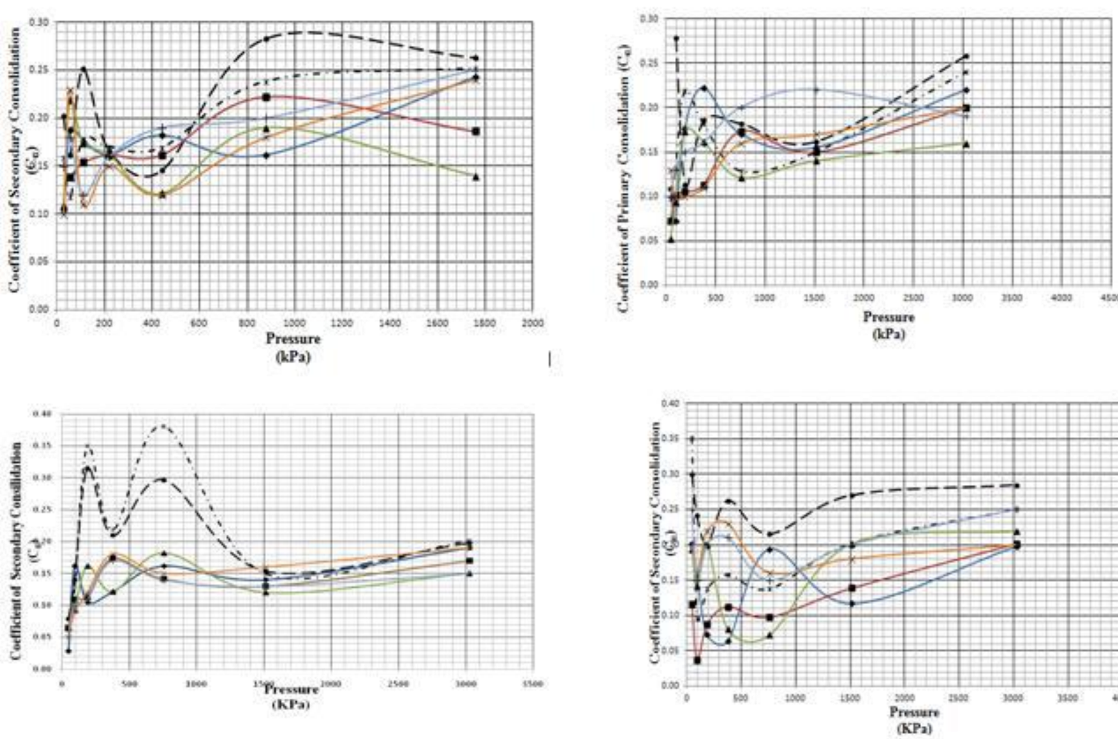


Fig 13 shows the rrelationshipn between Coefficient of Secondary Consolidation and Pressure for 2 (top left), 3 (top right), 4 (bottom left) and 5 feet (bottom right) depth samples

Settlement analysis: Consolidation tests were performed to establish the parameters for settlement analysis of KSK soil. These parameters are shown in Figure 14. The value of compression index (C_c) for a particular soil is not constant but it depends on the stress range over which it is calculated. Compression index which is used in settlement analysis is calculated for a stress increment of 100 kN/m^2 in excess of the effective overburden pressure of the in-situ soil at the depth of interest (Craig, 1987).

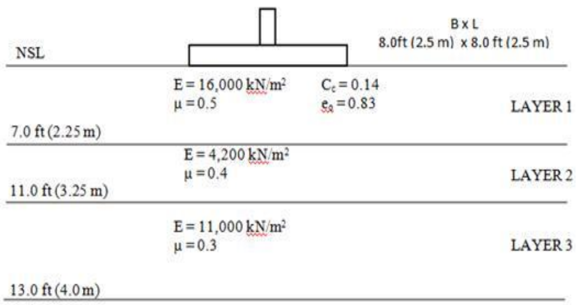


Figure 14: Soil Profile at Site For Settlement Analysis

Immediate and consolidation methods were used for settlement analysis. Immediate settlement is analyzed by using three methods, Timoshenko & Goodier's method, Janbu's method and Schmertmann's method for sand while consolidation settlement is used for the estimation of the settlement of clay layer. Table 2 gives a comparison of settlement values as calculated by empirical methods under load 105 kPa, 142 kPa and 200 kPa, It is clear that the settlement reduces as the depth of foundation increases.

Table 3 gives the settlement values determined by consolidation settlement method for clay only.

It is clear from Figure 15 indicates a comparison of settlement analysis for un-disturbed and samples after sand mixing under loads of 105, 142 and 200 kPa. This shows that the settlement reduces as the depth of foundation increases which is 2.28 mm. settlement in un-disturbed samples is 15.76 mm which is reduced to 5.85 mm as the percentage of sand increases under load of 105 kPa. The same pattern of results were obtained of 142 and 200 kPa.

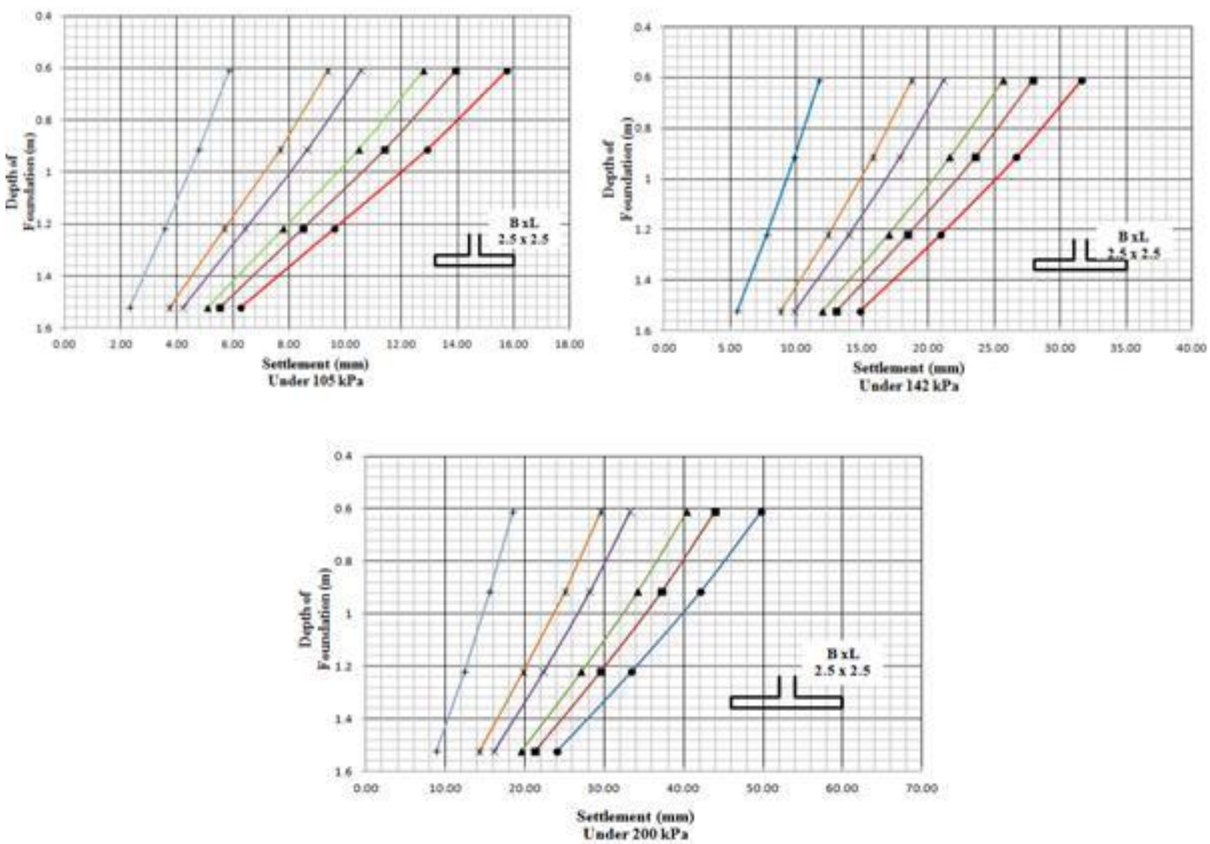


Figure 15: Comparison of Settlement Analysis for Un-Disturbed and samples after Sand mixing Under Load of 105, 142 and 200 kPa

Table 2: Comparison of settlement analysis under 105, 142 and 200 kPa load for different depth with Empirical Methods (Timoshenko & Goodier, Janbu and Schmertmann)

Method	D_f (ft)	Settlement (mm) Under 105kPa			Total Settlement	Settlement (mm) Under 142 kPa			Total Settlement	Settlement (mm) Under 200 kPa			Total Settlement
		Layer 1	Layer 2	Layer 3		Layer 1	Layer 2	Layer 3		Layer 1	Layer 2	Layer 3	
Timoshenko & Goodier	2	19.8	7.3	2.05	29.15	26.78	10.59	2.97	40.34	37.72	15.74	4.42	57.88
	3	14.54	7.03	1.85	23.42	19.66	10.02	2.64	32.32	27.69	14.7	3.88	46.27
	4	10.51	6.3	1.66	18.47	14.21	8.85	2.33	25.39	20.02	12.84	3.38	36.24
	5	4.76	5.62	1.5	11.88	6.44	7.78	2.08	16.3	9.07	11.16	2.98	23.21
Janbu	2	18.11	5.82	5.51	29.44	24.5	8.44	7.99	40.93	34.5	12.55	11.88	58.93
	3	15.58	5.45	4.84	25.87	21.06	7.76	6.9	35.72	29.67	11.39	10.12	51.18
	4	9.24	4.88	4.33	18.45	12.5	6.85	6.07	25.42	17.6	9.93	8.81	36.34
	5	6.85	4.29	3.86	15	9.27	5.93	5.35	20.55	13.05	8.51	7.67	29.23
Schmertmann	2	N/A	N/A	3.35	3.35	N/A	N/A	5.17	5.17	N/A	N/A	10.12	10.12
	3	N/A	N/A	3.03	3.03	N/A	N/A	5.06	5.06	N/A	N/A	9.07	9.07
	4	N/A	N/A	2.71	2.71	N/A	N/A	4.99	4.99	N/A	N/A	8.29	8.29
	5	N/A	N/A	2.34	2.34	N/A	N/A	4.98	4.98	N/A	N/A	7.72	7.72

Table 3: Settlement analysis under 105, 142 and 200 kPa load with Consolidation Settlement Method using 5, 10, 15, 20 and 25 percentage of sand mixing. UD indicates the undisturbed sample

D_f (ft)	**Settlement in mm Under 105 kPa**						**Settlement in mm Under 142 kPa**						**Settlement in mm Under 200 kPa**					
	UD	**5%**	**10%**	**15%**	**20%**	**25%**	**UD**	**5%**	**10%**	**15%**	**20%**	**25%**	**UD**	**5%**	**10%**	**15%**	**20%**	**25%**
2	15.76	13.91	12.79	10.54	9.37	5.85	31.58	27.88	25.62	21.11	18.76	11.73	49.72	43.89	40.33	33.23	29.54	18.46
3	12.91	11.4	10.47	8.63	7.67	4.8	26.65	23.52	21.61	17.81	15.83	9.89	42.12	37.18	34.17	28.15	25.03	15.64
4	9.61	8.48	7.8	6.42	5.71	3.57	20.92	18.47	16.97	13.98	12.43	7.77	33.43	29.51	27.12	22.34	19.86	12.41
5	6.28	5.54	5.09	4.2	3.73	2.33	14.79	13.06	12	9.89	8.79	5.49	24.02	21.21	19.49	16.06	14.27	8.92

Conclusions: On the basis of above data and its interpretation, the following conclusions are drawn;

1) The soil of the study area is classified as silty clay (CL-ML) up to 5ft depth with 3% to 7% sand. The natural moisture content to 4ft depth is very low and becomes 16% at 5ft and below. This was due to the seasonal impact on the soil during the month April when the samples were collected. Since the temperature starts rising in April in the study area, the surface is almost dry due to high evaporation rate.

2) Samples were collected. Since the temperature starts rising in April in the study area, the surface is almost dry due to high evaporation rate.

3) The soil is in semi-solid to solid state indicated by its characteristics. Such as plastic and liquid limits.

4) The trend of compression index is not definite trend with pressure; however, it is observed that it decreases with depth. The values of a_v and m_v decrease with increase in applied pressure and depth. They are in scattered formation at initial pressure and converge closer to each other as applied pressure increases.

5) The coefficient of primary consolidation decreases with increase in applied pressure and tends to be more or less constant at higher pressures. However, the coefficient of secondary consolidation, no definite conclusion can be drawn about the variation of C_α with depth.

6) The effect of sand mixing on compression index, coefficient of compressibility & coefficient of volume compressibility decreases 13% to 33% as the percentage of sand increases from 5% to 25%. Coefficient of primary consolidation decreases15 to 38% as the percentage of sand increases The effect of sand mixing on coefficient of secondary consolidation is not significant.

7) Finally, the settlement reduces 11.7% to 62.9 % as the percentage of sand increases from 5% to 25%.

Acknowledgement: Authors acknowledge the support and guidance of Dr. Muhammad Saleem Khan, Associate Professor, Geological Engineering Department, UET, Lahore and lab staff particular Mr. Muhammad Shoaib for their assistance in the lab work.

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