SOLUTION TO FOUNDATION PROBLEMS IN COLLAPSIBLE SOILS OF KALLAR KAHAR, DISTRICT CHAKWAL, PUNJAB, PAKISTAN

[a] Engr. Rais Agha, [b] Dr. Naveed Ahmad

a: MS Student-Civil Engineering Department, UET Taxila-Pakistan, raisagha@gmail.com
b: Assistant Professor, Civil Engineering Department, UET Taxila-Pakistan, naveed.ahmad@uettaxila.edu.pk

Abstract -This study aims at providing the solution to Foundation Problems in Collapsible Soils of Kallar Kahar, District Chakwal, Punjab, Pakistan. Kallar Kahar is located in a semi-arid area. Most of the structures built in Kallar Kahar are cracked after or even during the construction stage. Generally, such cracks are related to bearing capacity problem i.e. either sub-soils possess low shearing strength or foundations undergo excessive settlement. Apparently, this is not the case. Soils are seen hard possessing moderate shearing strength and similarly chances of excessive settlement under existing structural loads seems to be unlikely. With no apparent reason, this is a challenge to Geo-technical Engineers of this region. One of such problematic sites is identified as the Fauji Foundation Hospital and Model School, Kallar Kahar. This study is carried out to identify the collapsible soils, assess the collapse potential and employ appropriate mitigation measures of this particular site and adjacent area. The research work is found to be of practical importance and beneficial for soil and foundation engineers to deal with collapsible soils. After the detailed analysis, it is concluded that soils present around the FFHS, Kallar Kahar, are potentially collapsible and needs proper attention in this regard.

Keywords- Collapsible Soils, Collapse Potential, Single Oedometer, Double Oedometer, Kallar Kahar

1 INTRODUCTION

Settlement of structures has always been a major concern for the Geo-technical Engineers. Generally, attention is given to the following causes of settlements:

- Most important is the structural loads on the footing.
- Presence of week soils.
- Weight of a recently placed fill.
- Lowering Ground water Table.
- Underground tunneling and mining.
- Lateral movements because of nearby excavations.

Another important cause of foundation settlement is Collapsible Soils. The purpose of this paper is to present an estimate of collapse potential and the anticipated settlements that are expected to be experienced by the foundations founded on collapsible soils in Kallar Kahar. Estimates were made using Single Oedometer (ASTM D5333) and also the Double Oedometer Test. In addition to this, research paper provides an opportunity to study comparison of two methods and to derive any relationship between the results of two types of oedometer tests. Engineering solutions to mitigate the potential for settlement are also recommended. The study of collapse potential of Kallar Kahar soils is never studied before and this research paper helps to improve the awareness of the risk posed by collapsible soils of Kallar Kahar.

2 RESEARCH METHODOLOGY

2.1 *Problematic Site Identification*

In our region, one of such areas where collapsible soils can be found is **Kallar Kahar**, District Chakwal.

Fauji Foundation Hospital and Model School at Kallar Kahar is identified as a typical problematic site. This site is located on the off road of Motorway (M-2) and is opposite to Kallar Kahar Lake. Latitude and Longitude of site are noted as 32°46'57.74"N and 72°42'37.18"E.

Figure 1: Site Location

Mostly there are single story with one double and one triple story structures. Almost all of them have large and serious cracks. Officials informed us that they had got this site properly designed and constructed accordingly. When cracks were observed in relatively older buildings, they have reduced the bearing capacity to 0.50 kg/cm^2 which resulted in 3.65m x 3.65m footings, but still cracks are developed even during construction. Apparently, soils are dry and hard and reasons of settlement are beyond their imagination. They are facing this serious problem, which may result heavy monetary as well as human loss. Existing situation is well depicted in photographs followed by this page.

2.2 *Field Sampling & Testing*

High-quality undisturbed (block) samples were collected from nine (9) test pits and preserved and shifted to soil laboratory. Field Density Test by Sand Replacement Method (ASTM D1556) were also performed in all test pits along with the in-situ moisture content. Two water samples from nearby shallow water boreholes and one from the Kallar Kahar Lake were also collected. In addition to Test Pits and FDT, four boreholes were also drilled maximum up to 20 feet with the execution of Standard Penetration Tests (SPT). Results of SPT vary from 19 to Refusal. These results suggest that sub-strata present are very stiff to very hard.

2.3 *Laboratory Testing*

Following laboratory tests were performed on soil samples collected from field:

2.3.1 *Index Properties*

Index properties were measured on disturbed samples like grain size distribution (ASTM D422 & D4693), hydrometer analysis (ASTM D1140), Atterberg's limits (ASTM D4318), specific gravity (ASTM D854)) and also the soluble salts content. All of the samples are fine-grained soils and as per Uniform Soil Classification System (USCS) are classified as CL / CL-ML / ML. Results of index properties along with USCS classification and some important gravimetric-volumetric relationships like void ratio and initial saturation are shown in Table 1.

2.3.2 *Collapse Potential*

Soil Collapse Tests are performed by:

i) Single Oedometer Method
ii) Double Oedometer Method

2.3.2.1 *Single Oedometer Method*

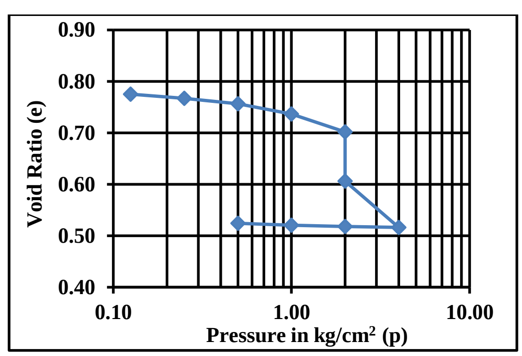

Figure 2: Results of Single Oedometer Test Pit-2

Single Oedometer Method for the measurement of Collapse Index (I_c) is an ASTM standardized test with the designation D5333-03. This test measures one-dimensional collapse in the oedometer apparatus using standard test procedures such as described in the aforementioned standard. In Single Oedometer Test, in-situ moisture is maintained up to 2.00 kg/cm^2. At 2.00 kg/cm^2, sample is inundated and monitored for hydrocompression. Test result of TP-2 are plotted, as shown in Figure 2. Results of I_c of all nine tests by single oedometer vary from 1.825 to 5.465%.

2.3.2.2 Double Oedometer Method

Double Oedometer Test Method for the measurement of the collapse potential was developed by Jennings and Knight (1956, 1957, 1975). Test result of TP-2 are plotted, as shown in Figure 3. Results of Collapse Index by double oedometer vary from 2.598 to 9.523%. Results of collapse index by Double Oedometer Method are generally found higher than those by Single Oedometer.

In addition to above, CBR Tests (ASTM D1883) were performed with lime as admixture in variable quantity to study its effect on MDD / OMC / CBR & Swell values of collapsible soils of the study area.

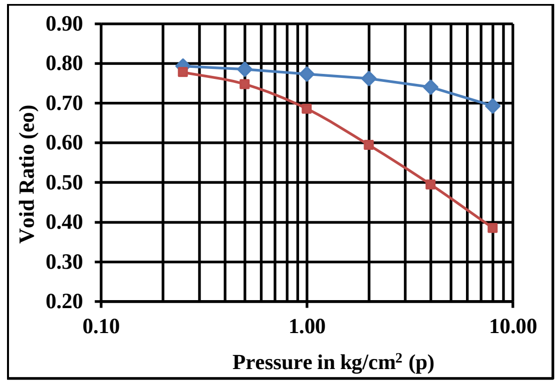

Figure 3: Results of Double Oedometer Test Pit-2

3 RESULTS AND DISCUSSIONS

3.1 Index Properties

Index properties were measured on disturbed bulk samples collected from 5'-0" of all Test Pits. Grains Size Analyses shows that fine content varies from 55 to 87%. Liquid limit (LL) values vary from 24.8 to 38.4 with plastic indices (PI) vary from 6.0 to 11.3. All of the samples are fine-grained soils and as per Uniform Soil Classification System (USCS) are classified as CL / CL-ML / ML. Results of Sieve Analysis, also the Atterberg Limits and USCS classification along with other index properties are shown in Table 1.

Table-1 Index Properties

Test Pit No.	Gravel	Sand	Fines	LL	PL	PI	USCS	w_N (%)	Dry Density Υ_d (g/cm^3)	G_s	Void Ratio (e_o)	Satu-ration (%)
TP-1	02	30	68	30.3	22.7	7.6	CL	8.1	1.464	2.615	0.786	26.9
TP-2	-	16	84	27.2	21.2	6.0	CL-ML	7.0	1.427	2.600	0.822	22.1
TP-3	-	31	69	28.4	20.7	7.7	CL	7.1	1.516	2.647	0.746	25.2
TP-4	01	34	65	33.1	22.8	10.3	CL	11.0	1.441	2.604	0.709	40.4
TP-5	-	16	84	38.4	27.1	11.3	ML	18.1	1.488	2.727	0.833	59.3
TP-6	-	34	66	30.1	23.7	6.4	ML	18.0	1.459	2.727	0.869	56.5
TP-7	-	32	68	24.8	20.8	4.0	CL-ML	9.3	1.444	2.647	0.833	29.5
TP-8	02	43	55	31.3	22.3	9.0	CL	9.7	1.366	2.717	0.989	26.6
TP-9	-	13	87	28.9	22.0	6.9	CL-ML	5.7	1.452	2.633	0.813	18.5

Particle Size Distribution Curves of nine samples are shown in Figure 4.

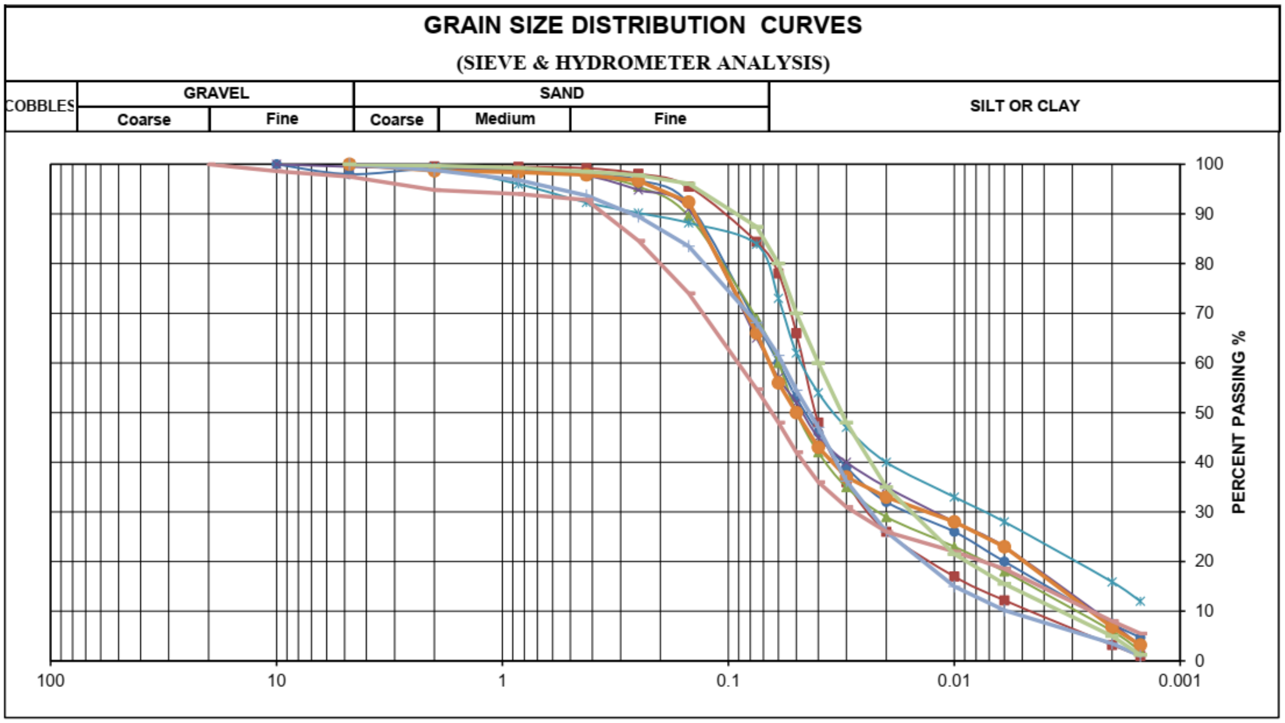

Figure 4: Particle Size Distribution Curves

3.2 *Laboratory Soil Collapse Tests*

3.2.1 *Results from Single & Double Oedometer Test*

Results of Collapse Index of all nine tests by single oedometer vary from 1.825 to 5.465% as shown in Fig. 5 and those by double oedometer vary from 2.598 to 9.523% as shown in Fig. 6.

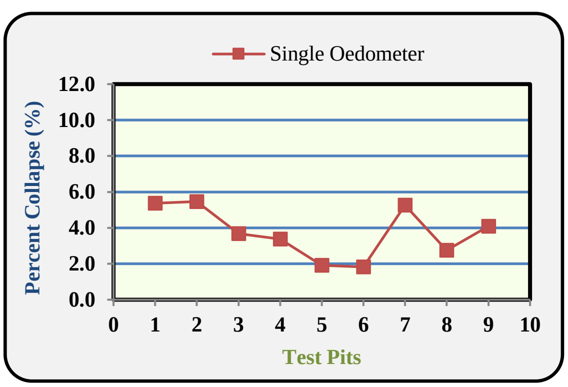

Figure 5: Results of Single Oedometer Test

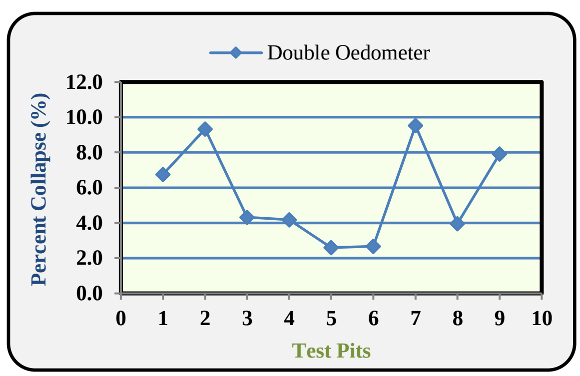

Figure 6: Results of Double Oedometer Test

3.2.2 Comparison of Collapse Index Obtained from Single Oedometer & Double Oedometer

Results from two methods are presented jointly in the Fig 10, which provides an opportunity to compare the results of two methods. Results of collapse index by Double Oedometer Method are generally found higher than those by Single Oedometer though mostly in a close range.

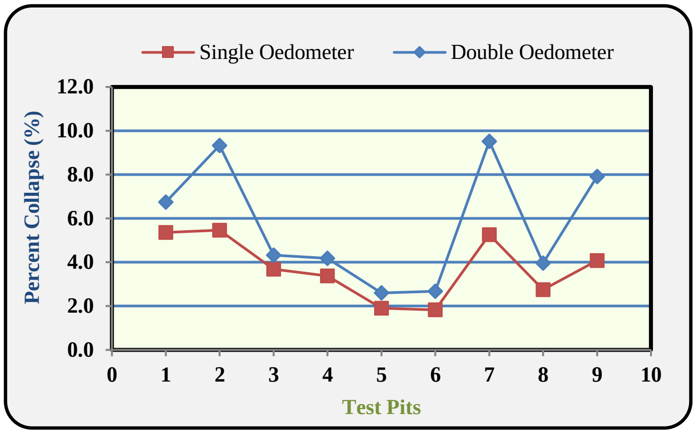

Figure 7: Comparison of Results of Single & Double Oedometer Test

Nine (9) collapse tests were performed on samples obtained from the selected site by two different methods, with the results shown in Figure 5, 6 & 7. The results are compared to the ranges categorized by ASTM 5333-03 as shown in Table 2, which corresponds to a degree of collapse mostly as moderate, with a few as slight. These results suggest that the subsoils present at Kallar Kahar have a high risk of collapse upon wetting.

Table 2 Collapse index categorized by ASTM D-5333 [3]

Degree of Collapse	**None**	**Slight**	**Moderate**	**Moderate to severe**	**Severe**
Collapse Index	0	0.0 – 2.0	2.1 – 6.0	6.1 – 10.0	>10.0

3.2.3 Comparison of Collapse Potential with Index Properties

Index properties of selected samples are given in Table 1 and Collapse Potential Test results are shown in Fig. 4. Comparison of different index properties with %C results provides a good opportunity to develop some relationship in between them. As can be seen from Fig 8 to 10 that with the increase in specific gravity, in-situ moisture content and liquid limit, percent collapse decreases. Fig 10 shows that with the increase in %change in saturation, percent collapse increases.

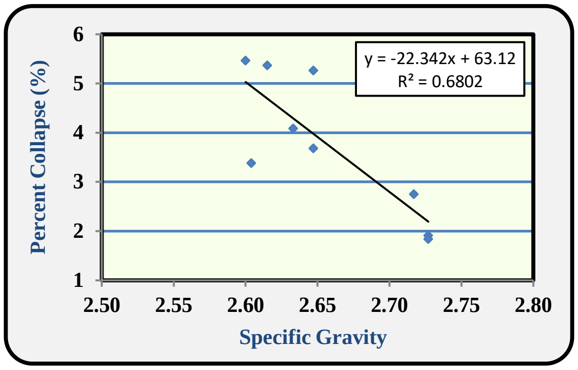

Figure 8: Comparison of % Collapse with Specific Gravity Test

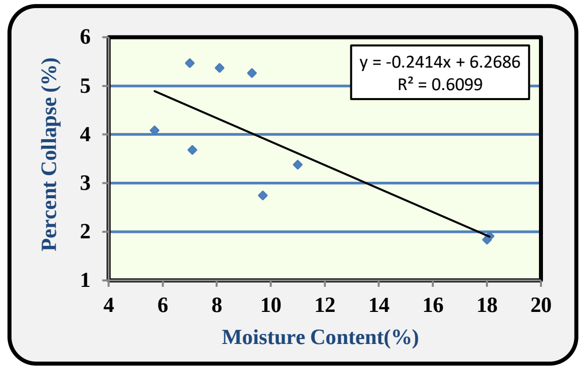

Figure 9: Comparison of % Collapse with Moisture Content Test

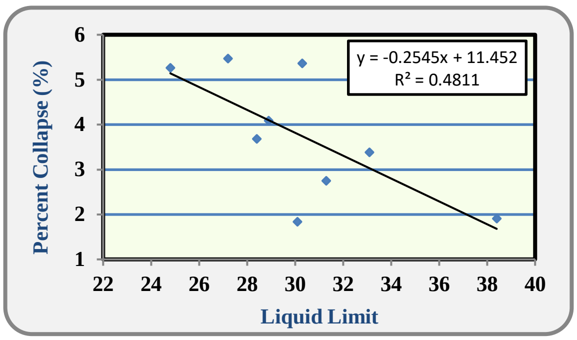

Figure 10: Comparison of % Collapse with Liquid Limit

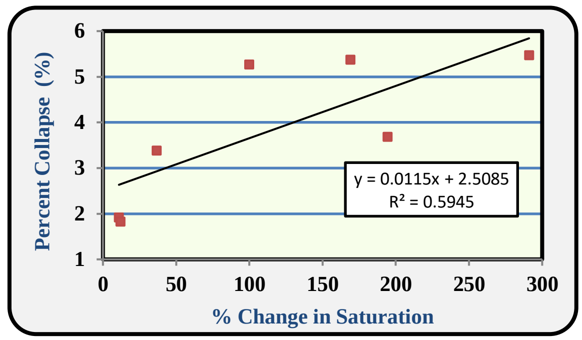

Figure 11: % Change in Saturation Vs Collapse

3.3 Effect of Lime on MDD, OMC, CBR & Swell of Collapsible Soils

3.3.1 Effect of Lime on MDD & OMC

Samples of TP-8 and TP-9 were selected to study the effect of use of lime on collapsible soil. Increase in lime content decreases the MDD values (Fig. 14) whereas OMC values increase with the increase in lime content.

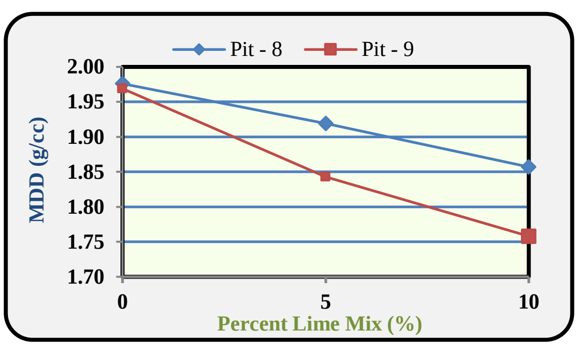

Figure 12: Variation in MDD with % Lime Mix

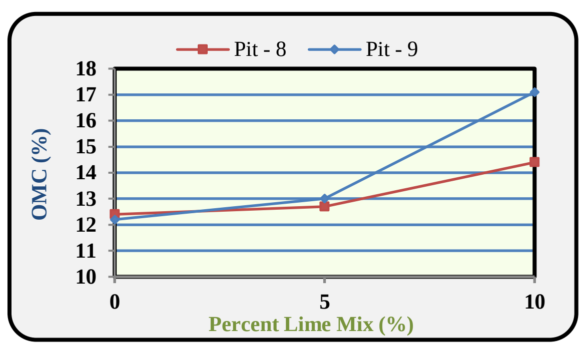

Figure 13: Variation in OMC with % Lime Mix

3.3.2 Effect of Lime on CBR values

In TP-8 (Fig 14), increase in lime content from 0 to 5% changes the CBR results intensely, but then increase from 5 to 10% increases CBR at slower rate. TP-9 shows same behaviour from 0 to 5%, but then a decrease is noted at 10% lime content (Fig 15) though still it is a good value.

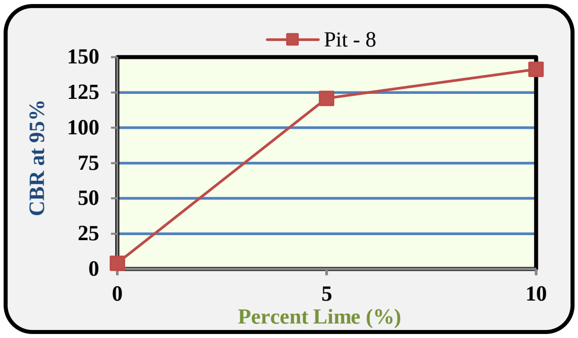

Figure 14: Variation in CBR with % Lime

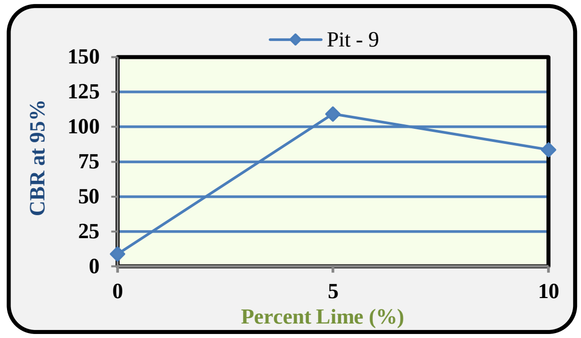

Figure 15: Variation in CBR with % Lime

3.3.3 Effect of Lime on Swell values

Interesting impact of variation in lime content is noted on swell values. CBR moulds at 10 blows, 30 blows and 65 blows show swell variably. But the most noticeable thing in both samples is the control in swell value though both samples show variable pattern.

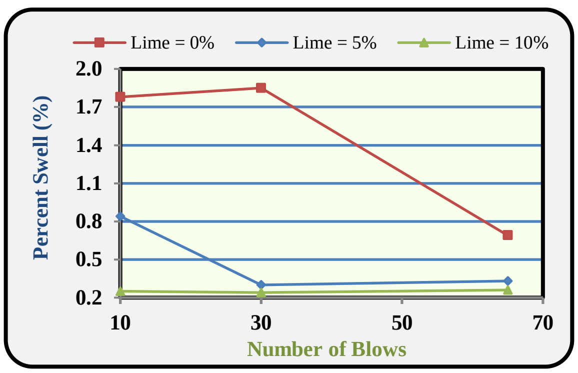

Figure 16: Variation in Swell with % Lime Mix in Pit – 8

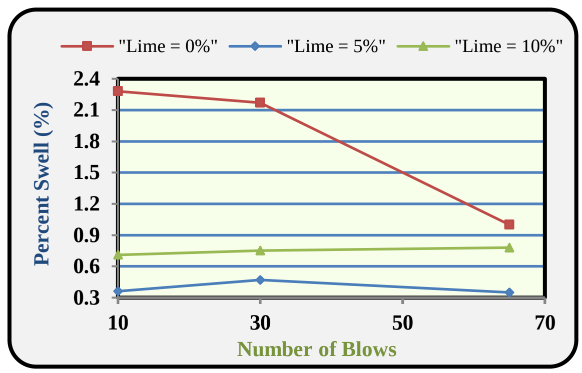

Figure 17: Variation in Swell with % Lime Mix in Pit – 9

3.4 Comparison of author's work with previous studies

It is the first study of this kind for this region and the results obtained in research are largely in confirmation with other authors like Mogadham et al (2006), Jennings and Knight (1975). However, results found in study partially confirm the findings of Handy, 1973. However, comparison on large scale needs detailed study and is beyond the scope of this research paper, but further study can be done in future."

4 SIGNIFICANCE & PRACTICAL IMPLEMENTATIONS

5.1 Significance

This study will serve to increase awareness about the settlement hazard posed by collapsible soils of Kallar Kahar. It will provide valuable information to the planners and developers and alert individuals to situations where additional site-specific investigation by an engineer or geologist would be appropriate.

5.2 Practical Implementations

The research work is found to be of practical importance and beneficial for soil and foundation engineers to deal with collapsible soils. Potential hazard is identified in Kallar Kahar soils. Data obtained from collapse potential tests not only help the geotechnical engineers to identify the severity of problem, which in turn help them to specify the remedial measures, but also help them to estimate the potential settlement due to hydrocollapse. This study will help foundation engineers in designing a safe foundation system for regions like Kallar Kahar.

6 CONCLUSION & RECOMMENDATION

6.1 Conclusions

1) After the detailed analysis of nine (9) samples from various locations of Fauji Foundation Hospital and School at Kallar Kahar, District Chakwal, it is concluded that soils present around the FFHS, Kallar Kahar, are potentially collapsible and needs proper attention in this regard.
2) Degree of collapse present at site is moderate to sever as per ASTM D5333 Test.
3) Apparently soils are quite hard with low moisture content, but due to collapse potential are certain to settle which is the reason of wall cracking in light load structures.

6.2 Recommendations

6.2.1 Generally the artificial sources of infiltration are the major source of collapse. These sources include lined or unlined canals or sewerage drains, sub-surface pipelines and storage tanks, swimming pools, water reservoirs or septic tanks etc. Thus, it is recommended to take extreme care of all water-bearing surface or sub-surface structures or other features.

6.2.2 If collapsible soils are present up to shallow depths as compare to foundation depth then same can be simply removed during excavation and foundations can be provided on underneath competitive or un-collapsible strata. For slightly deeper depths, this purpose can be achieved with the provision of basement.

6.2.3 If collapsible soils are present up to deeper depths, which cannot be handled by removal, structural loads will have to be transferred to deeper strata by means of Pile Foundations. But still ground floor will require structural support.

6.2.4 Another reason of collapse is low density. With the increase in density, collapsible soils can be used as an excellent load bearing stratum. For the purpose, all collapsible soils are required to be removed from influence zone depth and same must be placed again with proper compaction.

6.2.5 Dynamic compaction i.e. dropping of several tons' heavy weights from several meters heights is another option, but cannot be recommended for a site where buildings or other structures exist in nearby.

6.3 Suggestions for Future Research

1) Further study of collapse potential is needed not only in Kallar Kahar but for other areas of Pakistan.
2) It is suggested to develop some strategy for field testing of such soils to collect some quantitative data by means of Plate Load Test on soaked and un-soaked soils.
3) Study to asses the loss in shearing strength should be performed based on extensive unconfined compression and direct shear tests on un-soaked and soaked samples.
4) Study to asses the relationship between collapse and salt content of Kallar Kahar soils should also be performed.

ACKNOWLEDGMENT

I really enjoyed this research work under the guidance of Geotech Faculty of UET Taxila, Pakistan, which enhanced my practical knowledge. I thank them all very honestly for their magnificent guidance and help. The careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

REFERENCE

[1] Mahnam Roohi Hir, Michael Yousefadeh, and Rouzbeh Dabiri, 'Evaluation of Collapsibility Potential in Soil Layers Based on Practical Methods (Case study: Hir City-Ardabil Province)," *Advance Researches in Civil Engineering* Volume 1 No. 2, pp. 48-55, 2019

[2] Jennings, J. E. and Knight, K., "A Guide to construction or with materials exhibiting additional settlement due to collapse of grain structure", 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Durban, South Africa, September, 1, pp. 99-105, 1975

[3] *Tom* Schanz and *Hussein* H. Karim, "Geotechnical characteristics of some Iraqi gypseous soils", MATEC Web of Conferences 162, 2018.

[4] Rafie, B. M. A., Ziaie Moayed R., and Esmaeli. M., "Evaluation of Soil Collapsibility Potential: A Case Study of Semnan Railway Station", Electronic Journal of Geotechnical Engineering, EJGE; 13(G): pp. 1-7, 2008.

[5] Alan, J. L., & Robert, T. S. "Determination of collapse potential of soils", 1988.

[6] ASTM D5333-03. Standard Test Method for Measurement of Collapse Potential of Soils.

[7] Asuri, S., Konanur, P. R., & Sudhakar, M. R., "Collapse behavior of an artificially cemented clayey silt", 1995.

[8] Basma, A. A., & Tuncer, E. R. 1992, "Evaluation and control of collapsible soils", *Journal of Geotechnical Engineering*, *118*(10), pp. 1491-1504, 1992.

[9] Bell, F. G., & Bruyn, I. D., "Sensitive, expansive, dispersive and collapsive soils", *Bulletin of the International Association of Engineering Geology*, (56), pp. 19-38, 1997.

[10] Houston, S. L., & Houston, W. N., "Collapsible soils engineering", In *Unsaturated Soil Engineering Practice* (pp. 199-232). ASCE, 1997.

[11] Houston, S. L., Mahmoud, H. H., & Houston, W. N., "Down-hole collapse test system. *Journal of geotechnical engineering*, *121*(4), pp. 341-349, 1995.

[12] Ismael, N. F., Jeragh, A. M., Mollah, M. A., & Al-Khalidi, O., "Factors affecting the collapse potential of calcareous desert sands", In *Proceedings of the 9th Southeast Asian Geotechnical Conference* (Vol. 1, pp. 5-14)., 1987.

[13] Jennings, J. E., & Knight, K., "The additional settlement of foundations due to a collapse of structure of sandy subsoils on wetting", In *Proceedings* pp. 316-319, 1957

[14] Lovelace, A. D., Bennett, W. T., & Lueck, R. D., "*A test section for the stabilization of collapsible soils on Interstate 25* (No. MB-RR-83-1), 1982.

[15] Mashhour, I., "*Negative skin friction on single piles in collapsible soil* (Doctoral dissertation, Concordia University), 2009.

[16] Pells, P., Robertson, A., Jennings, J. E., & Knight, K., "*A guide to construction on or with materials exhibiting additional settlement due to" collapse" of grain structure* (No. Conf Paper), 1975.

[17] Pengelly, A. D., Boehm, D. W., Rector, E., & Welsh, J. P., "Engineering experience with in-situ modification of collapsible and expansive soils. In *Unsaturated Soil Engineering Practice* (pp. 277-298). ASCE, 1997.

[18] Rollins, K. M., & Rogers, G. W., "Mitigation measures for small structures on collapsible alluvial soils", *Journal of Geotechnical Engineering*,*120*(9), pp. 1533-1553, 1994.

[19] Souza, A., Cintra, J. C. A., Vilar, O. M., Alonso, E. E., & Delage, P., "Shallow foundations on collapsible soil improved by compaction", *Unsaturated Soils*, *Vols 1 and 2*, pp. 1017-1021, 1995

[20] Stumpf, A. J., "Collapsing Soil Hazards", In *Encyclopedia of Natural Hazards*, pp. 99-105, Springer Netherlands, 2013.