Geotechnical Investigations of an Earth-filled Site for Construction of a Building

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Abstract

There is a growing need of construction around the globe. This need tends to provide newer opportunities for construction of buildings over reclaimed lands or earth filled areas. Mostly, the earth is filled with soils as it is an easily available material. Soil is a complex materials, and its properties can vary due to several reasons. If not understood properly, it can damage undisturbed samples collected from earth-filled soils. The basic properties of soils, the stress-strain behavior and strength parameters are presented and discussed. Results show that soil exhibits strain hardening and normally consolidated behavior in direct shear and oedometer test respectively. It is observed that the compression index values are in the range of 0.157 to 0.182 which indicates that the material is silty soils with low plasticity. The allowable bearing capacity in our study was 305 kPa and allowable load on footing was 987 kN. The strength parameters, i.e., friction angle and cohesion are 37°and 2 kPa respectively.

Keywords—Oedometer Test, Direct Shear Test, Laboratory Investigation, Bearing Capacity, Shear Strength

1 Introduction

Due to the growing needs of construction industry and to facilitate human beings, sometimes the construction is done on locations where either land is reclaimed or earth filled [1]. Construction on such sites need a great deal of care and may have severe consequences of settlements if the material properties are not understood properly [2]. The depressions in the site are most often filled with borrowed soils to prepare the ground to a uniform surface for further construction [3][4]. The soil is a complex material having different properties which mainly depend upon the size of soil particles, moisture content, and particle packing due to different compactions, etc. [5][6][7]. These properties can influence the structure constructed above it. For example, if the structure is constructed on loose soils, it may later result in significant settlements leading to failures.

Several studies on failures in reclaimed soils are reported in literature [8]. Reclaimed soils usually contain clay and silt particles which can settle with time resulting failure of structures [9]. This is mostly because the soil is frequently dumped in mass scale, and does not allow it to settle properly and is exposed to creep on long term loading.

This study is conducted on an uneven surface which has been leveled by dumping the soil in depressions. The other reason apart from the leveled ground was to raise the elevation. It is a common trend in Pakistan that structures are constructed at raised elevations. This is done because, with time, the elevation of roads raise up and create several problems, especially drainage of nearby building. This research is presented based upon the collected samples which were tested at the laboratories of the Civil Engineering Department, QUEST, Nawabshah. The samples were collected as undisturbed and disturbed at the depth around 1m from the surface of dumped soils. Sieve analysis on disturbed samples from various depths, Specific Gravity SG, Oedometer tests and direct shear tests were performed. Based upon performed tests, the evaluations for bearing capacity are made for maximum allowable load.

ISSN: 2523-0379 (Online), ISSN: 1605-8607 (Print)
DOI: 10.52584/QRJ.1802.11

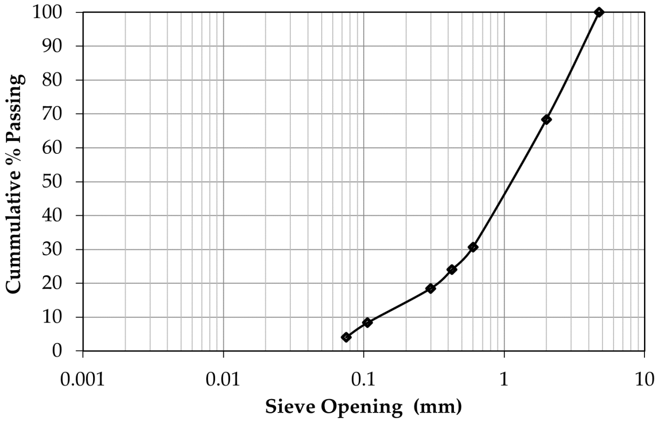

Fig. 1: Summary of sieve analysis performed for materials collected from 15 feet below the ground

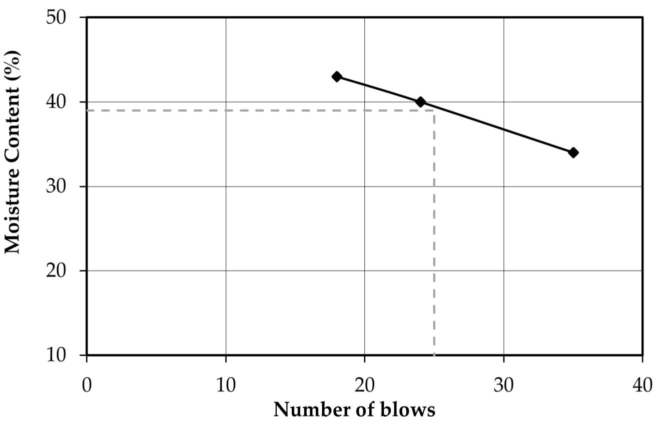

Fig. 2: The example of test performed for liquid limit for materials collected from 15 feet below the ground

2 Material & Methods

Based upon the collected samples and ocular analysis, it was concluded that mainly soil type was found to be clayey soils with the determined SG value of 2.68 and average moisture content around 20-25%. The typical sieve analysis curves are shown in Figure 1.
The liquid limits are plotted and shown in Figure 2. The liquid limits were found to be in the range of 20-40 WL (%) with plastic limits of 25-30.

3 Results

The following sections discuss the results of this study.

3.1 Compressibility and Compression Index

The collected soil samples were tested in oedometer tests. These tests were mainly performed to study soil behavior in response to applied vertical loading. Three oedometer tests were performed based upon ASTM [10] and evaluations are made for the consolidation

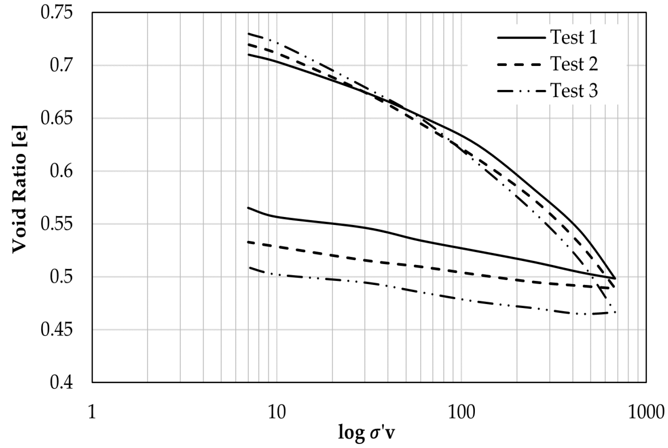

Fig. 3: The example of test performed for liquid limit for materials collected from 15 feet below the ground.

Description	Volume Compressibility (mv)	Compression Index (Cc)
Test 1	0.0002 m^2/MN	0.157
Test 2	0.00015 m^2/MN	0.168
Test 2	0.00015 m^2/MN	0.182

TABLE 1: The summary of tests

parameters.
The compressibility m_v can be defined as volume change due to increase in the effective vertical stresses [11]. The stress-strain behavior from oedometer tests, when plotted as void ratio versus logarithmic effective stresses ($e{-}\log\sigma'_v$), as shown in Figure 3, may form linear behavior which can be defined as the compression index C_c. The consolidation parameters are written as Equation 1 and Equation 2 respectively,

$$m_v = \frac{1}{1+e_0}\left(\frac{e_0 - e_1}{\sigma'_1 - \sigma'_0}\right)(m^2/MN) \tag{1}$$

$$C_c = \frac{e_0 - e_1}{\log\left(\sigma'_1/\sigma'_0\right)} \tag{2}$$

where, e is the void ratio and σ' is the effective stress. The compression index is used as a parameter to predict the settlement of the foundations. Higher the values of compression index, the higher the settlement will be.

The soil behavior in response to applied vertical loads in oedometer tests is shown below. It was observed that samples showed normally consolidated behavior NC and no sign of over-consolidation was observed. The specimens showed a significant void ratio reduction from 0.7 to 0.45 and the vertical strains showed up to 13.5% reduction. All the performed tests were subject to unloading as well. And it was observed

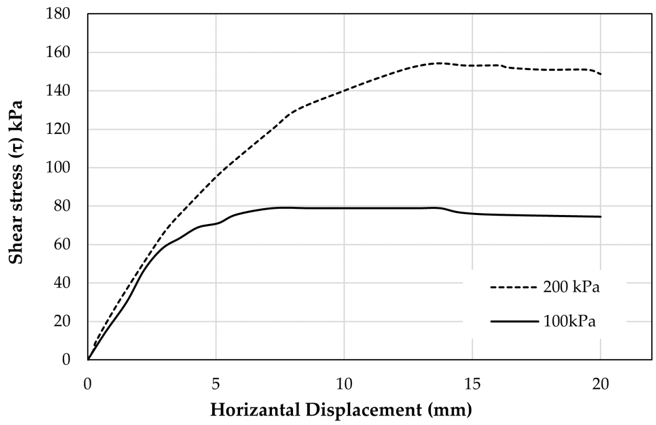

Fig. 4: The shear stress plotted against horizontal displacement of normal loads of 100 and 200 kPa.

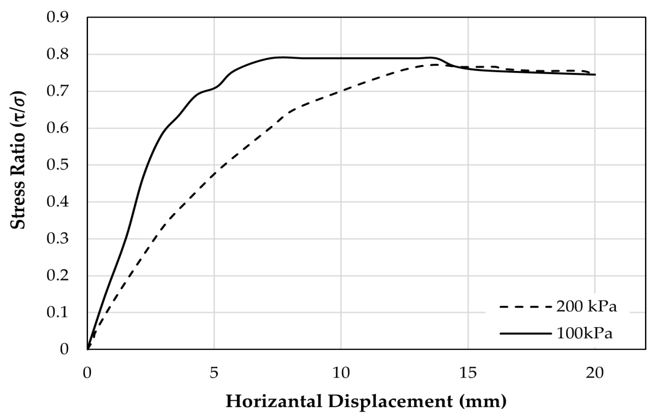

Fig. 5: Stress-strain behavior observed in direct shear tests.

that the material bounced back as much as 2.5% of its reduced height.

3.2 Shear Strength

Figure 4 shows the shear stress plotted against horizontal displacement at normal stresses. Whereas, Figure 5 shows the stress-stain behavior plotted against horizontal displacement in terms of stress ratios. The direct shear tests showed strain hardening behavior [12]. This behavior indicates that the sampling area is in loose state [13].

Figure 6 shows the strength parameters evaluated for the friction angle and cohesion. The strength parameters, i.e., cohesion and angle of internal friction were found to be 37.2°and 02 kPa respectively.

3.3 Bearing Capacity

The allowable bearing capacity of soil was calculated using the correlations as given in Equation 3 by using

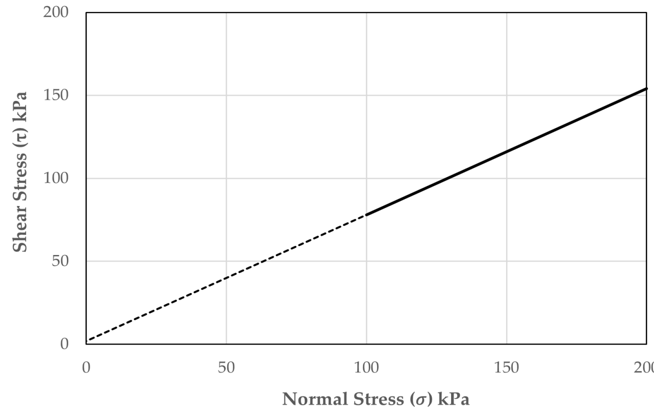

Fig. 6: Evaluation of strength parameters (c and phi).

Terzaghi's bearing capacity equation [14].

$$q_{ult} = cN_c s_c + qN_q + 0.5BN_y\gamma s_\gamma \quad (3)$$

The first part in Equation 3 cN_cs_c is related to cohesion term and denotes the strength due to cohesion. qN_q is the surcharge term and represents the breading capacity strength developed due to surcharge. $0.5BN_y\gamma s_\gamma$ is density term which represents strength of soil due to the density. c is Cohesion, N_c, N_q and N_y are Terzaghi's bearing capacity factors and values for friction angle of 35°are 57.8, 41.4 and 42.4 respectively [14]. B is the width of footing. s_c and s_γ are shape factors and their values for square and strip footings are 1.3, 0.8 and 1.0, 1.0, respectively.

The calculations are based on the following data. The unit weight of soils is 18 kN/m^3. Depth is assumed to be 5 ft below the natural ground (1.5 meters) and Factor of Safety (FOS) = 3.0.

The ultimate bearing capacity (q_{ult}) was found to be 916 kPa for column type footing of 1.5 square meters. Whereas, the allowable bearing capacity ($q_{allowable}$) = q_{ult}/FOS was 305 kPa. The total allowable load that can safely be placed on the footing of 1.5 × 1.5m was found to be 987 kN.

4 Discussion

It was observed that the compression index values were in the range of 0.157 to 0.182. This range is in comparison to silty soils of low plasticity as per previous studies [15]. However, soil types for collected samples were clayey type with low plasticity. Based upon the preliminary results that show the compression index of collected soils was similar as silty soils. However, the actual soils collected were more clayey and with low plastic values.

Considering the bearing capacity calculations, the calculated bearing capacity of 305 kPa was in accordance with range of silty soils. However, collected soils were more like silty clayey soils. The bearing capacity is mainly dependent of friction angle, which in this study, was found slightly higher. This can be the reason that the calculations returned slightly higher bearing capacity. At the same time, strain hardening behavior in direct shear test and normally consolidated behavior in oedometer test indicated the soils in loose state. Therefore, based upon laboratory tests in collected materials, it can be recommended that extreme care should be taken while designing the foundations on such soils. The foundations with a wider area to load bearing would be safer as compared to the foundations with shallow areas. Hence a raft footing is expected to perform better.

5 Conclusion

From the results of this study, it can be concluded that the materials collected were mainly silty soils with a specific gravity of 2.68 and having moisture content around 20-20%. Further conclusions are given as under.

- The liquid limits were found to be in the range of 20-40% with plastic limits in the range of 25-30.
- The volumetric compressibility (mv) was found to be 0.0002-0.00015 (m^2/MN).
- The strain hardening behavior in direct shear and normally consolidated behavior in oedometer tests were observed.
- The compression index (C_c) was found to be 0.157 to 0.182.
- Collected soils showed strain hardening behavior which implies loose soils.
- The friction angle was found to be 37°with negligible cohesion as 2 kPa.
- The allowable bearing capacity was found to be 305 kPa with maximum allowable load on footing of 1.5 × 1.5m was 987 kN.

Acknowledgement

This research was performed in the laboratories of Quaid-e-Awam University of Engineering Science and Technology, Nawabshah. The authors are grateful to QUEST for providing necessary resources to conduct this study.

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