REPORT ON GEOTECHNICAL INVESTIGATIONS

GARDEN CITY HOUSING SCHEME

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1. INTRODUCTION

1.1 General

A housing scheme named as Garden City Housing Scheme is being developed on link road connecting GT road ---------------------------. This report deals with geotechnical investigations conducted at the site of the proposed housing scheme.

The Geotechnical Engineering Laboratory of the Civil Engineering Department (CED), University of Engineering and Technology (UET), Lahore, was engaged by the Developers under the instruction of LDA, for carrying out sub-soil investigations at the proposed site.

The geotechnical investigations at the project site were conducted through the execution of seven (7) exploratory boreholes down to 80 ft depth below the existing ground level and seven test pits up to 9 ft depth. The fieldwork at the site was executed during ---------------2016.

1.2 Purpose and Scope of Work

The primary objective of this investigation was to determine the appropriate parameters for the design of foundations of the proposed facility. For this purpose, the following aspects were determined/evaluated:

1. Subsurface stratigraphy within the limits of exploratory borings.

2. Physical and engineering characteristics of the subsurface materials (strata) encountered.

3. Evaluation of subsoil parameters, recommendations for appropriate type of foundations, and allowable bearing capacity values to be used in the design of foundations of the proposed facility.

The scope of work for carrying out sub-soil investigations at the site included:

- Execution of seven (7) borings with auger/light percussion technique down to 80 ft depth below the existing ground level.
- Performance of standard penetration test (SPT) in the borehole at 3 ft interval up to 25 ft depth and thereafter at every 5 ft interval down to the investigated depth.
- Excavation of seven (7) test pits near the each borehole for recovering undisturbed soil samples and performing field density tests at every 2-3 ft interval. The test pits were excavated up to 9 ft depth below the existing ground level.
- Soil sampling with appropriate sampling techniques, sample preservation and transportation to the testing laboratory.
- Performance of laboratory tests on selected soil samples in accordance with relevant ASTM standard method.
- Preparation of geotechnical investigation report, which would include subsurface log, laboratory test data, and recommendations regarding allowable bearing capacity and type/depth of foundations.

1.3 Seismic Zone and Soil Profile Characterization

Seismic Zone

The project site is located in Zone-2A as per Seismic Zoning Map of Pakistan (BCP-2007) and for Zone-2A, the peak ground acceleration (PGA) is in the order of 0.08g to 0.16g. Therefore the foundation design must conform to the maximum peak ground acceleration of 0.16g.

Seismic Soil Profile

In accordance with the procedures described in Building Code of Pakistan (Seismic Provision 2007), the criteria for classification of un-cemented soil profiles are to be based on;

- Vs=average shear wave velocity of top 30m soil profile

- N=average field SPT resistance for the top 30m soil profile
- Su=average undrained shear strength for the top 30m soil profile

The following table on the next page defines the various seismic soil profile based on the above-mentioned soil parameters

Soil Profile Type	**Soil Profile Name/ Generic Description**	**Average Properties for Top 30 M (100 ft) of Soil Profile**		
		Shear Wave Velocity, v_s m/sec (ft/sec)	**Standard Penetration Tests, *N* [or N_{CH} for cohesionless soil layers] (blows/foot)**	**Undrained Shear Strength, s_u kPa (psf)**
S_A	Hard Rock	>1,500 (>4,920)		
S_B	Rock	750 to 1,500 (2,460 to 4,920)	–	–
S_C	Very Dense Soil and Soft Rock	350 to 750 (1,150 to 2,460)	>50	>100 (>2,088)
S_D	Stiff Soil Profile	175 to 350 (575 to 1,150)	15 to 50	50 to 100 (1,044 to 2,088)
S_E[1]	Soft Soil Profile	<175 (<575)	<15	<50 (<1,044)
S_F	Soil requiring Site-specific Evaluation. See 4.4.2			

Based on the above mentioned parameters derived through field and laboratory investigations for project site area, the average soil profile of the project site as per Building Code of Pakistan (Seismic Provision 2007) is classified as **S_E (i.e., soft soil profile).**

EXPLORATION METHODOLOGY

2.1 Field Investigations

The following activities were carried out in the field for accomplishing the geotechnical investigations in accordance with the scope of work.

- Execution of exploratory borings
- Conducting SPTs in the boreholes
- Excavation of test pits and performance of filed density tests
- Soil sampling

The following section briefly describes the field activities.

2.1.1 Execution of Exploratory Borings

The borings were advanced using auger/light percussion technique. The location of the exploratory borehole was marked by the representative of the client. The boreholes were kept stabilized below the ground water table by using a casing of diameter of 100 mm. Standard penetration tests (SPTs) were carried out in the borehole at 3 ft interval up to 25 ft depth and thereafter at 5 ft interval down to 80 ft depth. A careful record of all the materials encountered in the boreholes was maintained in the form of field boring logs. Data of in-situ tests (SPTs) conducted in the borings were also recorded on the borehole logs. The boring logs are presented in *Appendix-A*.

2.1.2 Conducting SPTs

For evaluating the consistency and compactness of the sub-soils, the standard penetration tests (SPTs) were performed in the borehole at 3-5 ft interval as mentioned above.

The SPTs were performed in accordance with ASTM D-1586. A donut type hammer, weighing 64 kg was used for conducting the test. Disturbed samples were recovered using Standard Penetration Test (SPT) split spoon sampler. Detailed description of the subsoils encountered and the depth at which samples were procured are given in borehole logs presented in Figures 2 thru

8 *Appendix-A*. Legends and symbols used in the boring logs are given in Figure 1-A. Soil descriptions on the boring logs are a compilation of field and laboratory testing data. The stratification lines represent the approximate boundary between soil types, and transitions may be assumed gradual.

Estimates of relative density of granular soils and consistency of the cohesive soils given on the boring logs are based on the SPT resistance as recommended by Terzaghi and are shown in Table 1 under *Appendix-A.*

2.1.3 Exploratory Test Pits

Seven (7) open test pits were excavated down to 9 ft depth below the existing natural surface level (NSL) using hand-digging tools near each borehole as shown in the layout plan (Figure-1). These test pits were excavated to assess excavability of on-site materials and to have a visual examination of the subsoil stratigraphy and estimation of in-situ density. The field density test (FDT) was performed at every 3 ft depth interval and the soil samples were recovered from each depth for the laboratory for compaction tests. Subsurface logs were prepared for the test pits. The boring logs of the test pits are presented in Figures 9 thru 15 under *Appendix-A* following the boring logs.

2.1.4 Soil Sampling

Undisturbed soil samples (UDS) were recovered from test pits using Shelby tubes and disturbed soil samples were obtained from the boreholes through split spoon sampler while performing SPTs. The SPT samples were placed in polythene bags. The polythene bags were clearly labeled to indicate the project name, boreholes designation and depth of the sample.

All the soil samples were carefully transported to Geotechnical Engineering Laboratory of UET Lahore for carrying out the laboratory testing.

2.2 Laboratory Testing

Selected representative subsoil samples were tested in GSC geotechnical engineering laboratory to determine the physical and engineering characteristics of the subsoils. The following tests were conducted according to the relevant ASTM standard methods.

- Natural Moisture Content

- Bulk Density
- Grain Size Analysis
- Atterberg Limit's Limits (LL and PL)
- Unconfined Compression Test
- Direct Shear Test
- Modified Proctor Compaction on Test Pit Samples
- 3-Point Soaked CBR on Test Pit Samples
- Chemical analysis on water and soil samples

A summary of laboratory test results is presented in Table 2 and Table 3 under *Appendix-A.* The detailed worksheets of the laboratory test results are presented under *APPENDIX-B.*

2.2.1 Discussion of Field and Laboratory Results

The field and laboratory findings are summarized below:

1. Based on the SPT-N values, the consistency of cohesive soil up to 7~8 ft depth exists in soft to medium stiff condition, whereas the sandy silt/sand stratum from 8 ft to 30 ft depth exists in loose condition followed by medium dense sand up to 48 ft and then followed by stiff clay stratum.
2. The natural moisture content of sub-soils up to 9 ft depth ranges between 10 % and 23 %.
3. The in-situ dry density up to 9 ft depth ranges from 93 pcf to 111 pcf at the locations of the FDTs.
4. The liquid limit values of the selected soil samples are between 38 % and 24 % and plasticity index values between 4 and 18.
5. Using grain size analyses and atterberg limits, soils were classified according to the Unified Soil Classification System (USCS), ASTM-2487 as indicated in Table 2. The cohesive subsoils up to about 7~8 ft depth is classified as CL-ML/ML (silty clay/sandy silt), whereas the non-cohesive stratum from 9 ft to 48 ft depth is classified as SM/SP-SM/SP (silty sand/poorly graded sand with silt/poorly graded sand). The stratum from 48 ft to about 78 ft depth is classified as CL (lean clay).

6. The unconfined compression test performed on undisturbed soil sample (UDS) recovered from test pits is in the order of 0.28~1.0 tsf except one value which is 4.6 ton/ft^2 where the sample was very stiff.

7. The direct shear tests performed on sand samples from various depths show the value of angle of internal friction (ϕ) between 26^o and 31^o with cohesion almost nil.

8. Modified Proctor compaction tests (ASTM D-1557) on three test pit composite samples give the value of maximum dry density (MDD) varying from 120 pcf to 121.5 pcf with optimum moisture content (OMC) varying between 12% and 13%. The results of modified compaction are summarized in Table 3.

9. Three point soaked CBR tests on three composite samples from test pits were conducted as per ASTM D-1883. The CBR value at 95% of modified proctor density is between 2.6 % and 4.0 %, whereas at 100% modified proctor density, the CBR value varies between 5% and 6%. The results of 3-point soaked CBR tests are summarized in Table 3.

10. The maximum sulphate and chloride contents in the subsoil samples are 0.002% and 0.015% where as in case of water samples the maximum sulphate content are 75PPM and Chloride 170 PPM, TDS 380PPM and pH as 7.7.

3. EVALUATIONS OF FIELD AND LABORATORY TESTS

3.1 General

The geotechnical investigation carried out at the proposed project site comprised field and laboratory work. The field and laboratory investigations were aimed at evaluating the engineering characteristics of the foundation soils. The subsurface conditions and the engineering characteristics of the soils existing at the proposed project site are discussed in the following section.

3.2 Stratigraphy

The field investigations at the project site have revealed the following subsoil stratigraphy along with range of SPT-N values and description of soil strata..

Depth below EGL (ft)	Legend	Classific-ation Symbol	Description of Subsoil Strata	Ground Water Table
7~8		CL/ CL-ML	Brown, soft to medium stiff lean Clay/silty Clay SPT-N= 4~8	GWT 7~13 ft below NSL during investigation GWT 11~17 ft below NSL as measured on 26-11-2016
11~15		ML	Light grey, loose, sandy Silt SPT-N=6~12	
43~48		SM/ SP-SM	Light grey to grey, loose to medium fine sand with variable amout of silt SPT-N=7~20	
74~78		CL	Brown, stiff to very stiff, lean Clay/ silty Clay *Note:* in case of BH-2 & BH-3, there encounters a sand layer between 53~64 ft depth within the clay layer SPT-N=12~22	
80		SP	Grey, medium dense, poorly graded Sand *Note:* in case of BH-2, this layer was not encountered	

The actual thickness of each stratum along with SPT resistance (N-values) is shown in the boring logs (Figures 2 thru 8) Appendix-A.

3.3 Groundwater Table

In order to monitor the ground water table in all the borings, piezometric pipes were inserted in all the boreholes with their ends plugged and with perforated pipe of about 9~10 ft at the bottom. The ground water table (GWT) was measured in all the boreholes through the pipes during the period of the investigation. Later on the indication of the client that the water table in the boreholes has dropped to some extent, our representative in the presence of the client again noted the water table observation in all the boreholes on 26-11-2016. Both the ground water table observations are summarized in the following table:

Sr. no.	**Borehole #**	**GWT depth below EGL during 15~23 October 2016 (investigation period)**	**GWT depth below EGL on 26-11-2016**
1	BH-1	12 ft ----on 15-10-2016	17 ft
2	BH-2	13 ft ----on 15-10-2016	17 ft
3	BH-3	13 ft ----on 18-10-2016	15 ft
4	BH-4	09 ft ----on 19-10-2016	14 ft
5	BH-5	07 ft ----on 20-10-2016	11 ft
6	BH-6	07 ft ----on 21-10-2016	12 ft
7	BH-7	13 ft ----on 23-10-2016	14 ft

During the excavation of the test pits, the ground water table was encountered at 7 ft depth below EGL in two of the test pits (TP-5 & TP-6). However, during the observations on 16-11-2016, the water in these pits was not found and did seep into the ground and the pits were found dry.

The fall of the ground water table in the order of 4~5 ft in the borings may be due to the reason that during the drilling process, the water was added in the boreholes which raised the level of the water table. The earlier observation was taken during the field work where the water table could not become in equilibrium to original ground water table which did happen as a result of sufficient time elapse in later observation. The disappearance of water in two of the test pits indicates that the water table encountered in these two pits was a perched water table and not the actual ground water table. From the above observations, it can be concluded that the ground water table at the site is within 11~17 ft depth below EGL. This difference of level may be due to difference in elevations of the investigation point which is up to about 3~4 ft.

3.4 Geotechnical Design Parameters

The basic subsoil parameters of different subsoils used in the engineering analyses and design are summarized below: The papameters have been selected from field and laboratory test data and using the general engineering judgment.

Soil Properties	**Stratum # 1** (0-9 ft)	**Stratum # 2** (9-48 ft)	**Stratum # 3** (48-80 ft)
USCS Classification Symbol	CL/CL-ML	SM/SP-SM	CL
Bulk unit weight (lbs/ft^3)	116	105	118
Cohesion (ton/ft^2)	0.50	0	1.0
Angle of internal friction, ϕ, (deg)	0	28	0
Elastic Modulus, Es (MPa)	5.0	20.0	15.0

4. RECOMMENDATIONS FOR FOUNDATION DESIGN

4.1 Foundation Design Criteria

When designing foundations for any structure, there are two criteria, which must be considered and satisfied separately:

- There must be an adequate factor of safety (FOS) against a shear failure or ground break, generally called bearing capacity failure. The factor of safety against shear failure is generally taken as 3.

- The settlement should remain within reasonable limits. In case of shallow spread foundations, the permissible settlement, in general, is 25 mm and for mat, the permissible settlement is 50 mm. The pile groups are expected to settle to a much lower value, depending upon the configuration of the pile groups selected.

Furthermore, the foundation system selected must be compatible, economical, and feasible for construction. Preferably, the foundation should be constructed using local resources and should be environment friendly.

4.2 Safety Factors

A safety factor of 3 has been taken in to account against shear failure in shallow foundation design and the permissible settlement limits are 25 mm and 50 mm for isolated/strip and mat, respectively. The differential settlements are 12 mm and 25 mm for isolated/strip and mat, respectively.

4.3 Allowable Bearing Capacity for Shallow Foundations

At the subject site, the subsoil within shallow depth exists in soft to medium condition (up to 9 ft depth; therefore proper compaction control is required to be implemented before placing the shallow foundations at the project site. Keeping in view the above situation, we recommend to found the shallow foundations at 1m to 1.5m depth below the finished level of the buildings on a properly prepared foundation subgrade as recommended in the following section.

The calculation of allowable bearing pressures for various shallow foundations are based on shear failure criterion against a factor of safety of 3 and for permissible total settlement of 25mm and 50mm in case of strip/isolated footings and mat foundation, respectively. The limits of differential settlement are 12 mm and 25 mm for the above mentioned foundations, respectively. However, it is recommended to ensure the rigidity of the foundation system by providing plinth and/or tie beams between the isolated footings so as to keep the angular distortion between the adjacent loaded areas to within 1/300.

Based on the bearing capacity analyses, the bearing pressures based on shear failure criterion and for permissible settlement of 25 mm were calculated and the lowest value of the bearing pressure is referred to as allowable bearing capacity. The following are the results of allowable bearing capacities for strip and isolated square footings for the project area.

Results of Bearing Capacity Analysis for Strip Footing

	Footing width	**B=1.0m**	**B=1.5m**	**B=2.0m**	**B=2.5m**
Depth of footing 1.0 m	Bearing capacity w.r.t shear	0.76	0.76	0.76	0.76
	Bearing capacity w.r.t 25 mm settlement	1.20	0.92	0.78	0.75
Depth of footing 1.5 m	Bearing capacity w.r.t shear	0.86	0.86	0.86	0.86
	Bearing capacity w.r.t 25 mm settlement	1.4	1.01	0.95	0.85

Results of Bearing Capacity Analysis for Isolated Square Footing

	Footing width	B=1.0m	B=1.5m	B=2.0m	B=2.5m
Depth of footing 1.0 m	Bearing capacity w.r.t shear	0.99	0.99	0.99	0.99
	Bearing capacity w.r.t 25 mm settlement	1.20	0.92	0.78	0.75
Depth of footing 1.5 m	Bearing capacity w.r.t shear	1.10	1.10	1.10	1.10
	Bearing capacity w.r.t 25 mm settlement	1.4	1.01	0.95	0.85

Recommended Bearing Capacity for Strip/Square Footings:

*Based on the above analysis, we recommend an allowable bearing capacity of **0.75 tsf** both for strip and square footing if the footing is placed at 1 m depth below the existing ground level and an allowable bearing capacity **of 0.85 tsf** when the footings are founded at 1.5m depth.*

Allowable Bearing Capacity for Raft Foundation

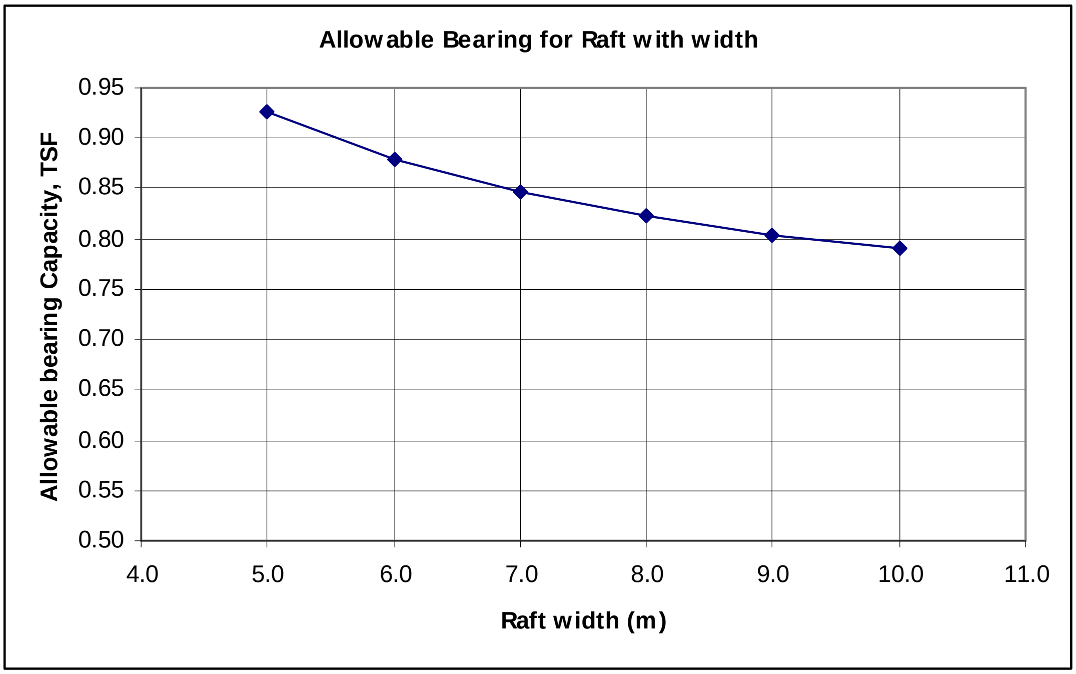
The evaluation of allowable bearing pressure for mat foundation has been made for a range of 5 m to 15 m width of raft to be founded at 1.5 m depth for permissible settlement of 50 mm using Bowles equation based on SPT-N value as given below.

$$q_a = (N/4)x(C_D/C_W)x\Delta_s$$

N = SPT-N value measured in the field
C_D = 1+0.33Df/B (less than or equal to 1.33)
C_W = 2-{D_W/(Df+B)}, Depth to GWT (between 1 & 2)
Δ_s = permissible settlement in inches, (2 inch for raft)

The results of bearing capacity analysis are summarized in the following table and also given as bearing capacity curve with varying width of raft foundation.

B (m)	B (ft)	B+Df	Cw	C_D=1+0.33D/B	q_a (ksf)	q_a (tsf)
5.0	**16**	**19.7**	1.5420	**1.0654**	3.10916	**0.93**
6.0	20	22.9	1.6075	1.0545	2.95193	**0.88**
7.0	23	26.2	1.6566	1.0467	2.84326	**0.85**
8.0	26	29.5	1.6948	1.0409	2.76369	**0.82**
9.0	30	32.8	1.7254	1.0363	2.70291	**0.80**
10.0	**33**	**36.1**	1.7503	**1.0327**	2.65498	**0.79**
11.0	36	39.3	1.7712	1.0297	2.61622	**0.78**
12.0	39	42.6	1.7888	1.0272	2.58423	**0.77**
13.0	43	45.9	1.8039	1.0252	2.55737	**0.76**
14.0	46	49.2	1.8170	1.0234	2.53451	**0.75**
15.0	**49**	**52.5**	**1.8284**	**1.0218**	2.51481	**0.75**



Preparation of Subgrade for Foundation Construction

The above analyses of bearing capacity are based on the assumption that the foundation subgrade will be properly compacted and the foundation will be constructed as mentioned below:

- Excavate the pit/ trench at the footprint of the foundation up to the foundation depth.

- Compact the bottom of the excavated area to 95% of Modified Proctor (ASTM-1557) density using appropriate compaction equipment. The field density should be checked either by core cutter or sand cone method to check the above compaction requirement.
- Provide a pad of lean concrete (1:4:8) under the foundation at least 6 inches thick.
- Construct the reverent foundation on the PCC layer.

4.4 Evaluation of Subgrade for Road Construction

Three samples of the on-site soils, collected from three test pits within 1~3 ft depth were tested for 3-point soaked CBR. A summary of the results is presented in Table 3. Appendix-B includes plots of CBR values versus dry density. The average soaked CBR value against maximum dry density (120~121.5 pcf) and optimum moisture content (12~13%) obtained from modified AASHTO compaction test is between 5 and 6 %. It is therefore recommended to adopt a CBR of 5% for designing the road pavement, in case the local on-site soils are to be used in the subgrade construction. In case, soils from some other source are to be used in the subgrade construction, CBR for pavement design should be determined by testing those materials.

4.5 Subgrade and Road Embankment Compaction

The following minimum compaction levels are recommended to be adopted in the earthwork for roadways:

Subgrade (30 cm):	98% Modified Proctor
Another 30 cm fill below subgrade:	95% Modified Proctor
Underlying fill:	92% Modified Proctor

4.6 Type of Cement and Protection of Substructure Concrete

The maximum sulphate and chloride contents in the subsoil samples are 0.002% and 0.015% and in case of water samples the maximum sulphate content are 75 PPM and Chloride 170 PPM which are very low values; therefore, the contents of sulphate and chloride are not injurious to the foundation structure. As per Concrete Manual of USBR, the British Standards and ACI Committee Report, no special precautions are required about the use of cement for the foundation construction. However, the cement contents not less than 310 kg/m^3 with maximum water/cement ratio of 0.55 should be adopted and a minimum rebar cover of the order of about 75 mm (3") should be ensured.

5. CONSTRUCTIONAL ASPECTS AND LIMITATIONS

We recommend the following measures for the long-term stability of structures.

- The analysis and recommendations submitted in this report are based on the results gathered from 7-borings at locations shown approximately in Figure 1 (Appendix-A). This report reflects an approximate variation of subsoil conditions between these locations. The nature and extent of variation may not become evident until the course of construction. It is recommended that all construction operations dealing with earthwork and foundations be observed by experienced personnel.

- The findings of this report are for general purpose and confirmatory borings in order to verify the finding of this report are recommended at the specific locations of various structures in the project area.

- Appropriate surface drainage should be ensured in the project area so as to reduce the subsequent ingress of surface water into the foundation subsoil. To assure positive protection, the plinth protection slab should extend beyond all round the structure at least 3 ft from the face of the periphery walls.

- This report has been prepared for the site of the Garden City Housing ------------. Paragraphs, statements, test results, boring logs, diagrams etc., should not be taken out of context and should not be utilized for any other structure at any site.