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SUBJECT. GEO TECHNICAL ENGINEERING

ASSIGNMENT TOPIC (BRT PESHAWAR GEO TECHNICAL REPORT),(SOFTWARE USED IN GEO TECHNICAL ENGINEERING)

DATE. 4JULY, 2020

Subsurface Lithological Profile across Peshawar City: A Case Study of Peshawar Sustainable Bus Rapid Transit Corridor

Abstract: Peshawar Sustainable Bus Rapid Transit Corridor Project (BRT Peshawar) is a large scale public transportation project initiated by Government of Khyber Pakhtunkhwa, encompassing 20 kilometers of elevated track along its 28km route across Peshawar City, from Chamkani to Hayatabad via Saddar. Based on the structural load requirements and subsurface conditions of Peshawar, deep pile foundations i.e. bored cast in-situ concrete piles were proposed for this elevated track. This track involved deep foundations in varying strata from silts and clays overlain by gravel, to a mix of gravel, sand and clay layers to a continuous sandy gravel stratum. It was proposed to carry out preliminary pile load tests following ASTM D1143 along the BRT alignment to validate the interpreted soil parameters obtained from initial geotechnical investigations and proof load tests to confirm the designed ultimate bearing capacity & settlement of piles under working load. For a total of 2500 piles, upto a maximum depth of 35m, 16 preliminary pile load tests and 21 proof load tests were performed. This paper discusses the collective results of static pile load tests performed across BRT Peshawar.

1 INTRODUCTION

1.1 Background

Peshawar Sustainable Bus Rapid Transit (BRT) Corridor Project, more commonly referred as BRT Peshawar, is a massive undertaking of revitalizing the road infrastructure and tackling Peshawar's chaotic and mismanaged traffic, and rundown urban transportation network. It primarily consists of a dedicated bus corridor for public transport, which runs across the Peshawar City, going through some of the busiest places in dire need of an efficient transport network.

Peshawar Development Authority (PDA) is the main proponent for the construction of this project, with funding provided by the Asian Development Bank (ADB). A joint venture of Mott MacDonald Ltd. (UK) and MM Pakistan (Pvt.) Ltd. were assigned as the Engineering, Procurement and Construction Management (EPCM) Consultant for this project.

The project is divided into three phases referred to as "Reaches", as shown in Figure 1.

Reach 1 corridor starts at Chamkani, going westward towards Fort Bala Hisar on the Main GT Road. Reach 2 turns from the fort towards Saddar via Railway and Saddar Roads and ending at Aman Chowk. Reach 3 continues on University Road entering Hayatabad through an elevated track erected in Tajabad Nallah, crossing Tatara Park on Ring Road, and finally concluding the 28km route at Karkhano Market.

Due to space constraints in the urban environment of Peshawar, around 20km of elevated tracks, consisting of 2500 piles, have been constructed in order to facilitate the main BRT corridor, the additional structures for mixed traffic and the connection to existing road infrastructure and feeder routes. The Reach 2 BRT corridor, in almost its entirety is elevated, whereas Reach 1 and 3 are mostly at grade.

Owning to the scale of the project and considering the erratic subsurface stratigraphy across Peshawar revealed at the design stage, it was decided to conduct the Preliminary Test Piles (PTP), in accordance with ASTM D1143 [3] and reaffirm the pile design from Proof Load Test (PLT) on working piles.

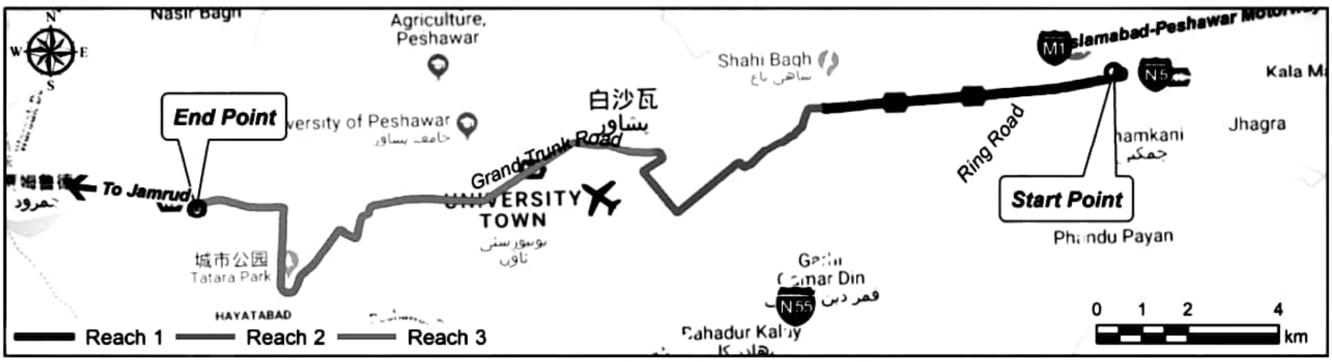


Figure 1: BRT Alignment Layout Plan across Peshawar City

2 GEOTECHNICAL INVESTIGATIONS

2.1 Borehole Drilling

The design stage investigations were conducted by the EPCM Consultants through subcontracting the works to third party drilling contractors. A total of sixty-nine (69) boreholes, with SPT (621) carried out in alternate boreholes, were conducted for the main corridor upto a maximum depth of 35m. SPT profiles for each of the Reaches have been shown in Figure 2.

Based on this information, the detail design was prepared and it was recommended to PDA to conduct PTP to finalize the pile design. It was however implied by PDA, that due to fast pace of the project the construction be carried out as per the detail design investigations and PTP to be conducted alongside the construction activities. Once the PTP were completed, the design of remaining piles can be optimized based on the results and PLT on working piles can validate the updated design.

In Reach 2, confirmatory investigations were conducted, owing to the variable strata encountered during construction and a total of twenty (20) confirmatory boreholes were drilled for the optimization of pile design. In Reach 3, upon instruction of PDA, an additional 1.8km of elevated track was augmented in to the exiting alignment, previously terminating in Hayatabad to extend the corridor to Karkhano Market. For this purpose five (5) additional boreholes were drilled. The following Table 1 summarizes the total borehole investigation carried out.

Table 1: Summary of Boreholes on BRT Peshawar*

Depth	Reach 1	Reach 2	Reach 3	Total
≤15m	12 + 0	7 + 0	18 + 0	37
15m-30m	6 + 0	5 + 20	5 + 0	36
>30m	1 + 0	13 + 0	2 + 5	21
Total	19	45	30	94

*No of boreholes conducted in design + construction phase

2.2 Subsurface Lithology

The investigations reveal a combination of various stratified layers across the BRT corridor. Generally Reach 1, in the east of the city, is at a lower elevation and a relatively flat alluvial plain in the main Peshawar Basin [9]. The soil consists of deep deposits of intermixed silt and clay layers, from the surface upto around 30m, with irregular pockets of sand, underlain by sandy gravels with occasional cobbles as large as 150mm (6in) in diameter. The clays are mostly soft and compressible in the upper 10m of the strata, underlain by medium stiff silty clays and sandy gravel with high internal friction.

Reach 2 has a mildly steep terrain with a diversity of soil stratifications. These stratifications include sandy gravel layer encountered at much shallower depths of around 17m, overlain by clays. In some areas there is complete reversal of stratification with sandy gravel at the top upto a depth of 17m underlain by deep entrenches of clay extending upto 35m in depth. A stratum near Aman chowk consists of stiff clays extending to a depth of 35m with no traces of either sand or gravel.

In Reach 3, off shooting from Aman chowk to Tehkal, the stratum generally consists of stiff clay on top of sandy gravel at around 25m. The elevation of this westward Reach is significantly higher and the terrain is considerably steeper, which is why towards the end of the alignment through Hayatabad, there are deposits of mixed layers of sandy gravel or gravelly sand, with occasional very stiff clay layers of thicknesses less than 1m.

The following Figure 3 summaries the types of generalized lithologies encountered during ground investigations and the design parameters that were ascertained based on extensive laboratory testing carried out in the design stage and the SPT-N values obtained from the field.

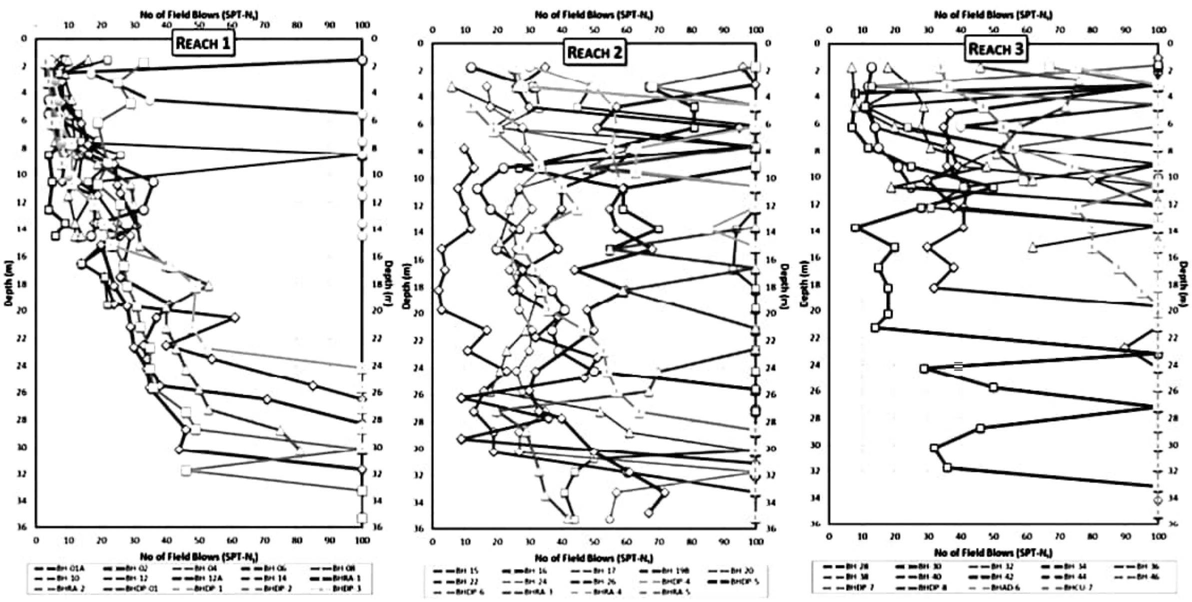


Figure 2: SPT Profiles across each Reach

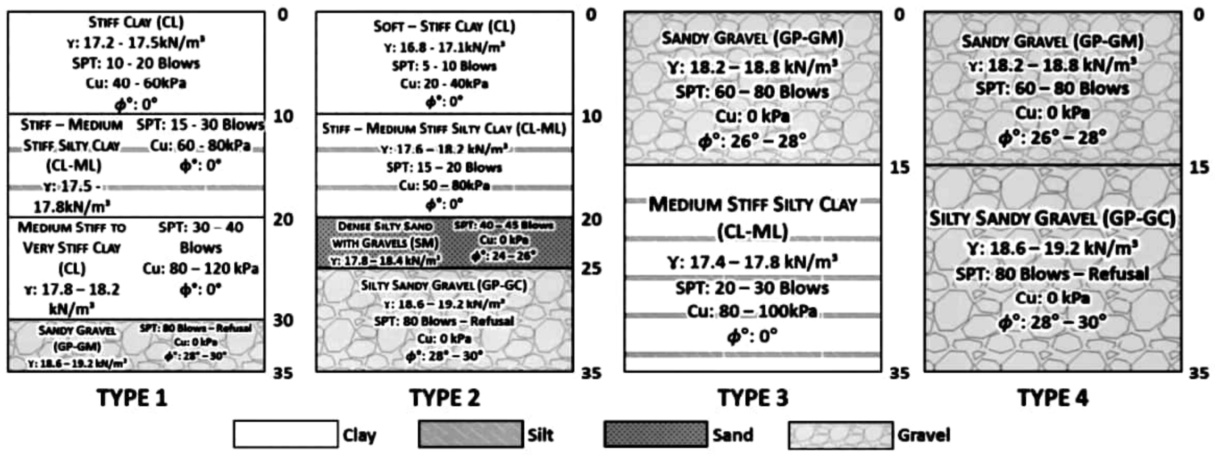


Figure 3: Type of Stratum encountered across BRT Peshawar

3 DESIGN METHODOLOGY

The following general equations [11] [14] have been used for calculating the ultimate bearing capacity of piles

$$Q_{ult} = f \times A_s + q \times A_b \tag{1}$$

Where:

Q_{ult} = Ultimate Bearing Capacity of Piles (kN)
A_s = Surface area of pile shaft (m^2)
A_b = Base area of tip of pile (m^2)
f = Shaft unit friction (kPa)
q = Capacity at Tip (kPa)

Since both cohesionless and cohesive stratification have been encountered along the BRT alignment, both design consideration must be taken. For cohesionless soils, the following equations have been used.

$$f = \sigma'_v\, k_o\, \mathrm{Tan}(\delta) \tag{2}$$

$$q = (\sigma'_v)_{tip}\, N_q \tag{3}$$

Where:

σ'_v = Effective overburden pressure (kPa)
k_o = Coefficient of Earth Pressure
δ = Angle of friction between pile and soil
N_q = Bearing Capacity factor

For cohesive soils, the shaft unit friction and the tip capacity have been calculated using these equations:

$$f = \alpha\, c \tag{4}$$

$$q = cN_c \tag{5}$$

Where:

α = Adhesion Factor
c = Cohesion (kPa)
N_c = Bearing Capacity factor = 9

Initially for the design of piles for BRT, both NAVFAC and USACE standards were considered for the determination of various parameters listed above. However, ultimately the design of the pile was based on USACE for allowable strength design. Equations used for both standards have been presented in Table 2.

Table 2: Pile capacity parameters

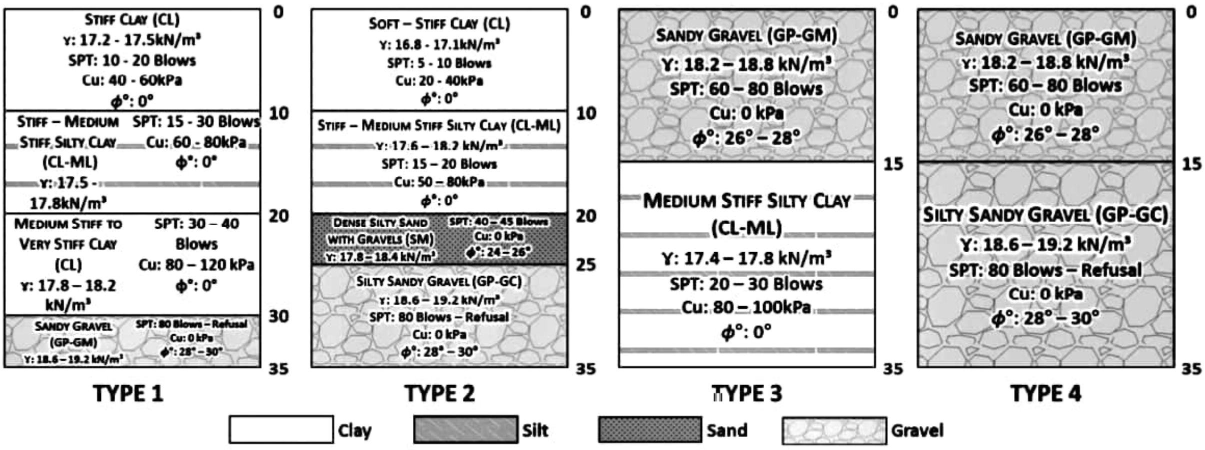
Standard	k_o (Compression)	δ (Concrete)	α	N_q
USACE EM 110-2-2906 [14]	1.0 – 2.0	$0.9\phi° - 1.0\phi°$	$c < 0.25$tsf (24kPa) $\alpha = 1.0$ $0.25 \leq c \leq 0.75$tsf $1.0 \leq \alpha \leq 0.5$ $c \geq 0.75$tsf (72kPa) $\alpha = 0.5$	$N_q = \dfrac{e^{2\left(\frac{3\pi}{4} - \frac{\phi^r}{2}\right) Tan\,\phi°}}{2\,Cos^2\left(45 + \frac{\phi°}{2}\right)}$ After Terzaghi [6]
NAVFAC DM 7.02 [11]	0.7 (for drilled pile less than 0.6m (2ft) in diameter)	$0.75\phi°$	See Figure 4	See Table 3

Where:

$\phi°$ = Angle of Internal Friction in degrees
ϕ^r = Angle of Internal Friction in radians

Table 3: $\phi°$ vs N_q after NAVFAC DM 7.02 [11]

$\phi°$	26	27	28	29	30	31	32	33
N_q	5	6.5	8	9	10	12	14	17
$\phi°$	34	35	36	37	38	39	40	-
N_q	21	25	30	38	43	60	72	-



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$$f = \sigma'_v \, k_o \, \text{Tan}(\delta) \qquad (2)$$

$$q = (\sigma'_v)_{tip} \, N_q \qquad (3)$$

Where:

σ'_v = Effective overburden pressure (kPa)

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δ = Angle of friction between pile and soil

N_q = Bearing Capacity factor

For cohesive soils, the shaft unit friction and the tip capacity have been calculated using these equations:

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$$q = cN_c \qquad (5)$$

Where:

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c = Cohesion (kPa)

N_c = Bearing Capacity factor = 9

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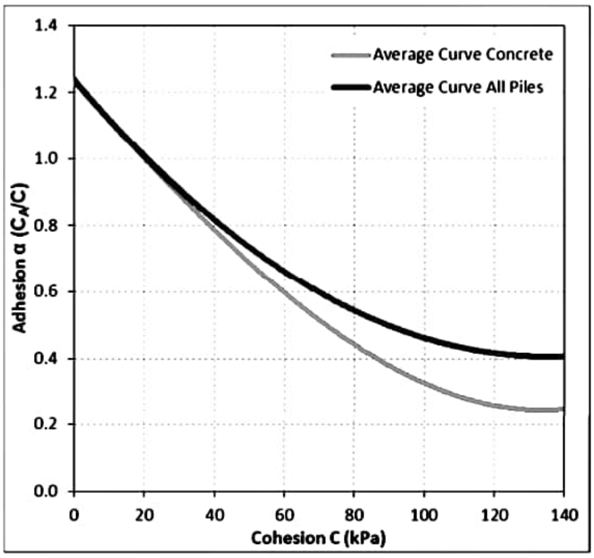

Figure 4: Adhesion vs. Cohesion converted from psf to kPa after NAVFAC DM 7.02 [11]

4 PILE LOAD TESTING PLAN

Considering the structural load requirements of the elevated BRT track, a pile diameter of 1.20m was selected en masse for the project, with varying lengths of pile depending on the strata. All the PTP and PLT's were conducted with this same diameter across the BRT alignment. The following Table 4 summarizes number of tests conducted, and Figure 5 shows the locations of these tests.

Table 4: Summary of PTP & PLT conducted:

Location	No of PTP	No of PLT
Reach 1	2	2
Reach 2	10	16
Reach 3	4	3
Total	16	21

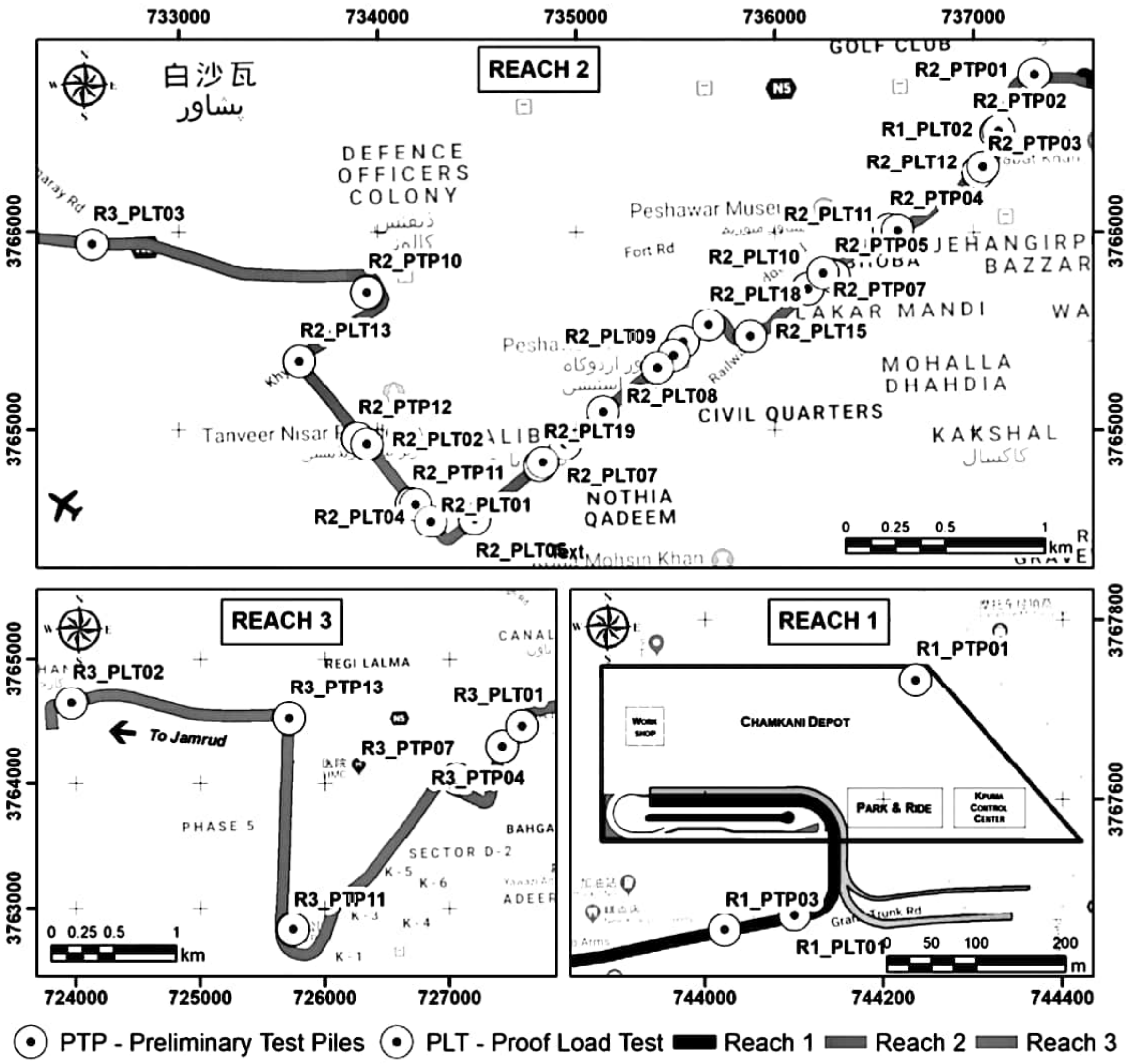

Figure 5: Pile Load and Proof Load Test Locations

4.1 Testing Arrangement & Procedure

The testing arrangements were carried out as per ASTM D1143 [3], by placing concrete blocks stacked in a pyramid scheme, resting on a steel girder platform, with similar concrete blocks as supports in the corners, embedded firmly in the ground as shown in Figure 6. The load was transferred to the pile through a hydraulic jack on a steel plate, placed on the evenly leveled and smoothened pile head, for uniform distribution of load.

Figure 6: Pile Load Test platform with concrete blocks in pyramid configuration in Reach 3 (R3_PTP13)

The reference beams were placed on either side with its supports at a clear distance of at least 2.5m. Three pre-calibrated deflection dial gauges, with a least count of 0.01mm, were mounted with magnetic clamps with their tips on smooth glass surface fixed on the reference beam as shown in Figure 7.

Loading was applied at an increment of 25% of the design load and was sustained for 1 hour and settlements were recorded at uniform intervals. The maximum loading was applied at 2.5 times the design load for PTP's and 1.5 times the design load for PLT's and was sustained for 12 hours. The removal of load was in a decrement of 50% of design load and sustained for 1 hour after each lowering, and 6 hours after final lowering.

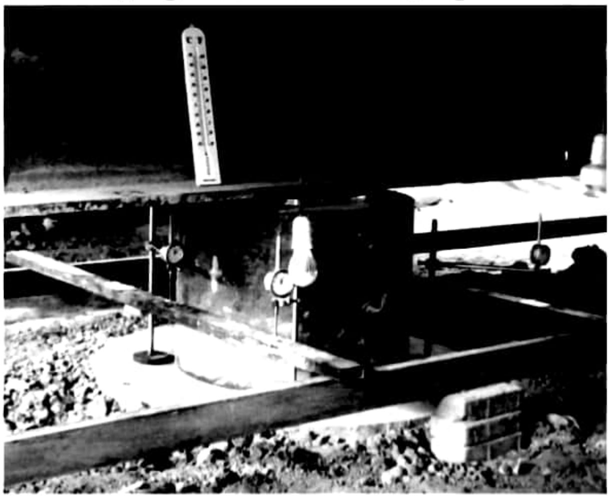

Figure 7: Arrangement of Hydraulic Jack, Reference Beam and settlement gauges in Reach 2 (R2_PLT13).

5 DISCUSSION ON RESULTS

The results of the all PTP conducted, including the total and net settlement, have been listed in Table 5 and results of all PLT have been listed in Table 6.

Table 5: Summary of PTP Results:

Test No	Strata	Pile Length (m)	Applied Load (Tons)	Total Settlement (mm)	Net Settlement (mm)
R1_PTP01	Type 2	35.0	1000	3.07	0.32
R1_PTP03	Type 1	32.5	1000	28.33	11.42
R2_PTP01	Type 1	20.5	1200	17.38	9.83
R2_PTP02	Type 3	32.5	1200	3.19	1.08
R2_PTP03	Type 3	30.5	1200	5.02	2.80
R2_PTP04	Type 3	32.5	1200	3.78	2.36
R2_PTP05	Type 3	20.5	1200	3.67	1.25
R2_PTP07	Type 3	20.5	1200	1.15	0.39
R2_PTP08	Type 1	32.5	1200	8.62	3.04
R2_PTP10	Type 2	20.5	1200	4.62	3.00
R2_PTP11	Type 3	20.5	1200	3.27	1.43
R2_PTP12	Type 1	20.5	1200	14.35	7.67
R3_PTP04	Type 4	25.0	900	7.05	6.46
R3_PTP07	Type 4	26.0	900	4.51	2.28
R3_PTP11	Type 4	25.0	900	2.32	0.36
R3_PTP13	Type 4	25.0	1000	8.28	4.75

Table 6: Summary of PLT Results:

Test No	Strata	Pile Length (m)	Applied Load (Tons)	Total Settlement (mm)	Net Settlement (mm)
R1_PLT01	Type 1	28.0	600	3.71	0.83
R1_PLT02	Type 1	33.0	600	3.39	0.98
R2_PLT01	Type 4	23.0	720	3.86	2.57
R2_PLT02	Type 1	23.0	600	4.23	1.26
R2_PLT03	Type 1	23.0	600	3.22	0.50
R2_PLT04	Type 3	17.0	450	3.50	0.57
R2_PLT05	Type 3	23.0	600	3.90	0.56
R2_PLT06	Type 3	17.0	450	2.41	1.70
R2_PLT07	Type 3	31.0	600	4.15	2.49
R2_PLT08	Type 3	23.0	450	2.37	1.80
R2_PLT09	Type 1	23.0	600	3.54	2.56
R2_PLT10	Type 4	23.0	600	2.15	0.58
R2_PLT11	Type 3	25.0	600	2.54	0.76
R2_PLT12	Type 3	25.0	600	4.24	0.97
R2_PLT13	Type 1	17.0	450	2.56	1.20
R2_PLT15	Type 3	17.0	600	3.22	0.89
R2_PLT18	Type 4	17.0	600	2.61	1.21
R2_PLT19	Type 3	23.0	450	3.84	1.30
R3_PLT01	Type 2	31.0	450	7.36	4.03
R3_PLT02	Type 4	27.5	600	2.26	1.42
R3_PLT03	Type 2	28.0	600	2.72	0.54

The load versus settlement profile for both PTP and PLT have been depicted in graphs with respect to each Reach, and have been presented in Figure 8, Figure 9 and Figure 10 for Reach 1, 2 and 3 respectively.

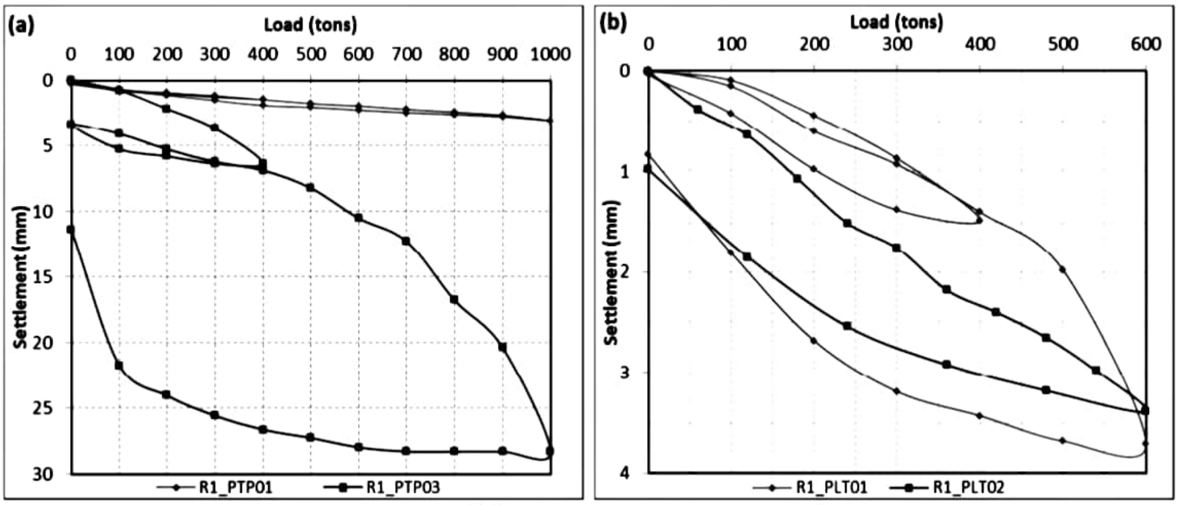

Figure 8: Reach 1 Pile load test results (a) PTP and (b) PLT

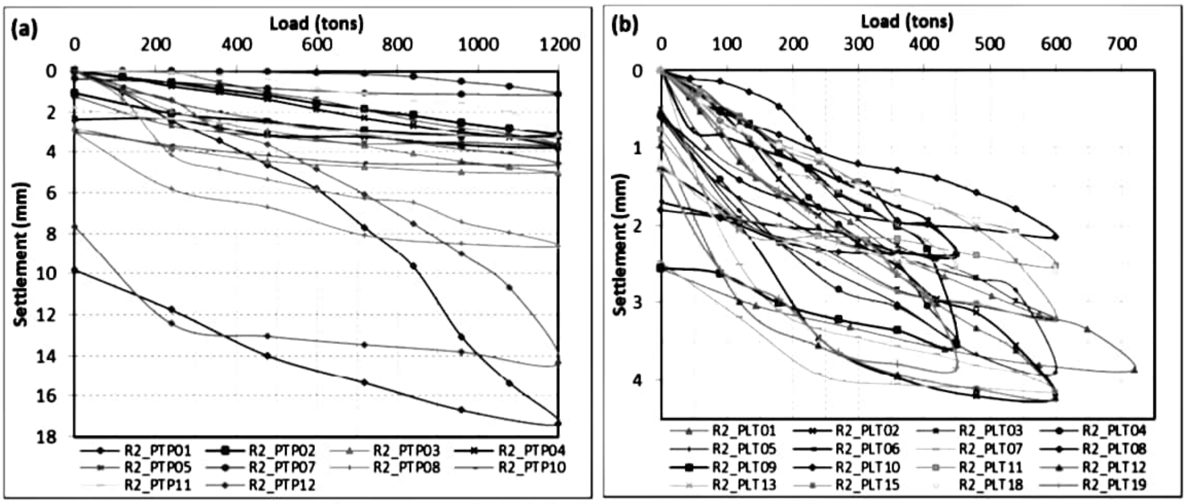

Figure 9: Reach 2 Pile load test results (a) PTP and (b) PLT

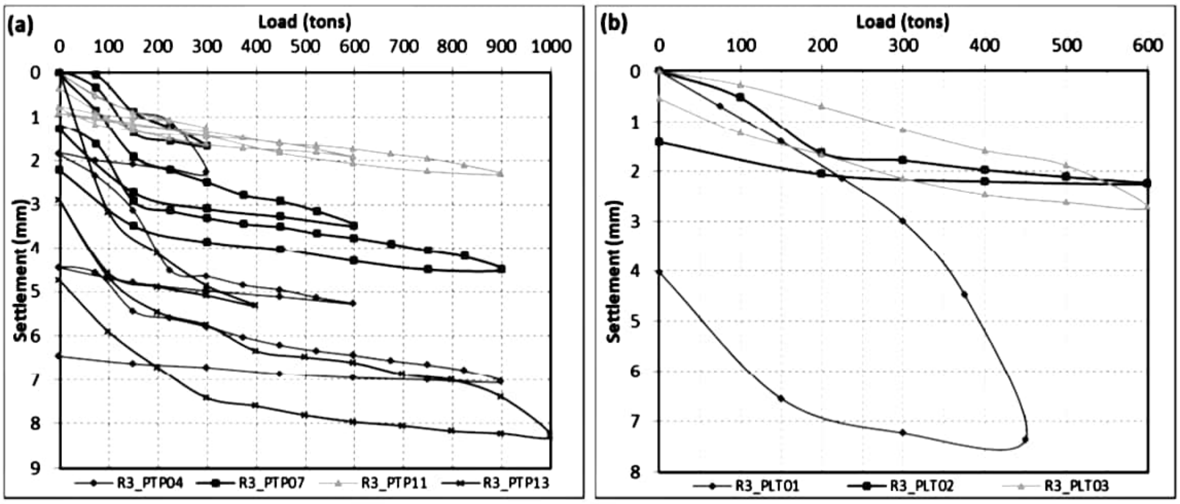

Figure 10: Reach 3 Pile load test results (a) PTP and (b) PLT

Generally for Type 1 strata identified above, where there is no clear hard stratum for tip bearing and both the skin and tip resistance is in stiff to medium stiff clay, the settlements produce plastic yielding more than 6mm, in line with criteria set forth by Tomlinson (1977) [7] [13], thus effectively mobilizing the skin friction.

In practice, these piles have been found to have collapsibility issues especially in regions with presence of water in the form of water table, seepage water from drainage nallah and / or saturation of soil through any other means. This has resulted in some instances of overconsumption of concrete ranging from 15% to 30%, where localized collapses occurred after the drilling activities were finished and during lowering of steel cages.

On the other end of the spectrum, Type 4 strata in the upper gradation of gravelly sand and sandy gravels, is fairly well compacted and results in immediate settlements less than 6mm, thus not fully utilizing the available skin friction.

Drilling in this stratum has been found to remain stable and cause only minor collapses, mostly due to vibration of the drilling equipment. However, due to variable sized deposits of gravels and occasional cobbles, some bits get dislodged from the shaft, producing a pile with an effective diameter larger than the original 1.2m drilled shaft, forming a more effective bond between the pile and the adjacent soil.

Inadvertently, this results in a uniformly distributed overconsumption of concrete, along the length of the pile. Sometimes, in some specific cases, this extra concrete quantity has even exceeded 30%.

5.1 Load Settlement Curves

Load Settlement curves of R1_PTP03 in Reach 1 shows a trend behavior which correlates to pure clay/silt deposits, as generalized in Type 1 stratification. The maximum total settlement observed was 28.33mm with a net settlement of 11.43mm. This is in agreement with the geotechnical investigations carried out, as this pile was purely in clay with no gravels encountered during drilling, and the SPT profile varies from less than 5 blows in the first 5m to less than 30blows at a depth of 30m, which is indicative of normally consolidated clay.

In contrast to this test, R1_PTP01 which has gravels mixed with clay as Type 2, due to which the load settlement profile is nearly linear with very little total and net settlement values. This trend correlates to the SPT profile where refusal was observed at shallower depths between 5-10m and below a depth of 24m. Since the length of the pile is more than 30m there is good interaction between the soil and the pile concrete, producing sufficient friction resulting in low settlement values.

In the start of Reach 2 near Fort Bala Hisar and at the end of Reach 2 near Aman Chowk, i.e. test no. R2_PTP01 and R2_PTP12 respectively, the behavior of the load settlement profile is somewhat similar to Reach 1, Type 1 stratification as discussed above. The total settlements observed are 17.38mm and 14.35mm and the net settlement is 9.83mm and 7.67mm respectively, which are higher values of settlement as compared to the rest of Reach 2.

The stratum is highly heterogeneous in Reach 2 where gravel and clay layers are mixed and in some cases there is a complete reversal of strata, in Type 2 and Type 3 as described previously. This was observed in the geotechnical investigations and can be seen in SPT profiles, which widely varies from less than 10 blows upto a depth of 20m to refusal upto the same depth. In some cases where refusal was observed upto a depth of 26m, it is followed by 20-30 blows in clay layer below it. This correlates to the trends of the load settlement observed, as the maximum total settlement does not exceed 5mm and the profile is almost linear for both Type 2 and Type 3 stratification.

In Reach 3, the geotechnical investigations indicate refusal throughout the depth. The test piles conducted in these four locations are in purely gravelly strata, as described in Type 4. Due to this the load settlement profile is mostly linear with maximum total settlement of 8.28mm in R3_PTP13 and maximum net settlement of 6.46mm in R3_PTP04, with very little elastic rebound.

All the PLT tests conducted in Reach 1 and 2 shows a maximum total settlement less than 4.25mm and in Reach 3 show a maximum total settlement of 7.26mm. These tests show that the working piles are in line with criteria set forth by Tomlinson (1977) [7] [13].

5.2 Comparison of Theoretical Calculations against the Pile Load Test Results for R1_PTP03

The following Table 7 enlists the summary of the ultimate pile bearing capacities for preliminary test pile R1_PTP03, obtained from the interpreted results of pile load tests, and from theoretical calculations using USACE and NAVFAC guidelines, as discussed earlier in the design methodology. The interpretation of pile load test done by Tangent Method and Limit Value (Davisson) method has presented in Figure 11 and Figure 12 respectively.

As can be understood from the results, the NAVFAC calculations are conservative as compared to USACE, however, NAVFAC is closer to the actual pile load results. The results of both methods of pile load test interpretation have almost the same ultimate capacity, as listed below.

Table 7: Comparison of theoretical and empirical calculations with interpreted pile load test results:

Method	Reference	Ultimate Pile Bearing Capacity (tons)
USACE EM 1110-2-2906 (1991)	[14]	1116
NAVFAC DM 7.02 (1986)	[11]	1089
Tangent Method (FHWA-RD-IR-77-8) [14]	[14]	992
Limit Value (Davisson 1972)	[14]	998

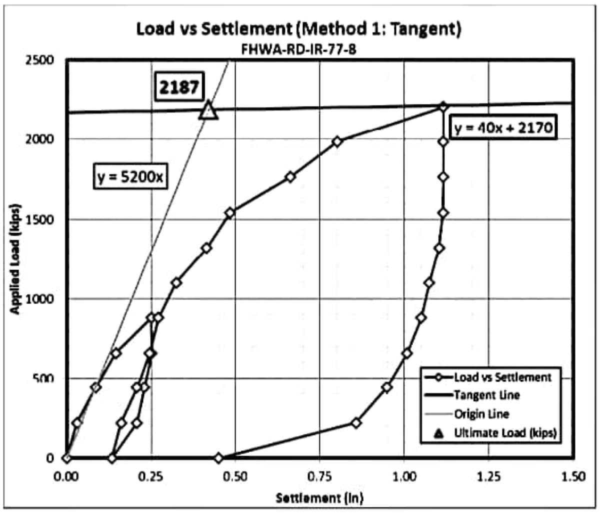

Figure 11: Ultimate Load Capacity of R1_PTP03 from Tangent Method [14].

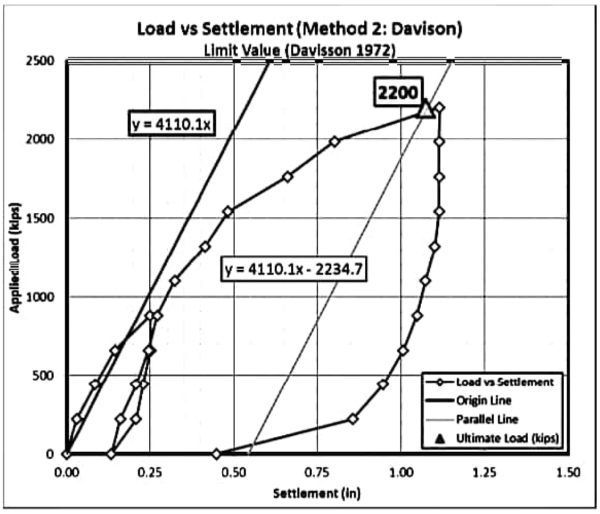

Figure 12: Ultimate Load Capacity of R1_PTP03 from Limit Value (Davisson 1972) [14].

6 CONCLUSIONS

The following conclusions have emerged from this extensive pile testing program across Peshawar City:

- Information pertaining to the sub surface investigation, was limited, as piling works had been previously carried out on only few other locations in Peshawar City.
- The testing conducted on this project has revealed the response of piles in different type of strata that have been encountered.
- In Reach 1, maximum total settlements in PTP tests were observed in Type 1 stratification 1 as 28.33mm and a net settlement of 11.43mm.
- In the start and end of Reach 2, two load settlement trends are somewhat similar to Reach 1, with Type 1 stratification, with a maximum total and net settlement of 17.38mm and 9.83mm respectively.
- In PTP tests across Reach 2, maximum total and net settlements in Type 2 and Type 3 stratums, yield similar results, with a maximum value of 8.62mm and 3.04mm respectively.
- In Reach 3, due to presence of gravel along the full profile of the pile, the maximum total settlement observed was of 8.28mm in R3_PTP13 and maximum net settlement of 6.46mm in R3_PTP04.
- The response of piles cast in cohesive stratum tends to give much higher settlements as compared to piles casted in cohesionless soil.
- Wherever gravels have been encountered during pile construction, the load tests indicate low settlements, and a linear trend of load vs settlement has been observed due to good pile to soil interaction with high friction.

Acknowledgements:

It has been gratifying to work with such hardworking professionals across this project, where we gained an invaluable collaborative experience. We acknowledge the help of Director General (DG) PDA, Mr. Israr Ul Haq and Mr. Uzair Khan, our Project Coordinator Mr. Hamid Khan who has been most supportive of our efforts, our Team Leader Teague Macreen and Project Director Mr. Pervez Anjum (MM Pakistan), for their help during the project and giving us this unique opportunity to write this paper.

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Software solutions for environmental enginneering, foundation engineering and soil mechanics

The geoengineering software suite covering a wide range of applications in geotechnical design, site investigation and laboratory analysis. The programs are used by geotechnical, structural and general consultants, site investigation firms, design offices, government agencies and universities.

Familiarization with the programs is very quick because of the consistent and user friendly Windows interface of all programs. Each program is provided with easy-to understand user manuals. A support hotline is also available for technical assistance.

Software

» Geotechnical Analysis

» Geohydraulic Analysis

» Field Investigation

» Laboratory Analysis

All programs are WYSIWYG (What You See is What You Get), ensuring ophisticated report quality output in Windows true-type fonts. Color output and bitmap graphics are supported. Output from all GGU programs can be "cut and paste" into other Windows programs such as word processors and spreadsheets.

Geotechnical Analysis

GGU-AXPILE

Calculation and graphical presentation of piles

GGU-CANTILEVER

Analysis and design of cantilever walls using global and partial safety factor concepts

GGU-CONSOLIDATE

Consolidation processes in single- and multi-layered systems

GGU-DOLPHIN (new)

Analysis and design of dolphins according to EAU 2012

GGU-ELASTIC

Calculation of linear-elastic deformation

GGU-FILTER-STABILITY

Analysis of the filter stability of soils and suffosion safety

GGU-FOOTING

Analysis of bearing capacity

GGU-GABION

Analysis and design of retaining structures manufactured using concrete elements, stacked blocks and gabions or noise abatement walls.

GGU-RETAIN

Analysis of retaining walls based on the Recommendations of the german Working Group for Excavations and Waterfront Structures (EAB + EAU)

GGU-SETTLE

Settlement analysis of triangular and rectangular foundations including mutual influence of neighbouring foundations.

GGU-SLAB

Analysis of elastically supported slabs based on the modulus of subgrade reaction and constrained modulus methods using the finite element method.

Geohydraulic Analysis

Flow processes of groundwater and mass transport calculations.

GGU-2D-SSFLOW

Calculation of steady-state groundwater flow

GGU-2D-TRANSIENT

Analysis of transient groundwater flow using the finite-element method, based on a groundwater system modelled using GGU-2D-SSFLOW

GGU-3D-SSFLOW

Modelling of steady-state groundwater flow in three-dimensional groundwater systems using finite-element-methods

GGU-3D-TRANSIENT

Calculation of non-steady-state groundwater flow

GGU-CONTAM-FE/-RW

Calculation of pollutant transport using a GGU 2D-SSFLOW groundwater system

GGU-DRAWDOWN

Analysis and optimisation of water management using multiple-well installations

GGU-SEEP

Analysis of systems for the infiltration of precipitation run-off

Field Investigation

Geotechnical investigations are the basis for meaningful reports. Drilling and penetration tests provide important soil parameters for the subsoil model.

GGU-BORELOG

To create well logs

GGU-CAD

2D CAD program

GGU-GEO-GRAPH

Presentation of isographs

GGU-PLATELOAD

Evaluation and presentation of field plate loading tests

GGU-PUMPTEST

In situ permeability from borehole pumping tests

GGU-SLUGTEST

Slug and bail tests

GGU-STRATIG

Drilled profiles

GGU-TIME-GRAPH

Presentation of hydrographs and contour lines

Laboratory Analysis

Various material properties can be determined by soil mechanical laboratory tests. The results of the various tests serve for further classification, for the determination of soil characteristics and thus for the improvement of the subsoil model.

GGU-ATTERBERG

Evaluation and visualisation of tests to determine consistency limit to German Standard DIN 18122 (Part 1)/DIN EN ISO 14688-2.

GGU-COMPACT

Evaluation and presentation of proctor compaction tests

GGU-DENSITY

Determination and visualisation of soil density to German Standard DIN 18125, Part 2

GGU-ENSLIN

Evaluation and visualisation of Enslin tests

GGU-GRAIN-DENSITY

Grain-Density determination

GGU-LABPERM

Evaluation and visualisation of permeability tests

GGU-LIME

Evaluation and presentation of lime ($CaCO3$) content

GGU-OEDOM

Evaluation and visualisation of compression tests to determine deformation behaviour due to constrained stress changes, and to determine the constrained modulus

GGU-SHRINKAGE

Shrinkage limit determination

GGU-SIEVE

Evaluation and presentation of grain size distribution

GGU-TIMESET

Evaluation and visualsation of time-settlement tests

GGU-TRIAXIAL

Evaluation and visualisation of triaxial compression tests

GGU-UNIAXIAL

Evaluation and visualisation of uniaxial compression tests

GGU-WATER

Evaluation and visualisation of water content using oven drying