Geotechnical characteristics of tehran alluvial fan for the detail design of metro stations

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ABSTRACT
Tehran Metro Line 7, with a total length of 26.4 km extends in the north/south-east direction in Tehran Municipal Metro System Plan. Line 7 consists of 25 underground stations. The ground along the proposed metro route is formed of the Quaternary aged Alluvial Fan Deposits, which are known as the Tehran Alluvial Formation. The thickness of the deposits has been reported as 60 meters in the project area. The particle size of the alluvial deposits in the station site areas varies from colloidal clays to oversize particles, with variable distribution, both in depth and horizontal extention. The oversize particles (cobbles and boulders) which are mostly formed of igneous and pyroclastic rocks are very strong, hard and abrasive. These particles dominantly exist at the northern parts of the area. The complementary geotechnical studies have been performed for providing and analysing the necessary data to obtain a better understanding of the subsurface ground conditions and to determine the basic geotechnical parameters for establishing the detailed design of the proposed metro structures. Concise geotechnical investigations were carried out in each station including field explorations, in-situ tests, laboratory tests, desk studies and data processing. This paper presents the general geotechnical investigation results of the site, consisting of the subsurface layer conditions, groundwater conditions, physical and mechanical specification of the soil layers and the geotechnical characteristics of the site.

RÉSUMÉ
Téhéran ligne 7 du métro, avec une longueur totale de 26.4 km s'étend dans le sens nord / sud-est de Téhéran municipale Plan du réseau de métro. Ligne 7 se compose de 25 stations de métro. Le terrain le long de la route de métro proposé est formé des Quaternaires âgés dépôts d'alluvial, qui sont connus comme l'Téhéran Formation alluviales. L'épaisseur des dépôts a été rapporté que 60 mètres dans la zone du projet. La taille des particules des dépôts alluvionnaires dans les domaines de site de la station varie d'argiles colloïdales à des particules de grande taille, avec une distribution variable, tant en extension profondeur et horizontale. Les particules surdimensionnées (galets et rochers) qui sont principalement formées de roches ignées et pyroclastiques sont très fortes, durs et abrasifs. Ces particules dominantes existent au nord de la région. Les études géotechniques complémentaires ont été effectuées pour fournir et analyser les données nécessaires pour obtenir une meilleure compréhension des conditions du sol sous-sol et de déterminer les paramètres de base en géotechnique pour établir la conception détaillée des structures de métro proposé. Concise études géotechniques ont été réalisées dans chaque station, y compris les explorations sur le terrain, des essais in situ, des tests de laboratoire, des études théoriques et de traitement des données. Ce document présente les résultats généraux étude géotechnique du site, comprenant les conditions de couches souterraines, des eaux souterraines, la spécification physique et mécanique des couches de sol et les caractéristiques géotechniques du site.

1 INTRODUCTION

Tehran Metro Line 7, with a total length of 26.4 km extends L-shape in the north to south-east direction in accordance with Tehran Municipal Metro System Plan including 25 underground stations. It passes through bustling urban zones with prosperous business centers en route. The operational final headway is 120 seconds with line capacity for 45000 passengers per hour per direction (pphpd).

Geotechnical studies have been performed in two phases, the preliminary and the complimentary investigations in the quaternary aged alluvial fan deposits, which are known as the Tehran Alluvial Formation(C Alluviums). The complimentary geotechnical investigations have been aimed in processing and analyzing the achieved data which will be needed for a better understanding of the subsurface ground conditions and to make a basis for establishing a detailed design of the tunnels and stations structures. The studies include the subsurface layer conditions, groundwater conditions and general geotechnical specifications of the site and have been investigated by performing field explorations and studies, in-situ testing, laboratory testing, desk studies and data processing.
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2 GEOLOGY AND HYDROGEOLOGY

2.1 Lithology

Tehran is located on relatively recent alluvial deposits extending toward the south from the foothills of Alborz

Mountains range. These deposits are the result of river activities and seasonal inundations. Tehran alluvium is comprised of four groups: A,B,C and D formation. “A” formation is the oldest and “D” is the youngest one.
“A” formation is a light gray conglomerate with hard cementation. The thickness of this formation varies between 150 to 1200 meters.
“B” formation is a heterogeneous conglomerate which consists of cobble, gravel and occasionally large boulders with over 1 meter of diameter that has a sandy, silty or clayey cement. Maximum thickness of this formation is 60 meters.
“C” formation largely consists of alluvial fan deposits with grain size ranges from clay and silt to cobbles and even boulders. The oversize particles (cobbles and boulders) which are mostly formed of igneous and pyroclastic rocks are very strong, hard and abrasive. These particles dominantly exist at the northern parts of the project area. The thickness of this formation is about 60 meters and mainly, stations will construct in these deposits.
“D” formation is the youngest deposit which is found in recent riverbeds. It consists of rounded cobbles and gravels in the north of Tehran and in the south, it is mostly consists of silts and clays. The thickness of these deposits is less than10 meters.

2.2 Structural elements

The structural elements of Tehran area mainly consists of a number of reveres and thrust faults. The two main faults that can be distinguished are defined as follows:
Ghasre firoozeh fault: the fault is about 7.5 km long and has a trend in northwest-southeast direction. This fault is in 2.8 km distance of A7 station.
North Ray fault: The fault is almost 16.5 km long and the overall alignment is in the east-west direction .Stations of east-west route are in more than 7.5 km distance from this fault.

2.3 Ground water condition

According to the geotechnical longitudinal section of the metro line, about 60% of the tunnel and stations will encounter the groundwater aquifers. So, the groundwater conditions will have a dominant role on design and construction of the stations.
There are a main (general) and some perched (local) well known aquifers in the project area that could impact on the stations civil works. These aquifers have been formed in the Tehran alluvial fan deposits. The main aquifer in the project area is predominantly unconfined, with variable thickness. This aquifer will encounter the tunnel and stations at the west-eastern portion of the metro line, between chainage 2+000 km. and 13+000 km. The perched aquifer which has been formed at shallow depths at northern portions of the project area, will encounter the tunnel and stations after chainage 19+000 km. to the end of the line. The formation of this aquifer can be related to the existence of some fine grained soil layers in the coarse grained soil mass, at north-west of the Tehran city.

3 INVESTIGATION SCOPE

3.1 Field exploration

During the detailed geotechnical investigations, 2 to 4 boreholes and 2 to 3 test pits were bored at proper locations in each station. Some boreholes and test pits were also bored in main parking yard, underground parking and depot areas. Totally 89 boreholes and 44 test pits were bored.
The soil core samples were taken continuously In boreholes for perfect geotechnical logging and effective laboratory testing purposes. The subsurface layer condition of the stations studied by carefully inspection of the core samples and the test pit logs. The soil strata were identified and classified in accordance with the British Soil Classification System (BSCS) and the Unified Soil Classification System (USCS).

3.2 Ground water studies

In order to investigate the groundwater conditions in any station, at least one of the boreholes was preserved as piezometers, by installing a PVC tube inside, and a suitable cap at the ground surface. The piezometers were used for measuring the groundwater level during the investigation period.

3.3 In-situ tests

The performed in-situ geotechnical tests in the site areas were subsequently consist of Standard Penetration Tests (SPT), Pressuremeter Tests, Borehole Permeability Tests, Downhole Seismic Tests, in-situ Direct Shear Tests and Plate Load Tests.

3.4 Laboratory tests

The geotechnical laboratory tests were carried out mostly in-accordance with the American Society for Testing and Materials [ASTM]. The purpose and the type of the performed tests induced standard methods and the test amounts are tabulated in Table 1.

3.5 Desk studies and data processing

The collected geotechnical (field & laboratory) data have been studied and processed by means of some proper scientific softwares in the office, and presented in various forms as: geotechnical sections, logs, tables and graphs. These data have then been synthesized and analyzed to define the geotechnical model of the station sites and to

determine some optimized soil design data, in order to give appropriate recommendations for the civil engineering design and construction of the stations.

Table1. Laboratory tests

Purpose	Type		Standard	Quantity
Soil Identification and Classification	Particle Size Analysis		ASTM D422	750
	Consistency Limits		ASTM D4318	750
	Phase Relationships	Water Content	ASTM D2216	475
		Total Unit Weight	-	475
		Specific Gravity of Solids	ASTM D854	475
Shear Strength Determination	Triaxial Compression (CU)		ASTM D4767	125
Compressibility Assessment	One Dimensional Consolidation test		ASTM D2435	30
Swelling Potential Assessment	Swelling strain determination		ISRM	275
	Swelling pressure determination		ISRM	275

4 INVESTIGATION RESULTS

This geotechnical studies have been aimed in collecting and analyzing all the data needed for a better understanding of the subsurface ground conditions and a basis for establishing the detailed design of the line stations structures. In these studies, the subsurface layer conditions, groundwater conditions and geotechnical characteristics of the ground have been investigated. In this paper, the author would like to focus in result of investigations for geotechnical characteristics of Tehran alluvial fan.

On the basis of the field exploration and geotechnical field and laboratory tests, grain size distribution, consistency limits, phase relationships, volume change capacity, permeability, shear strength, compressibility, deformability and chemical properties have been investigated. The conclusion given in this paper is based on the technical documents as various drawings, tables and graphs.

4.1 Grain size distribution

As noted before, the grain size of the soil layers in the project area lies in a wide range, from oversized boulders to colloidal clays. Where, the coarse grained soil strata are well graded and/or gap-graded (not uniformly graded), due to the unsorted nature of the Tehran alluvial fan deposits.

4.2 Consistency limits

According to the performed plasticity tests results, the consistency limits values of the fine fractions of the soil layers are as given in Table 2.

Table 2: Consistency limits of the fine grained soils

Consistency Limits	Values (%)				
	Minimum	Maximum	Mean	S.D.	C.V.
Shrinkage Limit, SL	8.7	23.9	14.69	3.66	24.91
Plastic Limit, PL	11	39	18.29	4.25	23.24
Liquid Limit, LL	18.22	56.4	29.99	7.69	25.64
Plasticity Index, PI	0.54	27.3	11.76	5.10	43.37

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4.3 Phase relationship

The phase relationships values of the soil are summarized in Table3.

4.4 Volume change capacity

Regarding the plasticity index and clay particles percentage of the tested soil samples, the Activity of the fine grained deposits in the project area is in the range of 0.3 to 2.5 with the mean value of around 1 (See Figure 1). Regarding the results, these deposits can be considered as inactive to normal with low to moderate volume change potential. The shrinkage limit value of the soil, which varies between 8.7% and 23.9% and the mean value of 14.7%, confirms this evaluation.

Table 3: Phase relationships of the soil

Phase Relationship	Unit	Value				
		Min.	Max.	Mean	S.D.	C.V. (%)
Water Content, w	%	0.7	37	17.86	9.65	54.03
Total Unit Weight, γ_t	gr/cm^3	1.31	2.13	1.83	0.2	10.93
Dry Unit Weight, γ_d	gr/cm^3	1.29	1.91	1.63	0.12	7.36
Specific Gravity of Solids, Gs	–	2.35	2.86	2.6	0.10	3.85
Void Ratio, e	–	0.39	0.92	0.63	0.12	19.05
Porosity, n	%	28.1	47.9	38.49	4.55	11.82
Degree of Saturation, s	%	2.8	100	53.53	35.85	66.97

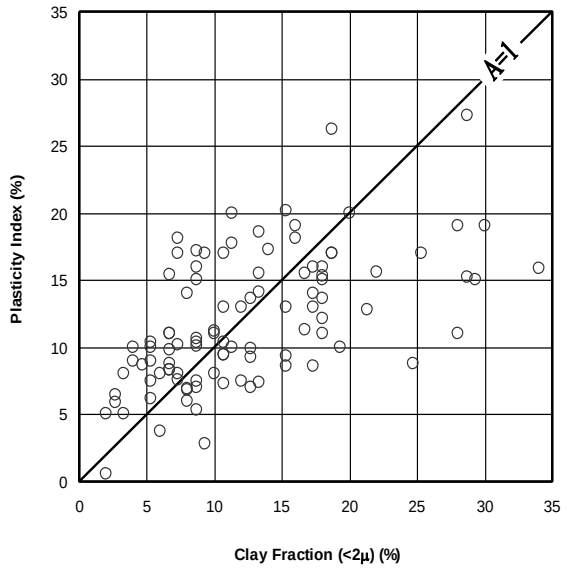


Figure 1: Relation between plasticity index and clay fraction of the soil

4.5 Permeability

The performed in-situ permeability tests results are summarized in Table4. It is evident from these test results that the soil permeability is so variable, which can be related to the non homogeneous nature of the alluvial fan deposits in the project area.

4.6 Direct Shear test result

In order to evaluate the shear strength parameters of the coarse grained soil strata along the tunnel line, large scale direct shear tests have been carried out, both in-situ and in the laboratory(Figures 2 and 3).

Table 4: Mean permeability coefficient values of the soil

Main Soil Groups (According to the BSCS)		Coefficient of Permeability, k (cm/s)
Group Symbols	Subgroup Symbols	
G-F S-F	GWM , GPM , GWC , GPC SWM , SPM , SWC , SPC	10^{-2}
GF SF	GML , GMI , GCL , GCI SML , SMI , SCL , SCI	10^{-3}
FG FS	MLG , MIG , CLG , CIG MLS , MIS , CLS , CIS	10^{-5}
F	ML , MI CL , CI	10^{-6}

4.7 Deformability

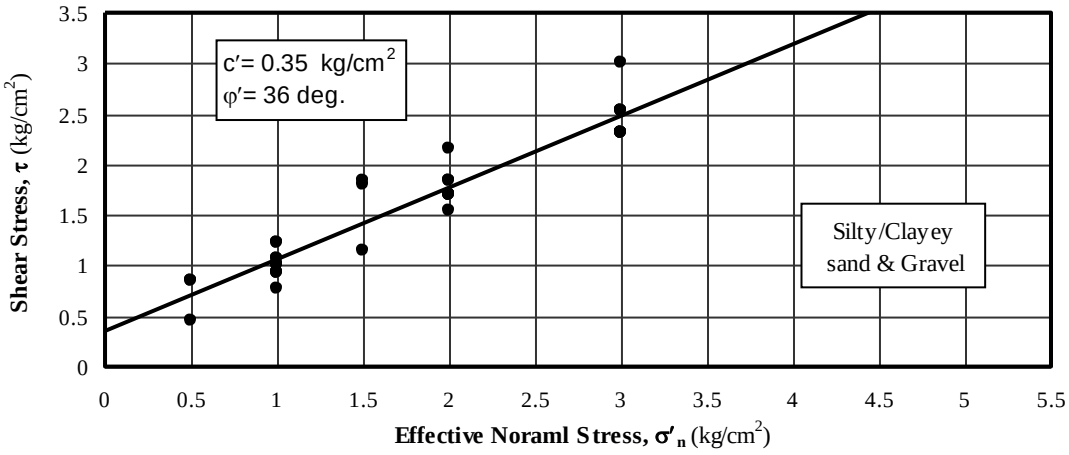
Regarding the type and the nature of the soil in the project area, the anticipated settlement of the ground under foundation loads would be distortion (rather than consolidation) type. The deformability characteristics of the ground were studied by performing Plate Load Tests. It is evident from the included results that there is no consistent relation between the modulus value of the soil and the depth in the project area.

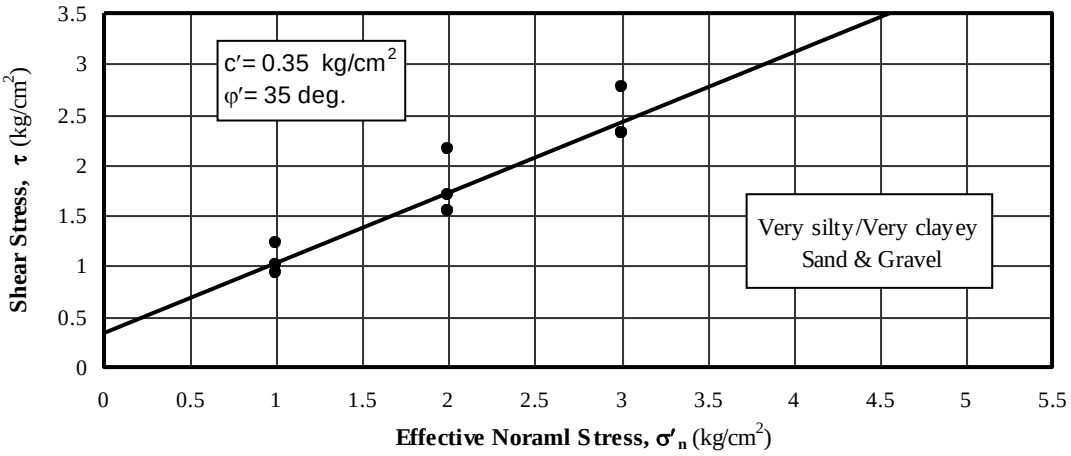
4.8 Dynamic properties

In order to study the dynamic properties of the soil and classify the ground type for the seismic resistant design of the buildings, the Downhole Tests was performed in the boreholes in the sites area. The downhole seismic test results are summarized in Table 5.

4.9 Chemical properties

The chemical properties of the soil which have been determined by performing some chemical tests in the laboratory are: PH, leach water properties (TSS & EC), water soluble ions (Cl^- & SO_4^{--}) and organic matter amount. These tests results are summarized in Table 6.





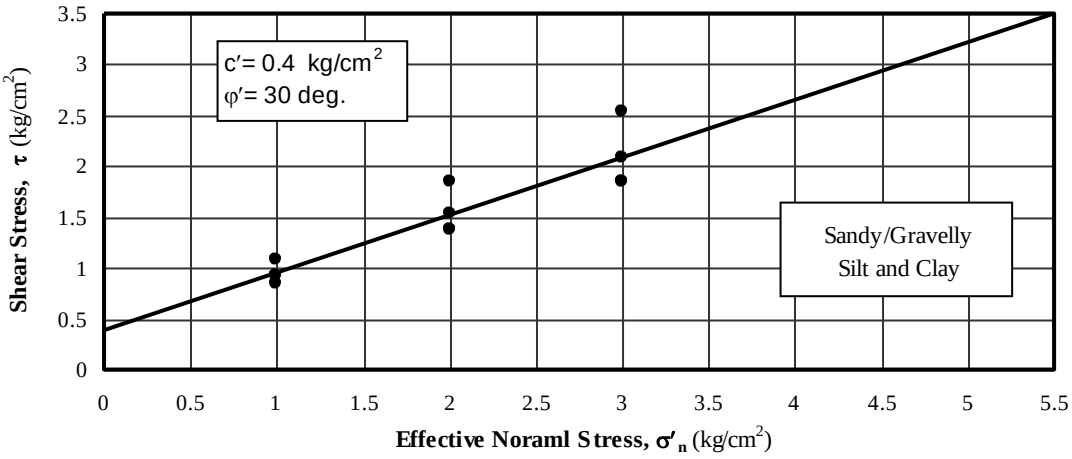
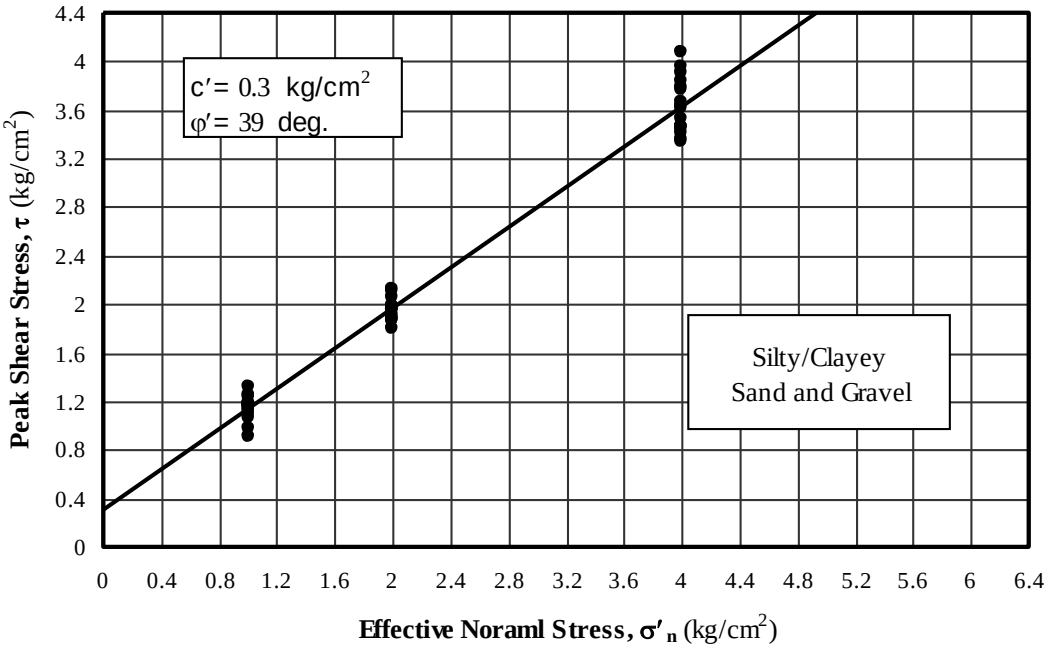


Figure2. In situ direct shear test results



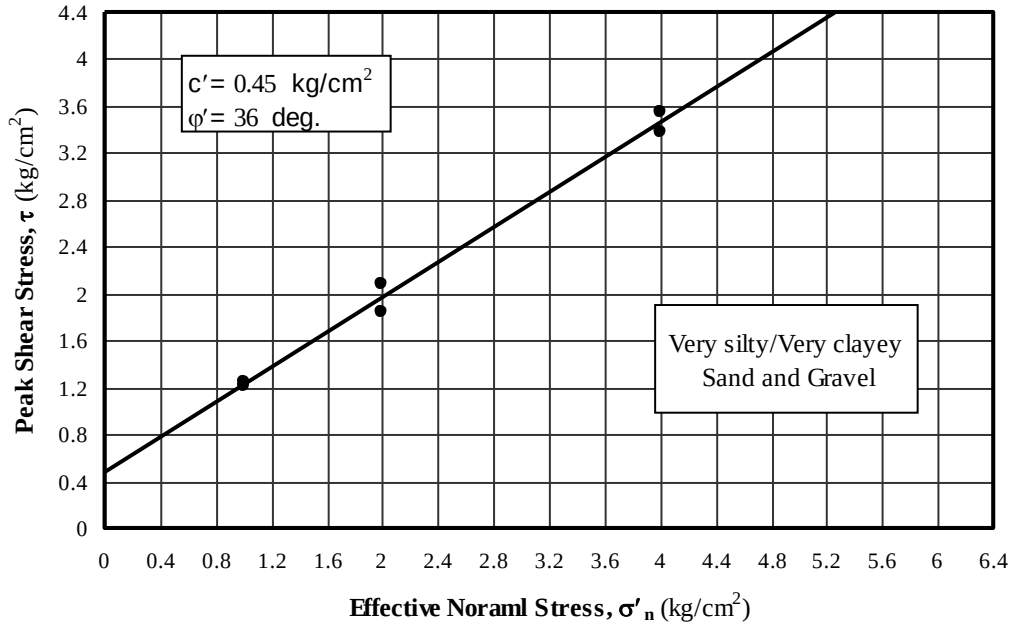


Figure3: Laboratory direct shear test results

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Table 5: The downhole seismic test results

SOIL TYPE / TEST RESULTS		Fill	Alluvium
Wave Velocity (m/s)	P Wave, V_P	315 to 710	910 to 1710
	S Wave, V_S	150 to 380	520 to 800
Velocity Ratio, $(V_P/V_S)^2$		2.96 to 4.41	2.46 to 4.90
Dynamic Moduli (MPa)	Young Modulus, E	97 to 619	1139 to 3481
	Shear Modulus, G	36 to 238	446 to 1280
	Bulk Modulus, K	111 to 514	848 to 4142

Table 6: Chemical properties of the soil

Chemical Properties		Unit	Quantity				
			Min.	Max.	Mean	S.D.	C.V. (%)
PH		Units	7.98	9.09	8.195	0.232	2.83
Leach water properties (soil water ratio 1:1)	Total Soluble Solids (TSS)	mg/l	96.81	351.89	217.35	64.44	29.65
	Electrical Conductivity (EC)	μmho/cm	164	561	357.70	95.80	26.78
Water soluble ions	Cl^-	%	0.009	0.022	0.014	0.004	28.57

5 CONCLUSION

-Proper design soil data have been determined based on geotechnical characteristics of the soil strata which were determined in the field and laboratory. The geotechnical numerical models for each station have been stimulated regarding the geotechnical characteristics and groundwater conditions of the station area.

-Based on the fact that the stations will be constructed underground or cut & cover method may be induced, the open cuts and shaft design would be of the most important aspects of the project, including the stability of the slopes, shaft excavation and ground stabilization.

-Open pumping and predrainage were recognized as the most suitable dewatering method for the stations and the shaft in the project area. The most cost-effective solutions may be a combination of them.

-The natural soil strata have enough potential to carry all type of shallow foundations. Mat foundations may be employed in case of heavy loads (like machineries). Continuous footings may be employed in case of non-homogeneous soils or localized subsurface variations.

-Based on the “Iranian code of practice for seismic resistant design of buildings” (Standard No. 2800), the subsurface ground type is in accordance with class II. The mean measured shear wave velocity was in the order of 700 m/s, up to the depth of 30 meters.

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