Geotechnical and geological aspects of Amir Kabir tunnel of Tehran

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Abstract
In construction of urban tunnels, site investigation and evaluating of geomechanical parameters of various layers are important. Tehran is located on alluvial deposits. These deposits are host of various tunnels, like as metro tunnels, road tunnels and water transition tunnels. This paper explains the geological and geotechnical aspects of Amir Kabir tunnel which is about 1500 m and extended between 17th Shahrivar street and Imam Ali highway at the south of Tehran. Considering the drilling results of boreholes and test pits and according to results of in-situ tests (pressurmeter, in-situ shear test, plate load test) and laboratory tests, geotechnical aspects of sediments are presented. In the greatest part of tunnel route, sediments belong to "C" series of Tehran alluvial and consisted of sandy gravel to gravely sand with some silty and sandy lenses. According to unified classification, their classification are mostly GM and GC. The depth of groundwater table along the tunnel is between 25 and 30m that is lower than tunnel line. According to results and parameters of laboratory and in-situ experiments, coarse soils are dense to very dens and deformation modules are between 25 to 50 MPa. Also, the relation of in-situ test results between laboratory test results are compared.

Key words: *Amir Kabir tunnel, C series alluvial, Pressurmeter, Deformation modulus*.

1. Introduction
Geotechnical studies play an important role in civil engineering projects, especially underground structures. This study included excavation of boreholes, test pits, laboratory and in-situ tests. Physical and shear strength parameters of subsurface layers including cohesion, internal friction angle and deformation parameters (Young modulus, shear modulus and Poisson's ratio), can be obtained by using the above tests. This paper explains the geological and geotechnical aspects of Amir Kabir tunnel which is about 1500 m and extended between 17th Shahrivar street and Imam Ali highway in the south of Tehran (Figure, 1).

2. Geology of study area
Tehran alluvium has been deposited by frequent flow of floods and rivers originating from mountains to the north of Tehran city. Based on geological aspects, Tehran alluvium is divided to 4 units, A, B, C and D [6]. Respect to the study area is located on C series, a brief explanation is presented here. This alluvial formation is shaped alluvial fan near the foothills and it is transformed to silty layers with low slope. These sediments are homogeneous and includes coarse grain with cobbles at north and fine grain at south of Tehran. Center parts of

city is transition zone of coarse to fine grain soils. Soil cementation of this unit is low to medium. In general, Tehran "C" alluvial sediments is homogeneous and due to low cementation, is more permeable than A and B alluviums units and it has high relative strength [4].

3. Geotechnical features of Amir Kabir tunnel area

For determining of subsurface conditions of study area, 12 boreholes up to 50m are drilled and some in-situ tests, sampling are conducted. Moreover 13 test pits are excavated and some in-situ tests are conducted [5]. An overall classification is conducted based on the soil grain distribution and consistency limits, that basic gravely layer (based on unified classification, GM and GC and GP-GM and GW-GM in frequency), sandy lenses (SM and SC), silty lenses (ML) are produced. Whereas, above classification is not presented true engineering judgment, obtained elasticity modulus of Plate load tests, Pressurmeter and Triaxial tests are added in above classification according to methods and equations in part 4. Then, in some places that was not possible to calculating elasticity modulus, wet density is used for alluvium and an applied classification for tunnel coarse alluvium is presented, that its obtained results are two kinds of gravely layers (G1 and G2), two kinds of sandy lenses (S1 and S2) and one kind of silty lens. These layers are recommender of study area's soils. The differences between 1 and 2 gravely layers and 1 and 2 sandy lenses are their elasticity modulus and wet density. So that elasticity modulus of area is lower than 30 MPa, dense layers of area are more than this value. And also the extents of wet density are higher than 20 kN/m^3 according to layers that is dense based on elasticity modulus. Therefore in some depth that was not possible to calculate elasticity of modulus, the extents that is higher than 20 kN/m^3, is used for differences between loose and dense layers. Also shear strength parameters (cohesion and internal friction angle) are obtained based on Triaxial, Direct shear and in-situ shear tests, finally geotechnical features of area soils are presented in Table (1). Geotechnical sections of tunnel course are presented in figures (2) and (3) based on logs of bore holes and test pits. Different thickness of man made soil is 1-5 meters. The depth of water table along the project course is lower than bottom of tunnel and is measured between 25-30 meters.

4. Determination the elasticity modulus

Determination of the elasticity modulus of the tunnel coarse sediments is determined by several in-situ tests (including Pressurmeter test, Plate load test, and in-situ shear test) and laboratory tests (including Direct shear and Triaxial tests). Elasticity and shear modulus of soil G are related to Poisson's ratio, according to elasticity laws, that elasticity modulus of soil is calculated by using the Direct shear tests according to equations 1 and 2. Triaxial test is also one of the methods to determine the elasticity modulus of soil. In this test, $\Delta\varepsilon$ calculated against the increased axial stress $\Delta\sigma$ and modulus of elasticity is obtained according to the equation 3 [3].

$$E_s = 2G\,(1+\nu) \quad (1)$$

$$G = \frac{Shear\,stress}{Shear\,displacement} \times sample\,height \quad (2)$$

$$E_s = \Delta\sigma / \Delta\varepsilon \quad (3)$$

In addition to the above tests, Plate load and Pressurmeter tests are considered of most accurate methods for determining in-situ elasticity modulus. Elasticity modulus is calculable based on the Plate load test results according to equation 4 [1]. Equation 4 is, implemented pressure increase in load plate and soil, B is breadth of load plate, $\Delta\rho$ is settlement according to soil implemented stress increase, I_w is shape factor, that its extents is presented technical references based on plate shape and its flexibility measure [7].
Elasticity modulus is calculable also based on Pressurmeter test results [4].

$$E_s = \Delta q B \frac{1-\nu^2}{\Delta\rho} I_w \qquad (4)$$

4.1. The evaluation of Direct shear test results
The obtained elasticity modulus of this test is 2.5-4.5 MPa (Table, 1). Whereas the obtained elasticity modulus of this test is less than Pressurmeter's tests (one of the most accurate methods in obtaining elasticity modulus), it is not recommended to use in engineering judgment. Generally obtained elasticity modulus of direct shear test is lower that other obtained tests, because of the lack of implemented confining pressure on sample and its damaged. Also probable reason is, registering shear displacement in great displacements.

4.2. The evaluation of Triaxial test results
Obtained elasticity modulus of Triaxial test is similar to Pressurmeter's obtained elasticity modulus test in S_1 and G_1 soils. But obtained elasticity modulus of Triaxial test is lower than Pressurmeter test in G_2 and S_2 soils (E_{PMT} =1.7 E_{TT}) (Table 1). The reasons of it, are sample disturbing, testing during the drainage condition and fine grain of sample.

4.3. The evaluation of Plate load and Pressuremeter tests results
Elasticity modulus obtained from Plate load test is measured only in G_2 soil. The plate load modulus is highly similar to Pressurmeter modulus (Table 1). Generally, elasticity modulus obtained from these two tests with reference to the performing the Pressurmeter and Plate load tests, modulus of elasticity obtained from the two last tests is precision according to the method of pressurmeter and plate load tests, and it is suitable engineering judgment.

5. Conclusion
Based on investigations, the most of the tunnel coarse sediments are related to Tehran C series alluviums and include two kinds of gravely layers (G_1 and G_2 groups), two kinds of sandy lenses (S_1 and S_2) and one kind of silty lens.
The depth of groundwater table during the project area is lower than bottom of tunnel and is measured between 25-30 meters. According to results and parameters of laboratory and in-situ experiments, the soils of course density is dense and very dense. Sediment deformation modulus is between 25 to 50 MPa.
In this project, using elastic modulus of Direct shear test is not suitable to engineering judgment. But the Pressurmeter and Plate load tests are recommended to estimating of elastic modulus.

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Table 1. Geotechnical parameters of soils

Title		Unit				
		G1	**G2**	**S1**	**S2**	**M**
Fine material (%)		17.2	13.5	24.6	25.6	54.7
Sand (%)		29	28	42	42	29
Gravel (%)		54	57	33	32	17
Plasticity Index (%)		7.8	8.9	9.3	7.2	6.7
γ_m (kN/m^3)		18.1	19.8	18.6	20.3	20.3
Water content (%)		7	12	9	15	16
Modulus of deformation (MPa)	Pressuremeter	22	68	19	54	-
	Triaxial	22	37	21	32	20
	Plate Load Test	-	75	-	-	-
	Direct Shear**	2.7	2.3	4	4.2	-
	In-situ shear test**	-	5.7	-	-	-
φ (deg)	In-situ shear test	-	34	-	-	-
	Direct Shear*	37	37	35	35	-
	Triaxial (φ_{cu})	32	33	29	30	24
C (kPa)	In-situ shear test	-	31	-	-	-
	Direct Shear*	3	4	3	4	-
	Triaxial (C_{cu})	10	13	13	20	36

* Obtained from the remolded sample

** Unacceptable

Figure 1. The location and plan of Amir Kabir tunnel at Tehran

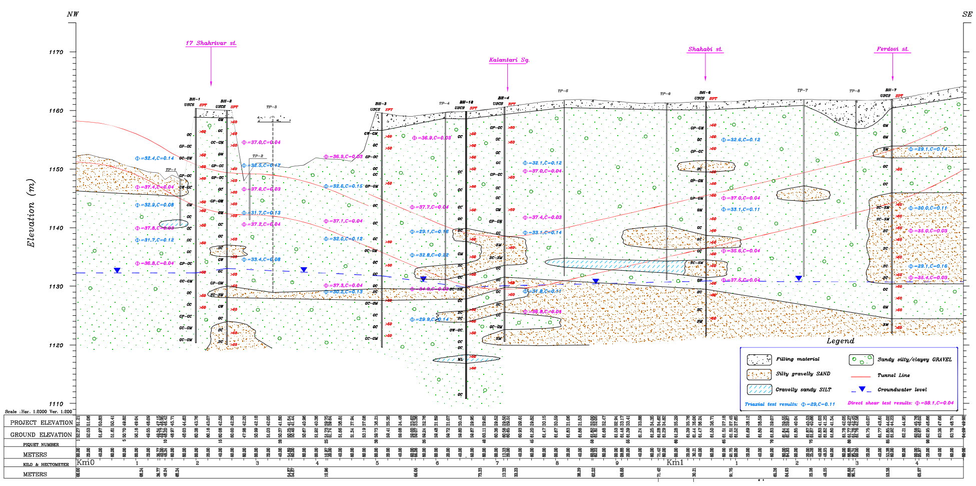

Figure 2. Geological section along the north tunnel (Doroudian street)

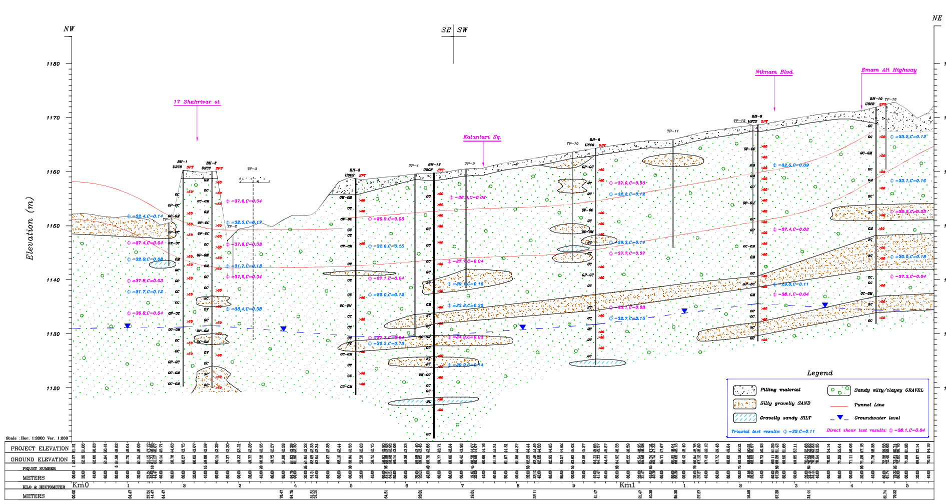

Figure 3. Geological section along the south Tunnel (Kerman Street)