Stiffness of cemented gravel of Tehran from pressuremeter and other in-situ tests

B.Pahlavan
Senior Geotechnical Engineer, Sahel Consulting Engineers Co., Tehran, Iran

A. Fakher
Associate Professor, Civil Eng. Dept., Tehran University, Tehran , Iran

M. Khamehchian
Assistant Professor, Eng. Geology Dept., Tarbiat Modarres University, Tehran, Iran

Keywords: Coarse- grained alluvium of Tehran, Pressuremeter, Plate loading, Shear wave, Shear modulus

ABSTRACT: A coarse-grained cemented alluvium deposit exist in the most parts of Tehran, the capital city of Iran. It has been difficult to obtain accurate strength and deformation parameters of the alluvium, using laboratory and conventional in-situ tests. The paper explains the problems associated with using Menard pressuremeter in Tehran coarse-grained alluviums and proposes the necessary adequate method. In addition the paper studies the variation in result of shear moduli, obtained from Menard pressuremeter, plate loading and shear wave tests. The studies show that the selection of adequate method of drilling and the use of slotted tube, are essential to perform quality pressuremeter tests in such soils. The results also show that the shear moduli of Menard pressuremeter (G_{PMT}) are about half of plate loading moduli (G_{PLT}) and about 0.017 times of shear wave moduli (G_o).

1 INTRODUCTION

Many authors have reported results about deformation parameters of sand but such researches are seldom for gravel, pebble or coarse-grained deposits (Crova et al., 1993, Lin et al., 2000). There are limited studies about the use of pressuremeter to obtain the stiffness of fine-grained soil of southern Tehran (Pahlavan, 1995). Also, Jafari et al. (2002) carried out a laboratory study on the effect of confining pressure and plasticity on shear modulus of fine-grained soil of southern Tehran. However, there is no published work on deformation features of coarse-grained cemented alluvium deposit of Tehran.

Coarse-grained cemented alluvium deposit has covered the most parts of Tehran area. However, the geotechnical exploration of the soil is extremely difficult. Undisturbed samples cannot be obtained for laboratory testing. It is also impractical to prepare reconstituted samples of the deposit because of the large particle size. Moreover, this deposit could have acquired structure over its geological history, and this would be damaged easily during the remolding process. On the other hand, the in-situ tests have difficulties. For example, the results of SPT N value are generally above 50 and are not value are generally above 50 and are not repeatable. CPT and Dilatometer tests cannot be performed in such a strongly cemented coarse gravel.

To circumvent the above difficulties, three alternatives namely, the pressuremeter, shear wave and plate-loading tests could be useful to provide information on stiffness of coarse-grained soils. However, the review of existing professional practical experiences in coarse-grained alluvium of Tehran show that the pressuremeter tests in this soil had not been carried out because of difficulties in preparing of adequate test packet.

2 SITE'S EXPERIMENTAL CONDITIONS

Three sites namely SITE1 (site of 5star hotel of Milad complex of Tehran), SITE2 (along side of Resalat highway, north of Gisha area) and SITE3 (about 100m north of Milad telecommunication tower) have been selected for the research (Fig.1). From the geological point of view, all of these sites are located on Hezardarreh formation (Rieben, 1966). Coarse and semi angular particles with a strong cementation are important features of the geological formation.

Figure 2 shows the location of boreholes and test pits excavated in the research. Table 1 summarizes geotechnical parameters of studied sites. The investigated soil could be commonly classified as gravel (G). Exceptionally, in site 3 at depths 2-3 m and 10-11.5m there are inter layers of CL-ML and CL and also at depth of 12m there is a SC layer. The results of SPT value (N) are generally above 50 in studied sites. Based on SPT value (N), the coarse-grained cemented alluvium deposit of investigated area could be classified as very dense soil.

3 PRESSUREMETER TESTS

The self–boring pressuremeter (SBP) is theoretically an ideal tool for determining the stiffness of many types of soils (Soliman and Fahey 1995). Unfortunately, SBP, high-pressure pressuremeter (Clarke et al., 1990), full displacement pressuremeter (Withers et al., 1986) and push-in pressuremeter (Handerson et al., 1979) cannot be used for coarse-grained alluvium deposits. This is attributed mainly to difficulties in drilling, pushing and driving of the penetration devices in such soils. With the above constrains, it seems that the only existing device that could be used in coarse-grained alluvium deposit of Tehran, is the pre–bored (Menard) pressuremeter (PMT) with slotted tube.

Menard pressuremeter, type GC (Baguelin et al., 1978), has been used for the research. The GC tricell probe was 44 mm in diameter with a maximum pressure capacity of 6 MPa. The central measuring cell with length of 210 mm was inflated with water, and the sheath of 600 mm length, which forms the two guard cells, with nitrogen gas. Water was used to allow volume changes to be measured. For accurate reading of volume and pressure changes an electronic device with accuracy of 10kPa for pressure and 1cc for volume change, along with conventional measuring system of pressuremeter was used. In order to prevent the bursting of rubber membranes due to coarse and angular particles of soil, a slotted tube of 63mm diameter and 1.5m lengths with 6 longitudinal slots of 1m lengths was used.

3.1 *Solution for preparation of adequate test pockets*

The past professional attempts for the execution of pressuremeter test in coarse-grained alluvium of Tehran were unsuccessful, mainly due to drilling problems. The boreholes were usually too tight or too wide for pressuremeter testing. So, the preparation of the test pockets was a main object of the research. Formulation and execution of three following methods were tried (Fig. 3):

I. Rotary drilling using tri - cone bit,
II. Drilling a pilot hole and driving of pressuremeter probe inside of slotted tube using SPT hammer,
III. Drilling with core barrel.

In all methods, drilling mud (water + bentonite) was used to remove cuttings and to assure the stability of boreholes.

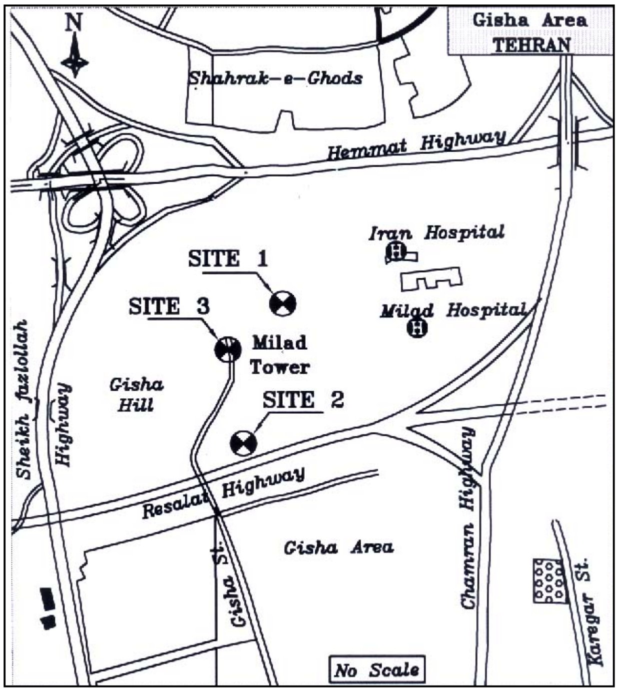
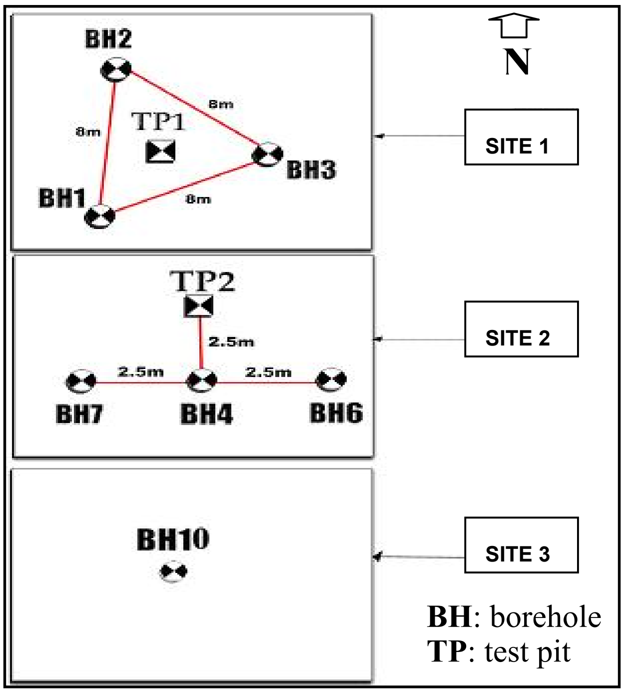


Figure 1.Locations of studied sites (Gisha area ,Tehran).



Note: Boreholes BH5, BH8 and BH9 were eliminated because they were drilled for other purposes.

Figure 2.Locations of boreholes and test pits excavated in this research.

Table 1. Geotechnical parameters of the research sites.

Unit Weight (t/m^3)	Water Content (%)	Gravel & Pebble (%)	Sand (%)	PI	Clay &Silt (%)	USCS	Depth (m)	Site No.
	8.20	49	40.10	18	11.1	GW - GM	0 -0.5	
	9.00	61	29.00	25	9.6	GP - GM	0.5 - 1.5	
2.20		55	27.70	19	17.2	GC	1.5 - 2	1
		61	32.00	25	6.3	GW - GC	2 - 3	
	9.00	62	26.00	34	11.5	GP - GC	3 - 5	
2.17	5.20	62	36.70	26	2	GW	0 - 1.5	2
	7.5 - 10	61	29 - 31	26 - 31	7.5 - 9	GP - GC	1.5 - 5	
		60	31.2	24	8.8	GP-GM	0-2	
		7.5	33.2	14	59.3	CL-ML	2-3	
		60.5	28.5	31	12	GP-GC	3-7.5	
2.20		60	33	27	6.5	GW-GC	7.5-10	3
		8	41	19	51	CL	10-11.5	
		30	40.2	20	29.8	SC	11.5-12.5	
		Variable				GW-GM, GC, GP	12.5-26	

In order to create proper test pockets, some modifications were made on the single core barrel of 59mm OD (Method III). Fixing a reamer of 64mm OD on the top of core barrel just below the head and another one, of the same size, behind of core bit were proved to be successful. Each reamer contains 6 longitudinal reaming segments of 50mm length, 10mm width and 2.5mm thickness. Difference between OD of core bit and reamer permits us to simultaneously create a pilot hole with ID of about 59mm and ream it to about 64mm and also, due to reaming process, create a regular test pocket of uniform diameter.

Figure 4 shows the results of studied methods. As it can be seen in figure 4, the preparation of test pocket by drilling with modified core barrel gives the best results and complies to the criteria of ASTM D4719 – 1994.

3.2 *Membranes bursting*

A problem at the early stages of the research was the frequent bursting of membranes even using the slotted tube. In general, the membranes burst laterally at upper end of the probe and in few cases it was happened longitudinally at high volumes. After visual inspection of about 10 membranes that have been burst at near top end of the probe, it was analyzed and concluded that this type of failure is due to laying of suspend coarse- grained angular cuttings of soils over a fulcrum created during expansion of membrane just between the probe and slotted tube (Fig. 5). During the test, the penetration of sharp cuttings into the membrane exacerbates its bursting at medium to high pressures.

To overcome the problem, two measures were undertaken. The mudflow was continued after drilling until no trace of cuttings is observed in the mud. In addition, extra drilling of borehole about 15 cm was undertaken below the test pocket for the deposition of cuttings. However, using the mentioned preparations comparatively reduced bursting of membranes and the results obtained were comparatively successful.

3.3 *Testing procedure*

The pressuremeter tests were carried out according to the stress control method (described as method A of ASTM D4719-1994). 8 to 14 pressure steps were applied from the start to the end of each test and the pressure and volume readings were recorded at intervals of 30 and 60 seconds for every loading step. Because of the nature of the soil (very dense, hard and cemented), the tests were stopped due to bursting of membrane at high pressures in a number of cases. A total of 37 pressuremeter tests in 7 boreholes have been performed at depths of 1 to 25m.

4 OTHER IN-SITU TESTS

In addition to pressuremeter tests, plate loading and shear wave tests were also carried out to have a comparison between stiffness parameters obtained from pressuremeter and other possible in-situ tests for Tehran alluvium.

4.1 *Plate loading tests*

Plate loading tests were carried out in test pits of 1m diameters in Sites 1 and 2 up to the depth of 4m. The specifications of used equipment are as below:

- A rigid circular loading plate with diameter of 300 mm and thickness of 25 mm;
- A hydraulic jack of 150 ton capacity with related hydraulic pump and pressure gauge;
- Settlement dial gauges of 0.01mm accuracy;

A total of 12 plate-loading tests were carried out according to ASTM D1194-1987.

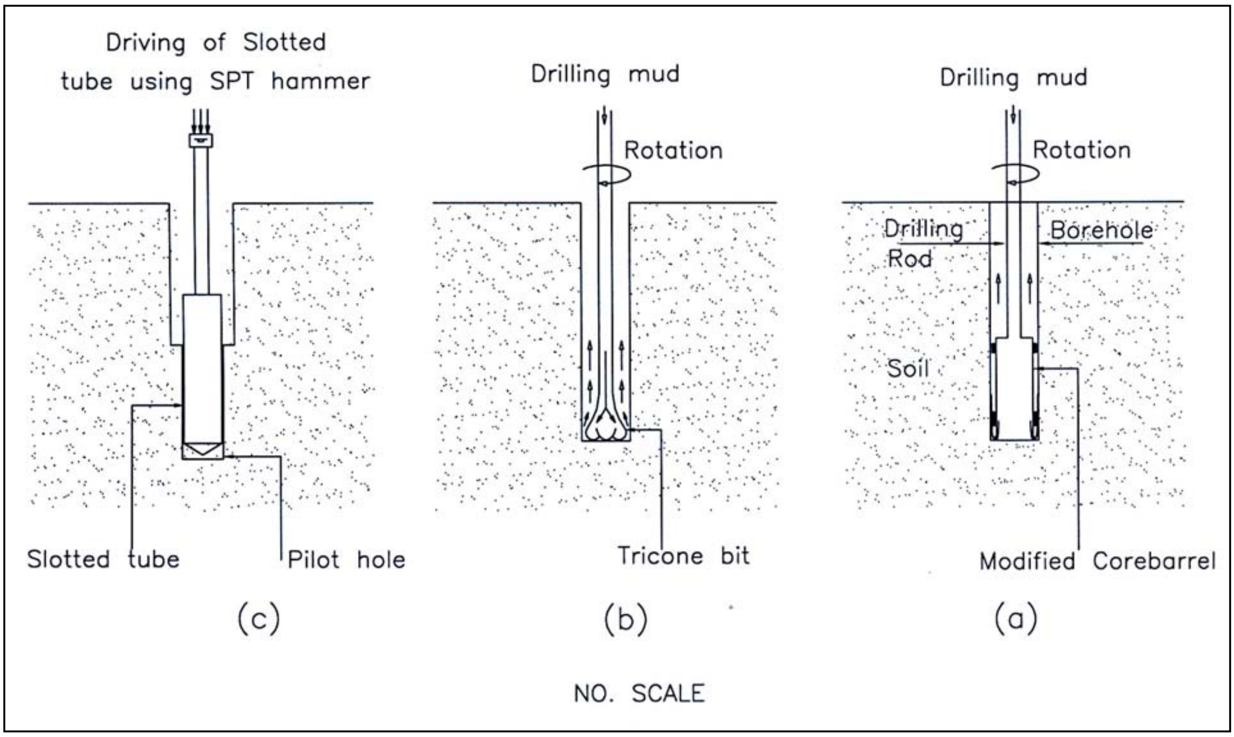


Figure 3. Three methods used for preparation of the test pockets; (a) drilling with modified core barrel, (b) rotary drilling using tri - cone bit and (c) drilling a pilot hole and driving of slotted tube using SPT hammer.

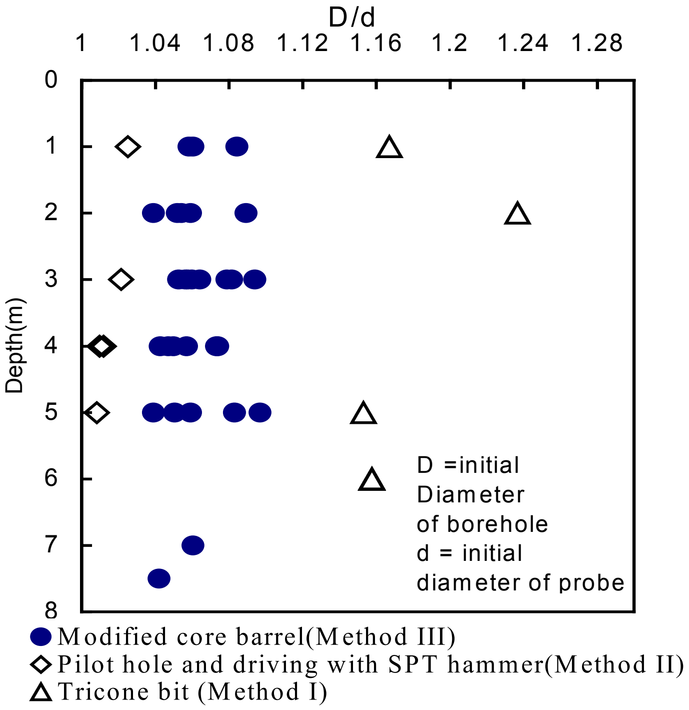


Figure 4. Results of three methods used for preparation of the test pockets (shown as D/d vs. Depth)

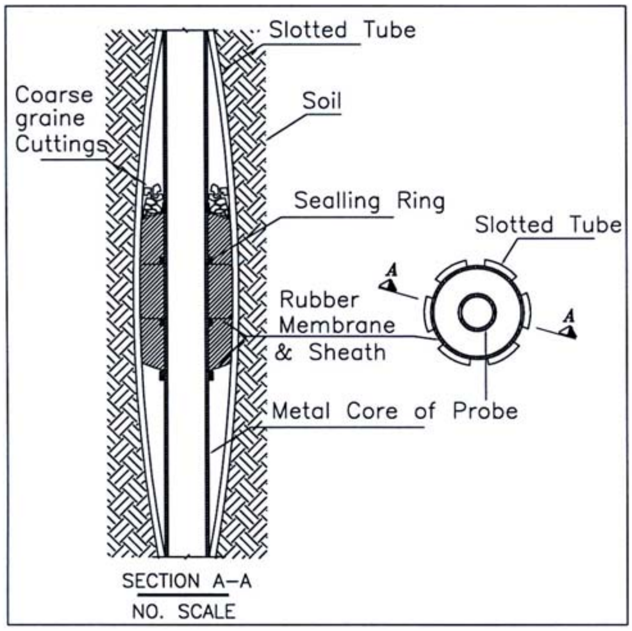


Figure 5. Suspend coarse- grained angular cuttings over a fulcrum created during expansion of membrane just between the probe and slotted tube.

4.2 *Shear wave tests*

Small strain stiffness of soil is often obtained using seismic methods, which are based on wave propagation. Down-hole seismic tests were carried out in Sites 1 and 2 through test pits. In addition, surface wave tests using spectral analysis of surface wave (SASW) technique (Rix & Lai, 1998) were performed in Site 3.

5 SHEAR MODULUS FROM DIFFERENT TESTS AND COMPARISION

To obtain the seismic shear modulus of soil from shear wave tests, the following equation was used:

$$G_o = \rho V_s^2 \quad (1)$$

where G_o = shear modulus; ρ = mass of unit weight of soil and V_s = shear wave velocity. According to

Pahlavan (2002) values of ρ were equal to 2.2 t/m^3 for Sites 1 and 3 and 2.17 t/m^3 for Site 2.

Equation (2) (Timoshenko & Goodier, 1951) was used to calculate shear modulus from load-settlement curves of plate loading tests:

$$G = \frac{q.D}{S} \cdot \frac{\pi}{8}(1-\nu).\mu(z) \quad (2)$$

where G = shear modulus; S = plate settlement; q = plate pressure; D = plate diameter; ν = Poisson's ratio and $\mu(z)$ = depth reduction factor. ν = 0.25 was used as Poisson's ratio for studied soil (after Asghari, 2002). The value of depth reduction factor was chosen depending on the test depth and the ratio of test pit diameter to plate diameter (Donald et al., 1980, Pells & Turner, 1979). Using above mentioned values and Equation (2), the shear moduli of plate loading tests obtained from initial part of load – settlement curves from point of q = 0 to q = $q_{ult}/2$, where q_{ult} = ultimate bearing capacity of plate.

For pressuremeter tests, the Menard shear moduli (G_m) were taken from pseudo-elastic part of pressure-volume strain curves. The volumetric strains were changed into circumferential strains at the cavity wall, using method presented by Briaud (1992). Then Menard shear moduli (G_m) were calculated using Equation (3):

$$G_m = \frac{1}{2}\frac{\Delta P}{\Delta\varepsilon_\theta} \quad (3)$$

where ΔP and $\Delta\varepsilon_\theta$ are change in pressure and cavity strain respectively within pseudo-elastic part of pressuremeter curve.

Figures 6 and 7 show the variations and comparison of Menard shear moduli (G_m), seismic shear moduli (G_o) and plate loading shear moduli with depth. As being seen from these figures, the shear moduli obtained from Menard pressuremeter are smaller than plate loading and very smaller than shear wave moduli. Marsland & Randolph (1977) presented similar results between Menard and plate loading shear moduli for London stiff clay. Shear moduli obtained from shear wave velocity are on average about 30 times of Menard pressuremeter moduli in Site 1, about 50 times in Site 2 and about 63 times of Menard pressuremeter in Site 3. Using linear regression, the correlation between pressuremeter moduli and shear wave moduli for all of studied sites is G_o = 60 G_m. Kalteziotis et al. (1990) also undertook Menard pressuremeter tests on a variety of soils (such as; clay, sand, sandy clay and gravely clay) in Greece and compared the Menard moduli with those from cross-hole seismic tests and resulted the following practical correlation; G_o = 45 G_m.

Pressuremeter moduli and also plate loading moduli show that shear moduli increase with depth because of the increasing of confining pressure with depth. Tatsuoka & Shibuya (1992) after the study of shear moduli from shear wave, plate loading, laboratory tests and foundation back analysis concluded that the comparison of shear moduli from different tests would be correct if non-linear behavior of stress-strain is regarded. It means that the differences are because of different level of strain.

The ratios of shear moduli obtained from plate loading tests to Menard pressuremeter moduli are on average about 1.68 in Site 1 and about 2.4 in Site 2. Al-Sanad et al. (1993) also suggested this ratio as equal to 1.5 for a very dense calcareous sand.

A tall building located in Site 3 was monitored. The result and monitoring methods was described by Pahlavan, (2002). The back analysis of results was undertaken to determine the stiffness of the soil. Shear moduli derived from unloading – reloading loops of pressuremeter curves showed a very good agreement with the result of monitoring (Pahlavan, 2002).

6 CONCLUSIONS

The conclusions of the research could be summarized as bellow:

- One of the difficulties associated with pressuremeter tests in coarse alluvium of Tehran is the creation of adequate test pockets. To overcome the problem, three methods of drilling were studied. The results show that a modified core barrel described in the paper could create adequate test pockets for pressuremeter tests in such a soil.
- To reduce the possibility of the bursting of membrane, the mudflow could be continued after drilling until no trace of cuttings of soil is observed and also an extra drilling of borehole about 15cm below the test pocket for deposition of cuttings could be useful.
- The shear moduli obtained from Menard pressuremeter, plate loading and shear wave tests in cemented gravel of Tehran increases with depth. Also the results show that the shear moduli of plate loading is about 2 times of Menard pressuremeter moduli and the shear moduli of shear wave tests is about 60 times of Menard pressuremeter moduli.

ACKNOWLEDGEMENTS

This project forms part of a research program funded by Tarbiat Modarres University and Sahel Consultant Engineers, Iran. The first author, when working on the project, was supported by a visiting fellowship in the Department of Civil Engineering at the University of Western Australia, where he benefited from valuable discussion with professor Martin Fahey and Dr. Sebastiano Foti. These supports are gratefully acknowledged.

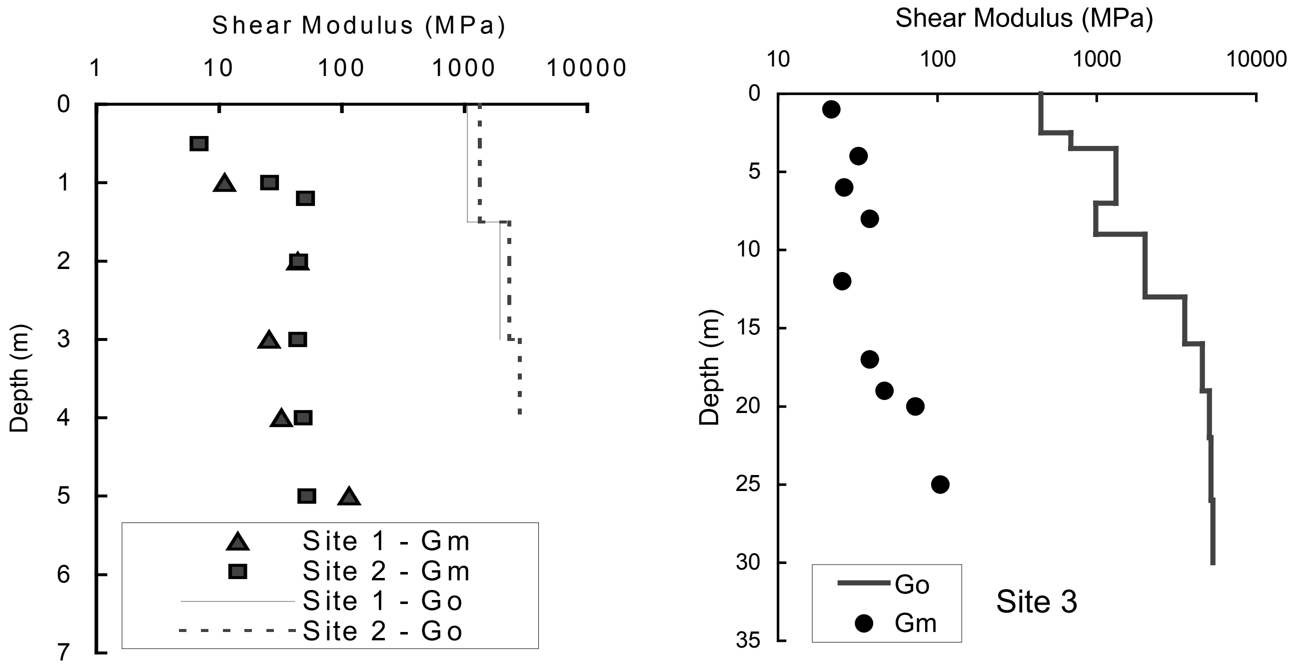


Figure 6. Comparison between Menard pressuremeter shear moduli (Gm) and shear wave shear moduli (Go) in studied sites.

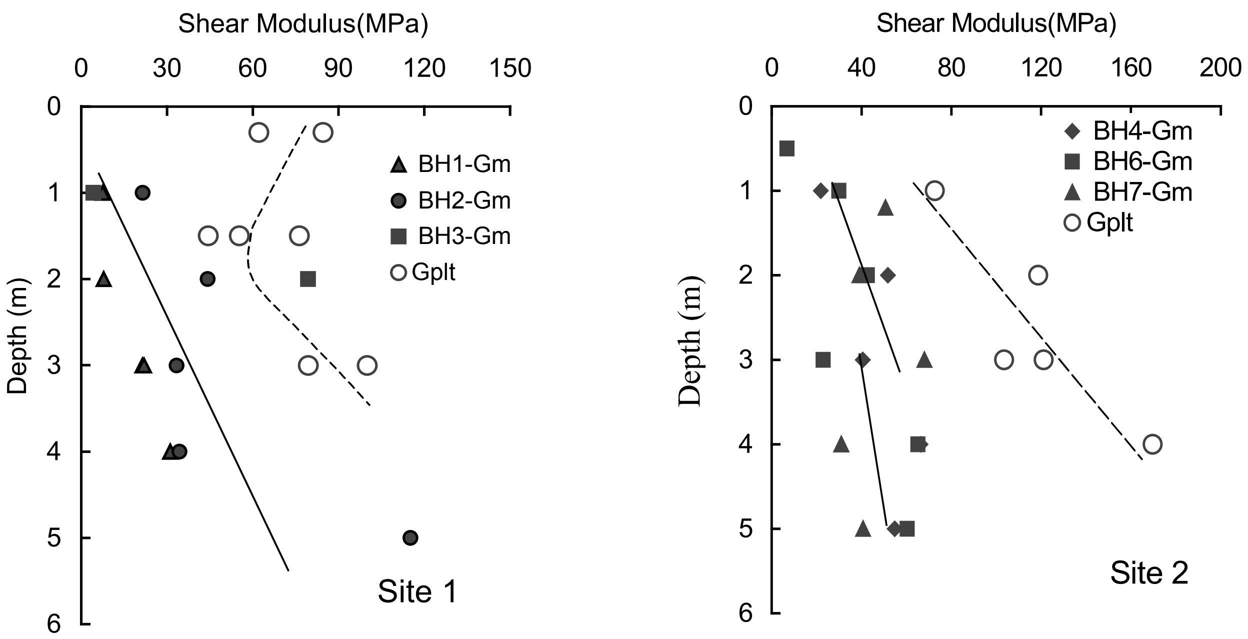


Figure 7. Comparison between Menard pressuremeter shear moduli (Gm) and plate loading shear moduli (Gplt) in sites 1 and 2.

REFERENCES

Al- Sanad, H.A., Ismael, N.F. and Brenner, R.P. (1993), Settlement of circular and ring plates in very dense calcareous sand, *J. Geotech. Engng*., ASCE, 119(4),PP. 622-639

Asghari, E. (2002), Effect of cementation on shear strength and deformation of coarse grain alluvium of Tehran, *PhD thesis*, Tarbiat Modarres University, Tehran, Iran. (In Farsi language)

A.S.T.M. D1194 (1987), Standard test method for bearing capacity of soil for static load on spread footings, *American society for testing and materials*, Philadelphia, U.S.A.

A.S.T.M. D4719 (1994), Standard test method for pressuremeter testing in soils, *American Society for testing and materials*, Philadelphia, U.S.A.

Baguelin, F., Jezequel, J.F. and shields, D.H. (1978), The pressuremeter and foundation Engineering, *Trans. Tech. Publication*.

Briaud, J.-L. (1992), The pressuremeter, *Balkema*, Rotterdam

Clarke, B.G. (1995), Pressuremeters in geotechnical design, *Chapman & Hall*, Cambridge, U.K.

Clarke, B.G., Newman, R. and Allan, P. (1990), Experience with a new high pressure self-boring pressuremeter in weak rock, *Ground Engng*, 22(5), 36-39; (6), 45-51.

Crova, R., Jamiolkowski, M. and Lo Presti, D.C.F.(1993), Geotechnical characterization of gravelly soils at Messina site : selected topics, *Proc. Predective soil mechanics*, Thomas Telford, London.

Donald, I.B., Sloan, S.W. and Chiu, H.K. (1980), Theoretical analyses of rock socketed piles, *Structural Fond. on Rock*, Balkema, PP. 303-316.

Henderson, G., Smith, P.D.K. and St John, H.D. (1979), The development of the push-in pressuremeter for offshore site investigation, *Proc. Conf. Offshore Site Invest*., Society for underwater technology, London, pp. 159-167.

Jafari, M. K., Shafiee, A. and Razmkhah, A. (2002), Dynamic properties of fine grained soils in south of Tehran, *J. Seismology and Earthquake Engng*., 40(1), PP.25 – 35.

Kalteziotis, N. A., Tsiambaos, G., Sabatakakis, N. and Zervogiammis, H. (1990), Prediction of soil dynamic parameters from pressurementer and other in situ tests, *Proc. 3rd Int. Symp. Pressuremeters*, Oxford, PP. 391-400

Lin, S.Y., Lin , P. S., Luo, H. S. and Juang C. H., (2000), Shear modulus and damping ratio characteristics of gravelly deposits, *Can. Geotech, J*., Vol., 37 , PP. 638 – 651.

Marsland, A. and Randolph, M.F. (1977), Comparisons of the results from pressuremeter tests and large in- situ plate tests in London clay, *Geotechnique*, 27(2), PP. 217-243.

Pahlavan, B. (2002), An investigation to deformation of coarse grained alluvium of Tehran using pressuremeter, *PhD thesis*, Tarbiat Modarres University,Tehran,Iran. (In Farsi language)

Pahlavan, B. (1995), The self boring pressuremeter and analysis of it's results for studying of engineering characteristics of south of Tehran soil, *Msc thesis*, Tarbiat Modarres University,Tehran,Iran. (In Farsi language)

Pells, P.J.N. and Turner, R.M. (1979), Elastic solutions for rock socketed piles, *Can. Geotechn. J.* Vol. 16, PP. 481-487.

Rieben , E. H., (1966), Geological observations on alluvial deposits in northern Iran, *Geol. Surv*. Iran. 9.

Rix, G.J. and Lai, C. G. (1998), Simultaneous inversion of surface wave velocity and attenuation, *Proc. Geotech. Site Characterization*, Vol.1, Balkema, PP.503-508.

Soliman, A.A. and Fahey, M. (1995), Measurement and interpretation of shear modulus in SBP tests in sand, *Proc. 4th Int. Symp. On the Pressuremeter and Its New Avenues*, Sherbrooke, Canada, pp. 115-122, Balkema, Roterdam.

Tatsuoka, F. and Shibuya, S. (1992), Deformation characteristics of soils and rocks from field and laboratory tests, *Report of the Institute of Industrial Science, The University of Tokyo*, 37(1),1 – 144.

Timoshenko, S. P. and Goodier, J. N. (1951), Theory of elasticity, *Mc Graw Hill*, New York.

Withers, N.J., Schaap, L.H.J. and Dalton, J.C.P. (1986) The development of a full displacement pressuremeter, *Proc. 2nd Int. Symp.Pressuremeter Marine Appl*., Texam,USA,ASTM ATP 950, pp. 38-56.