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Design, Manufacture, and Perform of First Electronic Seismic Sensor Dilatometer in Project of Tehran Metro line 6 as a Rapid Environmentally Friendly in-situ Test with Less Soil Disturbance

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Abstract

The soil's physical and mechanical properties are obtained through laboratory or in-situ tests. The dilatometer is an in-situ tool in rock mechanics and geotechnical engineering, and is widely used in developed countries. In the advanced version of this device, a geophone receives ground vibration. Thus V_s [1] could be obtained at the depth of the blade. This research work investigates the feasibility and performance of the first electronic seismic sensor due to its lower cost, more life span, more sensitivity instead of the geophone, and the ability to transfer signal. These changes make it an online tool connected to Arduino[2], a platform so the digital or analog result could be transferred automatically. The test is carried out under construction of Bahar Shiraz station of Tehran Metro Line 6 at the depth of 30 m. The hammer generates a shear wave, and after amplification, the received signals are measured with the software. The shear wave velocity at the test site is obtained at 504 m/s. The result compared to V_s reported geotechnical investigation done by "Darya-Khak-Pey consulting engineers" for Metro line 6 shows a 10% deviation. It is suggested to conduct more comparative tests to check the results and calibrate. Using an 801-S sensor with more life span (of more than 60 million times) and the ability to connect to the internet with an Arduino board is the innovation applied to introduce a new generation of this tool in the engineering world.

1. Introduction

Information of physical parameters and mechanical properties of soil and rocks and examining their behavior as a basis for the design and implementation of enormous mining and construction projects such as urban and intercity tunnels, airports, skyscrapers, specialized dam structures, hydropower plants, and water supply projects is of particular importance. Access to the physical and mechanical characteristics of soil and rock is obtained by conducting field or in-situ and laboratory tests, and is provided to the project designer. Estimating the bearing capacity of the foundation and checking the relevant coefficients, calculating the effective internal friction angle, common parameters such as modulus of elasticity and specific weight, and even predicting the amount of settlement of the project bed are all obtained by these tests. Laboratory and in-situ tests each have advantages and disadvantages. Among the advantages of laboratory tests, controlling the conditions and path of stress is more important.

On the other hand, laboratory tests also have disadvantages such as soil handling during sample preparation, transportation to the laboratory and placing it in the machine, time-consuming, and a higher cost than the existing methods. Thus one of the reasons for the popularity of in-situ tests is the lack of need to carry samples and touch the soil and

[1] Shear wave velocity
[2] an open-source hardware and software company

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perform with less cost and time compared to the laboratory tests. Other essential features of field tests are their compatibility with the environment and their not disturbing the soil [1]. Figure 1 shows various environmentally friendly geotechnical tools used by the engineers today.

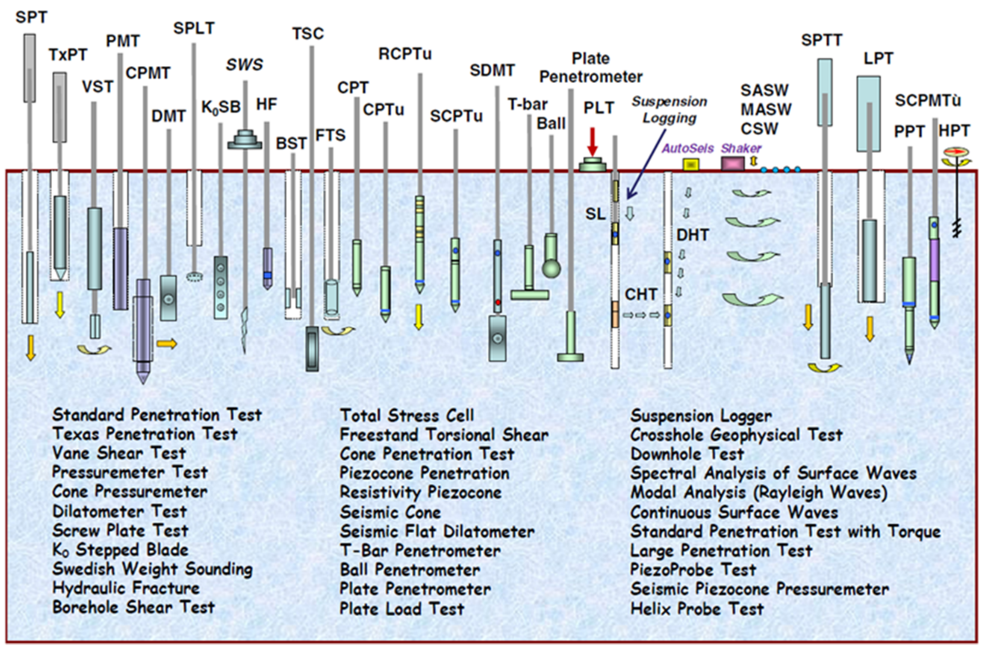


Figure 1. Various test tools in place [2].

The dilatometry is an in-situ test in the specialized field of soil and rock mechanics that has no need for any separate drilling. The blade shape creates the least amount of contact and regional disturbance at the penetration point into the soil; the results are also offered acceptable. The analysis of the results of in-situ tests is mainly based on the empirical relationships, so experience and increasing the number of tests play an essential role in interpreting the results. Figure 2 compares the amount of soil disturbance caused by the entrance of the dilatometer (right side) and the sloping edges of the CPT[3]. tip (left side).

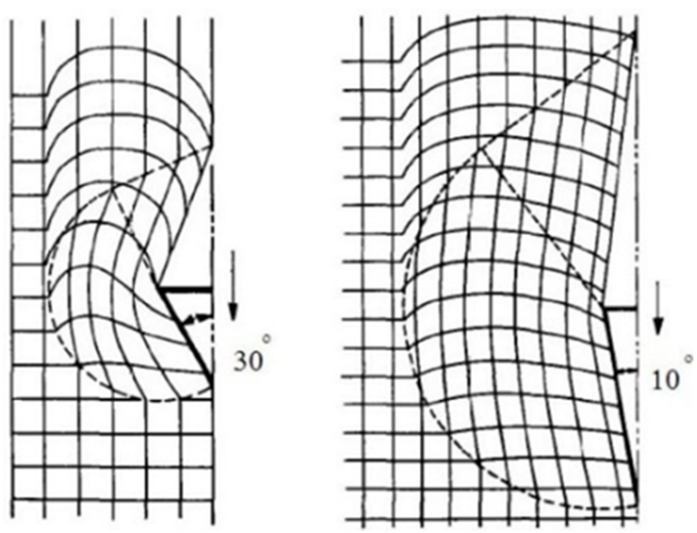


Figure 2. Comparison of soil disturbance model during penetration of blade dilatometer (right) and CPT (left) [3].

[3] Cone Penetration Test

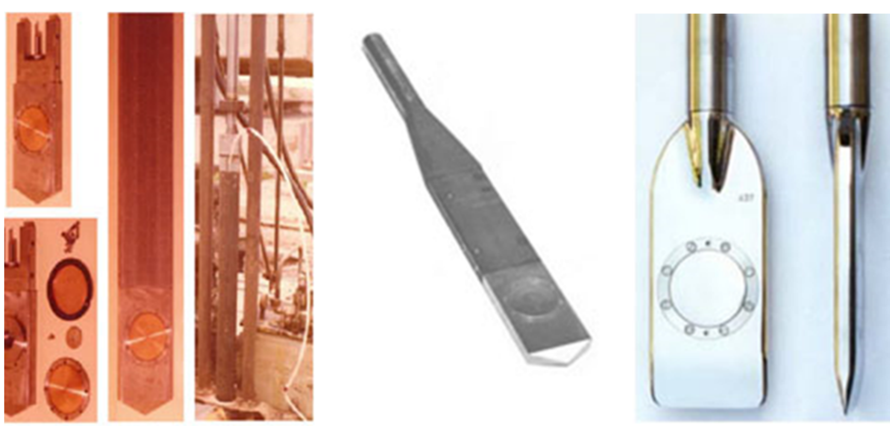
More than 40 years have passed since the invention and introduction of the flat dilatometer. Since its inception, it has been modified and equipped according to various project needs and the advancement of technology in various fields. Adding a geophone to determine the shear wave velocity V_s of the soil is one of the above cases, which led to the introduction of the SDMT[4] device [4].

2. Need to Design and Manufacture a Seismic Dilatometer with an Electronic Sensor

The advancement of technology in various fields, on the one hand, and the demand for improving and increasing the efficiency and effectiveness of machines and tools, on the other hand, have pushed the world of designing and manufacturing towards becoming competitive. However, a half-century has passed since introducing the dilatometer and providing service to the engineering community in advanced countries; there is still a long way to widespread use in projects. Thus, the first domestic dilatometer equipped with a seismic sensor has been designed to fill a lake of knowledge and instrument in this country. Also with the conducted research, an effort was made to invent a new generation tool while reducing the cost of production and increasing the life span and the sensor's sensitivity. Also the lack of installation angle limitation has made it possible to receive both S and P waves with one sensor. Therefore, an investigation was made, and the 801-S sensor was finally selected; installing it in the dilatometer rod, its efficiency was checked and evaluated.

3. History of dilatometer

Professor Silvano Marchetti introduced and unveiled his blade dilatometer for the first time in 1974 at the University of L'Aquila, Italy. The idea of making this tool came to Marchetti's mind when he was looking for a mechanism to measure the bending and reaction of the soil due to the force applied to the base of a beam. The initial design process and the construction of the first sample were presented at the 9th International Society of Soil Mechanics and Geotechnical Engineering, abbreviated as ISSMGE, which was held in Tokyo in 1977 [5]. For years after this achievement, much research and results from dilatometers were devoted to evaluating and designing parameters such as Su, M, and OCR. About 15 years after the introduction of the first example, Robertson et al. in 1987 and Marchetti et al. in 1991 presented designs for the effect of lateral pressure caused by pile loading; these methods led to the development and use of this device. Today, both are used in predicting the lateral pressure of loaded piles. As a result, according to Professor Marchetti's claim, the dilatometer is a tool developed by both of the above persons, namely Professor Marchetti and Robertson. In addition, it is used today for purposes that were not the original purpose of its invention [5]. Figure 3(a) shows the first blade dilatometer made by Professor Marchetti, which was used to measure soil modulus. In the prototype, two diaphragms with copper sheets were used on both sides of the steel blade. The blade is V-shaped at the bottom and has a rectangular section at the top and at the point of connection to the rods, which is why it took much work to connect and close it.



(a) (b) (c)

Figure 3. (a) First blade dilatometer made in 1974- (b) Blade made in 1975- (c) Current blade [5].

[4] Seismic dilatometer

In 1975, the cooper diaphragm changed to steel, and the connection point of the blade to the rod was changed to a circular shape. These changes can be seen in image (b) in Figure 3. Over time, there were other changes in its design, which led to the production of current samples, which have differences from the original sample, and were mainly aimed at facilitating its penetration into the soil and removing the blade from the soil. Figure 3, image (c) of the blades shows the present [5].

3.1. First practical use of dilatometer in America

Marchetti presented and described his dilatometer in detail at the American Society of Civil Engineers ASCE conference held in Raleigh, North California. Then in 1980, he published an article in ASCE, which is still used as one of the most reliable sources for implementing this test [6]. Next, Marchetti corresponded with Dr. Schmertmannn (former geotechnical professor at Florida State University) and encouraged him to use this device in research and consultations. The initial correlation of values in the dilatometer was very promising; however, Schmertmannn remained somewhat skeptical until his doubt was resolved, and he subsequently explained this. Schmertmannn retired from teaching at the university in 1978, and established the Schmertmannn and Crapps Institute to provide consulting services. In 1979, Marchetti provided the necessary equipment to be evaluated by our calculations. David Crapps and William Whitehead, and a technician, conducted the first dilatometry test in the United States at the University of Florida.

Shortly after conducting the first tests at the University of Florida, Schmertmannn was offered a consultation regarding the evaluation of the characteristics of the consolidated clay located under the foundations of the cooling tower of a power generation plant in North Florida. The purpose of this evaluation was to provide a different proposal by the contractor to participate in the tender. It suggested the foundation with pile bases or a ring foundation with a shallow depth. A dilatometry test was conducted for this purpose in August 1979, and it showed that the clay layer was more consolidated and, taking into account some limitations, the implementation of a shallow foundation was sufficient for it, and the proposing contractor won the tender. A few weeks after holding the tender, the contractor received the results of the tests taken from the consolidated clay layer, and the results confirmed the dilatometry test. Schmertmann and his colleagues were very satisfied with the results obtained from the first practical application of the dilatometer in the United States [6]. They were eager to use the device then and for years to come. Schmertmann and Crapps conducted more than 1000 dilatometer tests in geotechnical investigations of the Sunshine Skyway Highway Bridge project across Tampa Bay, Florida, and this was the first practical use of this device in a significant project in the United States [6]. This bridge, with a length of 6663 m and a height of 131 m, replaced the previous bridge on April 20, 1987, and was officially reopened [7]. Figure 4 shows the image of the Sunshine Skyway Bridge, which was the first basic application of the dilatometer in civil engineering projects [7].

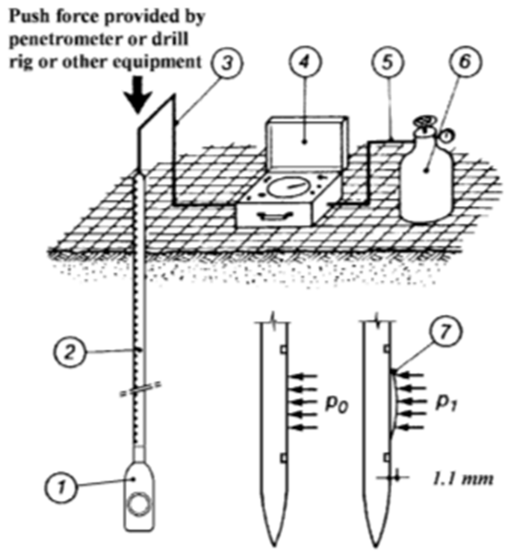
Figure 4. Sunshine Skyway Bridge in FL, USA, and the first use of dilatometer in construction projects [8].

3.2. Application history of dilatometer in Iran

The review of studies and history of using dilatometer shows that this tool is used more in dam construction projects (Javah Dam, Rudbar Dam, and Jamshir Dam), Lavarak hydropower plant site, Siahbesheh hydropower plant and during the years 2003 to 2008, and to determine the change modulus. The shape of the stones and the investigation of the construction characteristics of the mentioned projects have been used [1]. Although many laboratory companies and geotechnical engineering services have introduced this tool on their website and even described the method of performing the in-situ test, Iran's civil and mining engineering community still needs to gain familiarity with it.

4. General Description of Device

The dilatometer consists of a stainless steel blade on which a stainless steel diaphragm is installed. The blade is connected to the control section on the ground through a pneumatic-electric tube, which transmits air pressure and electric current. This blade is sent from the earth's surface to the desired depth through the connecting rods. The compressed air capsule on the ground is connected to the control device through pneumatic-electric tubes. The control unit has a pressure regulating valve, a pressure gauge, an air discharge valve, and an audio warning system. The blade is sent into the ground using conventional equipment such as the equipment used in the CPT test or drilling rigs. Pressure rods also transfer the thrust force from the drilling machine and penetrate deeper into the blade [9]. The overview of the dilatometer test implementation is shown in Figure 5.



1. Dilatometer blade	4. Control box
2. Push rods (eg.: CPT)	5. Pneumatic cable
3. Pneumatic-electric cable	6. Gas tank
7. Expansion of the membrane	

Figure 5. Overview of implementation of blade dilatometer test [9].

The test starts by sending the blade into the ground, and after the blade penetrates the ground, the operator inflates the metal diaphragm by opening the compressed air valves, and the reading of the pressure gauges begins. This reading will consist of 2 parts:

Pressure A: To create a distance between the diaphragm and the body due to the pressure of the soil on the blade, which is called "lift-off."

Pressure B: to expand the metal diaphragm by 1.1 mm from its initial state against the pressure from the soil [9].

The A and B pressures should be corrected after reading based on ΔA and ΔB values obtained by calibrating the device to take into account the stiffness of the diaphragm and become P0 and P1 values. Relations 1 and 2 show the values of P0 and P1 based on the readings of A and B and ΔA and ΔB [10]:

$$P_0 = 1.05\,(A - Z_M + \Delta A) - 0.05\,(B - Z_M - \Delta B) \quad (1)$$

$$P_1 = B - Z_M - \Delta B \quad (2)$$

Z_m is the deviation from zero of the pressure gauges, and is determined by reading the gauges at atmospheric pressure [10].

4.1. Intermediate parameters

The primary method is to use the results of the blade dilatometer in such a way that these results are interpreted as soil parameters and characteristics from the point of view of engineering. In this way, they check the parameters obtained from different methods, select the design profiles, and then use the usual design methods. This interpretation evolved by identifying three DMT parameters, E_D, K_D, and I_D. These three basic parameters are also called intermediate parameters. Then their relationship with soil parameters is used in engineering, and other parameters are derived from these three [11].

4.1.1. Material index I_D soil type

In general, the I_D index expresses the characteristics of the soil section, and in normal soils, it provides a complete description of the soil. Whenever I_D is used, it should be considered that I_D is not the result of a sieve; rather, it is a parameter that reflects the mechanical behavior of the soil and is a hardness index. With a little exaggeration, for someone interested in the mechanical behavior of the soil, a description based on the mechanical behavior and reaction may be more important than the actual grain size distribution. For example, if clay behaves harder than most clays for various reasons, such clay soil with an I_D index will be known as silt. Such an explanation needs to be revised in terms of granularity, and it may be more related to the fact that based on the type of soil; we expected a different mechanical behavior. On the other hand, if the focus is on permeability, then the I_D should be supplemented by another indicator called U_D [11]. According to relation 3, the value of I_D is obtained through the following relation:

$$I_D = (P_1 - P_0)/(P_1 - U_0) \quad (3)$$

In this regard, U_0 is the pore water pressure before the blade penetrates the soil.

Figure 6 shows the process of determining the parameters derived from the mediator.

Also according to Table 1, soil classification based on the I_D index is more detailed [12].

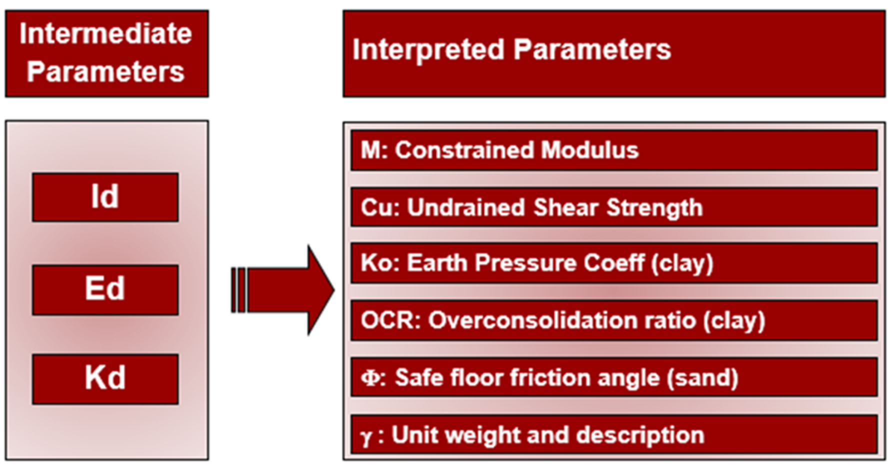


Figure 6. Parameters derived from intermediate parameters.

Table 1. Classification of soil according to I_D substance index.

	Soil type	Material index I_D (-)
Organic soils and cohesive soils	Peat/sensitive clays	< 0.10
	Clay	0.1-0.35
	Silty clay	0.35-0.60
	Clayey silt	0.60-0.90
	Silt	0.90-1.20
Non- cohesive soils	Sandy silt	1.20-1.80
	Silty sand	1.80-3.30
	Sand	> 3.30

4.1.2. Horizontal stress index K_D

K_D can be considered as a K_0, which is strengthened by infiltration in the soil. The K_D chart is very similar to the OCR chart in terms of shape; hence, K_D will generally help a lot in knowing the storage and the stress history. For example, the value of K_D for OC clays is equal to 2 [12]. Equation 4 is provided to calculate the K_D value:

$$K_D = (P_0 - U_0)/(\sigma'v_0) \quad (4)$$

4.1.3. E_D dilatometer module

E_D is obtained based on P_0 and P_1 and the theory of elasticity for appropriate dimensions and limited boundary conditions. Due to the unavailability of information such as stress history, E_D should only be used with K_D and I_D [12]. Equation 5 shows how to calculate the dilatometer modulus, and Table 2 fully shows the intermediate and derived parameters:

$$E_D = 34.7(P_1 - P_0) \quad (5)$$

Table 2. Relationships of the parameters derived from three main and intermediate parameters of dilatometer [13]

Symbol	Description	Formula
P_0	Corrected first reading	$P_0 = 1.05\ (A - Z_M + \Delta A) - 0.05\ (B - Z_M - \Delta B)$
P_1	Corrected second reading	$P_1 = B - Z_M - \Delta B$
I_D	Material index	$I_D = (P_1 - P_0)/(P_0 - u_0)$
K_D	Horizontal stress index	$K_D = (P_0 - u_0) / \sigma'_{V0}$
E_D	Dilatometer modulus	$E_D = 34.7\ (P_1 - P_0)$
K_0	Coeff. earth pressure *in situ*	$K_{0,\ DMT} = (K_D / 1.5)^{0.47} - 0.6$
OCR	Over-consolidation ratio	$OCR_{DMT} = (0.5\ K_D)^{1.56}$
C_u	Undrained shear strength	$C_{u,DMT} = 0.22\ \sigma'_{V0}\ (0.5\ K_D)^{1.25}$
ϕ	Friction angle	$\phi_{Safe,DMT} = 28^{\circ} + 14.6^{\circ} \log K_D - 2.1^{\circ} \log^2 K_D$
C_h	Consolidation coefficient	$C_{h,DMT} \approx 7\ cm^2 / t_{flex}$
K_h	Permeability coefficient	$K_h = C_h\ \Upsilon_W / M_h\ (M_h \approx K_0\ M_{DMT})$
γ	Unit weight and description	*(See chart)*
M	Vertical drained constrained modulus	$M_{DMT} = R_M\ E_D$ If $I_D \leq 0.6$ $R_M = 0.14\ 2.36 \log K_D$ If $I_D \geq 3$ $R_M = 0.5 + 2 \log K_D$ If $0.6 < I_D < 3$ $R_M = R_{M.0} + (2.5 - R_{M.0}) \log K_D$ Where $R_{M.0} = 0.14 + 0.15\ (I_D - 0.6)$ If $K_D > 10$ $R_M = 0.32 + 2.18 \log K_D$ If $R_M < 0.85$ set $R_M = 0.85$
U_0	Equilibrium pore pressure	$U_0 = p_2 = C - Z_M + \Delta A$
G_0	Maximum shear modulus	$G_0 = \rho.(V_S)^{\wedge}2$
V_s	Shear wave velocity	$V_S = (S2-S1)/\Delta t$

5. Design and manufacture

According to the dimensions and dilatometer sizes provided in the publications and articles by the leading manufacturer, the design of the blade was started using the 3D AutoCAD software. This design included several separate sections, which are only referred to in this article:

1- Main blade design

2- Design of blade and rod interface

3- Rod design and placement of sensitive sensors

4- Central displacement sensor design

5- Mold design for making steel diaphragm

6- Electronic circuit design for 801-S sensitive sensors

7- Control unit design including pneumatic and electronic parts

After the complete design of the blade, Rod, and other parts, the AutoCAD file was converted to the CNC format. Thus machining and milling operations were performed on the steel block. The parts were assembled after preparation and dimensional control. The driver circuit design was done using the Fritzing software, and after that, the PCB printed circuit fiber was prepared by acid dissolution method and ready to assemble the electronic components. The electronic part of the control unit was for connecting the sensors to the circuit, and the output was for connecting to the computer. Also an active buzzer was used to measure diaphragm expansion. Compressed air inlet valves, pressure control, a dry gauge, air discharge valves, and connecting pipes were installed in the pneumatic section. Using the images and dimensions available on the Marchetti's website, a metal pad was made to create a shear wave. The Multi-Instrument-Pro software was used to observe the generated waves.

6. In-situ test performing

6.1. Necessity and location of test

After designing and manufacturing the dilatometer and equipping its first rod with a vibration-sensitive sensor, it was imperative to carry out an in-situ test to evaluate the device's performance and identify possible defects to fix. After obtaining the necessary permits, this test was conducted in under construction of Bahar Shiraz station, located at the intersection of Shariati Street and Bahar Shiraz Street, in the excavation phase of the passenger section of the station, at ticket hall level in the depth of 30 meters from the ground.

6.2. Method and results of test implementation

A simple dilatometry test was performed according to the ASTM D6635 standard [13] and in the sensitive sensor test section according to the ASTM D7400-14 standard [14]. First, the ΔA and ΔB parameters were measured and recorded according to the calibration instructions. These values were 0.1 bar for ΔA and 0.5 bar for ΔB. The penetration speed was about two cm/s. After penetration of 20 cm with compressed air, A and B values were read, and after correction, they were named P_0 and P_1. Table 3 shows the readings of A and B as well as the corrected values of P_0 and P_1.

Figure 7 shows the test implementation at Bahar Shiraz station of Tehran Metro Line 6.

Table 3. Readings done in the on-site test.

Depth	A	B	P0	P1
0.2	2.8	4.7	2.835	4.2
0.4	2.9	5	2.925	4.5
0.6	3.2	5.2	3.23	4.7
0.8	3.3	5.5	3.32	5.0

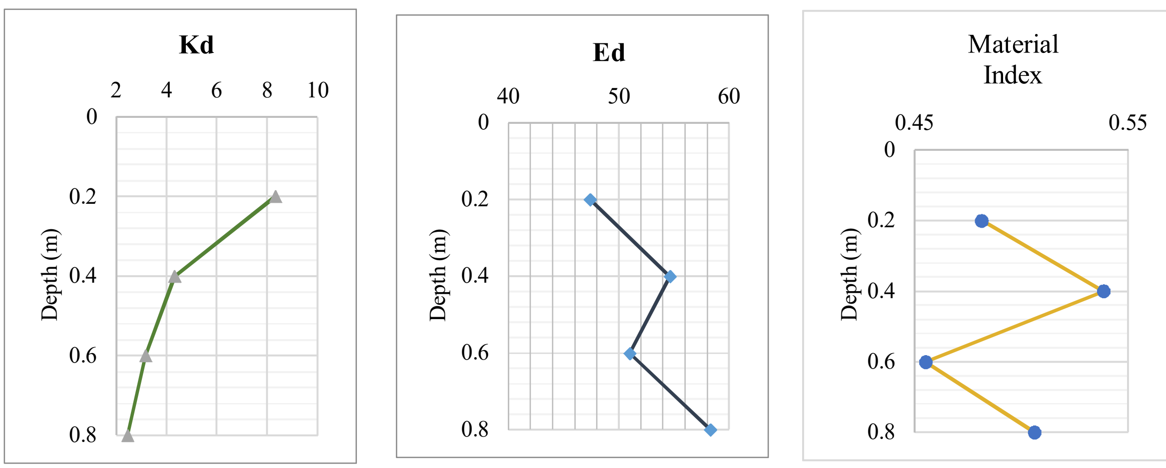


Diagram 3: Horizontal stress index **Diagram 2: Dilatometry modulus** **Diagram 1: Material index**

Figure 7. Implementation of test in under construction Bahar Shiraz station of Tehran Metro Line 6.

Based on the relationships presented in Table 2, the intermediate parameters of DMT including E_D, K_D, and I_D, were calculated. Diagrams 1 to 3 show the intermediate parameters in the penetration depth. As seen in diagram 1, the value of I_D is in the range of 0.45-0.55. According to the description of Table 1, which deals with the soil type characteristics based on the material index, the type of soil can be considered silty clay.

The dilatometry modulus of E_D in Figure 2 was in the range of 47-58 bars at the depth of the test. According to chart X1.1 presented by Marchetti in the ASTM 6635 standard [13] and based on the relationship between the material index and dilatometry modulus, the relative specific gravity of soil is 1.7. The horizontal stress index K_D has decreased logarithmically due to the increase in depth and has decreased from the range of 8-2. These changes can be seen in diagram 3. Some of the parameters derived from the intermediate parameters are also shown in diagrams 4 to 6.

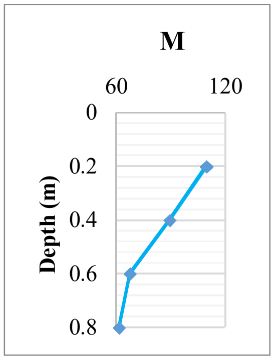


Diagram 4: Variations of finite tangential modulus M

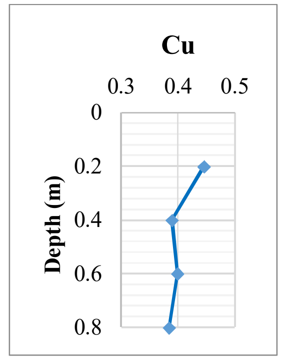


Diagram 5: Undrained shear strength

The drained finite tangential modulus M is obtained from Table 2, and based on the values of intermediate parameters. This modulus has been reduced from 110 bars to 61 bars under the influence of increased penetration. Diagram 4 shows the changes in the limited tangent modulus. Diagram 5 shows the changes in the undrained shear strength of Cu, which had little changes in the range of 0.44 -0.38 bar, and seems to have been influenced by the parameters σ'_{V0} and K_D. Figure 6 shows the loading history or OCR. Based on the findings, this chart is very similar to the K_D chart, and in $K_D = 2$, the OCR value will be 1.

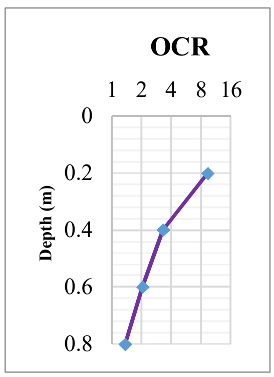


Diagram 6: OCR

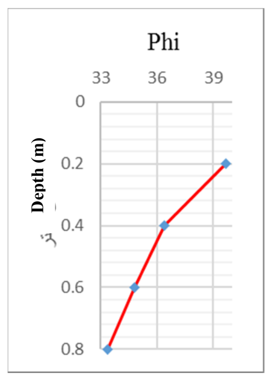


Diagram 7: Internal friction angle

The angle of internal friction was also calculated through intermediary parameters. Although the value of this parameter was near the level of 39.6 degrees, with the increase of penetration in soil, it showed a more stable numerical value, so between the third to fourth readings, the difference of angle and the slope of the graph became less. Diagram 7 shows the changes in the angle of internal friction. This parameter shows more changes under the influence of soil type or intermediate parameter I_D.

Seismic test and shear wave velocity measurement were also performed according to ASTM D7400 standard [14], which is provided for the Downhole test. For this purpose, an iron pad was placed on the soil at a distance of 2 m from the rod and the dilatometer assembly, and the blow was applied with a 10 kg hammer. The generated vibration is received by the sensors, and after processing in the control unit, it is sent as an output signal from the control unit and enters the software through the input of the sound card of the computer. The blue and red waves shown in Figure 8 show the impact signal received by the upper and lower sensors of the rod.

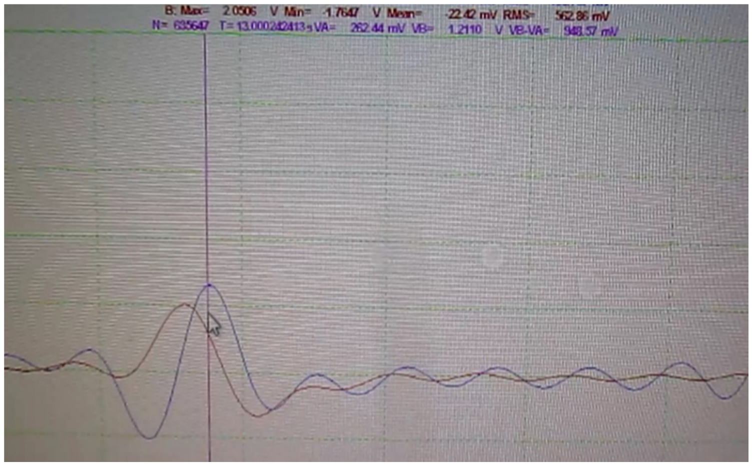


Figure 8. Waves received by the rad sensors.

After synchronizing the blue and red waves, Δt is calculated. The values of S_1 and S_2 are also easily calculated according to the distance from the wave generation source and the depth of the test. Finally, based on the relationship presented in Table 2, the speed of the shear waves in the soil and at the depth of the test was calculated, and 504 m/s was obtained. On the other hand, another derived parameter will be calculated from the shear wave speed. This parameter is the maximum shear modulus, which was calculated to be 4.33 MPa according to the soil unit weight obtained from the I_D and K_D diagram and also the speed of the shear wave.

$$G_0 = \rho\ (V_s)\ \hat{}2 = 17\times(504)\ \hat{}2 = 4.32\ MPa$$

6.3. Comparison of test results with results of final geotechnical report of Tehran Metro Line 6 [15]

According to the logarithmic diagram prepared based on the intermediate parameters of E_D and I_D and the results obtained from the dilatometry test, the value of I_D at the test site was between 0.33 and 0.6 (on the horizontal axis) and E_D between (47 and 58) times, which indicates SC (silty clay) and corresponds to the type of soil introduced in the BH14 report at the appropriate depth. The average results of the soil internal friction angle will be equal to 36.05 degrees. Therefore, there is a difference of 3.05 degrees with the value of the geotechnical report at the mentioned depth, which is 33 degrees. Also the undrained shear strength for the in-situ test was obtained as an average of 40.44 kPa, which differs by 4.56 kPa compared to the declared value in the report, which is 45 kPa. On the other hand, it can be seen that the dry weight of the soil in the final report is 18.5 kN/m^3, compared to the result of the in-situ test is 1.5 kN/m^3 more. (relative to the water gamma.) In terms of shear wave velocity, the value announced in the final geotechnical report was 560 meters per second, which is about 10% higher than the value obtained from the in-situ test, and this 90% accuracy in the test seems to be an acceptable value for this measurement.

7. Conclusions

The implementation of this project as a practical step towards localization, on the one hand, and the innovation in the type of sensor used in it, on the other hand, was of particular importance. The results of the field test and the physical and mechanical parameters of the soil show the performance and efficiency of the device. Although to validate the values, it is suggested to measure the same parameters with a calibrated dilatometer or to use other laboratory methods. Also due to the reproducibility, it is possible to obtain more accurate results by repeating the test at a specific site and determining the correction factor for dependent and derived parameters. In general, the value of the correction coefficient for the manufactured device according to the results of the final report, which can be considered an authentic and official report, can be considered as follows:

In undrained shear strength, about a 10.13% deviation from the value declared in the final report can be seen, which could be corrected by applying a factor of 1.11276.

Regarding the specific gravity, this deviation reaches 8.11%, and therefore, the correction factor for it is 1.08823.

The shear wave velocity obtained with the value declared in the report shows a deviation of 9.91%, which seems that by increasing the depth and removing the influence of environmental factors (vibrations and environmental noises), it is possible to achieve more realistic values; it will be possible.

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طراحی، ساخت و اجرای آزمون برجای اولین دیلاتومتر لرزه‌ای مجهز به سنسور الکترونیکی در پروژه خط ۶ مترو تهران، به عنوان یک آزمایش سریع و سازگار با محیط زیست با کمترین میزان آشفتگی خاک

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چکیده:

خواص فیزیکی و مکانیکی خاک از طریق آزمون‌های آزمایشگاهی یا برجا به‌دست می‌آید. دیلاتومتر یک ابزار آزمون برجا در مهندسی مکانیک سنگ و ژئوتکنیک است که به طور گسترده در کشورهای توسعه یافته استفاده می‌شود. در نسخه پیشرفته این دستگاه یک ژئوفون لرزش زمین را دریافت می‌کند. بنابراین V_s را می‌توان در عمق تیغه به‌دست آورد. این تحقیق عملکرد اولین دیلاتومتر مجهز به سنسور الکترونیکی حساس به لرزش را با توجه به هزینه کمتر، طول عمر و حساسیت بیشتر و همچنین توانایی در انتقال سیگنال به جای ژئوفون مورد بررسی و امکان‌سنجی قرار می‌دهد. این تغییرات آن را به یک ابزار آنلاین متصل به آردوینو تبدیل می‌کند، پلتفرمی که می‌تواند به‌طور خودکار خروجی دیجیتال یا آنالوگ را منتقل کند. آزمون برجا در ایستگاه در حال ساخت بهار شیراز در خط ۶ مترو تهران در عمق ۳۰ متری انجام شد. موج برشی توسط یک چکش ایجاد و پس از تقویت، سیگنال‌های دریافتی با نرم‌افزار اندازه‌گیری شدند. سرعت موج برشی در محل آزمایش ۵۰۴ متر بر ثانیه به‌دست آمد. این نتیجه در مقایسه با مقدار اعلام شده در گزارش نهایی مطالعات ژئوتکنیک خط ۶ که توسط مهندسان مشاور دریا-خاک-پی انجام شده ۱۰ درصد انحراف را نشان می‌دهد. برای بررسی نتایج و کالیبراسیون، انجام آزمایش‌های مقایسه‌ای بیشتر پیشنهاد می‌شود. استفاده از سنسور S-۸۰۱ با طول عمر بیشتر (بیش از ۶۰ میلیون ارتعاش) و قابلیت اتصال به اینترنت با برد آردوینو، نوآوری اعمال شده برای معرفی نسل جدید این ابزار در دنیای مهندسی است.

کلمات کلیدی: دیلاتومتر تیغه‌ای، سنسور S-801، سرعت موج برشی، آزمون برجا، ژئوتکنیک، مکانیک سنگ، ESDMT.