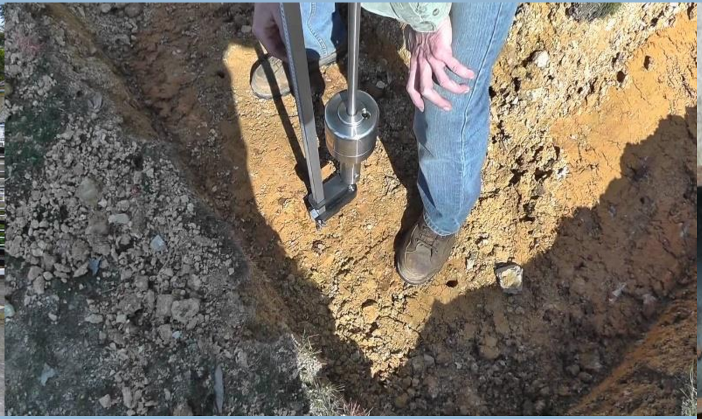
SUBSURFACE EXPLORATION FIELD TESTS & FOUNDATION DESIGN (TBDY,2018)



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Yıldız Technical University

Outline of the Presentation

- Subsurface Exploration, Site Investiagtion & Field Tests
- The New Turkish Seismic Design Code (2018)
- Chapter 16: Special Rules for the Design of Foundation Soil and Foundations Under Earthquake Effect (TBDY 2018)
- Design Example according to TBDY (2018)
- Project Steps for Geotechnics Team

Purpose of Subsurface Exploration

The process of identifying the layers of deposits that underlie a proposed structure and their physical characteristics is generally referred to as *subsurface exploration*. The purpose of subsurface exploration is to obtain information that will aid the geotechnical engineer in

- Selecting the type and depth of foundation suitable for a given structure.
- Evaluating the load-bearing capacity of the foundation.
- Estimating the probable settlement of a structure.
- Determining potential foundation problems (e.g., expansive soil, collapsible soil, sanitary landfill, and so on).
- Determining the location of the water table.
- Predicting the lateral earth pressure for structures such as retaining walls, sheet pile bulkheads, and braced cuts.
- Establishing construction methods for changing subsoil conditions.

Subsurface exploration may also be necessary when additions and alterations to existing structures are contemplated.

Reconnaissance Work

The engineer should always make a visual inspection of the site to obtain information about

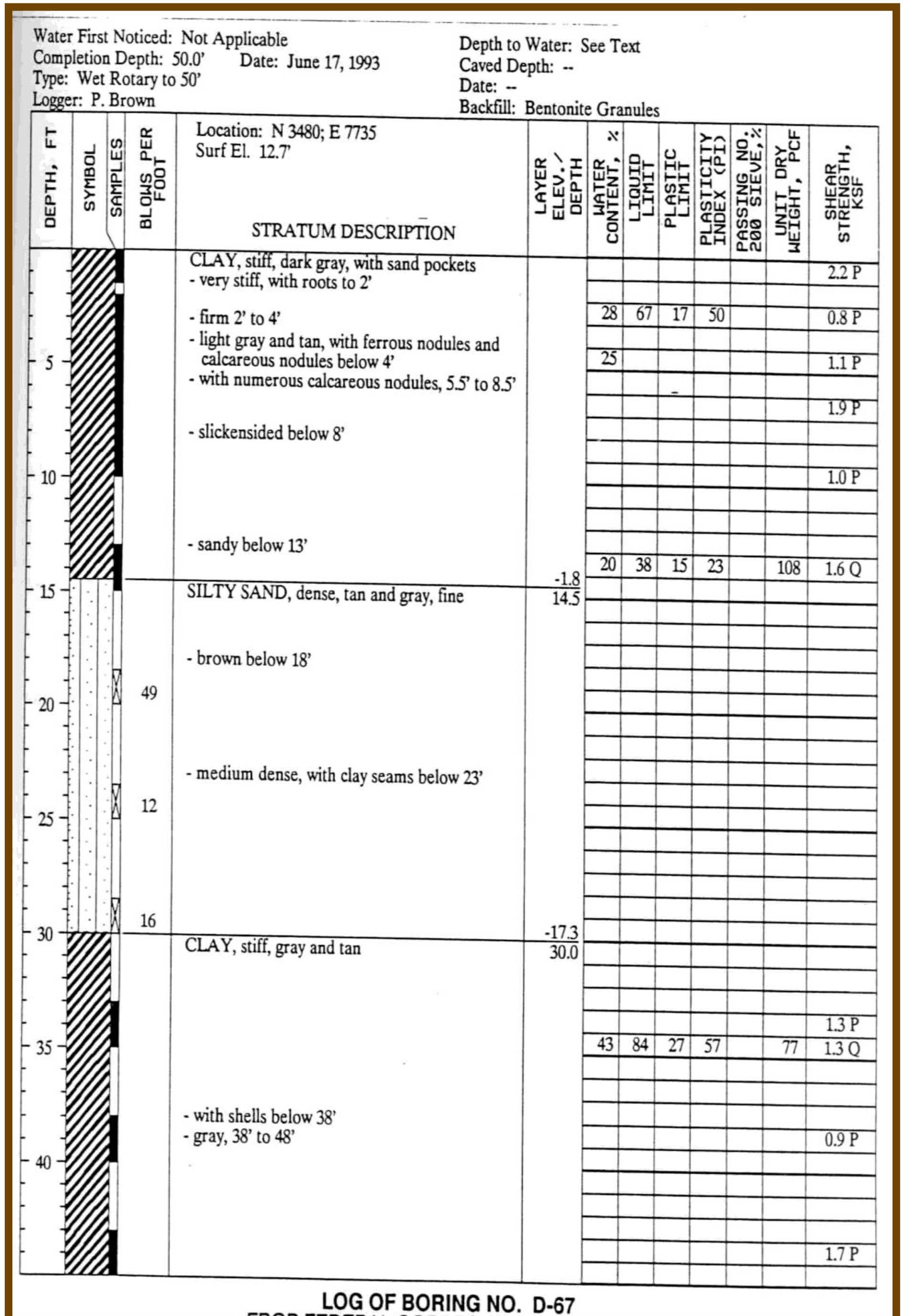
- The general topography of the site, the possible existence of drainage ditches, abandoned dumps of debris, and other materials present at the site. Also, evidence of creep of slopes and deep, wide shrinkage cracks at regularly spaced intervals may be indicative of expansive soils.
- Soil stratification from deep cuts, such as those made for the construction of nearby highways and railroads.
- The type of vegetation at the site, which may indicate the nature of the soil. For example, a mesquite cover may indicate the existence of expansive clays that can cause foundation problems.
- High-water marks on nearby buildings and bridge abutments.
- Groundwater levels, which can be determined by checking nearby wells.
- The types of construction nearby and the existence of any cracks in walls or other problems.
- The nature of the stratification and physical properties of the soil nearby also can be obtained from any available soil-exploration reports on existing structures.

Site Investigation

The site investigation phase of the exploration program consists of

- Planning
- Making test boreholes
- Collecting soil samples at desired intervals for subsequent observation and laboratory tests

The approximate required minimum depth of the borings should be predetermined. The depth can be changed during the drilling operation, depending on the subsoil encountered.



Water First Noticed: Not Applicable
Completion Depth: 50.0' Date: June 17, 1993
Type: Wet Rotary to 50'
Logger: P. Brown

Depth to Water: See Text
Caved Depth: --
Date: --
Backfill: Bentonite Granules

Location: N 3480; E 7735
Surf El. 12.7'

DEPTH, FT	BLOWS PER FOOT	STRATUM DESCRIPTION	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX (PI)	PASSING NO. 200 SIEVE, %	UNIT DRY WEIGHT, PCF	SHEAR STRENGTH, KSF
		CLAY, stiff, dark gray, with sand pockets								
		- very stiff, with roots to 2'								2.2 P
		- firm 2' to 4'		28	67	17	50			0.8 P
		- light gray and tan, with ferrous nodules and calcareous nodules below 4'		25						1.1 P
5		- with numerous calcareous nodules, 5.5' to 8.5'								1.9 P
		- slickensided below 8'								
10										1.0 P
		- sandy below 13'		20	38	15	23		108	1.6 Q
15		SILTY SAND, dense, tan and gray, fine	-1.8 / 14.5							
		- brown below 18'								
20	49									
		- medium dense, with clay seams below 23'								
25	12									
	16									
30		CLAY, stiff, gray and tan	-17.3 / 30.0							
										1.3 P
35				43	84	27	57		77	1.3 Q
		- with shells below 38'								
40		- gray, 38' to 48'								0.9 P
										1.7 P

LOG OF BORING NO. D-67

Laboratory Tests

-Index Properties and Sieve analysis

-Compressibility parameters

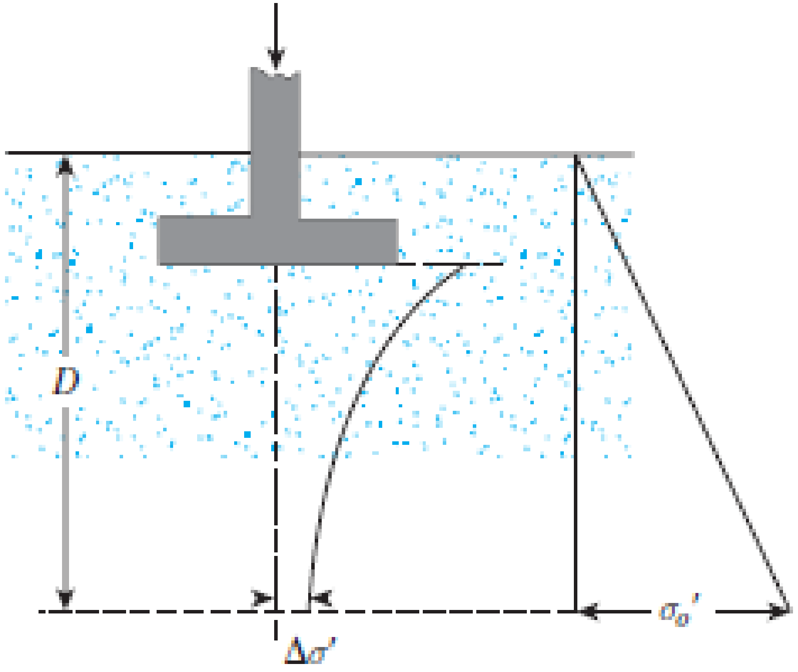
-Strength parameters

-Permeability properties

Site Investigation

To determine the approximate minimum depth of boring, engineers may use the rules established by the New Turkish Seismic Design Code (2018)

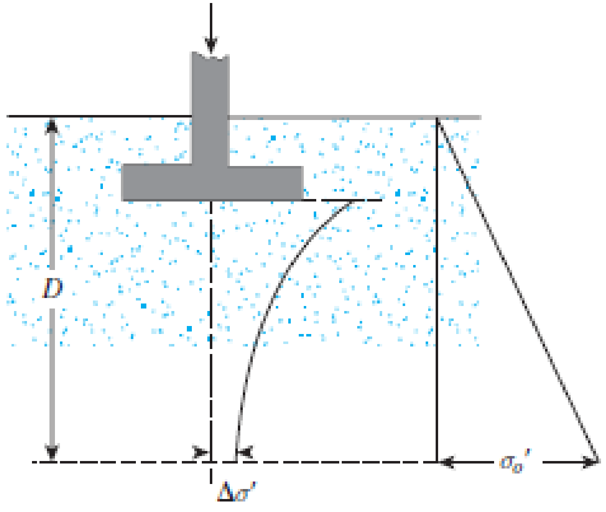
- Determine the net increase in the effective stress, $\Delta\sigma'$, under a foundation with depth as shown in the below Figure.
- Estimate the variation of the vertical effective stress, σ_o', with depth.



Determination of the minimum depth of boring

Site Investigation

3. Determine the depth, $D = D_1$, at which the effective stress increase $\Delta\sigma'$ is equal to $(\frac{1}{10})q$ (q = estimated net stress on the foundation).
4. Determine the depth, $D = D_2$, at which $\Delta\sigma'/\sigma'_o = 0.05$.
5. Choose the smaller of the two depths, D_1 and D_2, just determined as the approximate minimum depth of boring required, unless bedrock is encountered.



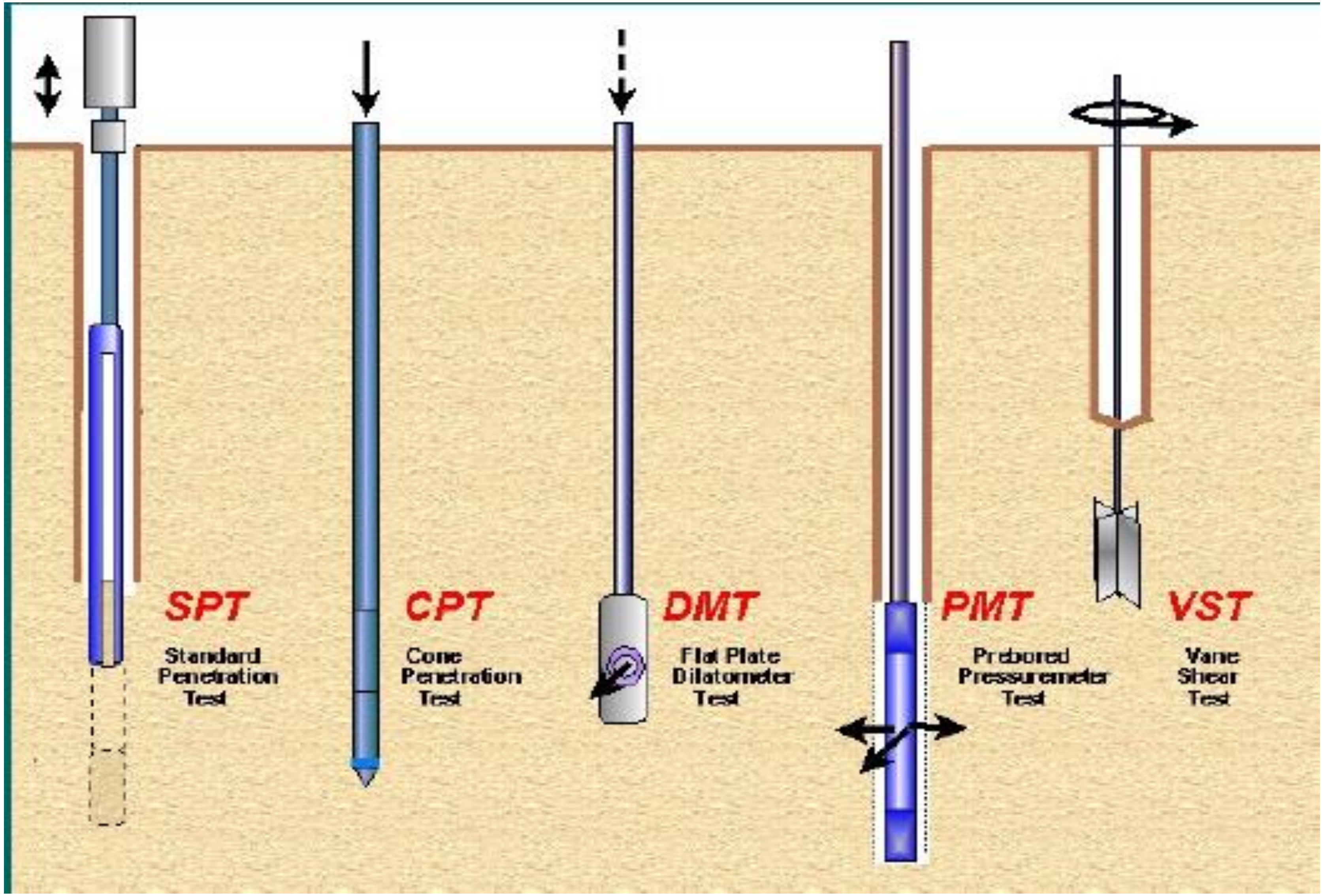
When deep excavations are anticipated, the depth of boring should be at least 1.5 times the depth of excavation.

- Sometimes, subsoil conditions require that the foundation load be transmitted to bedrock. The minimum depth of core boring into the bedrock is about 3 m. If the bedrock is irregular or weathered, the core borings may have to be deeper.
- There are no hard-and-fast rules for borehole spacing. Table 2.4 gives some general guidelines. Spacing can be increased or decreased, depending on the condition of the sub- soil. If various soil strata are more or less uniform and predictable, fewer boreholes are needed than in nonhomogeneous soil strata.

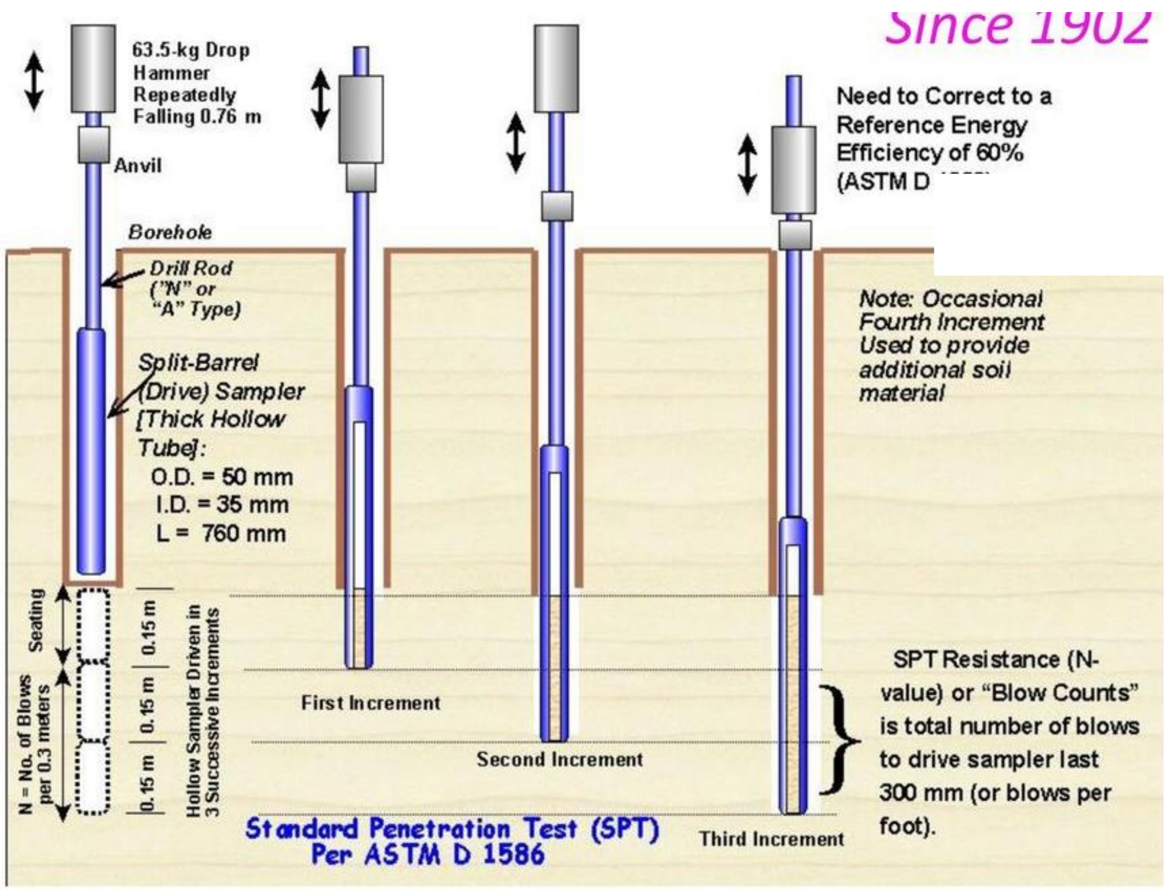
Table 2.4 Approximate Spacing of Boreholes

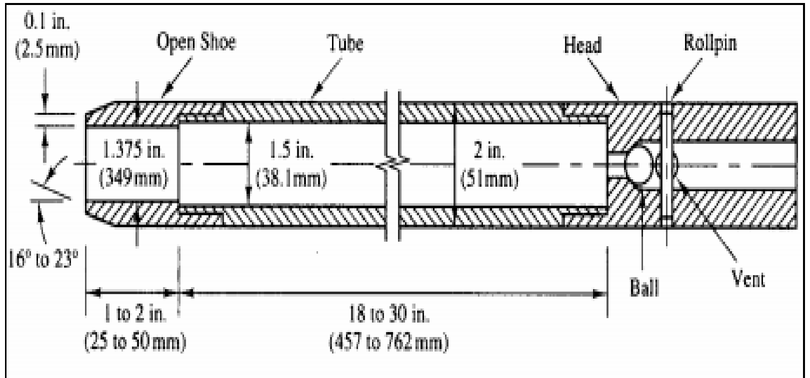
Type of project	Spacing (m)
Multistory building	10–30
One-story industrial plants	20–60
Highways	250–500
Residential subdivision	250–500
Dams and dikes	40–80

Subsurface Exploration and Field tests



1)Standard Penetration Test(SPT)





The SPT sampler (Adapted from ASTM D1586; Copyright ASTM, used with permission)

Figure 3 – *Standard dimensions for the SPT sampler, as given in ASTM D1586.*

- It is a simple and inexpensive test to estimate the relative density of soils and approximate shear strength parameters.
- The sum of the number of blows required for the second and third 150 mm of penetration is reported as SPT blow count value, commonly termed "standard penetration resistance" or the "N-value".

1)Standard Penetration Test(SPT)

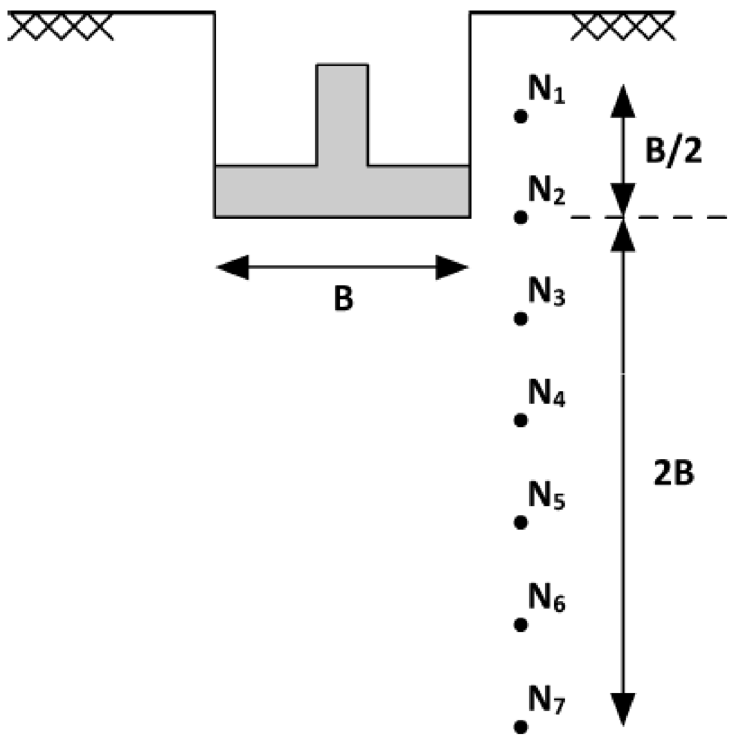
Project: Borehole Samples		**B.H. No.** : I	**Sheet:** 1/1
Owner: Western University		**Start Date:** 17/07/2012	**End Date:** 17/07/2012
Location: Western Environmental Site	Western	**Casing Depth:** 9.00 m	**E:** ---
Rig Type: CME 55 Mount Drill		**G.W. Depth (m):** 6.41 m	**N:** ---
Drilling Method: Rotary Drilling		**Weather :** Sunny	**B.H. Elev:** ---

Depth. (m)	Thick. (m)	Description	SPT Counts 15cm	15cm	15cm	w %	LL %	PL %
		200 mm to 300 mm Top Soil						
	4.00	Firm to Stiff, brown becoming gray at a depth of 3.8 m, lean CLAY with coarse sand and some gravel.	2	6	12	---	---	
1.00			5	5	6	23.3	30.6	16.5
2.00			5	6	11	12.28	28.32	16.12
3.00			5	7	11	13.07	25.72	15.68
4.00			5	7	11	13.86	24.92	15.87
	1.00	Firm to Stiff, light gray becoming dark gray at a depth of 6.5 m, lean CLAY with fine sand and some gravel.	5	5	7	13.00	17.53	12.76
5.00			5	6	7	12.99	24.05	14.27
	1.00	Soft, light gray becoming dark gray at a depth of 6.5 m, lean CLAY fine sand and some gravel.	1	2	2	23.78	37.46	21.09
6.00	0.50	Firm, light gray becoming dark gray at a depth of 6.5 m, lean CLAY	2	3	7	14.79	29.65	15.91
7.00	1.50	Very Stiff, dark gray, lean clay with seams fine sand.	2	8	12	16.55	23.65	12.37
8.00			13	16	22	11.92	18.62	13.10
	0.75	Very Stiff to hard, dark gray, lean clay with seams fine sand.	11	19	26	13.06	21.30	12.43
9.00	0.25	Hard, gray CLAY						

END OF BORING

1)Standard Penetration Test(SPT)

Evaluation of SPT-N Test Results



- An average value of SPT-N is recommended to be used for determining the representative value to determine the soil properties.

$$N_{60} = \frac{N \eta_H \eta_B \eta_S \eta_R}{60} \qquad (2.6)$$

where

N_{60} = standard penetration number, corrected for field conditions
N = measured penetration number
η_H = hammer efficiency (%)
η_B = correction for borehole diameter
η_S = sampler correction
η_R = correction for rod length

Tablo 16B.1. SPT Düzeltme Katsayıları

Düzeltme Katsayısı	Değişken	Değer
C_R	3m ile 4m aralığında	0.75
	4m ile 6m aralığında	0.85
	6m ile 10m aralığında	0.95
	10m'den derin	1.00
C_S	Standart numune alıcı (iç tüpü olan)	1.00
	İç tüpü olmayan numune alıcı	1.10-1.30
C_B	Çap 65mm-115mm arasında	1.00
	Çap 150mm	1.05
	Çap 200mm	1.15
C_E	Güvenli tokmak	0.60-1.17
	Halkalı tokmak	0.45-1.00
	Otomatik darbeli tokmak	0.90-1.60

CORRELATIONS BASED ON SPT-N FOR GRANULAR SOILS

Correlation between Angle of Friction and Standard Penetration Number

The peak friction angle, ϕ', of granular soil has also been correlated with N_{60} or $(N_1)_{60}$ by several investigators. Some of these correlations are as follows:

1. Peck, Hanson, and Thornburn (1974) give a correlation between N_{60} and ϕ' in a graphical form, which can be approximated as (Wolff, 1989)

$$\phi'(\text{deg}) = 27.1 + 0.3N_{60} - 0.00054[N_{60}]^2 \qquad (2.26)$$

2. Schmertmann (1975) provided the correlation between N_{60}, σ'_o, and ϕ'. Mathematically, the correlation can be approximated as (Kulhawy and Mayne, 1990)

$$\phi' = \tan^{-1}\left[\frac{N_{60}}{12.2 + 20.3\left(\frac{\sigma'_o}{p_a}\right)}\right]^{0.34} \qquad (2.27)$$

where

N_{60} = field standard penetration number
σ'_o = effective overburden pressure
p_a = atmospheric pressure in the same unit as σ'_o
ϕ' = soil friction angle

3. Hatanaka and Uchida (1996) provided a simple correlation between ϕ' and $(N_1)_{60}$ that can be expressed as

$$\phi' = \sqrt{20(N_1)_{60}} + 20 \qquad (2.28)$$

CORRELATIONS BASED ON SPT-N FOR GRANULAR SOILS

Correlation between Modulus of Elasticity and Standard Penetration Number

The modulus of elasticity of granular soils (E_s) is an important parameter in estimating the elastic settlement of foundations. A first order estimation for E_s was given by Kulhawy and Mayne (1990) as

$$\frac{E_s}{p_a} = \alpha N_{60} \tag{2.29}$$

where

p_a = atmospheric pressure (same unit as E_s)

$$\alpha = \begin{cases} 5 \text{ for sands with fines} \\ 10 \text{ for clean normally consolidated sand} \\ 15 \text{ for clean overconsolidated sand} \end{cases}$$

$$CI = \frac{LL - w}{LL - PL} \tag{2.7}$$

where

w = natural moisture content
LL = liquid limit
PL = plastic limit

The approximate correlation between CI, N_{60}, and the unconfined compression strength (q_u) is given in Table 2.6.

Hara, et al. (1971) also suggested the following correlation between the undrained shear strength of clay (c_u) and N_{60}:

$$\frac{c_u}{p_a} = 0.29 N_{60}^{0.72} \tag{2.8}$$

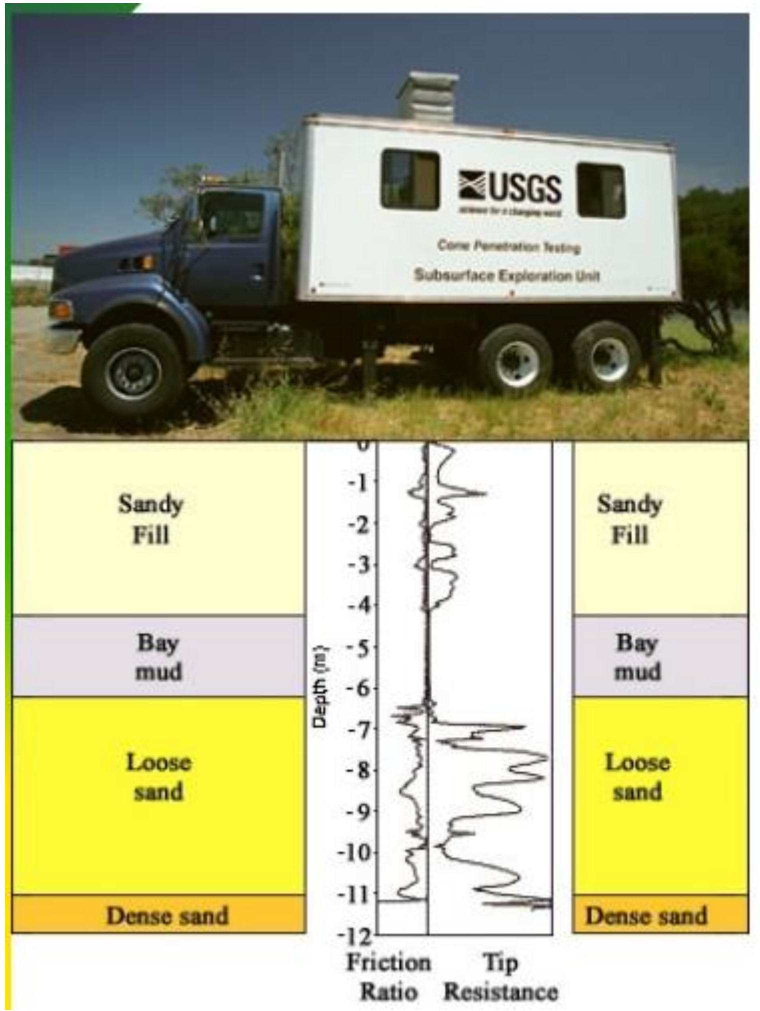
where p_a = atmospheric pressure ($\approx$ 100 kN/m^2; $\approx$ 2000 lb/in^2).

Table 2.6 Approximate Correlation between CI, N_{60}, and q_u

Standard penetration number, N_{60}	Consistency	CI	Unconfined compression strength, q_u (kN/m^2)
<2	Very soft	<0.5	<25
2–8	Soft to medium	0.5–0.75	25–80
8–15	Stiff	0.75–1.0	80–150
15–30	Very stiff	1.0–1.5	150–400
>30	Hard	>1.5	>400

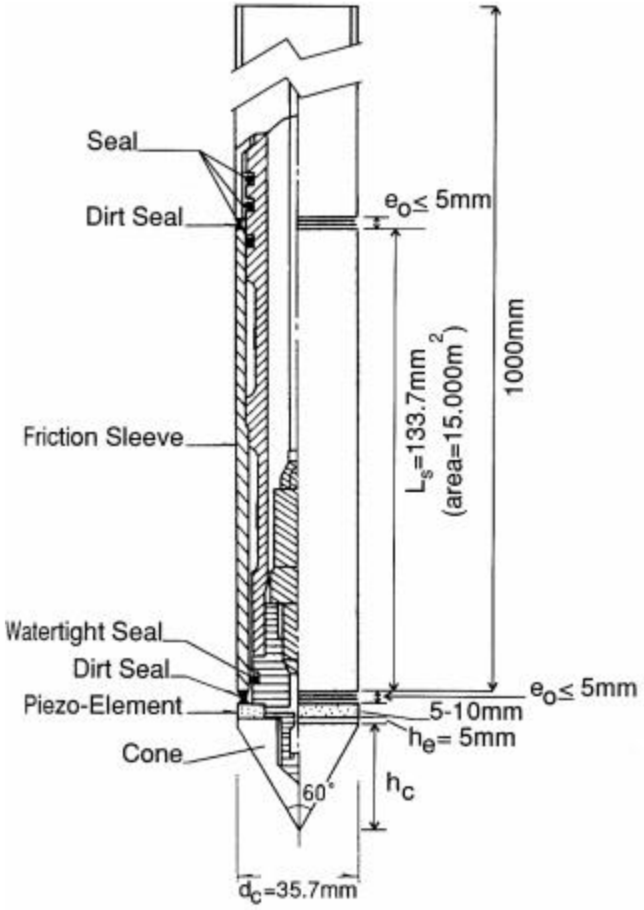
CORRELATIONS FOR N_{60} IN COHESIVE SOIL

2) Cone Penetration Test (CPT)



- It is a valuable method of assessing subsurface stratigraphy associated with soft materials, discontinuous lenses, organic materials (peat), potentially liquefiable materials (silt, sands and granule gravel), and landslides.

2) Cone Penetration Test (CPT)

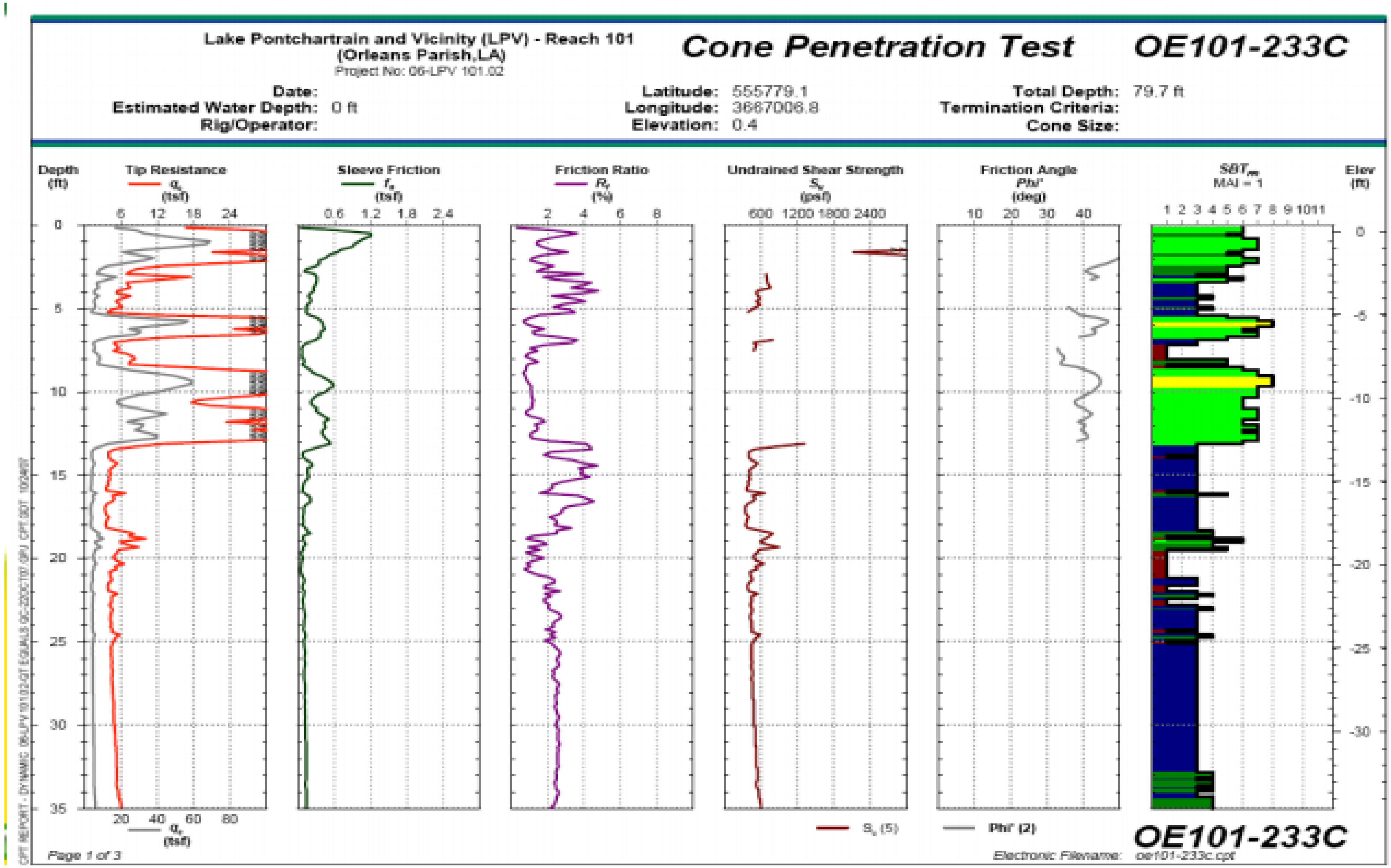


Example of a Reference Penetrometer With a Fixed Cone and With Friction Sleeve

- The standardized cone penetrometer test (CPT) involves pushing a 1.41- inch diameter 55° to 60° cone through the underlying ground at a rate of 1 to 2 cm/sec.

2) Cone Penetration Test (CPT)

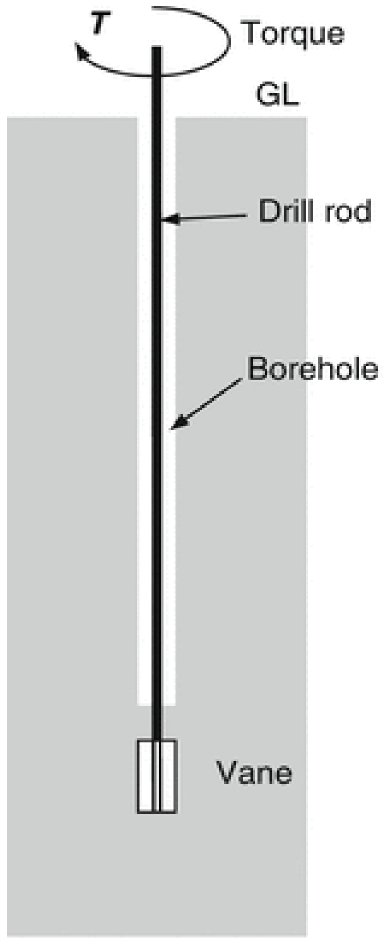
- Typical CPT summary logs

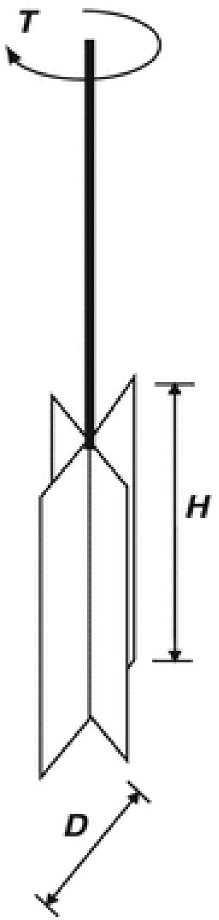


3)Vane Shear Test

- The vane shear test is an in-situ geotechnical testing methods used to estimate the undrained shear strength of fully saturated clays without disturbance. The test is relatively simple, quick, and provides a cost-effective way of estimating the soil shear strength; therefore, it is widely used in geotechnical investigations. The results of the test are not reliable if clay contains silt or sand. Under special condition, the vane shear test can be also carried out in the laboratory on undisturbed soil specimens; however, the use of the vane shear test in in-situ testing is much more common.

3)Vane Shear Test





4)Seismic Reflection Test

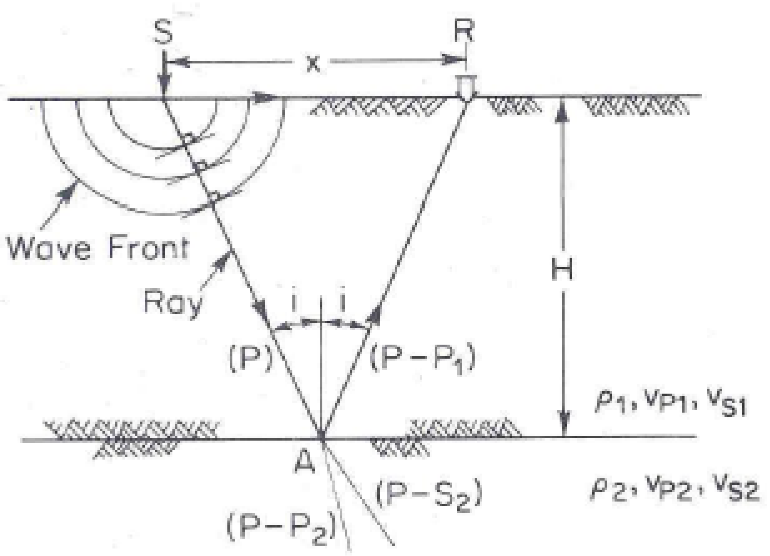
- Wave velocity and the thickness of the soil layers are determined.

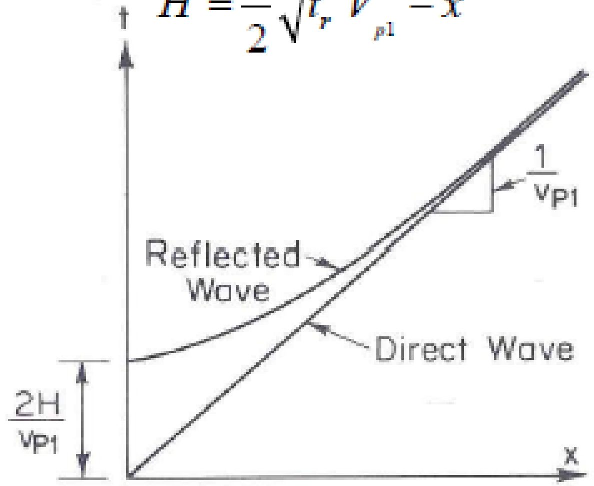
$$t_d = \frac{\text{distance of travel}}{\text{wave velocity}} = \frac{x}{V_{p1}}$$

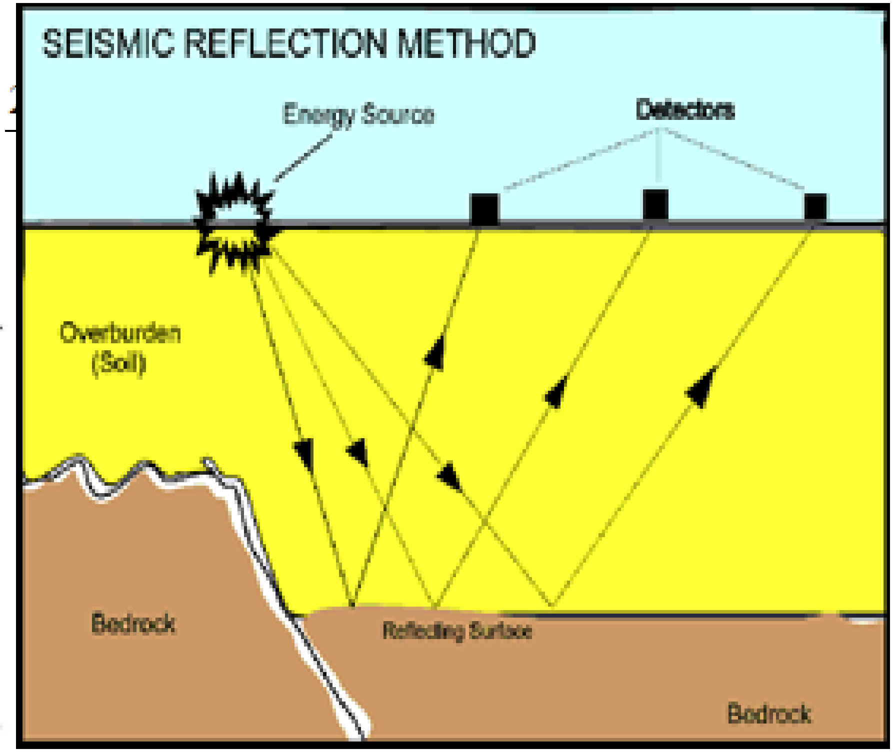
$$i = \tan^{-1}\frac{x}{2H}$$

$$t_r = \frac{\text{distance of travel}}{\text{wave velocity}} =$$

$$H = \frac{1}{2}\sqrt{t_r^{\,2} V_{p1}^2 - x^2}$$



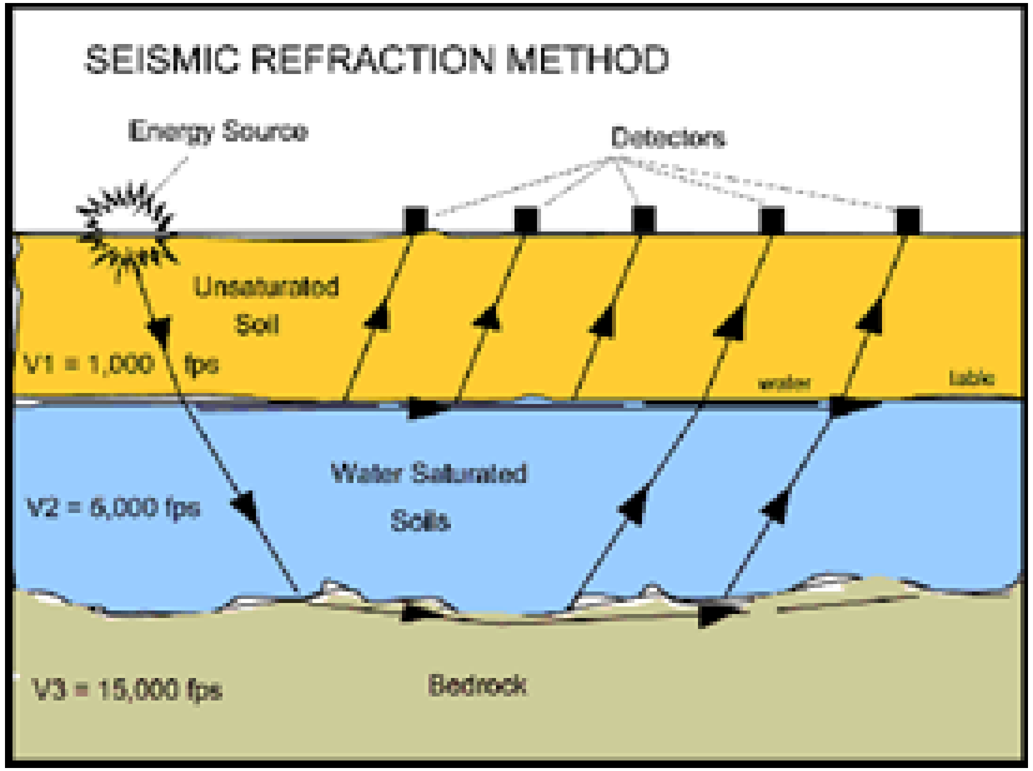




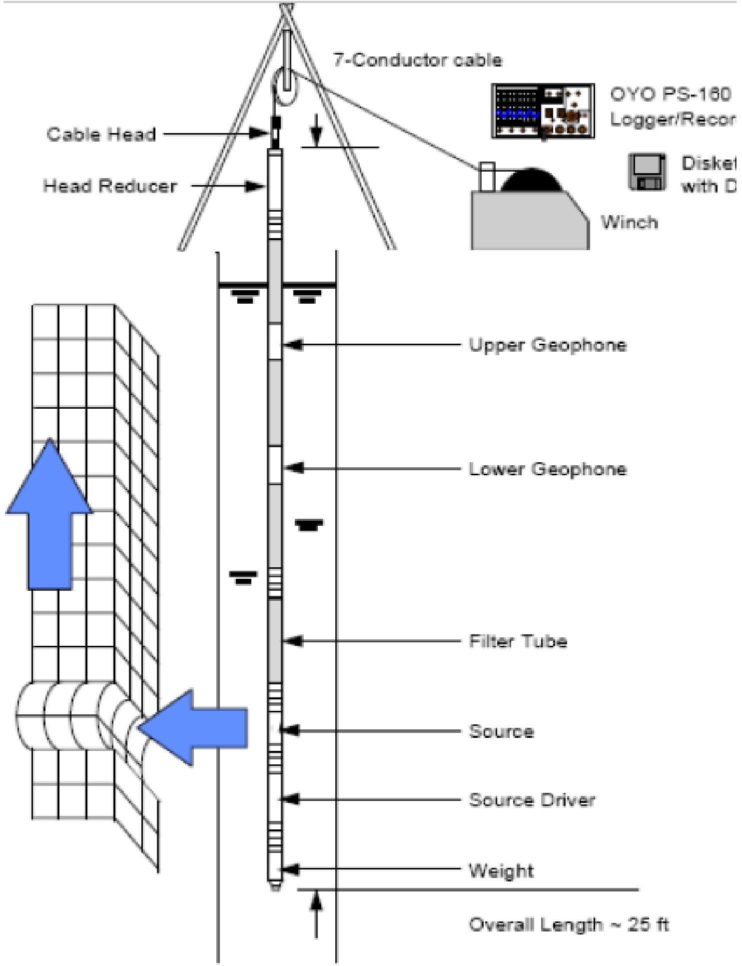
From Richart, Hall and Woods

5)Seismic Refraction Test

- Wave velocity and the thickness of soil layers can be determined using the refracted wave velocity.

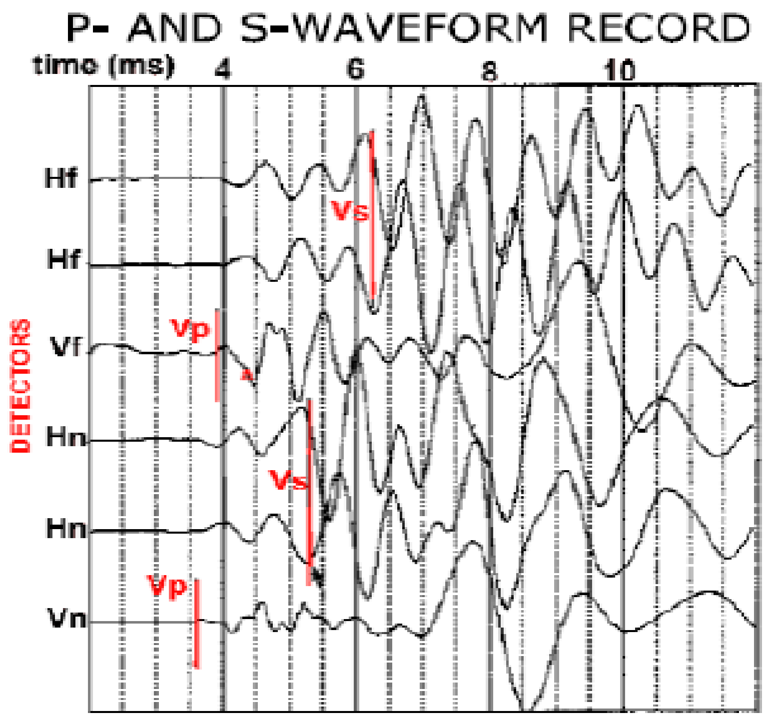


6)PS Logging Test

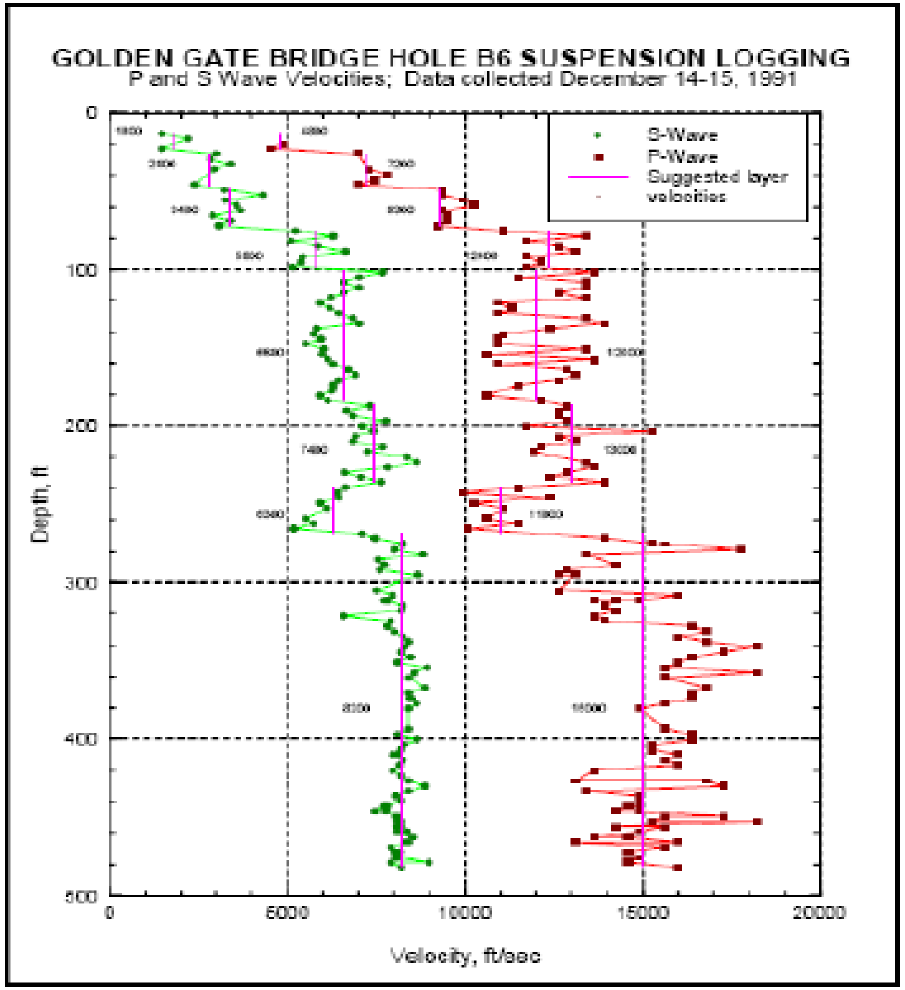


- Suspension P-S velocity logging (also known as suspension logging) is a method for determining shear (VS) and compressional (VP) wave velocity profiles as a function of depth, in addition to supplementing stratigraphic information obtained in soil and rock formations.

6)PS Logging Test



Norcal Geophysical Consultants



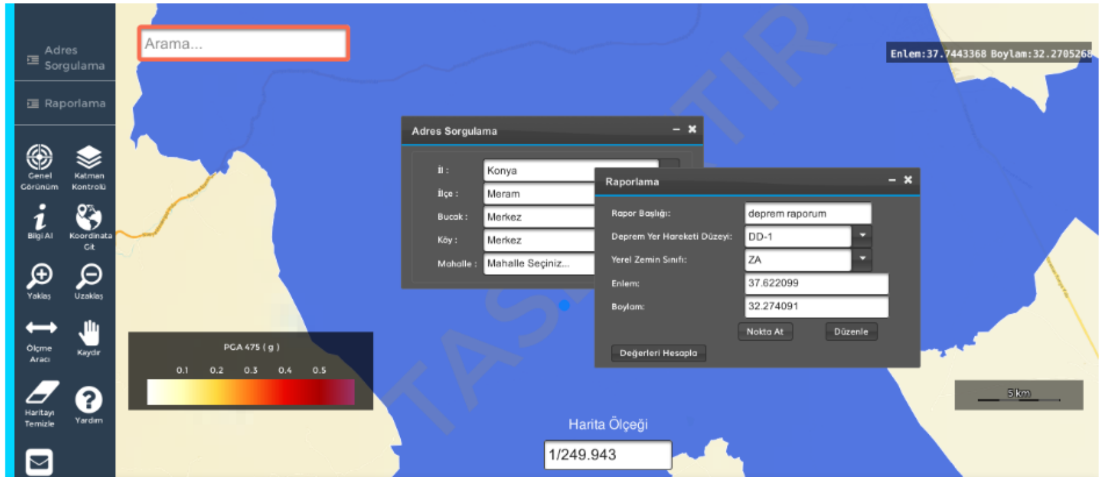
THE NEW TURKISH SEISMIC DESİGN CODE (2018)

The new Turkish Building Earthquake Code is a comprehensive revised version of the previous one dated 2007. The new code consists of 17 chapters.

Chapter 16: Special Rules for the Design of Foundation Soil and Foundations Under Earthquake Effect (Geotechnical Considerations)

In New Turkish Seismic Design Code, the geotechnical design issuses are explained as follows;

- The scope of subsurface exploration
- Determination of site soil conditions, soil class and soil parameters
- Design of foundations and basement shear walls under earthquake loading
- Soil-Structure Interaction Analysis
- Evaluation of liquefaction potential of soils
- Design principles of soil retaining structures and slopes under earthquake loading effects
- Rules are defined for in-situ soil improvement of soils (explained in the annex part of the design code)



TO DETERMINE S_S AND S_{DS} GO TO AFAD 'S WEB PAGE (OR SEE MAPS IN THE CODE):

https://tdth.afad.gov.tr/

Determination of site soil class

- The site soil will be classified in accordance with the Table below based on the upper 30 m of the site profile. Steps for Classifying a site:
- **Step 1**: Check for the categories of site class ZF requiring site-specific evaluation. If the site corresponds to any of these categories, classify the site as Site Class ZF and perform a site-specific evaluation.
- **Step 2**: Check for the existence of a total thickenss of soft clay > 3m where a soft clay layer is defined by: $c_u<25$ kPa, $w\geq40\%$ and $PI>20\%$. If these criteria are satisfied, classify the site as Site Class ZE.
- **Step 3:** Categorize the site using one of the following three methods with $(V_s)_{30}$, $(N_{60})_{30}$ and $(c_u)_{30}$ computed in all cases as defined with below equations;

$$(V_S)_{30} = \frac{30}{\sum_{i=1}^{N}\left(\frac{h_i}{V_{S,i}}\right)} \quad ; \quad (N_{60})_{30} = \frac{30}{\sum_{i=1}^{N}\left(\frac{h_i}{N_{60,i}}\right)} \quad ; \quad (c_u)_{30} = \frac{30}{\sum_{i=1}^{N}\left(\frac{h_i}{c_{u,i}}\right)} \qquad \textbf{(16.2)}$$

TBDY Table 16.1 – Local Site Class

Yerel Zemin Sınıfı	Zemin Cinsi	Üst 30 metrede ortalama $(V_S)_{30}$ [m/s]	Üst 30 metrede ortalama $(N_{60})_{30}$ [darbe /30 cm]	Üst 30 metrede ortalama $(c_u)_{30}$ [kPa]
ZA	Sağlam, sert kayalar	> 1500	–	–
ZB	Az ayrışmış, orta sağlam kayalar	760 – 1500	–	–
ZC	Çok sıkı kum, çakıl ve sert kil tabakaları veya ayrışmış, çok çatlaklı zayıf kayalar	360 – 760	> 50	> 250
ZD	Orta sıkı – sıkı kum, çakıl veya çok katı kil tabakaları	180 – 360	15 – 50	70 – 250
ZE	Gevşek kum, çakıl veya yumuşak – katı kil tabakaları veya $PI > 20$ ve $w > \%\,40$ koşullarını sağlayan toplamda 3 metreden daha kalın yumuşak kil tabakası $(c_u < 25 \text{ kPa})$ içeren profiller	< 180	< 15	< 70
ZF	Sahaya özel araştırma ve değerlendirme gerektiren zeminler: 1) Deprem etkisi altında çökme ve potansiyel göçme riskine sahip zeminler (sıvılaşabilir zeminler, yüksek derecede hassas killer, göçebilir zayıf çimentolu zeminler vb.), 2) Toplam kalınlığı 3 metreden fazla turba ve/veya organik içeriği yüksek killer, 3) Toplam kalınlığı 8 metreden fazla olan yüksek plastisiteli ($PI > 50$) killer, 4) Çok kalın (> 35 m) yumuşak veya orta katı killer.			

TBDY Table 16.1 – Local Site Class

Yerel Zemin Sınıfı	Zemin Cinsi	Üst 30 metrede ortalama		
		$(V_S)_{30}$ [m/s]	$(N_{60})_{30}$ [darbe /30 cm]	$(c_u)_{30}$ [kPa]
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SOILS REQURING SITE SPECIFIC EVALUATION

Soils requiring site specific evaluations:

1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weaky cemented soils.
2. Peat and /or highly organic clays (H> 3 m of peat and or highly organic clay, where H=thickness of soil)
3. High plasticity clays (H> 8m clay layer with PI >50%)
4. Very thick soft /medium stiff clay layers (H>35m)

Bearing Capacity of Foundations (Turkish Seismic Design Code Clause 16.8.3)

- For both static and earthquake loading conditions the following expression needs to be satisfied:

$$q_o \leq q_t$$

where, q_o: foundation pressure including vertical load, shear and moment effects acting on the foundation.

q_t: design bearing capacity value → $q_t \leq \frac{q_k}{\gamma_{Rv}}$

γ_{Rv} **: Strength factor which is determined in accordance with Table 16.2**

TBDY Tablo 16.2 - Yüzeysel Temeller İçin Dayanım Katsayıları

Dayanımın Türü	Dayanım Katsayısı Simgesi	Dayanım Katsayısı Değeri
Temel Taşıma Gücü	γ_{Rv}	1.4
Sürtünme Direnci	γ_{Rh}	1.1
Pasif Direnç	γ_{Rp}	1.4

Characteristic Bearing Capacity (q_k):

$$q_k = cN_c s_c d_c i_c g_c b_c + qN_q s_q d_q i_q g_q b_q + 0.5\gamma B' N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$$

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$$q_t \leq \frac{q_k}{\gamma_{Rv}}$$

$$q_o \leq q_t$$

Sliding Check Along the Base (TBDY 2018 clause 16.9)

For static and earthquake loading conditions, the resistance of the foundation along its base needs to be determined in accordance w/ TBDY (2018). For sliding check, the procedure is defined in New Turkish Seismic Design Code (2018) is as follows:

1. The following inequality needs to be satisfied

Here, Vth is the design ba $V_{th} \le R_{th} + 0.3R_{pt}$ ng along the base of the foundation

Rth : Design Frictional Resistance:

2. Design Frictional Resistance will be computed as below for cohesive soils (considering undrained conditions)

$$R_{th} = \frac{A_c \, c_u}{\gamma_{Rh}}$$

Design Frictional Resistance will be computed as below for cohesionless soils (considering drained conditions)

$$R_{th} = \frac{P_{tv} \tan\delta}{\gamma_{Rh}}$$

Sürtünme Ara Yüzeyi	$\tan\delta$
Yerinde Dökme Beton – Sıkıştırılmış Temel Taban Zemini	0.6
Önüretimli Beton – Sıkıştırılmış Temel Taban Zemini	0.4
Yerinde Dökme Beton – Beton	0.5
Beton – Taban Kayası	0.5

Design passive resistance R_{pt}, is computed by dividing the characteristic passive resistance value by strength factor γ_{RP}

$$R_{pt} = \frac{R_{pk}}{\gamma_{Rp}}$$

Settlements:

- Consolidation settlements need to be computed for saturated clay layers underneath the foundation system.

- Compressibility parameters ($m_{v,}$ $C_{s,}$ C_c) wiil be determined based on the laboratory tests or will be correlated by using the available fied test data (Liquid limit value, SpT-N value etc.)

- For cohesionless soils, consolidation settlement is not the major concern, only immediate settlements will be computed.