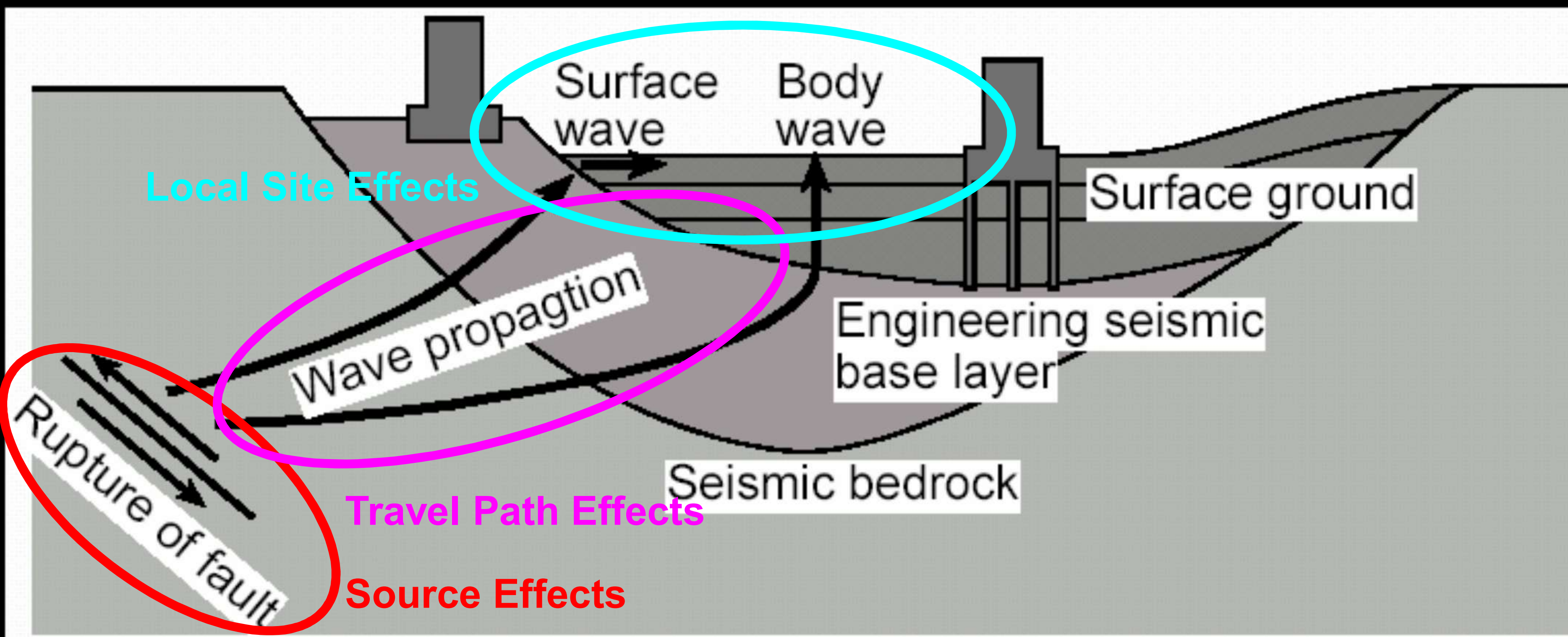
CYCLIC BEHAVIOUR of SOILS

Atilla Ansal

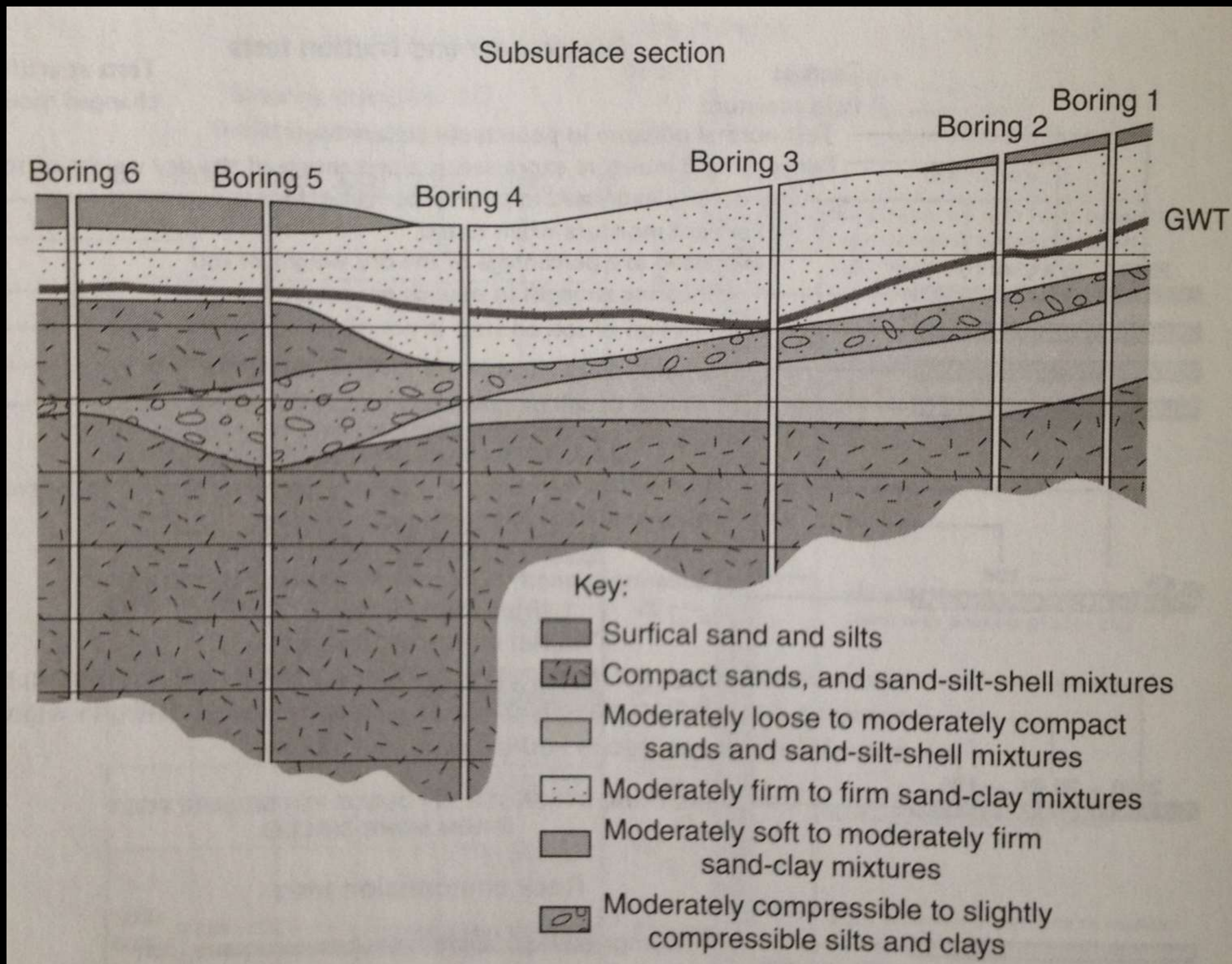
Ground Motion Characterization

Proper design of earthquake-resistant structures requires estimation of the level of ground shaking to which they will be subjected



Level of ground shaking depends on the characteristics of the source, the path and the site

Field Testing in Geotechnical Engineering



LOCAL SITE CONDITIONS

- Soil Stratification
- Geological Structure
- Ground water table level
- Bedrock Depth
- Properties of soil layers

SOILS

- Fine grained soils, silts and clays
- Coarse grained soils, sands and gravels

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART

COARSE-GRAINED SOILS
(more than 50% of material is larger than No. 200 sieve size.)

	Clean Gravels (Less than 5% fines)	
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (More than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
	Clean Sands (Less than 5% fines)	
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures

FINE-GRAINED SOILS
(50% or more of material is smaller than No. 200 sieve size.)

SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

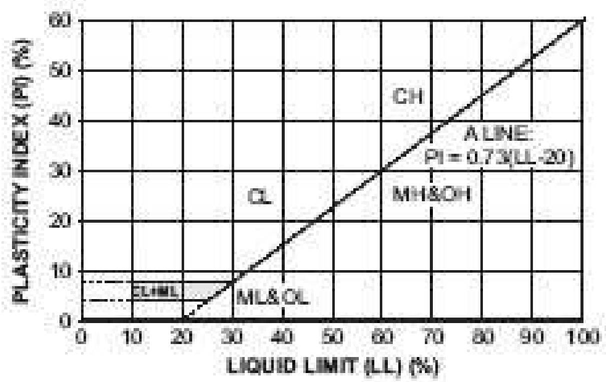
LABORATORY CLASSIFICATION CRITERIA

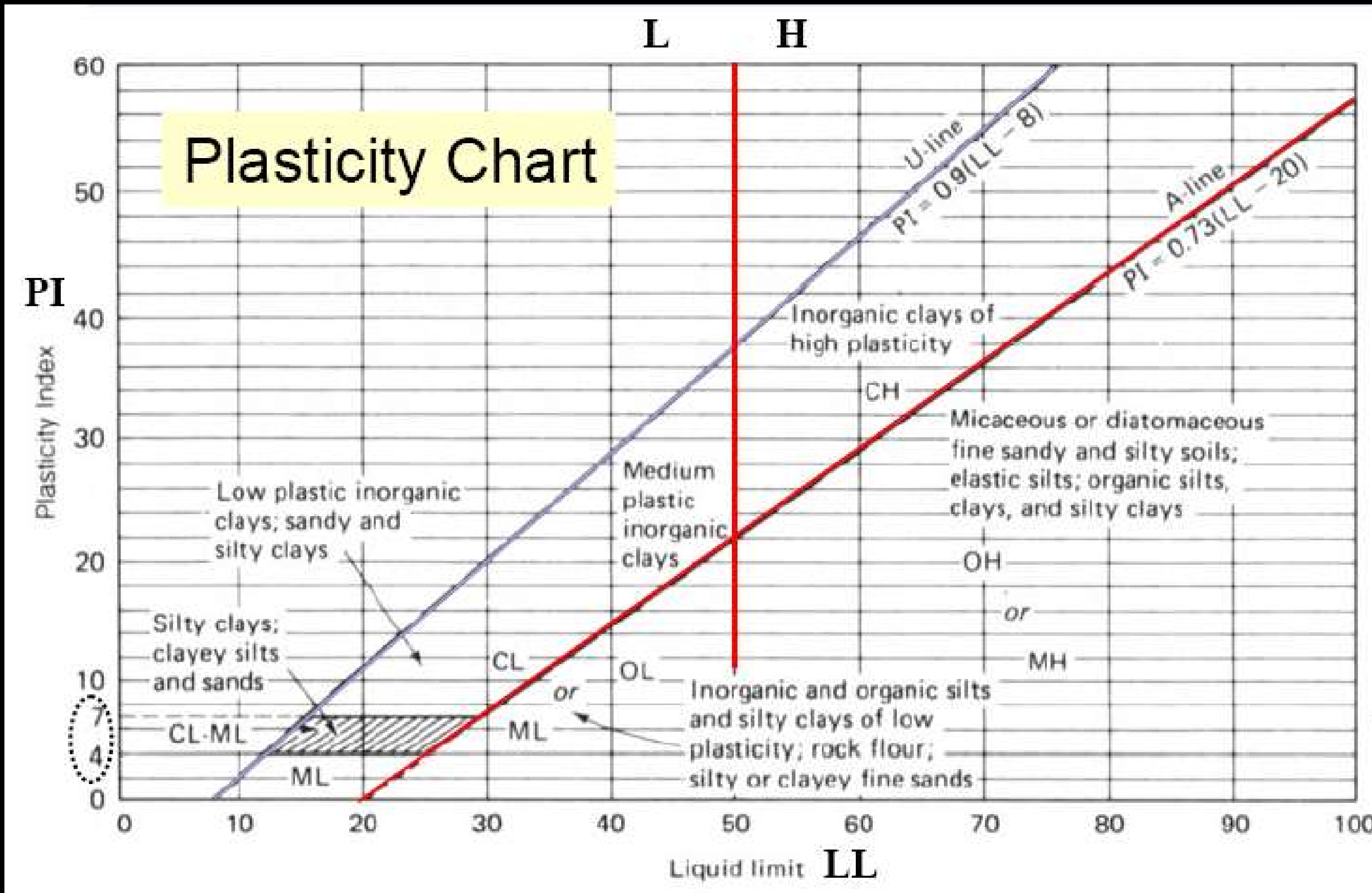
GW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
GP	Not meeting all gradation requirements for GW	
GM	Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
GC	Atterberg limits above "A" line with P.I. greater than 7	
SW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
SP	Not meeting all gradation requirements for GW	
SM	Atterberg limits below "A" line or P.I. less than 4	Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
SC	Atterberg limits above "A" line with P.I. greater than 7	

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent .... GW, GP, SW, SP
More than 12 percent .... GM, GC, SM, SC
5 to 12 percent .... Borderline cases requiring dual symbols

PLASTICITY CHART

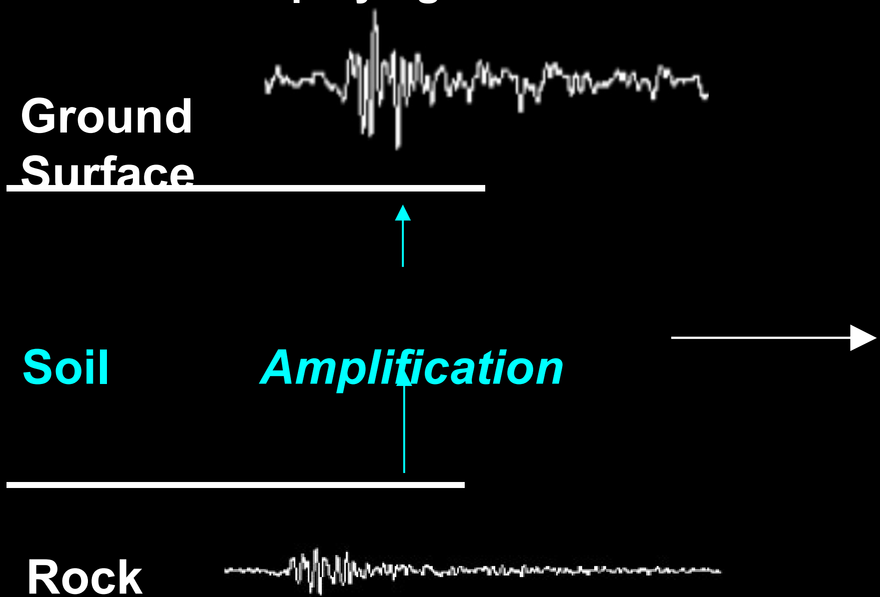




Plasticity Chart
L
H
PI
Plasticity Index
Liquid limit LL
U-line PI = 0.9(LL − 8)
A-line PI = 0.73(LL − 20)
Inorganic clays of high plasticity
CH
Micaceous or diatomaceous fine sandy and silty soils; elastic silts; organic silts, clays, and silty clays
OH
or
MH
Medium plastic inorganic clays
Low plastic inorganic clays; sandy and silty clays
Silty clays; clayey silts and sands
CL
OL
or
ML
CL-ML
ML
Inorganic and organic silts and silty clays of low plasticity; rock flour; silty or clayey fine sands
0
10
20
30
40
50
60
70
80
90
100
0
4
7
10
20
30
40
50
60

Why do we want to know dynamic soil properties?

Characteristics of the soil can greatly influence the nature of shaking at the ground surface. Soil deposits tend to act as 'filters' to seismic waves by attenuating motion at certain frequencies and amplifying it at others.



One major uncertainty:
dynamic soil properties and their dependency on the excitation level (i.e. nonlinear behavior of soil with increasing strain amplitude).

One of the most important aspects of geotechnical earthquake engineering practice involves evaluation of the effects of local soil conditions on strong motion.
Evaluation of the effects of local soil conditions requires quantification of the soil behavior under dynamic loading.
The behavior of soil subjected to dynamic loading is governed by what have come to be known as 'dynamic soil properties'.

CHARACTERISTICS of DYNAMIC BEHAVIOUR

SOIL BEHAVIOUR UNDER
DYNAMIC LOADING

STRESS – STRAIN RELATIONS

- Shear Modulus
- Damping Ratio
- Strain Dependent Modulus and Damping

SHEAR STRENGTH PROPERTIES

- Number of Cycles
- Cyclic Stress Ratio

During earthquake

After earthquake

Cyclic Stress-Strain Behaviour of Soils

- ➔ **Dynamic shear modulus**
- ➔ **Damping Ratio**

1. Definition of

   Dynamic Shear Modulus

   Damping Ratio

   A. Empirical

   B. Not a material property

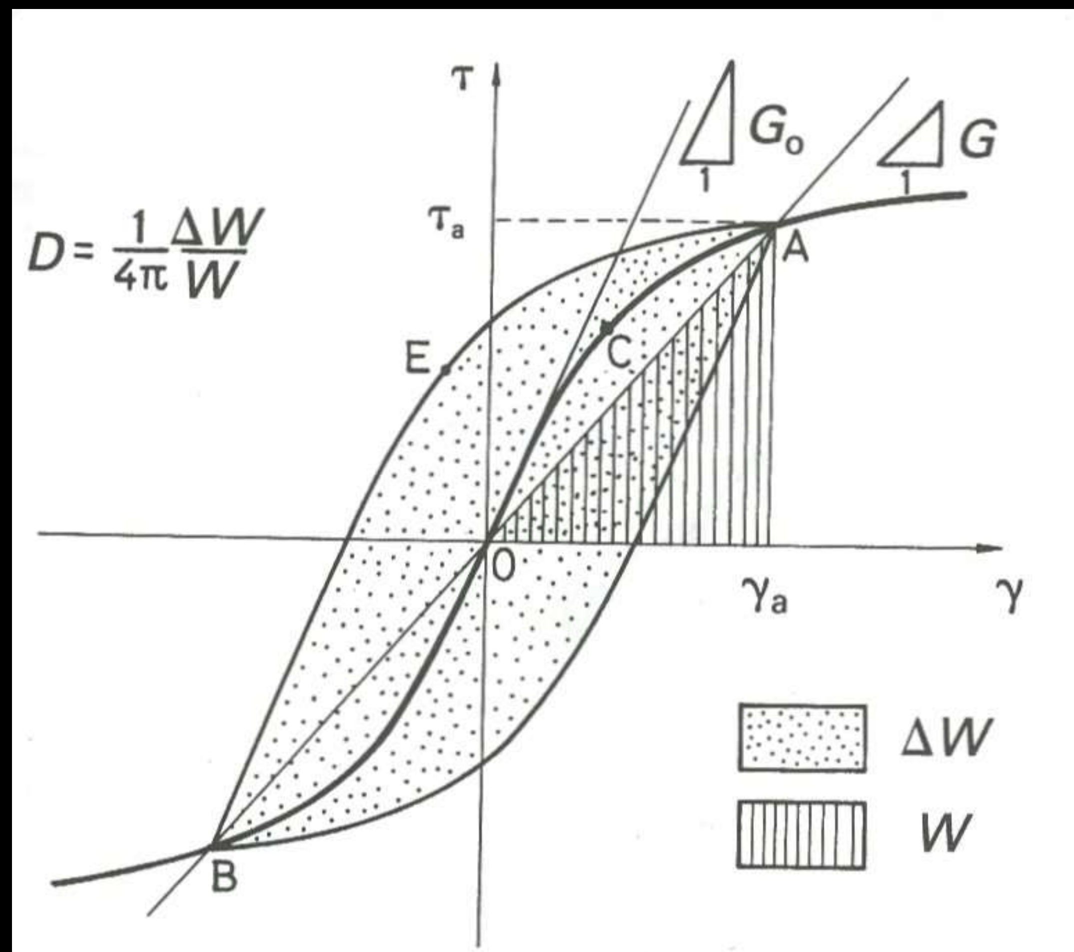
   C. Modeling Cyclic Behavior

   D. Single phase model

2. Determination

   A. Stress Controlled Tests

   B. Strain Controlled Tests



Factors Affecting Cyclic Behaviour Of Soils

- Shear Strain
- Void ratio
- Effective confining pressure
- Plasticity
- Overconsolidation ratio
- Saturation
- Number of cycles
- Frequency

LABORATORY TESTS

Soil element tests: Classified into two categories considering the shear strain levels at which they are able to measure accurately of these properties:

- Low-strain element tests:
  Resonant column test
  Piezoelectric bender element test
- High-strain element test:
  Cyclic direct simple shear test
  Cyclic triaxial test
  Cyclic torsional shear test.

Model tests: Use a small-scale physical model of a full-scale prototype structure and aim to simulate the boundary conditions of a geotechnical problem. Shaking table tests and centrifuge tests are among the most referred model tests in these studies.

Laboratory Measurement of Dynamic Soil Properties

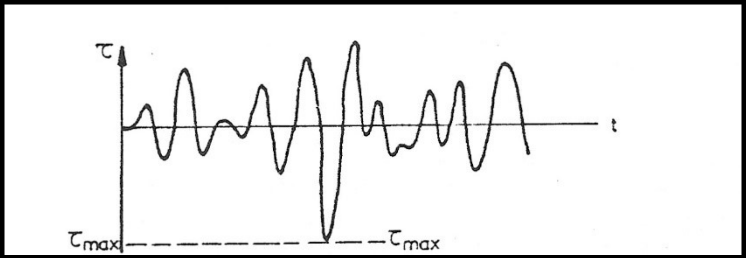
Laboratory Methods in General

1. Reproduction of Initial In Situ Conditions

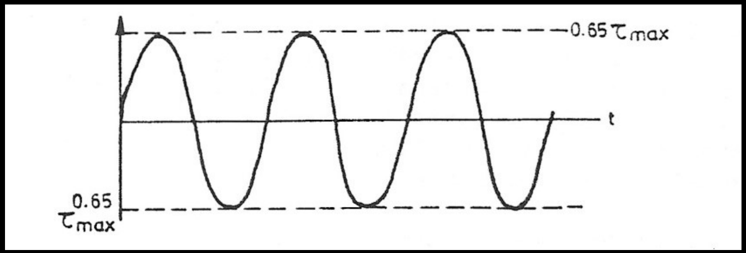
A specimen typically sized ~38-50 mm in diameter with similar moisture content, density and structure as in the field is consolidated under estimated in situ stress

2. Stress- or Strain-Controlled Loading

Earthquake Loading in the Field



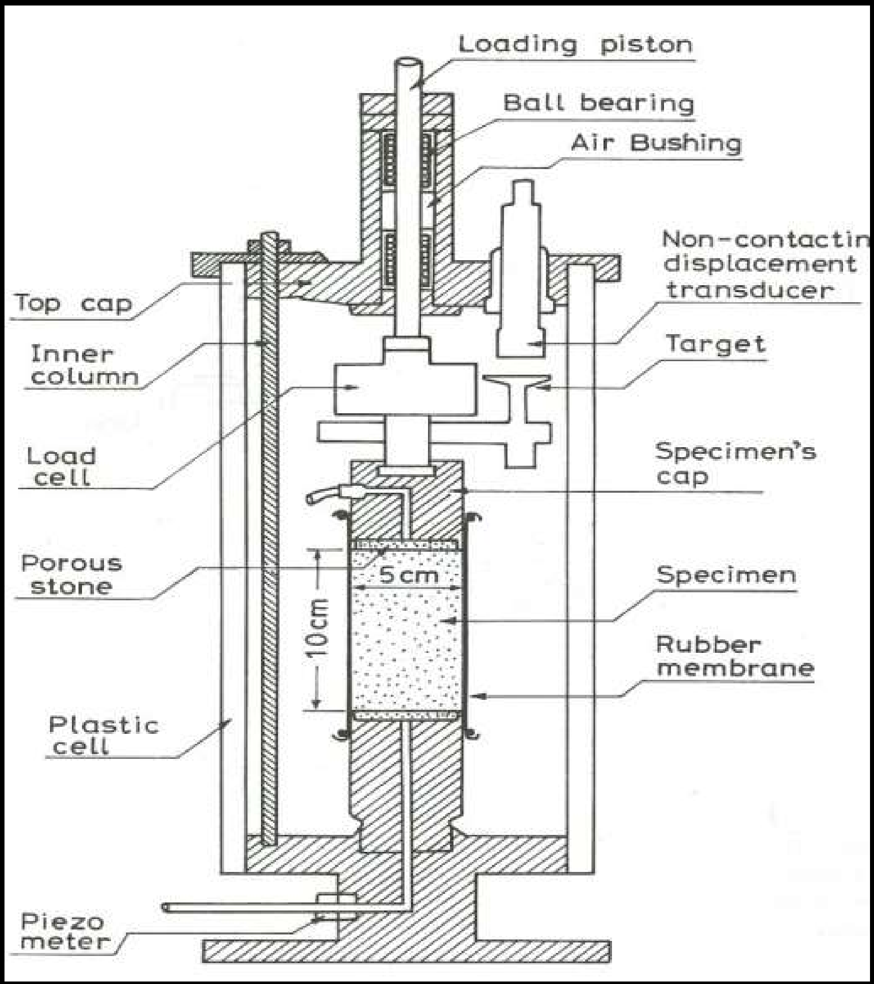
Harmonic Loading in the Laboratory



3. Measurement of Soil Response

Load → Stress
Deformation → Strain
Pore Pressure → Excess Pore Pressure

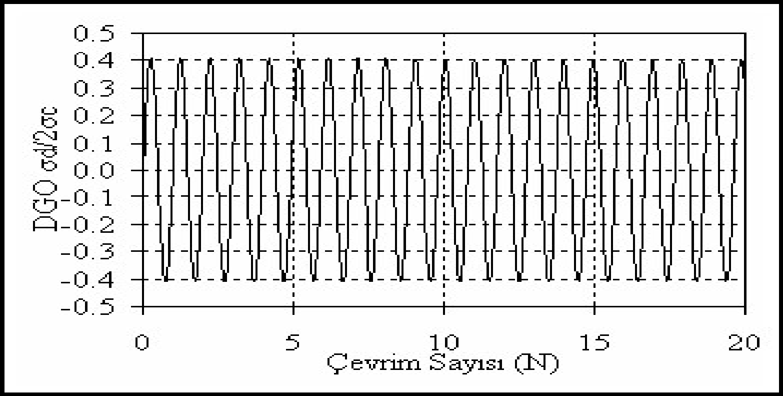
Cyclic Triaxial Test (CTT)



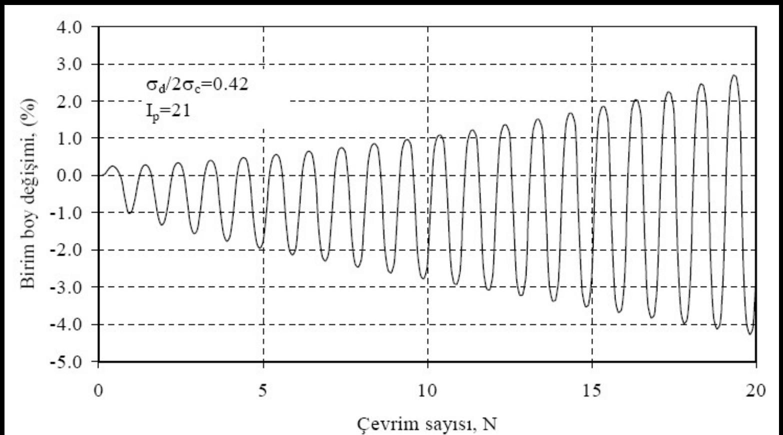
- cylindirical specimen placed between top and bottom loading plates sealed by a rubber membrane
- confined in a triaxial chamber subjected to radial stress through pressurized cell fluid
- axial stress applied on top through loading rod

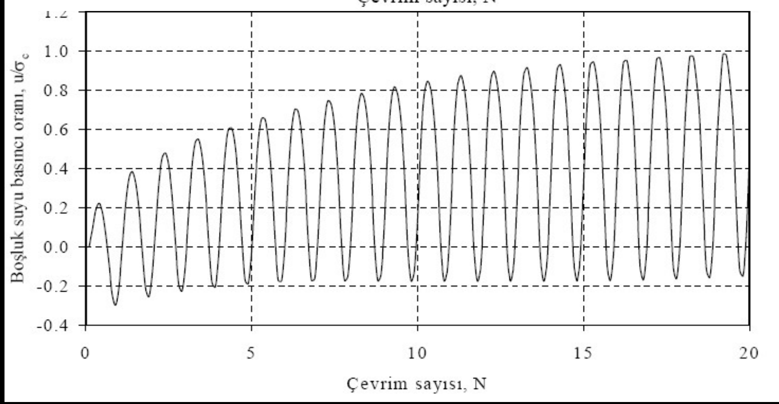
Testing procedure:

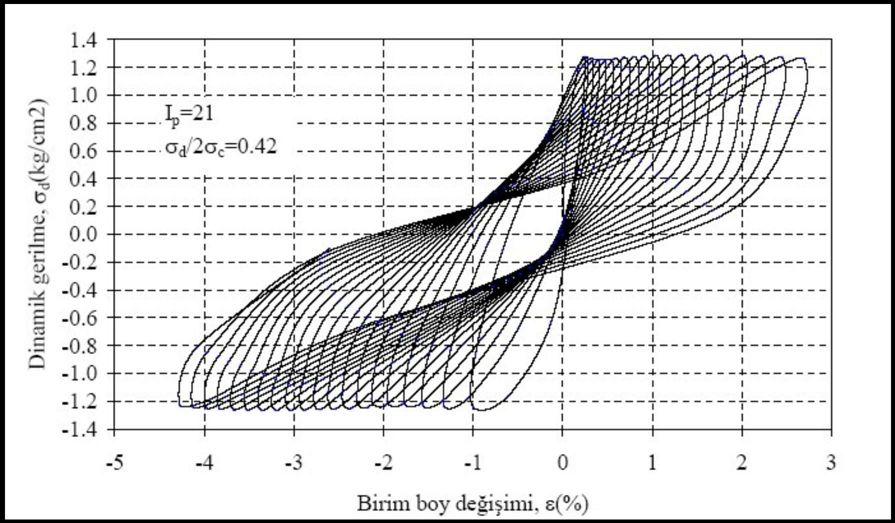
1. saturation and consolidation to reproduce initial in situ conditions
2. cyclic loading under undrained conditions by applying sinusoidally varying axial load
3. axial load, axial deformation, and porewater pressure development with time are monitored.

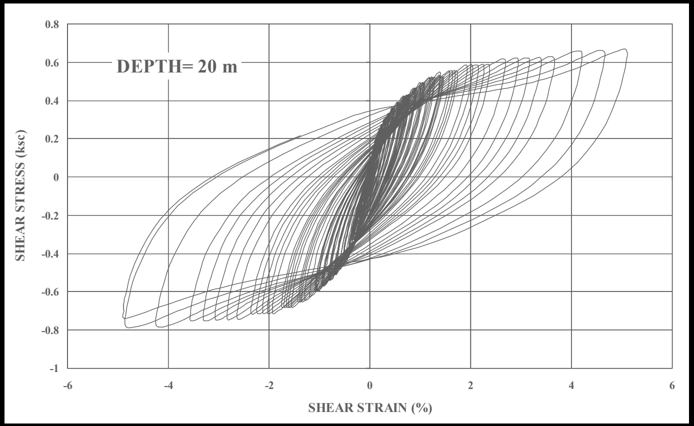


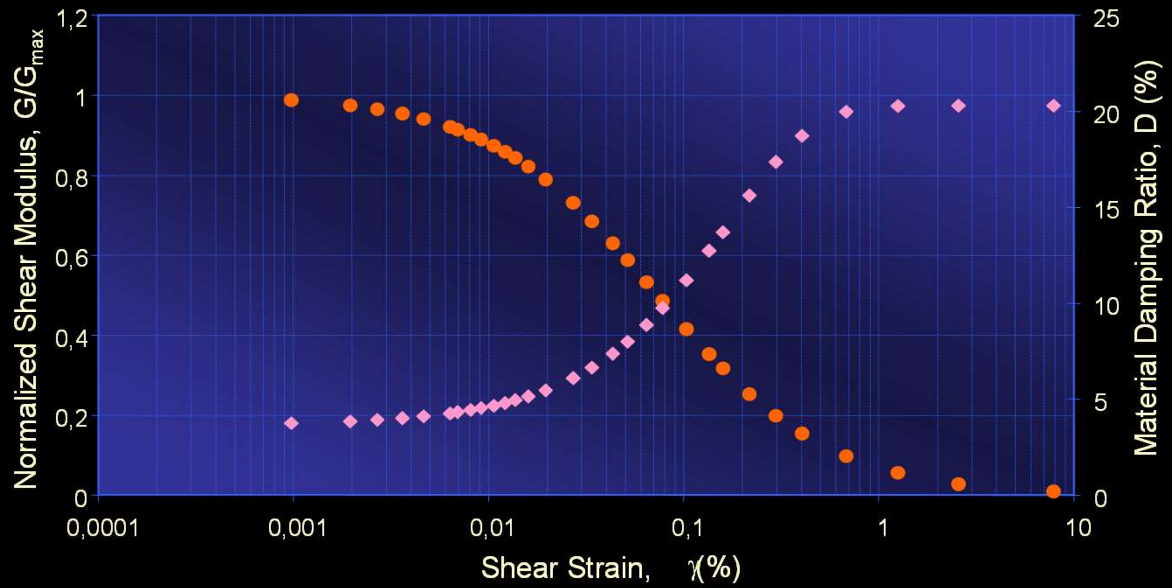
The cyclic loading generally causes an increase in the pore-water pressure in the specimen, resulting in a decrease in the effective stress and an increase in the cyclic axial deformation of the specimen.

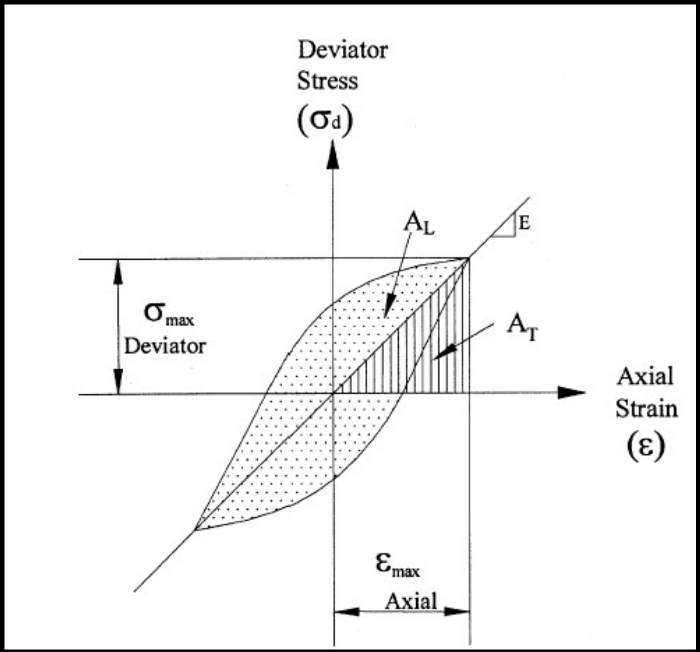












for a given hysteresis loop;

- **calculate the Young's Modulus (E)**
- **calculate the material damping ratio (D)**

$$D = A_L / (4 \pi A_T)$$

3. **calculate the shear modulus (G)**

$$G = E / 2 (1+\nu)$$

4. **calculate the shear strain (γ)**

$$\gamma = \varepsilon_a (1+\nu)$$

Cyclic Triaxial Test (CTT)

Limitations

- **Measurement of shear strain is indirect**

  Typically obtained through the normal strain and an assumed value of Poisson's ratio
- **Stress concentrations at the top and bottom platens.**

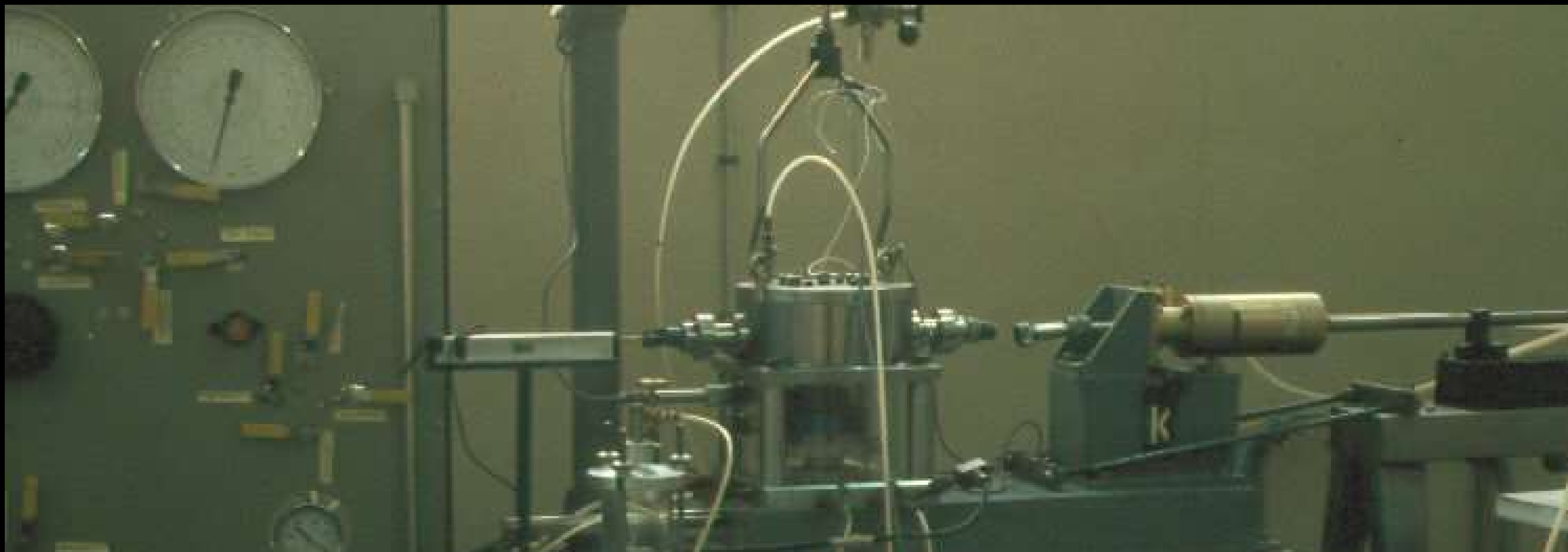
  Nonuniform stress conditions within the test specimen are imposed by the specimen end platens. This can cause a redistribution of void ratio within the specimen during the test.
- **Stress path is not representative of those in the field.**

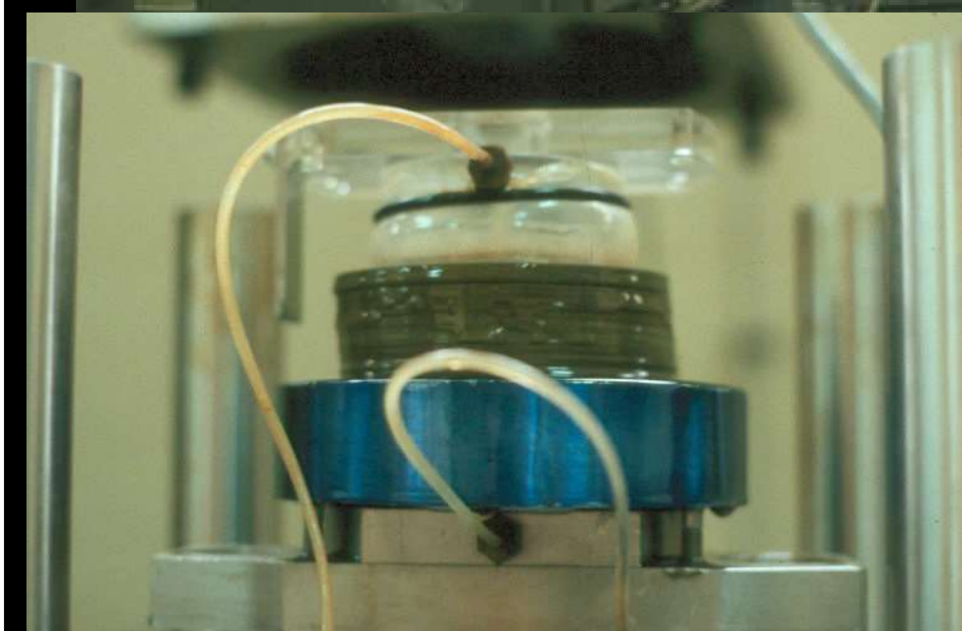
  A 90° change in the direction of the major principal stress occurs during the two halves of the loading cycle on isotropically consolidated specimens.
- **System compliances such as membrane penetration effects, piston friction etc.**

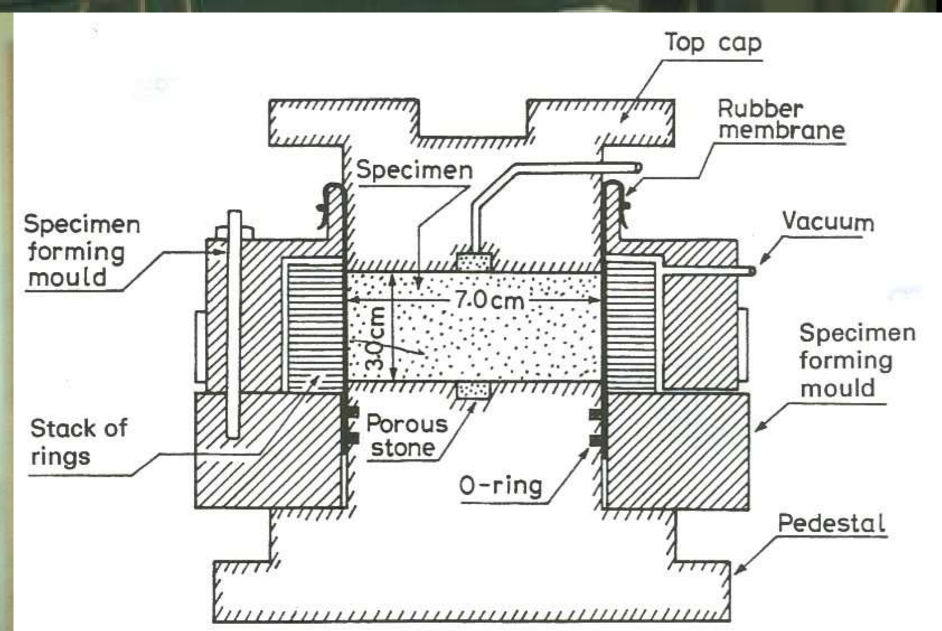
  The interaction between the specimen, membrane, and *confining fluid has an influence on cyclic behavior. Changes in pore-water pressure can cause changes in membrane penetration in specimens of cohesionless soils. These changes can significantly influence the test results.*
- **Usually can not measure strains below 10^{-2}%.**

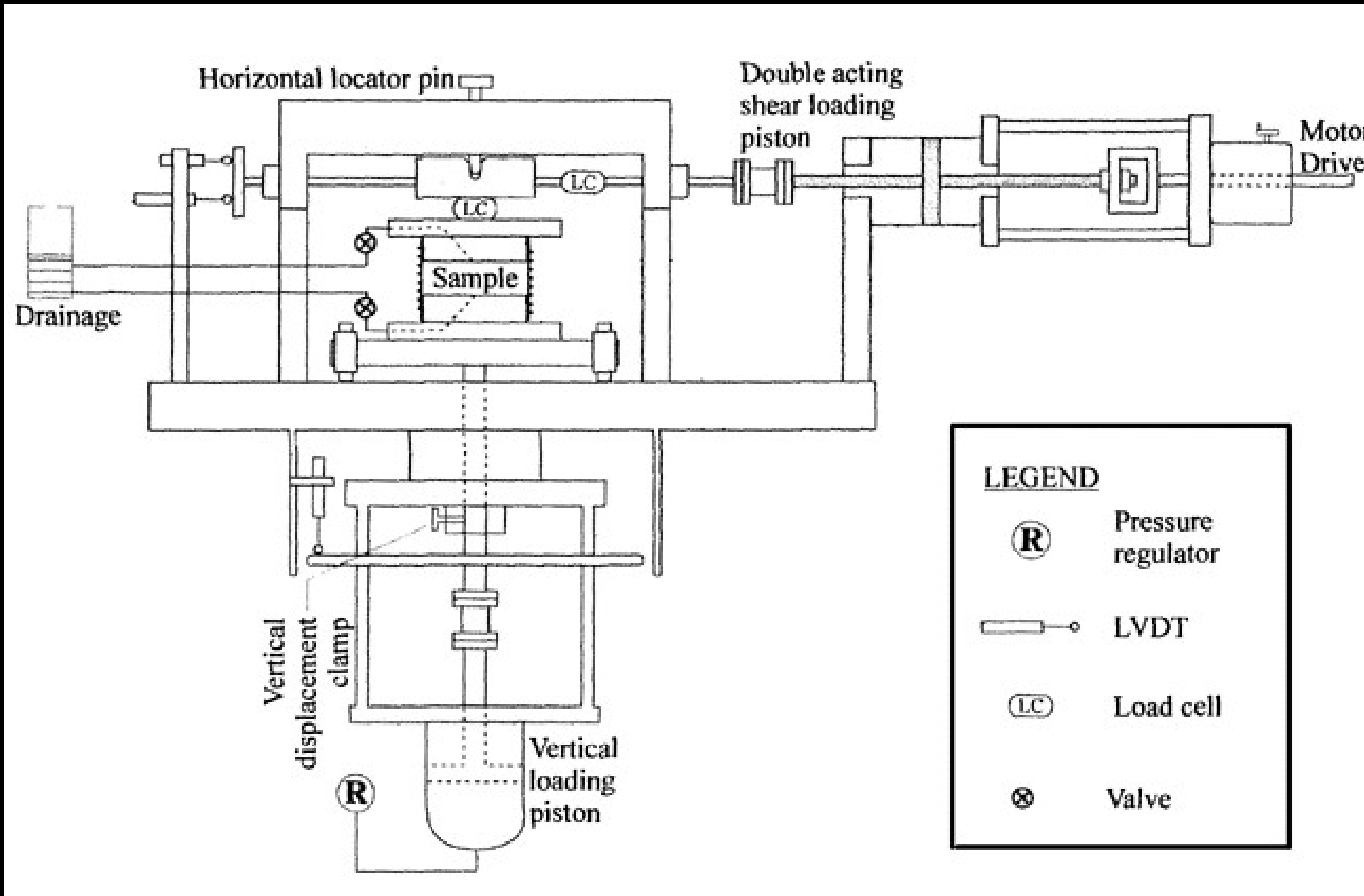
  Typically G_{max} is measured at strains less than 0.001%

Cyclic Simple Shear Test (CSST)



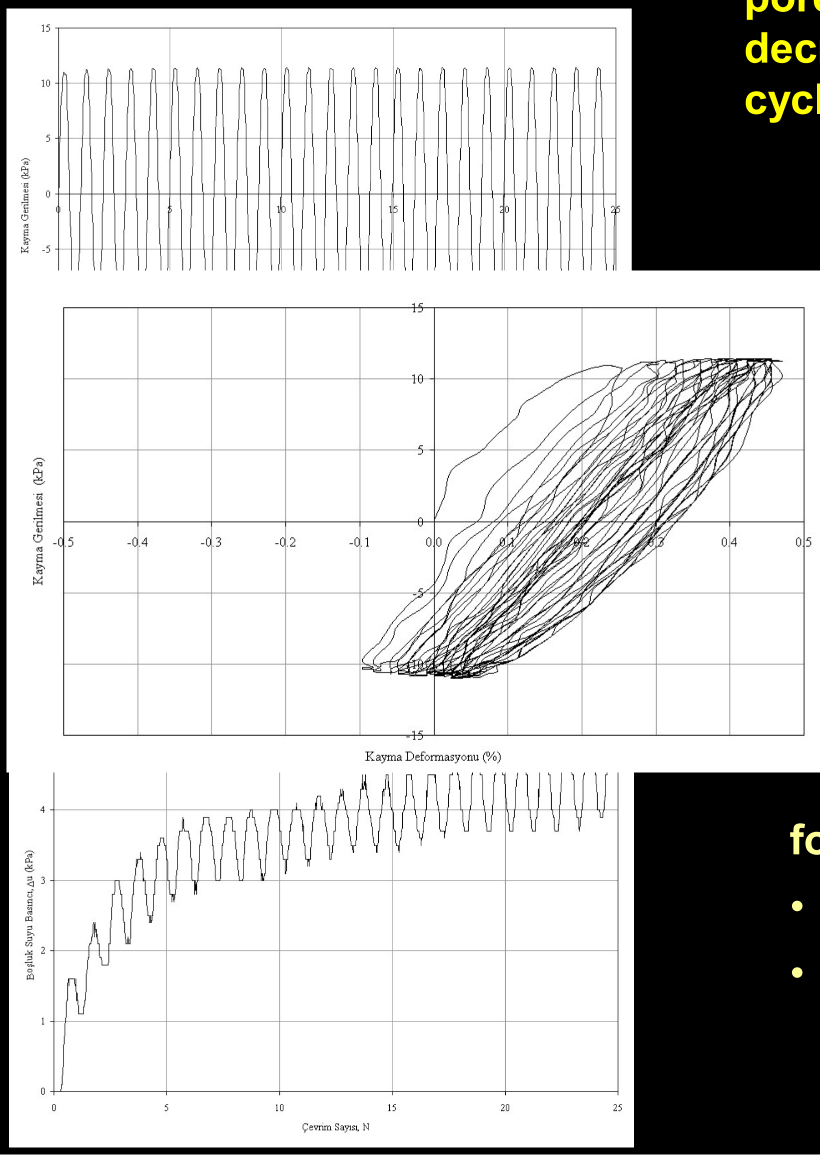




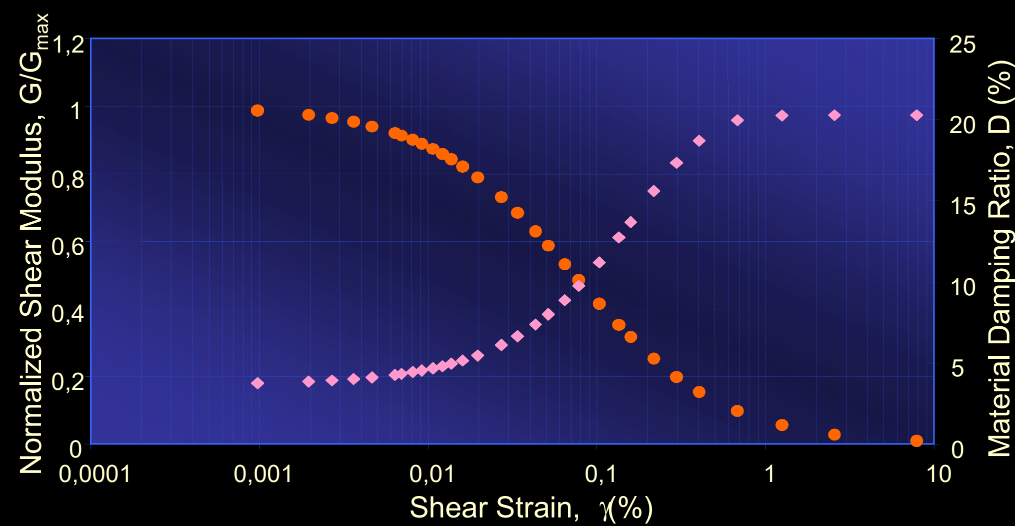


Horizontal locator pin
Double acting
shear loading
piston
Motor
Drive
LC
LC
Sample
Drainage
Vertical
displacement
clamp
Vertical
loading
piston
R
LEGEND
R
Pressure
regulator
LVDT
LC
Load cell
Valve

Cyclic Simple Shear Test (CSST)



- The cyclic loading generally causes an increase in the pore-water pressure in the specimen, resulting in a decrease in the effective stress and an increase in the cyclic shear deformation of the specimen.



for a given hysteresis loop;

- calculate the shear modulus **(G)**
- calculate the material damping ratio **(D)**

$$D = A_L / (4 \pi A_T)$$

Cyclic Simple Shear Test (CSST)

Limitations

Significant nonuniformity in the stress distribution at the specimen boundaries

Shear stress is only applied to the top and bottom surfaces of the specimen and since no complimentary shear stresses are imposed on the vertical sides the moment caused by the horizontal shear stresses must be balanced by non uniformly distributed shear and normal stresses.

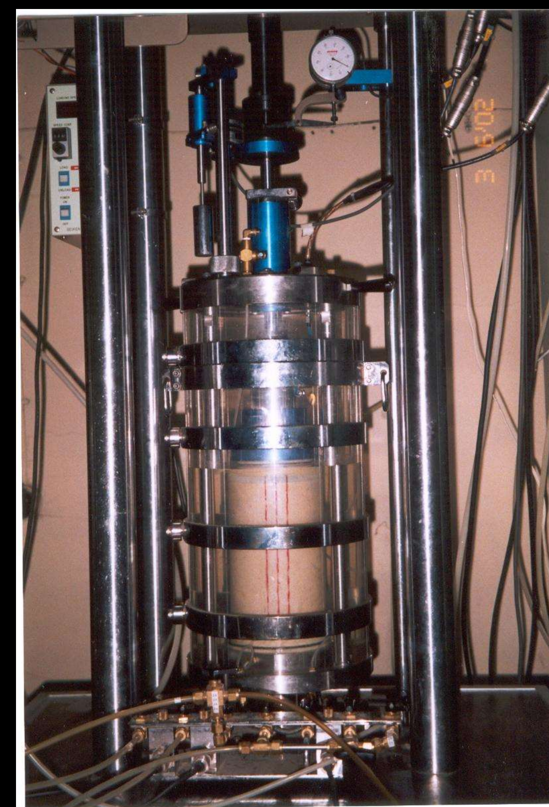
Advantages

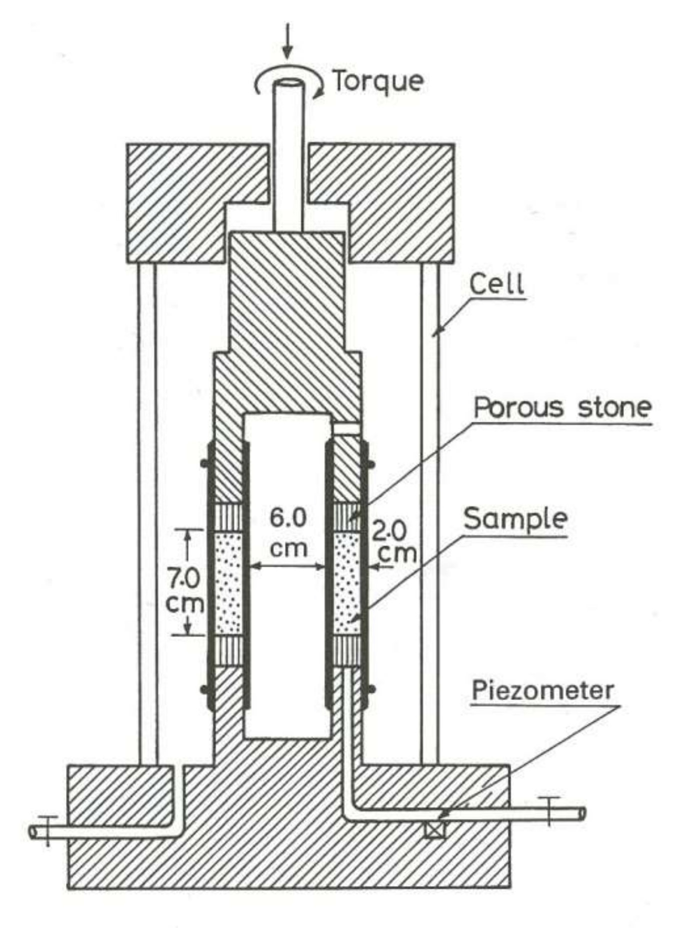
A better representation of the idealized field stress conditions (plane strain conditions)

Principle stresses continuously rotate due to the application of shear stress as similar to those imposed on the soil element in the field subjected to vertically propagating shear waves.

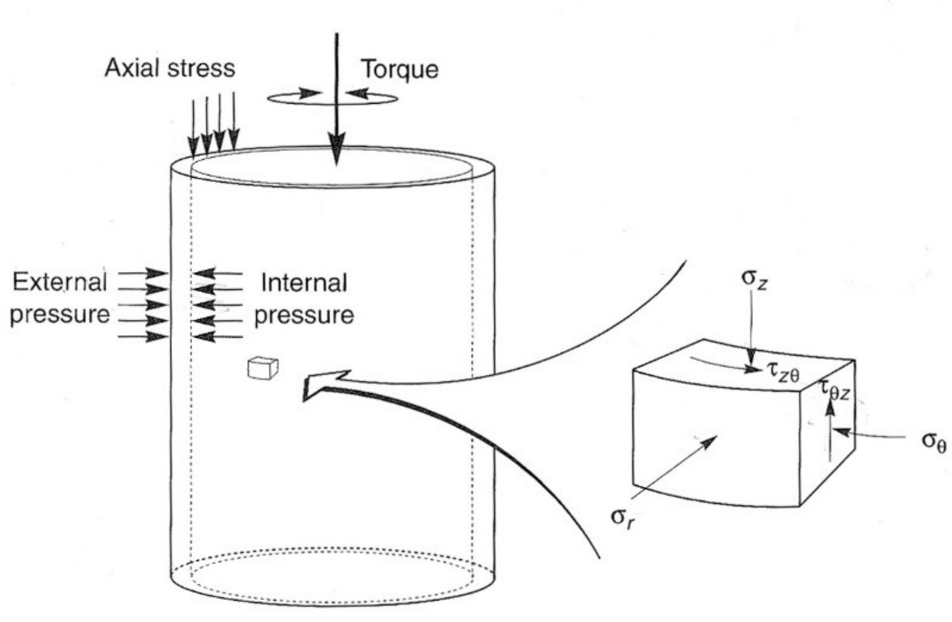
Direct measurement of shear stress and shear strain

Cyclic Torsional Shear Test (CTST)

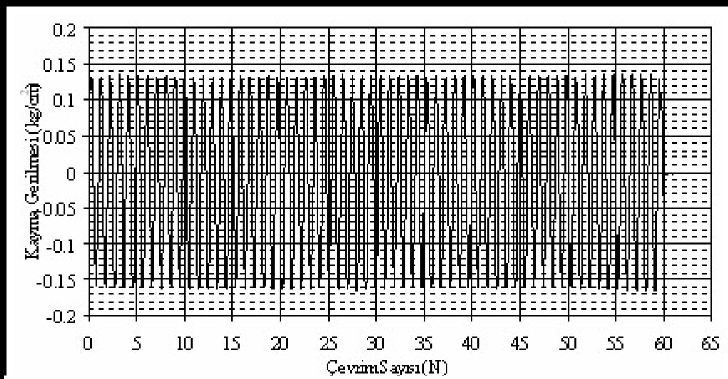


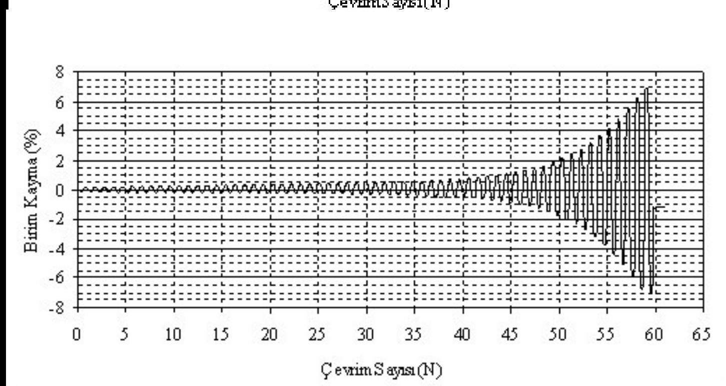


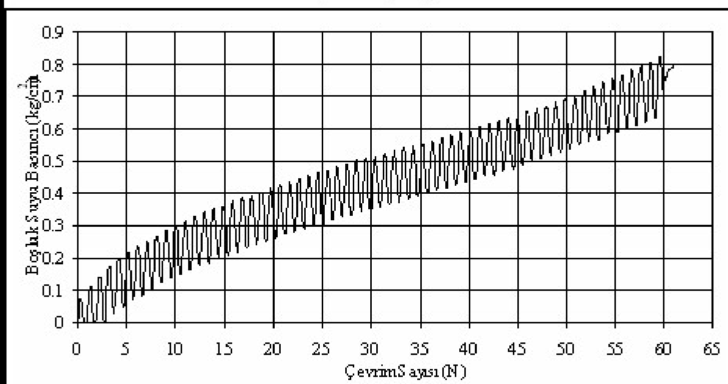
- A cylindrical or hollow cylindrical soil specimen is enclosed in rubber membrane and confined in a triaxial chamber where it is subjected to in situ confining pressure.
- Axial load and torque is applied to the top of the specimen.
- Axial load, torque, axial deformation, angular rotation and porewater pressure development with time are monitored.

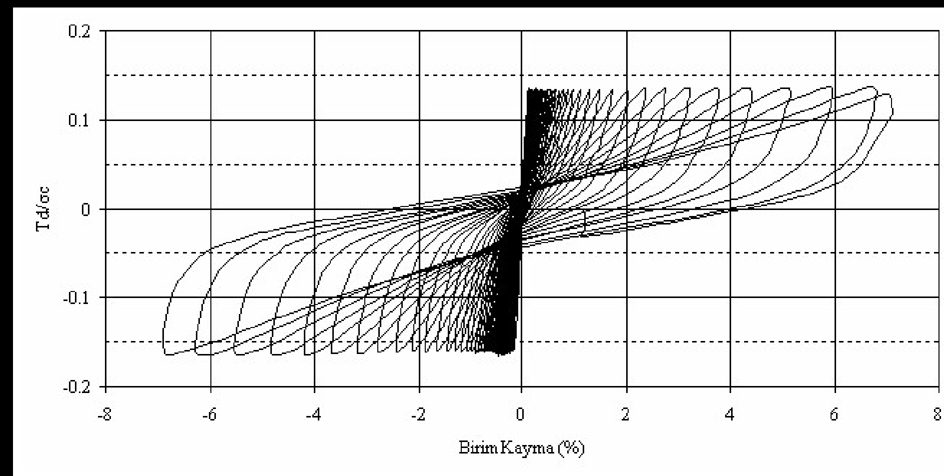


Cyclic Torsional Shear Test (CTST)









for a given hysteresis loop;

- **calculate the shear modulus (G)**
- **calculate the material damping ratio (D)**

$$D = A_L / (4 \pi A_T)$$

Cyclic Torsional Shear Test (CTST)

Limitations

Equipment not so common.

Specimen preparation can be difficult for hollow cylinder specimens.

Cylindrical specimens suffers from stress nonuniformity.

Shear strain varies radially within the specimen, from zero at the center to a maximum at the perimeter for a solid specimen.

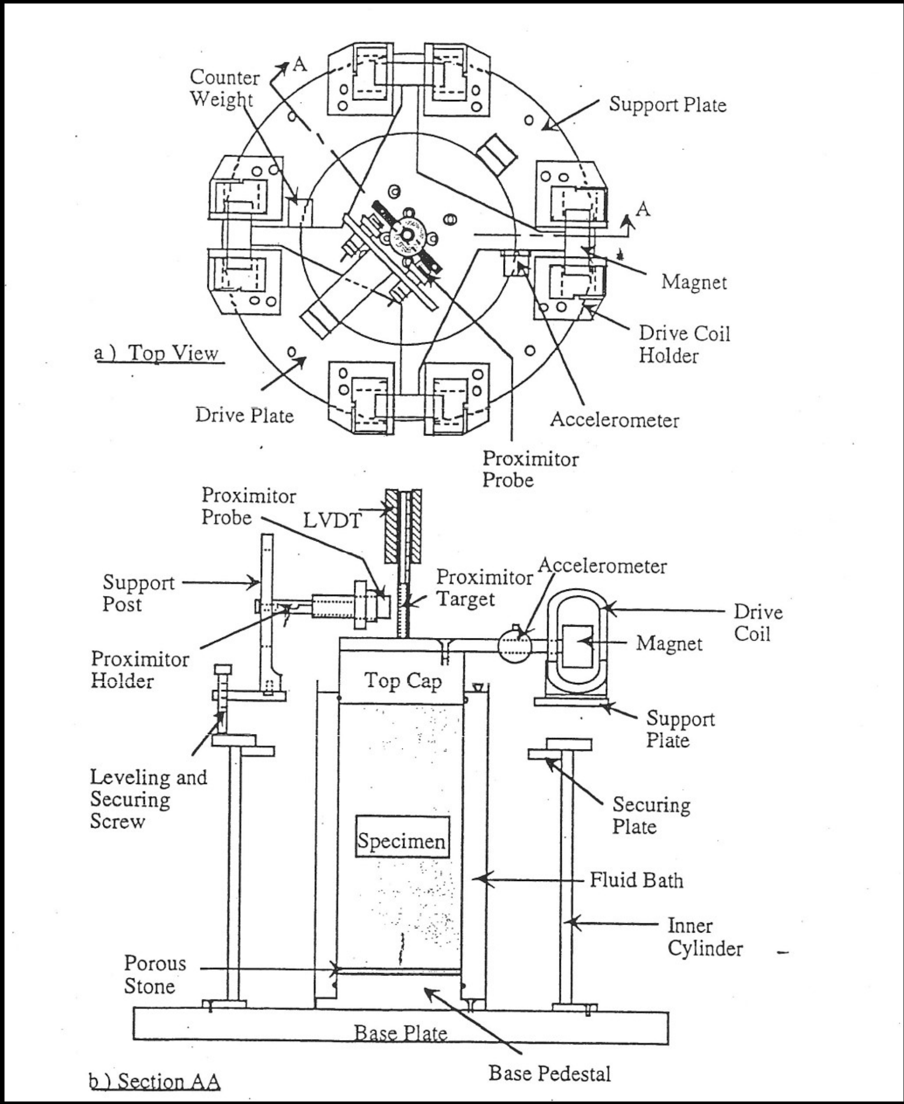
Advantages

A better representation of the idealized field stress conditions (plane strain conditions).

Cyclic shear stresses on horizontal planes with continuous rotation of principal stresses

Can measure properties over a wider range of strains.

Resonant Column and Torsional Shear Test (RCTS)



- **A cylindrical soil specimen placed in a confining chamber and pressurized to the in situ confining pressure**
- **Specimen is vibrated in harmonic torsional motion using a coil-magnet drive system and the response to torsional loading is measured.**
- **Combination of two tests can be performed on the same specimen**

  1. Resonant Column Test

  2. Torsional Shear Test

  Switching from one type of test to the other is done outside of the chamber by changing,

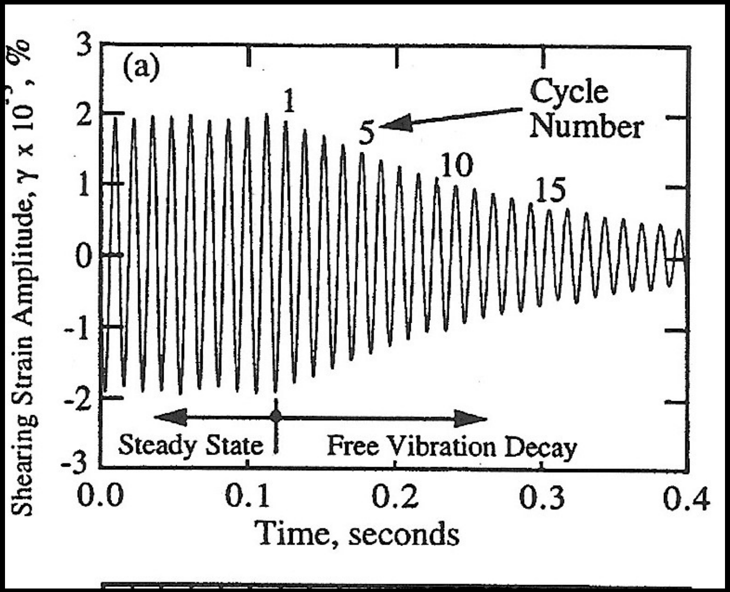
  excitation frequency used to drive the specimen and

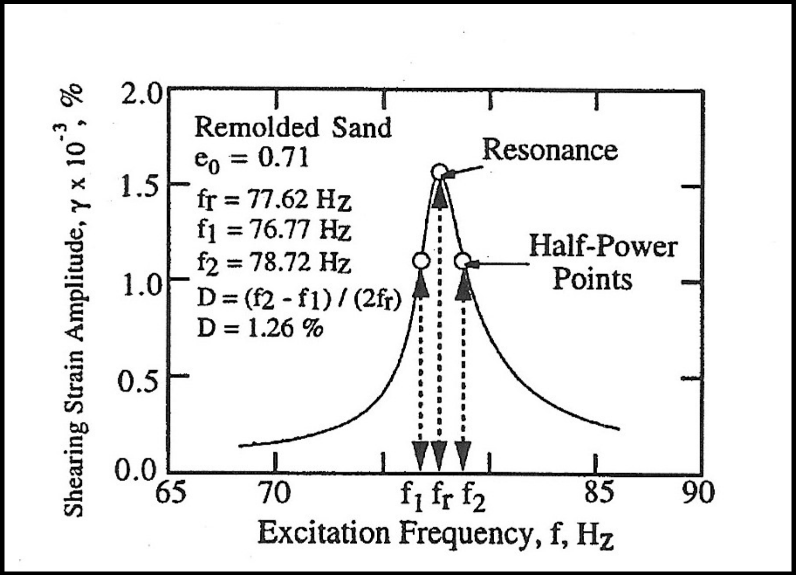
  the motion monitoring devices used to record the specimen response

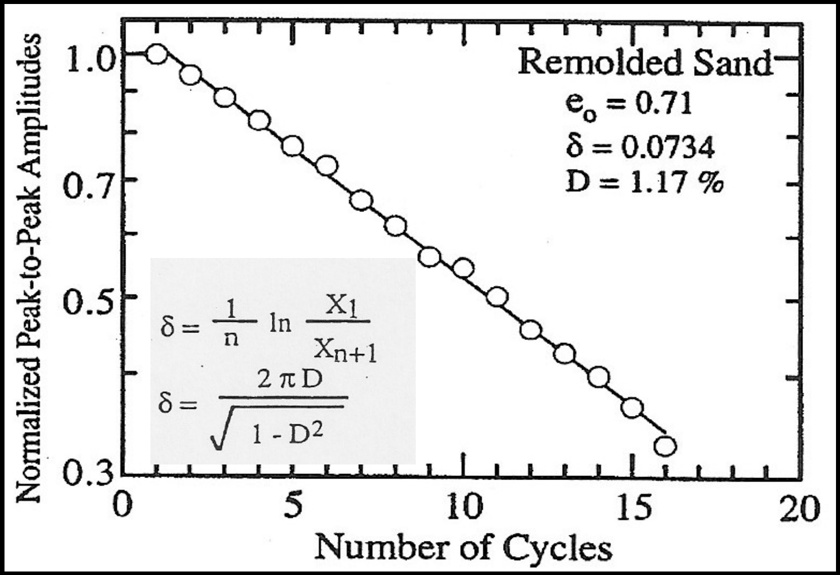
Resonant Column and Torsional Shear Test (RCTS)

Material damping is evaluated using either

1. Free-vibration decay curve is recorded by shutting off the driving force after specimen is vibrating in steady-state motion at the resonance frequency.
2. half-power bandwidth method is based on measurement of the width of the dynamic response curve around the resonance peak.



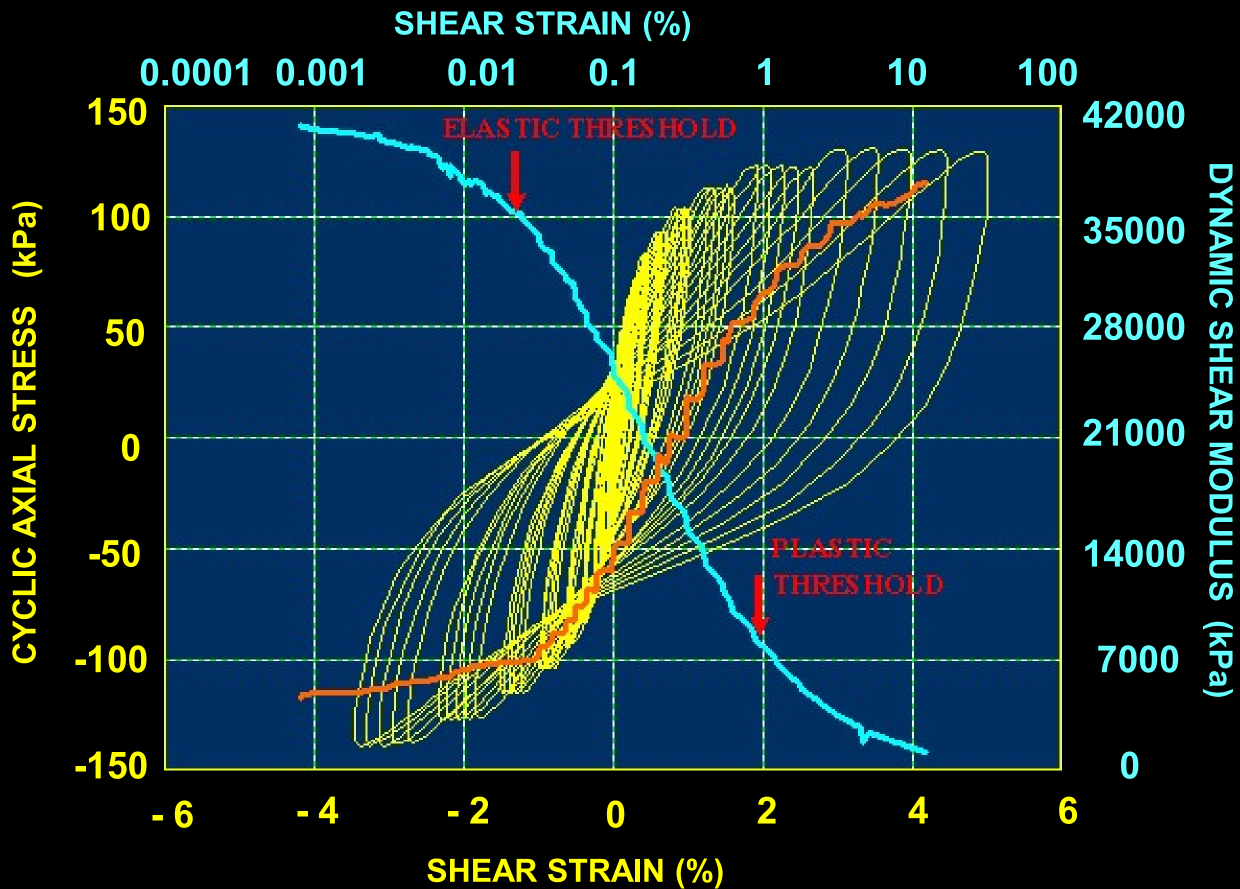


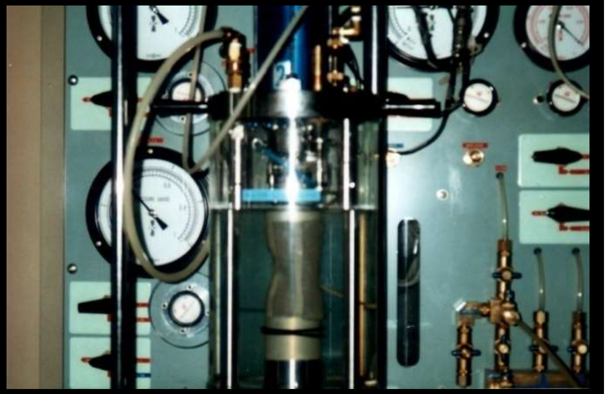


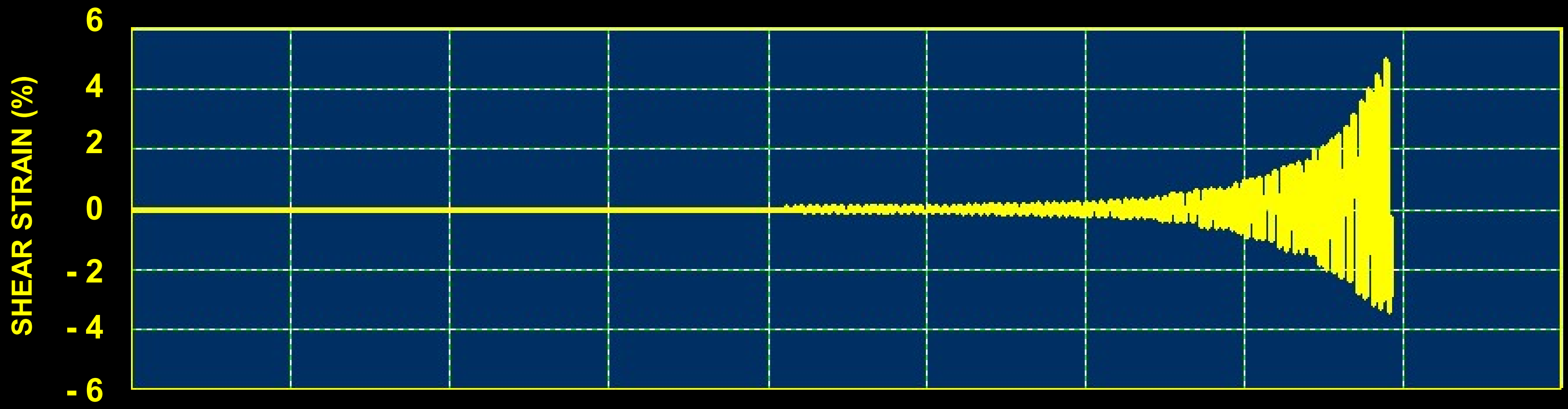
Disturbance caused by sampling and sample preparation alters soil properties such as;

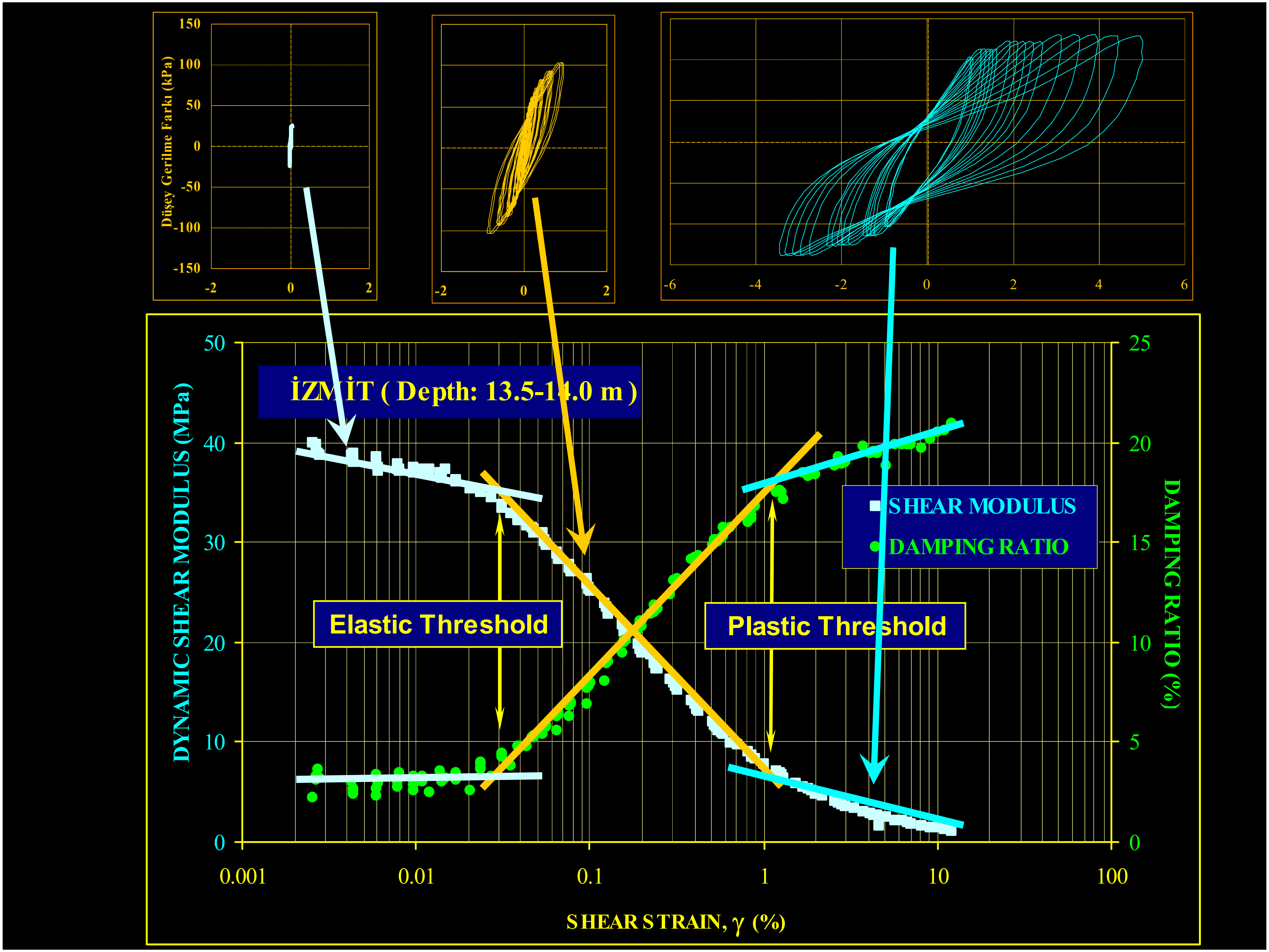
- **fabric and structure** ***(geometric or spatial arrangement of individual soil particles and voids, organization of soil constituents into larger compound particles)***
- **stress history**
- **strain history**
- **density**
- **degree of saturation**

all of these adversely effect the ability of laboratory tests to accurately measure dynamic soil properties …


SHEAR STRAIN (%)
0.0001 0.001 0.01 0.1 1 10 100
150
100
50
0
-50
-100
-150
CYCLIC AXIAL STRESS (kPa)
42000
35000
28000
21000
14000
7000
0
DYNAMIC SHEAR MODULUS (kPa)
ELASTIC THRESHOLD
PLASTIC THRESHOLD
- 6 - 4 - 2 0 2 4 6
SHEAR STRAIN (%)




6
4
2
0
- 2
- 4
- 6
SHEAR STRAIN (%)



Düşey Gerilme Farkı (kPa)
150
100
50
0
-50
-100
-150
-2
0
2
-6
-4
-2
0
2
4
6
İZMİT (Depth: 13.5-14.0 m)
DYNAMIC SHEAR MODULUS (MPa)
DAMPING RATIO (%)
SHEAR MODULUS
DAMPING RATIO
Elastic Threshold
Plastic Threshold
0.001
0.01
0.1
1
10
100
SHEAR STRAIN, γ (%)

$$\left(\frac{G_{maks}}{p_a}\right) = 321\frac{(2.97-e)^2}{1+e}AKO^M\left(\frac{\sigma'_c}{p_a}\right)^N$$

$$\frac{G}{G_{maks}} = \frac{35.09}{\dfrac{\gamma_a}{1-0.99\exp(-18.97\ PI^{-1.27})}+34.74}$$

Elastic threshold:

$$\gamma_e = \frac{0.035}{1+11.92.\exp(-0.1PI)}$$

Plastic threshold:

$$\gamma_p = \frac{1}{1.39-0.33PI^{0.28}}$$

- ***Cylic Behaviour: Elastic and Plastic threshold***
- ***Thresholds are functions of Plasticity Index***

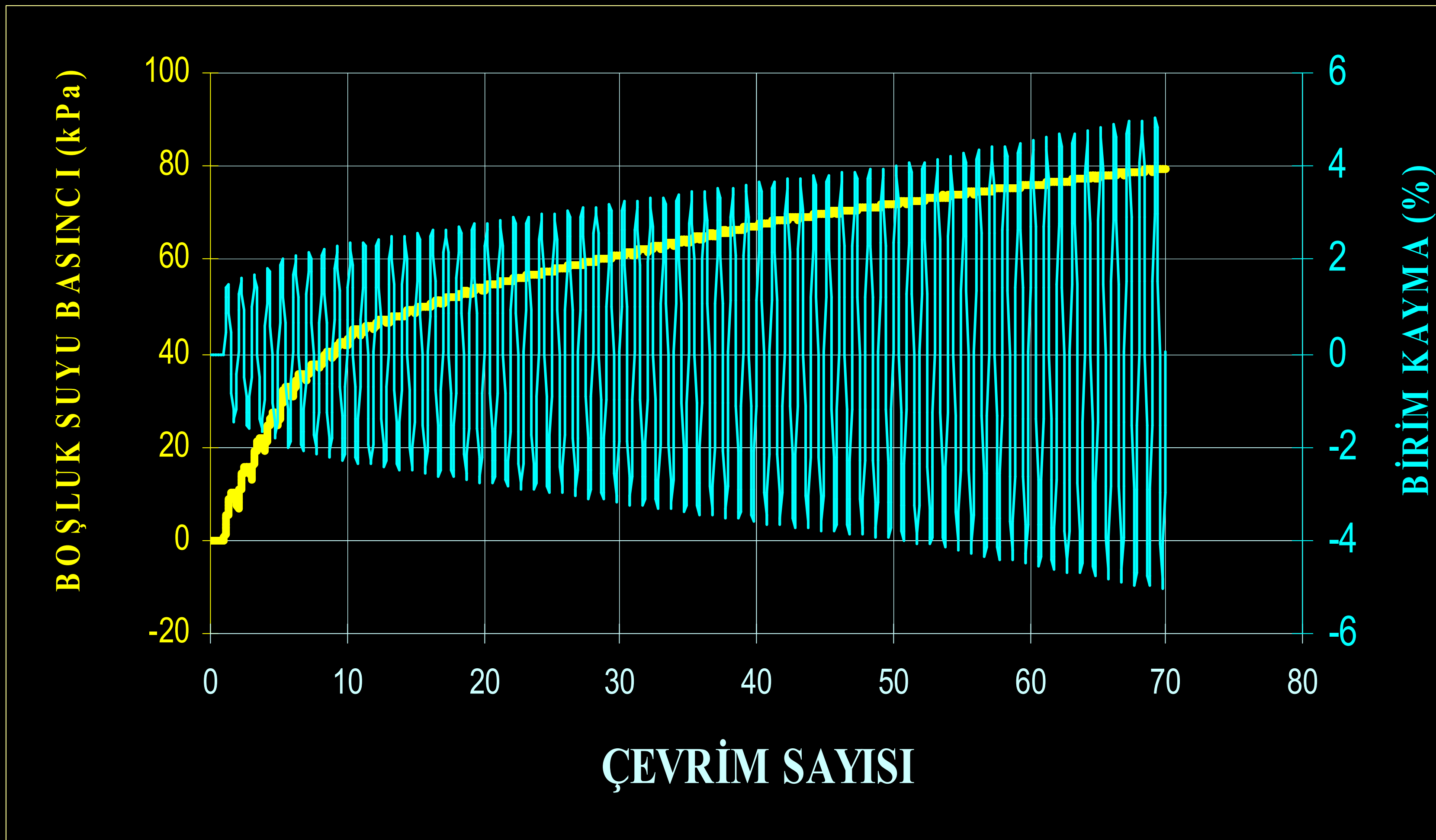
Shear Strength Properties

- **Shear Stress Amplitude**
- **Number of Cycles**

GOLDEN HORN CLAY

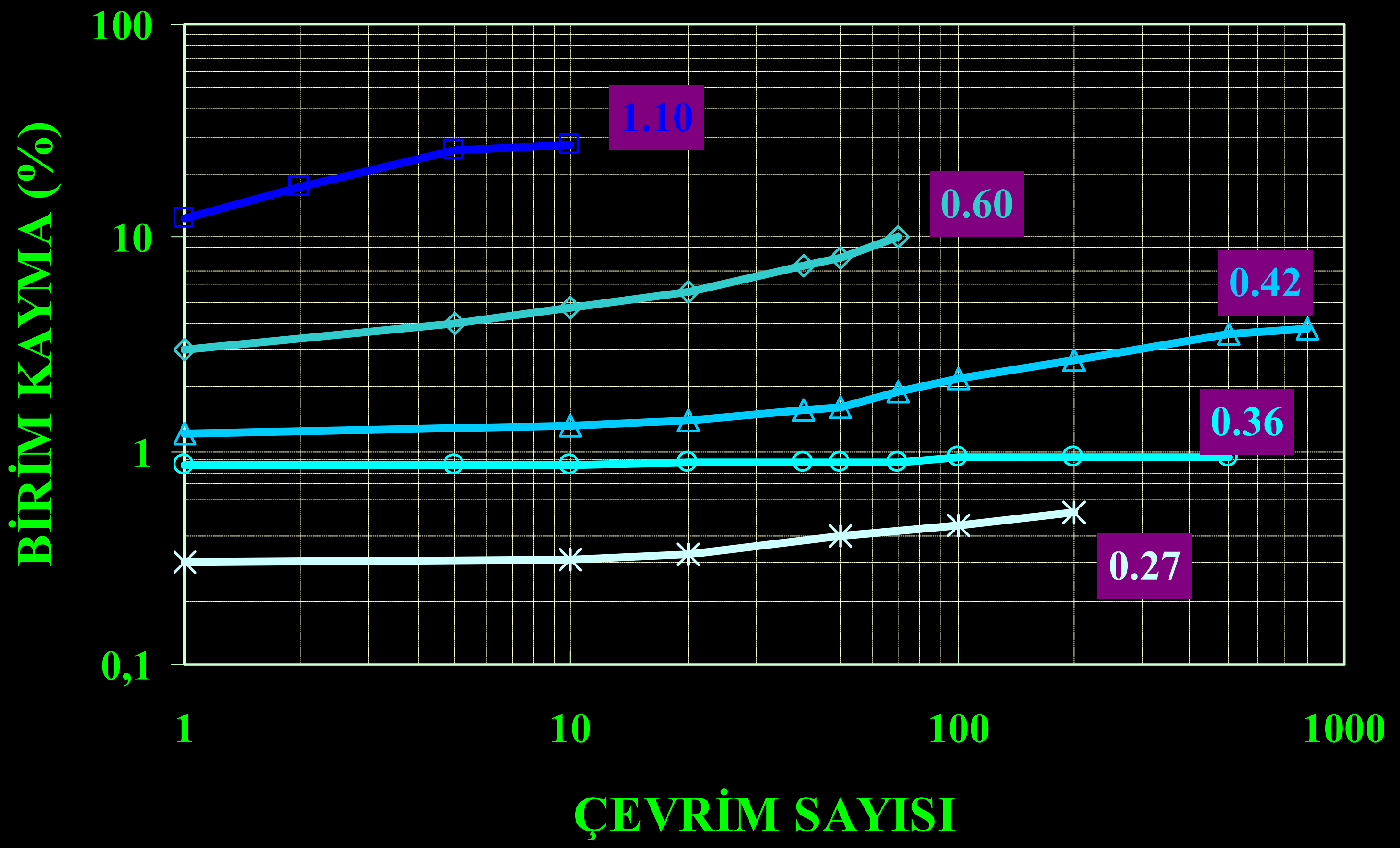
Normally consolidated, organic, fat clay (CH/OH)

- Uniform Cyclic Shear Stresses
- Static Shear Tests Following Uniform Cyclic Shear Stresses
- Uniform Cyclic Loading Under Sustained Shear Stresses
- Simultaneous Application of Cyclic and Static Shear Stresses



BOŞLUK SUYU BASINCI (kPa)
100
80
60
40
20
0
-20
6
4
2
0
-2
-4
-6
BİRİM KAYMA (%)
0
10
20
30
40
50
60
70
80
ÇEVRİM SAYISI

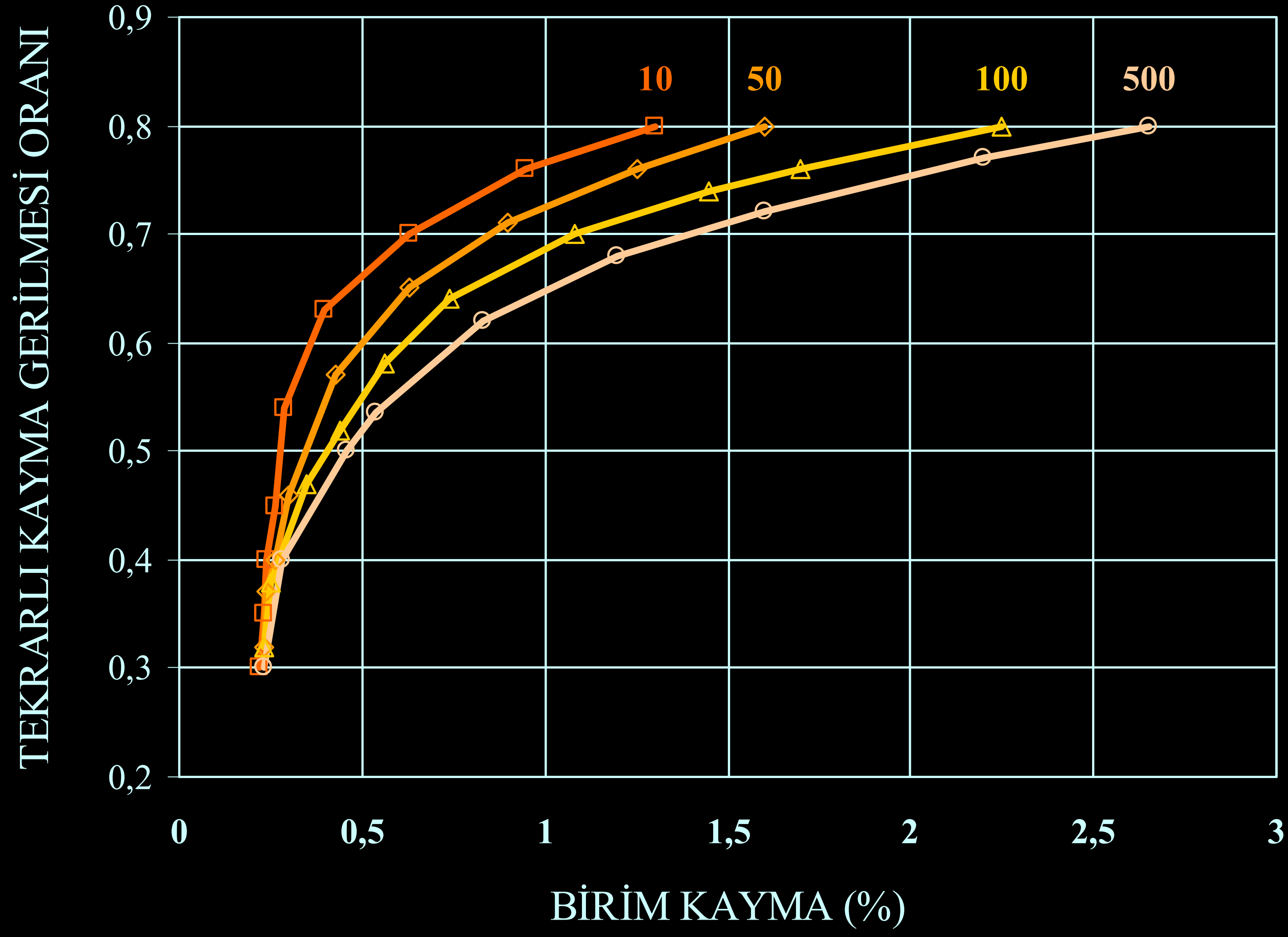
BEHAVIOUR DURING UNIFORM CYCLIC LOADING



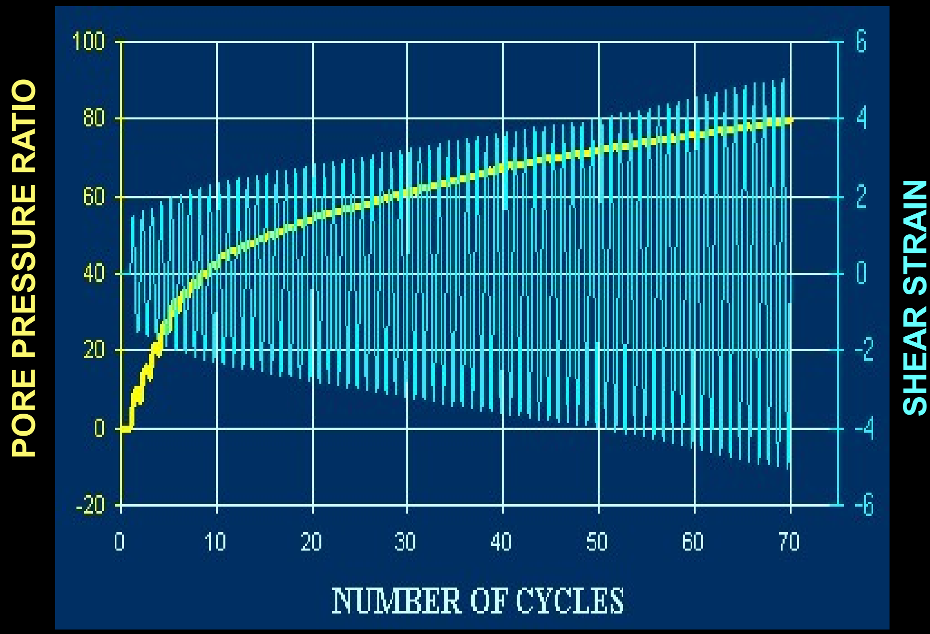
Cyclic Shear Stress Ratio - Shear Strain Amplitude Relationship

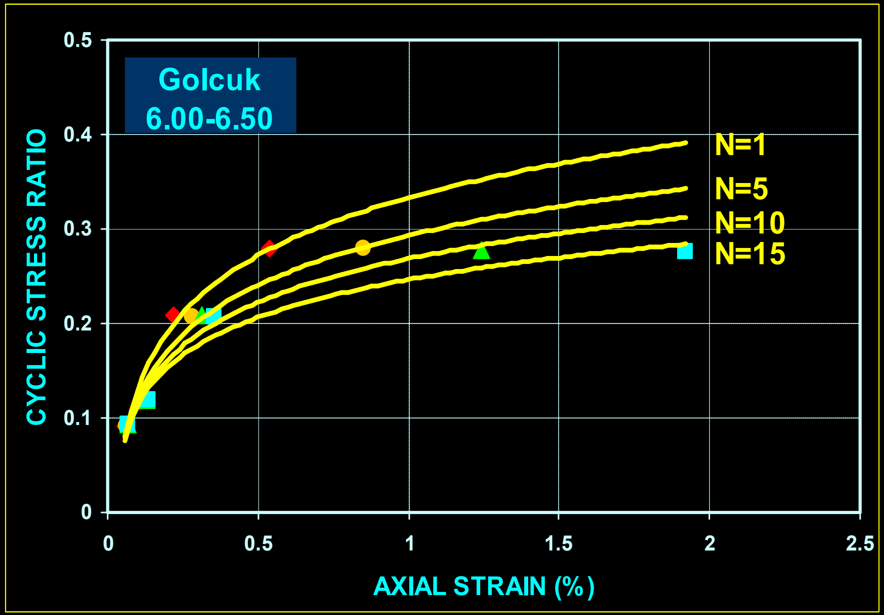
cyclic yield strength

for different number of cycles



TEKRARLI KAYMA GERİLMESİ ORANI
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
10
50
100
500
0
0,5
1
1,5
2
2,5
3
BİRİM KAYMA (%)


PORE PRESSURE RATIO
SHEAR STRAIN
NUMBER OF CYCLES
100
80
60
40
20
0
-20
6
4
2
0
-2
-4
-6
0
10
20
30
40
50
60
70

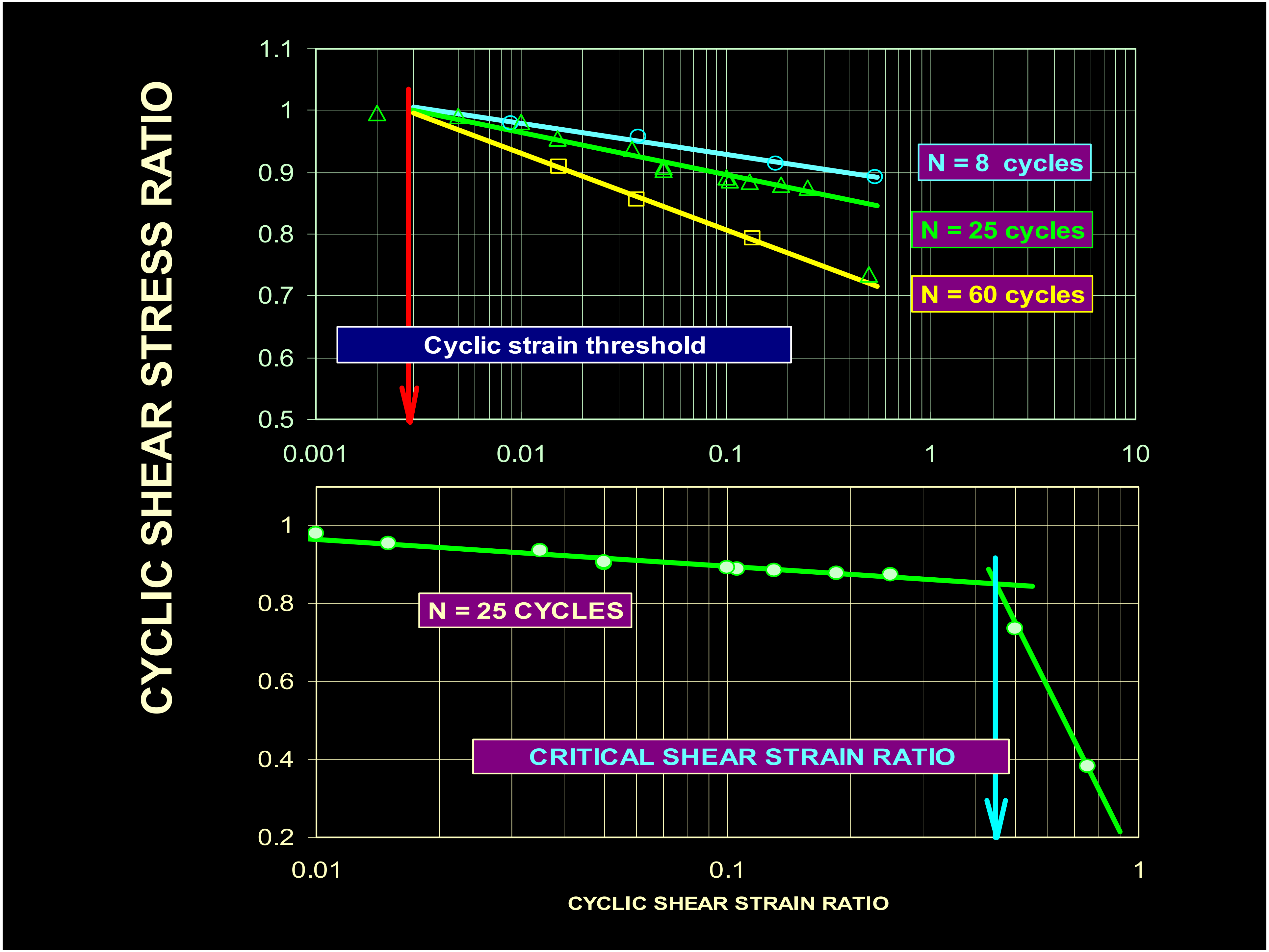

Golcuk
6.00-6.50
N=1
N=5
N=10
N=15
CYCLIC STRESS RATIO
AXIAL STRAIN (%)
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5

Shear Strength Ratio =

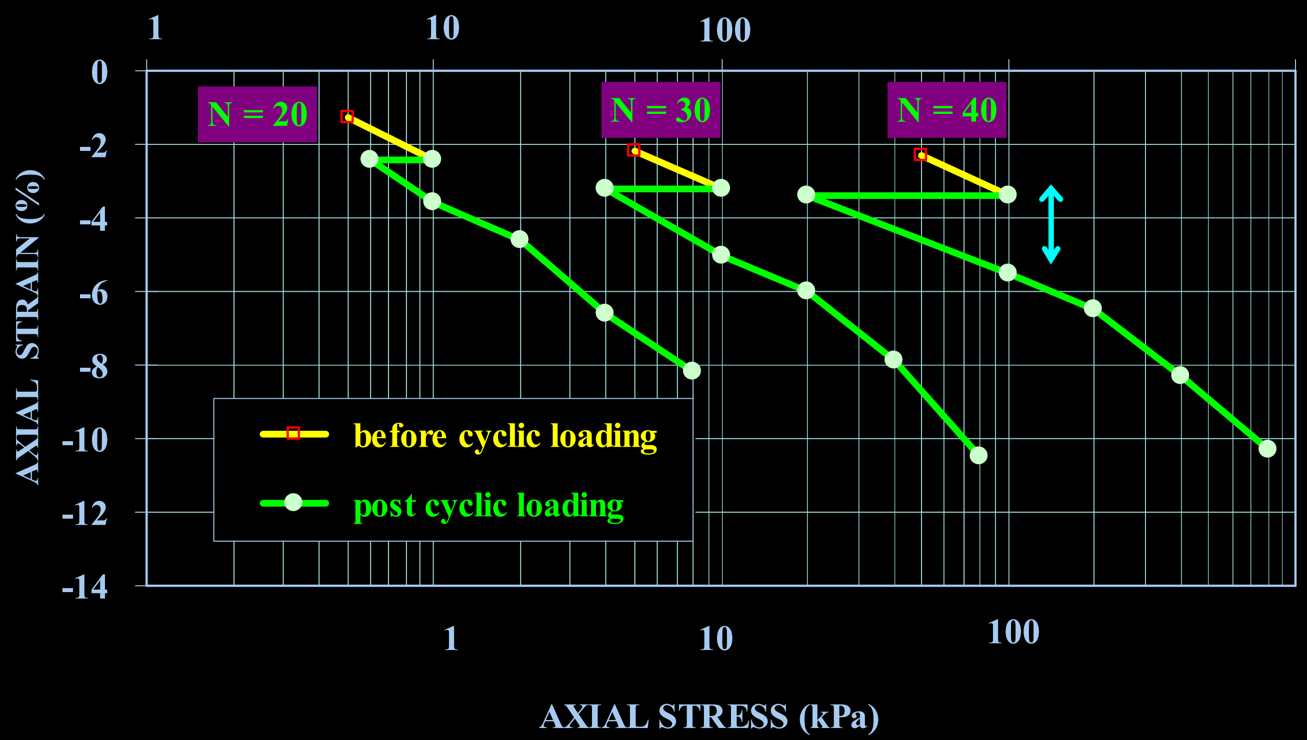
$$= \frac{\text{Post Cyclic Shear Strength}}{\text{Static Undrained Shear Strength}}$$

Cyclic Shear Strain Ratio =

$$= \frac{\text{Maximum Shear Strain Amplitude}}{\text{Failure Strain in Static Shear Test}}$$



CYCLIC SHEAR STRESS RATIO
1.1
1
0.9
0.8
0.7
0.6
0.5
0.001
0.01
0.1
1
10
N = 8 cycles
N = 25 cycles
N = 60 cycles
Cyclic strain threshold
0.8
0.6
0.4
0.2
N = 25 CYCLES
CRITICAL SHEAR STRAIN RATIO
CYCLIC SHEAR STRAIN RATIO



1
10
100
0
-2
-4
-6
-8
-10
-12
-14
N = 20
N = 30
N = 40
AXIAL STRAIN (%)
before cyclic loading
post cyclic loading
1
10
100
AXIAL STRESS (kPa)

POST EARTHQUAKE BEHAVIOUR

- ➔ Decrease in Effective Stresses
- ➔ Particle Structure Breakdown

Softening
Shear Strength Reduction
Additional Settlements

Soil Layers modify

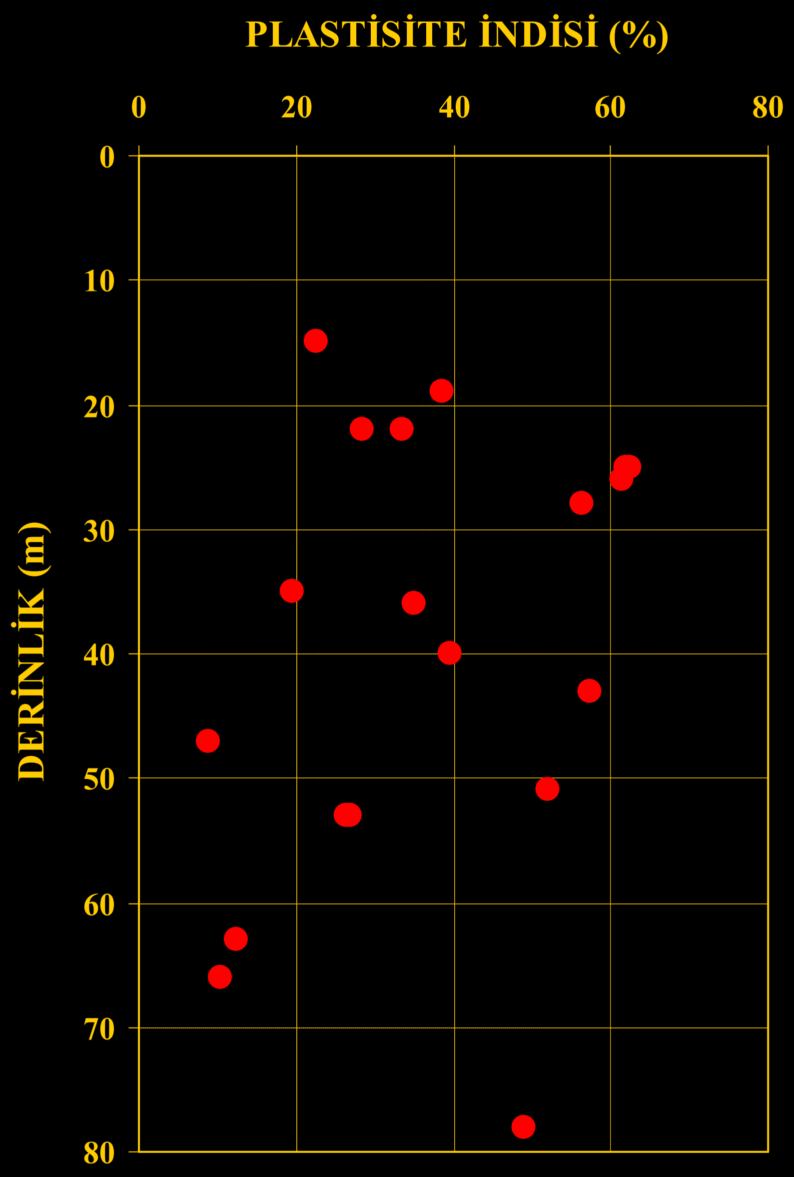
Earthquake Characteristics

and

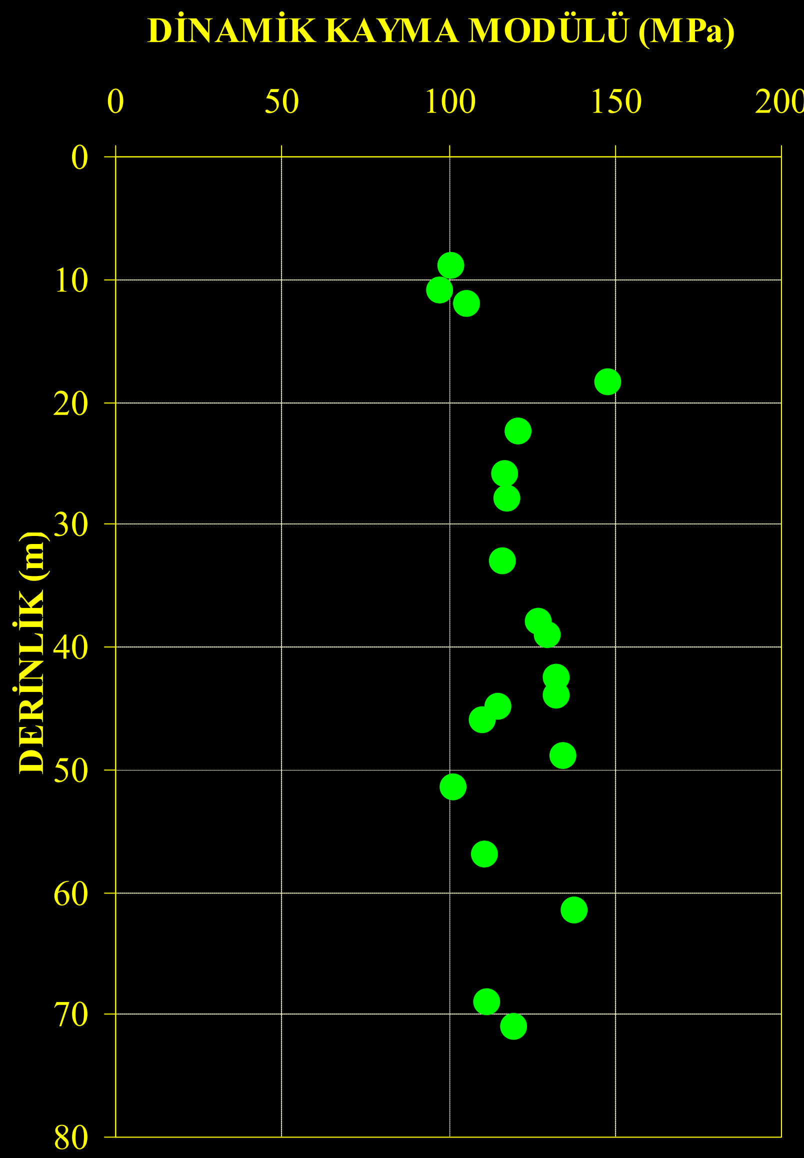
Earthquake Excitations modify

Engineering Characteristics

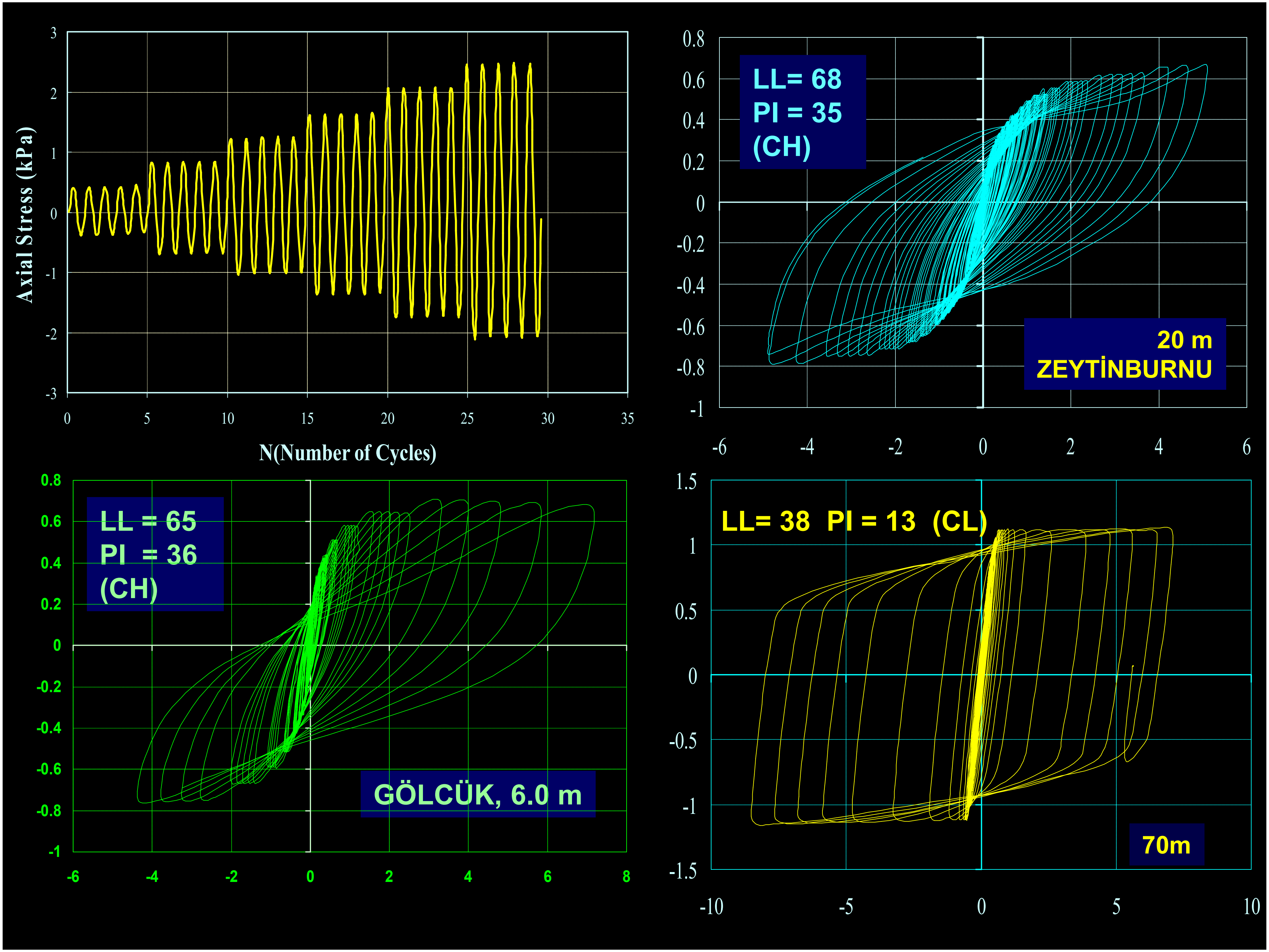
of Soil Layers



PLASTİSİTE İNDİSİ (%)
0
20
40
60
80
DERİNLİK (m)
0
10
20
30
40
50
60
70
80



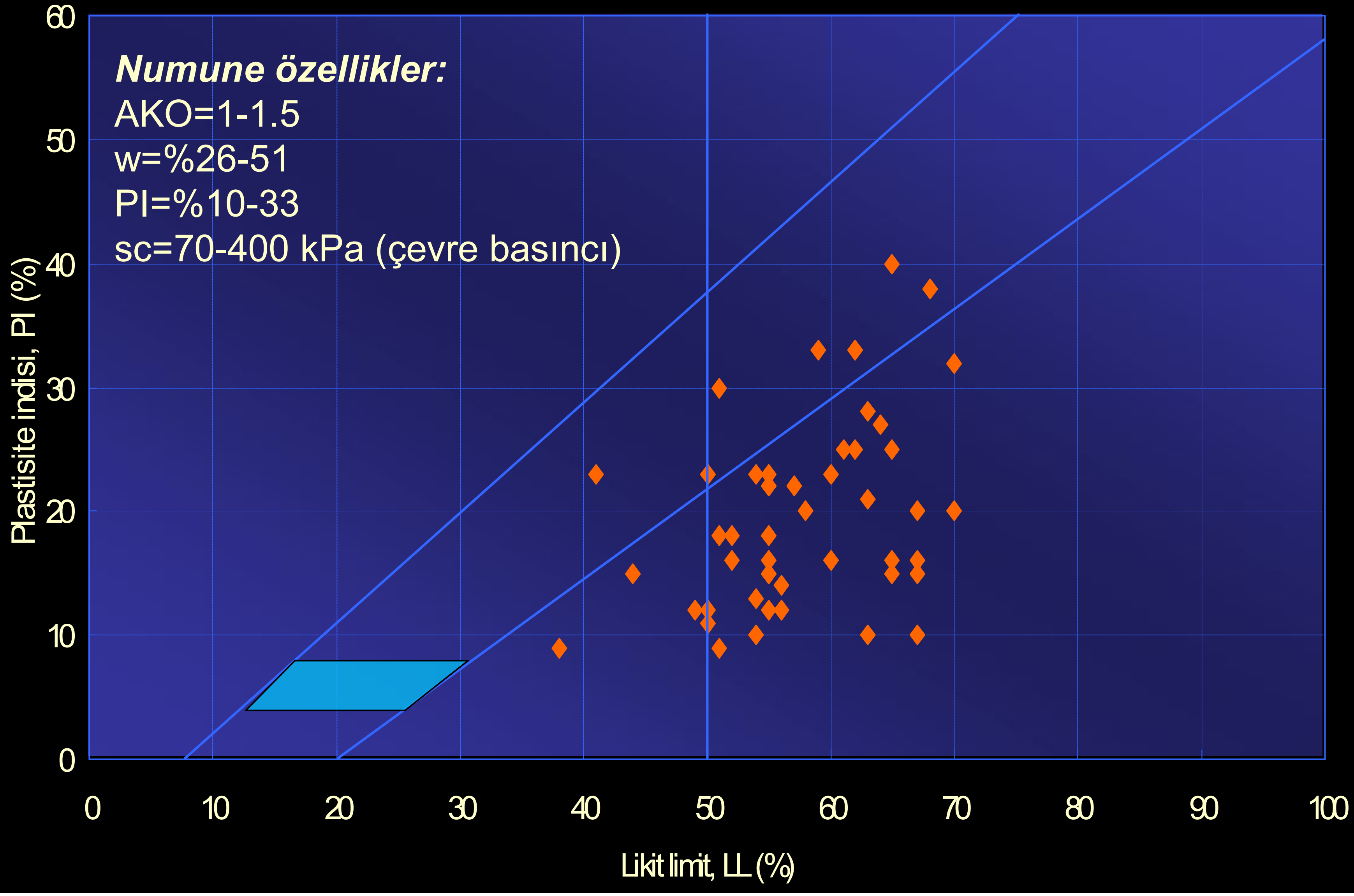
DİNAMİK KAYMA MODÜLÜ (MPa)
0
50
100
150
200
DERİNLİK (m)
0
10
20
30
40
50
60
70
80

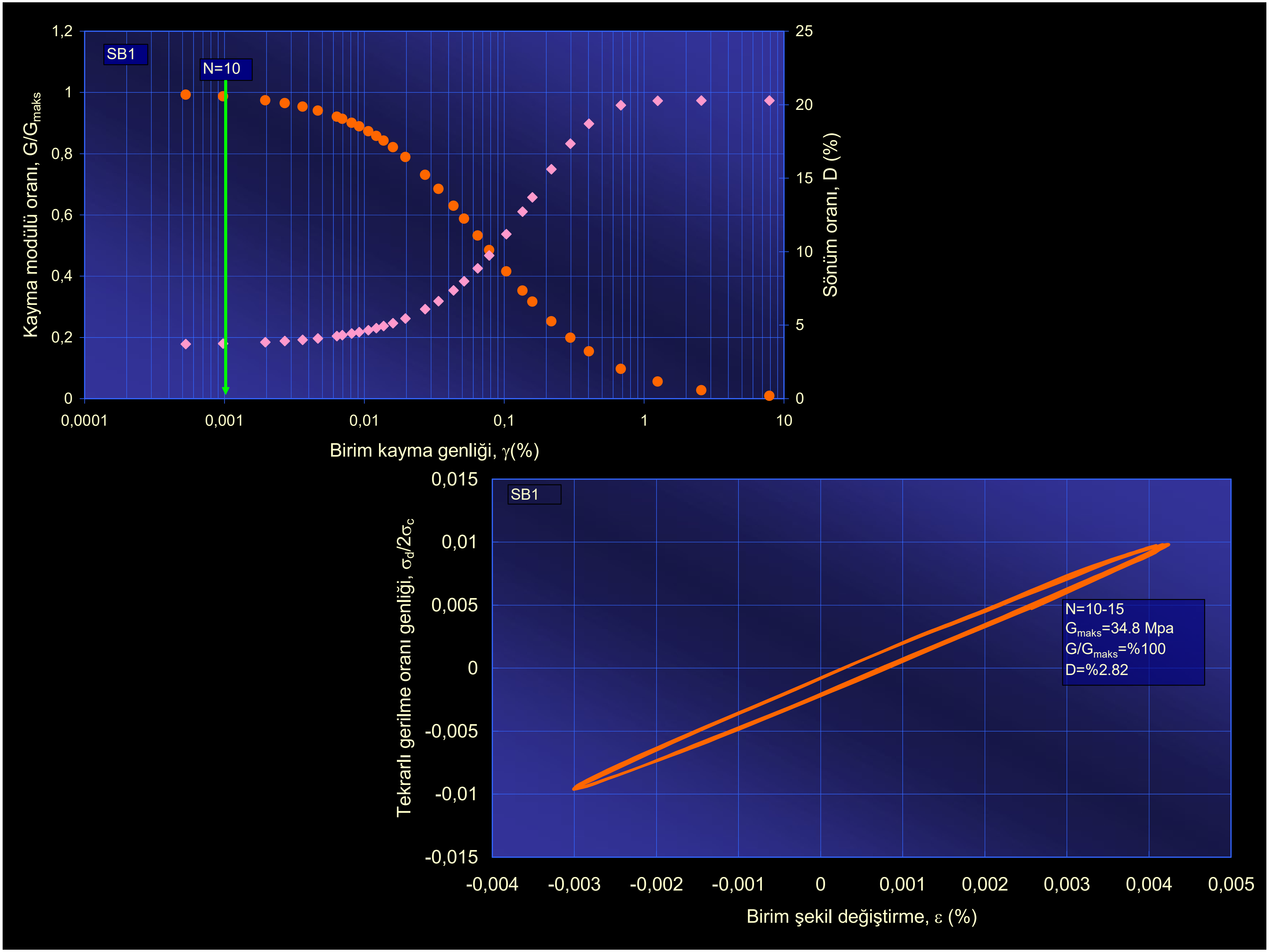


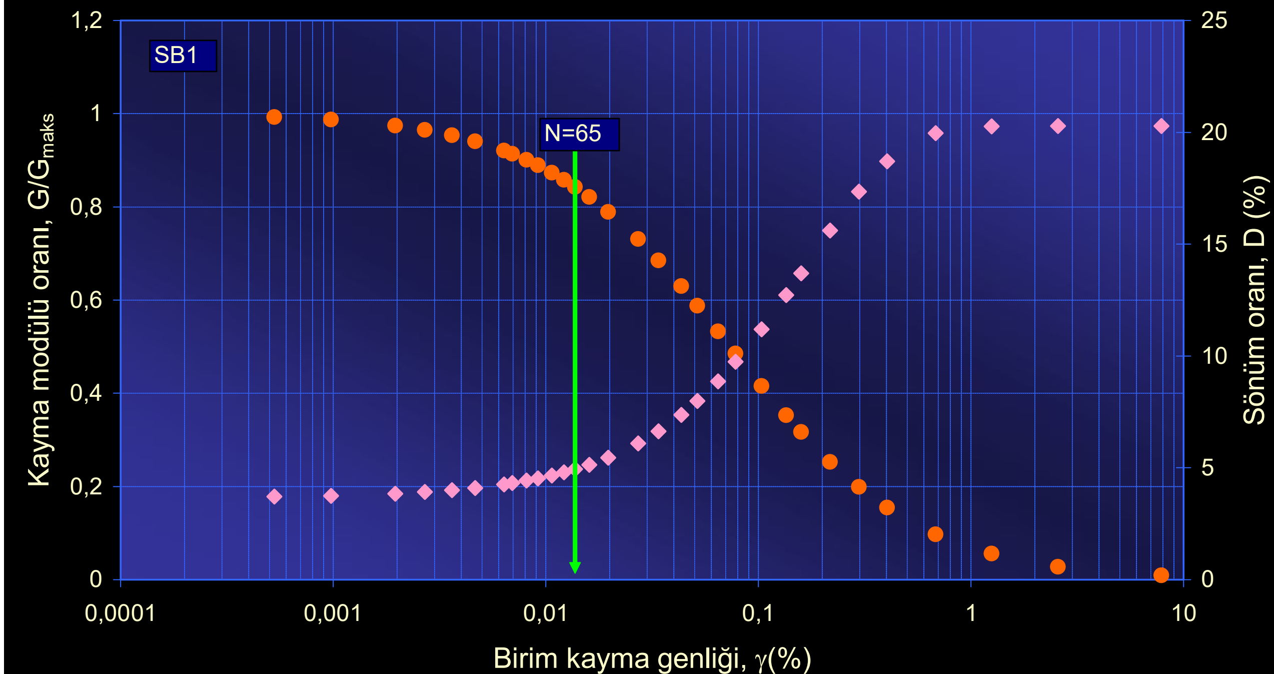
Axial Stress (kPa)
N(Number of Cycles)
LL= 68
PI = 35
(CH)
20 m
ZEYTİNBURNU
LL = 65
PI = 36
(CH)
GÖLCÜK, 6.0 m
LL= 38 PI = 13 (CL)
70m

STATİK KAYMA GERİLMESİ OLMADAN
STATİK KAYMA GERİLMESİ ALTINDA
DİNAMİK KAYMA MODÜLÜ (MPa)
35
30
25
20
15
10
5
0
0,01
0,1
1
10
TEKRARLI BİRİM KAYMA GENLİĞİ (%)

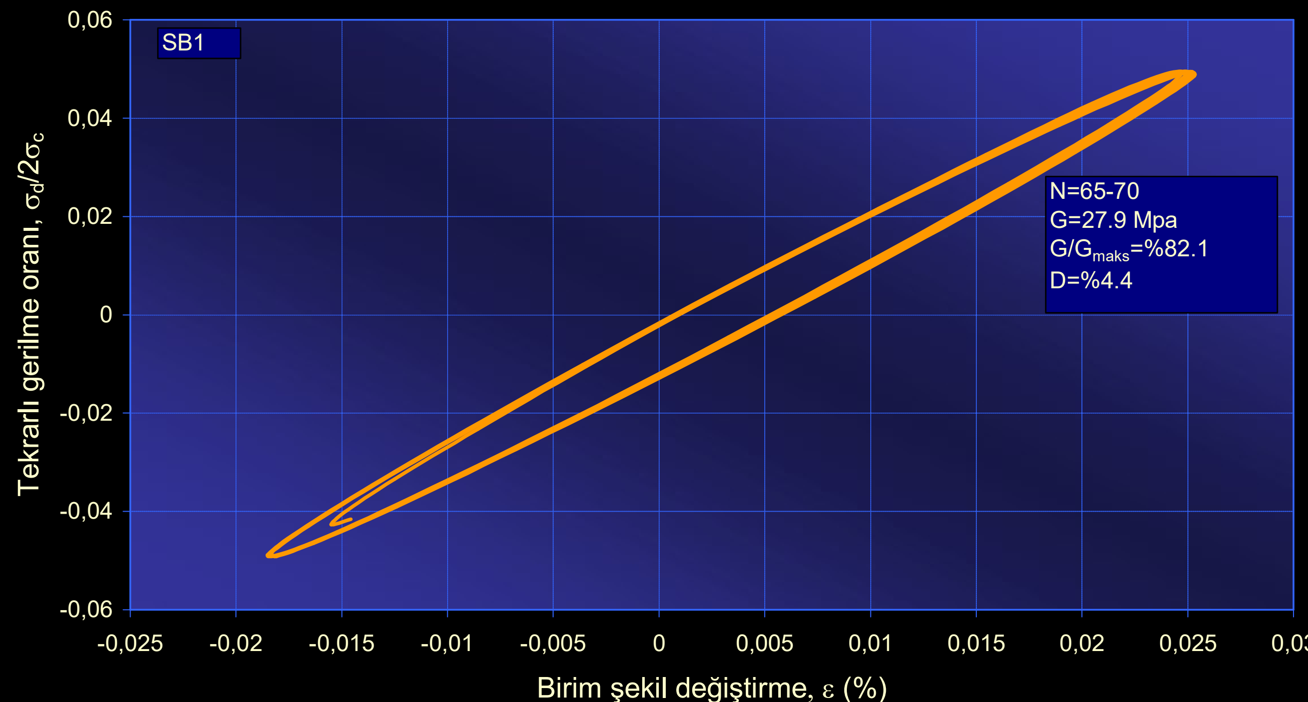
Çalışmada Okur, Ansal (2000); Okur, Ansal (2001) çalışmalarına ek olarak 21 sondaj kuyusundan alınan örselenmemiş numuneler kullanılmıştır



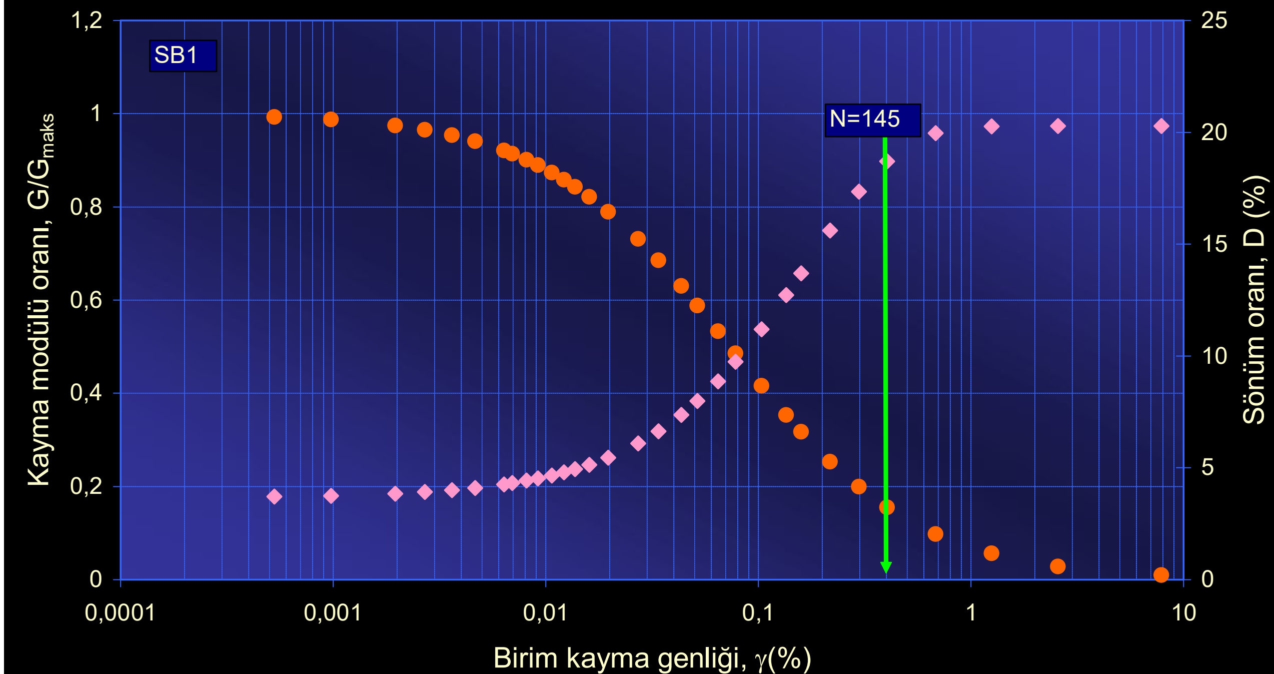

SB1
N=10
Kayma modülü oranı, G/G_{maks}
Sönüm oranı, D (%)
Birim kayma genliği, γ(%)
1,2
1
0,8
0,6
0,4
0,2
0
25
20
15
10
5
0
0,0001
0,001
0,01
0,1
1
10
SB1
N=10-15
G_{maks}=34.8 Mpa
G/G_{maks}=%100
D=%2.82
Tekrarlı gerilme oranı genliği, $\sigma_d/2\sigma_c$
Birim şekil değiştirme, ε (%)
0,015
0,01
0,005
0
-0,005
-0,01
-0,015
-0,004
-0,003
-0,002
-0,001
0
0,001
0,002
0,003
0,004
0,005

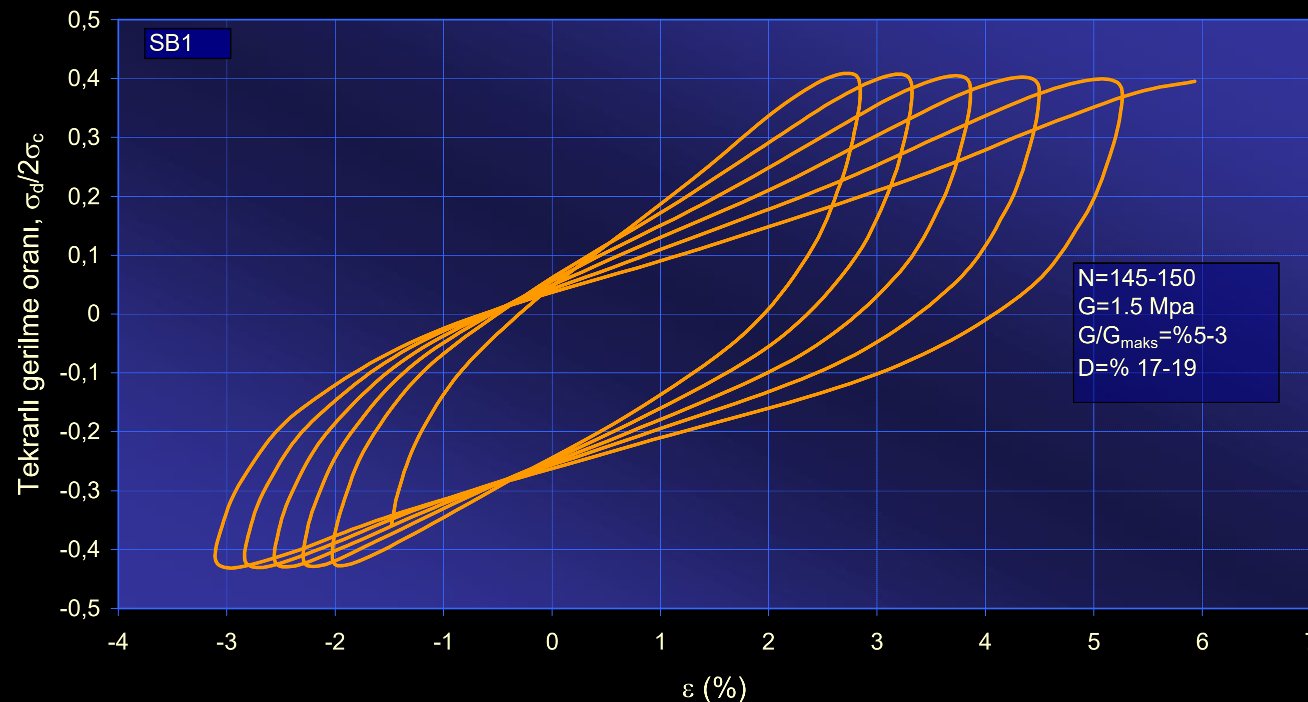


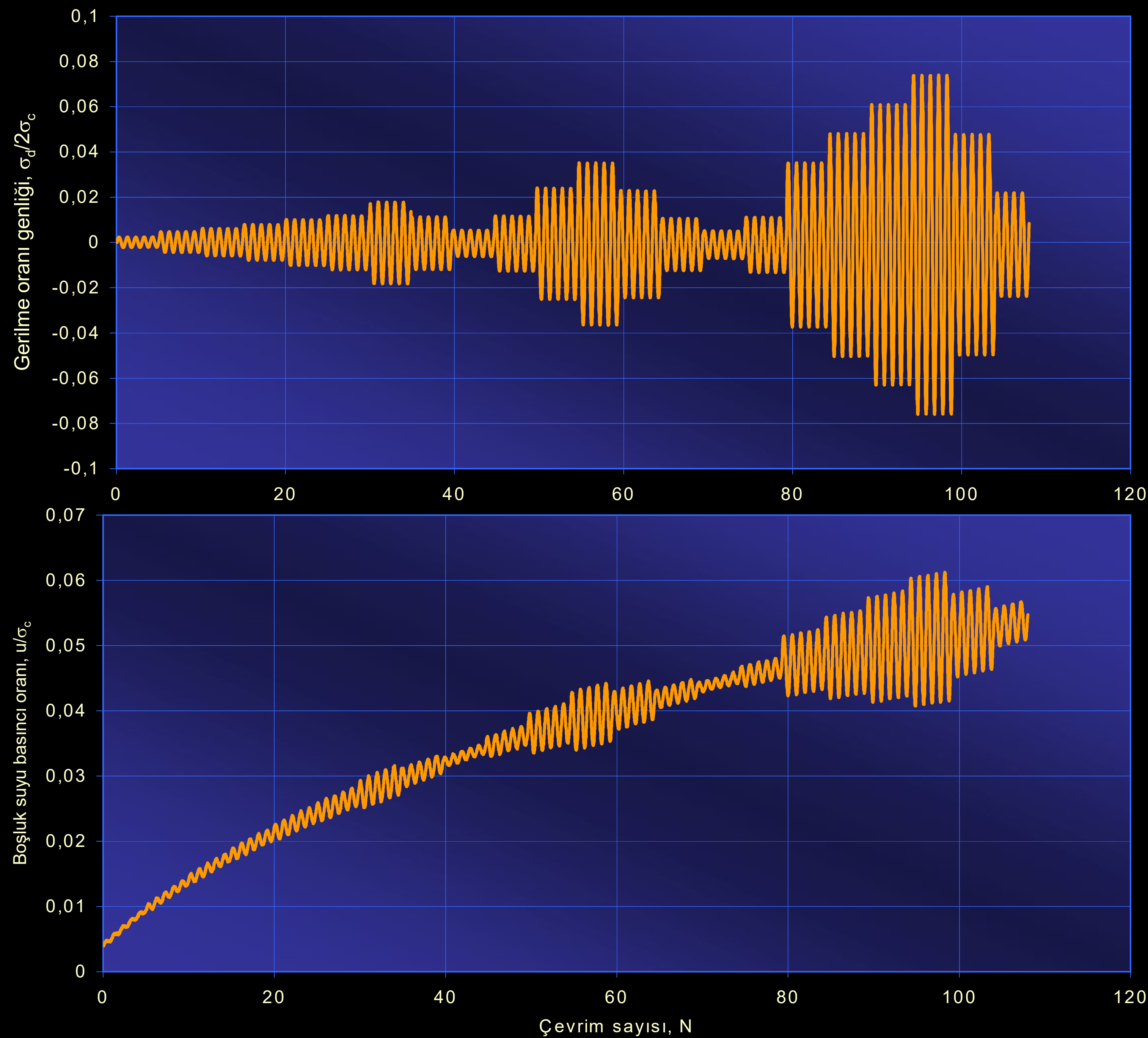
SB1
N=65
Kayma modülü oranı, G/G$_{maks}$
Sönüm oranı, D (%)
Birim kayma genliği, γ(%)
1,2
1
0,8
0,6
0,4
0,2
0
25
20
15
10
5
0,0001
0,001
0,01
0,1
1
10



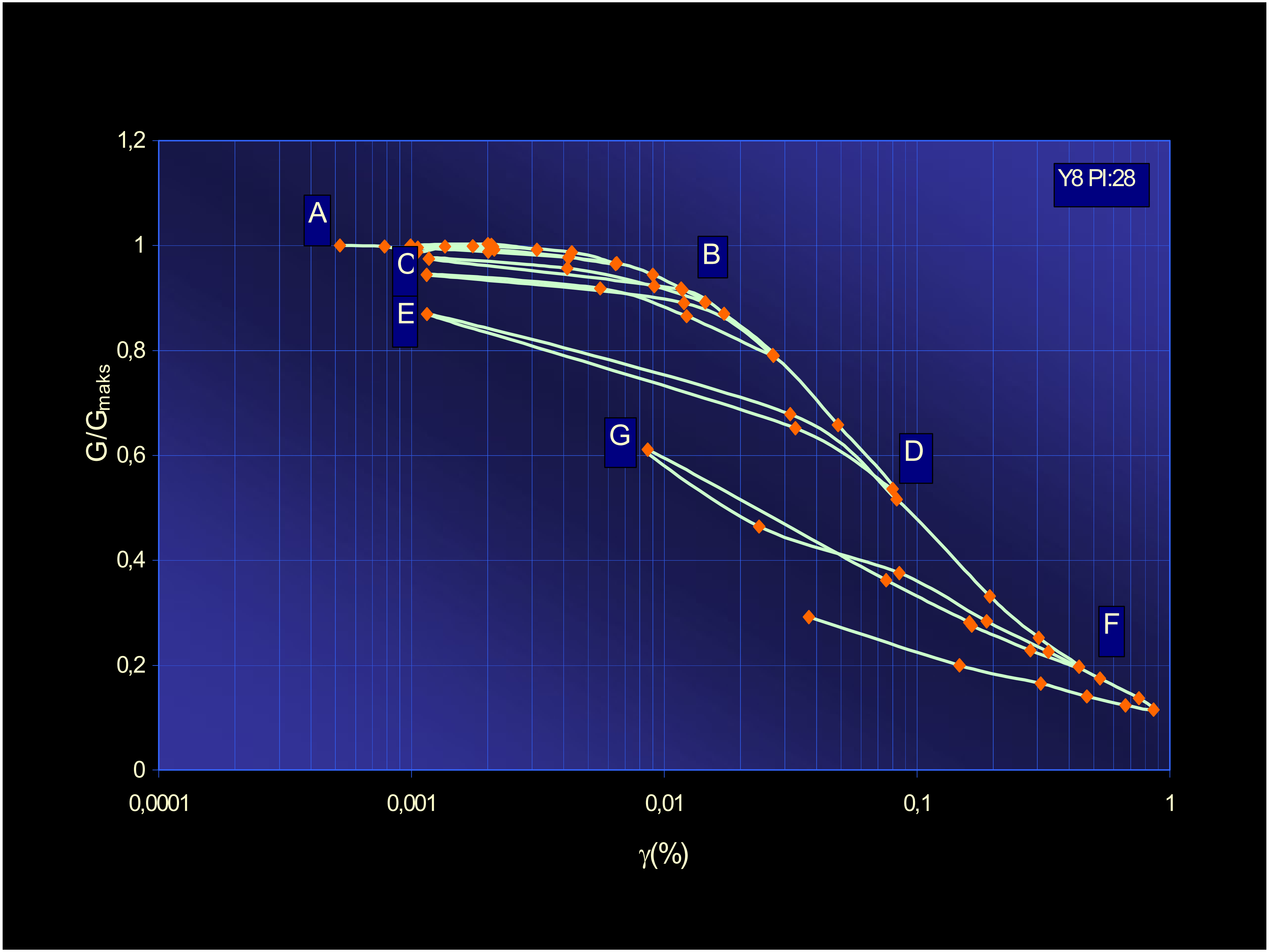
SB1
N=65-70
G=27.9 Mpa
G/G$_{maks}$=%82.1
D=%4.4
Tekrarlı gerilme oranı, $\sigma_d/2\sigma_c$
Birim şekil değiştirme, ε (%)
0,06
0,04
0,02
0
-0,02
-0,04
-0,06
-0,025
-0,02
-0,015
-0,01
-0,005
0
0,005
0,01
0,015
0,02
0,025
0,03


SB1
N=145
Kayma modülü oranı, G/Gmaks
Sönüm oranı, D (%)
Birim kayma genliği, γ(%)
1,2
1
0,8
0,6
0,4
0,2
0
25
20
15
10
5
0
0,0001
0,001
0,01
0,1
1
10


SB1
N=145-150
G=1.5 Mpa
G/Gmaks=%5-3
D=% 17-19
Tekrarlı gerilme oranı, σd/2σc
ε (%)
0,5
0,4
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
-0,4
-0,5
-4
-3
-2
-1
0
1
2
3
4
5
6
7



Gerilme oranı genliği, $\sigma_d/2\sigma_c$
0,1
0,08
0,06
0,04
0,02
0
-0,02
-0,04
-0,06
-0,08
-0,1
0 20 40 60 80 100 120
Boşluk suyu basıncı oranı, u/σ_c
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0 20 40 60 80 100 120
Çevrim sayısı, N



Y8 PI:28
A
B
C
D
E
F
G
1,2
1
0,8
0,6
0,4
0,2
0
G/Gmaks
0,0001
0,001
0,01
0,1
1
γ(%)

FIELD TESTS

- **Low-strain tests:**
  - Seismic Reflection / Refraction Test
  - Seismic Cross-Hole / Down-Hole / Up-Hole Test
  - Steady-State Vibration (Rayleigh Wave) Test
  - Spectral Analysis of Surface Waves (SASW)
  - Suspension PS Logging
  - Seismic Cone Penetration Test (SCPT)
- **High-strain element test:**
  - Standard Penetration Test, SPT
  - Cone Penetration Test, CPT
  - Dilatometer Test, DMT
  - Pressuremeter Test, PMT

Measurement of Dynamic Soil Properties

Laboratory **methods involve testing small specimens of soil samples (~38-70 mm in diameter) that are assumed to be representative of the soil in the field.**

Field **methods involve testing soil in place by measuring seismic wave propagation**

Factors such as testing procedure, testing errors and interpretation errors effects measurements.

Laboratory Testing Methods

(+) Pros. conditions can be controlled
wide range of strains
can do parametric studies

(-) Cons. sample disturbance
specimen size
reproduction of actual field conditions (stress, chemical, thermal and structural)

Field Testing Methods

(+) Pros. properties measured in existing state
do not require sampling
testing relatively large volume of soil

(-) Cons. conditions cannot be controlled
indirect measurement
limited strain range

Field Testing in Geotechnical Engineering

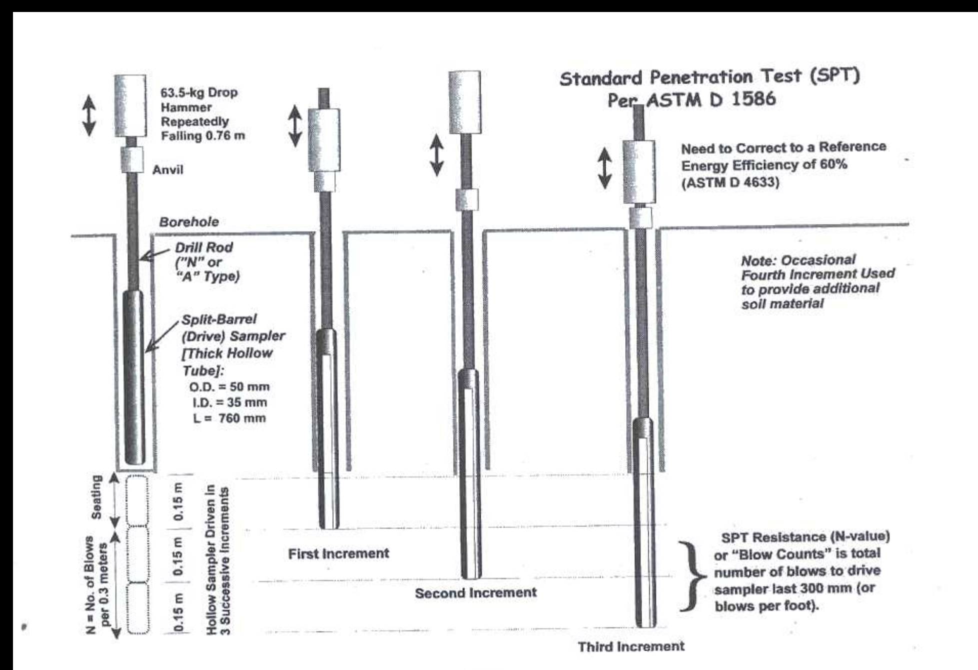
Standard Penetration Test (SPT)

- **Quantifies penetration resistance of soils**
- **Provides some correlation with in-place (in-situ) soil properties**

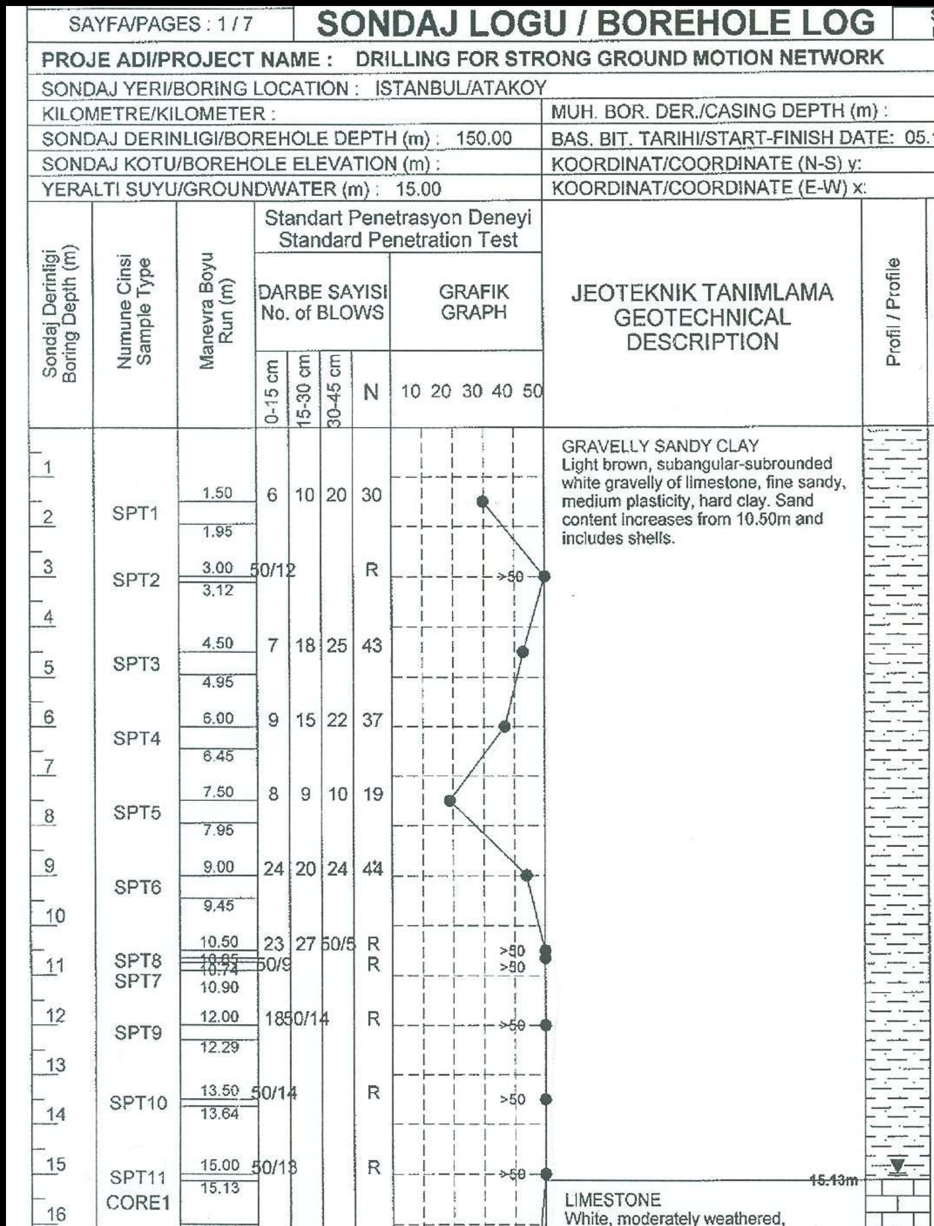
2-in. (51mm) split-spoon sampler is driven into the undisturbed soil by using 140-lb(63.6kg) weight falling 30 in. (0.76m) until 18-in penetration is achieved.
Blow counts for driving the sample for each 6-in. (152mm) of penetration is recorded seperately.
Number of blow counts required for the last 12-in (0.3m) of driving is reported as the SPT result at that depth (N_{SPT})
Repeat at regular depth intervals (typically 1-2m) to obtain N_{SPT} with depth.





Standard Penetration Test (SPT)



SAYFA/PAGES : 1 / 7 — **SONDAJ LOGU / BOREHOLE LOG**

PROJE ADI/PROJECT NAME : DRILLING FOR STRONG GROUND MOTION NETWORK
SONDAJ YERI/BORING LOCATION : ISTANBUL/ATAKOY
KILOMETRE/KILOMETER :
SONDAJ DERINLIGI/BOREHOLE DEPTH (m) : 150.00
SONDAJ KOTU/BOREHOLE ELEVATION (m) :
YERALTI SUYU/GROUNDWATER (m) : 15.00
MUH. BOR. DER./CASING DEPTH (m) :
BAS. BIT. TARIHI/START-FINISH DATE: 05.1
KOORDINAT/COORDINATE (N-S) y:
KOORDINAT/COORDINATE (E-W) x:

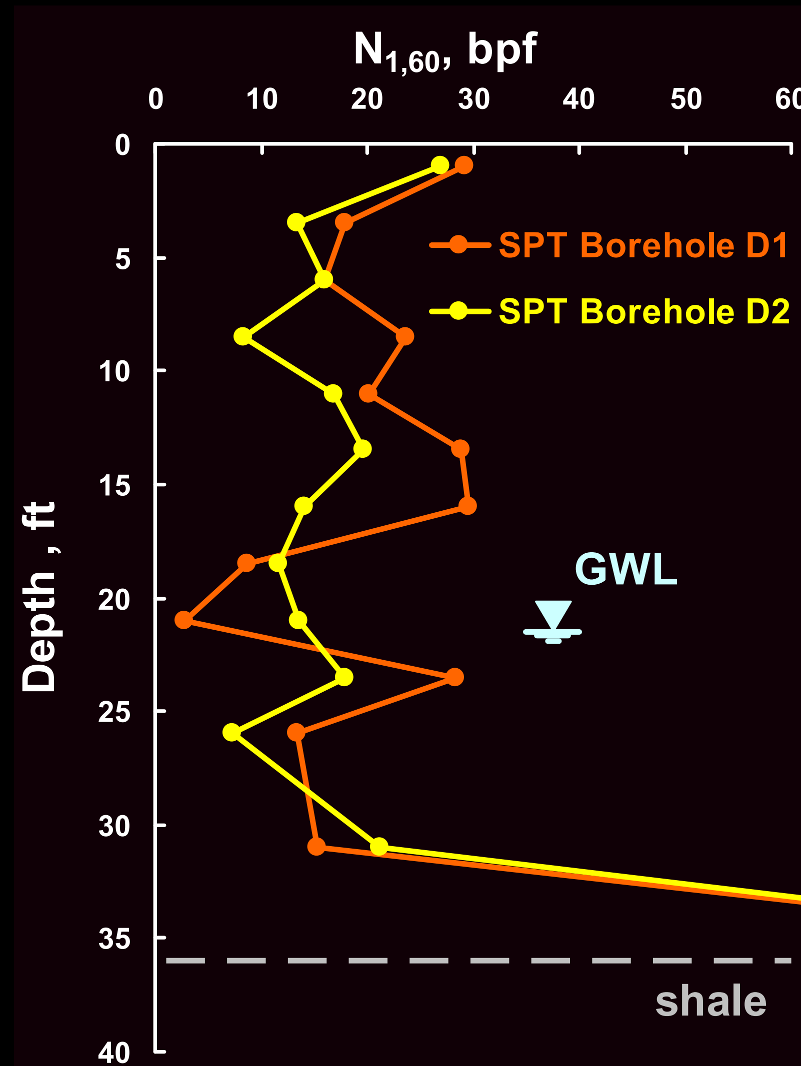
Numune Cinsi / Sample Type	Manevra Boyu / Run (m)	0-15 cm	15-30 cm	30-45 cm	N	Grafik / Graph
SPT1	1.50 – 1.95	6	10	20	30	
SPT2	3.00 – 3.12	50/12			R	>50
SPT3	4.50 – 4.95	7	18	25	43	
SPT4	6.00 – 6.45	9	15	22	37	
SPT5	7.50 – 7.95	8	9	10	19	
SPT6	9.00 – 9.45	24	20	24	44	
SPT8	10.50 – 10.65	23	27	50/5	R	>50
SPT7	10.74 – 10.90	50/9			R	>50
SPT9	12.00 – 12.29	18	50/14		R	>50
SPT10	13.50 – 13.64	50/14			R	>50
SPT11	15.00 – 15.13	50/13			R	>50
CORE1	15.13 – 16.00					

JEOTEKNIK TANIMLAMA / GEOTECHNICAL DESCRIPTION:

GRAVELLY SANDY CLAY
Light brown, subangular-subrounded white gravelly of limestone, fine sandy, medium plasticity, hard clay. Sand content increases from 10.50m and includes shells.

15.13m

LIMESTONE
White, moderately weathered,



Standard Penetration Test (SPT)

Need to apply corrections to N_{SPT} to have a standardized value ($N_{1,60}$)
Corrected $N_{1,60}$ values are calculated as

$$N_{1,60} = N\ C_N C_R\ C_S\ C_B\ C_E\ C_N$$

N = measured standard penetration resistance,

C_N = factor to normalize N to a reference effective overburden stress,

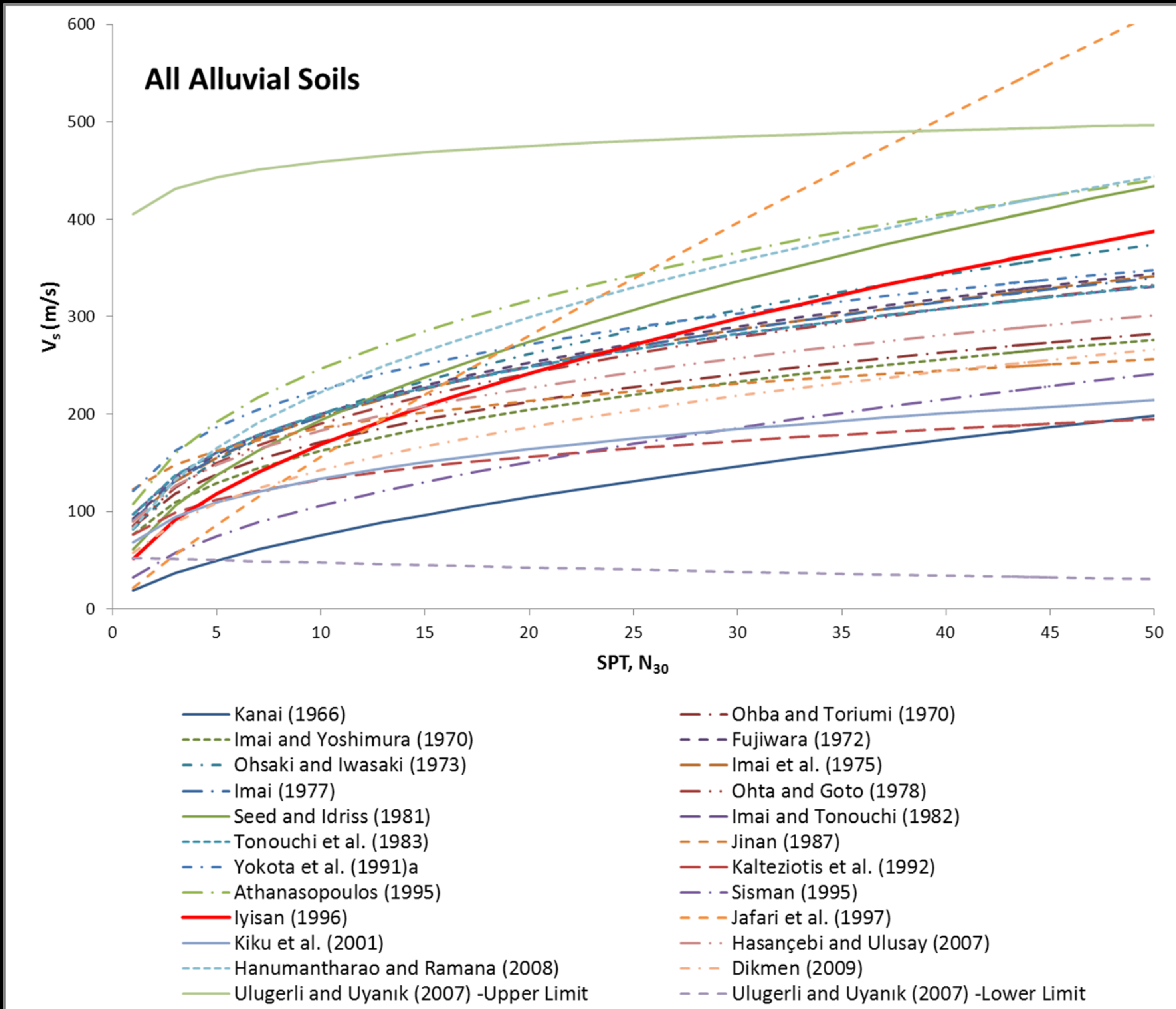
C_R = correction for rod length,

C_S = correction for non-standardized sampler configuration,

C_B = correction for borehole diameter,

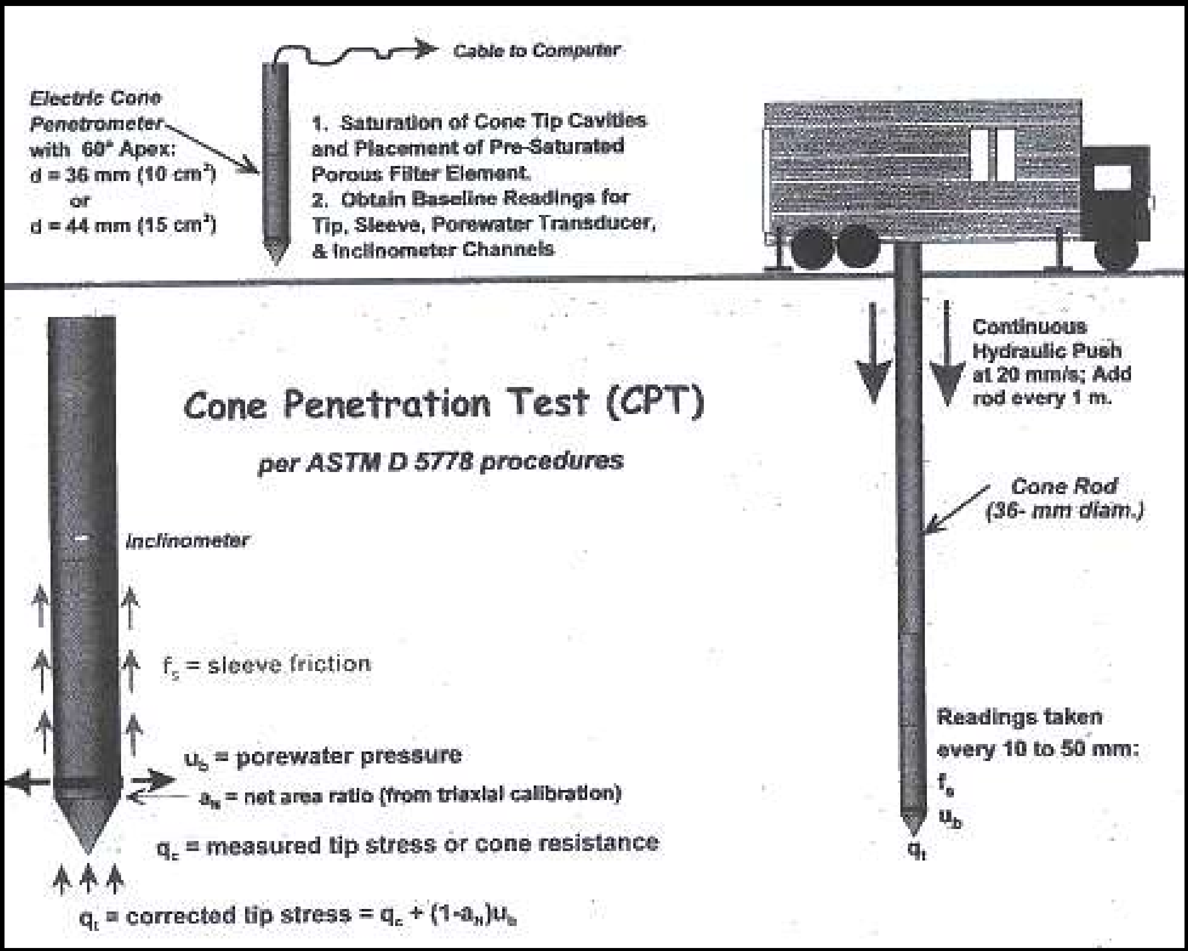
C_E = correction for hammer energy ratio.

Correlations between shear wave velocity, V_S and N_{SPT}



Cone Penetration Test (CPT)

- Quantifies penetration resistance of soils
- Provides some correlation with in-situ soil properties



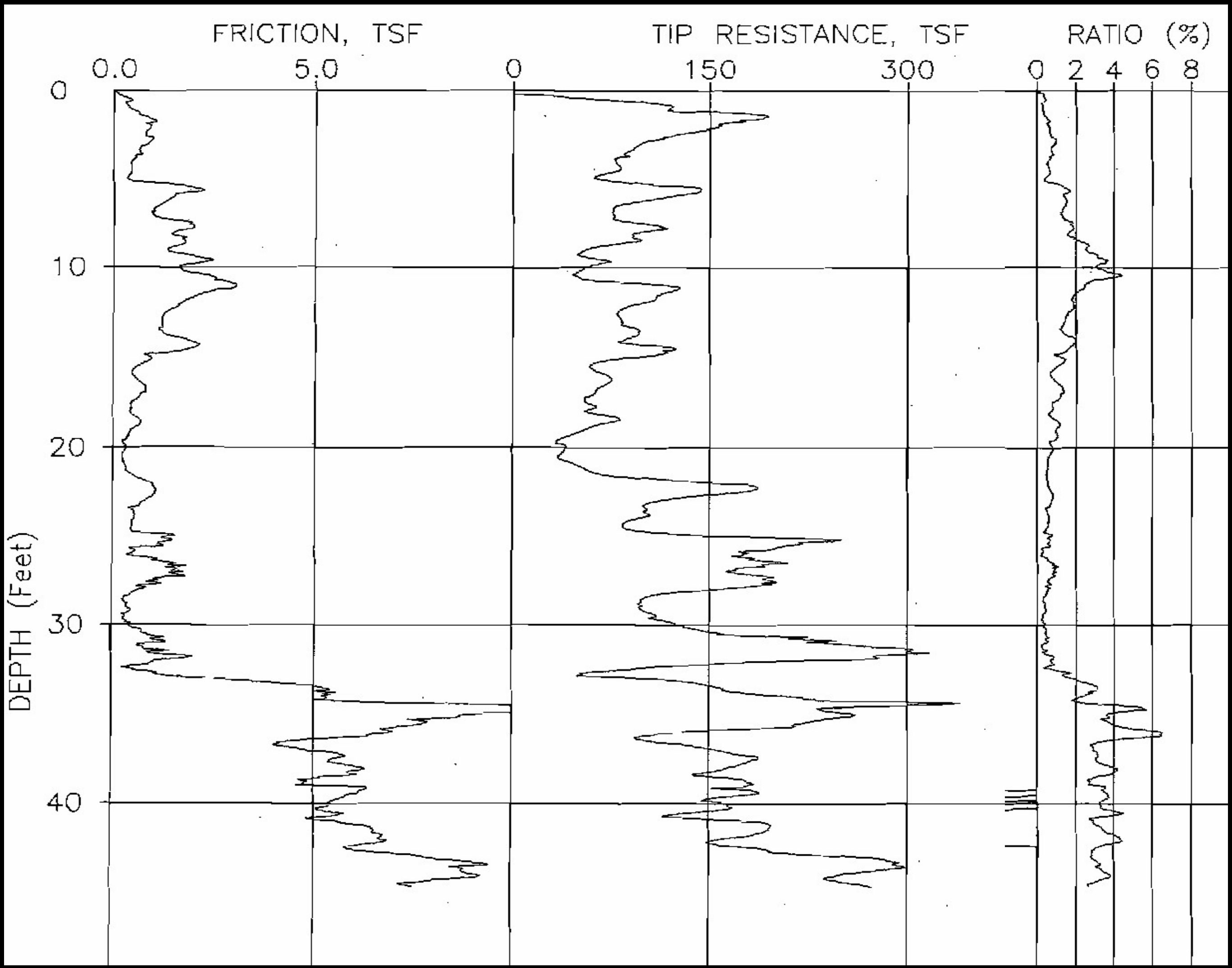
- A cylindrical probe with a cone-shaped tip with different sensors that allow real-time continuous measurements by pushing it into the ground at a speed of 2 cm/s.

Measures:

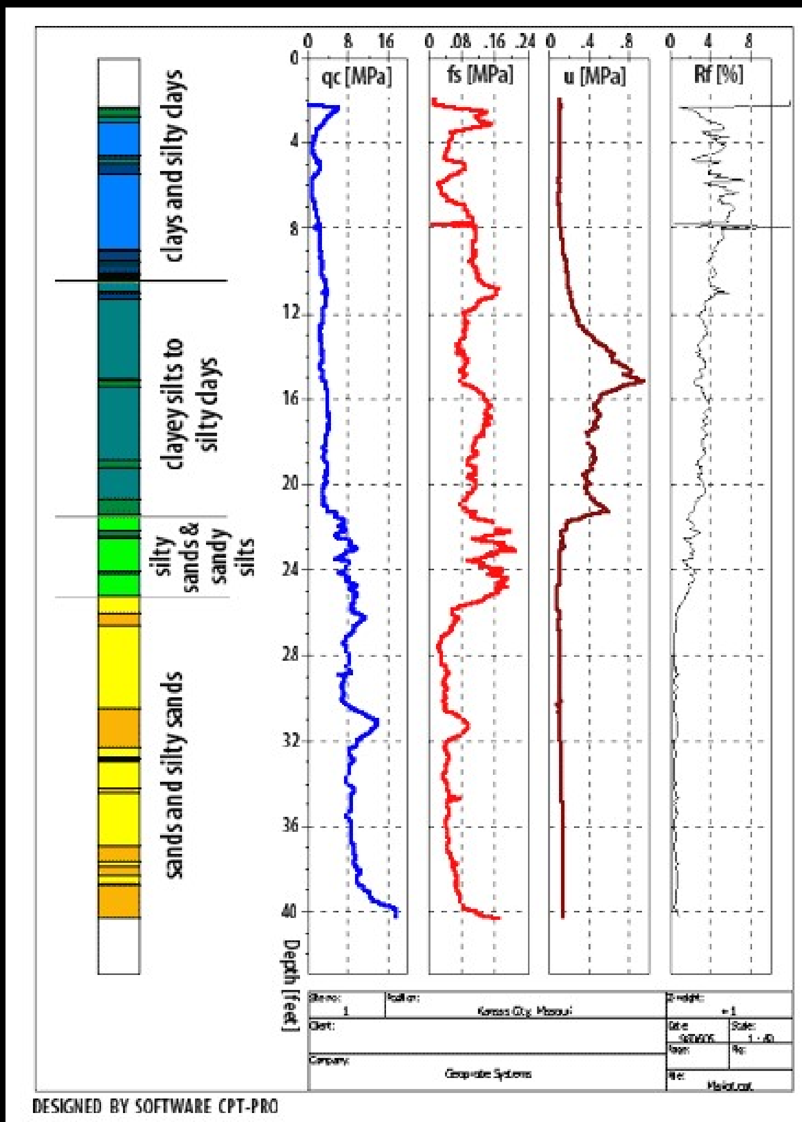
1. cone resistance, q_c at the tip
2. the sleeve friction, f_s
3. pore water pressure, u

- Field computer displays the data in real-time and stores it at regular depth intervals.

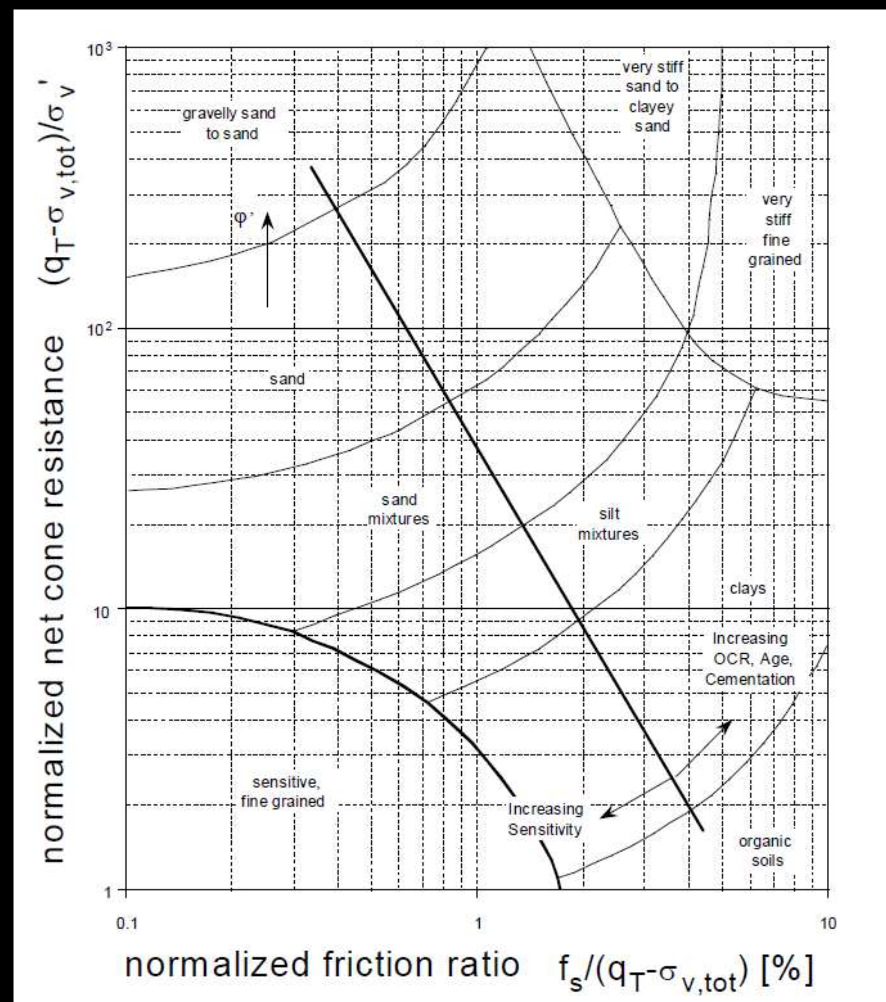
Field Site – CPT Profile, May 2006



Cone Penetration Test (CPT)



Identification and classification of soil layers



Cone Penetration Test (CPT)

Advantages

- Fast method,
- Gives detailed profiles,
- Relatively cheap,
- A lot of correlations exist,
- Allows measurements at in situ conditions, avoiding problems relating to sample disturbance.

Limitations

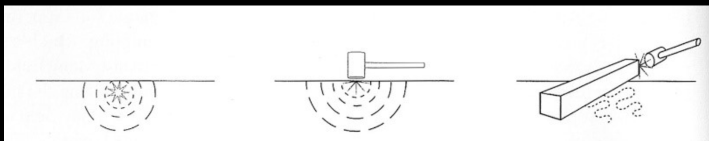
- Only usable in soft to medium stiff materials without boulders,
- No samples are obtained for visual examination and laboratory testing.

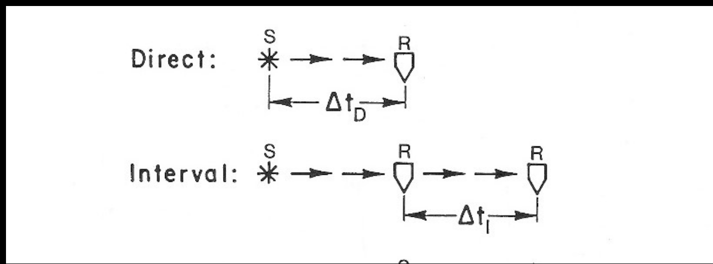
PENETRATION TESTS

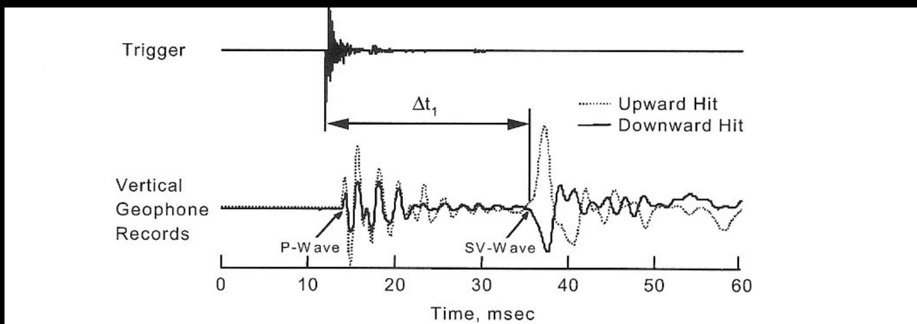
SPT	**CPT**
SPT-N	Point resistance
↓	↓
Shear Wave Velocity	Shear Wave Velocity
$Vs = 51.5 N^{0.516}$	$Vs = 55.3 q_c^{0.377}$

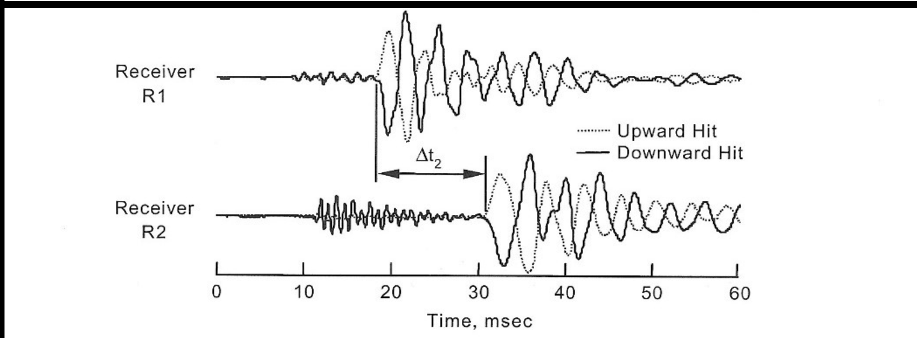
(İYİSAN, 1996)

Wave Propagation and Geophysical Methods









Seismic Test Method in General

1. Creation of transient and/or steady state stress waves using an energy source
2. Monitoring of particle motion with transducers (i.e. receivers) located at one or more locations away from the source
3. Times of wave arrivals are determined from the waveforms recorded at receiver locations and wave velocity is calculated from

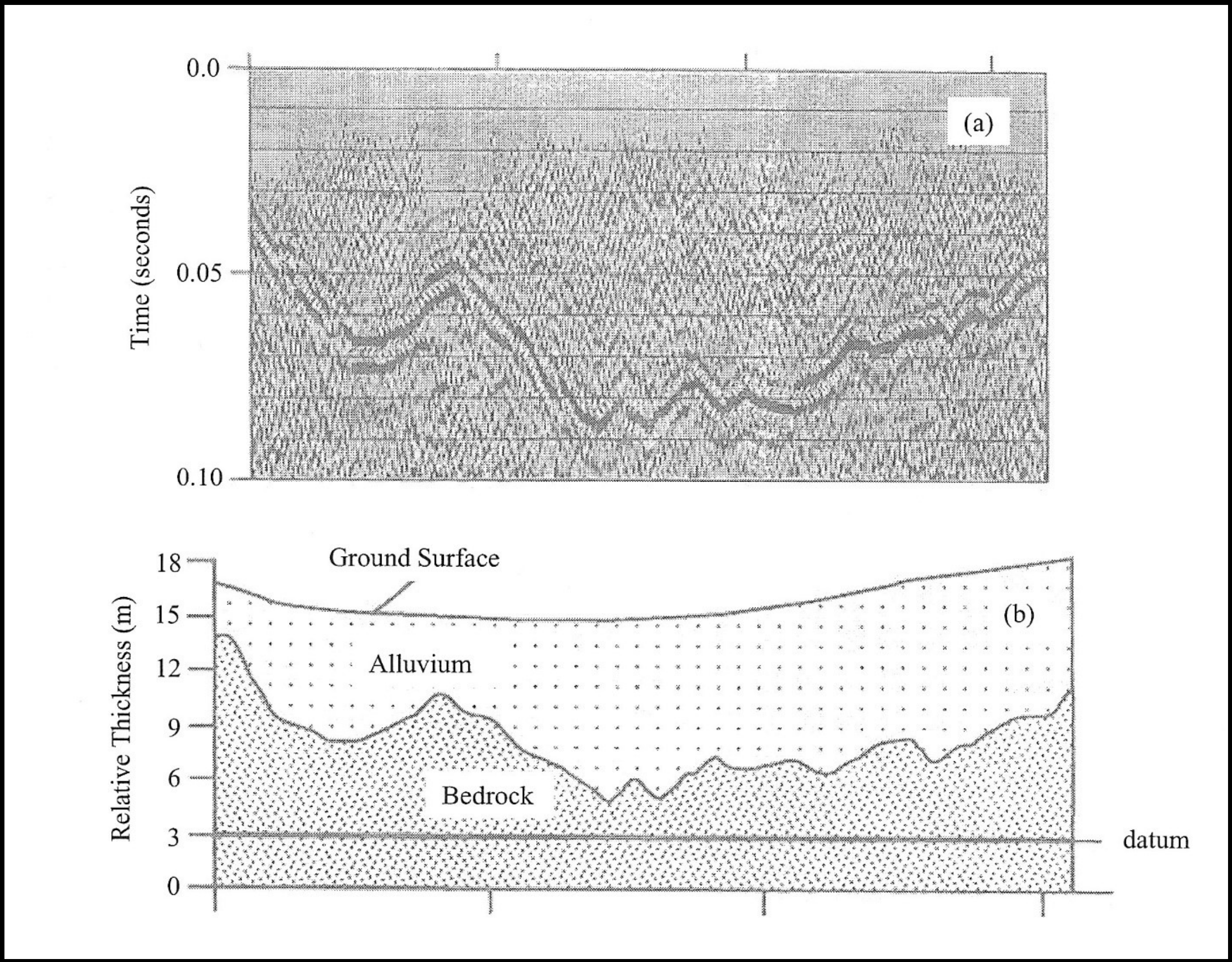
$$V = \Delta x / \Delta t$$

should take into account:

- The size of the receivers that are used to monitor wave motions should be much smaller than the wavelength
- Receivers should be at least two to four wavelengths away from the source

Seismic Reflection Test

- Useful for investigation of large-scale and/or very deep stratigraphy
- Many source and receiver locations must be used to produce meaningful images
- Interference between the reflected waves and surface waves requires careful signal processing and usually restrict the use of this method at shallow-depths

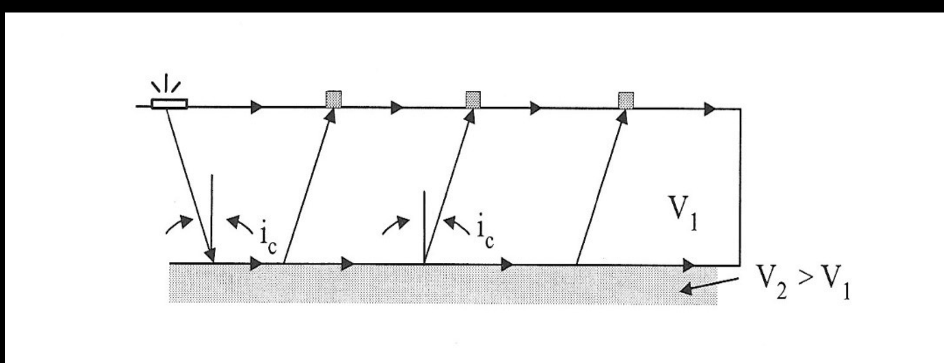


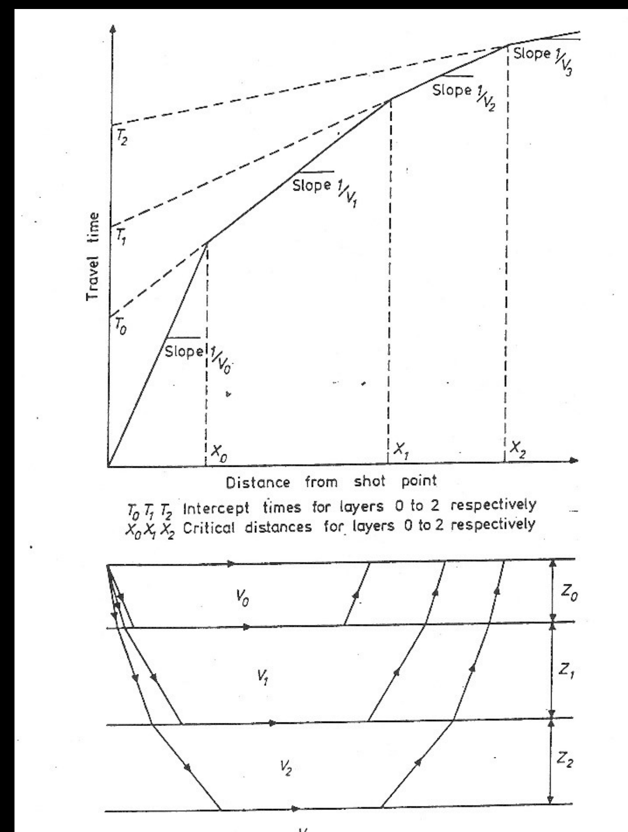
Seismic Refraction Test

An active source and a series of receivers are placed on the ground surface in a linear array

- Output of all receivers are recorded when the source is triggered
- Arrival times of the first waves to reach each receiver is determined and plotted as a function of source-receiver distance

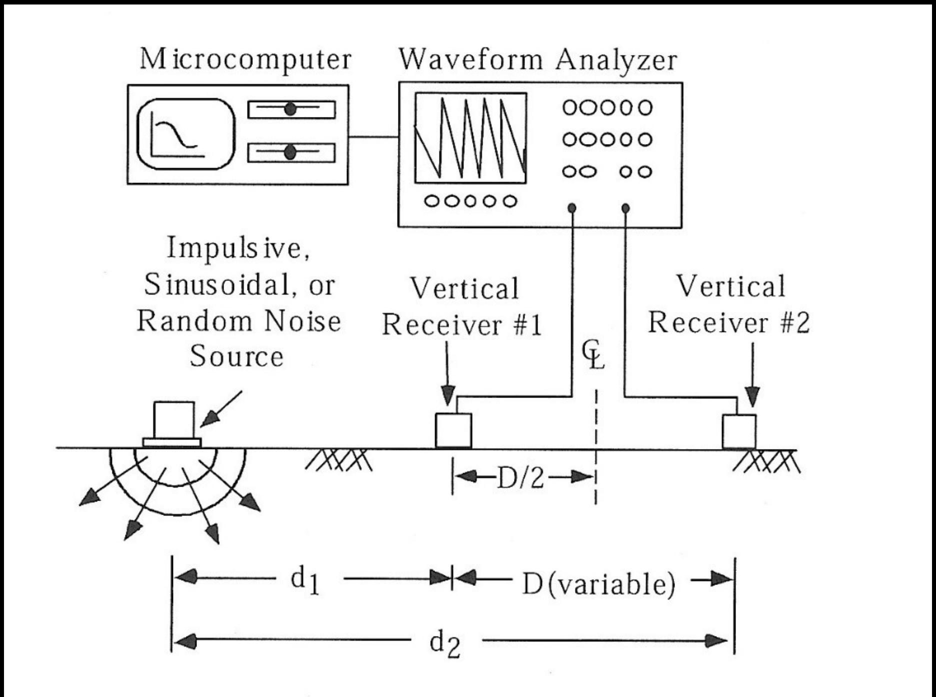
The method is based on the ability to detect the arrival of wave energy that is critically refracted (traveling parallel to the boundary) from a higher velocity layer which underlies lower velocity sediment.





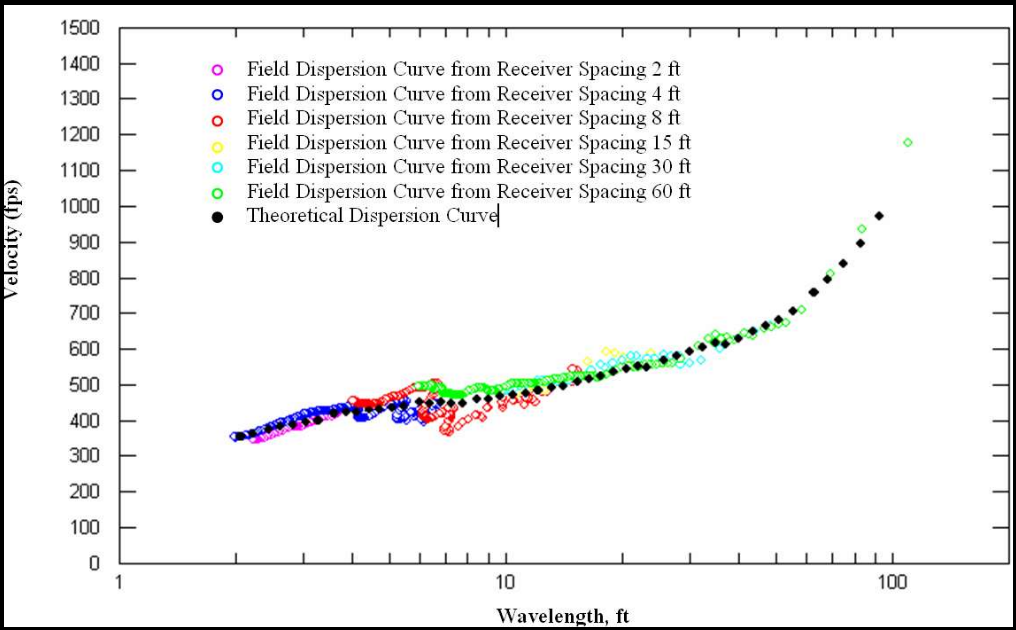
Spectral-Analysis-of-Surface-Waves-Test (SASW)

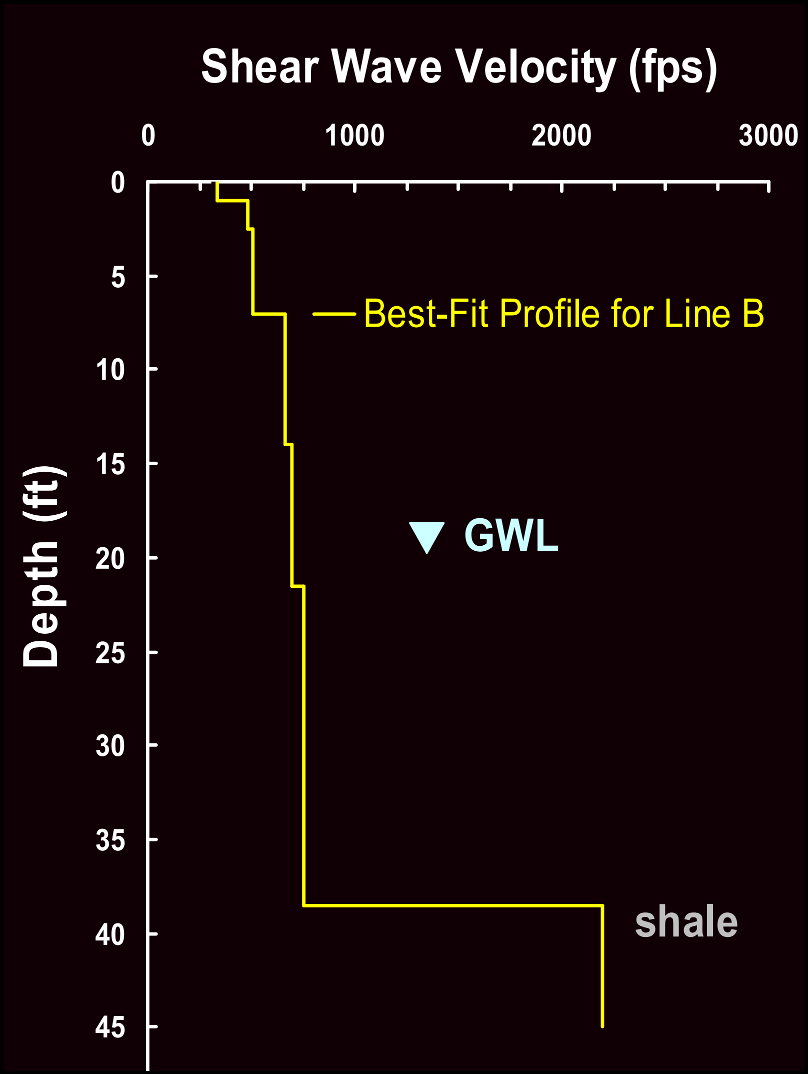
- Rayleigh wave energy is created at one point and resulting vertical surface motions at two or more measurement points (receiver points) away from the source are monitored.
- Measurements are performed at multiple source-receiver spacings along a linear array placed on the ground surface.



Spectral-Analysis-of-Surface-Waves-Test (SASW)

- Variation of V_R with different λ or f is called the 'dispersion curve'
- An initial estimate of the V_s profile is made and iteratively changed to match the theoretical dispersion curve with the experimental dispersion curve to obtain the best estimate for Vs profile





Spectral-Analysis-of-Surface-Waves-Test (SASW)

Advantages

- Quick and easy to perform
- Does not require drilling
- Can measure V_s profile up to 100 m depth

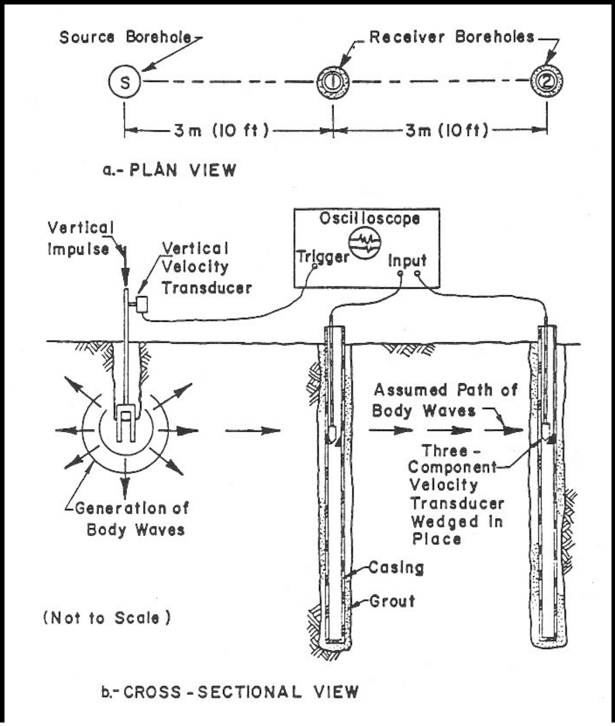
Limitations

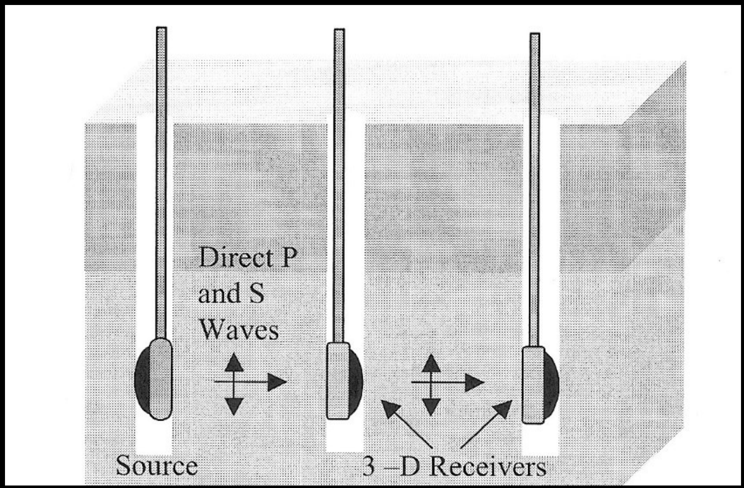
- Resolution decreases with depth
- Thin layers are hard to detect
- Provides 'global measurements'

  Determines averaged properties over the lateral measurement distance

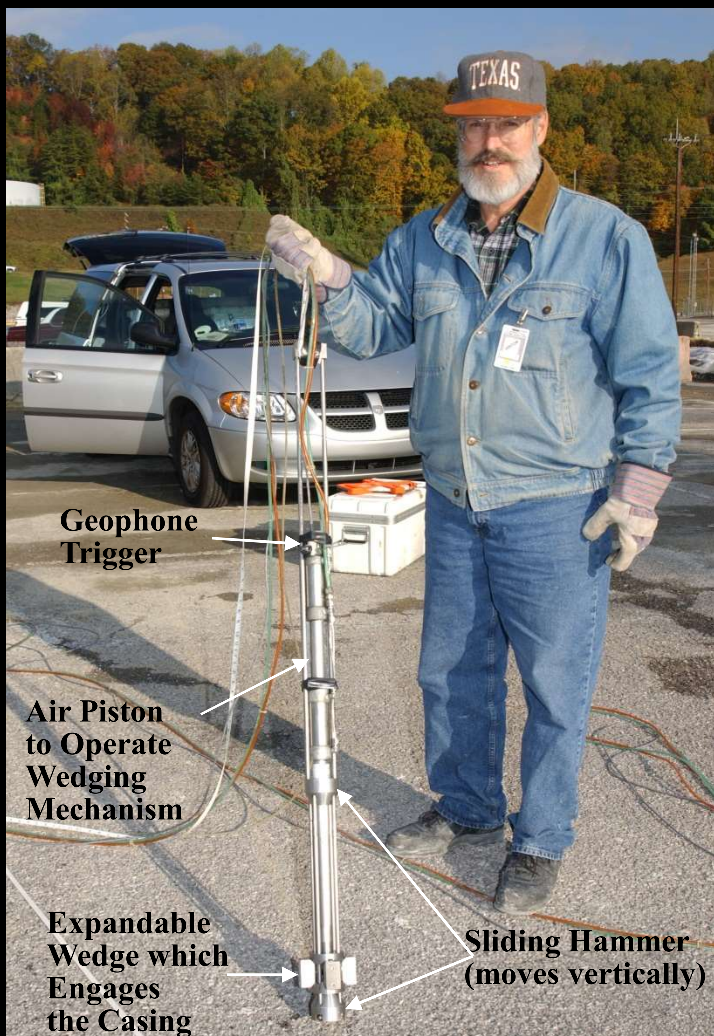
Crosshole Seismic Test (CST)

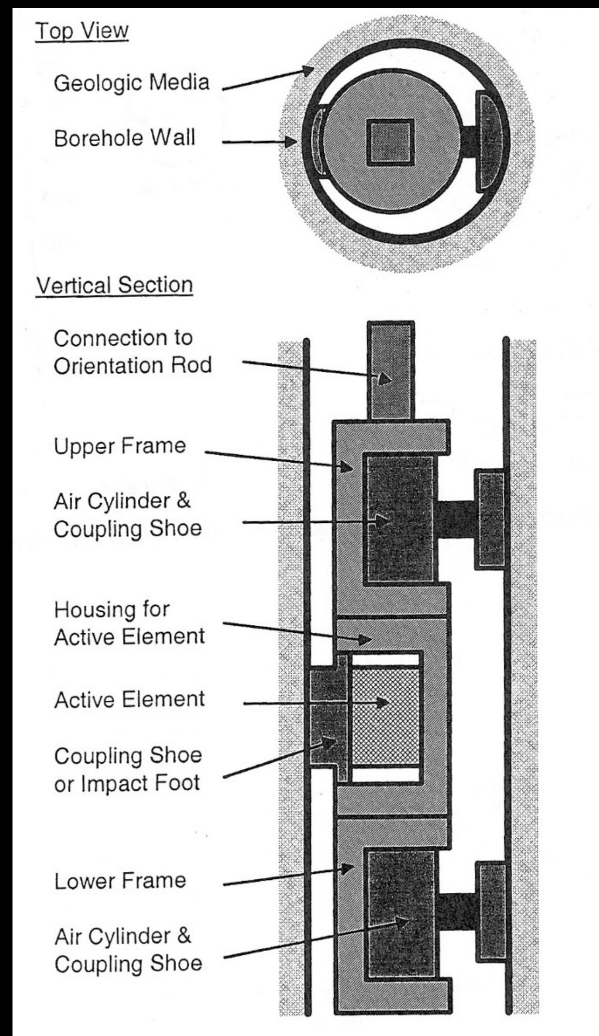
- Source and receivers are placed at the same depth in adjacent boreholes.
- P and S waves are generated using the source mechanism and waves propagating along horizontal path are measured at the receiver boreholes.
- Travel time from the source to receivers (direct travel time) and the travel time between the receivers (interval travel time) are measured.
- By testing at various depths variation of velocity with depth is obtained.





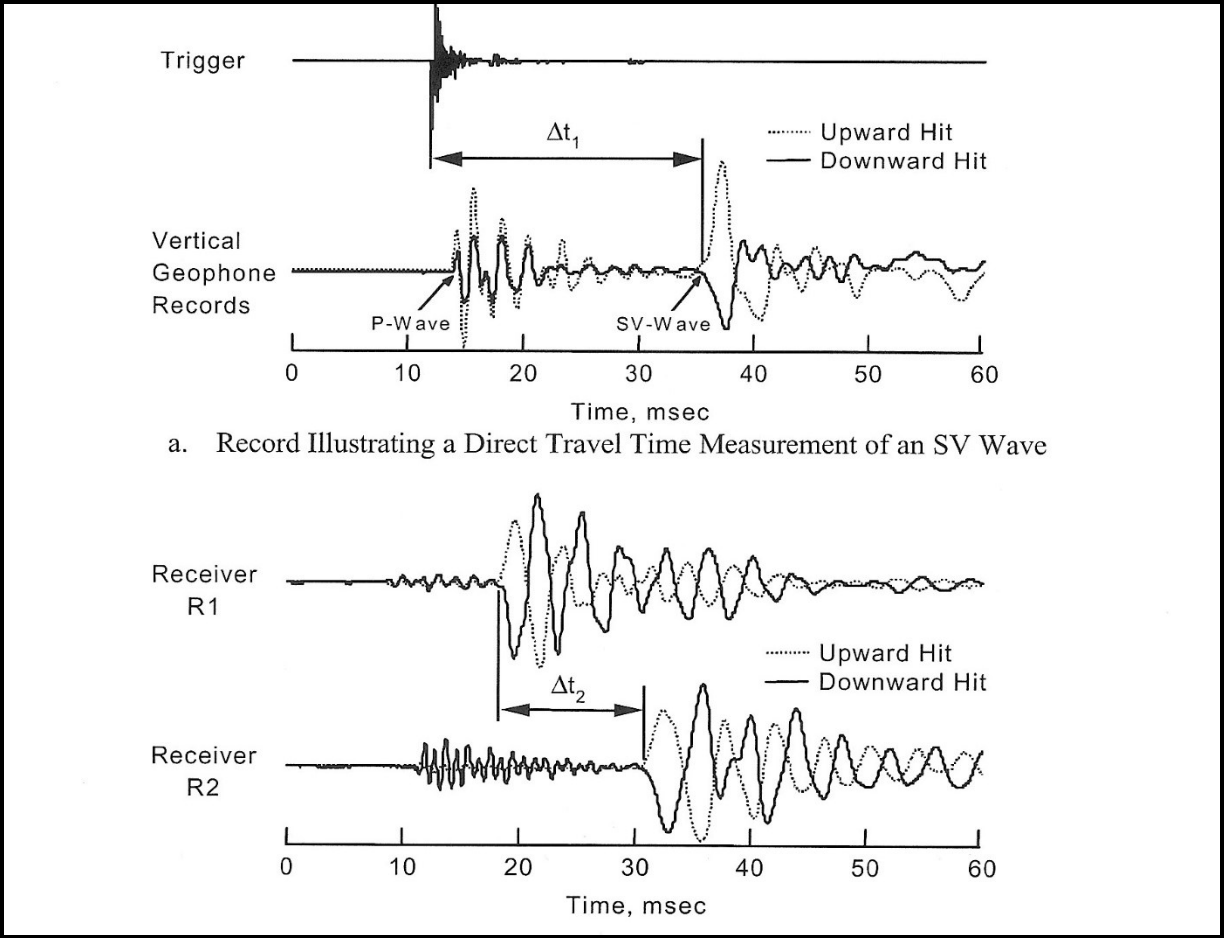
Crosshole Seismic Test (CST)





- A wedged source is used to generate P and S waves at depth inside the source borehole,
- The wedging mechanism operates with compressed air to lock the hammer against the casing in the borehole,
- A sliding hammer that moves vertically produces impulses of reversed polarity.

Crosshole Seismic Test (CST)



- **Wave propagation velocities** are calculated from difference in arrival times at adjacent pairs of boreholes
- **Arrival times** can be determined by eye using points of common phase (first arrival, first peak, first trough)

Crosshole Seismic Test (CST)

Advantages

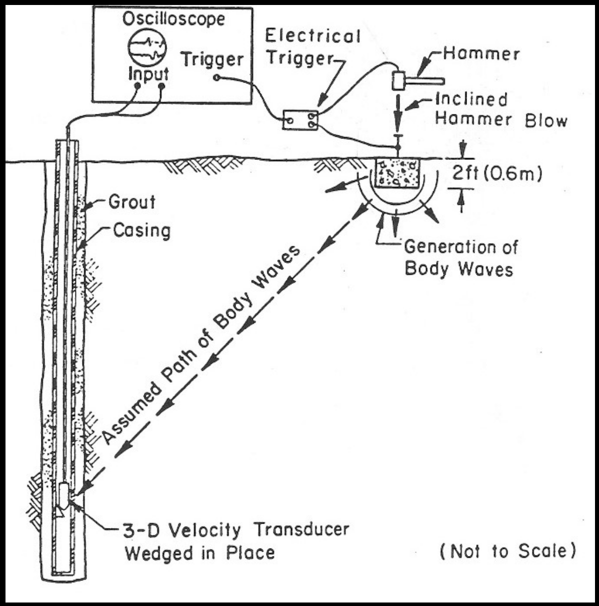
- Resolution is high since source and receivers are placed close to the material to be evaluated
- Direct measurement of wave velocities are performed
- Individual soil layers can be tested
- Can detect thin layers
- Reliable data up to 100 m

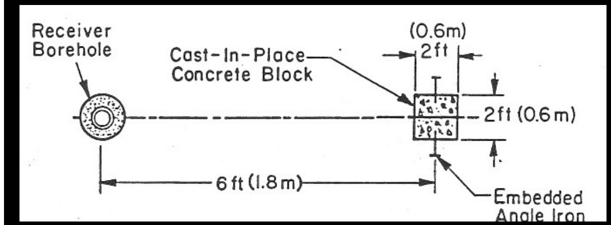
Limitations

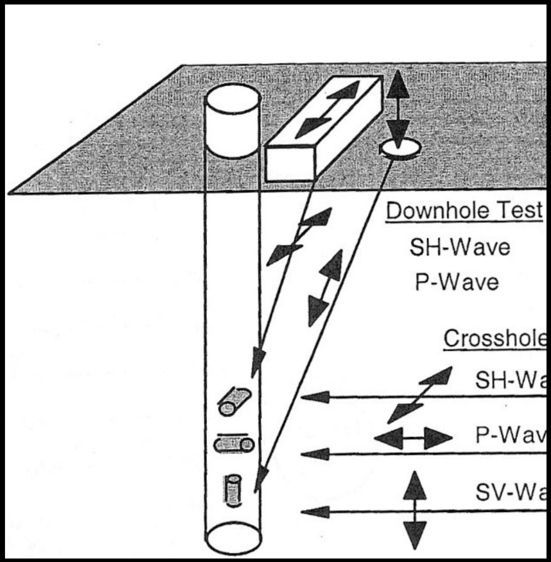
- Requires two or three boreholes, expensive and time consuming
- Requires vertical deviation survey for the boreholes
- Provides ‘local measurements’

Downhole Seismic Test (DST)

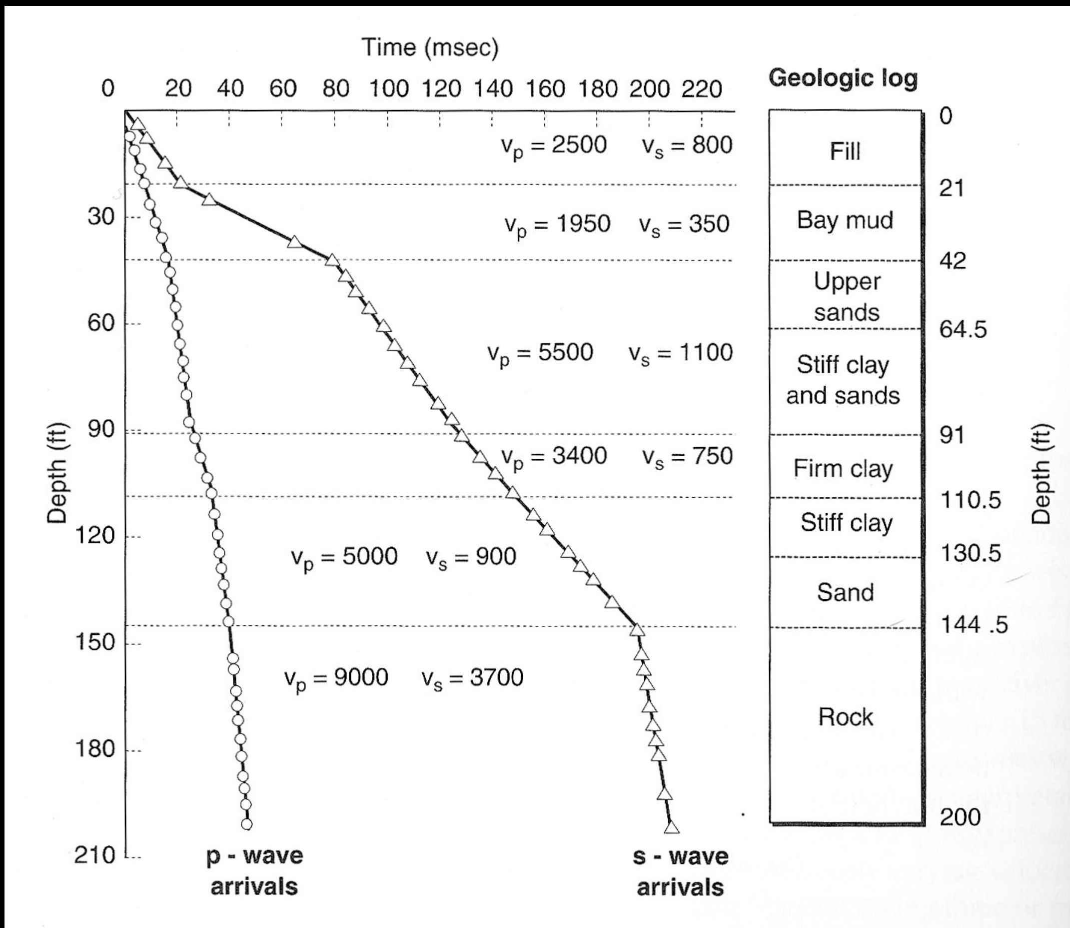
- An impulse source is located on the ground adjacent to a single borehole and one or more receivers are placed in the borehole.
- P and S waves are generated from the source on the surface and waves propagating along a direct path between the source and the receivers are measured .
- Travel time from the source to receivers (direct travel time) and the travel time between the receivers (interval travel time) are measured
- Travel distances are typically based on assuming straight ray paths between the source and the receivers.
- By testing at various depths variation of velocity with depth is obtained.







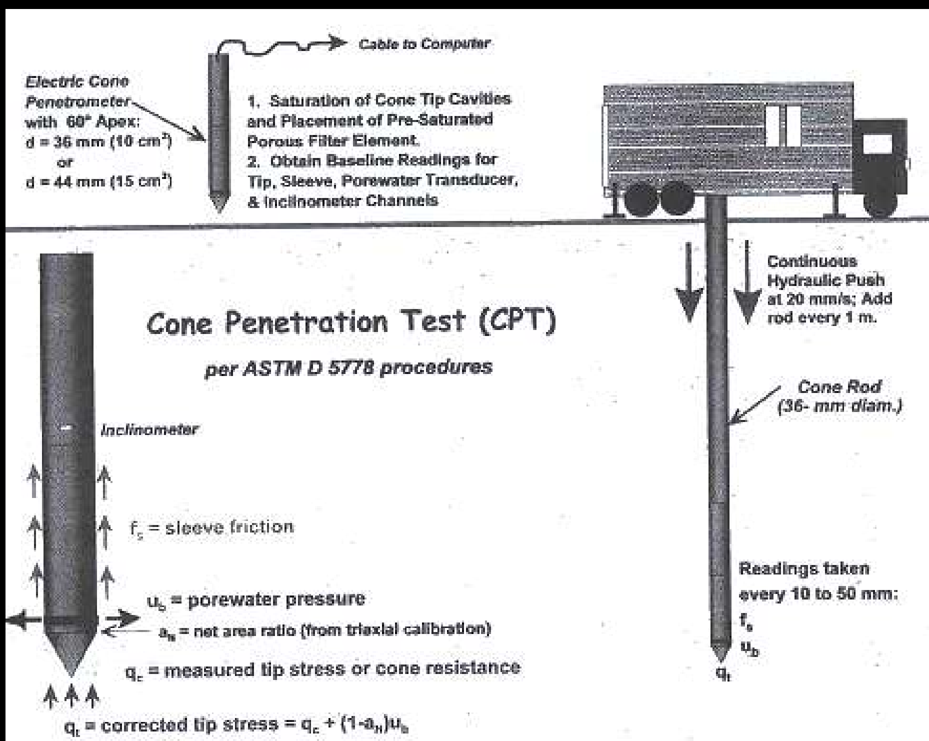
Downhole Seismic Test (DST)

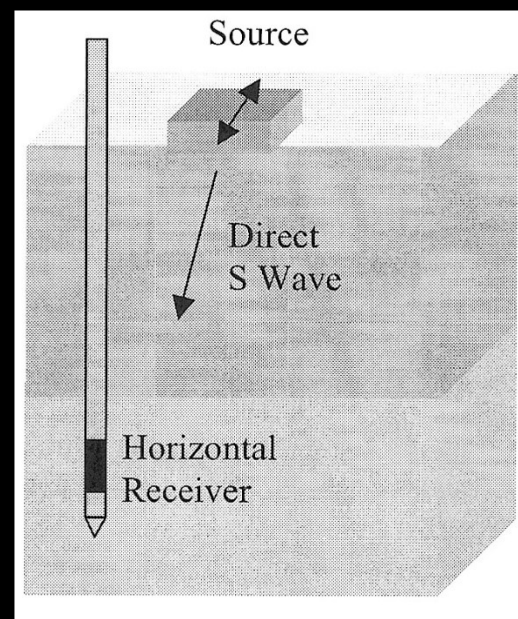


- A plot of **travel time with depth** can be generated using the **arrival times** identified on the waveforms recorded at various depths
- Slope of travel-time curve at any depth represents the **wave propagation velocity** at that depth

Seismic Cone Penetration Test (SCPT)

- A cone penetrometer that measures tip and side resistances on a probe pushed into the soil that allows measurement of shear wave velocitoes ina downhole testing arrangement.
- SH waves are generated at the surface near the insertion point of the cone by applying a horizontal impact on an embedded beam and travel times of the shear wave energy are measured at one or more locations above the cone tip. Travel time-depth curves can be generated and interpreted in the same way as for downhole tests.
- By testing at various depths variation of velocity with depth is obtained.





Downhole Seismic Test (DST)

Advantages

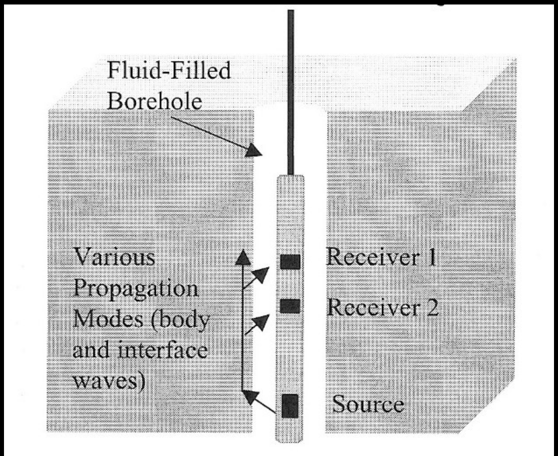
- Direct measurement of wave velocities are performed
- Reliable data up to 50 m
- Less expensive than CST *(requires one borehole)*

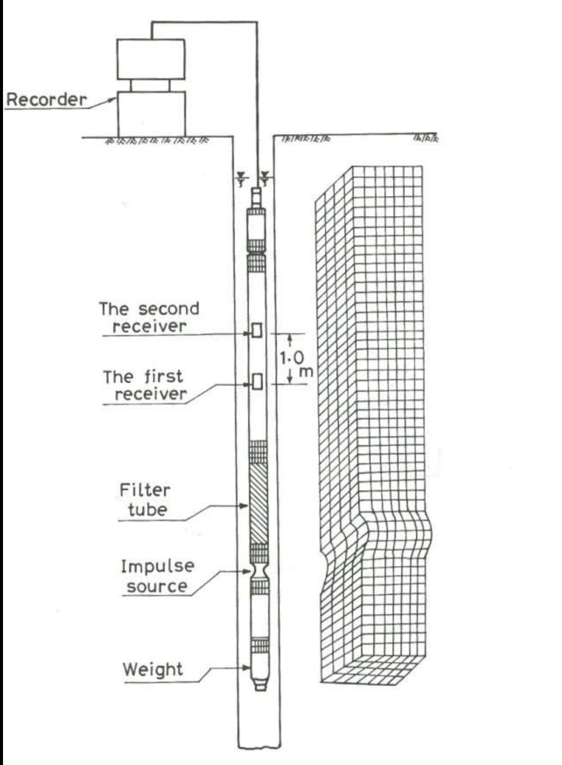
Limitations

- Energy that can be generated by the source on the ground surface limits the testing depth
- Provides 'local measurements'

PS-Logging Test

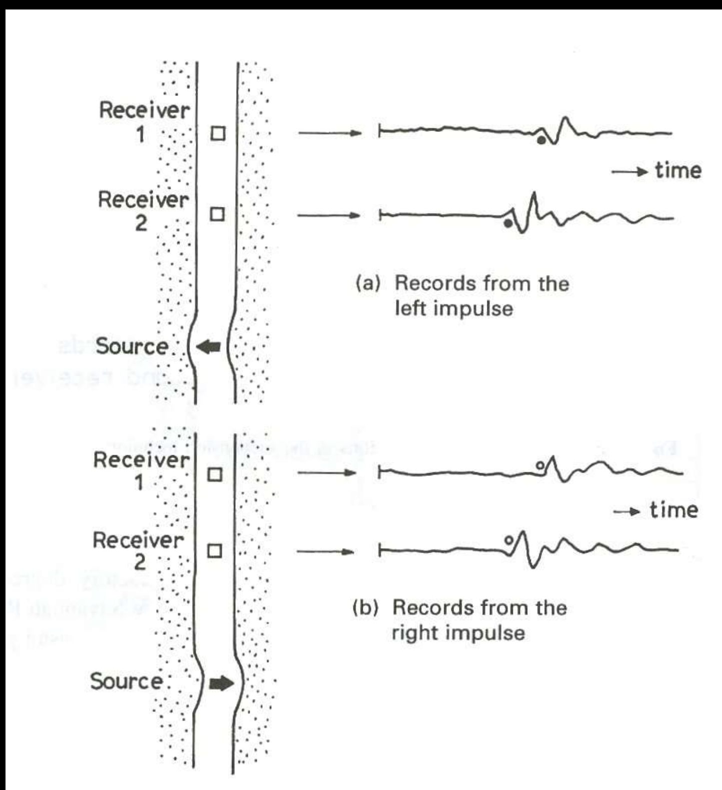
- Measurements are made in a single, cased/uncased fluid-filled borehole.
- An acoustic wave is generated in the borehole fluid by activating a solenoid source which is located at the end of the suspending probe.
- The impact of this wave on the borehole wall creates both P and S waves which travel radially away from the borehole. A portion of the wave energy travels along the soil as a head wave and transmits energy back into the fluid.
- These waves are detected with two 2-D geophones on the probe. The vertical and horizontal components of the geophone correspond to P- and S-wave energies, respectively.
- By testing at various depths variation of velocity with depth is obtained.





PS-Logging Test

- The travel time differences between horizontal and vertical receivers of the two 2-D geophones on the probe are used to calculate the interval S- and P-wave velocities, respectively, over the 1-m interval.
- The results of a suspension logging test consist of a Vs and a Vp profile, with data points as many as measurement intervals.



PS-Logging Test

Advantages

- Effective at greater depths (up to 1 km)
- Source travels with the receivers down the borehole

Limitations

- Frequencies generated by the source are too high (500to 2000Hz for S wave)
- Indirect measurement of S waves
- Can be significantly effected from grouting around the casing

Comparison of CST, DST and PS