FOUNDATION ENGINEERING

Application of Knowledge gained in

Geotechnical Engineering-I and II

Topics

- Introduction to Geotechnical Engineering
- Review of site characterization/soil exploration
- **Introduction to Foundation Engineering**

Definitions, purpose and types of foundations, general requirements of foundations, depth of footings, selection of foundation types, foundation design criteria

- **Geotechnical Design of Shallow Foundations**

Evaluation of BC, Proportioning of footings, Typical design problems

- **Geotechnical Design of Deep Foundations**

Introduction to deep foundations. Types of piles, load carrying capacity of piles, Group action, negative skin friction, pile load test, Foundation construction

- **Foundations on Difficult soils: Expansive soils, Collapsible soil, Sanitary fills etc.**

BOOKS

- Elements of Soil Mechanics (7th Ed.) by G. N. Smith and Ian G. N. Smith
- Foundation Design (2nd Ed.) by Donald P. Coduto
- Foundation Engineering by B. M. Das
- Foundations (Analysis and Design) (5th Ed.) by JOSEPH E. BOWLES
- Foundation Design and Construction by M. J. Tomlinson
- Practical Foundation Engineering: Handbook by ROBERT WADE BROWN

- **Foundation**

  Bottom most part of the structure which carries the load of the structure including its own weight and transmits it to the underlying / surrounding soil and /or rock safely.

- **Foundation Engineering** (deals with sub-structures)

  An art that deals with (i) determining the ability of the earth to support the load (ii) designing the proper transition member to transmit the super-structure load into the ground safely.

- **Purpose of the Foundation**

  The enlarged base area of the column/wall (i.e. footing) reduces the contact pressure between the footing and soil. This prevents excessive settlement and shear failure (BC failure).

- **Basic Foundation Types**
- Shallow $D_f/B \leq 1$ (after Terzaghi)

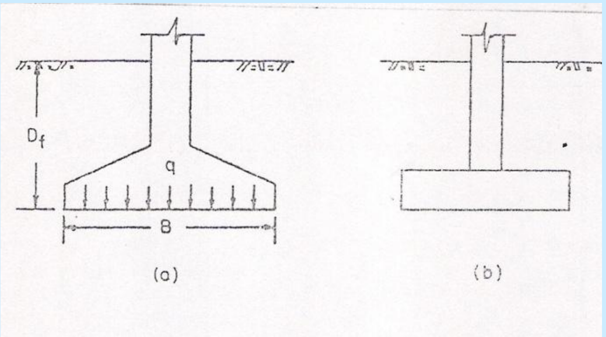
  Generally $D_f \leq 3$ m
- Deep $D_f/B > 4+$ or depth > 3 m

TYPES OF FOUNDATION

1) Shallow Foundation System

a) Spread Foundation

b) Mat / Raft Foundation

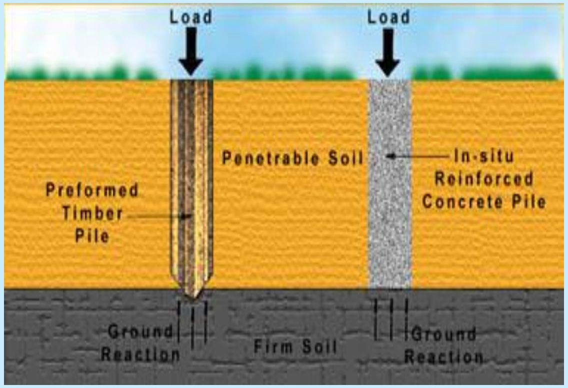


2) Deep Foundation System

a) Piles

b) Piers

c) Caissons



Typical Geotechnical Engineering Issues

- **Determination of stress in the soil at a given depth. What is the safe stress that ground can safely bear? Bearing Capacity Issue**

- **How much settlement under Structures and how long will it take for this settlement to occur? Settlement Estimation**
- **Evaluation of Suitability of Construction and/or Foundation material**
- **Effects of ground water table on ground capacity**

- **Effects of volume change of foundation soil.** (Expansive soil, Collapsible soil)
- **Site Characterization, i.e., Soil exploration**

Types of failure in soil

- **<u>Foundation soil failures</u>, (Bearing capacity failure and excessive settlement)**
- **Pavement Failures, bumpy roads resulting from differential settlement within a fill or at the junction of a cut and fill, pavement cracking, rutting etc.**
- Embankment failure, which may be slope (landslide) failure or excessive settlement in the foundation soil or within the fill itself.
- Embankment / Dam failure the form of slope sliding or due to excessive leakage (piping).

Job of Geotechnical Engineer

- To predict the soil behavior under the application of imposed loading, i.e., the stress ~ strain behavior

  (Bearing Capacity Evaluation)

- To design the structures according to the prevailing soil conditions or improve the soil conditions for a particular structure to be built (Soil Stabilization).

How to Predict?

- By conducting soil investigation which may include field testing and soil sampling
- Evaluation of soil properties both physical and engineering through detailed laboratory testing
- By performing various geotechnical analyses in order to determine the safety margin to failure, i.e., factor of safety against impending failures.

Reliability in Geotechnical Prediction

Prediction of soil response to load application may not be very accurate or reliable as compared with other material like steel or concrete because:

- Soil is heterogeneous material, not uniform in properties like steel or concrete
- The extent of soil mass involved in the construction process is too large and relying on testing limit extent may not be sufficient or accurate
- Less control over environmental agents. Less control over moisture change in the soil mass, temperature variation etc.

What to do?

To design/construct safe structures:

- Try to assess the soil behavior accurately as it can be within the available resources and design accordingly.

- By incorporating the experience and judgment of experienced geotechnical engineers keeping in mind the local environmental and site conditions.

- Ensuring suitable safety factor (relatively higher in geotechnical engineering).

Introduction to Soil and Rock

- Soil: Unconsolidated agglomerate of minerals above solid Rock
- Rock: Hard and durable material that can not be excavated without blasting

Difference between Rock and Soil

- Rocks are generally cemented; soils are rarely cemented
- Rocks usually have much lower porosity than soils

- Rocks are more susceptible to weathering than soils.
- Rocks are often discontinuous; soil masses usually can be represented as continuous.
- Rocks have more complex and unknowable stress history than soils.
- In many rocks, minor principal stress is vertical but in most soils, this is horizontal.
- Stability of rock mass is controlled by the strength of discontinuities while in soil, the strength of soil is applicable.

Why main focus is on the soil?

- Geotechnical Investigations cover studies of soils as well as rocks. In civil engineering construction, mostly more emphasis is given on soil than rocks.
- Generally we construct more on soils than rocks, also rocks have more bearing capacity.
- For large projects like dams, rocks needs more investigation as they are more complex.

Formation of Soil

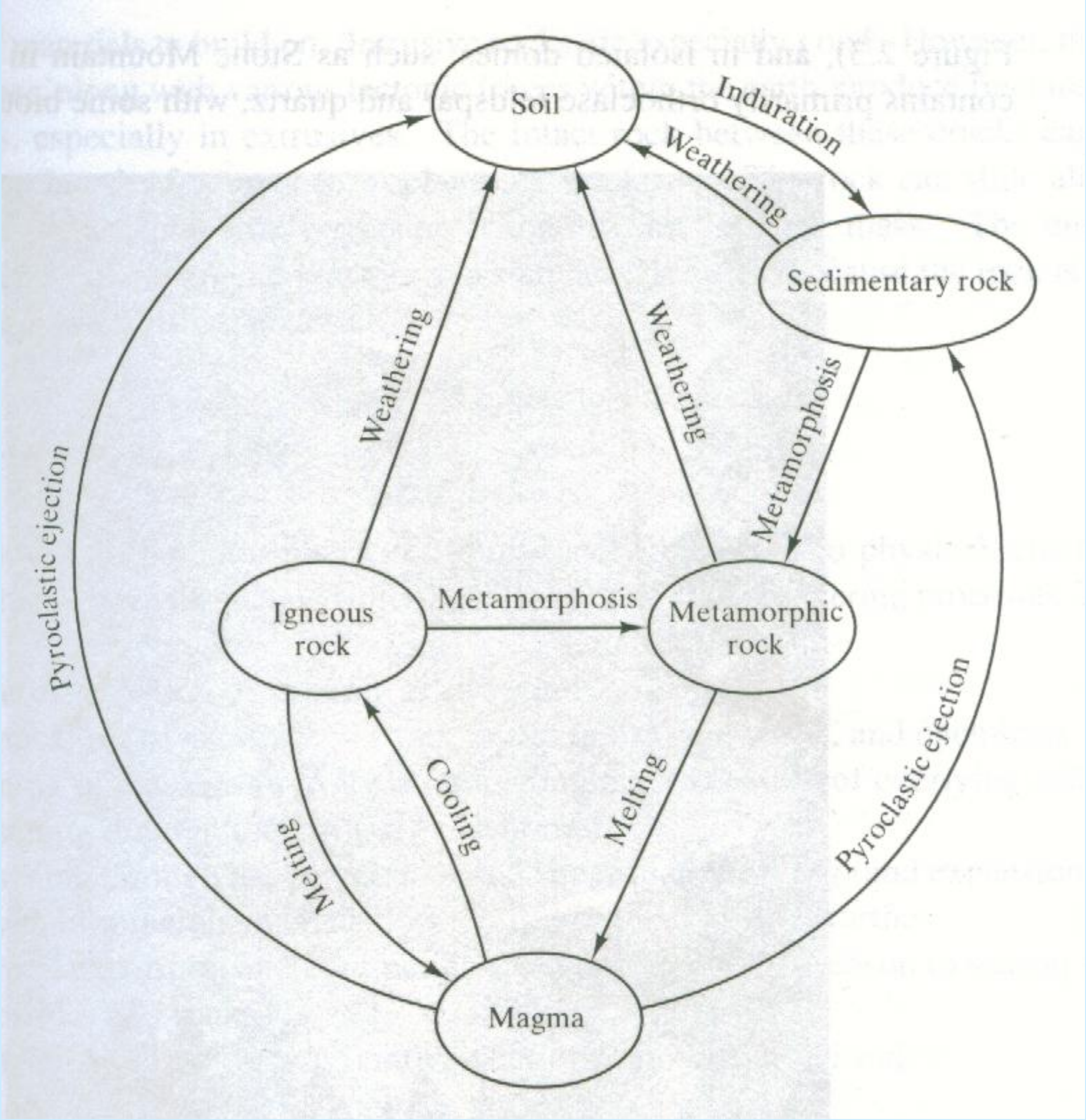
- Soil is formed as a result of weathering of rocks.

- Weathering: It is a process whereby an intact rock mass is decomposed or disintegrated by atmospheric agents.

    - » Physical or Mechanical weathering agents
    - » Chemical weathering agents

Rock-Soil Cycle

- Weathering of all three kinds of rocks form soils.
- Pressure and cementation of sediments (soil) forms sedimentary rock
- Pressure, heat and solution of both igneous and sedimentary rock forms Metamorphic rocks
- Melting of rocks forms Magma. Cooling of Magma forms igneous and pyroclastic soils



Mechanical Weathering Agents

- Temperature changes
- Freezing and thawing (vol. of frozen water increases by 9%)
- Erosion/abrasion by flowing water, wind and ice
- Natural disasters, e.g. earthquakes, landslides etc.
- Activities by plants and animal including men

-- Soil formed by mechanical weathering retains the minerals and material fiber of parent rock.

(Coarse-grained soils such as gravels, sands and their mixtures)

Chemical Weathering agents

-- Chemical weathering results from reactions of rock minerals with oxygen, water, acids, salts etc. The various chemical weathering processes are

» Oxidation
» Carbonation
» Hydration
» Leaching
» Solution

Soil Deposits

- Residual soils
- Transposed soils
    - » Alluvial or fluvial or Alluvium
    - » Aeolian soil deposits
    - » Glacial soil deposits
    - » Colluvial or colluvium
- Organic soils
- Marine soils
- Pyroclastic soils

Alluvial Deposits

- Meander Belt Deposits

Stream with winding Course

- Point par
- Natural levee
- Flood plain or backswamp deposit (highly plastic clay)
- Channel fill

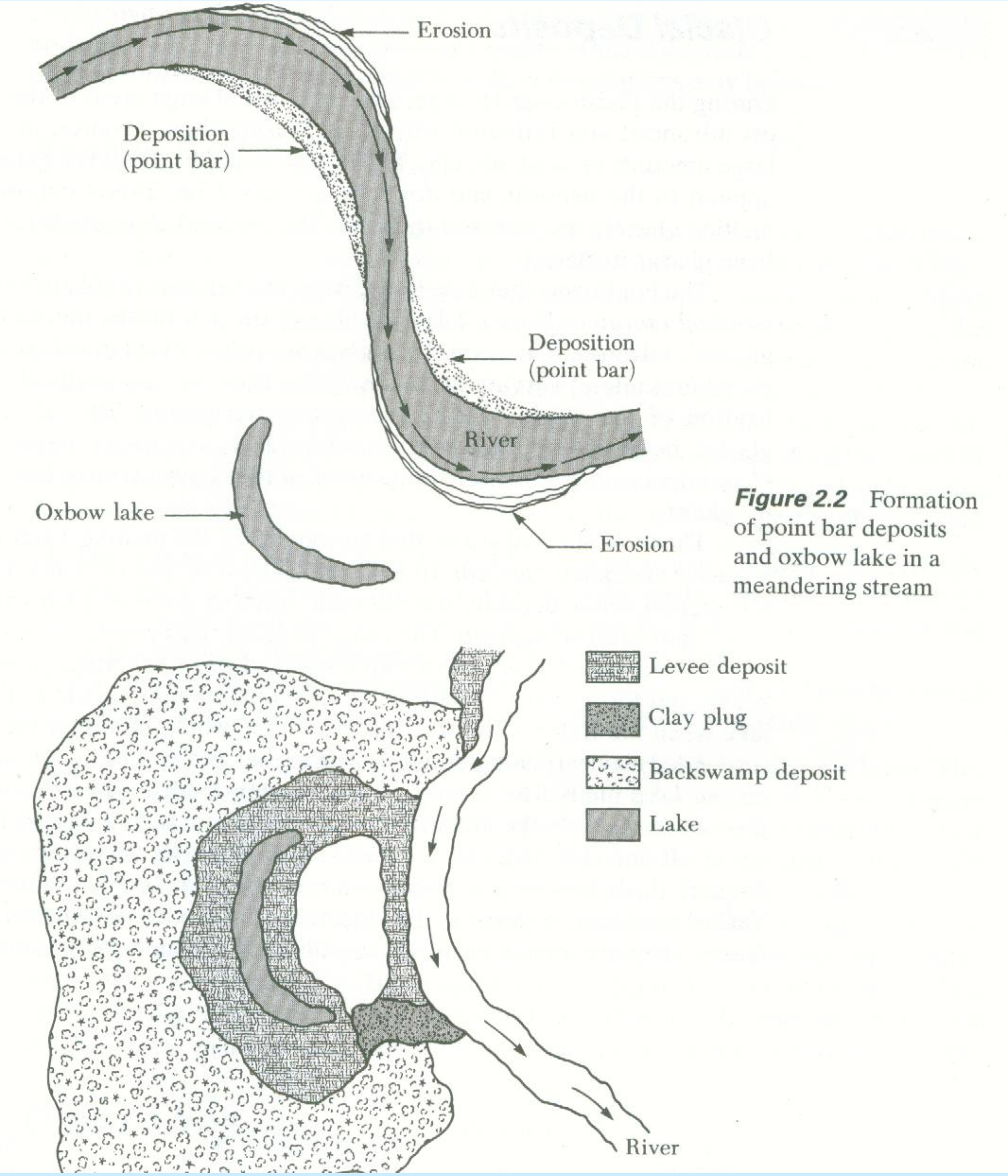


Figure 2.2 Formation of point bar deposits and oxbow lake in a meandering stream

Alluvial Deposits

- Alluvial Terrace deposits

  Relatively narrow, flat-surfaced, river flanking remnant of flood plain deposits formed by entrenchment of river

- Alluvial fans

  When a river channel widens significantly or its slope decreases substantially, coarse soil particles settle forming submerged, flat, triangular deposits known as Alluvial Fans

- Delta Deposit: soil deposited at mouth of river or stream entering a lake or reservoir.

Aeolian Deposits

Soils transported and deposited by wind action; two types of soils are famous.

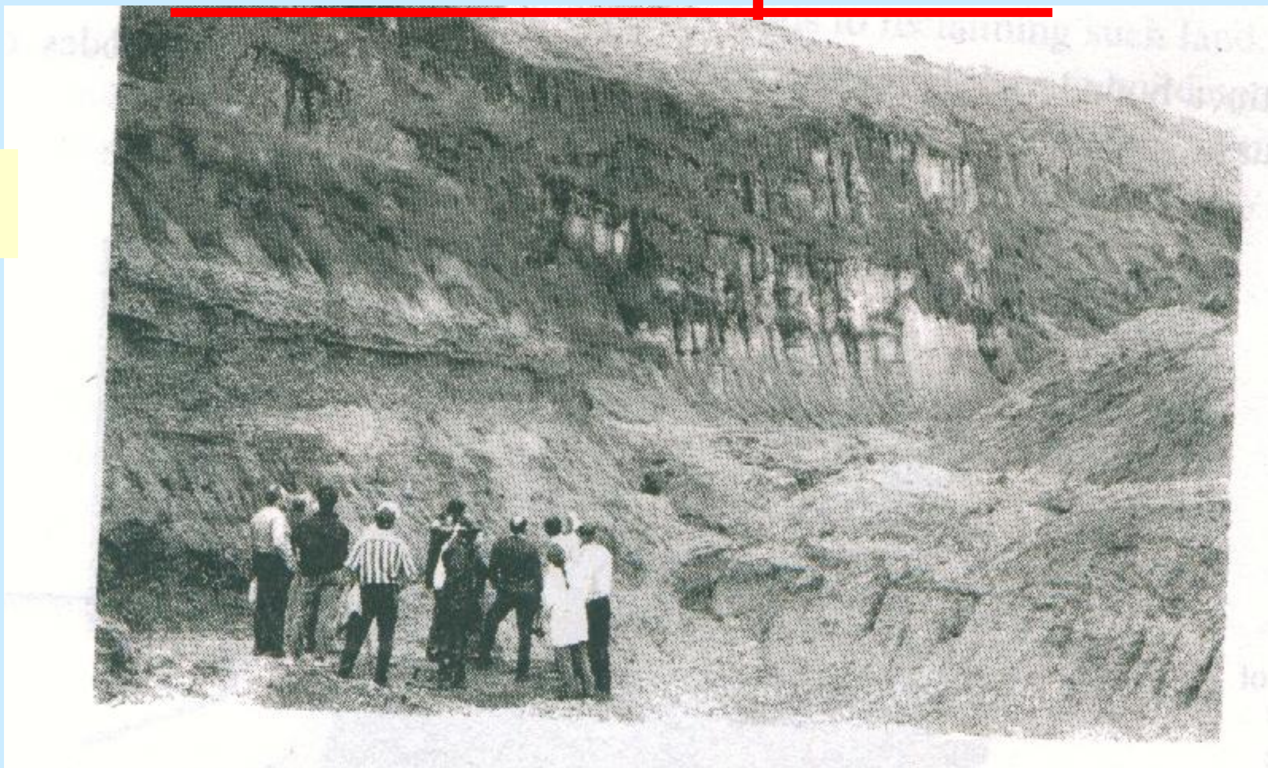
- Loess: is a soil consisting of silt and silt-size particles. The grain size tends to be uniform. Cohesion is developed by clay coating or by chemical leached by rainwater. Loess is quite stable under unsaturated condition. It is collapsible upon saturation.
- Sand Dune: Mounds ridges of uniform fine sand. They are formed when the sand is blown over the crest of the dune by wind action. Sand dunes have the properties:

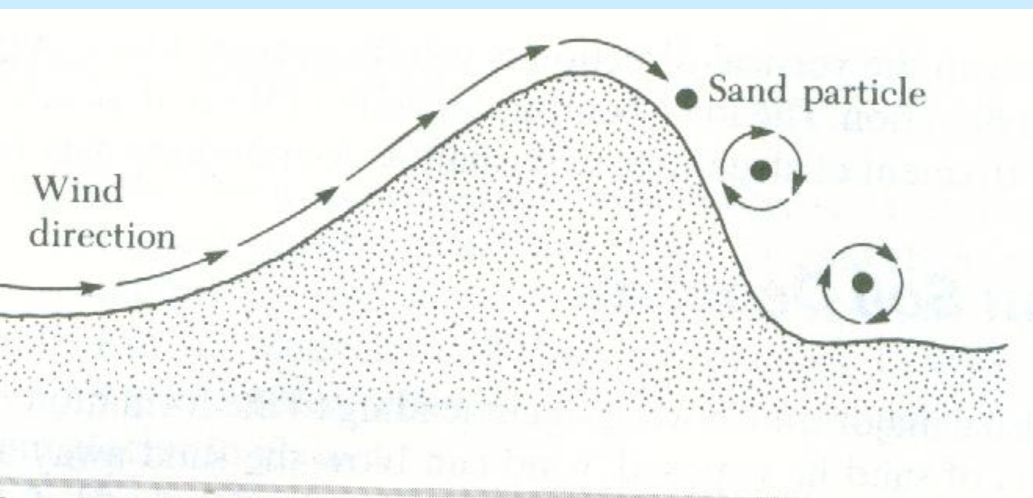
Uniform in grain size

Relative density on windward side is more than leeward side

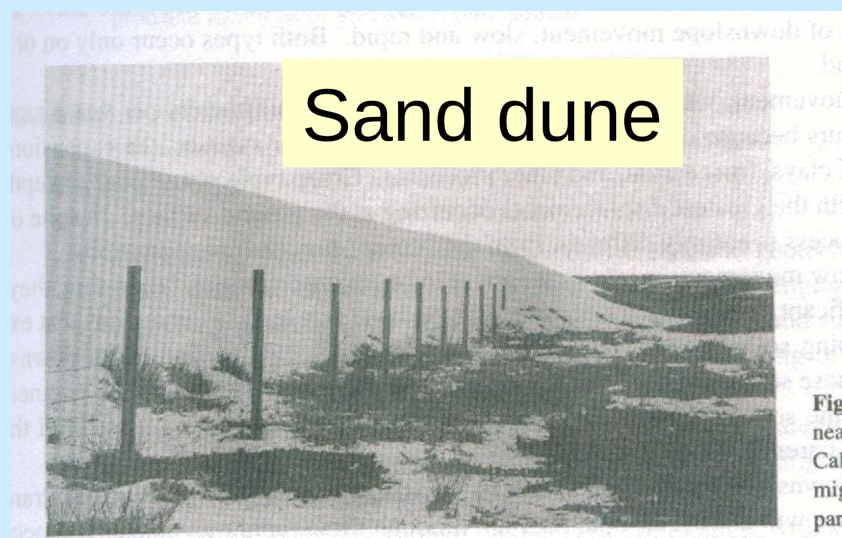
Aeolian Deposits

Loess





Sand dune



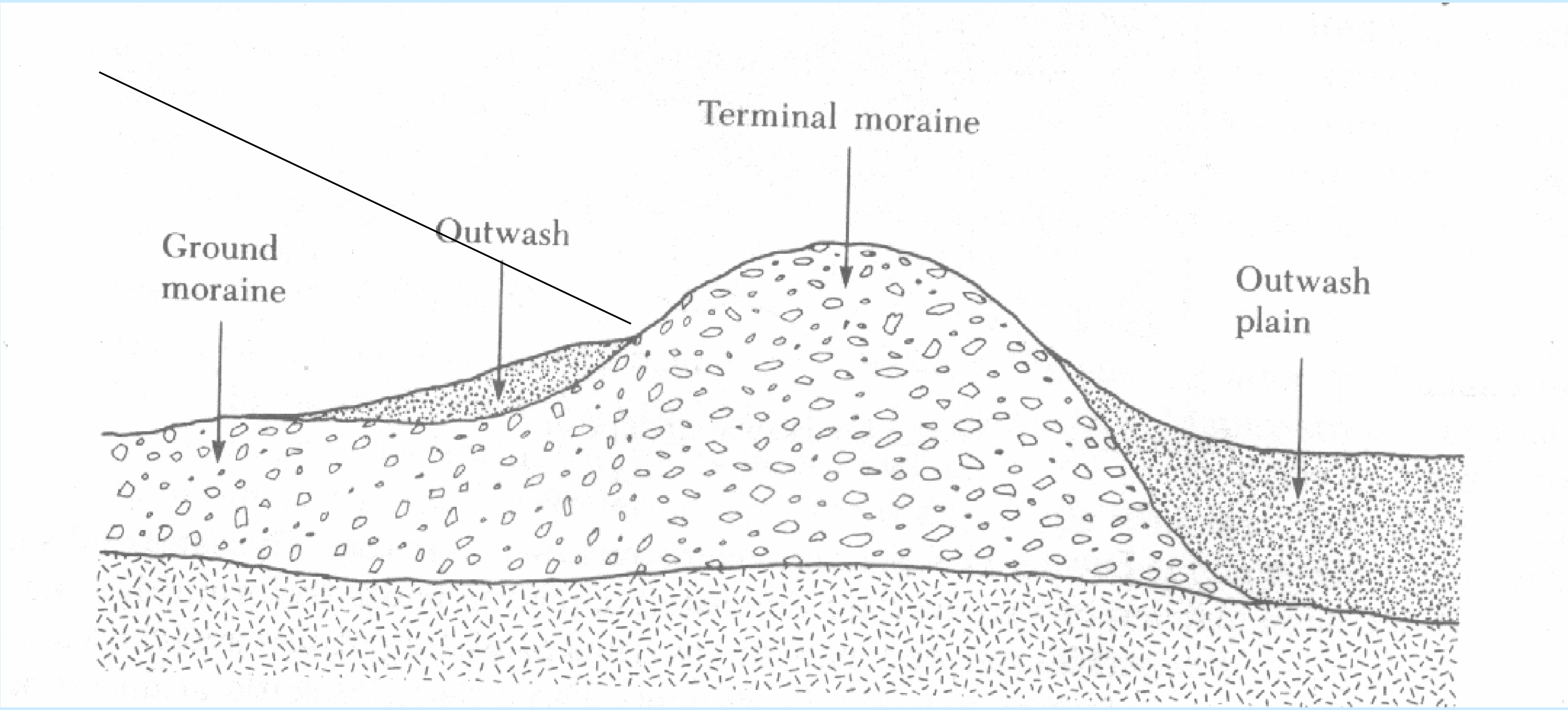
Glacial Deposits

They are transported and deposited by the movements of glaciers.

The general name is glacial till or Moraines.

- Terminal moraine (Ablation till)
- Ground Moraine or lodgments till (hard pan)
- Lateral Moraine
- Glaciofluvial deposit or out wash
- Glacio-lacustrine deposit (varved clay)

Glacial Deposits



Colluvial Deposits

Soils transported and deposited by the action of gravity.

- Talus: formed by gradual accumulation of unsorted rock fragments and debris at the base of cliffs
- Hill Wash:

  Fine colluvial consisting of clayey sand, sand silt or clay washed from top hills
- Landslide deposit:

  Large mass of soil or rock which have stepped down as a unit

Organic Soil Deposits

Formed by in-place growth and subsequent decay of animal and plant life

Peat: A fibrous aggregate of decaying vegetation matter with dark color and bad odour.

Muck:

Peat with advanced stage of decomposition.

Properties:

- NMC may range 200 to 300%
- Highly compressible
- Likely to undergo secondary consolidation
- Not suitable for engineering purposes.

Marine Deposits

Material transported and deposited by ocean waves and currents in shore and offshore areas:

- Shore deposits: deposits of sand and/or gravel by waves on the shoreline
- Marine clays: Organic and inorganic deposit of fine-grained soil at the bed of sea or lake.

Pyroclastic Soil Deposits

Materials ejected from volcanoes and transported by wind, air, gravity etc.

- Volcanic ash:

Lava thrown in air and subsequent cooling

- Pumice: is rock form by cooling of lava flow on earth surface during volcanic eruption.

(very porous, light weight material)

Some Typical Soil Names

- Loam: mixture of sand, silt and clay
- Mud: a pasty mixture of soil and organic matter
- Conglomerate: cemented sand and gravel mixture.
- Marl: Clay with calcareous material
- Boulder clay: clays containing wide range of particle sizes varying from boulder to very fine
- Bentonite: clays with main mineral of montmorillonite formed by chemical weathering of volcanic ash
- Black cotton soils: Highly expansive and compressible clays of dark to black color commonly found in India

CLASSIFICATION OF SOIL

Classification tests include:

- Grain size analysis

(Sieve Analysis +Hydrometer Analysis)

- Atterberg Limits (LL and PL)
- Specific Gravity of Soil Solids

Soil Classification as per

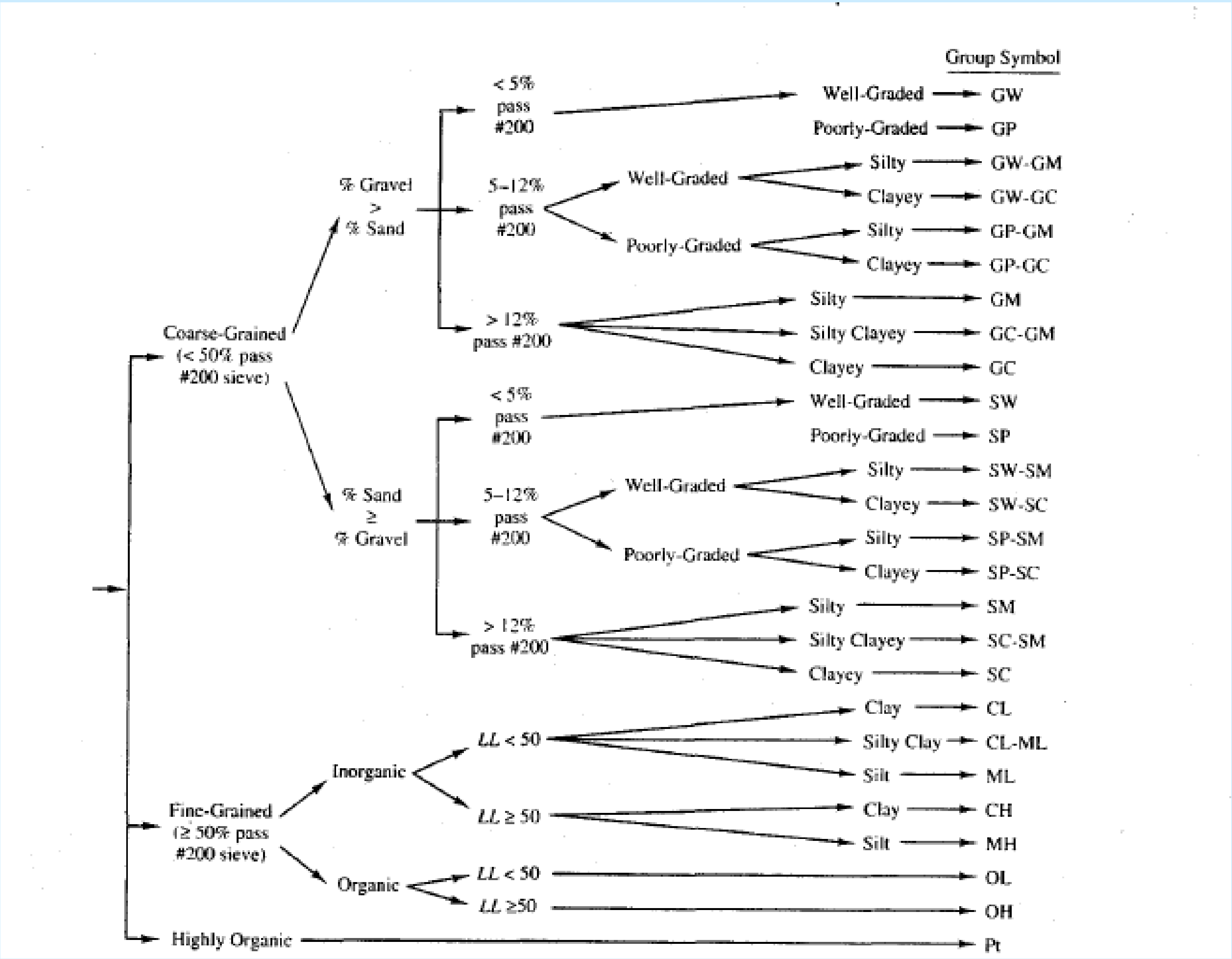
- USCS (generally for foundation design)
- AASHTO (generally for pavements)

Textural Classification by ASTM

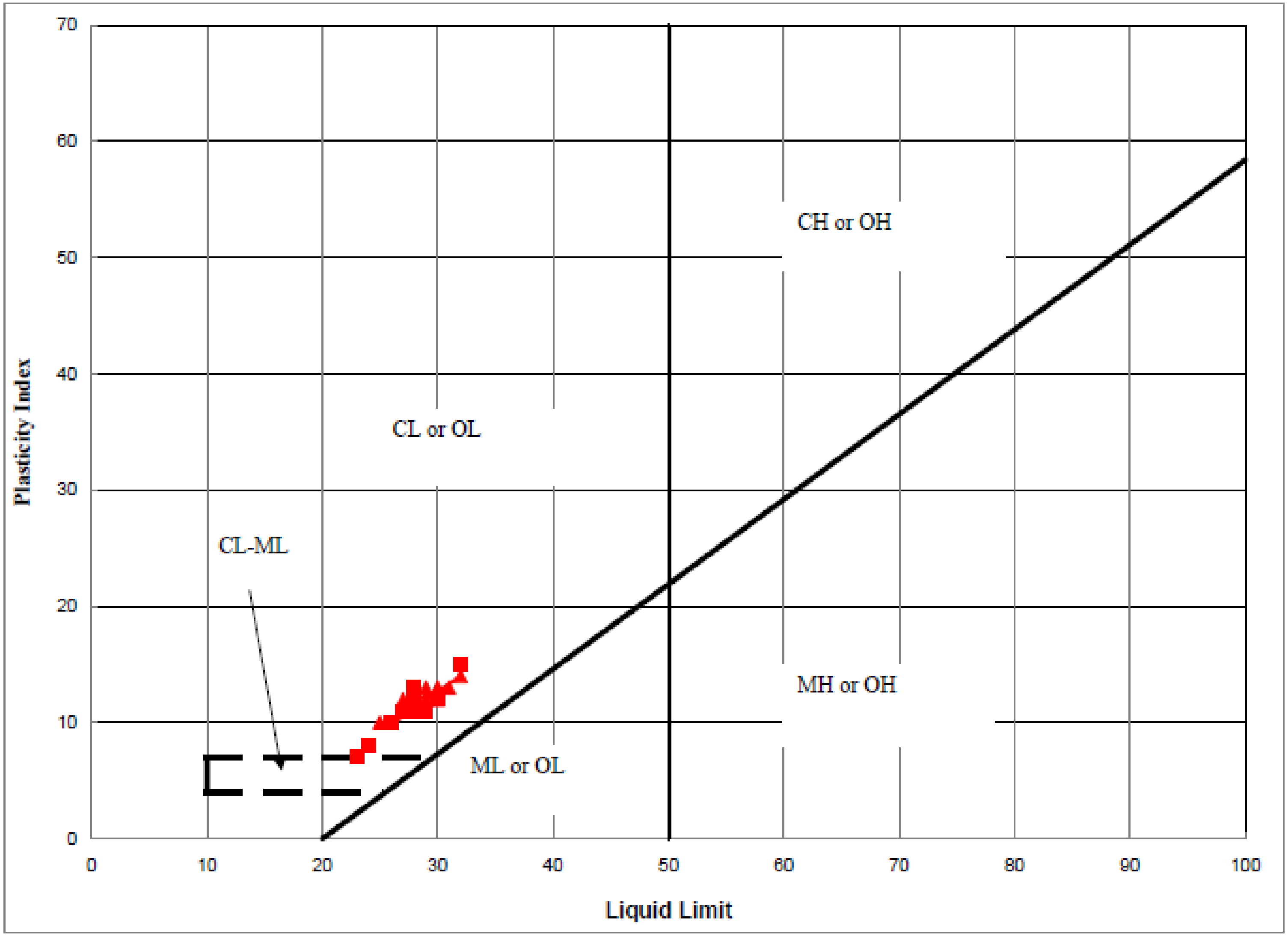
TABLE 3.4 ASTM PARTICLE SIZE CLASSIFICATION (Per ASTM D2487)

Sieve Size		Particle Diameter		Soil Classification	
Passes	Retained on	(in)	(mm)		
	12 in	> 12	> 350	Boulder	Rock
12 in	3 in	3–12	75.0–350	Cobble	Fragments
3 in	3/4 in	0.75–3	19.0–75.0	Coarse gravel	
3/4 in	#4	0.19–0.75	4.75–19.0	Fine gravel	
#4	#10	0.079–0.19	2.00–4.75	Coarse sand	Soil
#10	#40	0.016–0.079	0.425–2.00	Medium sand	
#40	#200	0.0029–0.016	0.075–0.425	Fine sand	
#200		< 0.0029	< 0.075	Fines (silt + clay)	

Unified Soil Classification System (USCS)



A-Line chart for classification of fine grained soil



Consistency of Fine Grained Soil

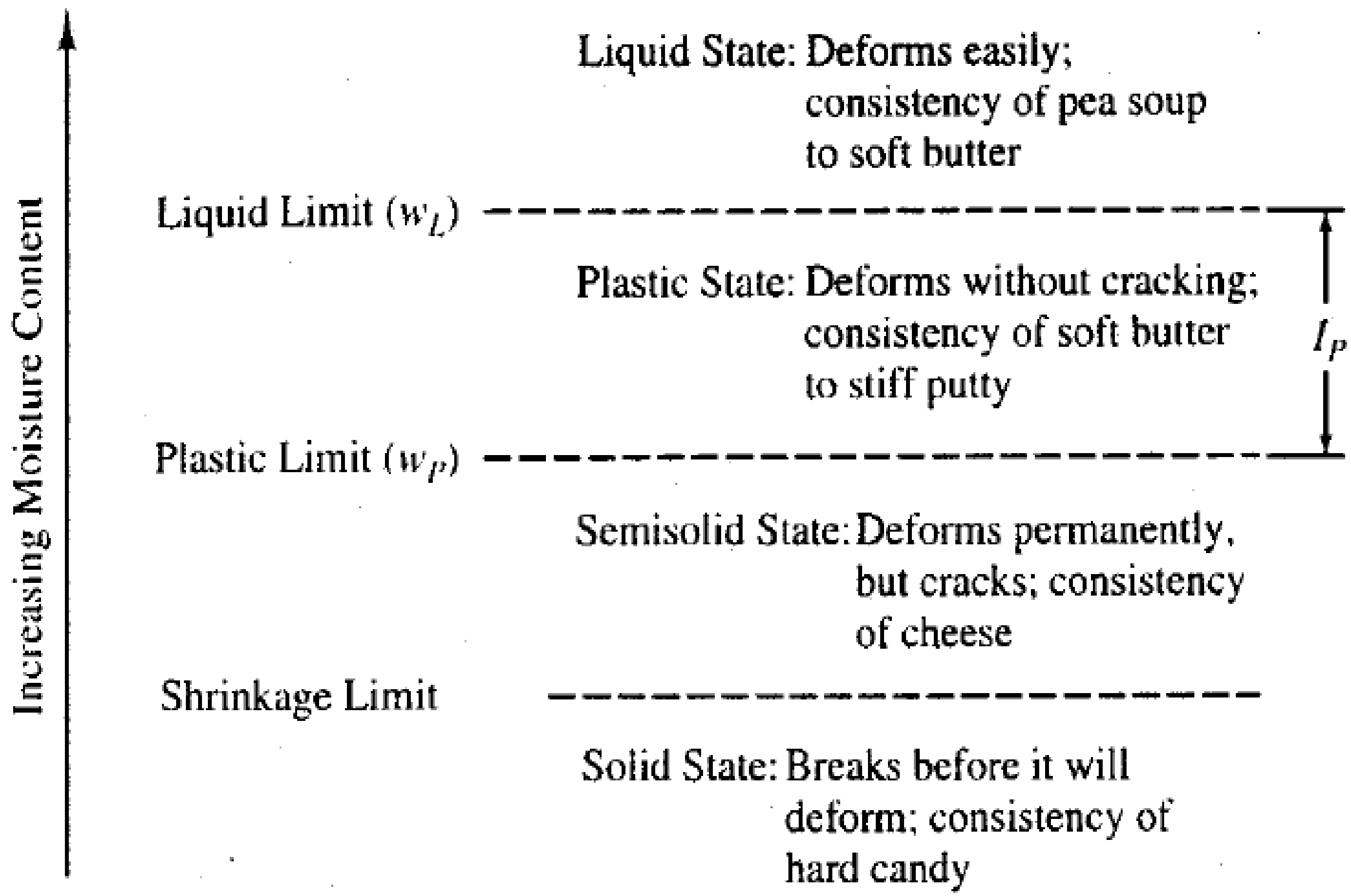


Figure 3.2 Consistency of fine-grained soils at different mositure contents (Sowers, 1979).

AASHTO Classification System

Table 4-2 AASHTO soil classification system

Note that *A*-8, peat or muck, is by visual classification and is not shown in the table.

General classification	Granular materials (35% or less passing No. 200)							Silt-clay materials (More than 35% passing No. 200)			
	A-1		*A*-3	*A*-2				*A*-4	*A*-5	*A*-6	*A*-7
Group classification	*A*-1*a*	*A*-1*b*		*A*-2-4	*A*-2-5	*A*-2-6	*A*-2-7				*A*-7-5; *A*-7-6
Sieve analysis:											
Percent passing:											
No. 10	50 max.										
No. 40	30 max.	50 max.	51 min.								
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit:				40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.
Group index	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.
Usual types of significant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

Example:

Classify the following Soils

Sieve #	***Soil 'A'***	***Soil 'B'***	***Soil 'C'***	***Soil 'D'***
	% passing			
# 4	75	69	95	40
#10	73	54	90	20
# 40	58	46	83	30
#100	43	41	71	15
# 200	35	25	55	9
C_u	5	4	2	3
C_c	1.5	2	2.2	0.5
LL	21	39	55	20
PL	15	29	24	15
USCS Classification				
AASHTO Classification				