Classificação dos solos

Fernando A. M. Marinho
2020

Introdução

Os sistemas de classificação foram desenvolvidos para fornecerem a engenheiros e técnicos informações gerais sobre a natureza do solo de um local específico. O uso do sistema de classificação para aplicações específicas exige um sólido conhecimento sobre o comportamento dos solos e suas limitações.

De modo geral, ambientes que possuam características semelhantes produzem tipos de solos similares. É isto que permite o sucesso de sistemas de classificação.

Por que Classificar?

- O propósito da classificação é organizar o nosso conhecimento de forma que as propriedades dos 'objetos' possam ser lembradas e suas relações entendidas visando um determinado objetivo."
- "O processo envolve a formação de classes por meio do agrupamento dos 'objetos' com base nas suas propriedades comuns."
- "Em qualquer sistema de classificação os grupos são formados tomando-se os aspectos dos quais se tem o maior número, as mais precisas e mais importantes informações."

Marlin G. Cline, "Basic Principles of Soil Classification", Soil Science 67, 1949:81-91.

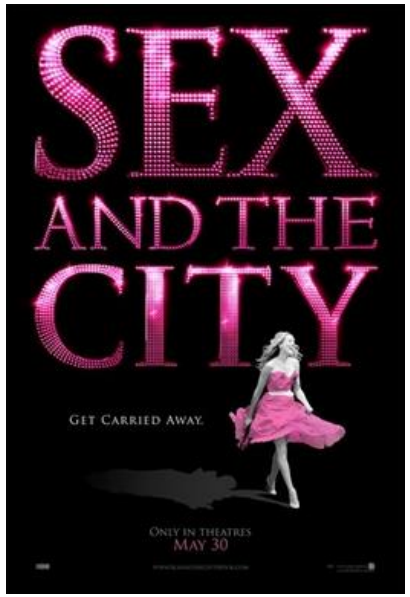



Sistemas de classificação de solos

- USCS – Unified Soil Classification System
- CSA – Canadian Standards Association
- European Standards (Euro-standards)
- AASHTO – American Association of State Highway and Transportation Officials
- ASTM – American Society for Testing and Materials

Por que existem tantos sistemas de classificação?

Aplicações



Modos de Classificar os Solos

Procedimento:

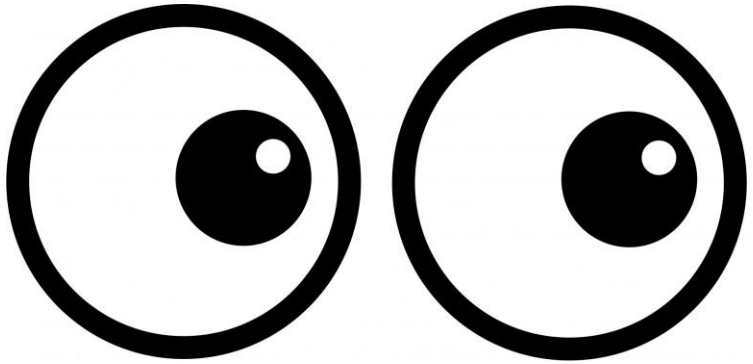
- **Natural:** Agrupa os solos por meio de alguma propriedade intrínseca, comportamento ou gênese do solo, sem fazer referência ao uso.
- **Técnico:** Agrupa os solos com base em alguma propriedade ou função que se relaciona diretamente ao uso do solo.

O solo como um material de engenharia

O solo significa coisas diferentes dependendo de quem defina:

Para o engenheiro – é uma material onde se pode:

- Construir sobre e dentro dele
- Construir com ele



O olhar para a classificação

Como é possível “traduzir” uma classificação em outra?

- Um relação direta entre classificações é rara.
- No entanto, alguns conceitos dos diferentes sistemas são semelhantes, e algumas ideias de um sistema podem ser correlacionadas com outro.

Traduzir uma parte
na outra parte
— que é uma questão
de vida ou morte —
será arte?

Traduzir-se de Ferreira Gullar

Encyclopedia of Knowledge Organization

https://www.isko.org/cyclo/soil

Tamanho relativo das partículas de solo

Barril

Areia

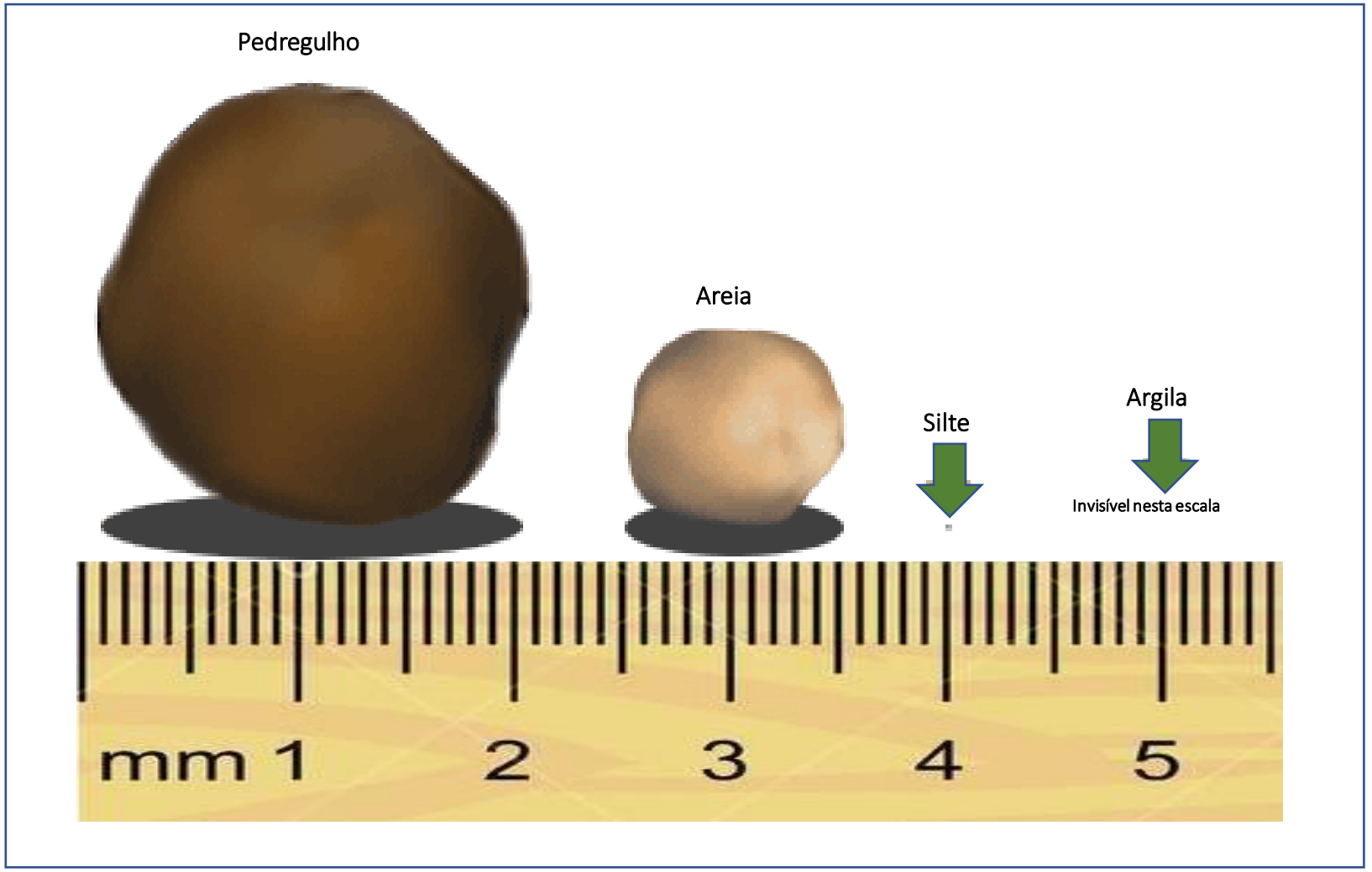
Prato

Silte

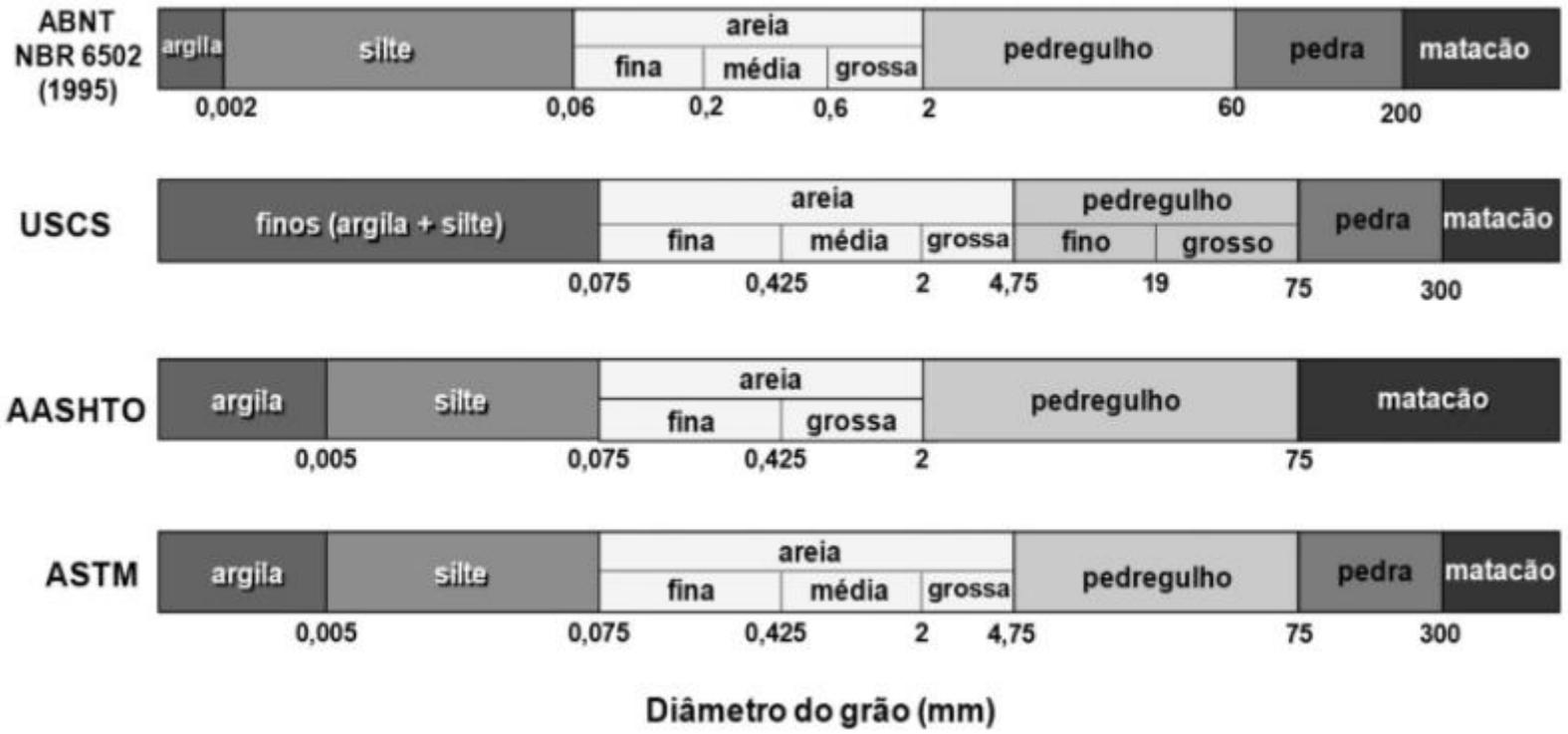
Moeda

Argila

Tamanho relativo das partículas de solo



Classificação por tamanho das partículas

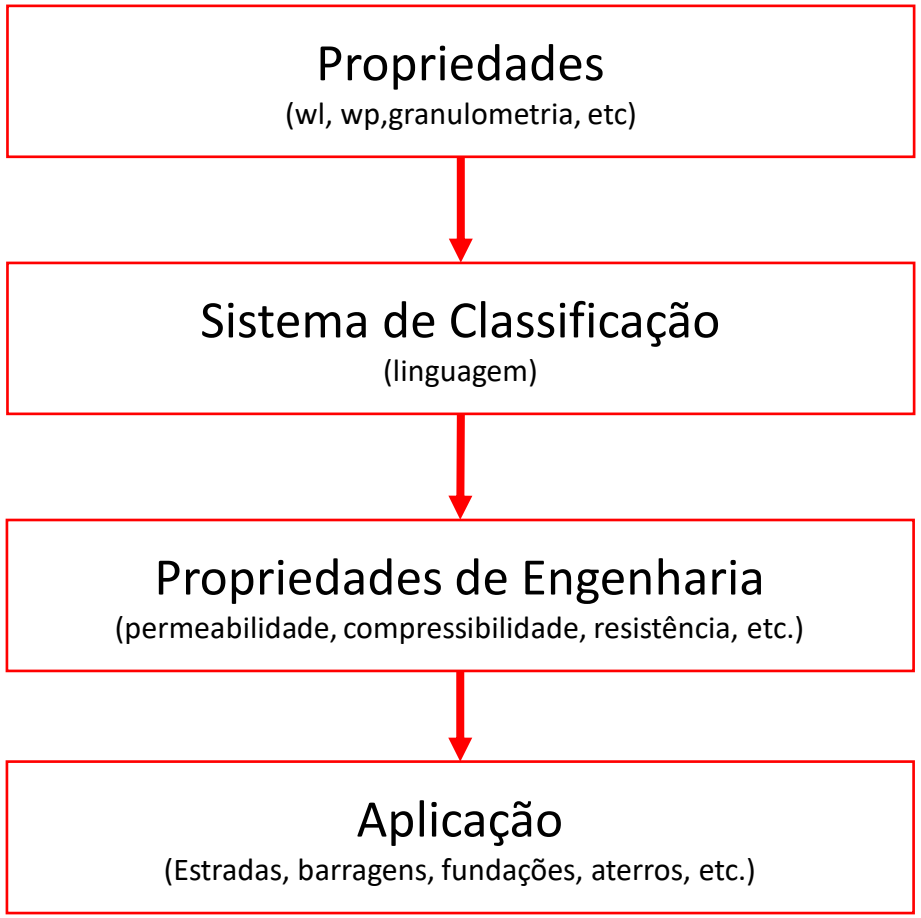


Termos e Qualificações

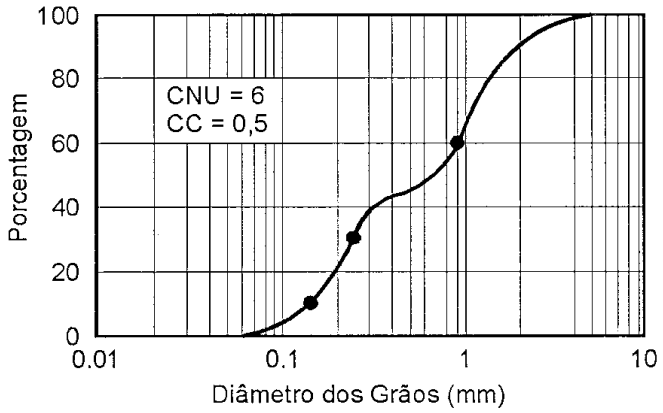
Main terms		Qualifying terms	
GRAVEL	G	Well graded	W
SAND	S	Poorly graded	P
		Uniform	Pu
		Gap-graded	Pg
FINE SOIL, FINES	F	Of low plasticity ($w_L < 35$)	L
SILT (M-SOIL)	M	Of intermediate plasticity (w_L 35–50)	I
CLAY	C	Of high plasticity (w_L 50–70)	H
		Of very high plasticity (w_L 70–90)	V
		Of extremely high plasticity ($w_L > 90$)	E
		Of upper plasticity range ($w_L > 35$)	U
PEAT	Pt	Organic (may be a suffix to any group)	O

Craig (1997)

Papel do sistema de classificação na engenharia

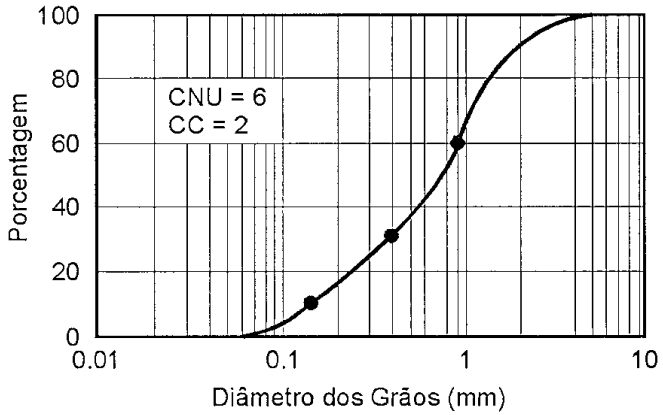


Modificado de Holtz & Kovacs (1981)



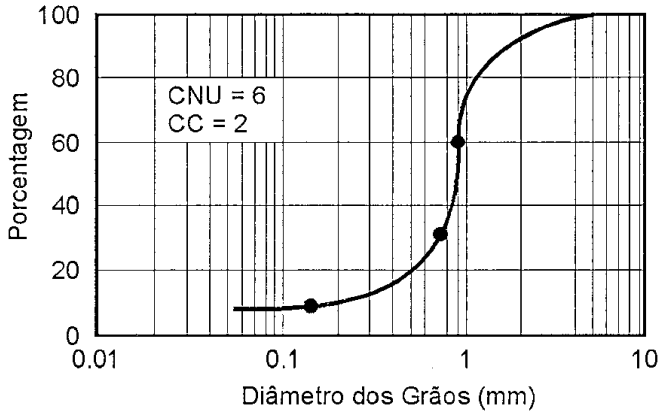
$$C_U = \frac{D_{60}}{D_{10}} = CNU$$

- Quanto maior o CNU mais bem graduada e a areia.
- Areias com CNU menor que 2 são chamadas uniformes.



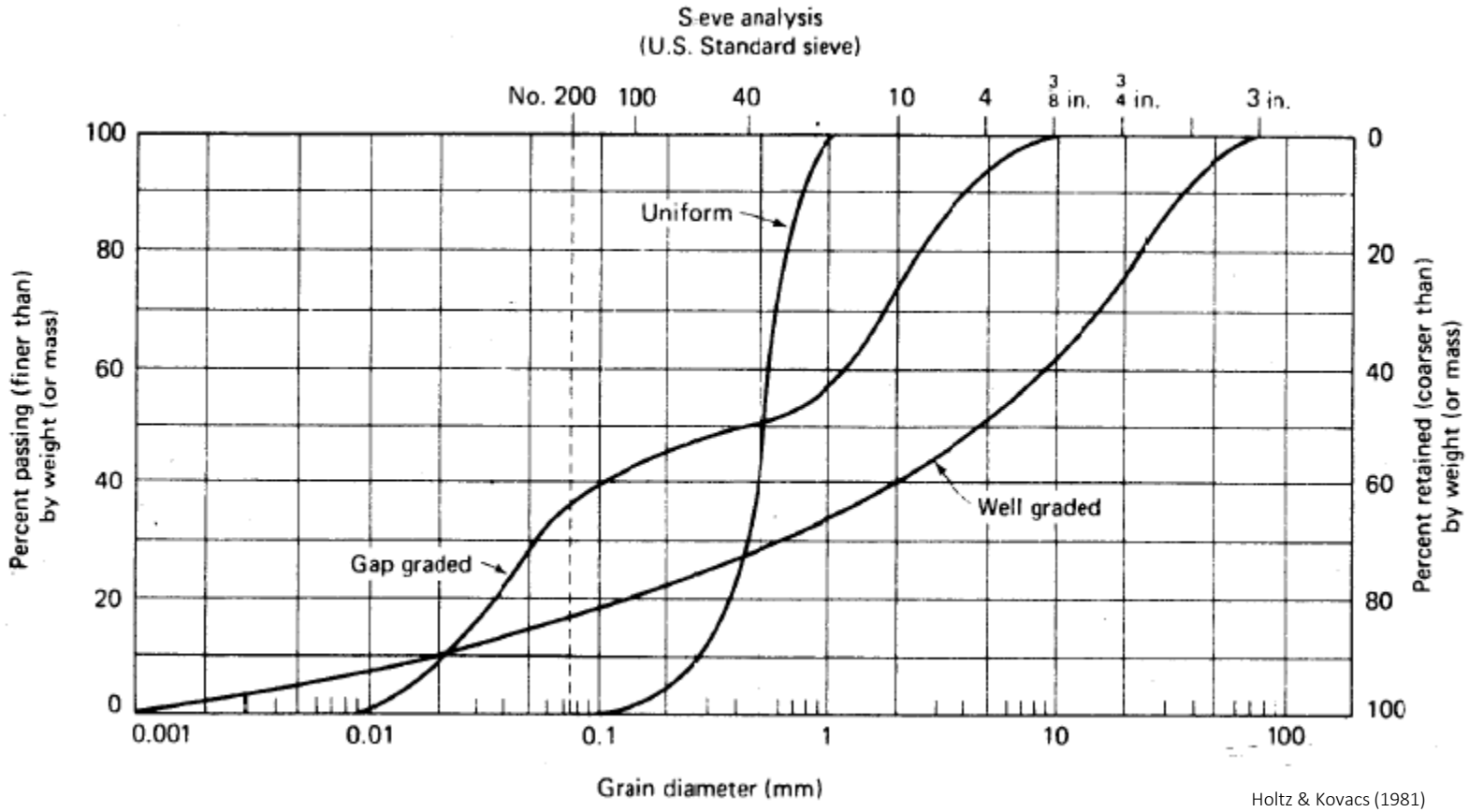
$$C_Z = \frac{(D_{30})^2}{D_{10}D_{60}} = CC$$

- O material é bem graduado quando CC está entre 1 e 3.
- Quando CC é menor do que 1 a curva é descontínua.
- Quando CC é maior do que 3 a curva tende a ser muito uniforme na parte central.



Pinto (2000)

Distribuição granulométrica



Holtz & Kovacs (1981)

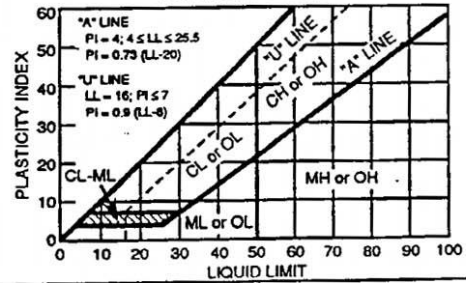
UNIFIED SOIL CLASSIFICATION SYSTEM

Soils are visually classified for engineering purposes by the Unified Soil Classification System. Grain-size analyses and Atterberg Limits tests often are performed on selected samples to aid in classification. The classification system is briefly outlined on this chart. Graphic symbols are used on boring logs presented in this report. For a more detailed description of the system, see "Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)" ASTM Designation: 2488-84 and "Standard Test Method for Classification of Soils for Engineering Purposes" ASTM Designation: 2487-85.

MAJOR DIVISIONS				GRAPHIC SYMBOL	GROUP SYMBOL	TYPICAL NAMES
COARSE-GRAINED SOILS Less than 50% passes No. 200 sieve)	GRAVELS (50% or less of coarse fraction passes No. 4 sieve)	CLEAN GRAVELS (Less than 5% passes No. 200 sieve)			GW	Well graded gravels, gravel-sand mixtures, or sand-gravel-cobble mixtures
					GP	Poorly graded gravels, gravel-sand mixtures, or sand-gravel-cobble mixtures
		GRAVELS WITH FINES (More than 12% passes No. 200 sieve)	Limits plot below "A" line & hatched zone on plasticity chart		GM	Silty gravels, gravel-sand-silt mixtures
			Limits plot above "A" line & hatched zone on plasticity chart		GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS (50% or more of coarse fraction passes No. 4 sieve)	CLEAN SANDS (Less than 5% passes No. 200 sieve)			SW	Well graded sands, gravelly sands
					SP	Poorly graded sands, gravelly sands
		SANDS WITH FINES (More than 12% passes No. 200 sieve)	Limits plot below "A" line & hatched zone on plasticity chart		SM	Silty sands, sand-silt mixtures
			Limits plot above "A" line & hatched zone on plasticity chart		SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more passes No. 200 sieve)	SILTS Limits plot below "A" line & hatched zone on plasticity chart	SILTS OF LOW PLASTICITY (Liquid Limit less than 50)			ML	Inorganic silts, clayey silts of low to medium plasticity
		SILTS OF HIGH PLASTICITY (Liquid Limit 50 or more)			MH	Inorganic silts, micaceous or diatomaceous silty soils, elastic silts
	CLAYS Limits plot above "A" line & hatched zone on plasticity chart	CLAYS OF LOW PLASTICITY (Liquid Limit less than 50)			CL	Inorganic clays of low to medium plasticity, gravelly, sandy, and silty clays
		CLAYS OF HIGH PLASTICITY (Liquid Limit 50 or more)			CH	Inorganic clays of high plasticity, fat clays, sandy clays of high plasticity
	ORGANIC SILTS AND CLAYS	ORGANIC SILTS AND CLAYS OF LOW PLASTICITY (Liquid Limit less than 50)			OL	Organic silts and clays of low to medium plasticity, sandy organic silts and clays
		ORGANIC SILTS AND CLAYS OF HIGH PLASTICITY (Liquid Limit 50 or more)			OH	Organic silts and clays of high plasticity, sandy organic silts and clays
ORGANIC SOILS		PRIMARILY ORGANIC MATTER (dark in color and organic odor)			PT	Peat

NOTE: Coarse-grained soils with between 5% and 12% passing the No. 200 sieve and fine-grained soils with limits plotting in the hatched zone on the plasticity chart have dual classifications.

PLASTICITY CHART



DEFINITION OF SOIL FRACTIONS

SOIL COMPONENT	PARTICLE SIZE RANGE
Boulders	Above 12 in.
Cobbles	12 in. to 3 in.
Gravel	3 in. to No. 4 sieve
Coarse gravel	3 in. to 3/4 in.
Fine gravel	3/4 in. to No. 4 sieve
Sand	No. 4 to No. 200 sieve
Coarse sand	No. 4 to No. 10 sieve
Medium sand	No. 10 to No. 40 sieve
Fine sand	No. 40 to No. 200 sieve
Fines (silt and clay)	Less than No. 200 sieve

Classificação Unificada para Solos

Name			Group Symbols	Laboratory criteria			
				Fines (%)	Grading	Plasticity	Notes
Coarse grained (more than 50% larger than 63 μm BS or No. 200 US sieve size)	Gravels (more than 50% of coarse fraction of gravel size)	Well graded gravels, sandy gravels, with little or no fines	GW	0–5	$C_U > 4$ $1 < C_Z < 3$		Dual symbols if 5–12% fines. Dual symbols if above *A*-line and $4 < I_P < 7$
		Poorly graded gravels, sandy gravels, with little or no fines	GP	0–5	Not satisfying GW requirements		
		Silty gravels, silty sandy gravels	GM	>12		Below *A*-line or $I_P < 4$	
		Clayey gravels, clayey sandy gravels	GC	>12		Above *A*-line and $I_P > 7$	
	Sands (more than 50% of coarse fraction of sand size)	Well graded sands, gravelly sands, with little or no fines	SW	0–5	$C_U > 6$ $1 < C_Z < 3$		
		Poorly graded sands, gravelly sands, with little or no fines	SP	0–5	Not satisfying SW requirements		
		Silty sands	SM	>12		Below *A*-line or $I_P < 4$	
		Clayey sands	SC	>12		Above *A*-line and $I_P > 7$	

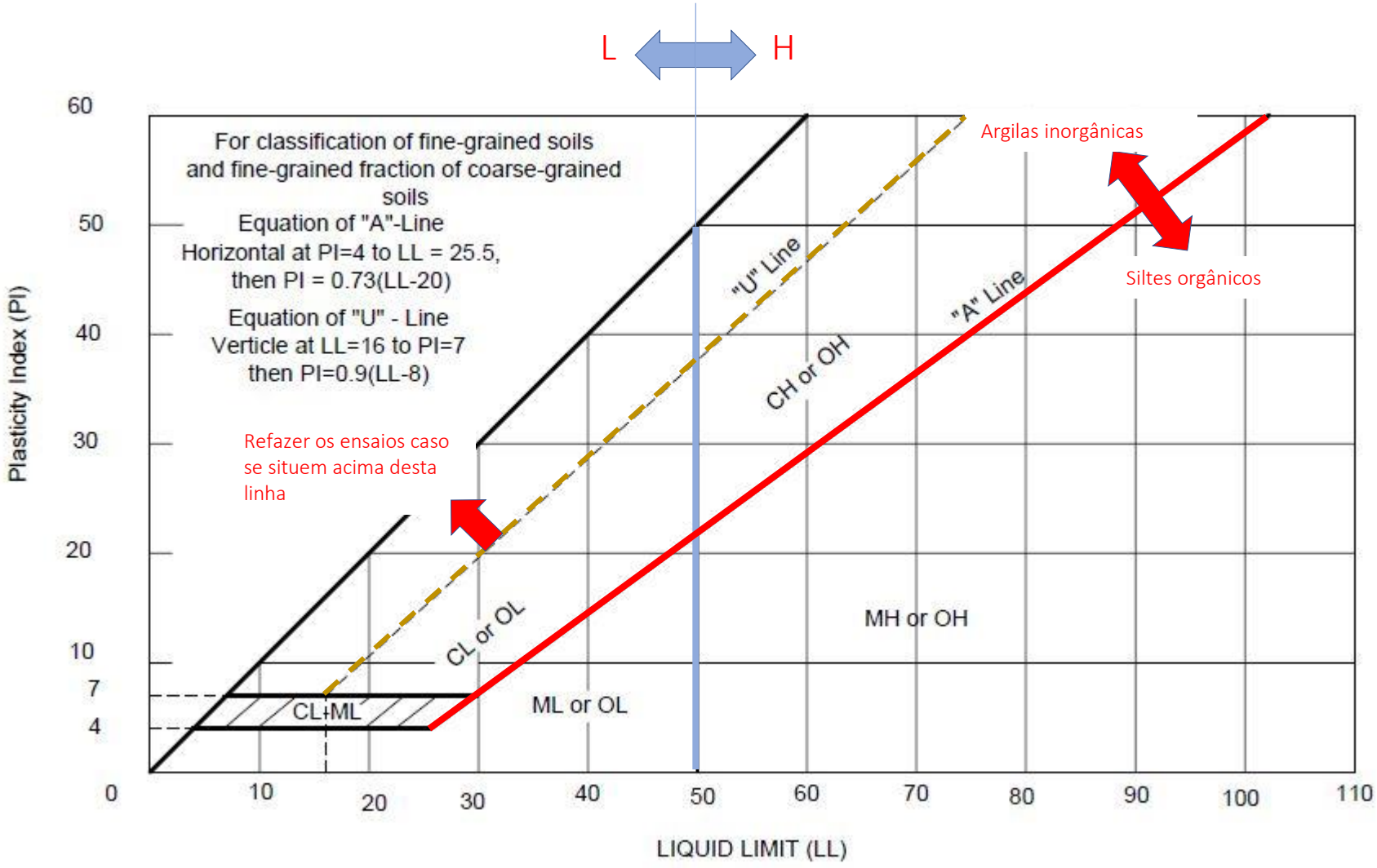
Craig (1997)

Classificação Unificada para Solos

Name			Group Symbols	Laboratory criteria
Fine grained (more than 50% smaller than 63 μm BS or No. 200 US sieve size)	Silts and clays (liquid limit less than 50)	Inorganic silts, silty or clayey fine sands, with slight plasticity	ML	Use plasticity chart
		Inorganic clays, silty clays, sandy clays of low plasticity	CL	Use plasticity chart
		Organic silts and organic silty clays of low plasticity	OL	Use plasticity chart
	Silts and clays (liquid limit greater than 50)	Inorganic silts of high plasticity	MH	Use plasticity chart
		Inorganic clays of high plasticity	CH	Use plasticity chart
		Organic clays of high plasticity	OH	Use plasticity chart
Highly organic soils		Peat and other highly organic soils	Pt	

Craig (1997)

Carta de Plasticidade



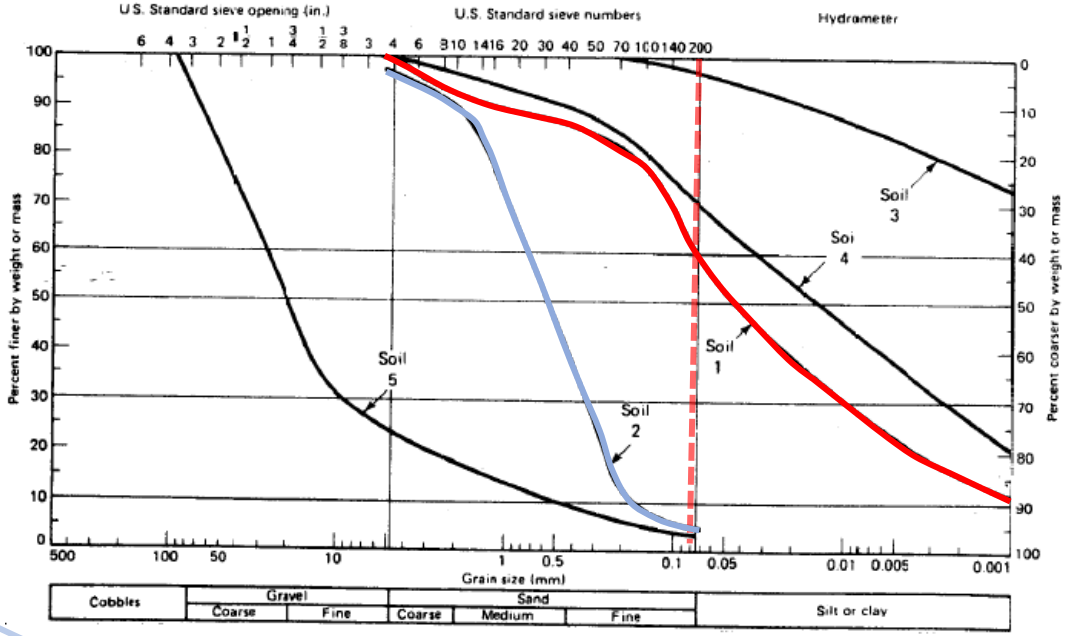
http://epg.modot.org/index.php?title=Image:321.2.11.2_Plasticity_Chart.jpg

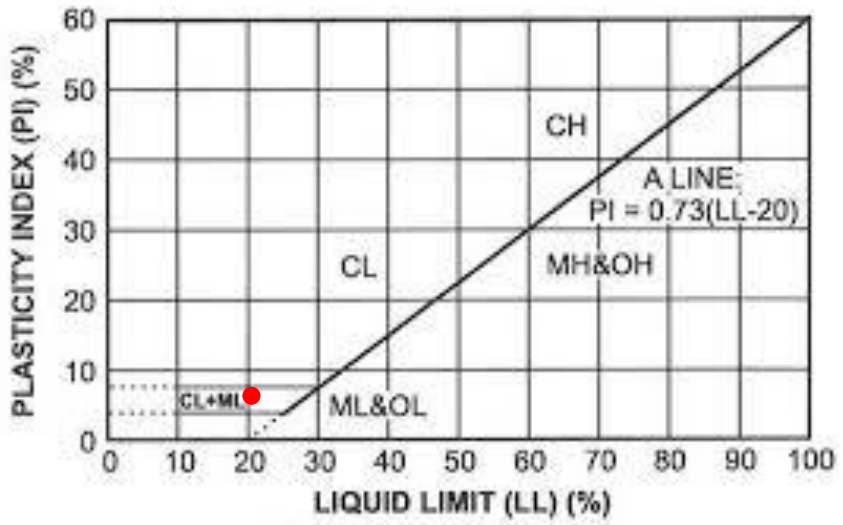
Exemplo

Sieve Size	Soil 1, % Finer	Soil 2, % Finer	Soil 3, % Finer
No. 4	99	97	100
No. 10	92	90	100
No. 40	86	40	100
No. 100	78	8	99
No. 200	60	5	97
LL	20	—	124
PL	15	—	47
PI	5	NP*	77

*Nonplastic.

+50% passa na #200
Necessita dos limites para classificar





Name			Group Symbols	Laboratory criteria			
				Fines (%)	Grading	Plasticity	Notes
Coarse grained (more than 50% larger than 63 µm BS or No. 200 US sieve size)	Gravels (more than 50% of coarse fraction of gravel size)	Well graded gravels, sandy gravels, with little or no fines	GW	0–5	$C_U > 4$ $1 < C_Z < 3$		Dual symbols if 5–12% fines. Dual symbols if above *A*-line and $4 < I_P < 7$
		Poorly graded gravels, sandy gravels, with little or no fines	GP	0–5	Not satisfying GW requirements		
		Silty gravels, silty sandy gravels	GM	>12		Below *A*-line or $I_P < 4$	
		Clayey gravels, clayey sandy gravels	GC	>12		Above *A*-line and $I_P > 7$	
	Sands (more than 50% of coarse fraction of sand size)	Well graded sands, gravelly sands, with little or no fines	SW	0–5	$C_U > 6$ $1 < C_Z < 3$		
		Poorly graded sands, gravelly sands, with little or no fines	SP	0–5	Not satisfying SW requirements		
		Silty sands	SM	>12		Below *A*-line or $I_P < 4$	
		Clayey sands	SC	>12		Above *A*-line and $I_P > 7$	

Cu = 3.9
Cz = 0.91

Classificação

+

Aplicação

Classificação e Aplicação

Typical names of soil groups	Group symbols	Important properties: Permeability when compacted	Important properties: Shearing strength when compacted and saturated	Important properties: Compressibility when compacted and saturated	Important properties: Workability as a construction material	Relative desirability for various uses: Rolled earth dams: Homogeneous embankment	Rolled earth dams: Core	Rolled earth dams: Shell	Canal sections: Erosion resistance	Canal sections: Compacted earth lining	Foundations: Seepage important	Foundations: Seepage not important	Roadways: Fills: Frost heave not possible	Roadways: Fills: Frost heave possible	Roadways: Surfacing
Well-graded gravels, gravel–sand mixtures, little or no fines	GW	Pervious	Excellent	Negligible	Excellent	—	—	1	1	—	—	1	1	1	3
Poorly graded gravels, gravel–sand mixtures, little or no fines	GP	Very pervious	Good	Negligible	Good	—	—	2	2	—	—	3	3	3	—
Silty gravels, poorly graded gravel–sand–silt mixtures	GM	Semipervious to impervious	Good	Negligible	Good	2	4	—	4	4	1	4	4	9	5
Clayey gravels, poorly graded gravel–sand–clay mixtures	GC	Impervious	Good to fair	Very low	Good	1	1	—	3	1	2	6	5	5	1
Well-graded sands, gravelly sands, little or no fines	SW	Pervious	Excellent	Negligible	Excellent	—	—	3 if gravelly	6	—	—	2	2	2	4
Poorly graded sands, gravelly sands, little or no fines	SP	Pervious	Good	Very low	Fair	—	—	4 if gravelly	7 if gravelly	—	—	5	6	4	—
Silty sands, poorly graded sand–silt mixtures	SM	Semipervious to impervious	Good	Low	Fair	4	5	—	8 if gravelly	5 erosion critical	3	7	8	10	6
Clayey sands, poorly graded sand–clay mixtures	SC	Impervious	Good to fair	Low	Good	3	2	—	5	2	4	8	7	6	2
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	ML	Semipervious to impervious	Fair	Medium	Fair	6	6	—	—	6 erosion critical	6	9	10	11	—
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silky clays, lean clays	CL	Impervious	Fair	Medium	Good to fair	5	3	—	9	3	5	10	9	7	7
Organic silts and organic silt–clays of low plasticity	OL	Semipervious to impervious	Poor	Medium	Fair	8	8	—	—	7 erosion critical	7	11	11	12	—
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	MH	Semipervious to impervious	Fair to poor	High	Poor	9	9	—	—	—	8	12	12	13	—
Inorganic clays of high plasticity, fat clays	CH	Impervious	Poor	High	Poor	7	7	—	10	8 volume change critical	9	13	13	8	—
Organic clays of medium to high plasticity	OH	Impervious	Poor	High	Poor	10	10	—	—	—	10	14	14	14	—
Peat and other highly organic soils	Pt	—	—	—	—	—	—	—	—	—	—	—	—	—	—

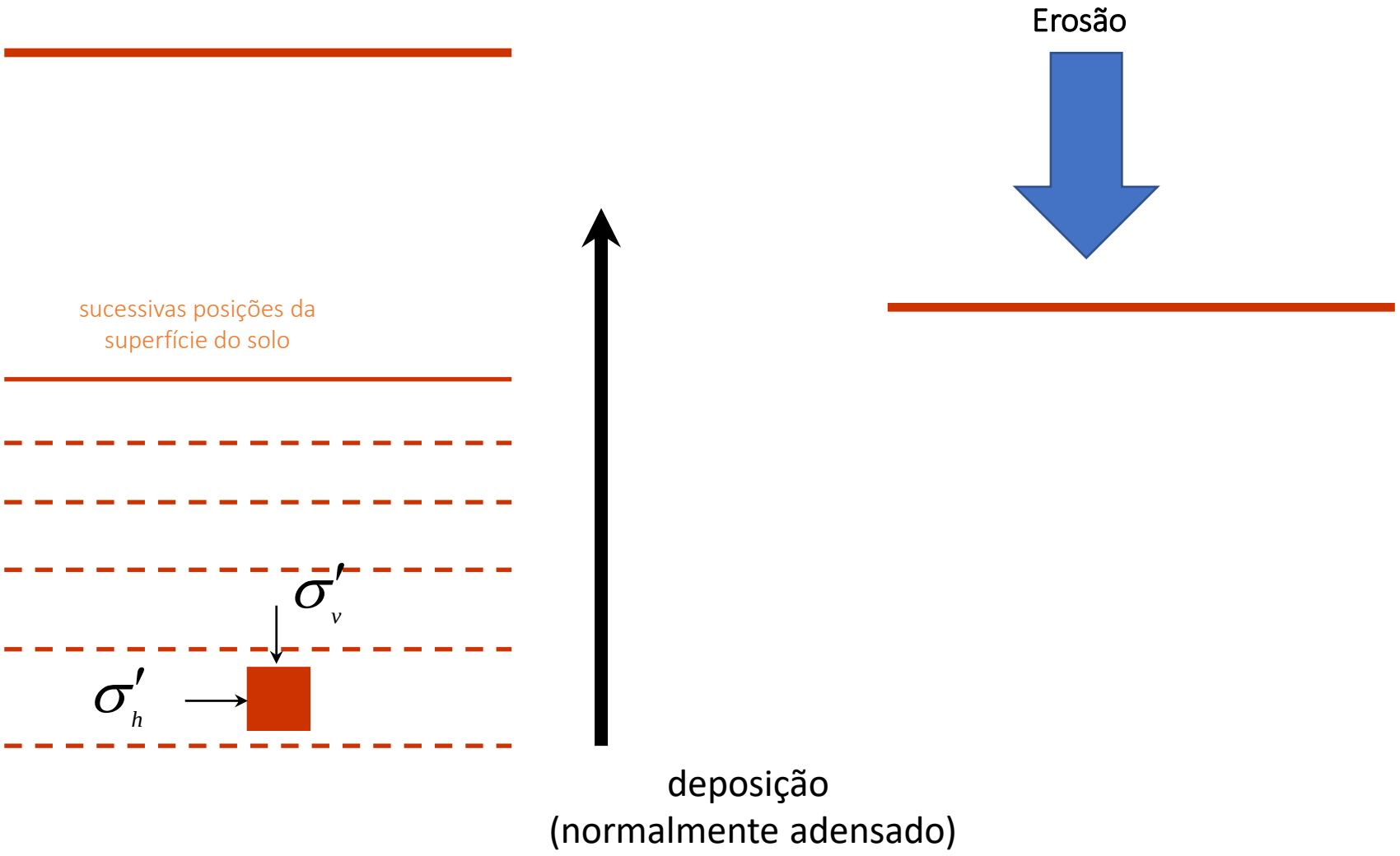
Caracterização das Argilas e Areias

A Natureza e o Estado

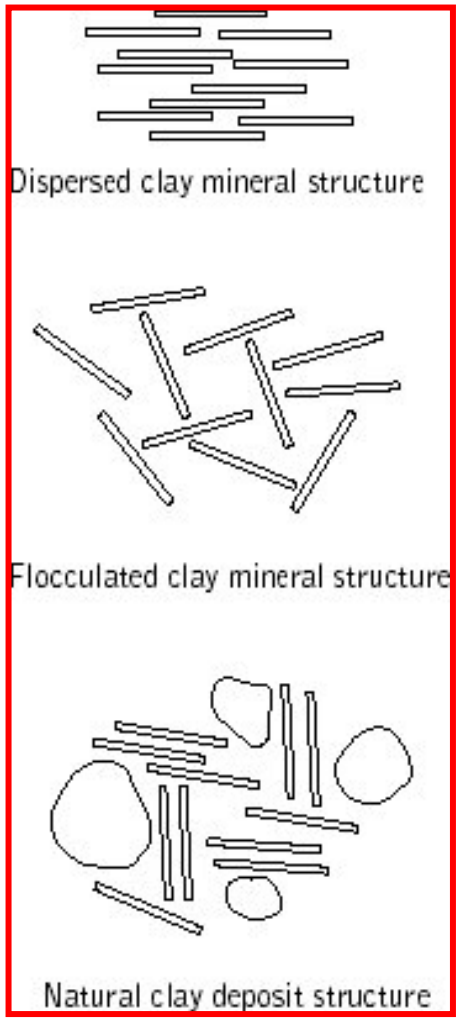
Fernando A M Marinho

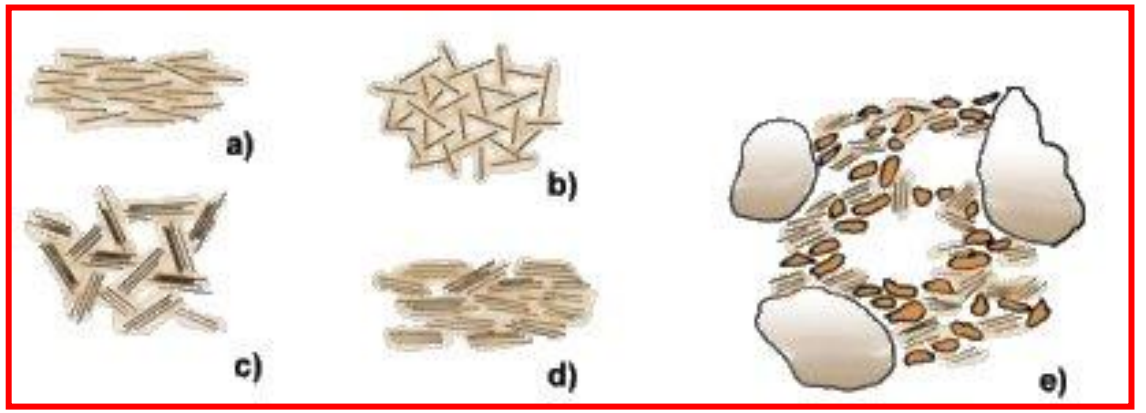
2020

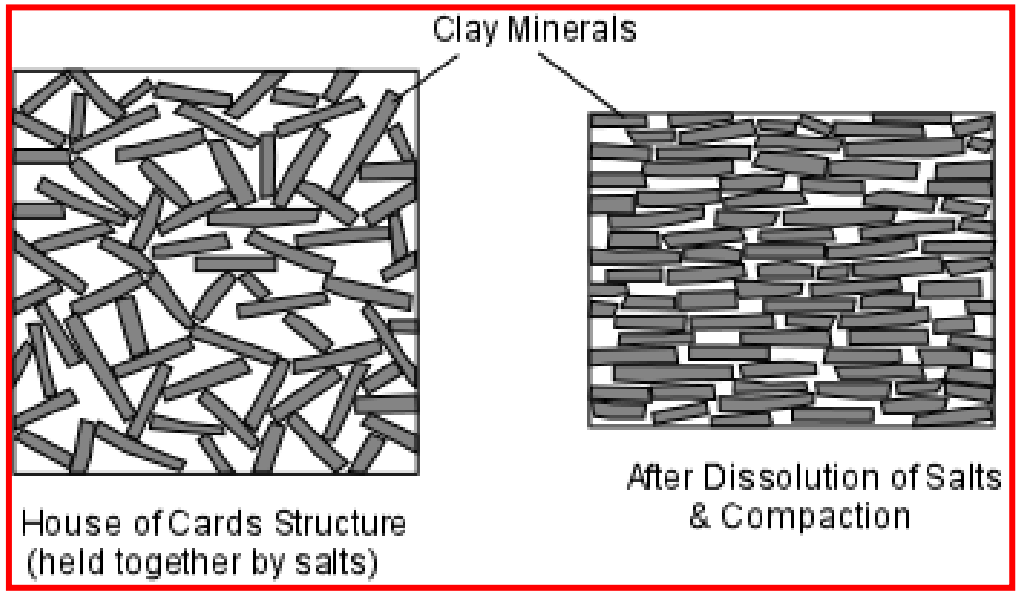
Formação das Argilas



Sensibilidade das Argilas

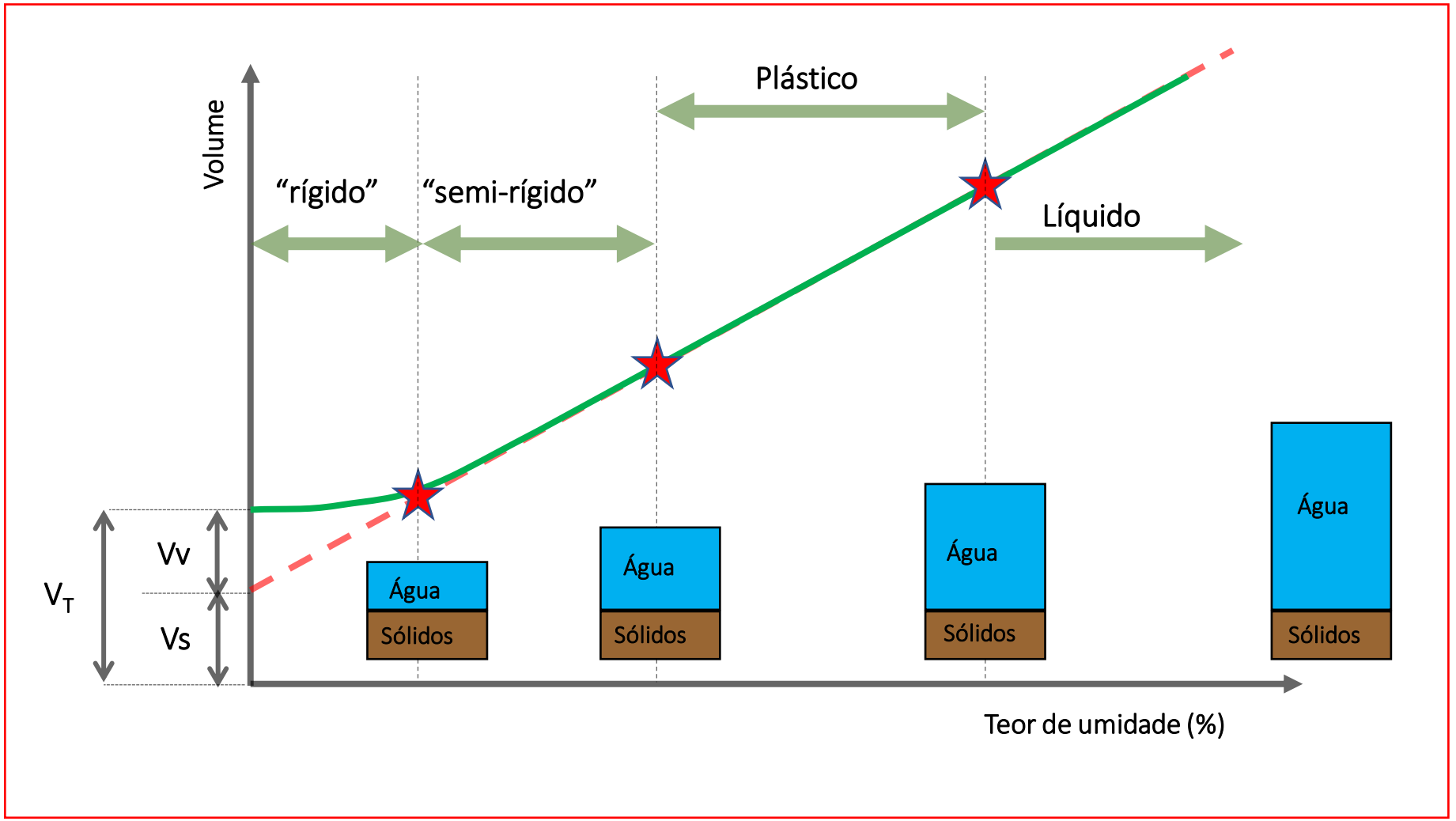






http://www.tulane.edu/~sanelson/geol204/slopestability.htm

Á agua nos solos plásticos



Comportamento das Argilas

- Estrutura
  - Sensibilidade das argilas (Índice de estrutura)
    - Ensaio de compressão simples (não confinada)
      - Indeformado (R_I)
      - Remoldado (R_R)

$$Sensibilidade(S) = \frac{R_I}{R_R}$$

S	Classificação
1	Insensível
1 a 2	Baixa sensibilidade
2 a 4	Média sensibilidade
4 a 8	Sensível
>8	Ultra-sensível

- Índice de vazios
  - Consistência
    - Índice de consistência

$$IC = \frac{LL - w}{LL - LP}$$

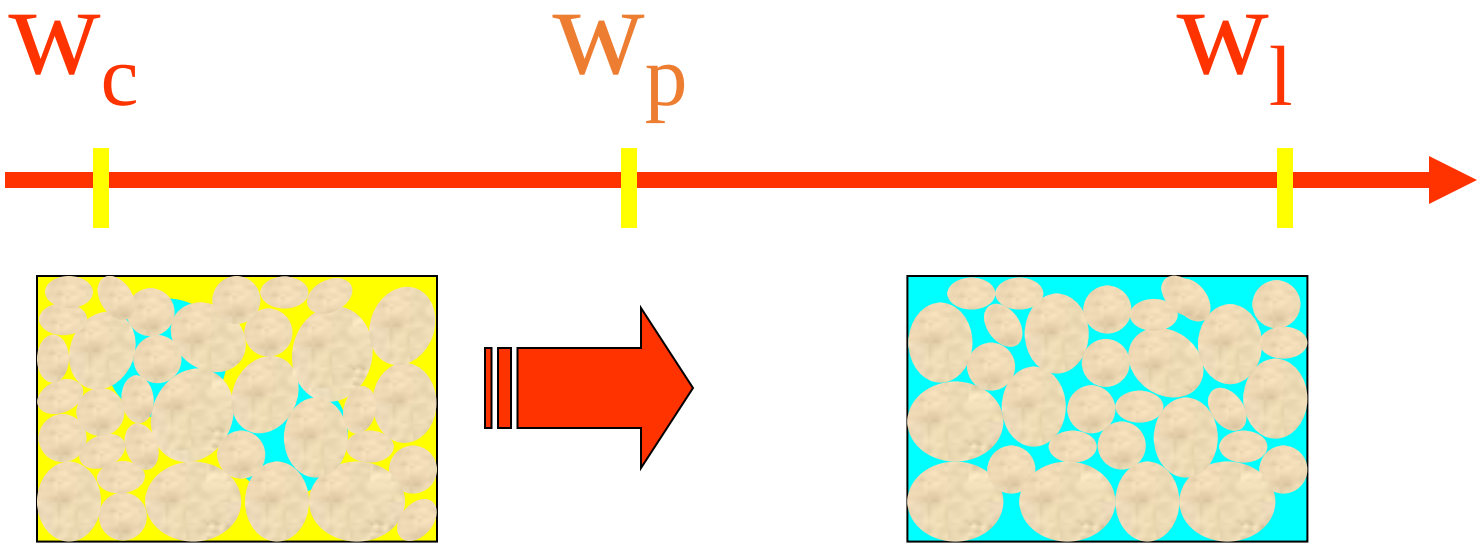
    - Ensaio de compressão simples (não confinada)

Consistência	Resistência (kPa)	IC
Muito mole	< 25	
Mole	25 a 50	< 0,5
Média	50 a 100	0,5 a 0,75
Rija	100 a 200	0,75 a 1,0
Muito rija	200 a 400	> 1,0
Dura	> 400	

    - Índice de liquidez

$$IL = \frac{w - LP}{LL - LP}$$

Limites de Atterberg



$$e = \frac{V_v}{V_s}$$

$$Se = wG$$

$$S = \frac{V_w}{V_v}$$

Índice de Consistência

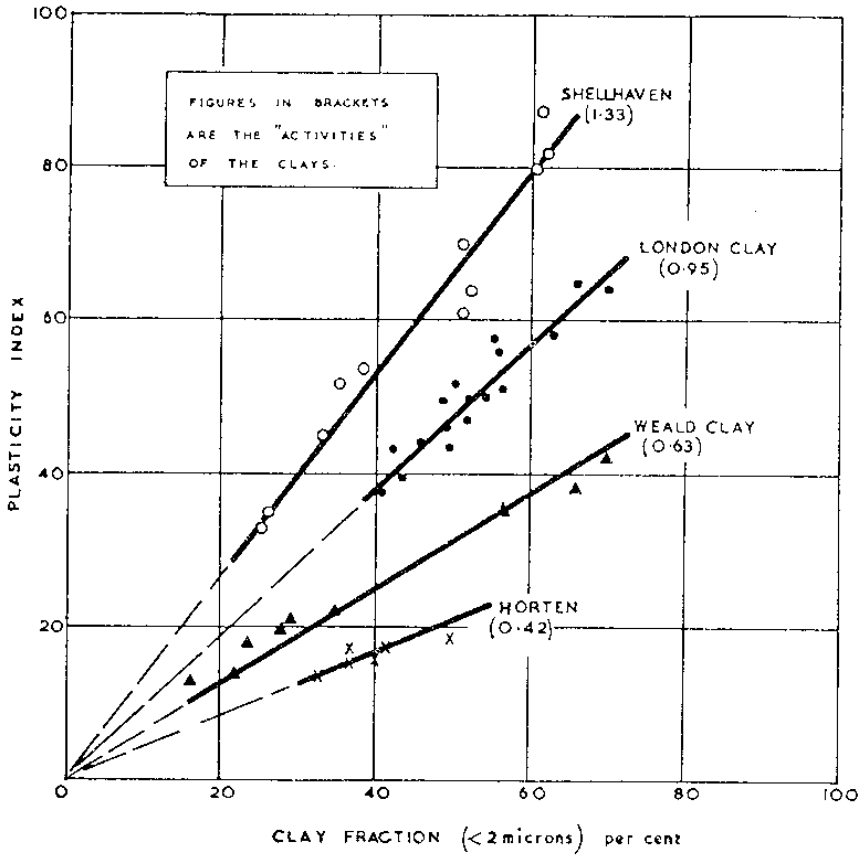
$$IC = \frac{LL - w}{LL - LP}$$

Índice de Liquidez

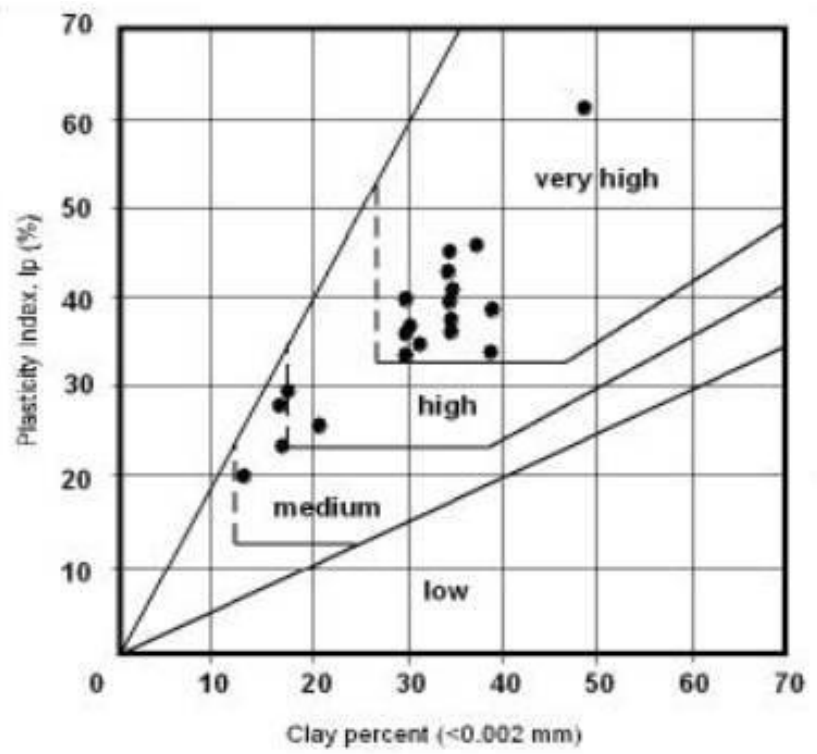
$$IL = \frac{w - LP}{LL - LP}$$

Atividade de uma Argila

$$Índice\ de\ Atividade = \frac{Índice\ de\ plasticidade\ (I_p)}{Fração\ Argila\ (< 0.002mm)}$$

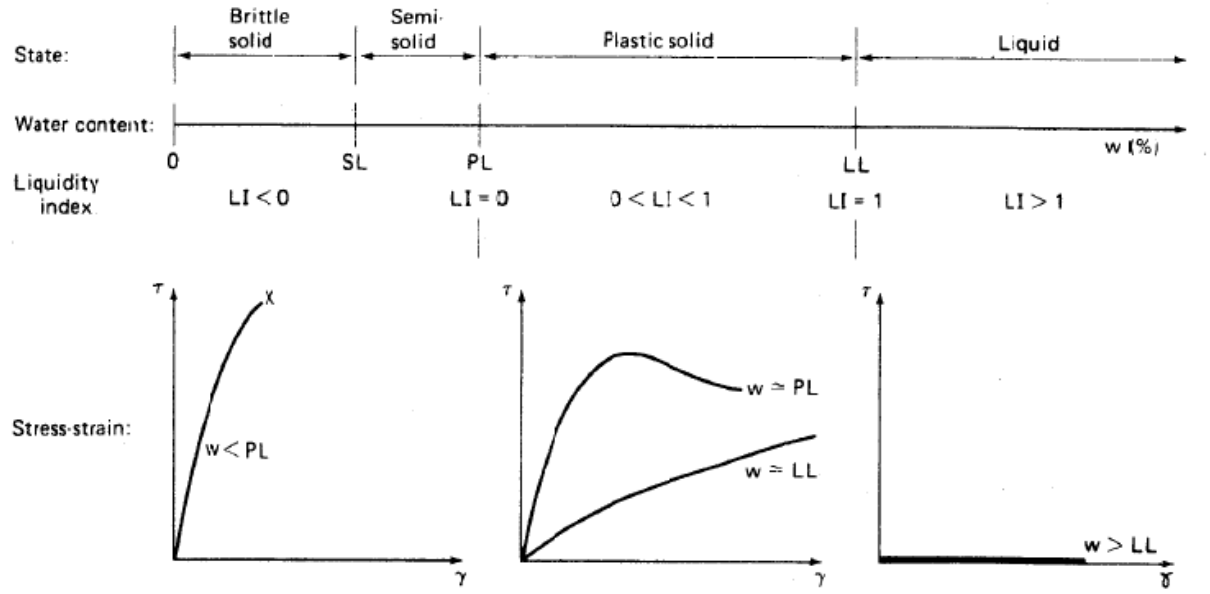


Skempton (1953)



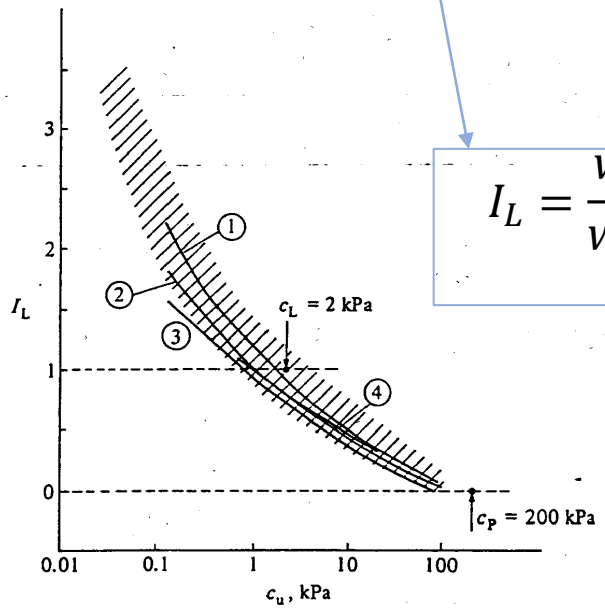
Ylmaz & Erzin (2004)

Estados do solo e sua relação tensão deformação



Holtz & Kovacs (1981)

$$I_L = \frac{w - w_p}{w_l - w_p}$$



Muir Wood (1990)

Comportamento das Areias

- Forma dos Grãos
- Compacidade
- Distribuição granulométrica

Índice de vazios

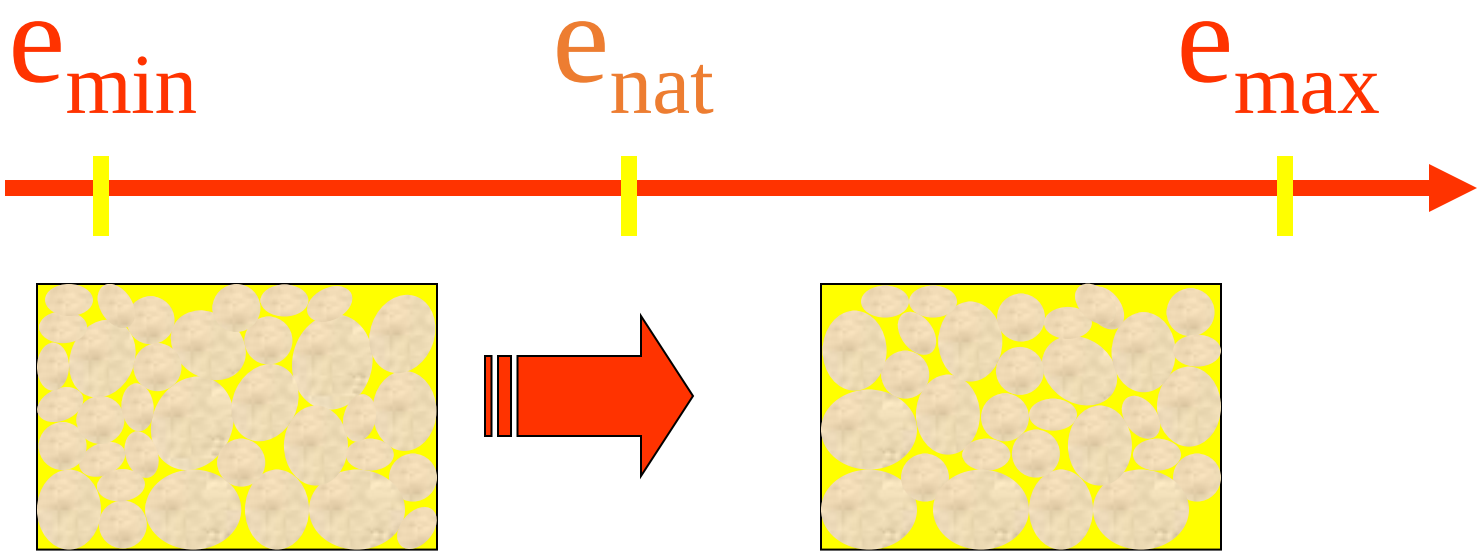
	Máximo	Mínimo
Areia uniforme de grãos angulares	1,1	0,70
Areia bem graduada de grãos angulares	0,75	0,45
Areia uniforme de grãos arredondados	0,75	0,45
Areia bem graduada de graõs arredondados	0,65	0,35

Índice de Compacidade Relativa

$$CR = \frac{e_{max} - e_{nat}}{e_{max} - e_{min}}$$

	CR
Areia fofa	< 0,33
Areia de compacidade média	0,33 a 0,66
Areia compacta	> 0,66

Índice de Vazios Máximo e Mínimo de Areias



$$e = \frac{V_v}{V_s}$$

Compacidade Relativa

$$CR = \frac{e_{max} - e_{nat}}{e_{max} - e_{min}}$$