Some thougths
about teaching Soil Mechanics to
Civil Engineering undergraduates

Manuel de Matos Fernandes
october 2016

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

Faculty of Engineering of University of Porto

Photo by Francisco Piqueiro

Since September 2000

Position of UNIV. of PORTO in the field of CIVIL ENGINEERING in some rankings in 2016

• QS, Quacquarelli Symonds:	World	51-100
	Europe	15-33
• NTU, National Taiwan Univ.:	World	58
	Europe	13
• ARWU Shanghai Ranking:	World	78
	Europe	28

Teaching Soil Mechanics to Civil Eng. undergraduates

Context of our work

- Integrated master in Civil Engineering – 5 years course
- Soil Mechanics – 7th semester (in parallel with Concrete Structures, Roads, Project Management and Hydraulics)
- Introduction to Geotechnics – 8th semester
- Block of specialization disciplines in the 9th semester (Structures, Hydraulics, Geotechnics, Buildings, etc.)
- Dissertation in the 10th semester
- Around 160 students (this year)

Teaching Soil Mechanics to Civil Eng. undrgraduates

Context of our work

- Semester with 13 weeks
- This allows 24/25 theoretical classes (1 hour)
- In complement, 12 practical classes (3 hours) to solve exercises and lab works

Physical indices
Grain distribution
Clay minerals
Atterberg limits
Classification

→

Shear strength and stress-strain relationships for sands and clays

Students that have learned the EFFECTIVE STRESS PRINCIPLE past week

City of Porto

Photo by José Paulo Andrade

A remarkable collection of bridges over river Douro estuary.

Photo by Francisco Piqueiro

Maria Pia Bridge, the largest iron arch in the world at the date of its conclusion, G. Eiffel and T. Seyrig, 1877

Photo by Luís Ferreira Alves

Luíz I Bridge, the unique XIX century iron bridge with two decks in the world, T. Seyrig, 1886

Photo by Francisco Piqueiro

Arrábida Bridge, the largest reinforced concrete arch in the world at the date of its conclusion, Edgar Cardoso, 1963

Photo by Luís Lousada Soares

S. João Bridge, the prestressed concrete railway bridge of this type with the largest span (250 m) until today, Edgar Cardoso, 1991.

The best students dream to become bridge designers!

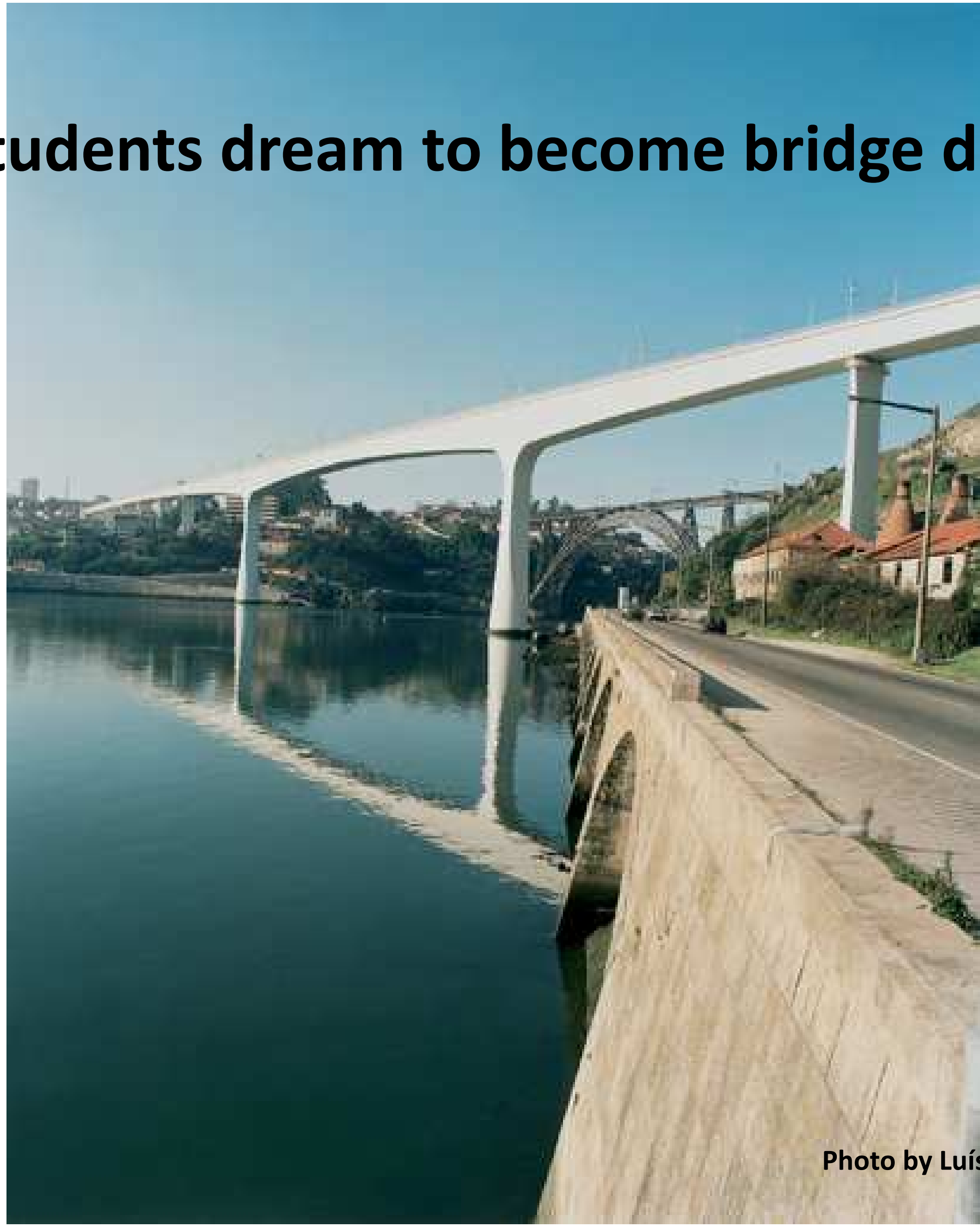

Photo by Luís Lousada Soares

- 3D heterogeneous mass
- Formed by grains, water and air
- Non elastic material. Failure
- Time dependent behaviour
- Influence of stress/geological history (overconsolidation, ageing, weathering)
- Dilatancy
- Effective stress and total stress analyses

SOIL MECHANICS

- 3D heterogeneous mass
- Formed by grains, water and air
- Non elastic material. Failure
- Time dependent behaviour
- Influence of stress (geological) history (overconsolidation, ageing, weathering)
- Dilatancy
- Effective stress and total stress analyses

SOIL MECHANICS

The natural science built by civil engineers.

CONVENTIONAL CHAPTERS OF SOIL MECHANICS

Physical indices
Grain distribution
Clay minerals
Atterberg limits
Classification

Effective stress principle
Permeability
Seepage

Shear strength and stress-strain relationships for sands and clays

Mechanics

Physical indices
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Classification

Effective stress principle
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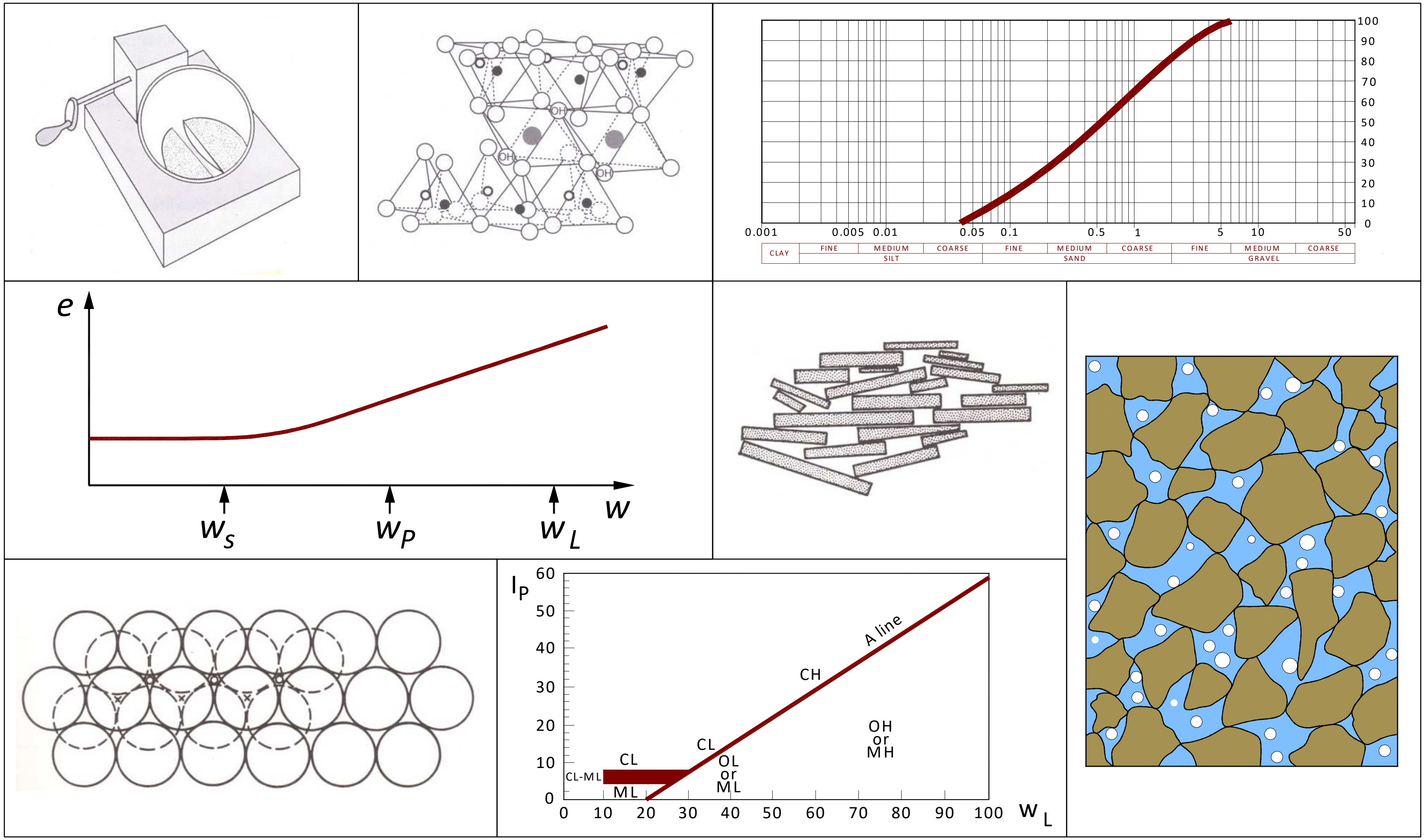
Seepage

Shear strength and stress-strain relationships for sands and clays

Issues usually treated in the first chapter(s)



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GAP!

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Shear strength and stress-strain relationships for sands and clays

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The contents of Soil Mechanics syllabus of the degree courses in many universities, as well as many text books, do not emphasize and analyse the strong relationships between the physical/identification parameters and the main trends of the mechanical behaviour of soils.

This is not in agreement with the capital importance they have in geotechnical practice.

In fact, most of the main decisions of an experienced engineer are made on the basis of the interpretation of the site geology and of the physical/identification parameters of the relevant soil layers.

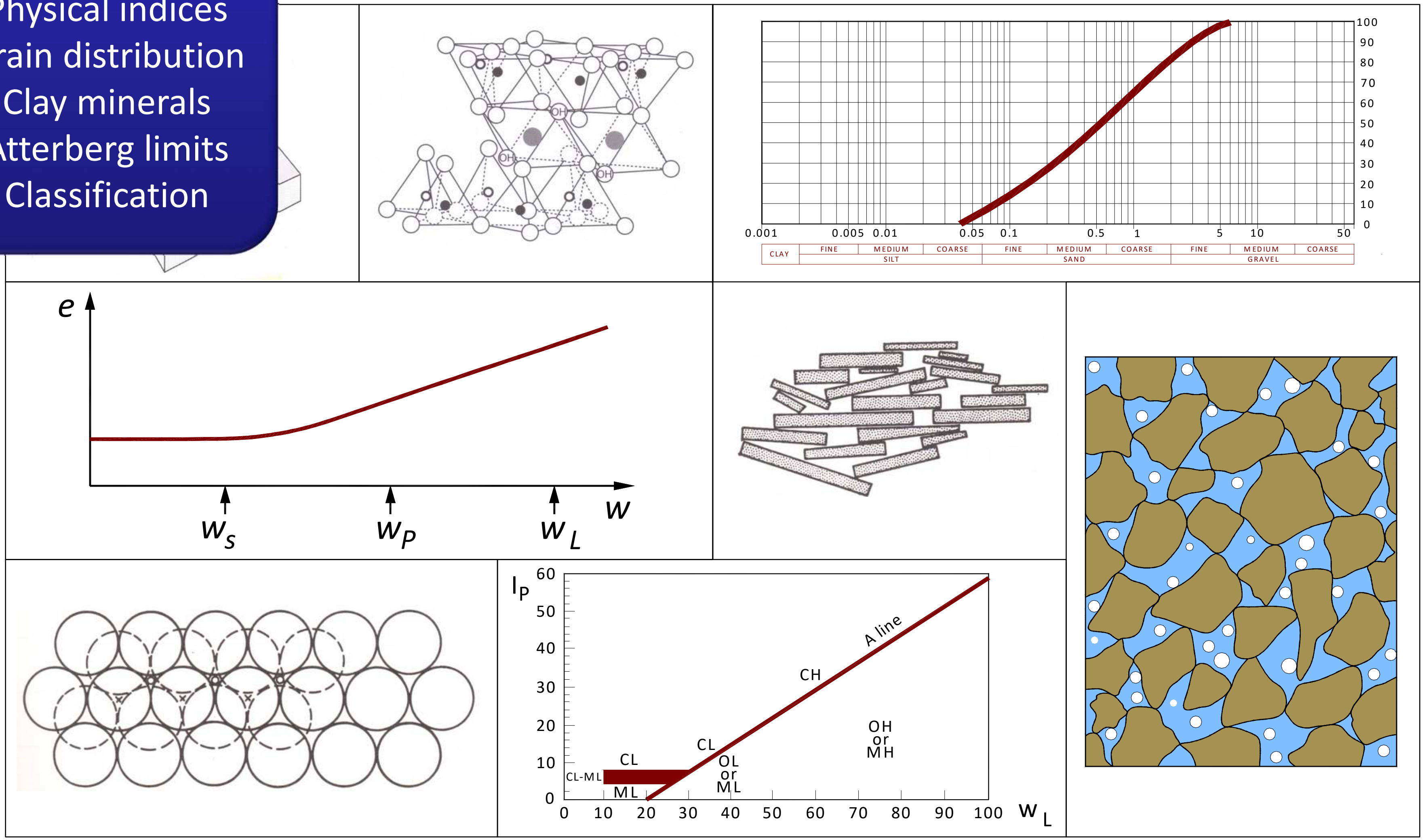
This means that experienced engineers have a clear idea on how the basic mechanical trends of soils are influenced by site geology and by the physical/identification parameters of the relevant soil layers.

Why this matter is not discussed in detail in our Soil Mechanics courses and books?

Is it impossible to obtain this skill at the University?

We reflect on the soil at micro-scale: mineral particle or sample

Physical indices
Grain distribution
Clay minerals
Atterberg limits
Classification



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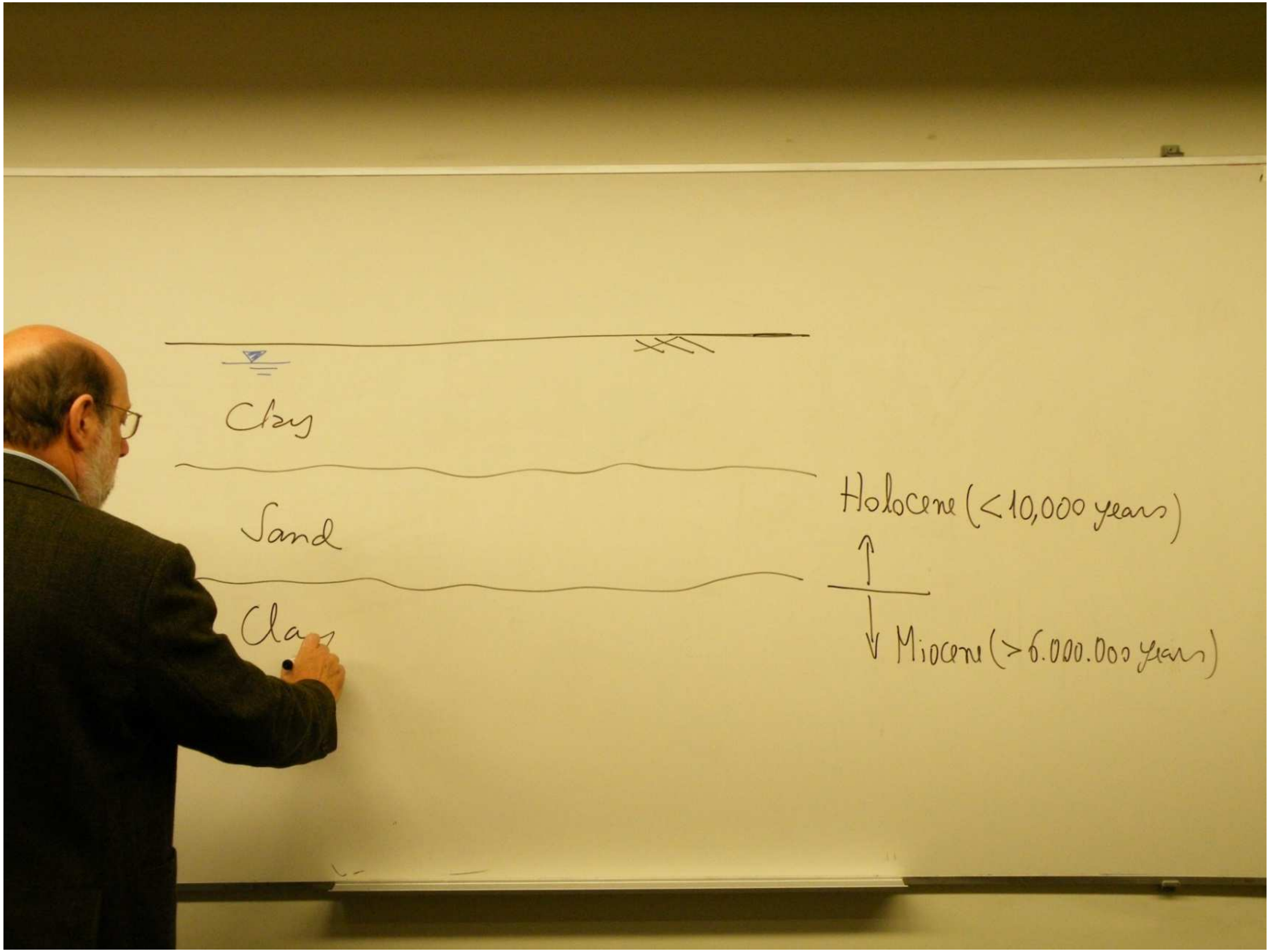
But we should in the following think macro!



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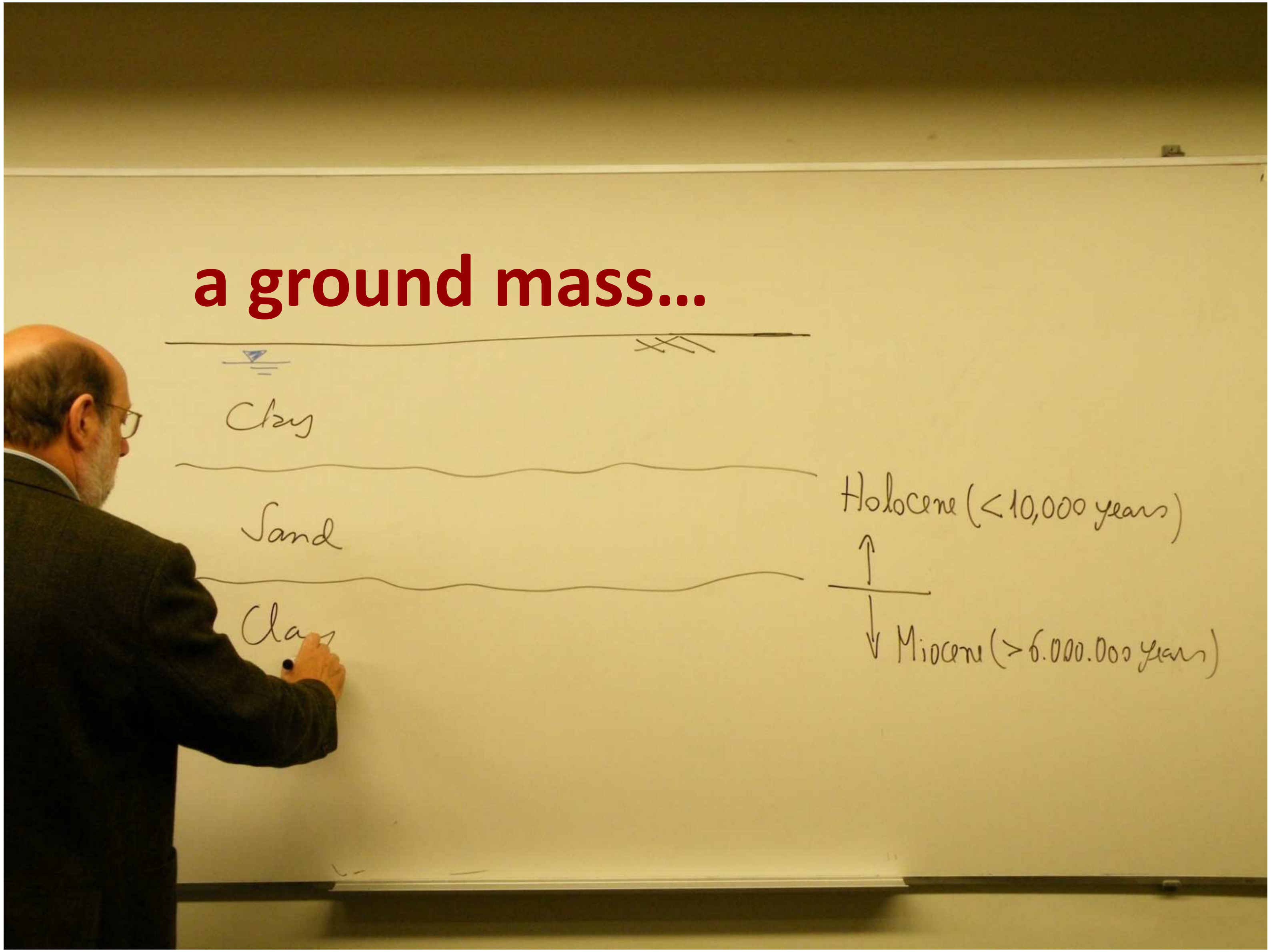

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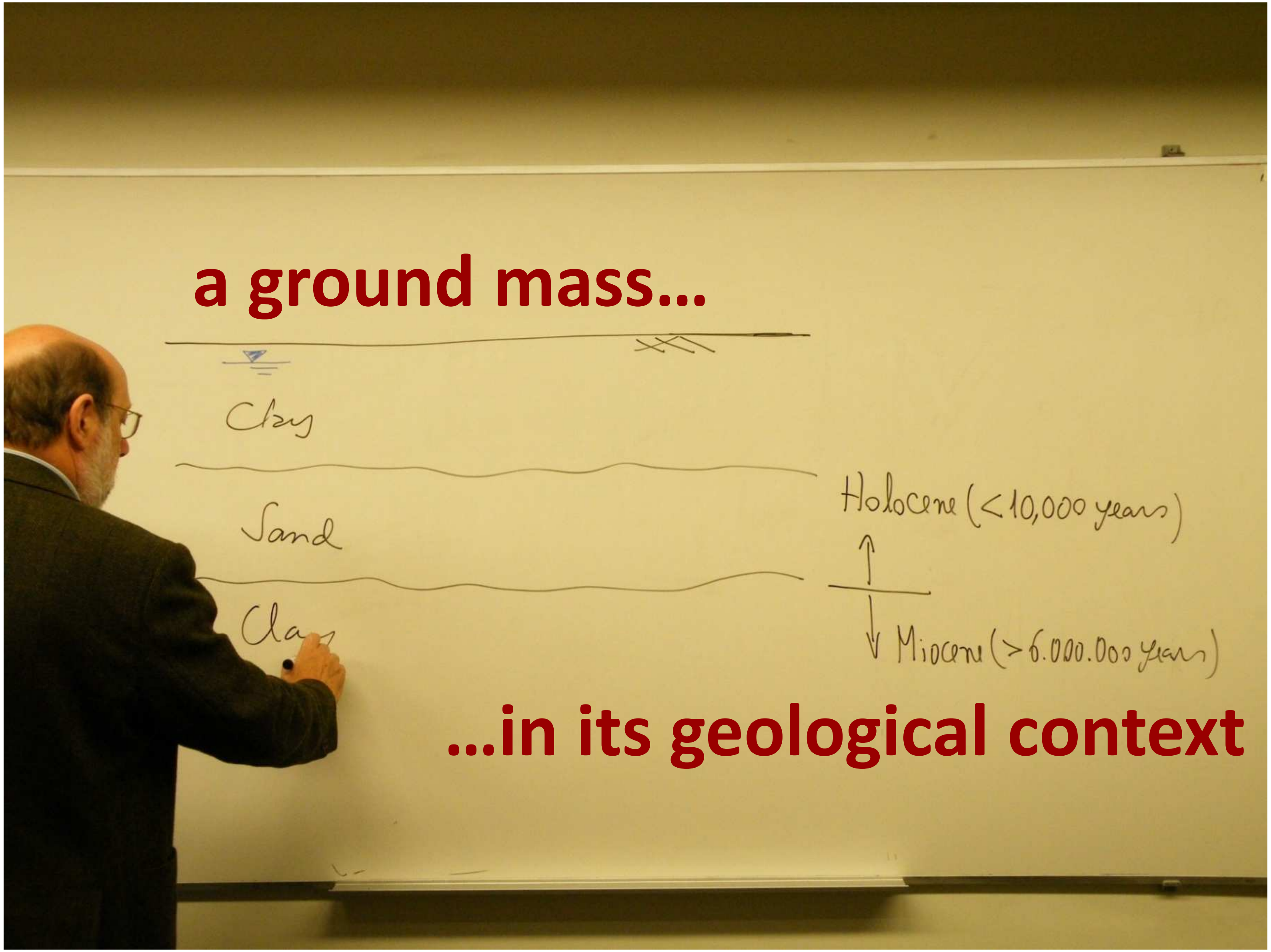

Physical indices
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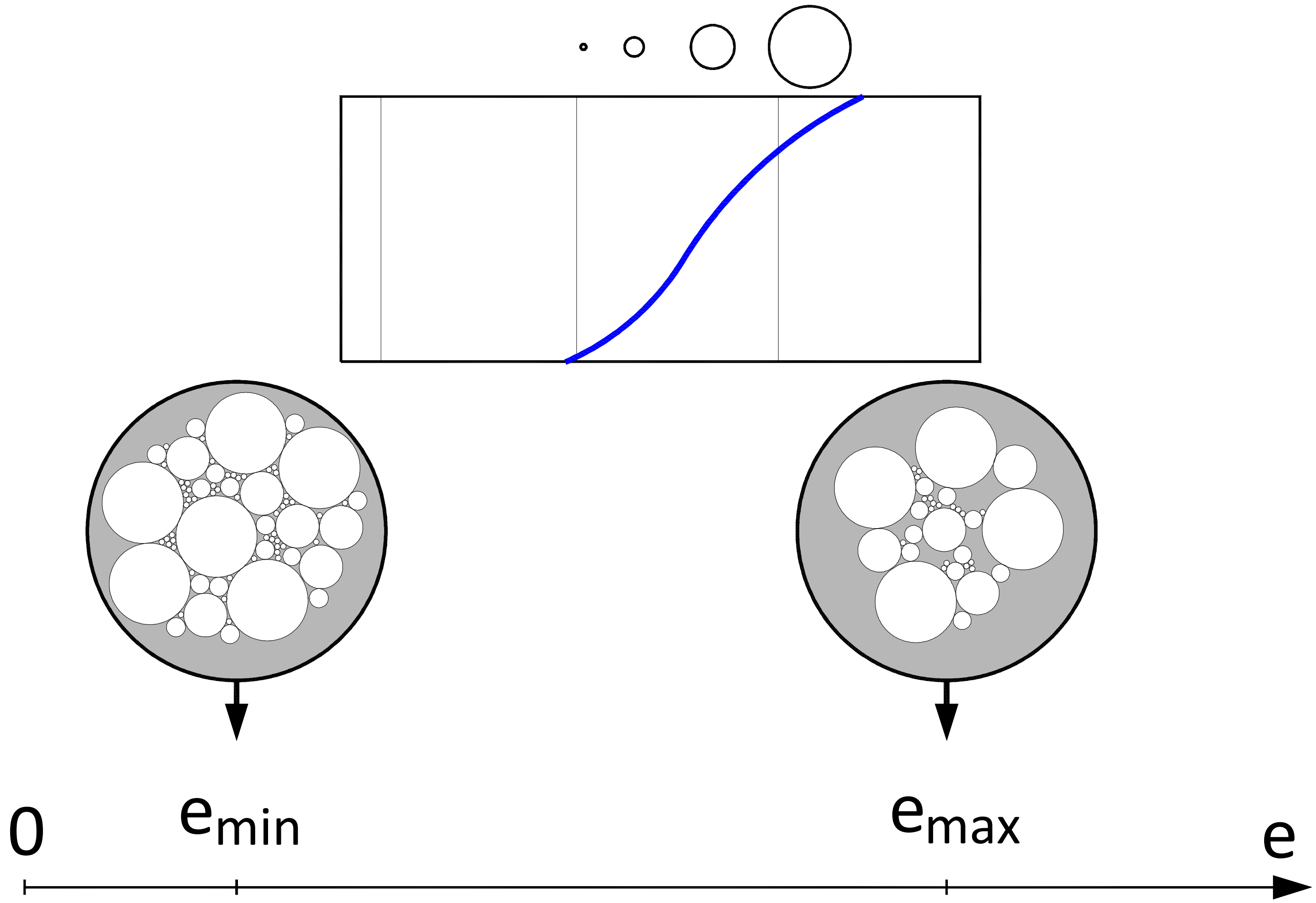
Basic trends of sedimentary sands and clays and of residual soils

Effective stress principle
Permeability
Seepage

This is a good time to discuss these matters!

Shear strength and stress-strain relationships for sands and clays

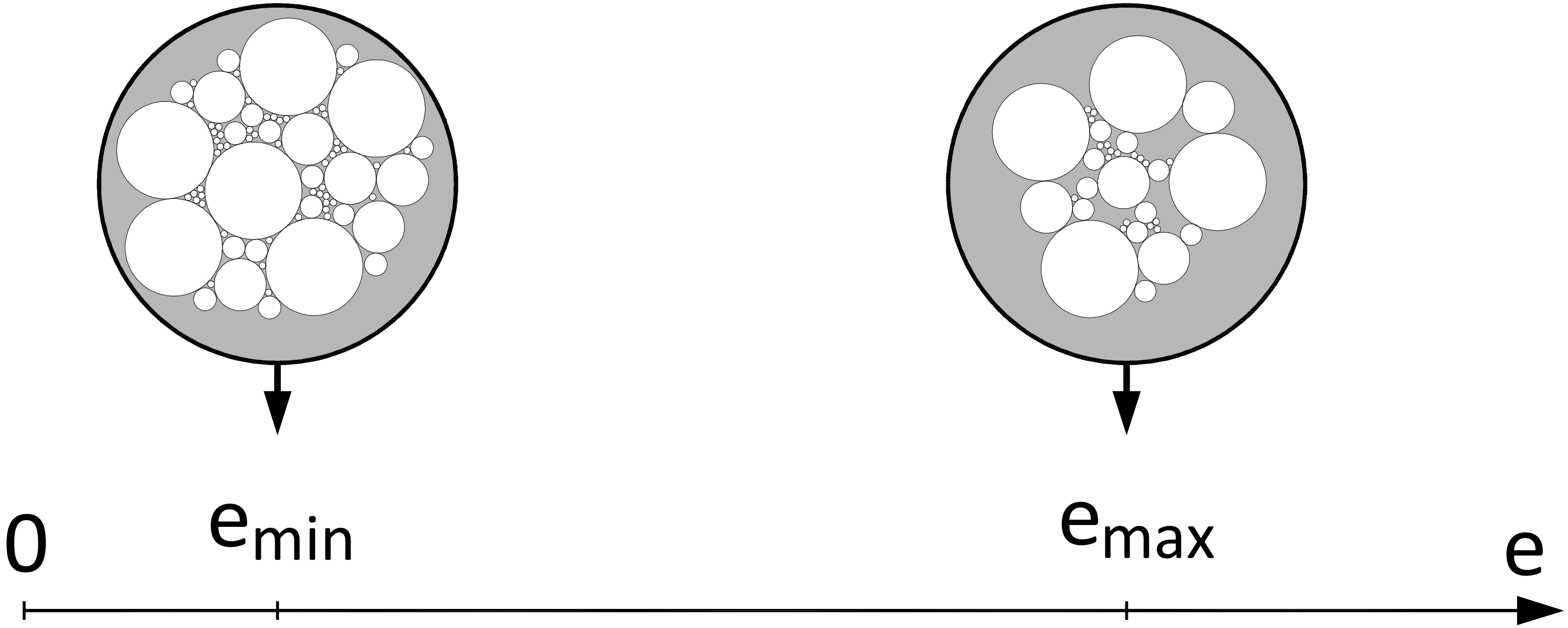
$e_{min} - e_{max}$ interval for sands



SIMPLE, ESSENTIAL, BUT OFTEN OMMITED QUESTIONS!

- **Where is the sand just after the sedimentation?**
- Which natural mechanisms lead to a progressive reduction of the void ratio?
- What are the consequences of such reduction to the response of the soil to static and dynamic loading?
- How can we prevent a poor performance if the natural void ratio is close to e_{max}?
- If at a given site we have two sandy layers, how can we compare their density index?

Where is the sand just after the sedimentation?!



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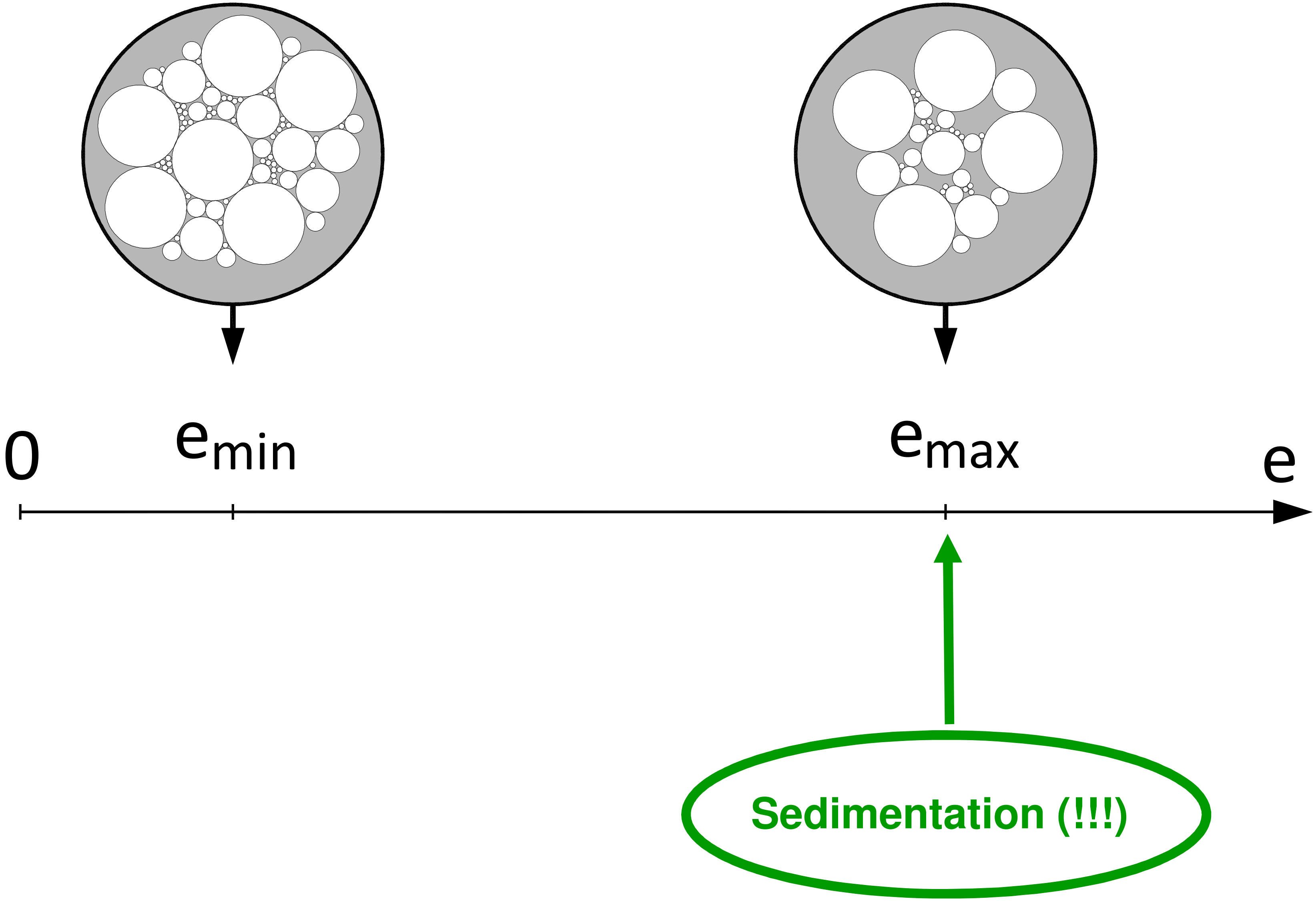

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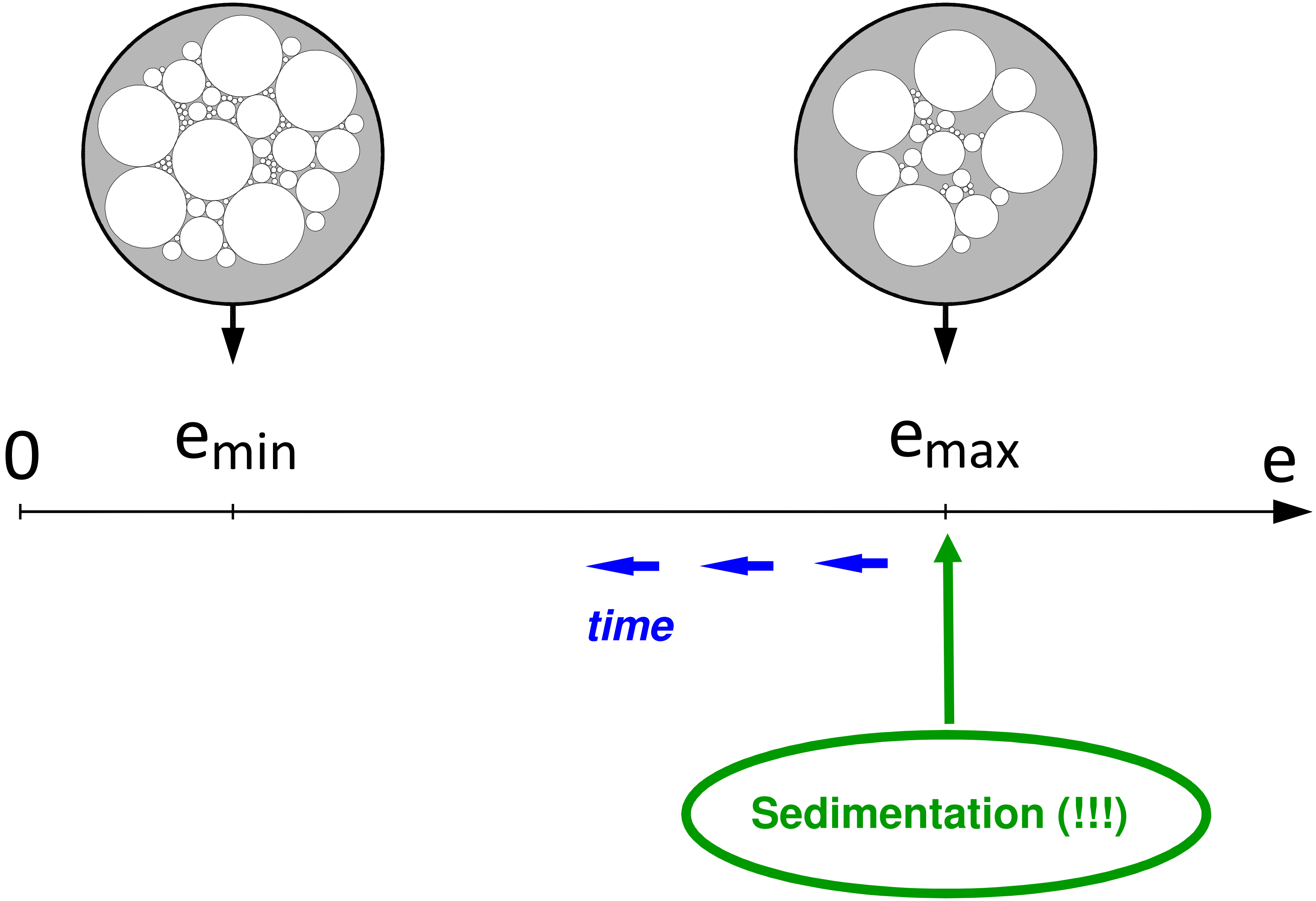

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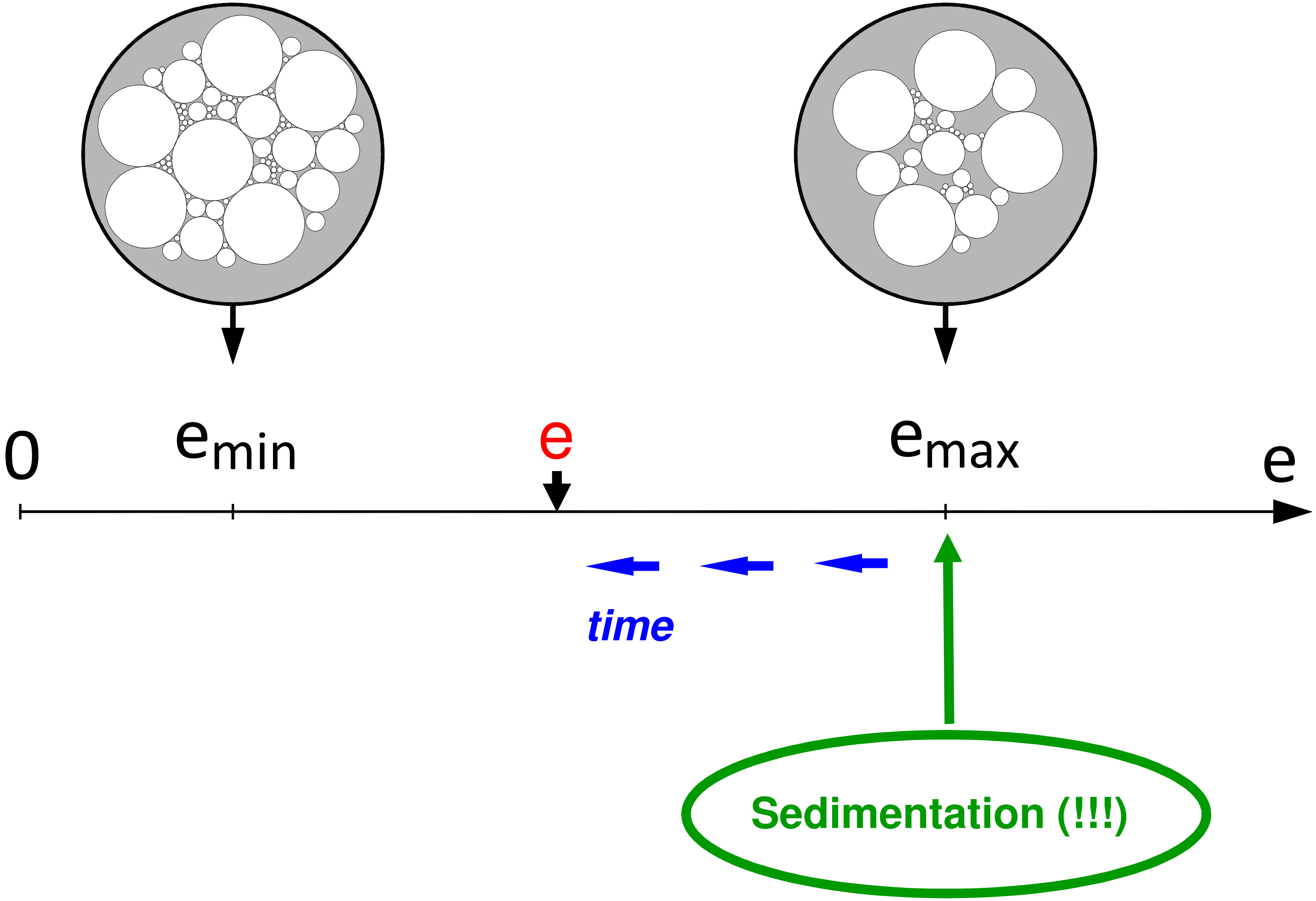

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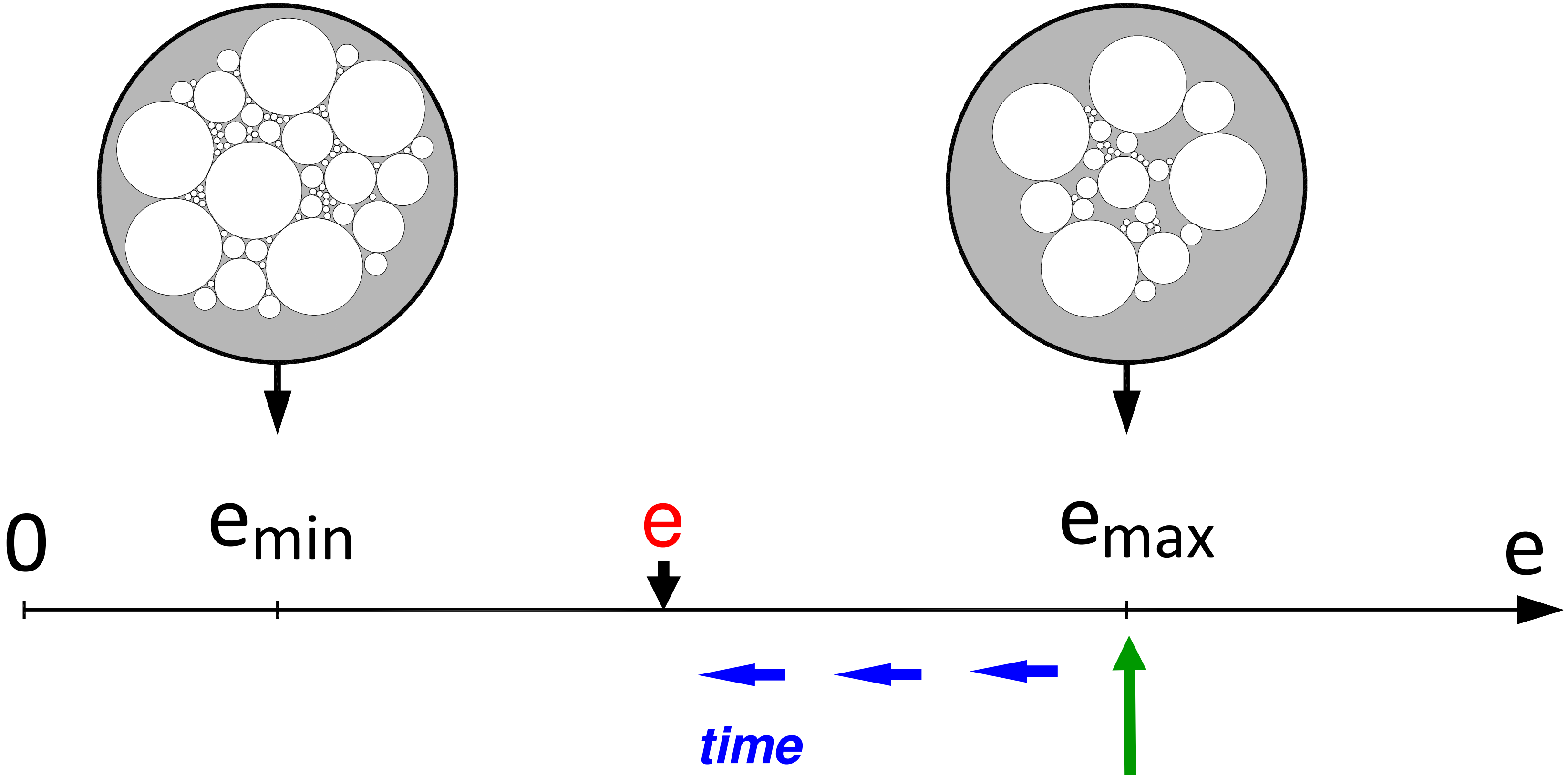
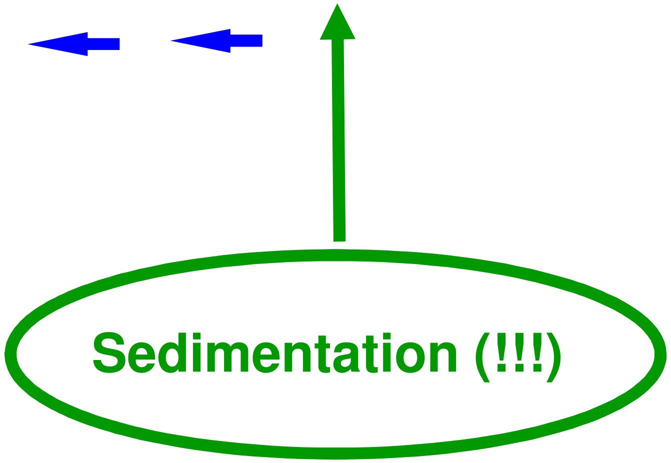


$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$$

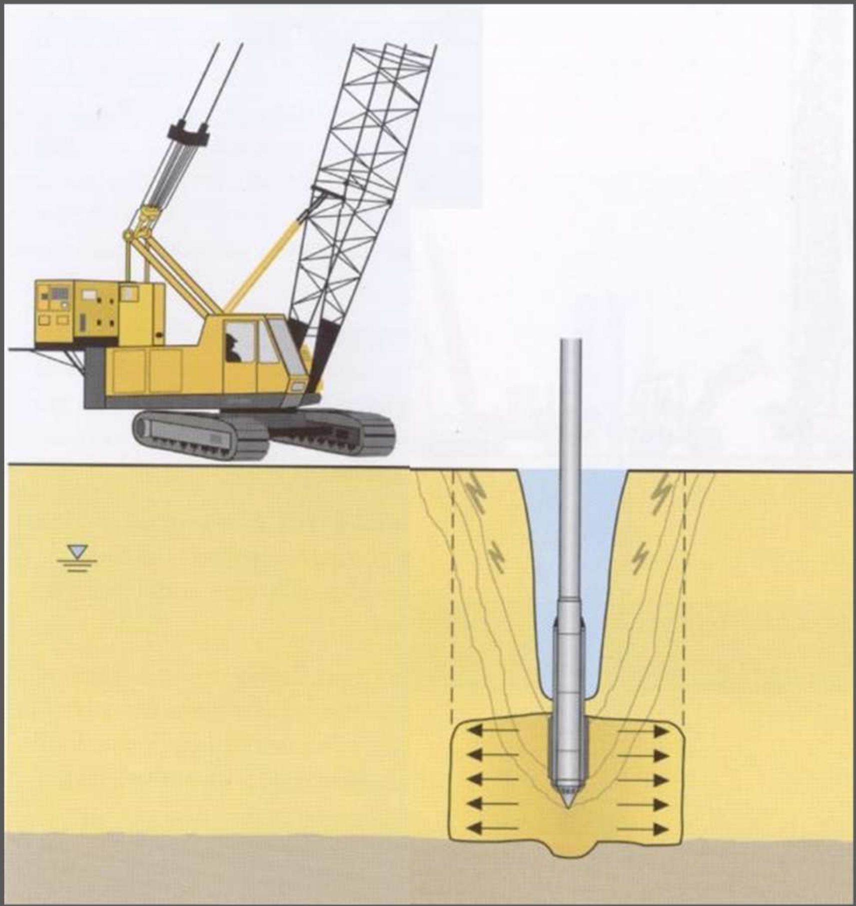


How does Nature improve loose sands?

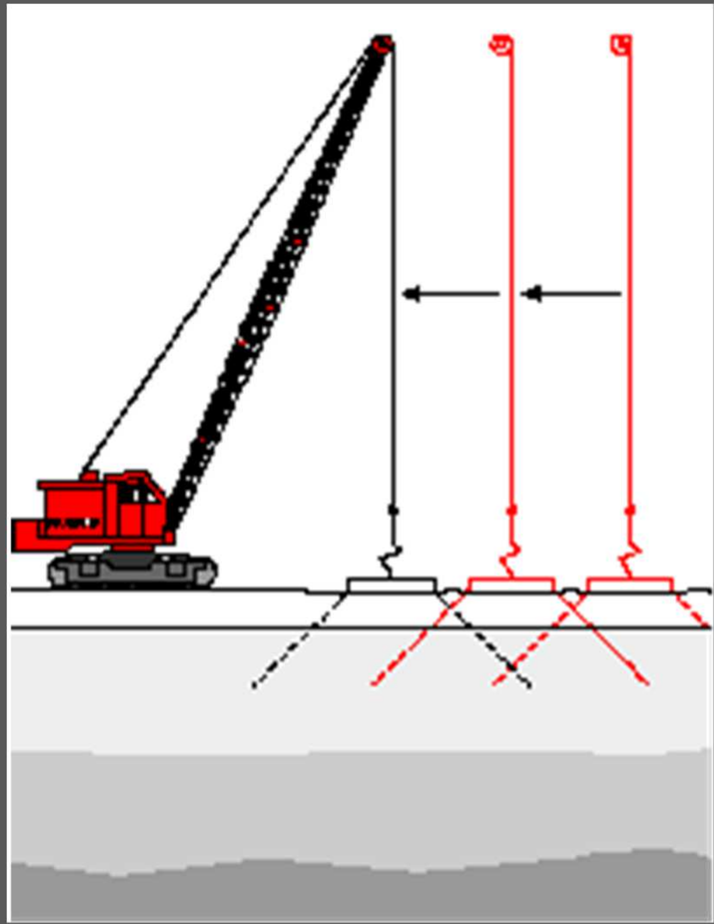
Kobe, Japan, 1995 earthquake

Photo by António Gomes Coelho

How can we prevent a poor performance if the natural void ratio is close to e_{max}?



Vibrocompaction



Dynamic compaction

SIMPLE, ESSENTIAL, BUT OFTEN OMMITED QUESTIONS!

- **Where is the sand just after the sedimentation?**
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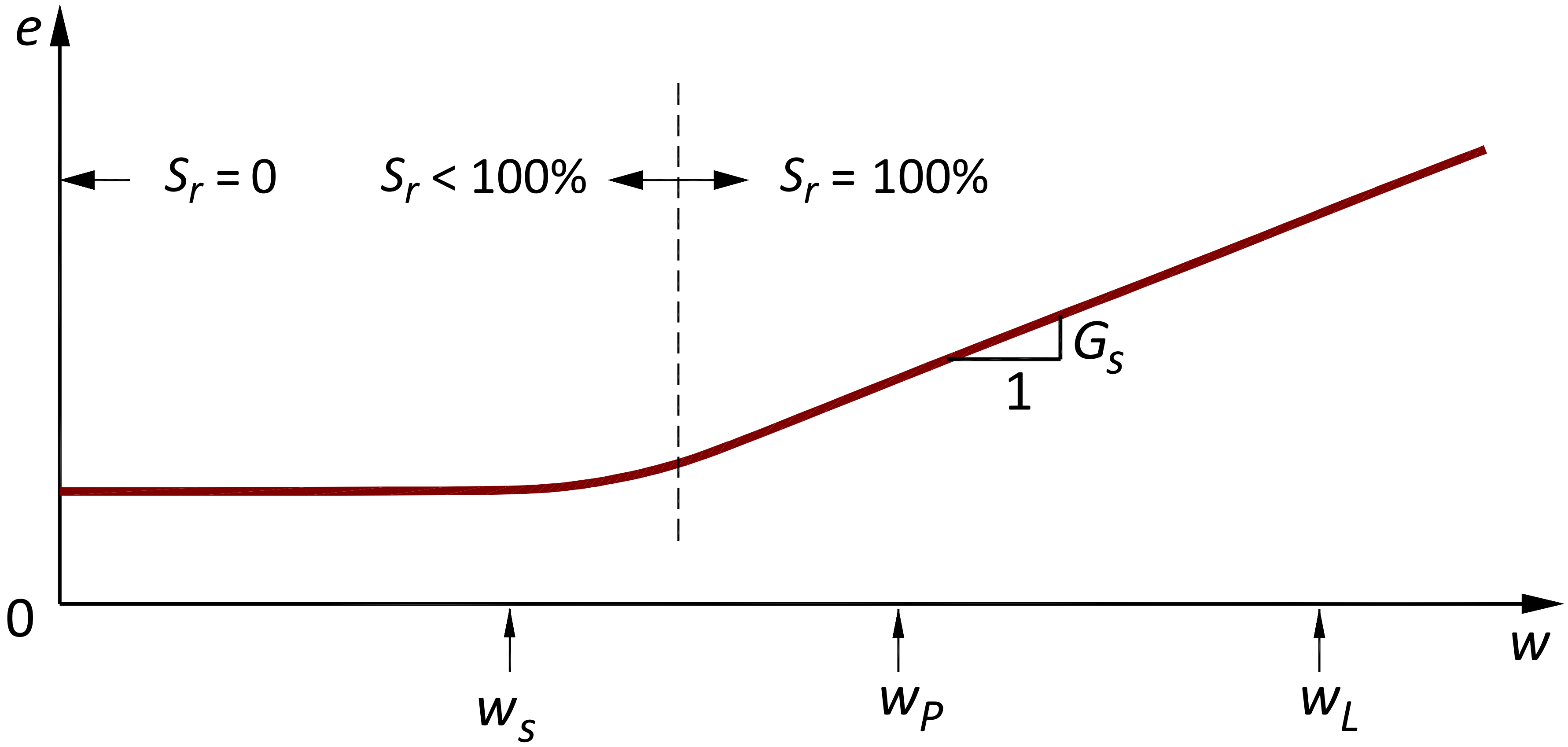
- **If at a given site we have two sandy layers how can we compare their density index?**

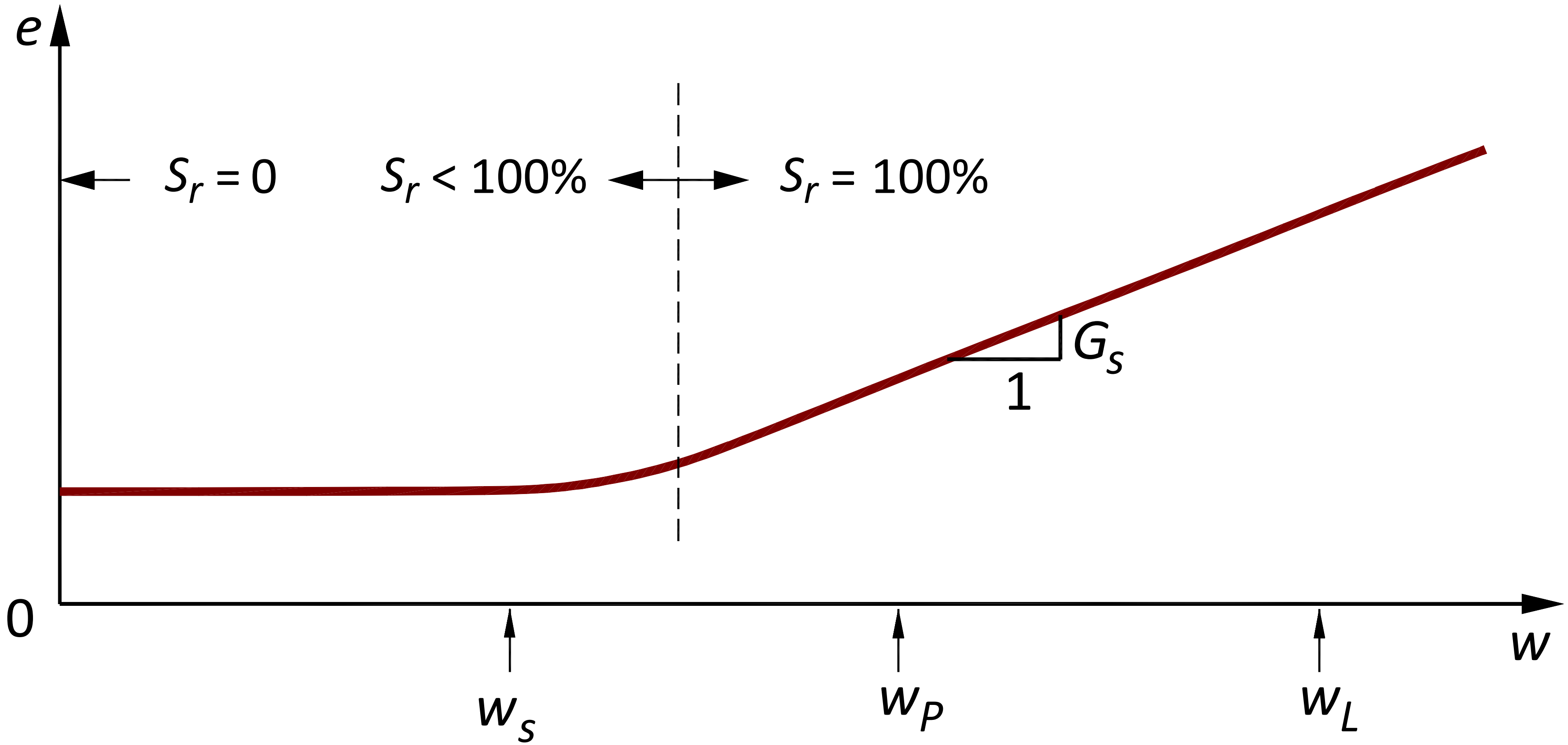
Atterberg limits for clayey soils



SIMPLE, ESSENTIAL, BUT OFTEN OMMITED QUESTIONS!

- **Where is the clay just after the sedimentation?**
- How does Nature improve clayey soils?
- What are the consequences of such reduction to the response to static loading?
- If we apply a static load on a clay whose water content is close to w_L, what can we expect?
- How can we prevent such poor performance?
- If at a given site we have two clayey layers, how can we compare their consistency index?

Where is the clay just after the sedimentation?!



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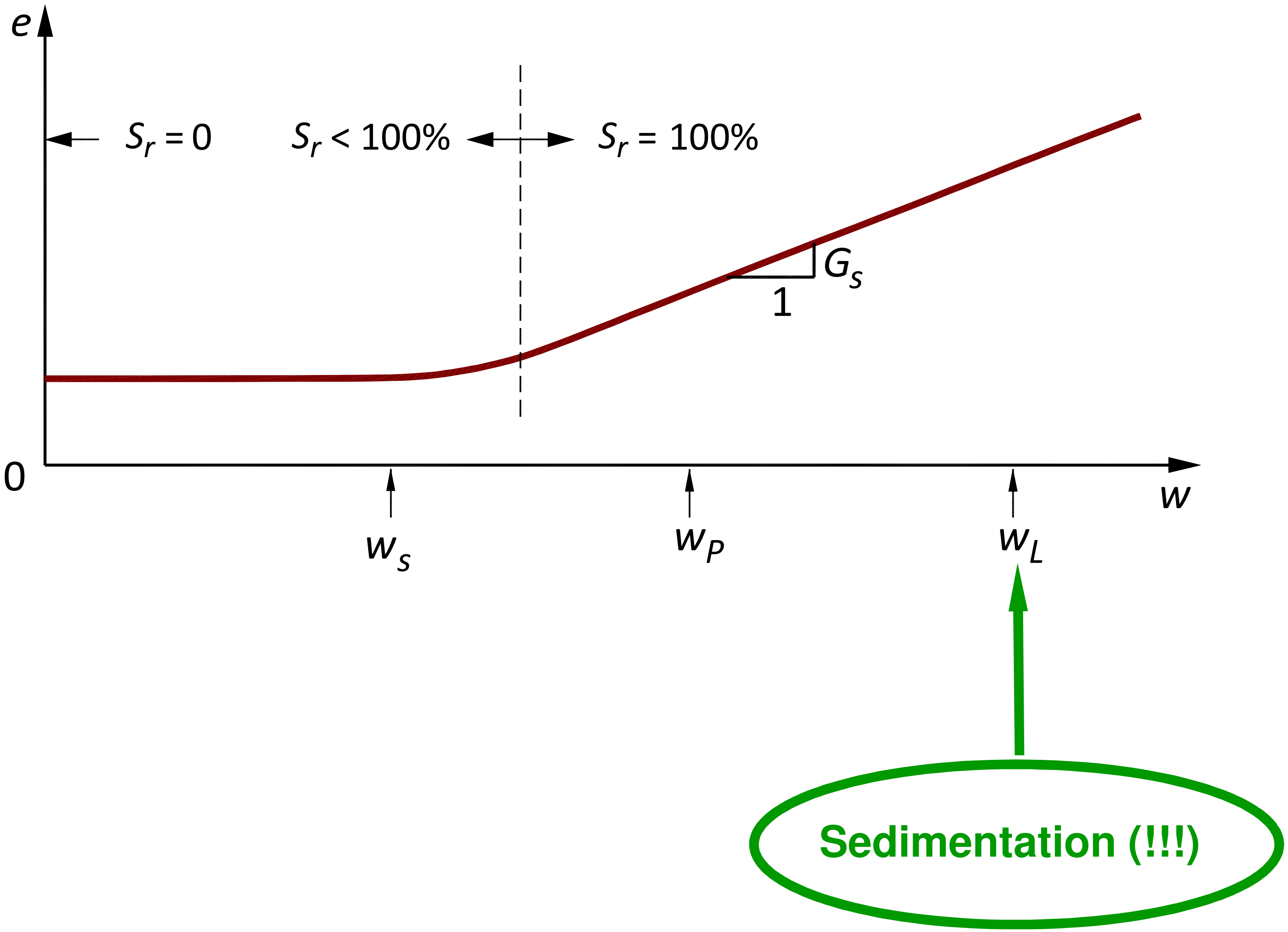

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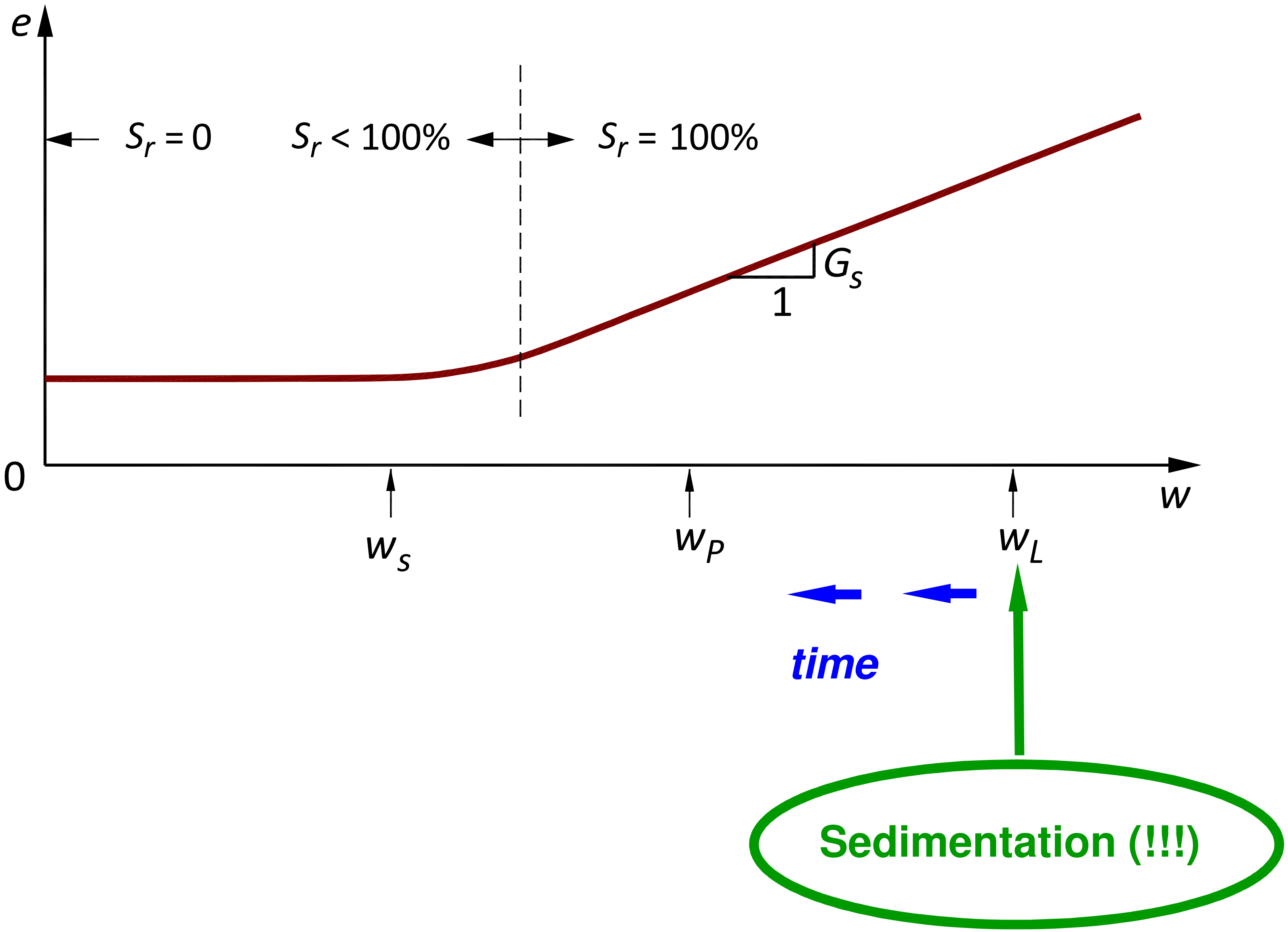

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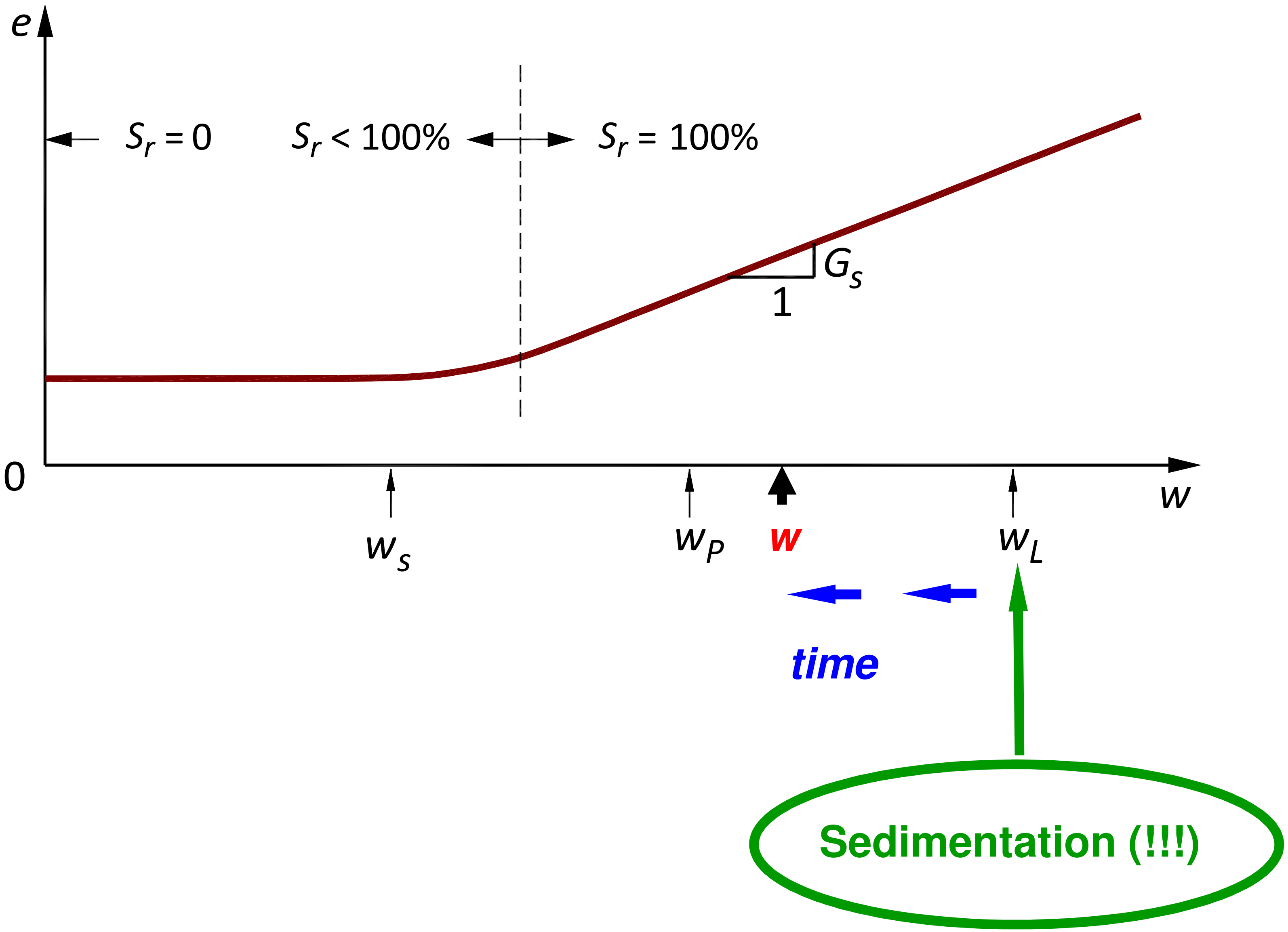

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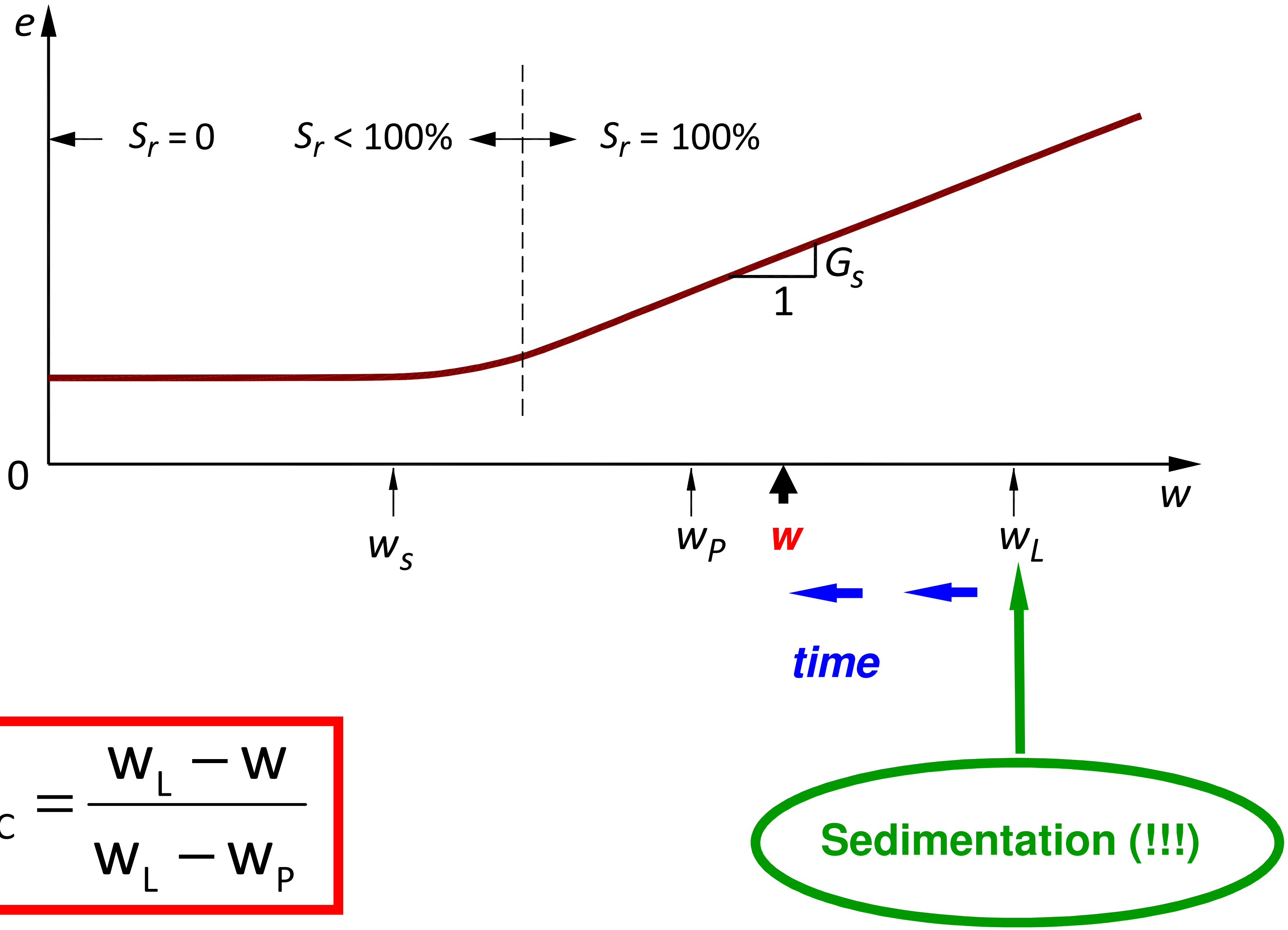
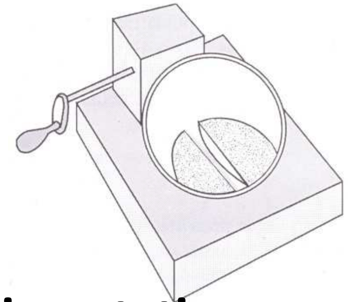


$$I_C = \frac{w_L - w}{w_L - w_P}$$

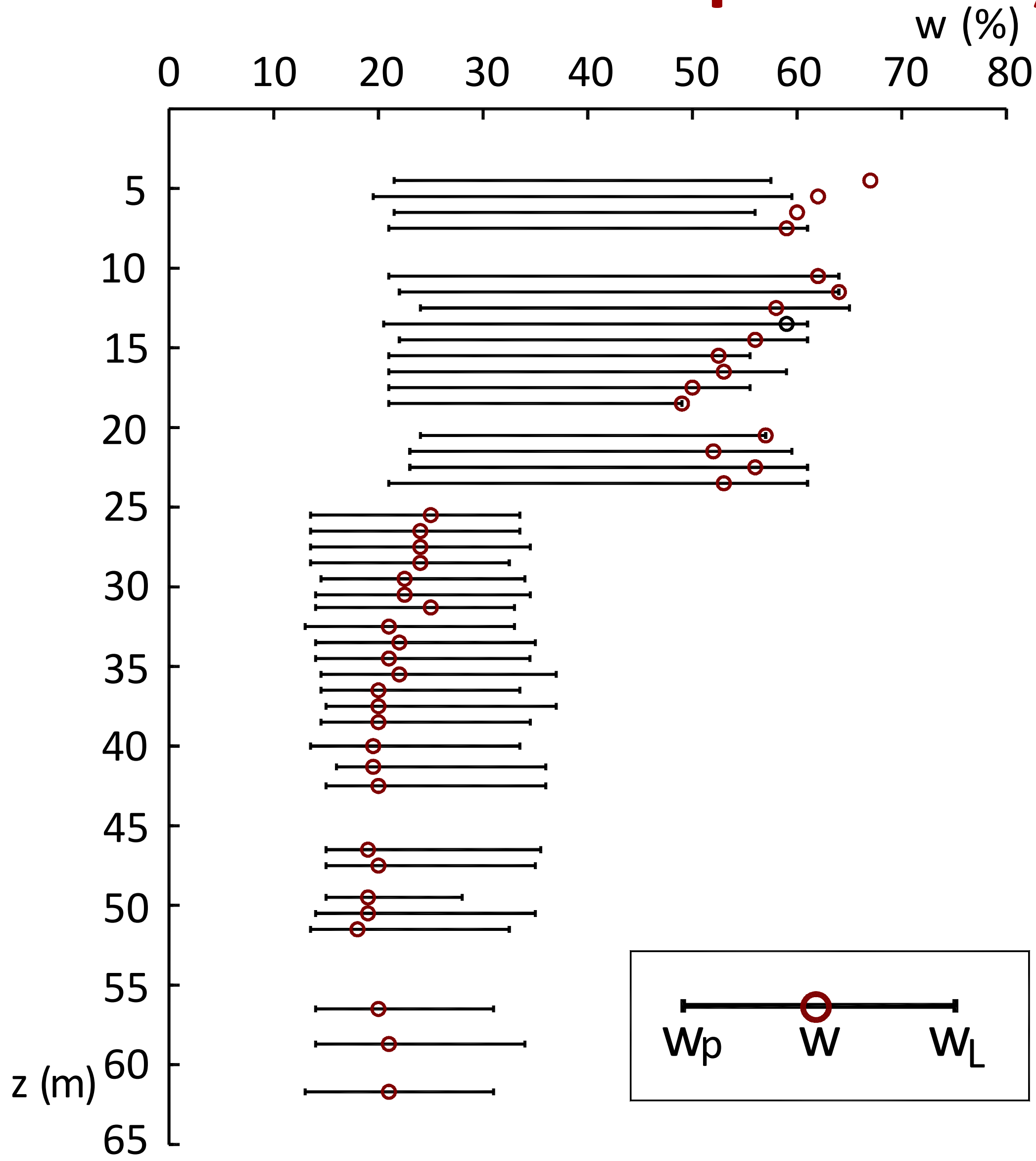
Some topics for discussion:

- **this idea is a simplification, and should be taken as a basic approximation (as will be observed in the next slide);**
- **further, there are exceptions to this idea; we will have oportunity to comment these exceptions (quick clays, etc.);**
- **if the lab test for e_{max} is basically a simulation of a grain pack of a sand that has just sedimented, why the liquid limit is determined through this strange test?!**



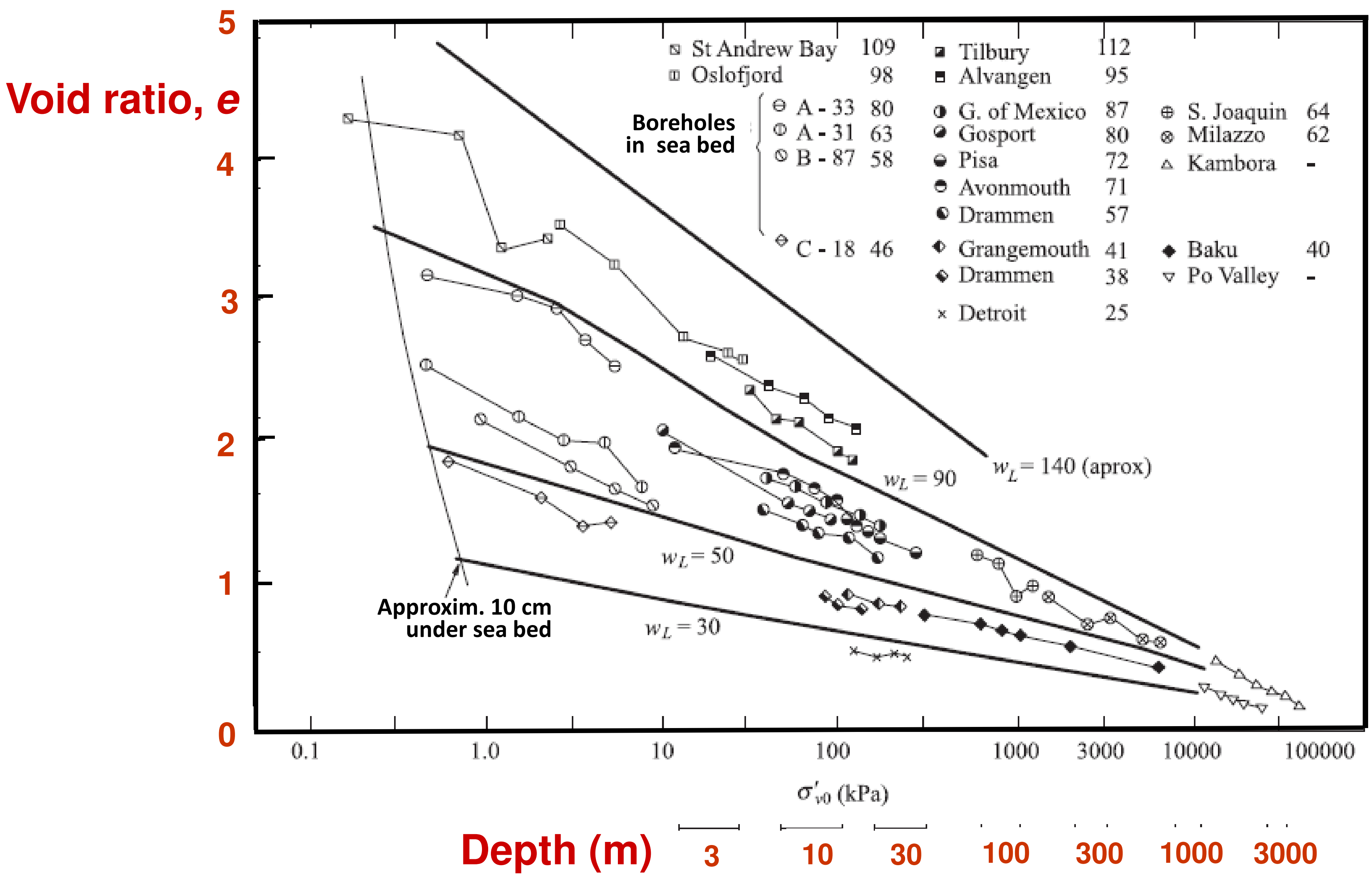
- **Since it would not be feasible to replicate in the lab the sedimentation process for fine soils, the tests for determining w_L were conceived in order to provide a result of the water content corresponding to a very small consistency of the soil.**

Where is the clay just after the sedimentation? How does Nature improve clayey soils?



Burland, 1990

How does Nature improve clayey soils?



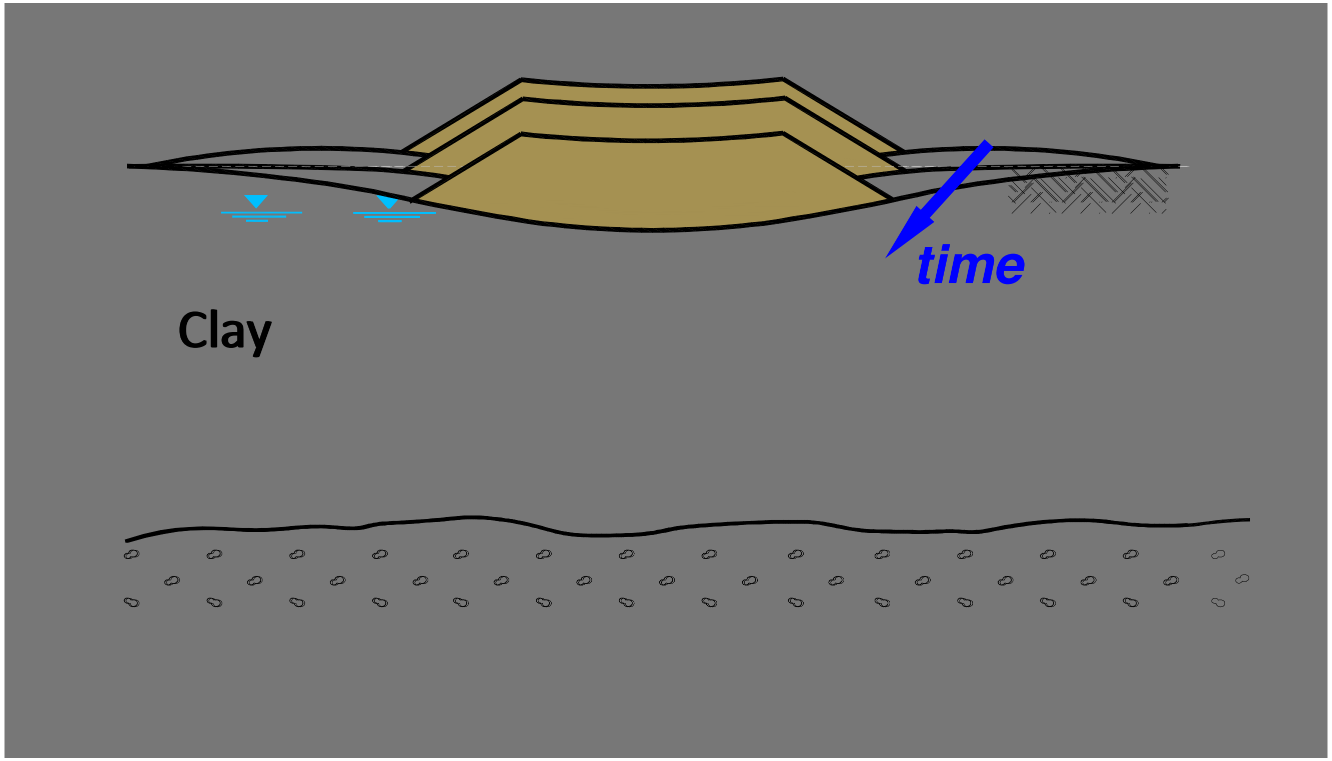
A. W. Skempton, "The consolidation of clays by gravitational compaction", 1970

If a static load is applied on a clay whose water content is close to w_L, what can be expected?

Basilica de Guadalupe and Templo de Las Capuchinas, Mexico City

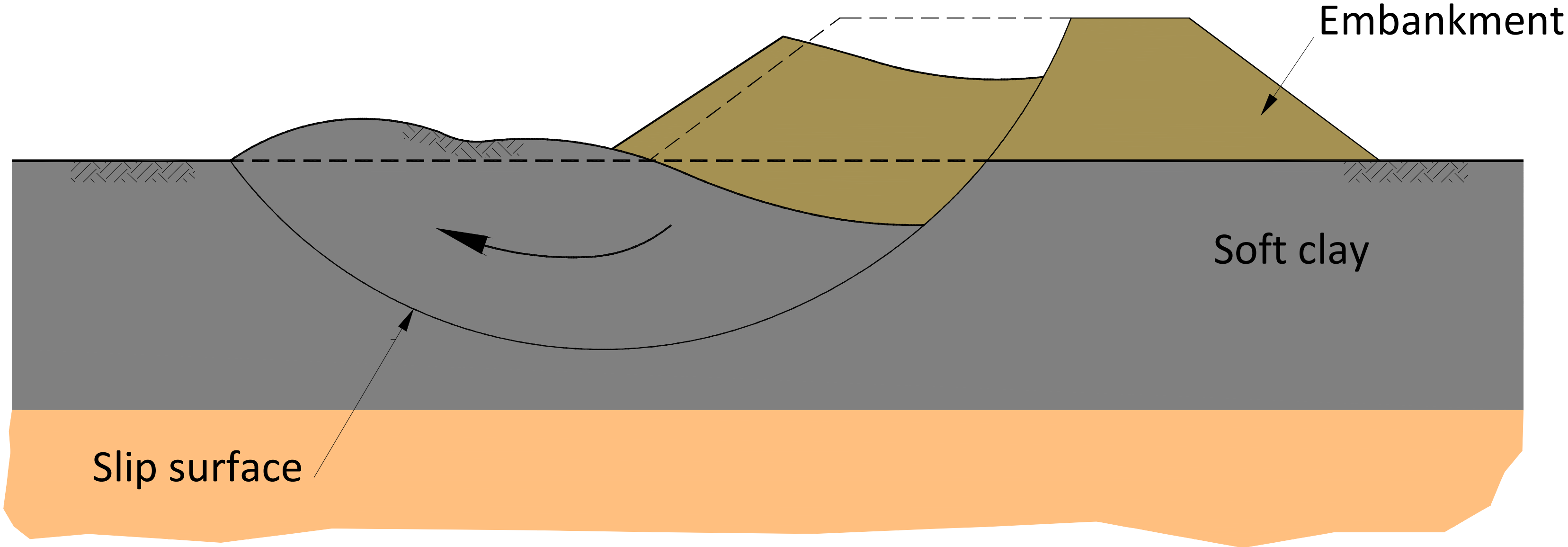
Courtesy of Sociedad Mexicana de Mecanica de Suelos

If a static load is applied on a clay whose water content is close to w_L, what can be expected?



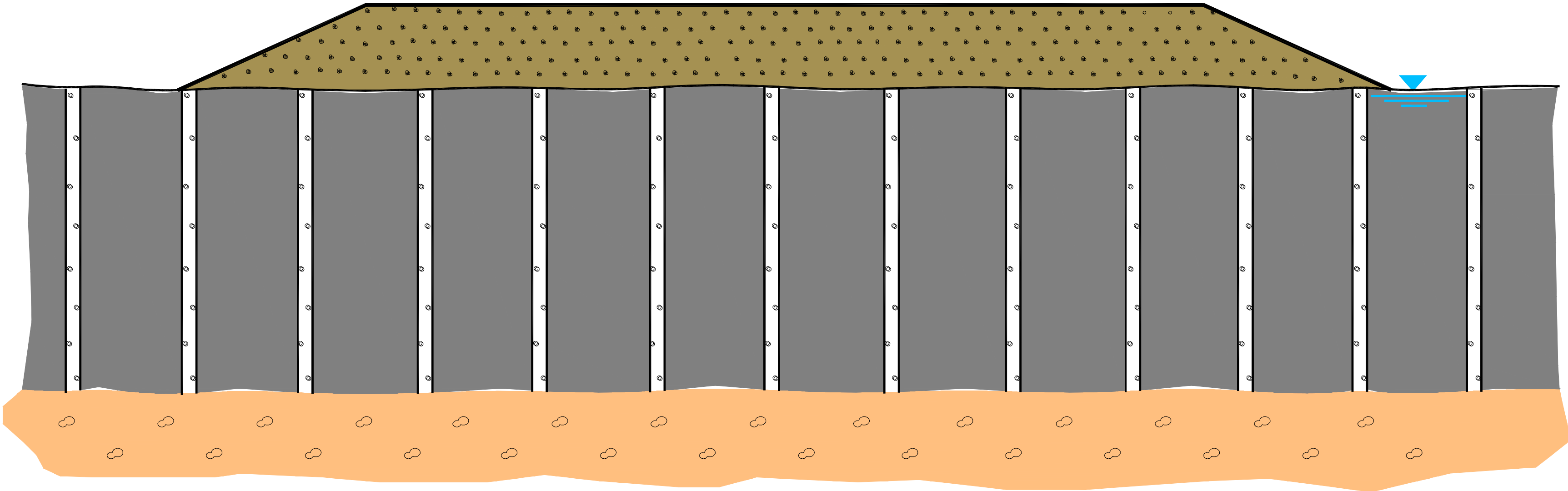
Large delayed settlements due to reduction of the water content.

If a static load is applied on a clay whose water content is close to w_L what can be expected?



... or even a slip failure involving the soft clay and the embankment.

How can we prevent such poor performance?



Settlement acceleration - vertical drains

Soil reinforcement – stone columns

SIMPLE, ESSENTIAL, BUT OFTEN OMMITED QUESTIONS!

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- How can we prevent such poor performance?
- **If at a given site we have two clayey layers, how can we compare their consistency index?**

SIMPLE, FUNDAMENTAL, but OFTEN OMMITED IDEAS!

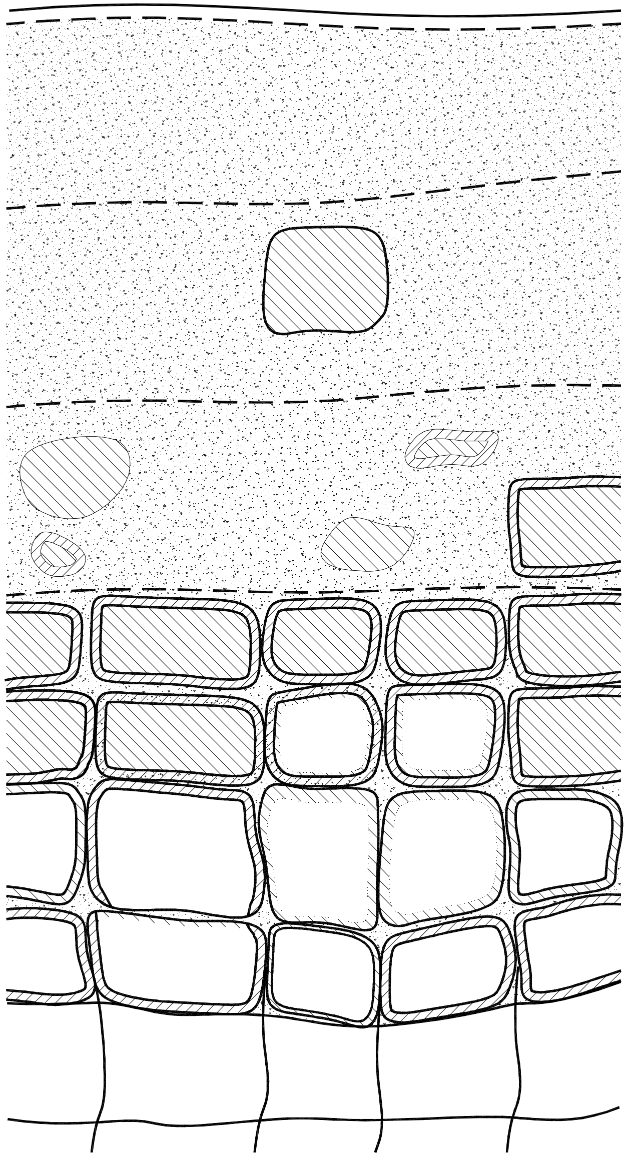
- Sedimentary soils are born in Nature very weak (loose/soft).
- They become stronger over time.
- Aged soils are typically sound soils.

THIS HAS AN OBVIOUS RELATION WITH GEOLOGICAL PERIODS/EPOCHS

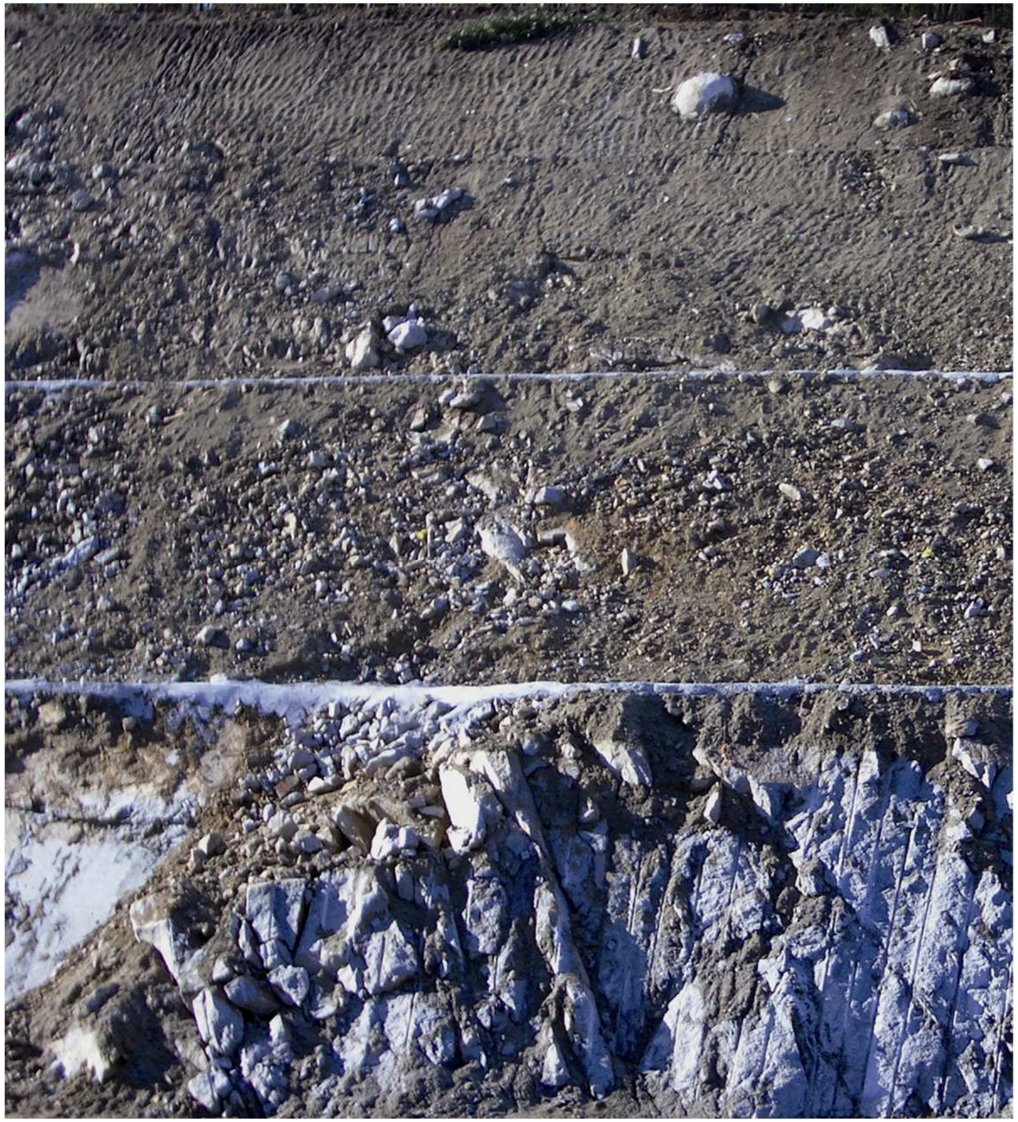
- a Holocene clay is certainly a soft clay.
- a Holocene sand is probably a loose sand.
- a Pliocene sand is likely a dense sand.
- a Eocene clay is surely a stiff/ hard clay.

In Nature, relations between Geology and Mechanics are fecund!

Residual soils from granite (saprolite)

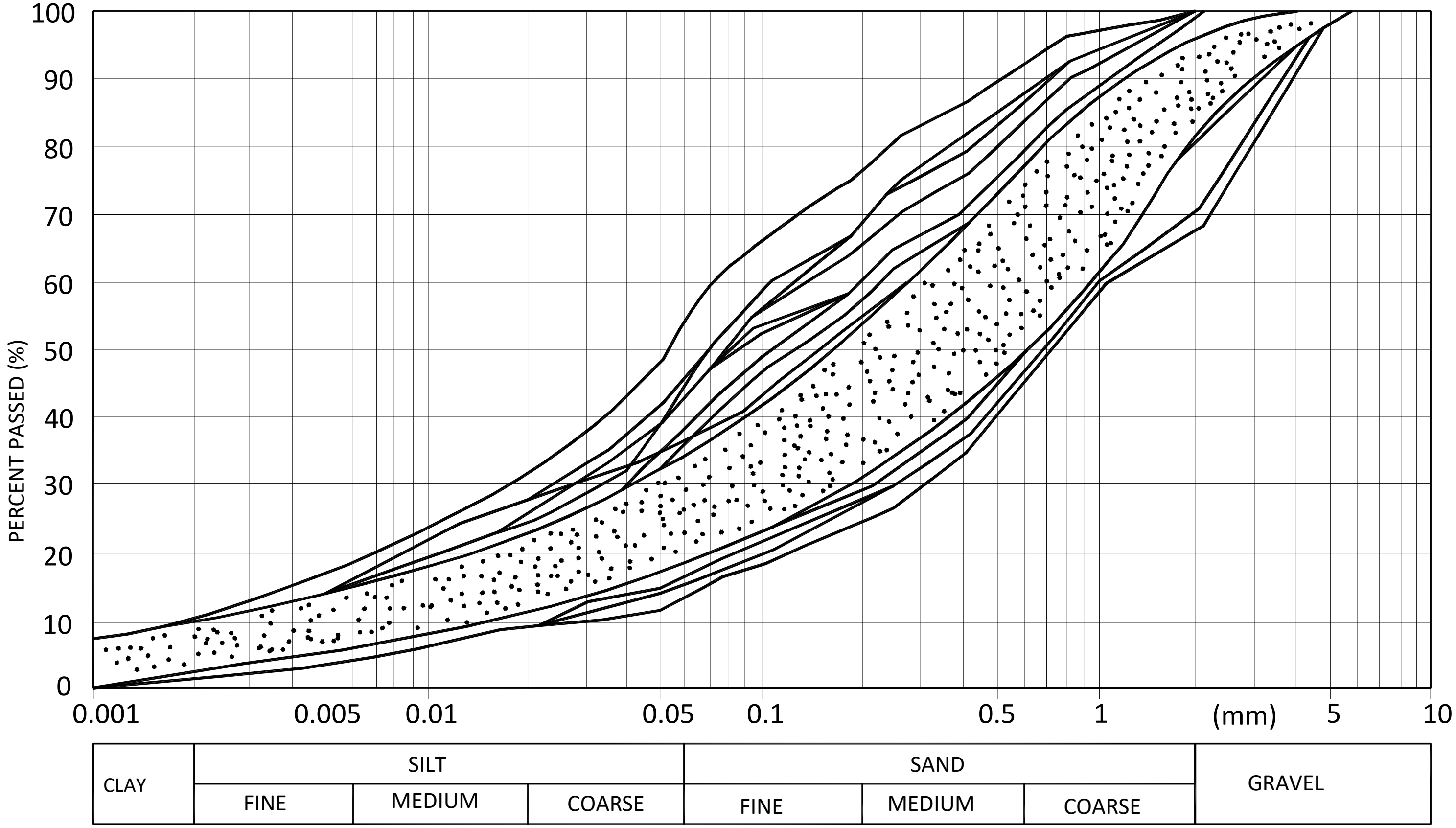


Little, 1969



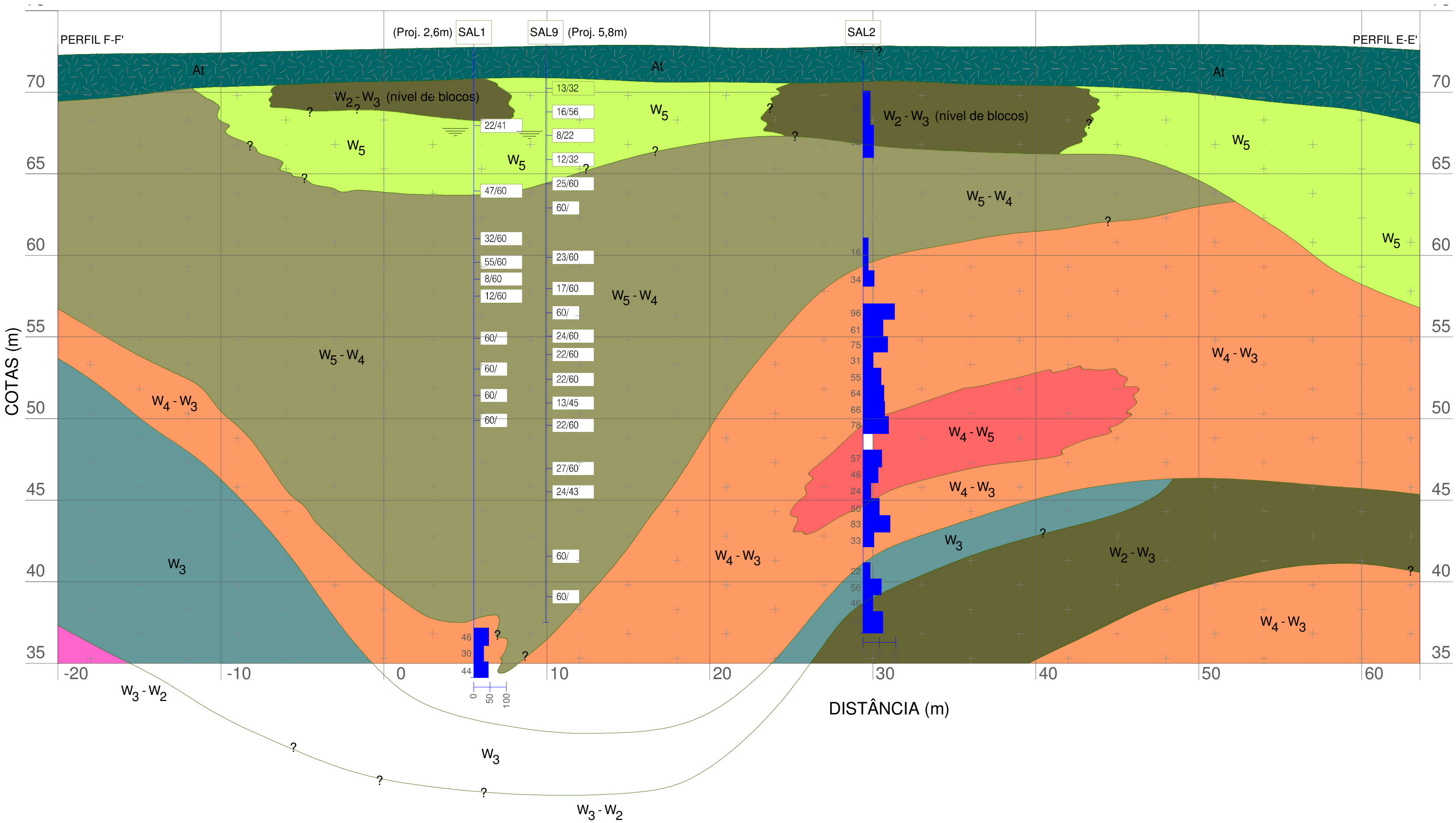
Weathering profile in northern Portugal

Residual soils from granite (saprolite)



γ_s (kN/m³)	w_L (%)	I_P (%)	w (%)	S_r (%)	e	γ (kN/m³)
25.5 – 26.7	25 - 40	< 13	10 - 30	60 - 100	0.40 – 0.85	17.0 – 22.0

Granite residual soils – typical heterogeneity



Av. Aliados, Porto, Portugal

Courtesy of Metro do Porto

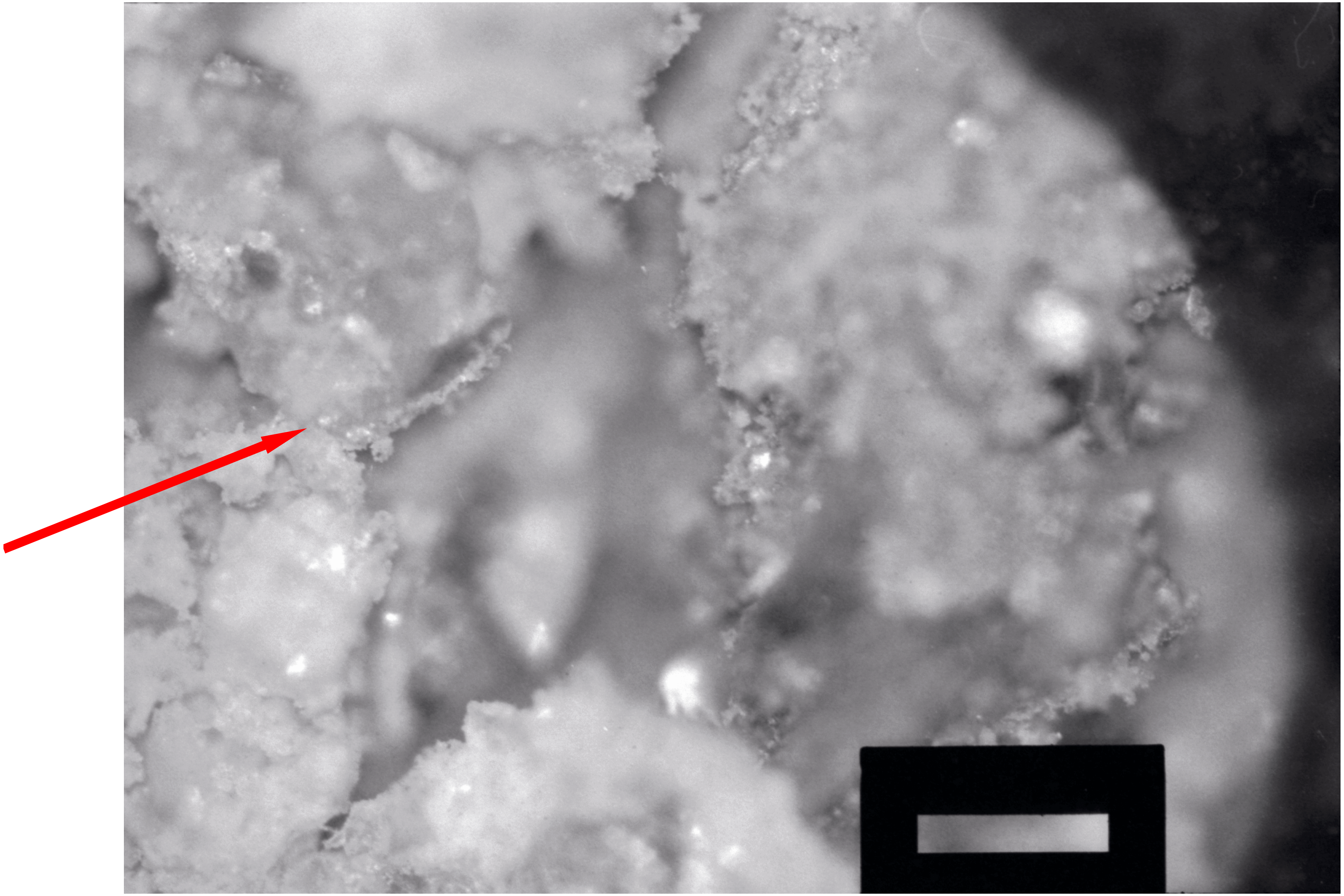


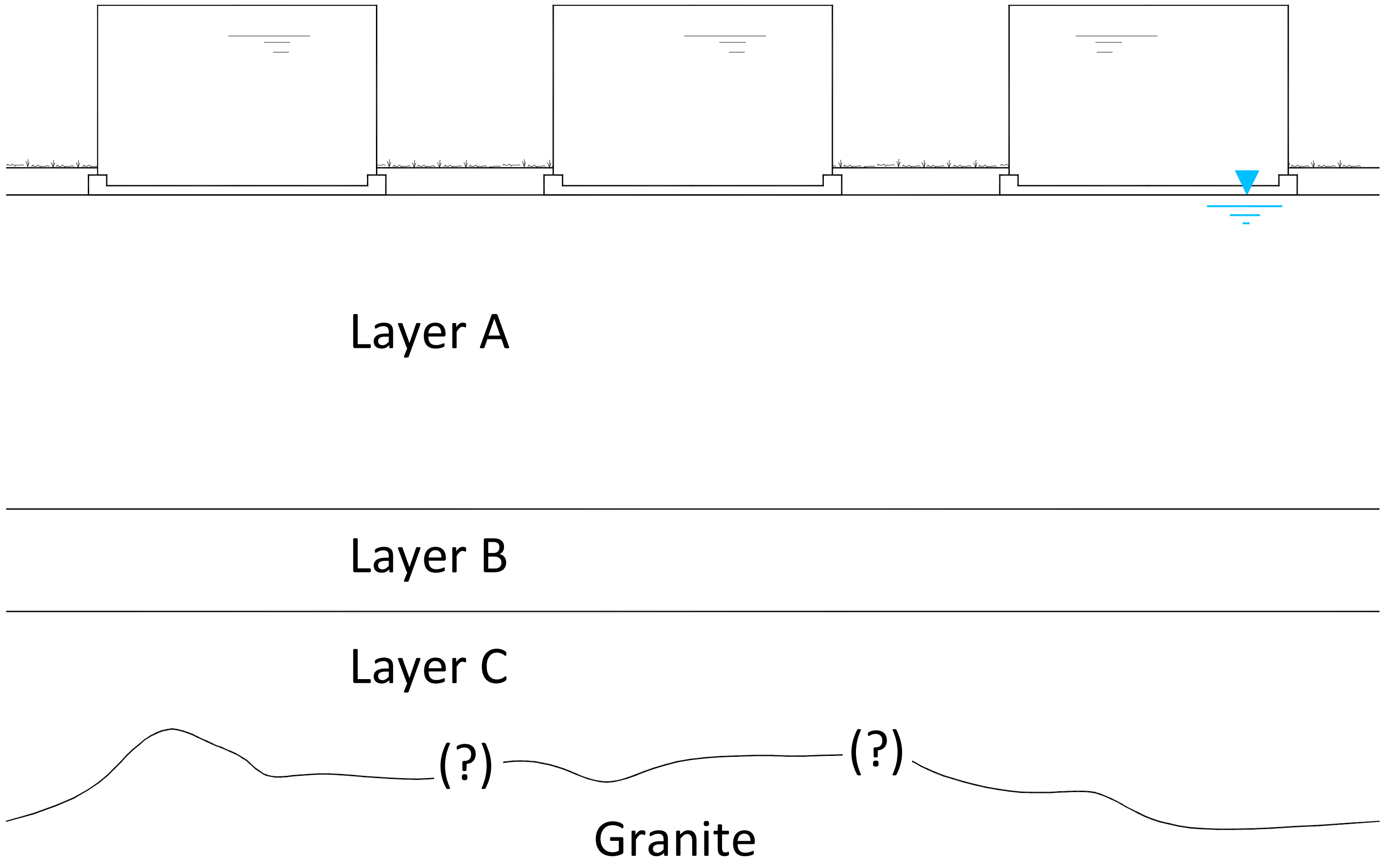
Photo by António Viana da Fonseca

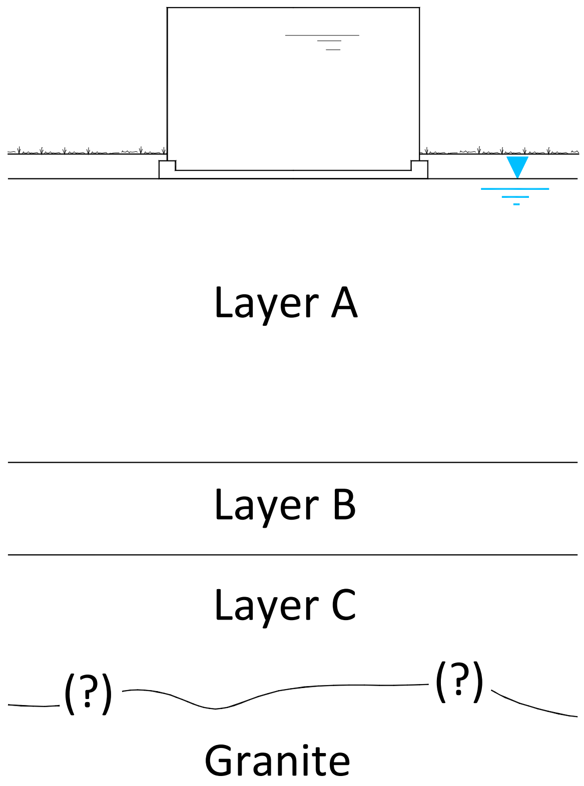
Granite saprolitic soils - relic structures

Examples of exercises solved in weeks 3 and 4 of the semester.

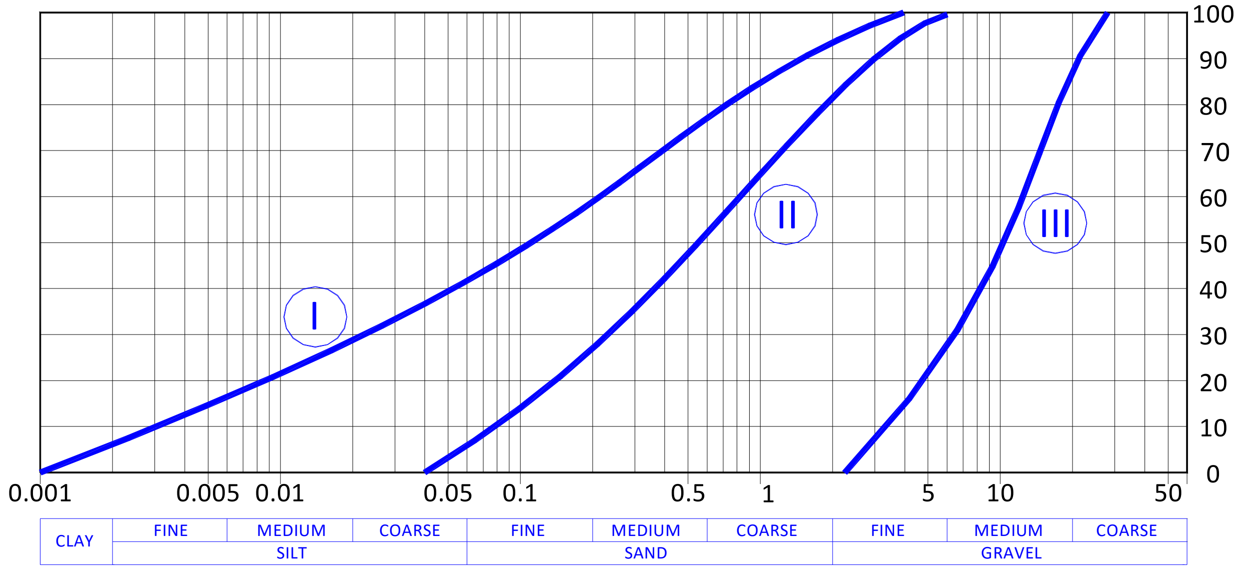
This week (week 5) students are solving a short test with similar questions.

Example 1: Cylindrical storage tank installation over sedimentary and residual soils on a granite substratum.

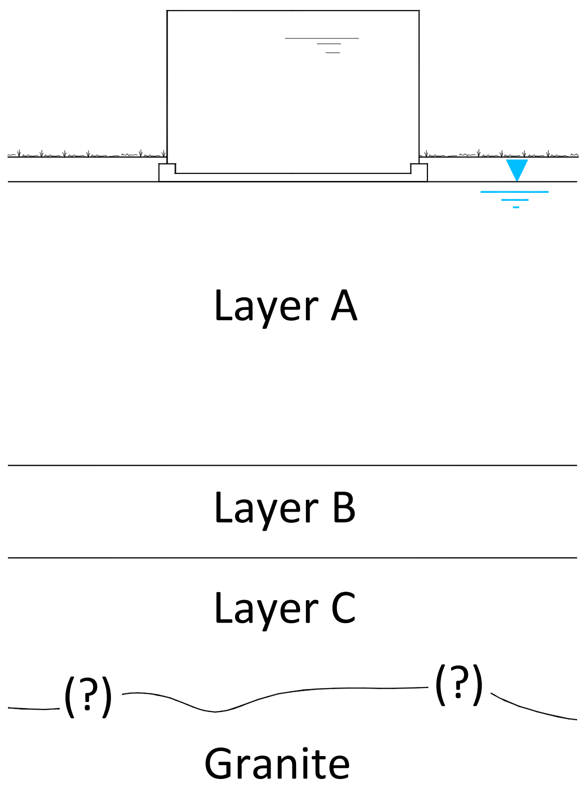




Soil	w (%)	γ_s (kN/m³)	w_L (%)	w_P (%)	e_{min}	e_{max}
1 (sedim.)	19	26.1	---	---	0.40	0.98
2 (residual)	23	25.8	34	25	---	---
3 (sedim.)	18	26.0	---	---	0.20	0.89



- Establish the most plausible correspondence between the soils of the table and the grain size curves.



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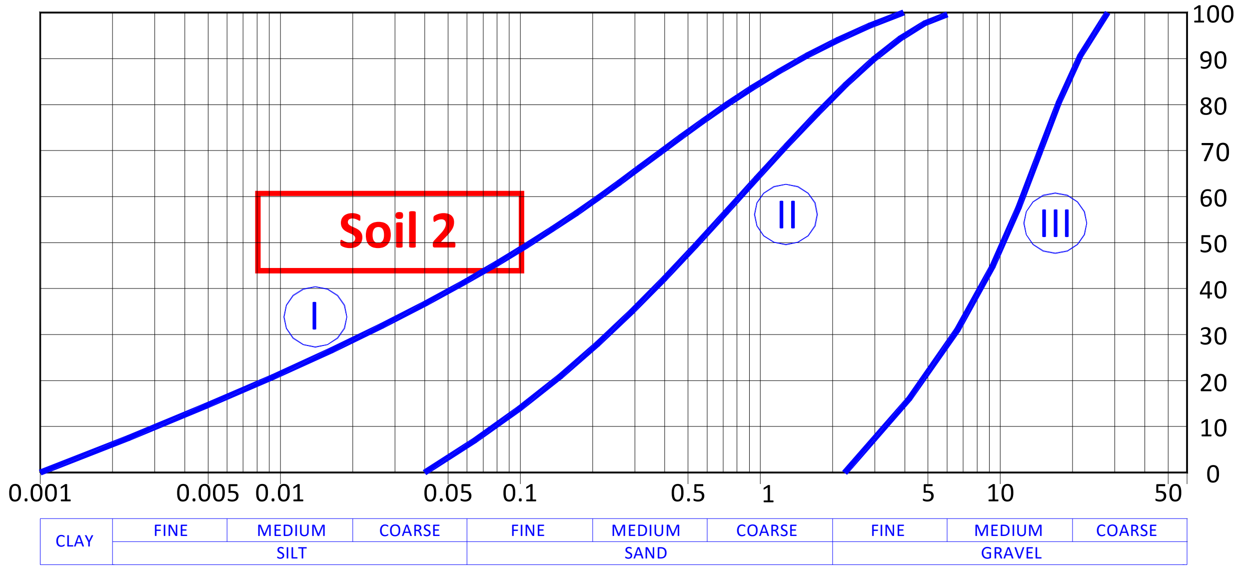

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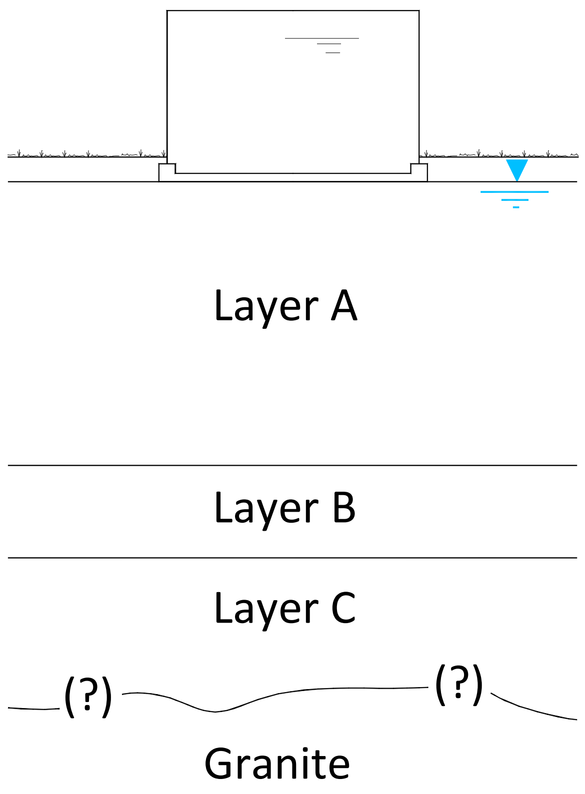

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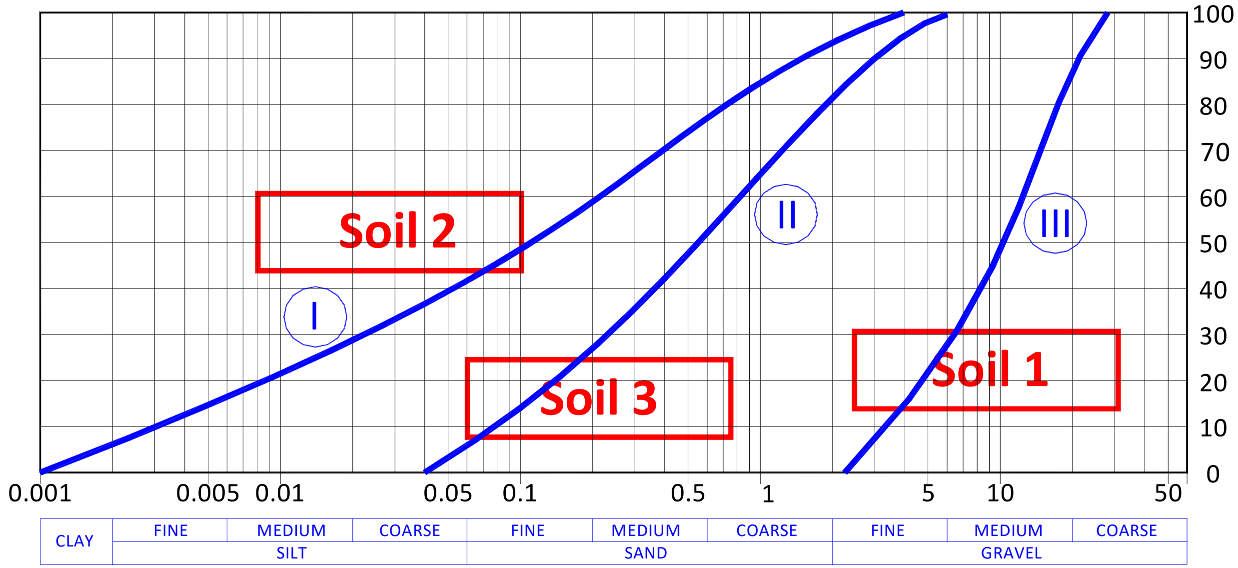

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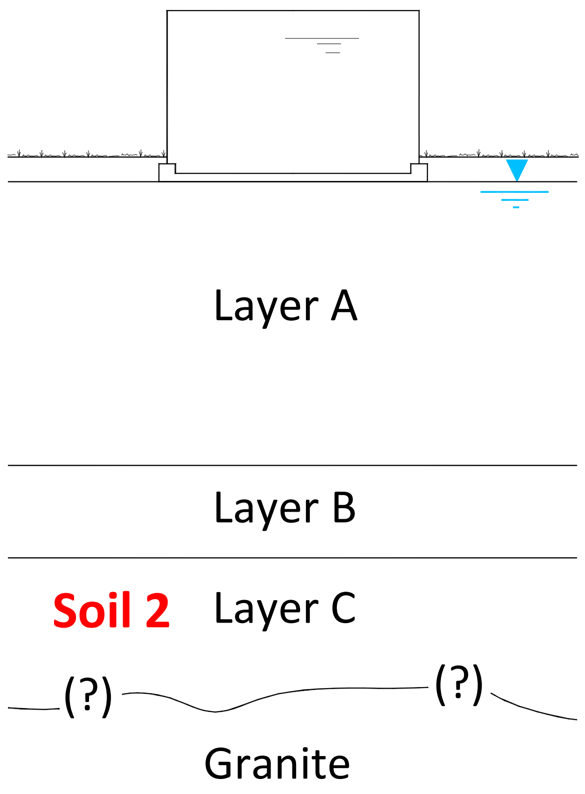

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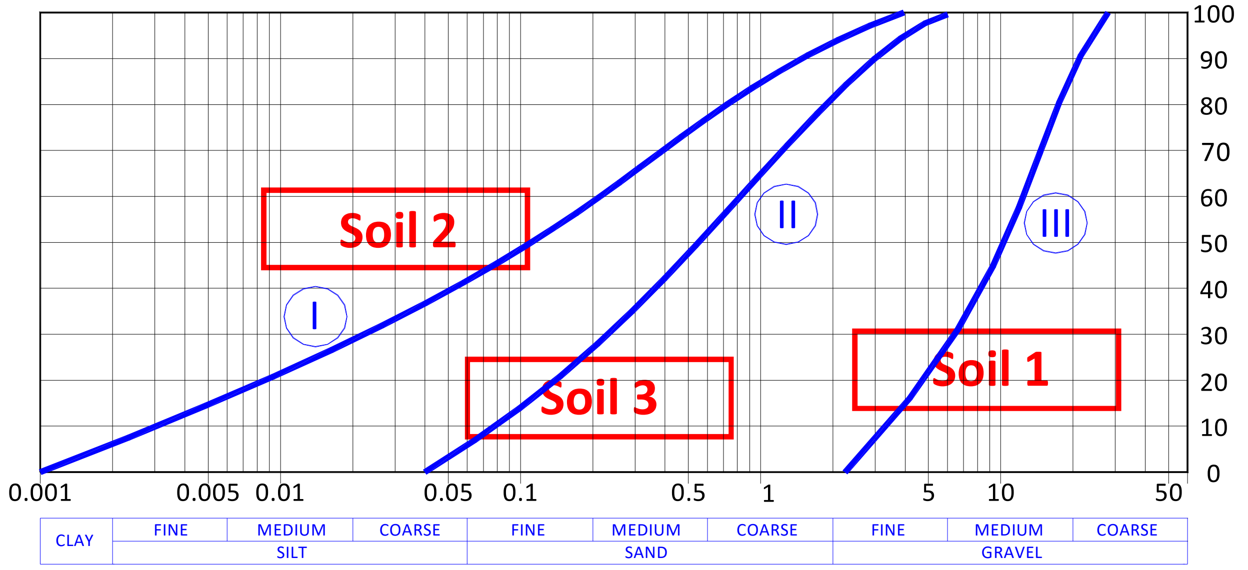
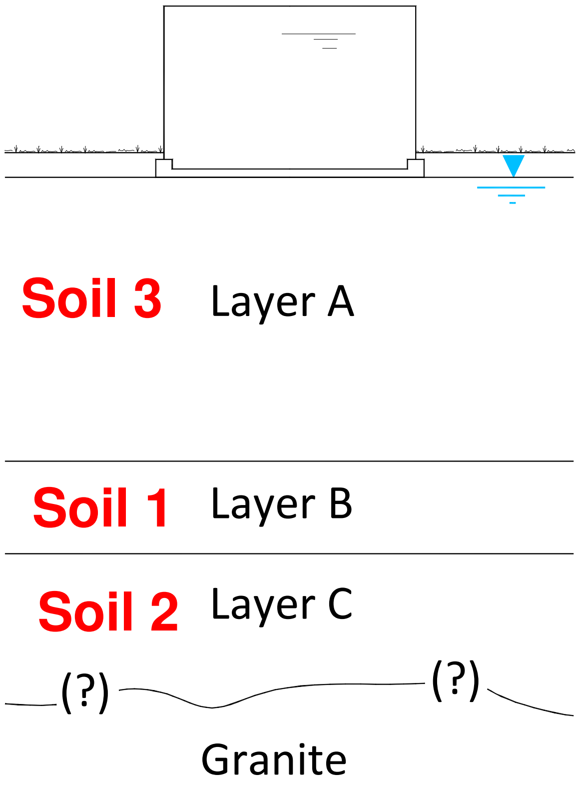
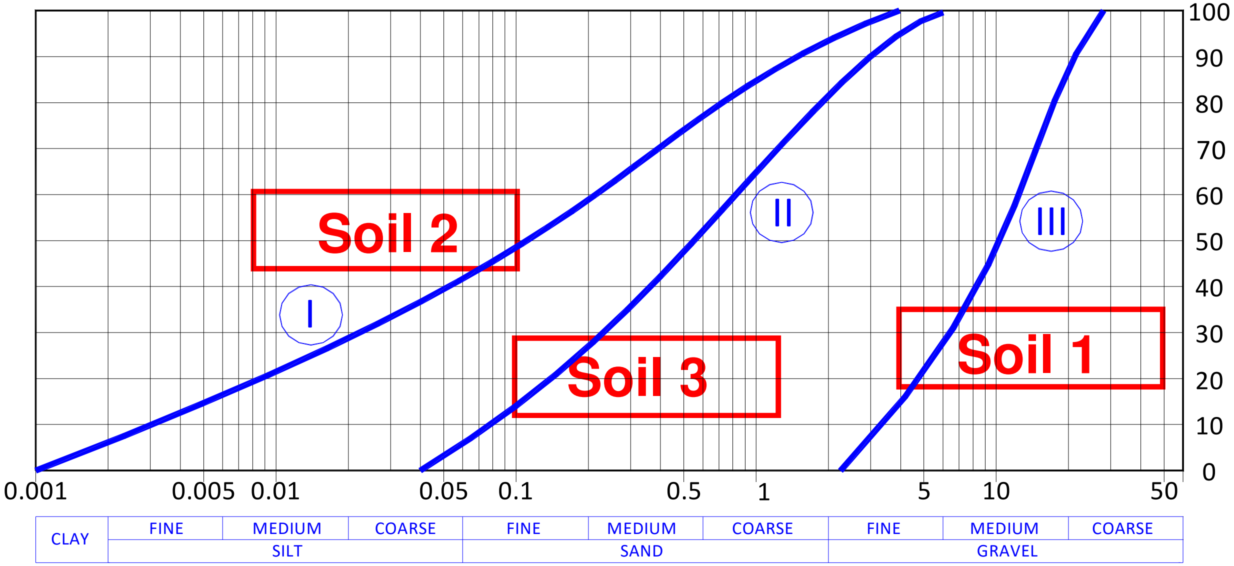


- Establish the most plausible correspondence between layers A, B and C of the figure and soils of the table. Present the computations which justify your answer.



Soil	w (%)	γ_s (kN/m^3)	w_L (%)	w_P (%)	e_{min}	e	e_{max}
1 (sedim.)	19	26.1	---	---	0.40	0.51	0.98
2 (residual)	23	25.8	34	25	---	---	---
3 (sedim.)	18	26.0	---	---	0.20	0.74	0.89



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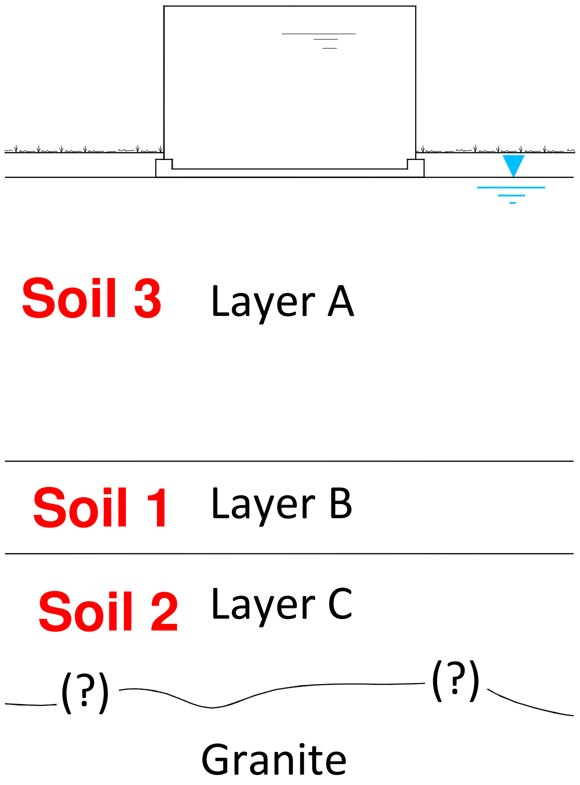
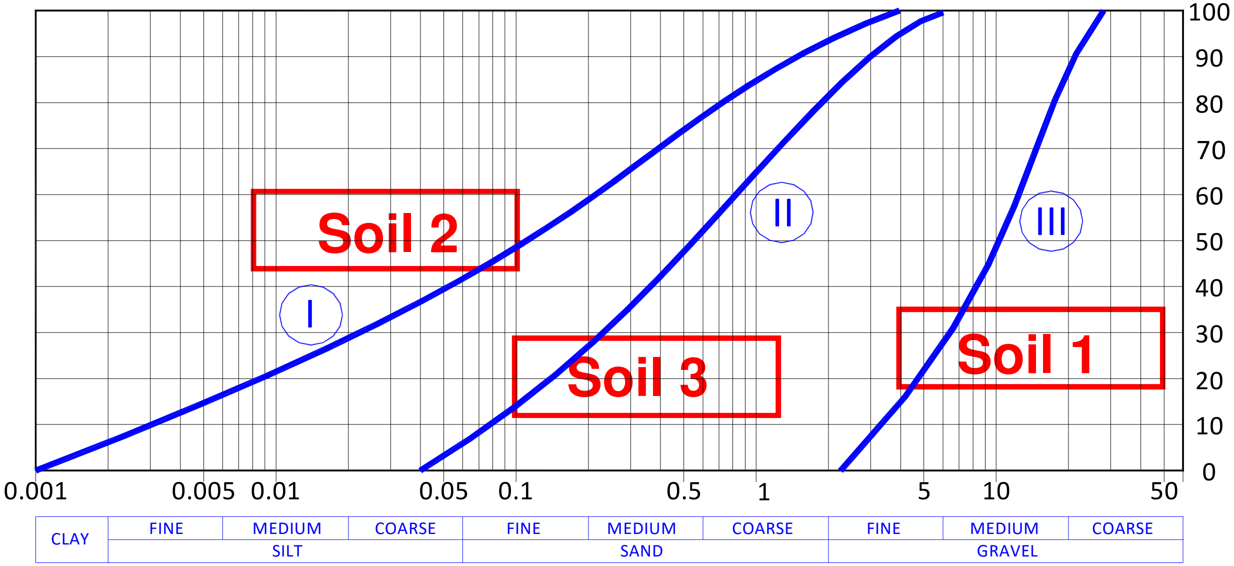
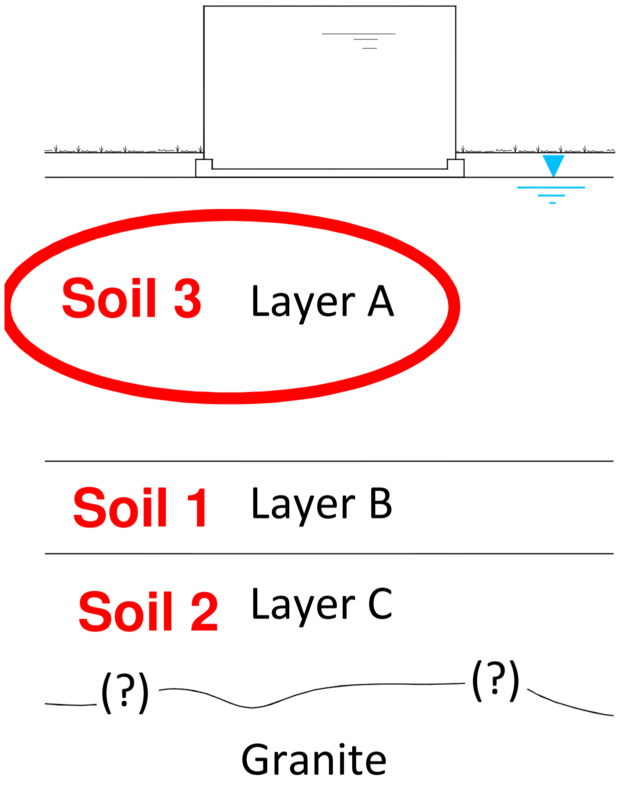


Soil	w (%)	γ_s (kN/m³)	w_L (%)	w_P (%)	e_{min}	e	e_{max}
1 (sedim.)	19	26.1	---	---	0.40	0.51	0.98
2 (residual)	23	25.8	34	25	---	---	---
3 (sedim.)	18	26.0	---	---	0.20	0.74	0.89



- In case of a strong earthquake, is it probable that one (or more) layer(s) exhibit poor performance? If that is the case, describe what may happen. Propose a method that can prevent it.



Soil	w (%)	γ_s (kN/m³)	w_L (%)	w_P (%)	e_{min}	e	e_{max}
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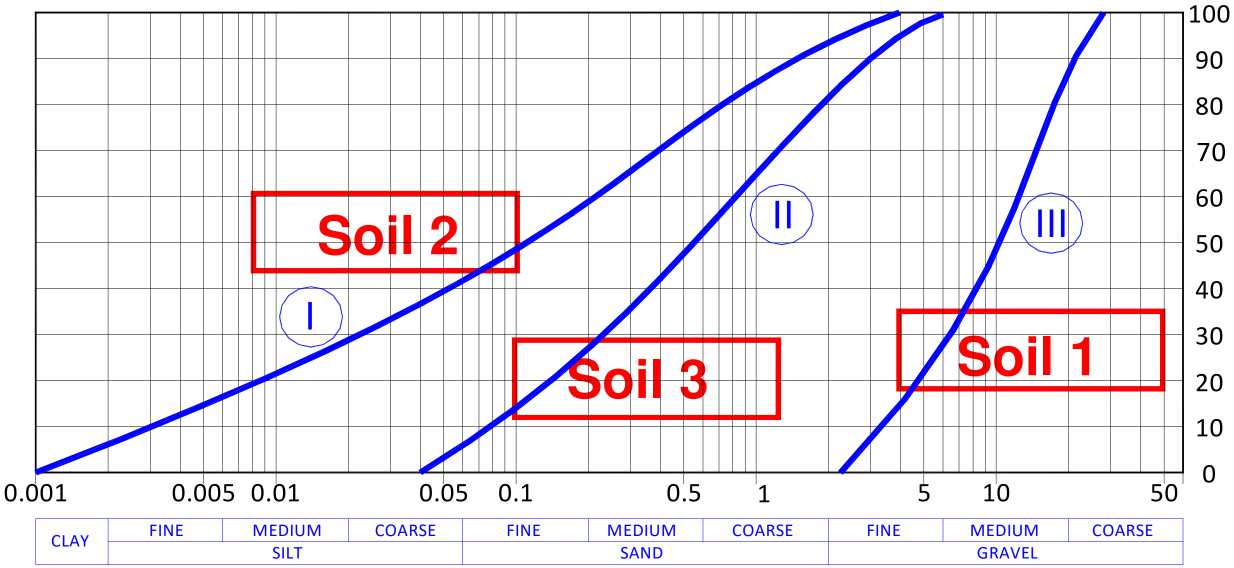
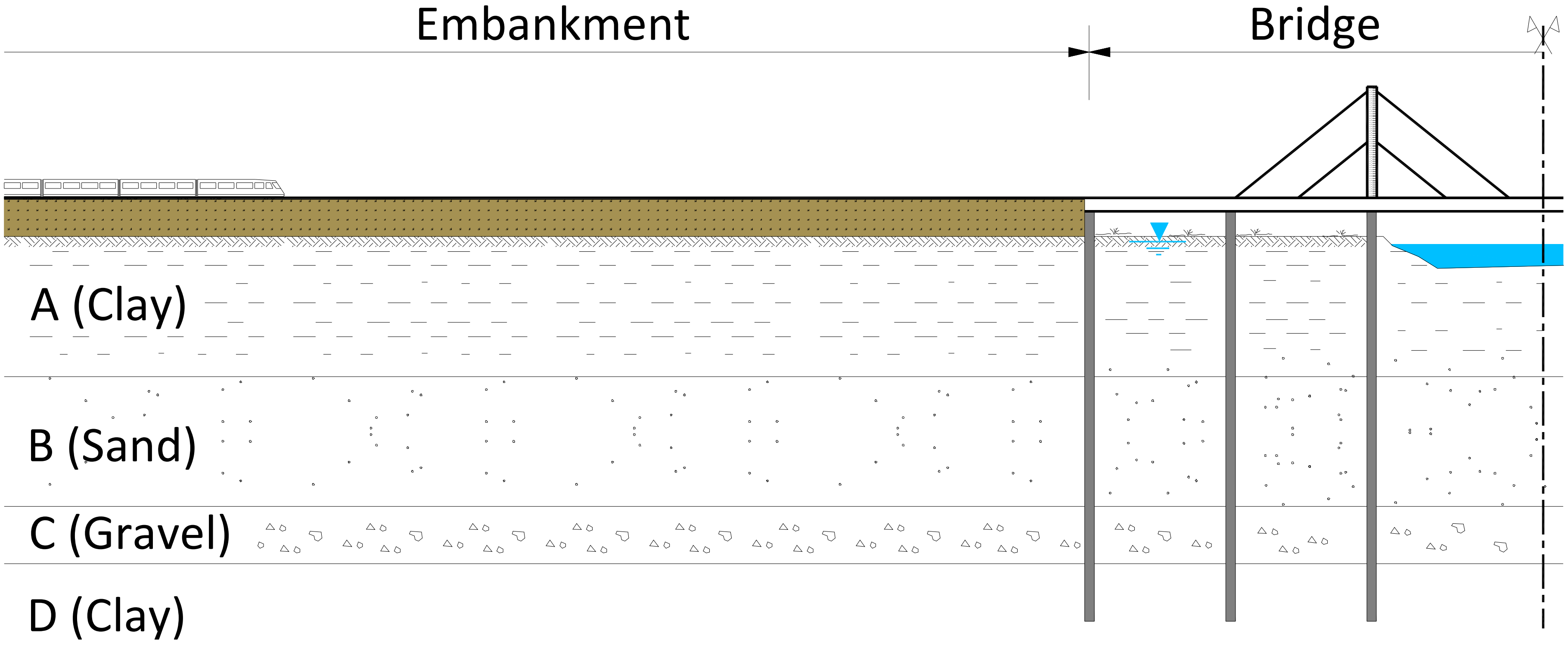


- In case of a strong earthquake, is it probable that one (or more) layer(s) exhibit poor performance? If that is the case, describe what may happen. Propose a method that can prevent it.

Example 2: crossing a wide alluvial plain by a new railway.



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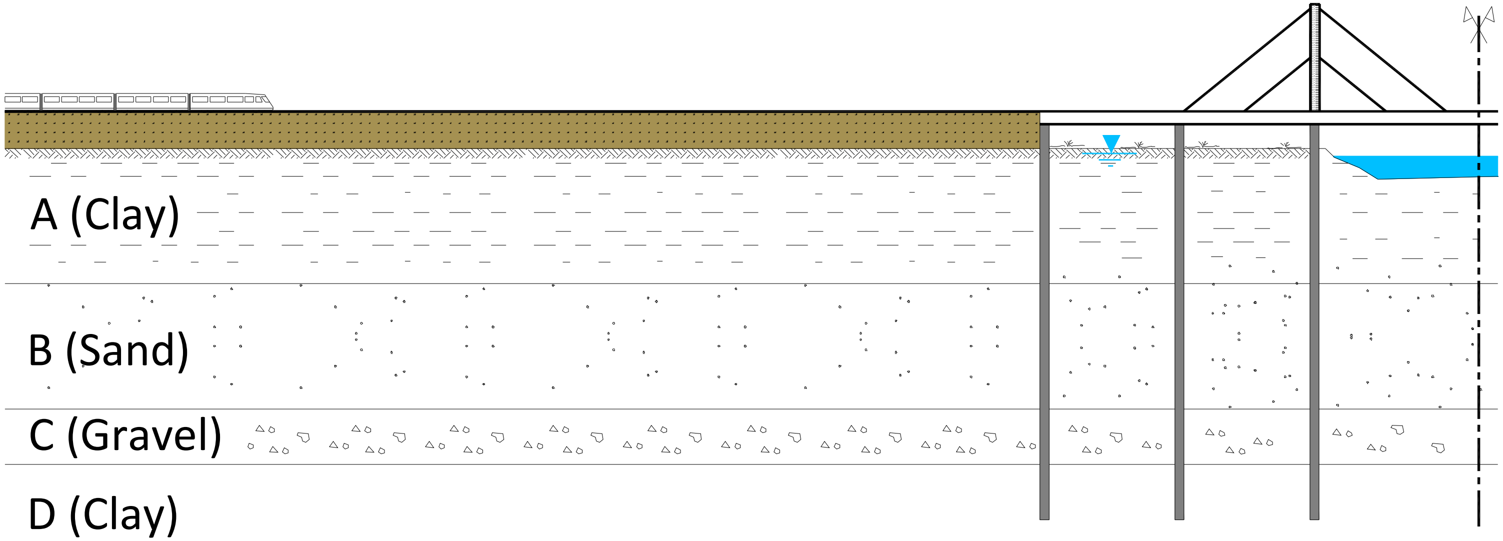
Manuel de Matos Fernandes

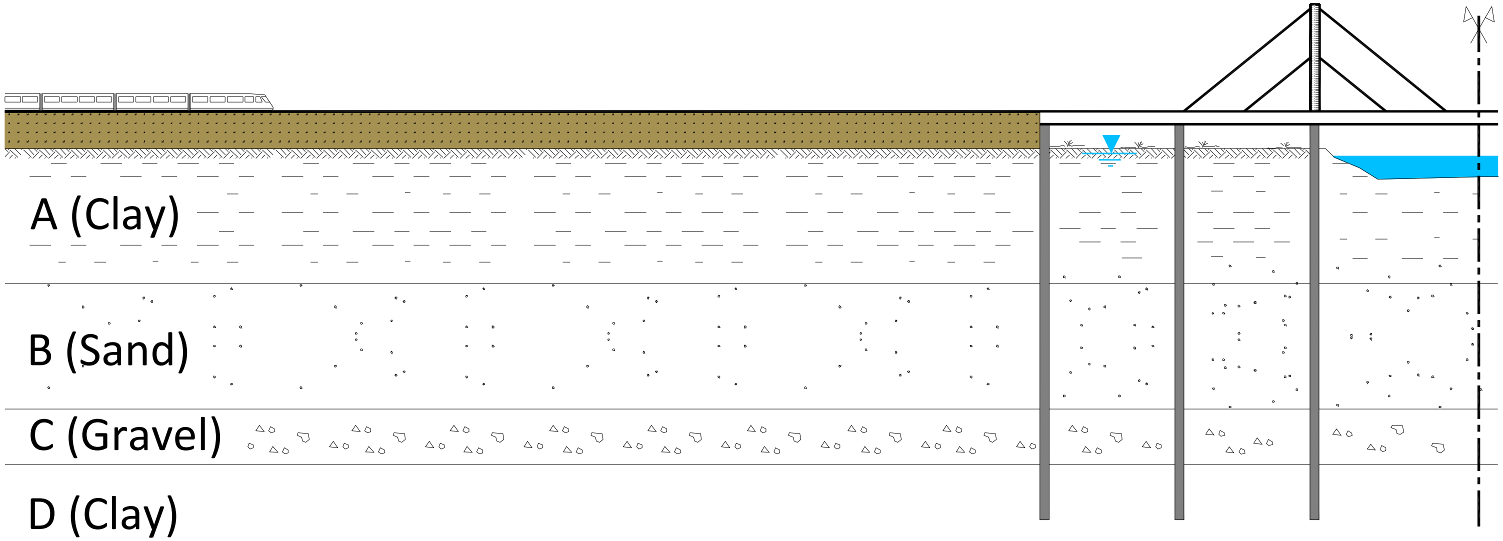


Soil	γ_s (kN/m³)	γ (kN/m³)	w_L (%)	w (%)	w_P (%)	e_{min}	e_{max}
1	26.0	18.5	---	33	---	0.25	0.95
2	25.8	20.1	---	21	---	0.46	0.89
3	26.3	15.0	88	81	40	---	---
4	26.1	20.9	53	18	22	---	---

- Establish the most plausible correspondence between layers of the figure and the soils of the table.

Present the computations which justify your answer.

Manuel de Matos Fernandes



Soil	γ_s (kN/m³)	γ (kN/m³)	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}
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2	25.8	20.1	---	21	---	0.46	0.55	0.89
3	26.3	15.0	88	81	40	---	2.17	---
4	26.1	20.9	53	18	22	---	0.48	---

- Establish the most plausible correspondence between layers of the figure and the soils of the table.

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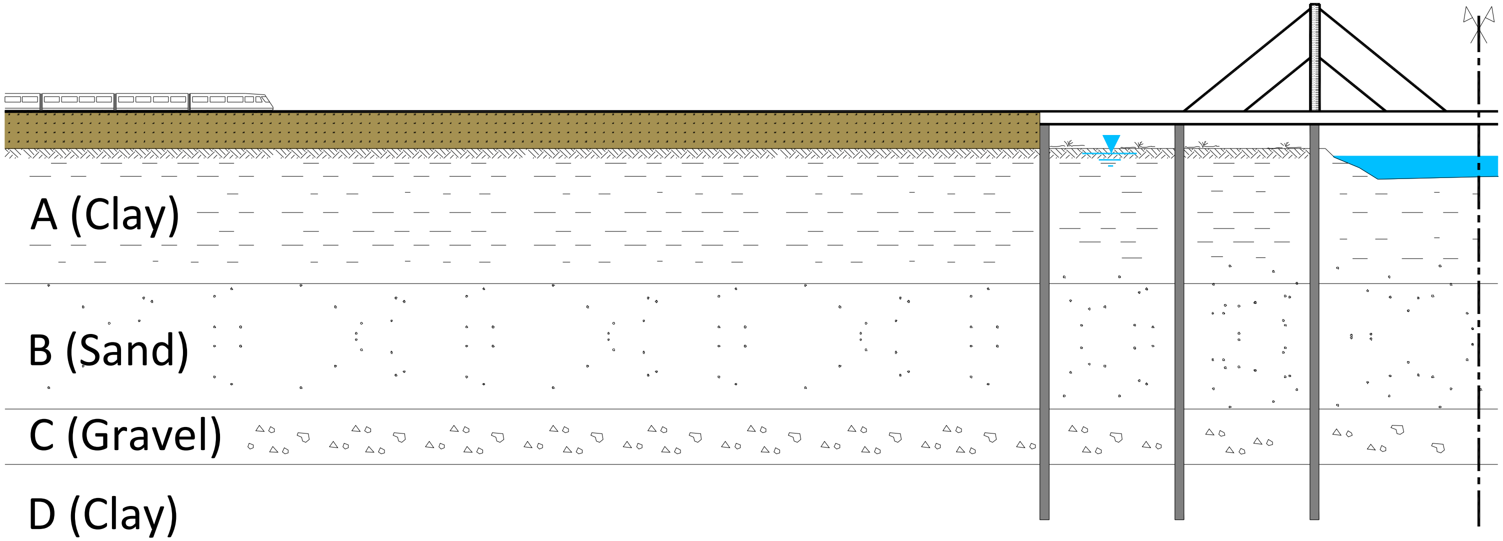

Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
1	---	33	---	0.25	0.87	0.95	---	11
2	---	21	---	0.46	0.55	0.89	---	79
3	88	81	40	---	2.17	---	0.15	---
4	53	18	22	---	0.48	---	1.13	---

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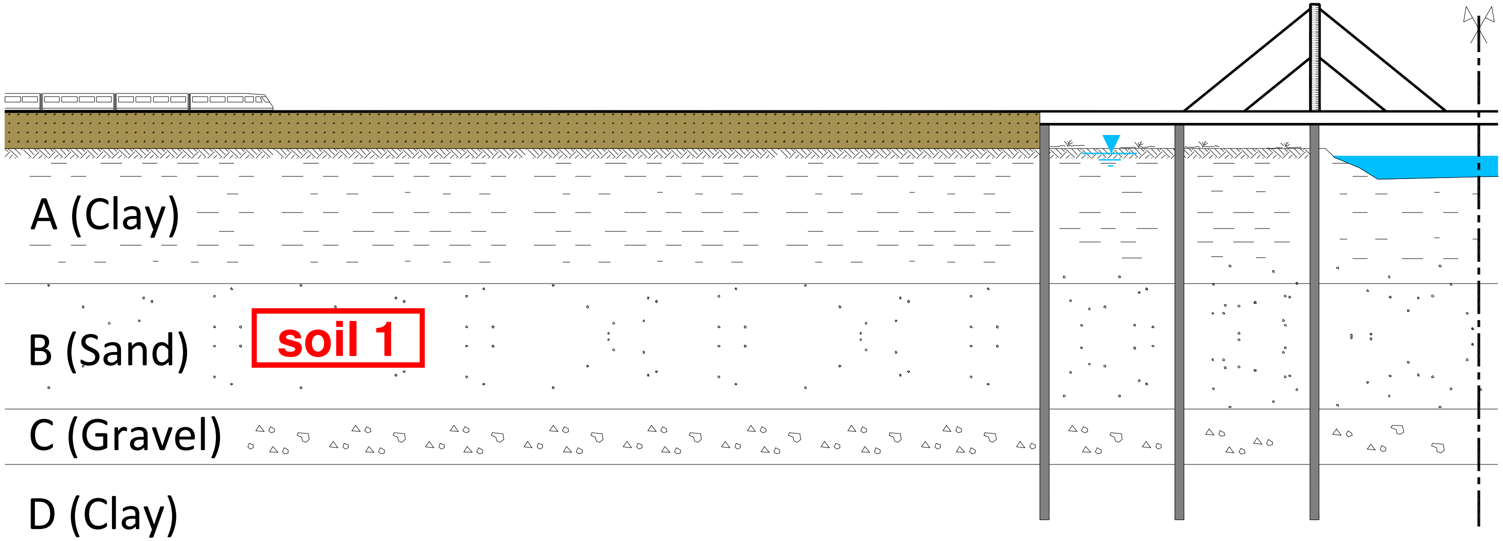

Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
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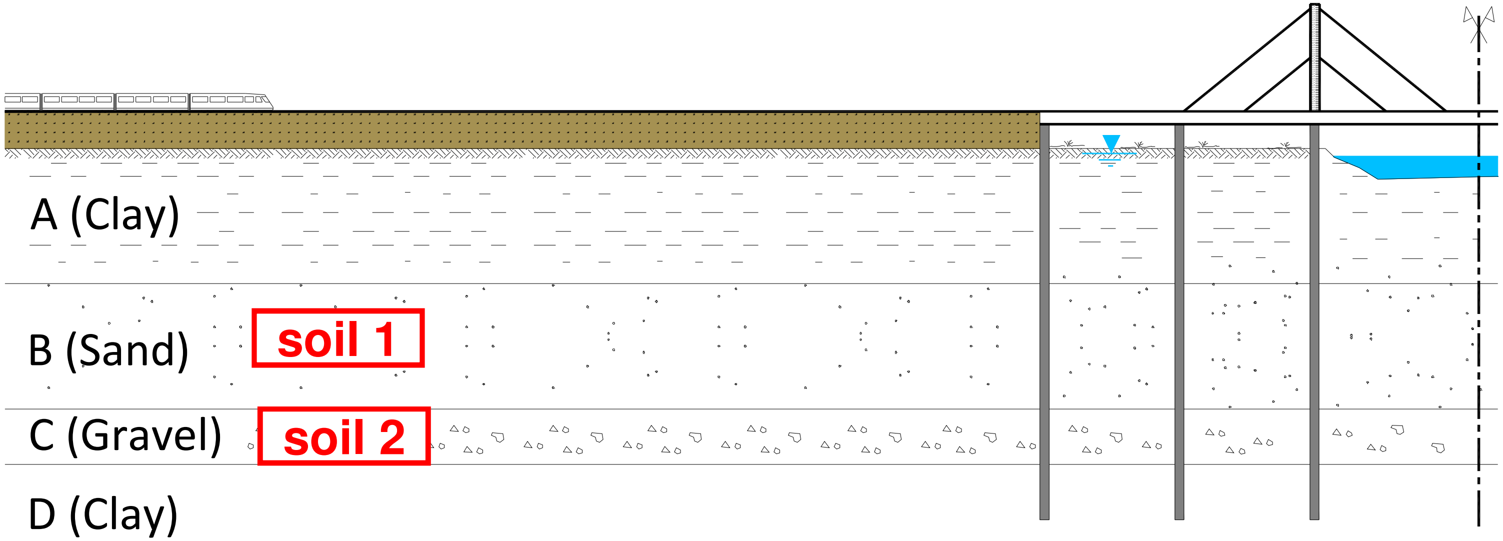

Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
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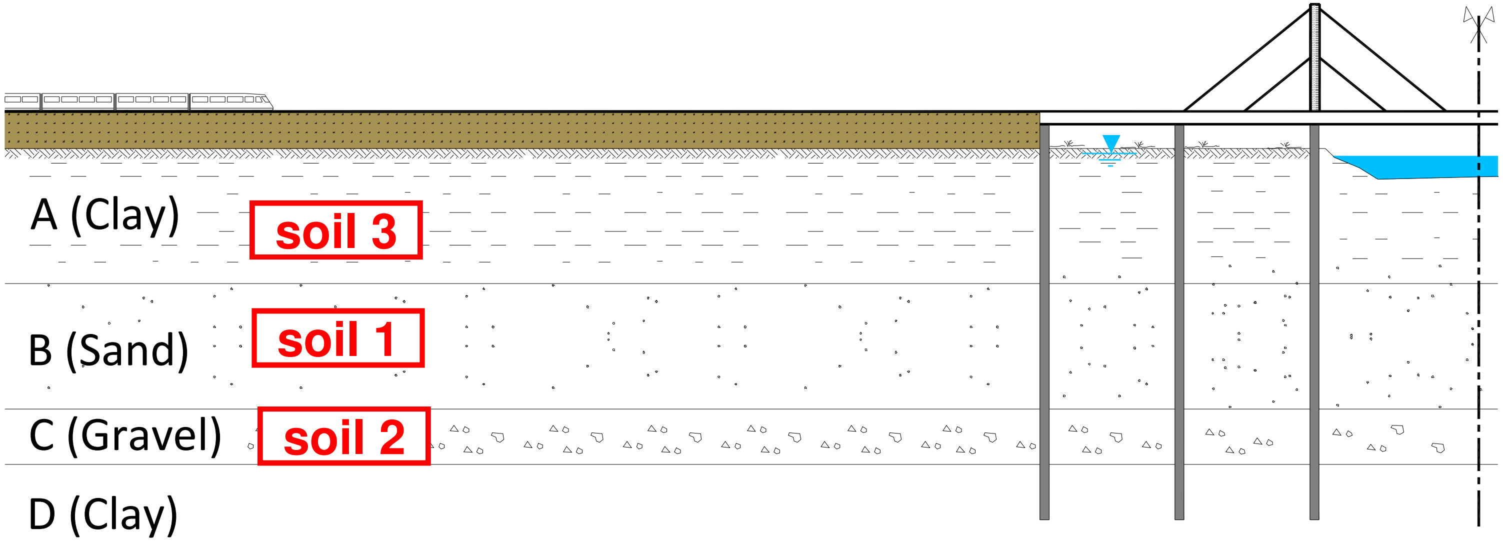

Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
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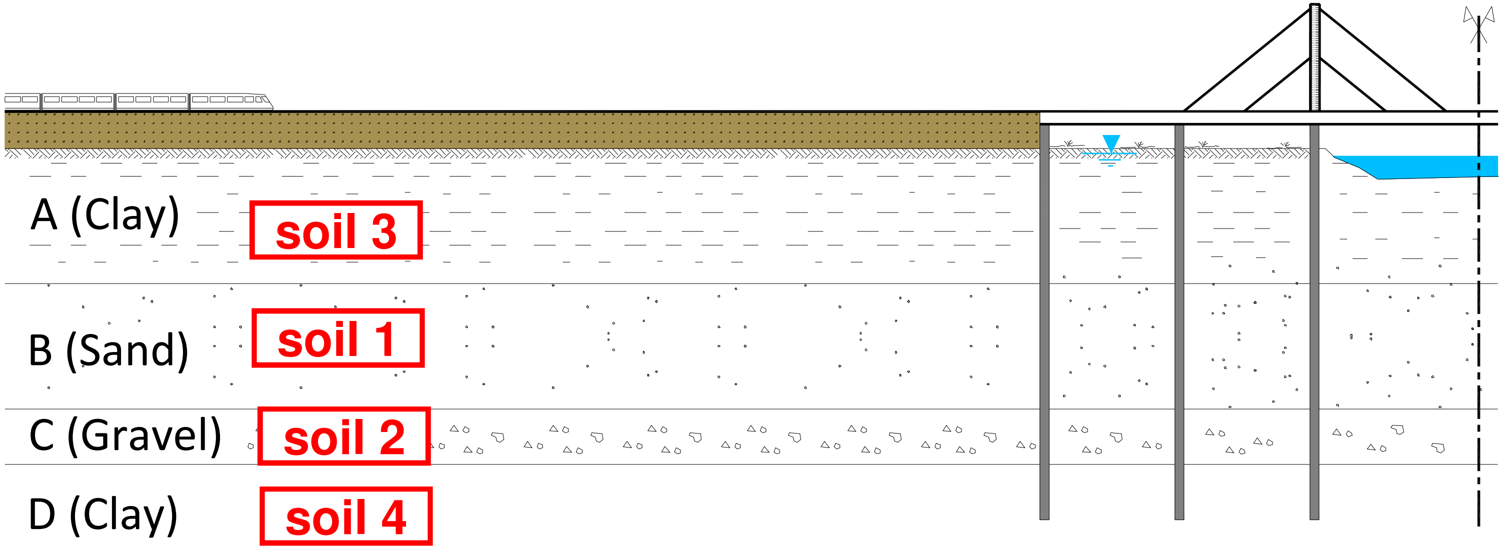

Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
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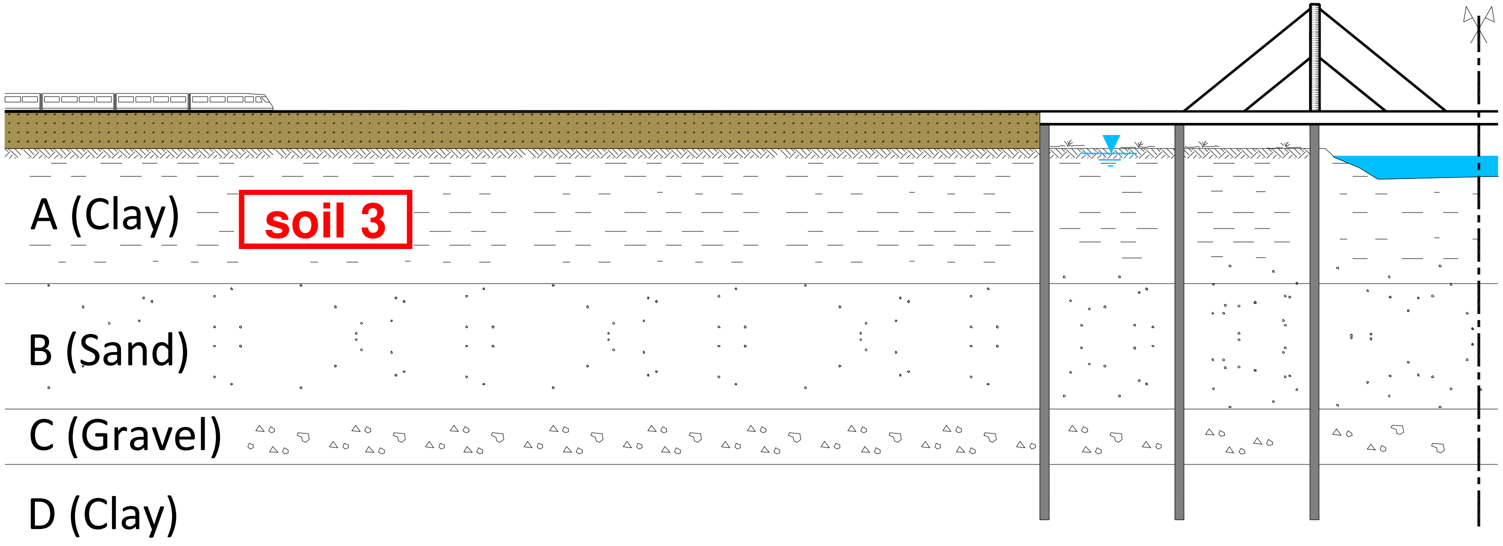
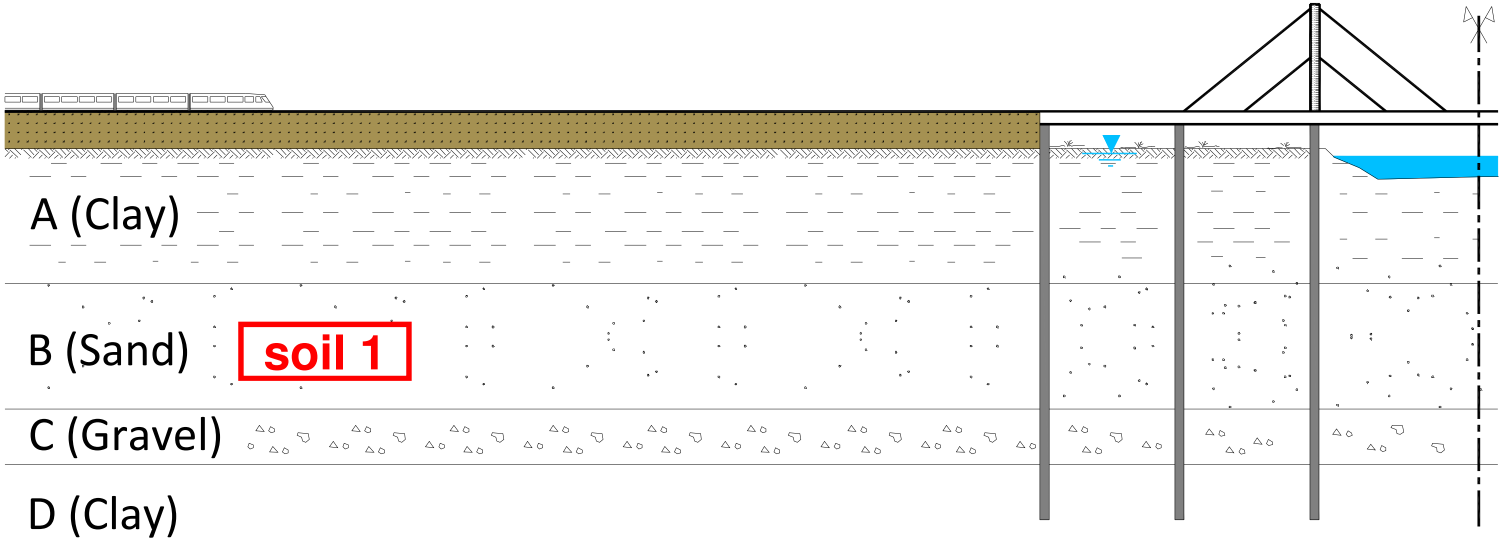


Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
1	---	33	---	0.25	0.87	0.95	---	11
2	---	21	---	0.46	0.55	0.89	---	79
3	88	81	40	---	2.17	---	0.15	---
4	53	18	22	---	0.48	---	1.13	---

- Will any of the soils suffer large delayed settlements? If that is the case, identify the soil and propose a method for ensuring the settlement stabilization in a shorter time.



Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
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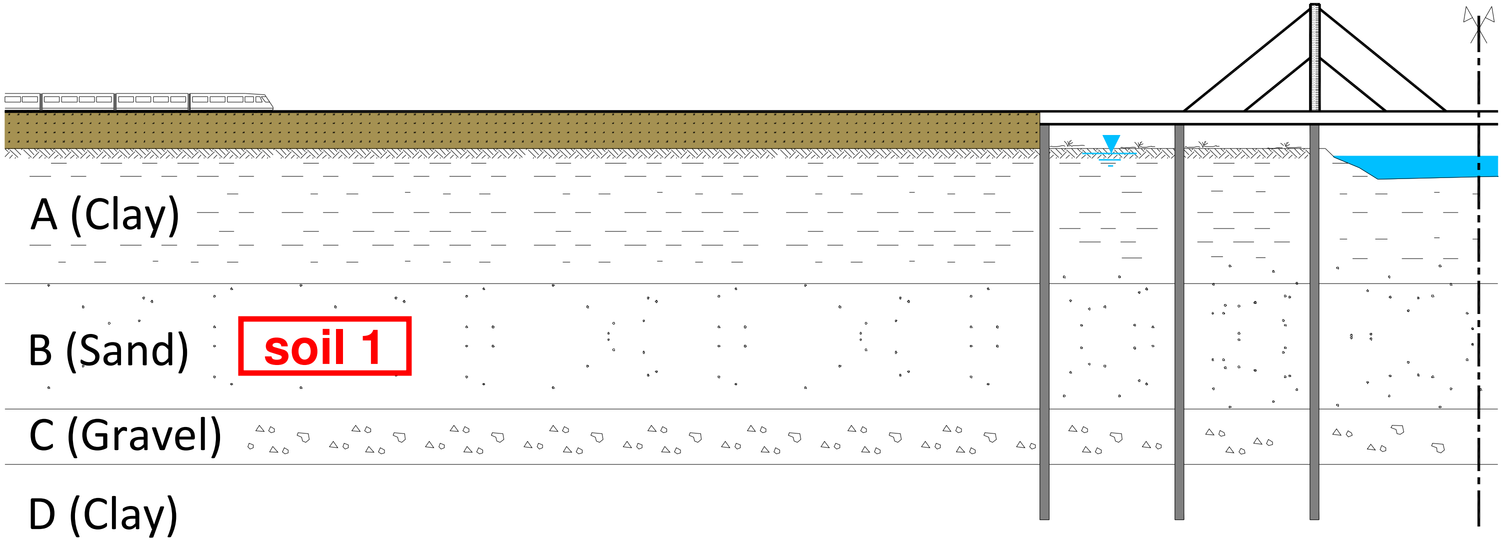
- In case of a strong earthquake, is it probable that one (or more) layer(s) exhibit poor performance? If that is the case, describe what may happen. Propose a method that can prevent it.



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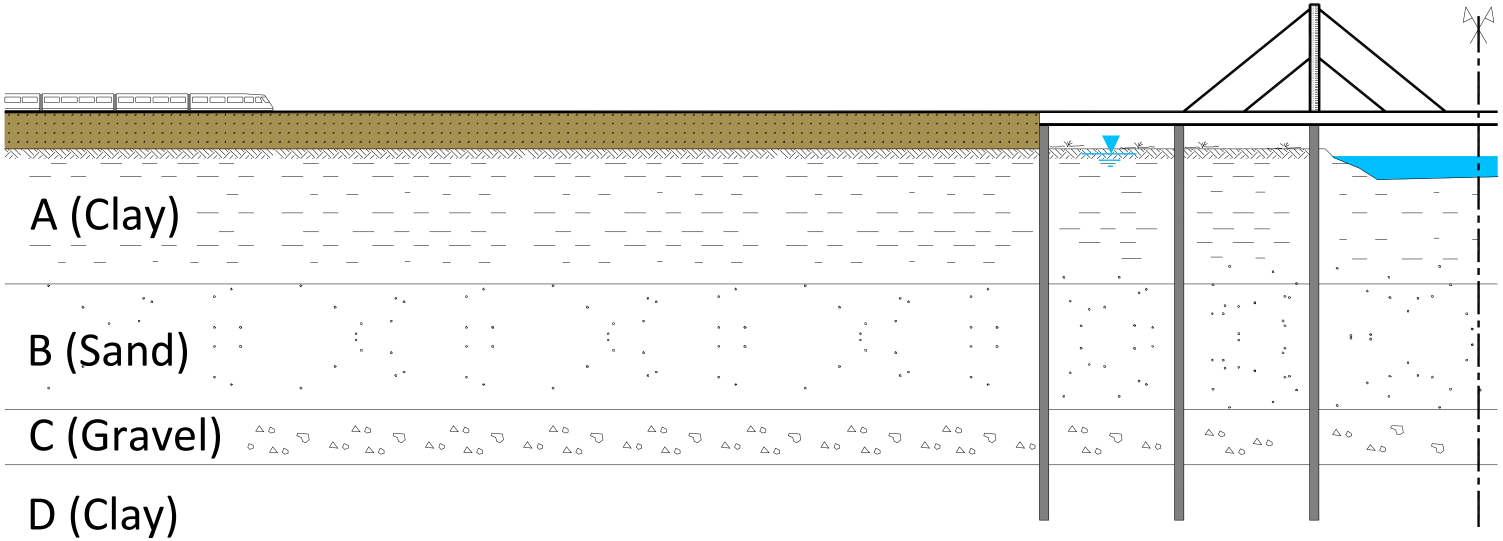
3	88	81	40	---	2.17	---	0.15	---
4	53	18	22	---	0.48	---	1.13	---

- Which soil would you select (regardless its concrete position) as fill material for the embankment?

OTHER POSSIBLE QUESTIONS (for the following weeks):

- Sort the soils in ascending order of permeability.



Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
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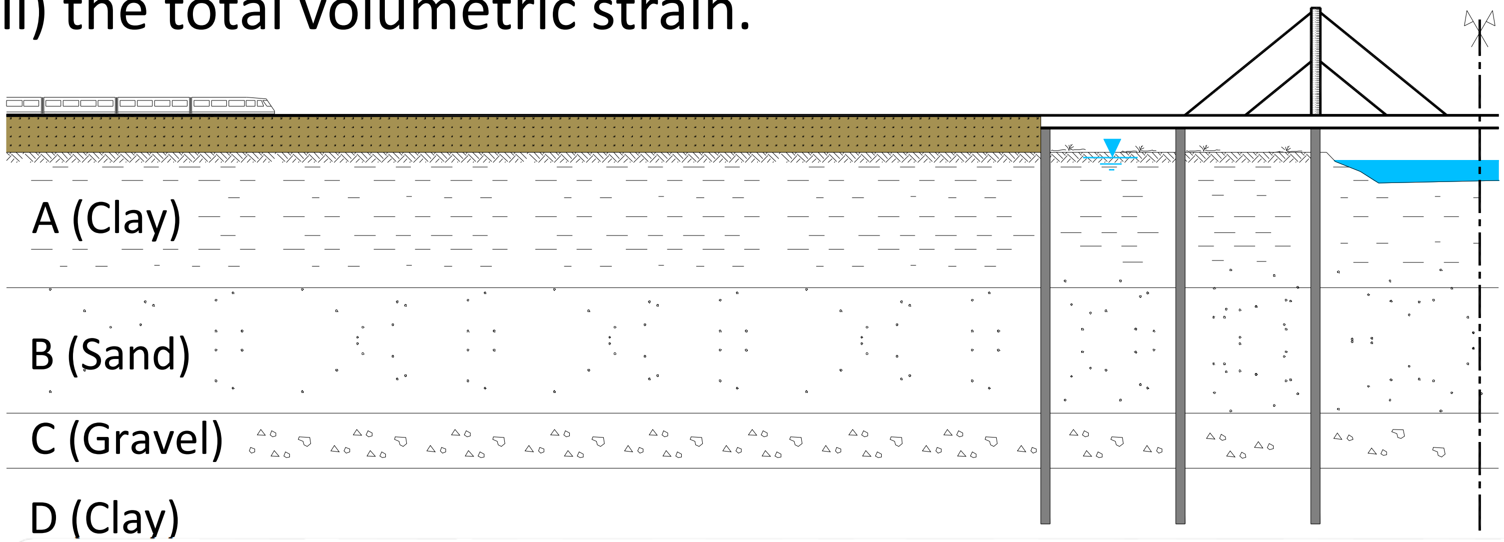
3	88	81	40	---	2.17	---	0.15	---
4	53	18	22	---	0.48	---	1.13	---

OTHER POSSIBLE QUESTIONS (for the following weeks):

- Sort the soils in ascending order of compressibility, considering:
  i) only immediate volumetric strain;
  ii) only time dependent volumetric strain;
  iii) the total volumetric strain.



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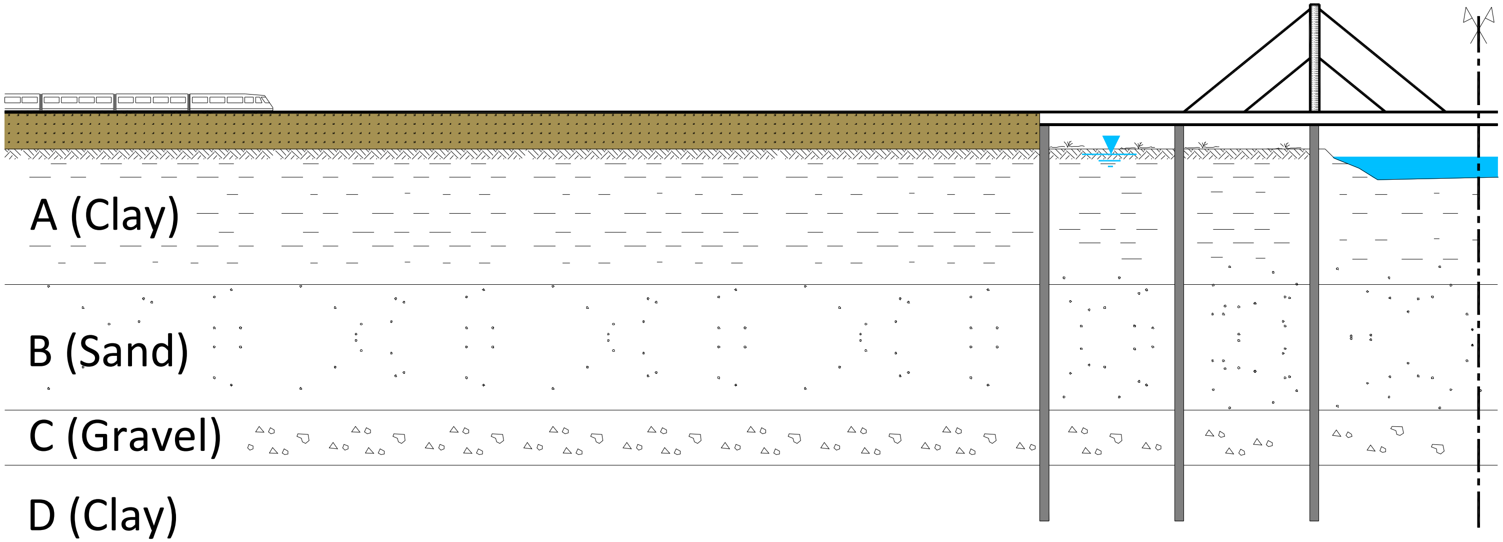
3	88	81	40	---	2.17	---	0.15	---
4	53	18	22	---	0.48	---	1.13	---

OTHER POSSIBLE QUESTIONS (for the following weeks):

- Is any soil(s) to behave as a normally consolidated soil?
- Is any soil(s) to behave as an overconsolidated soil?



Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
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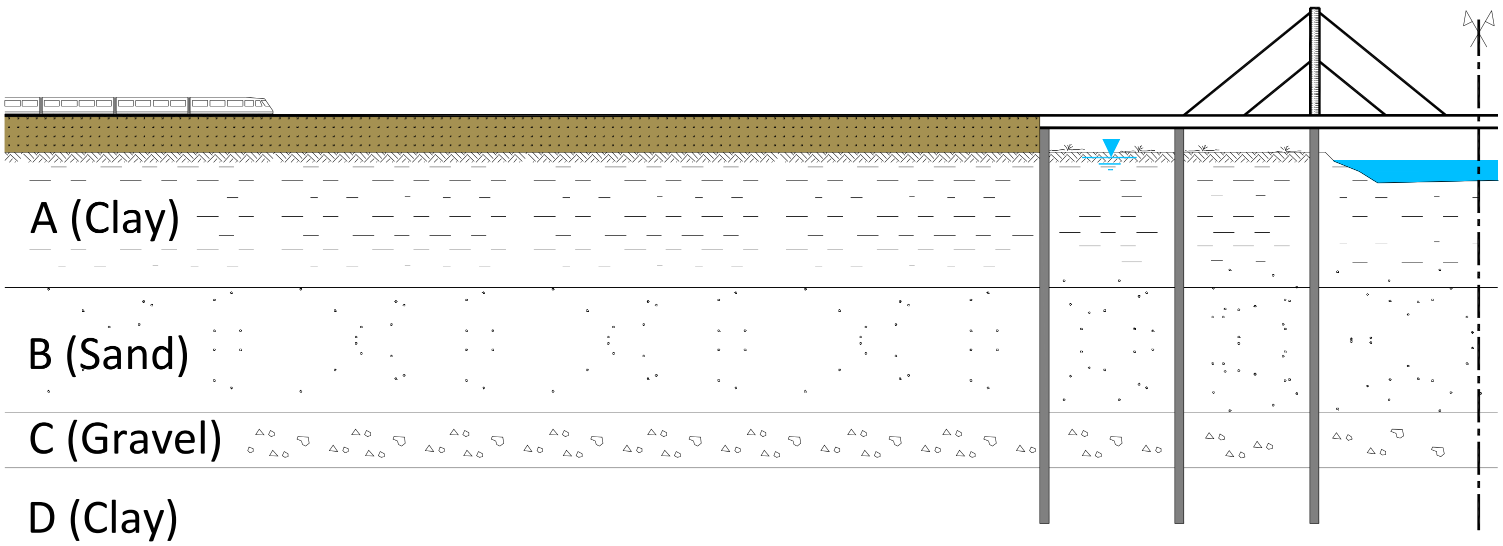
3	88	81	40	---	2.17	---	0.15	---
4	53	18	22	---	0.48	---	1.13	---

OTHER POSSIBLE QUESTIONS (for the following weeks):

- What would you say about the expected dilatancy (positive/negative) of the soils?



Soil	w_L (%)	w (%)	w_P (%)	e_{min}	e	e_{max}	I_C	I_D (%)
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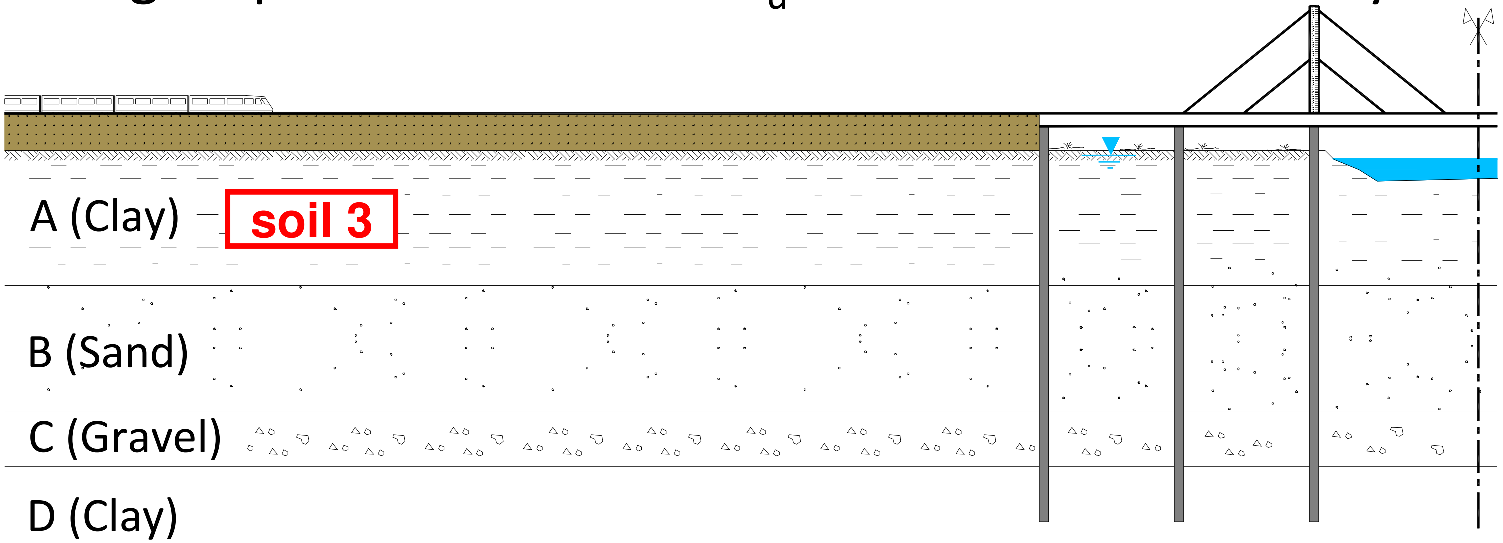
3	88	81	40	---	2.17	---	0.15	---
4	53	18	22	---	0.48	---	1.13	---

OTHER POSSIBLE QUESTIONS (for the following weeks):

- For soil 3 (soft clay) depict the evolution in depth of the undrained shear strength s_u at the tidal flat and at the river bed.
- Assign a plausible value for s_u at the centre of the layer.



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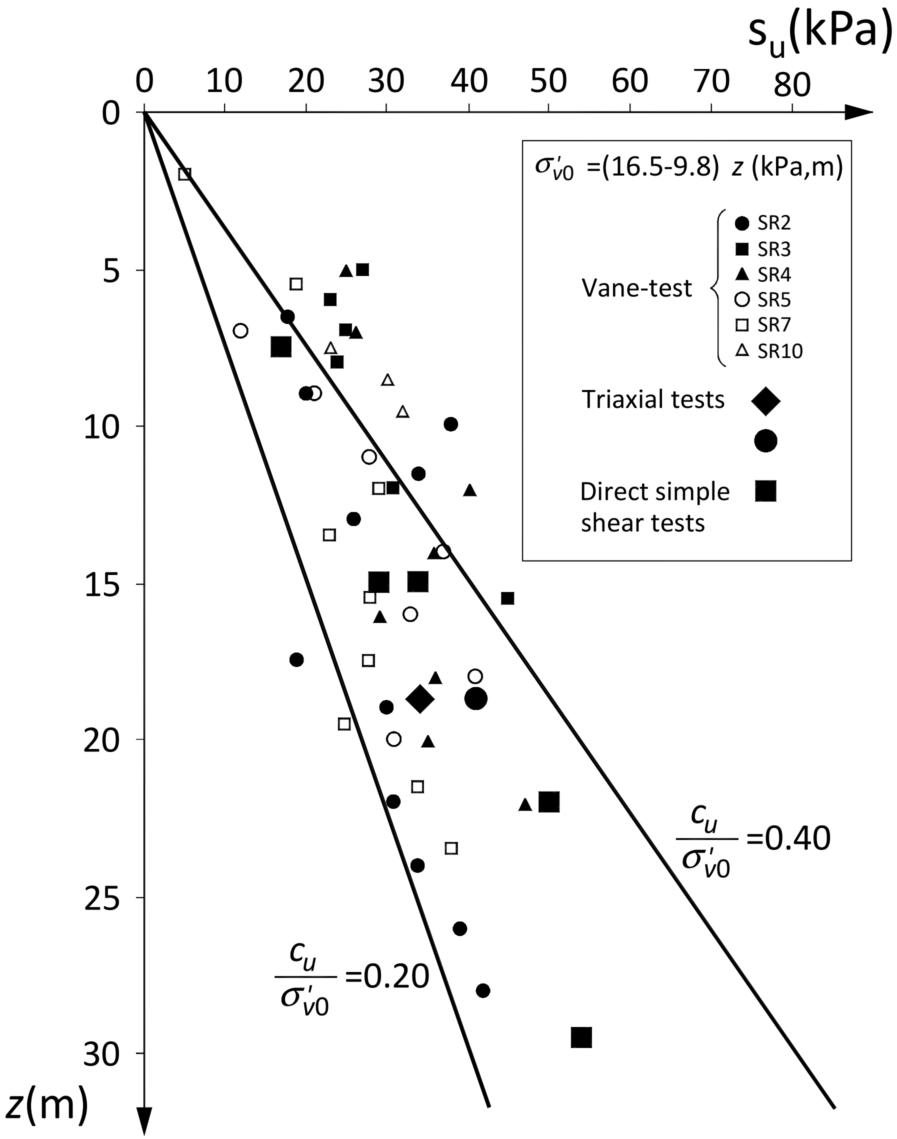
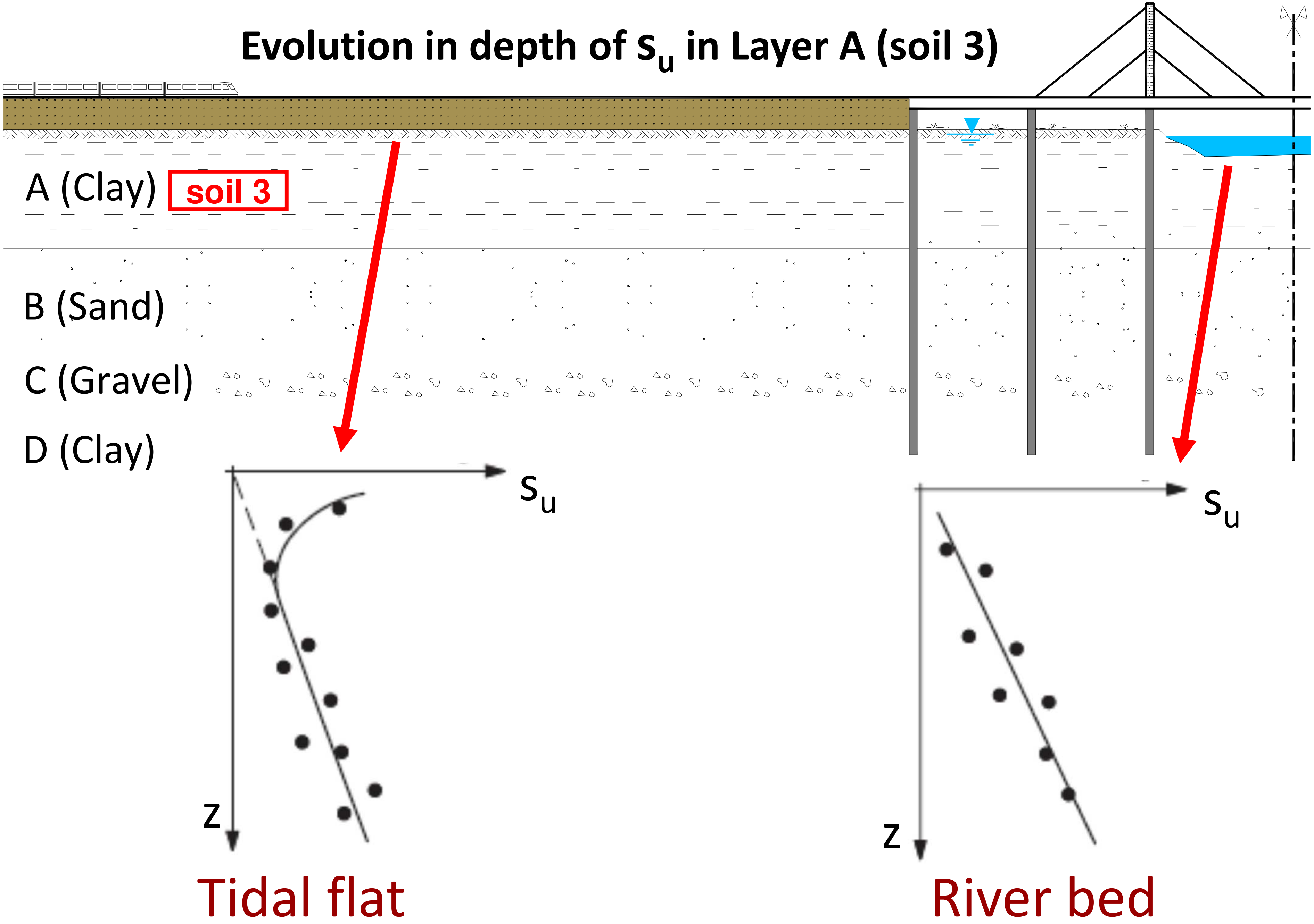
3	88	81	40	---	2.17	---	0.15	---
4	53	18	22	---	0.48	---	1.13	---

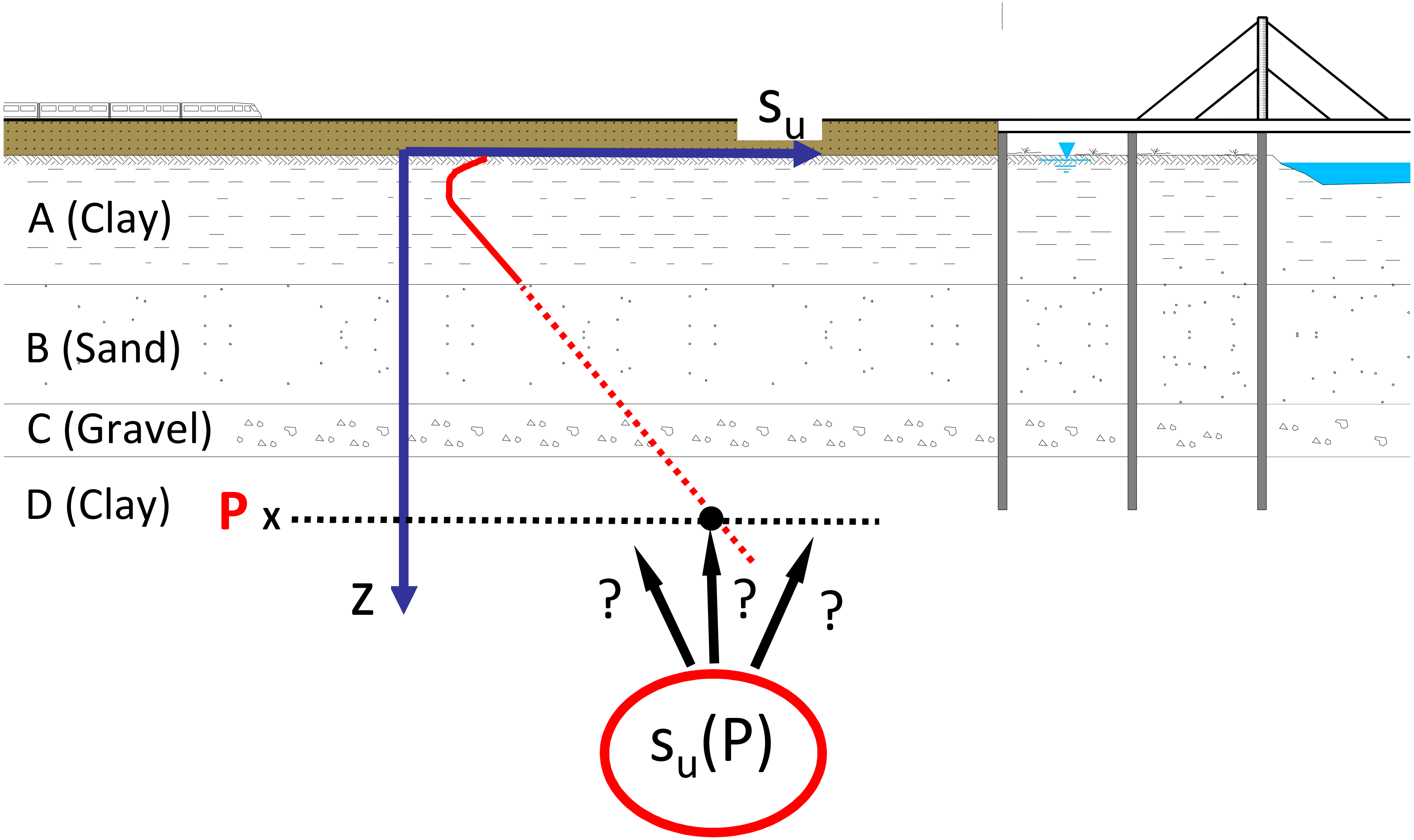
Evolution of s_u under the bed of river Tagus at the site of Vasco da Gama Bridge, Lisbon



Evolution in depth of s_u in Layer A (soil 3)



- What would you say about the expected value of the undrained shear strength at point P in layer D, in comparison with the one obtained by simply extending the line drawn for layer A?



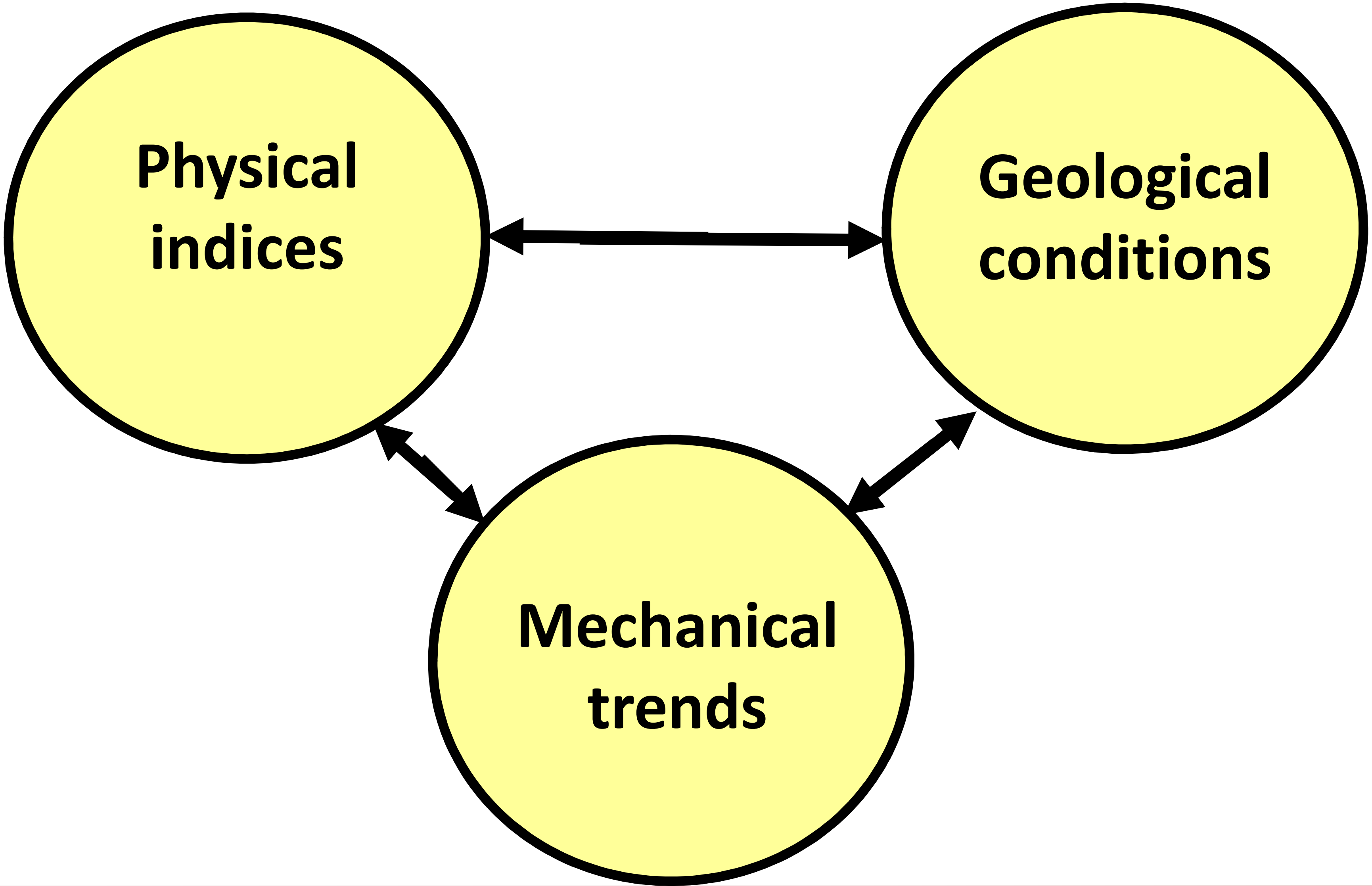
CONCLUSIONS

In the presentation it was identified a *GAP* in the usual process of teaching/learning Soil Mechanics.

This *GAP* seriously affects the understanding that the mechanical behaviour – expressed by a series of abstract concepts – is totally controlled by the physical/geological soil characteristics…

… and these physical/geological characteristics are much easier to realize because they are intrinsecally concrete!

Then, the rational synthesis is not properly achieved.



CONCLUSIONS

Most of the main decisions of an experienced engineer are made on the basis of the interpretation of the site geology and of the physical/identification parameters of the relevant soil layers.

The characterization via mechanical lab and field tests and the calculations are essential in design but seldom lead to significant changes in the conception of the solution based on the aforementioned interpretation.

CONCLUSIONS

The acquisition of expertise to assess "field atmosphere" usually requires years of experience but can be prepared at the University.

This requires training the ability to interpret the geological conditions and the physical-identification indices and to associate them to trends of the mechanical soil behaviour.

This training should begin even before studying the approaches that quantitatively characterize the mechanical soil behaviour. **But should continue and be improved in parallel with these approaches**!!!

This strategy has many relevant advantages!

- Train the *eagle eye*: much can be extracted from the physical indices to assess the expected mechanical trends!
- Those simple but powerfull ideas are easier to remain acquired in the future, as a *general knowledge*.
- They form an impressive *background* for the following (mechanical) chapters, whose subjects become more "realistic".
- This is a good opportunity to introduce solutions to prevent undesirable soil behaviour (just the basic idea).
- This gives rise to very vivid classes, in which students gain enthusiasm because they discuss real engineering problems.

This is done in weeks 3 and 4 of the semester.

Soil Mechanics and **Introduction to Geotechnics** have been the two best rated disciplines by the students in the official educational surveys, over the last 20 years.

Thank you for your attention!