International Society for Soil Mechanics and Geotechnical Engineering

Technical Committee TC306 Geo-engineering Education

Case-study webinar

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The project

Porto Tolle test embankment

A full scale experiment on the consolidation of a thick clay layer

Location of the Porto Tolle thermoelectric power plant

Late 1960's
more than half a century ago!

Italian Electricity Board (ENEL)
huge nuclear power plant in Porto Tolle

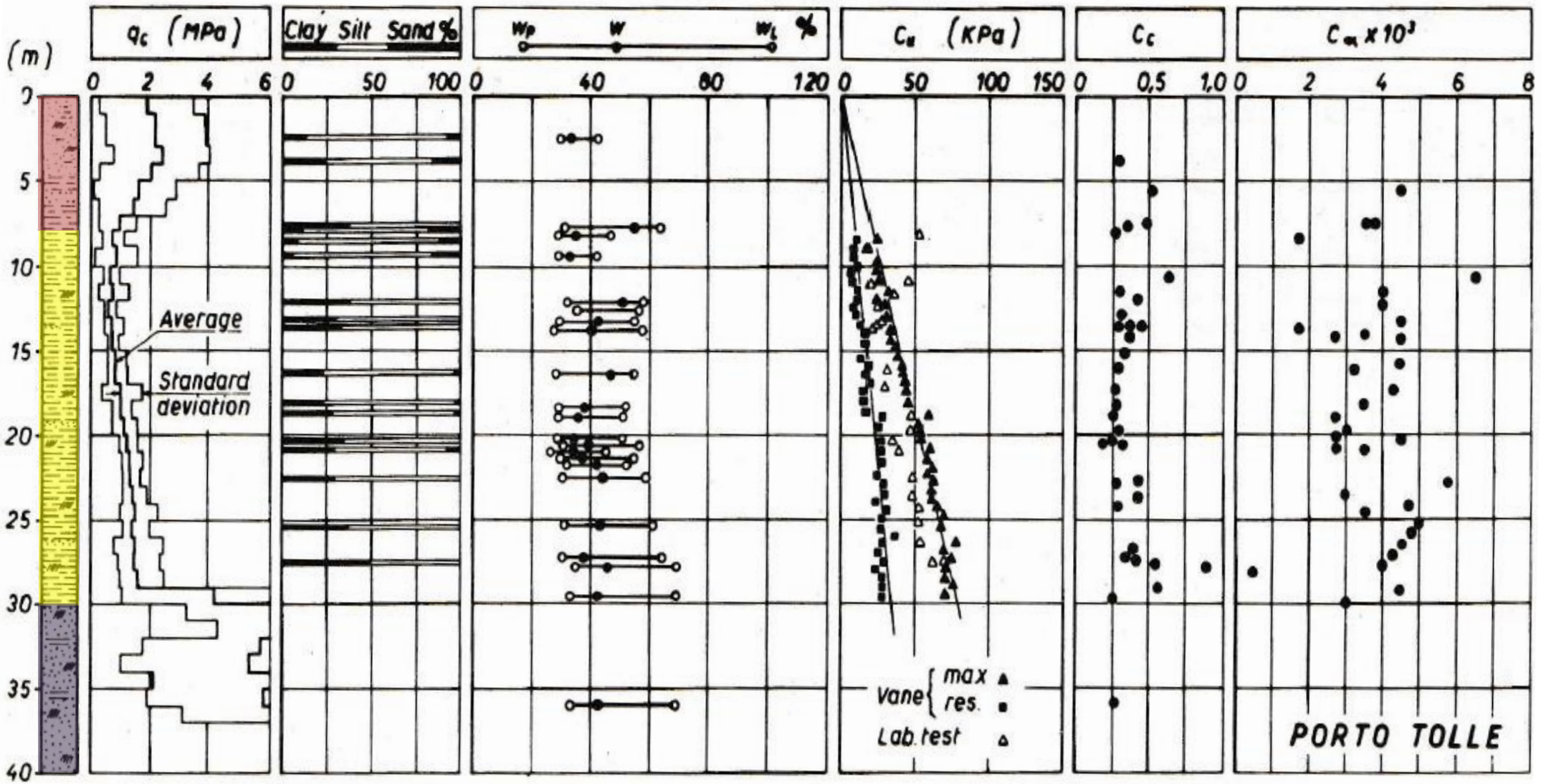
widespread trend against nuclear energy in Italy
(1987 referendum definitively banning it)

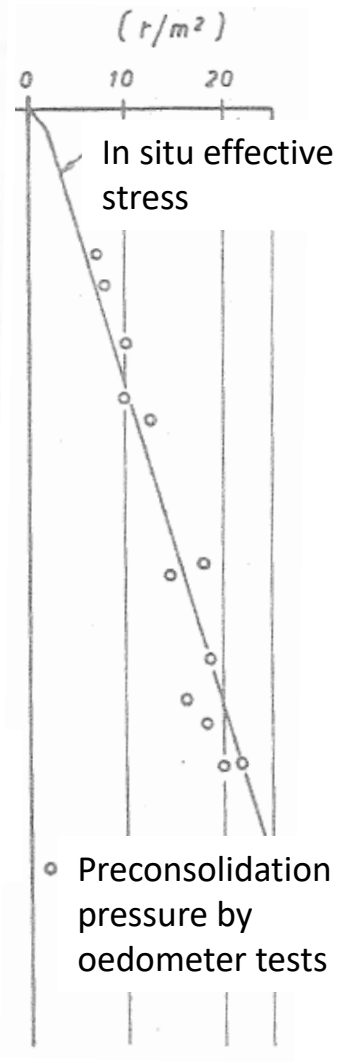
PortoTolle project reverted to a thermal plant
built in the 1980's

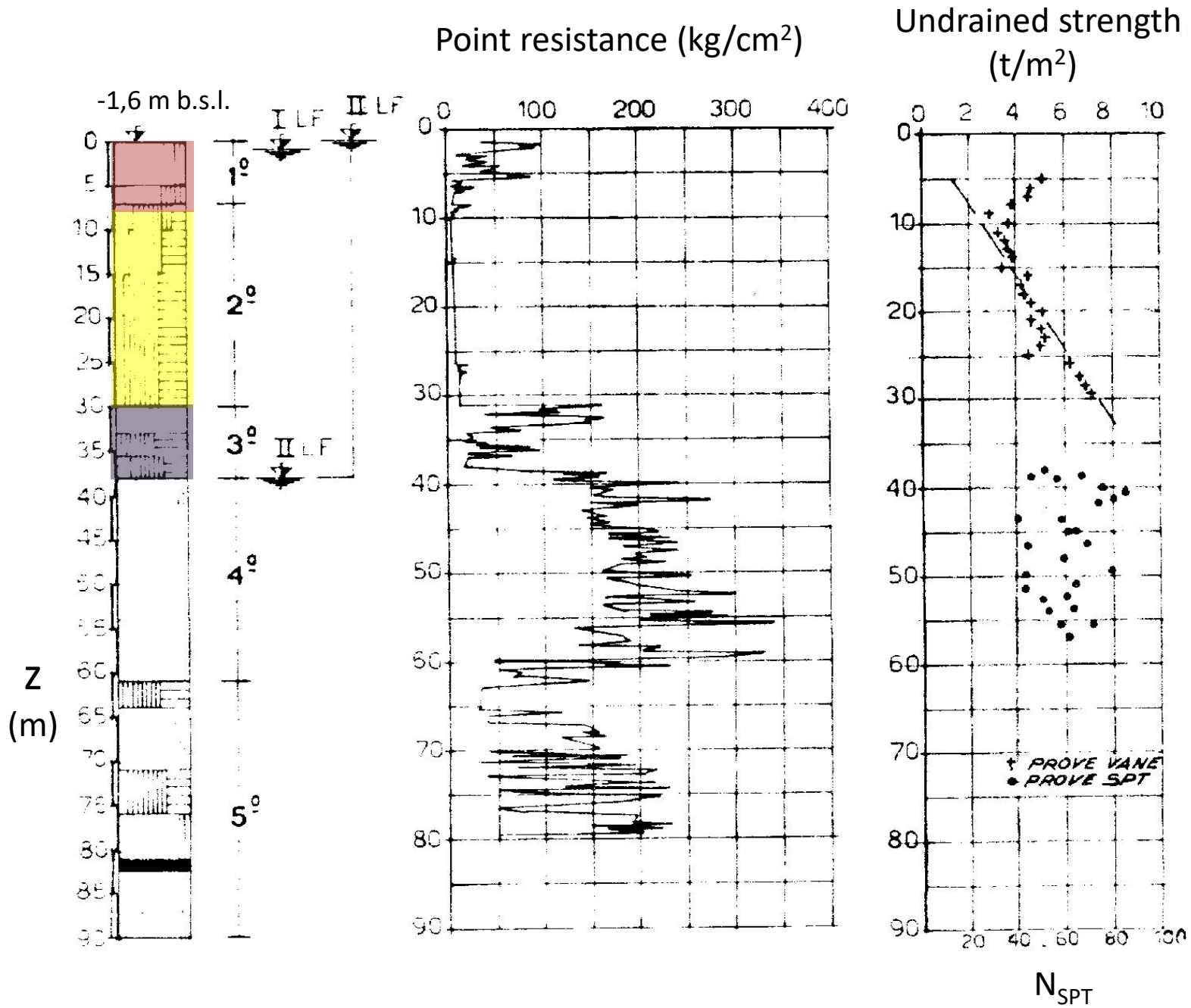

From: http://pinoschiesari.blogspot.it/

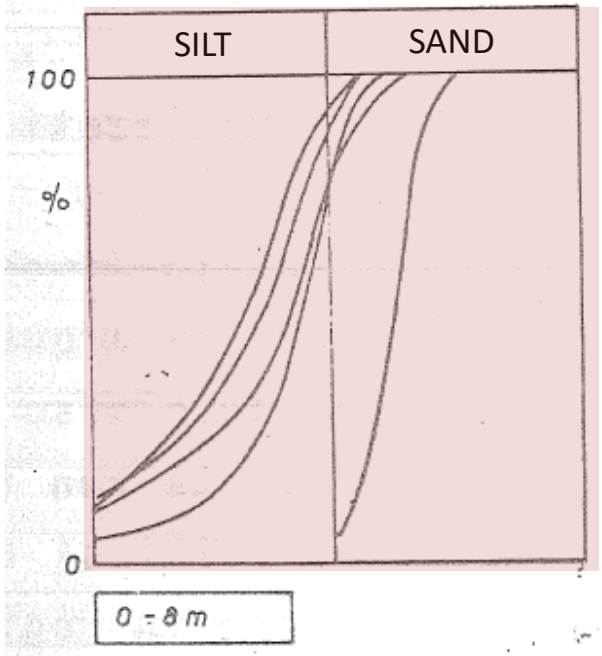

From: https://www.vvox.it

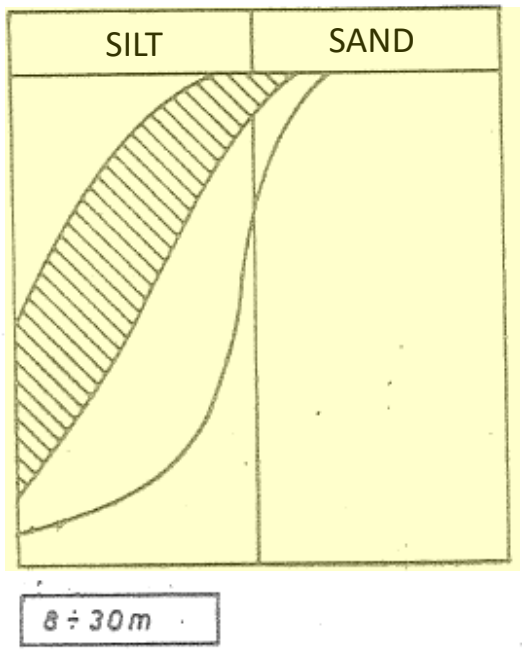
Soil exploration

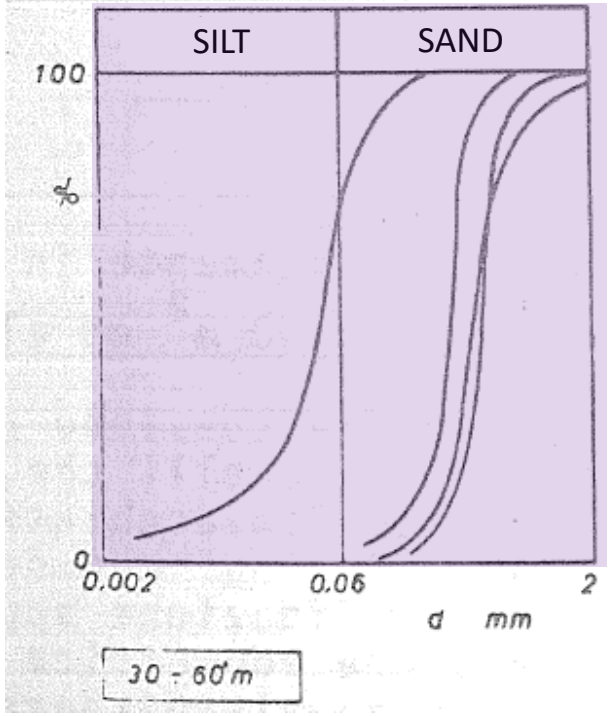

(m)
q_c (MPa)
Clay Silt Sand %
w_p w w_L %
C_u (KPa)
C_c
$C_{\alpha} \times 10^3$
Average
Standard deviation
Vane max
res.
Lab. test
PORTO TOLLE

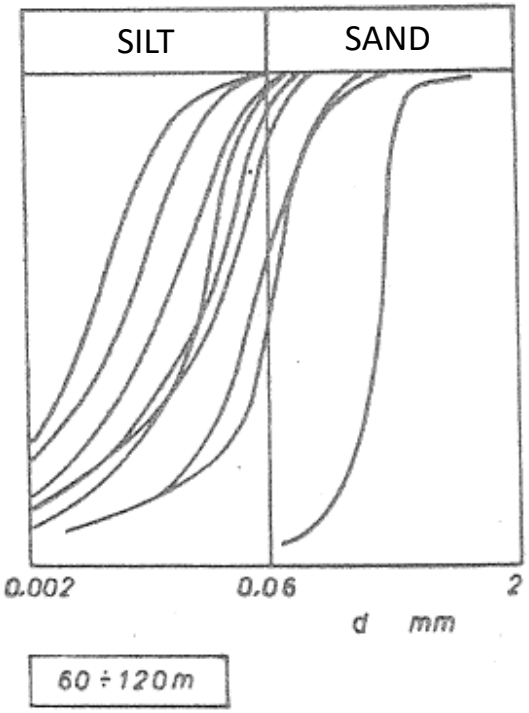

(t/m²)
In situ effective stress
Preconsolidation pressure by oedometer tests

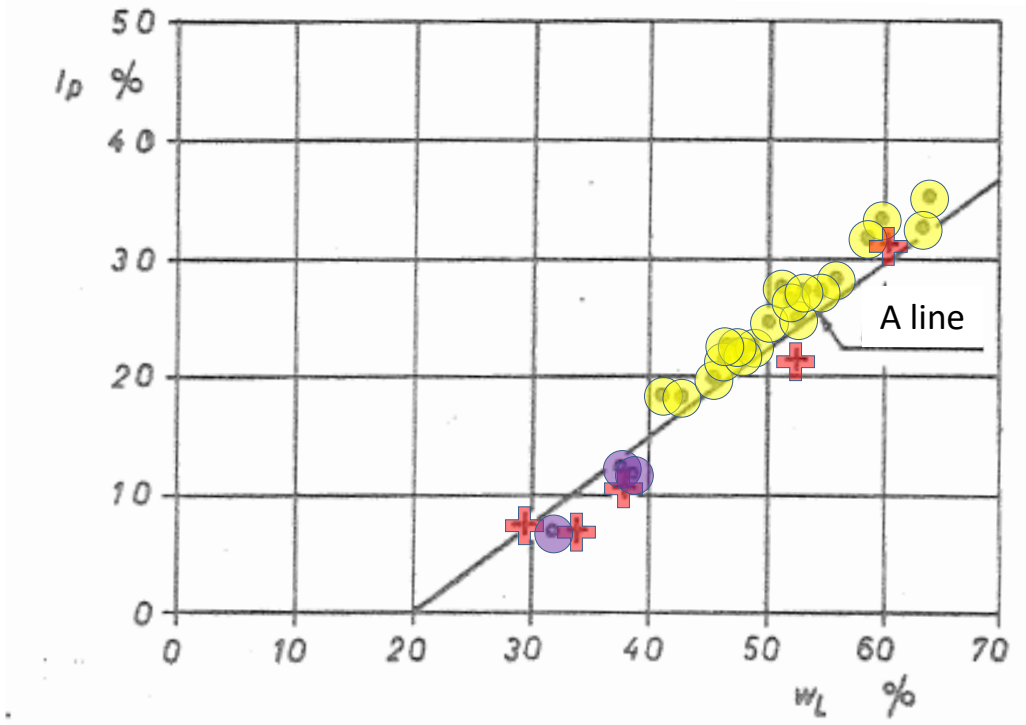

Point resistance (kg/cm²)
Undrained strength (t/m²)
-1,6 m b.s.l.
I LF
II LF
II LF
1º
2º
3º
4º
5º
Z (m)
PROVE VANE
PROVE SPT
N_SPT

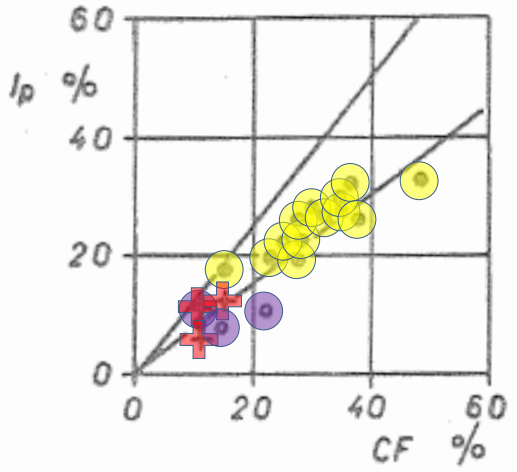












Upper sandy-silty soil (fine-grained component)

Intermediate clay layer

Lower sandy-silty soil (fine-grained component)

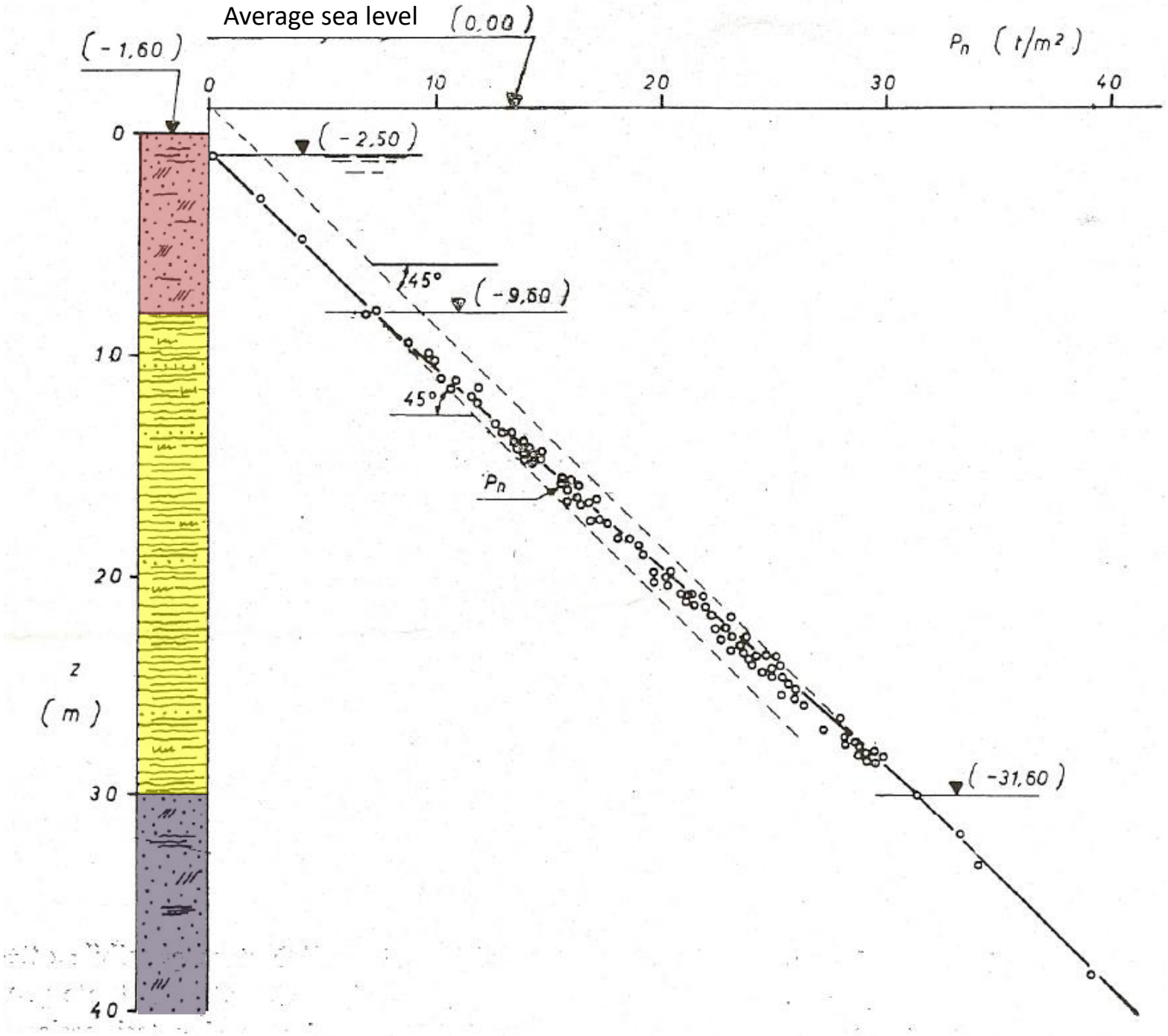
Coefficient of consolidation

$c_{v,\,av} = 1.3 \times 10^{-3}\ cm^2/sec$

(oedometer tests on small specimens)

Anisotropy of permeability

$k_h = (2 \div 5)k_v$



Ground surface
1.6 m below sea level

Pumping plant keeping groundwater level to depth of ~ 1 m below ground surface

Sandy layers below clay in hydraulic contact with the sea

The construction of the thermal power plant implied the previous realization of a large embankment to bring the elevation of the plant floor well above sea level

Preliminary evaluation:
fill 7 m high

over 2 m settlement

It was compulsory that such a settlement had substantially to occur before the installation of the plant

Need for a reliable prediction
of the time-settlement behaviour

Reliable prediction of the value of the settlement
in essentially 1D conditions
routine matter for geotechnical engineers

on the contrary

Reliable prediction of the time needed
to achieve substantial conclusion of the consolidation process

rather uncertain!

Widespread experience

c_v values in situ
as deduced from time-settlement and/or
time-pore pressure dissipation

many times larger than
c_v values determined in lab on small samples

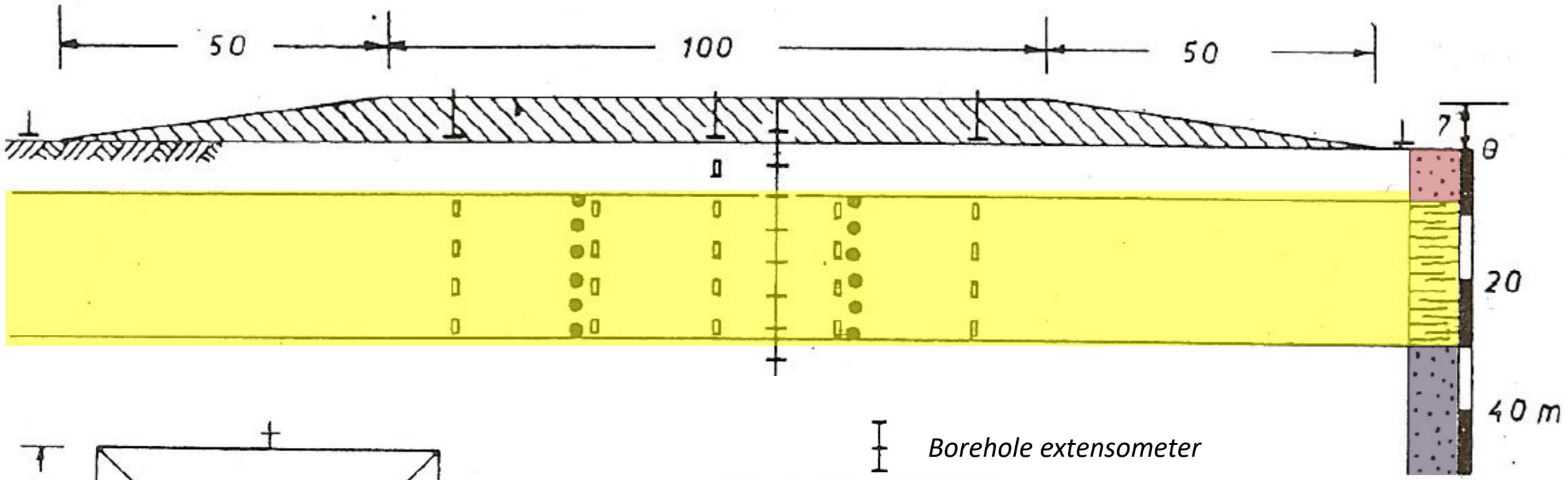
comprehensive investigation
on 7 typical Italian soft clay deposits
$1 \leq c_{vsite}/c_{vlab} \leq 23$

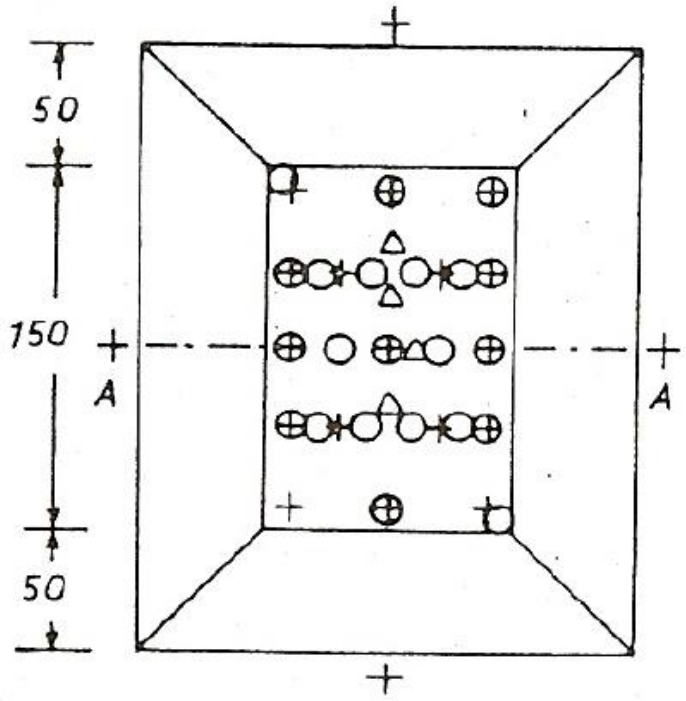
(AGI, Brighton 1979)

At Porto Tolle, prediction badly needed
to formulate a reliable construction program and
to confirm whether interventions (e.g., sand drains)
needed to speed up the process.

In the early stages of design, it was then decided to start
immediately the construction of part of the fill,
to be used as a test embankment
after having properly instrumented the subsoil.

The test embankment





Borehole extensometer

Hydraulic twin tube piezometer (n. 48)

Vibrating wire piezometer (n.62)

Settlement plate (n.21)

Borehole extensometer (n. 8)

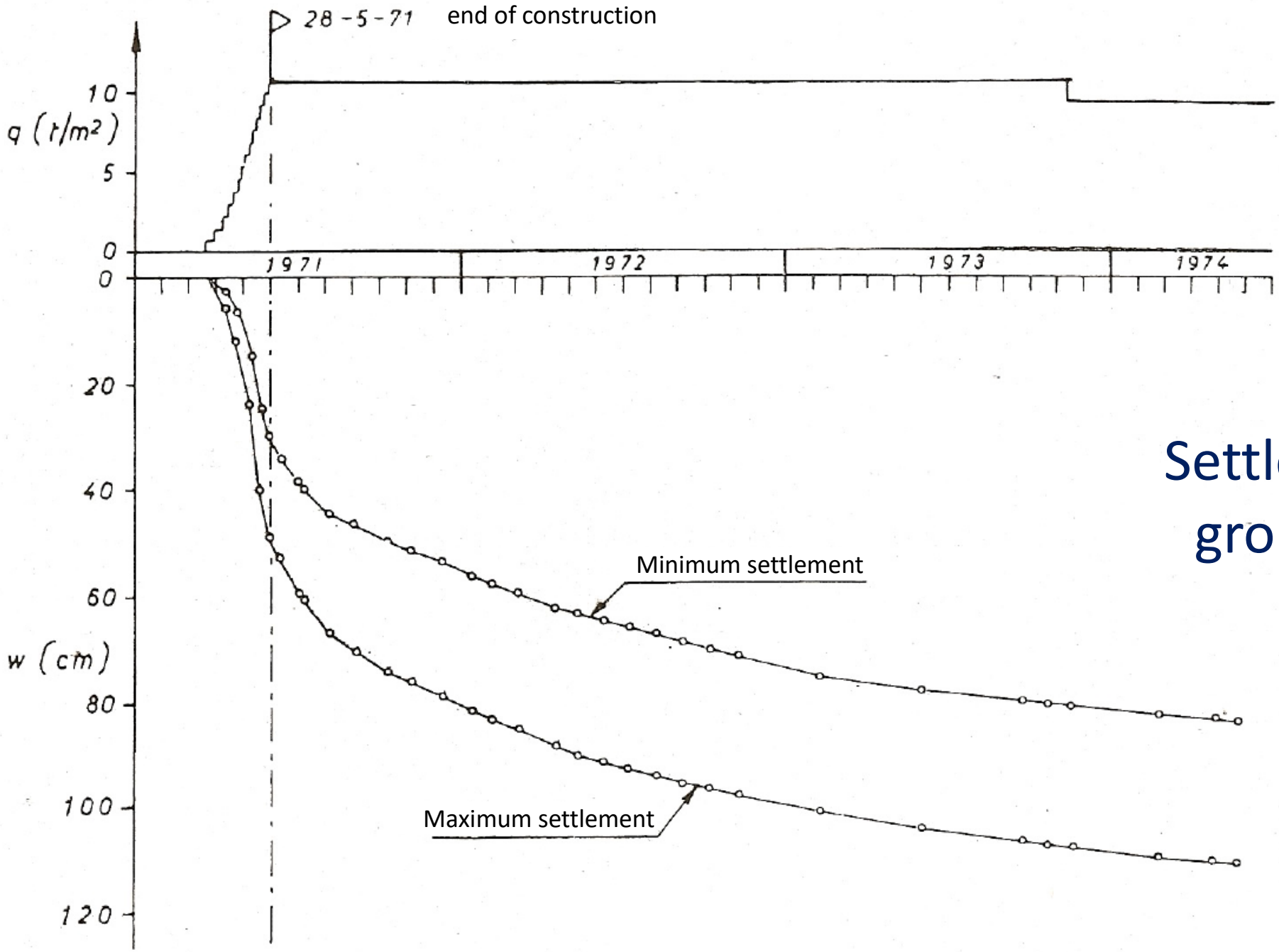
Group of 4-10 piezometers

Installation of instruments
and subsequent monitoring of the embankment performance

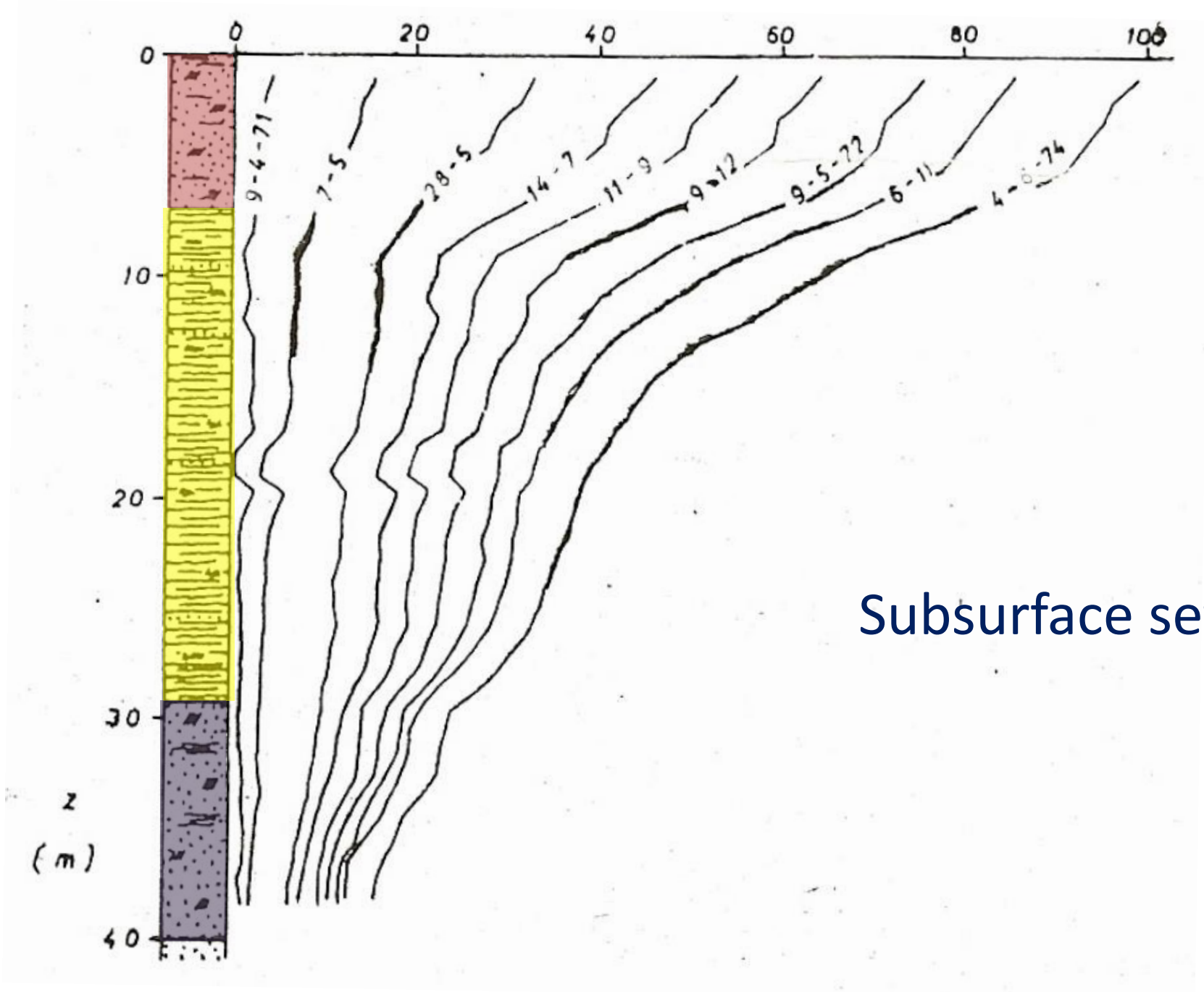
Task of a team including
an engineer and two technicians

Their role in installation,measurements
and timely interpretation of the data
central in the success of the investigation

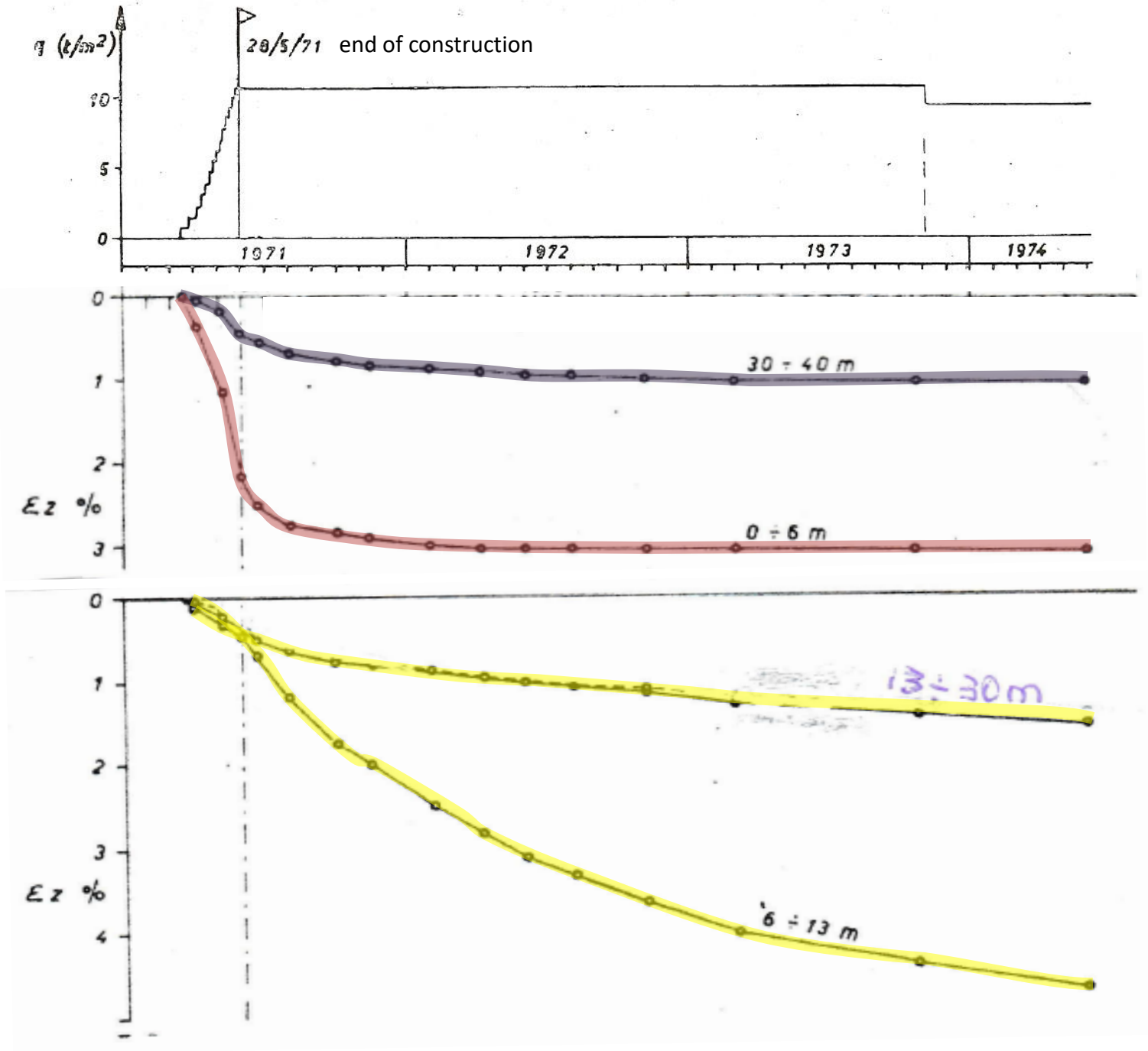
This is a central aspect of site investigations
It is often neglected
Even if modern techniques of data recording and processing
have simplified the matter
it remains extremely important



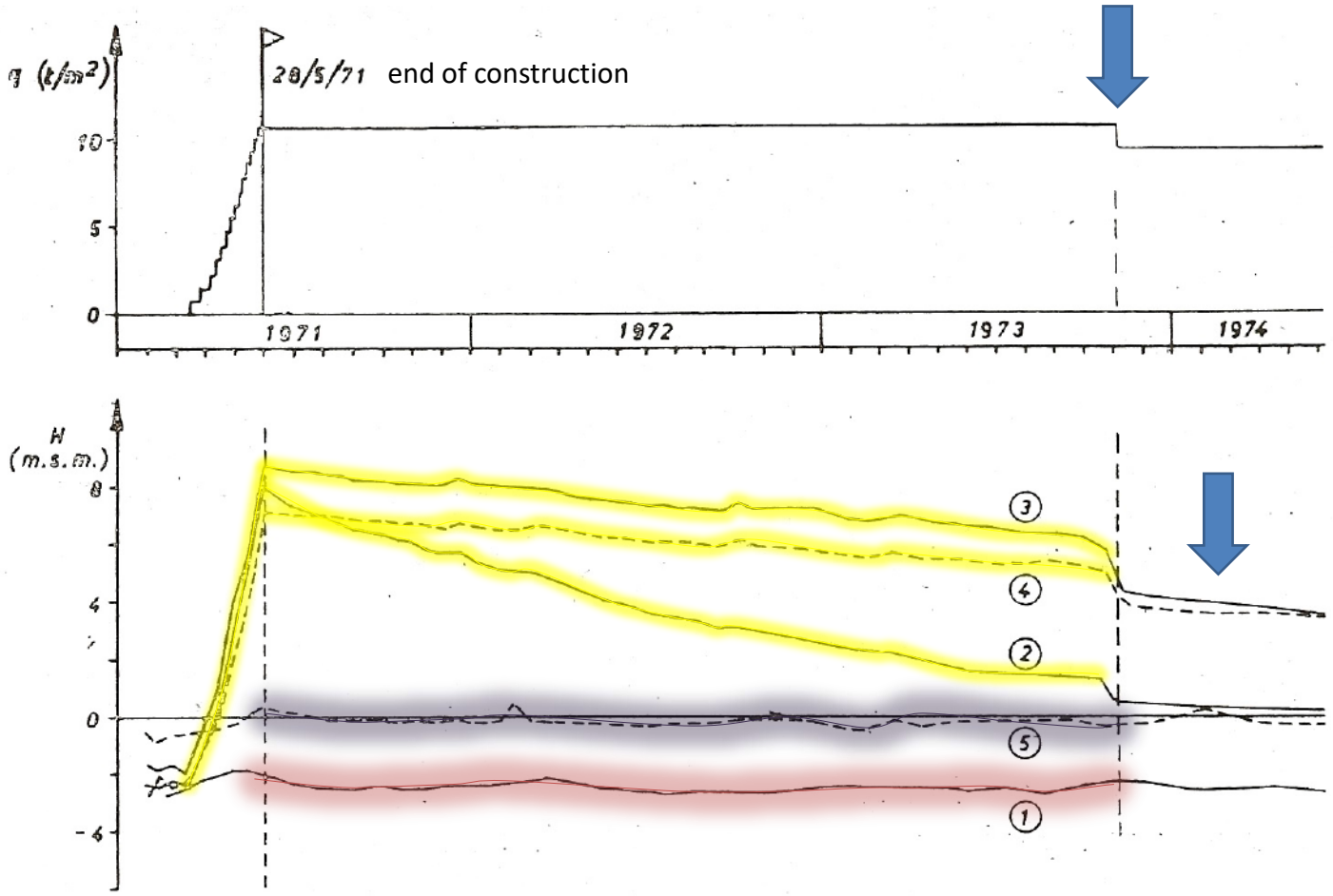
Settlement at the ground surface



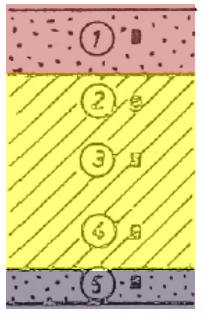
Subsurface settlements



Unit vertical deformations of the different layers



Depth
from ground surface



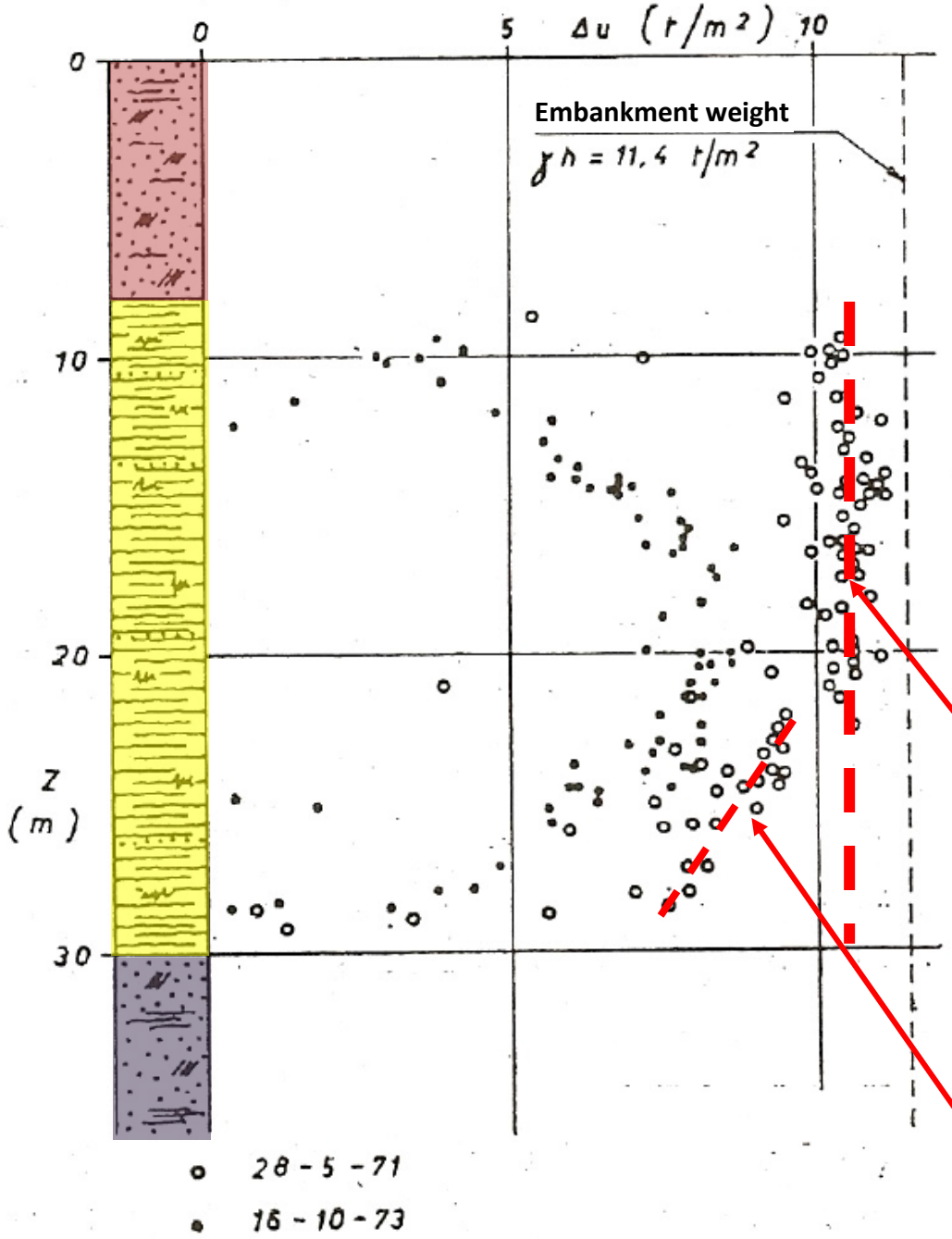
① m 2,85
② ~ 11,00
③ ~ 17,50
④ ~ 24,50
⑤ ~ 30,00

Development and dissipation of the excess pore pressure

Interpretation of results

(Part 1)

Undrained excess pore pressures



Excess pore pressures in the clay layer at the end of construction and 2.4 years later

In 1D condition one would expect values of Δu constant with depth and close to the embankment weight q

Why this does not occur in the lower part of the clay layer?

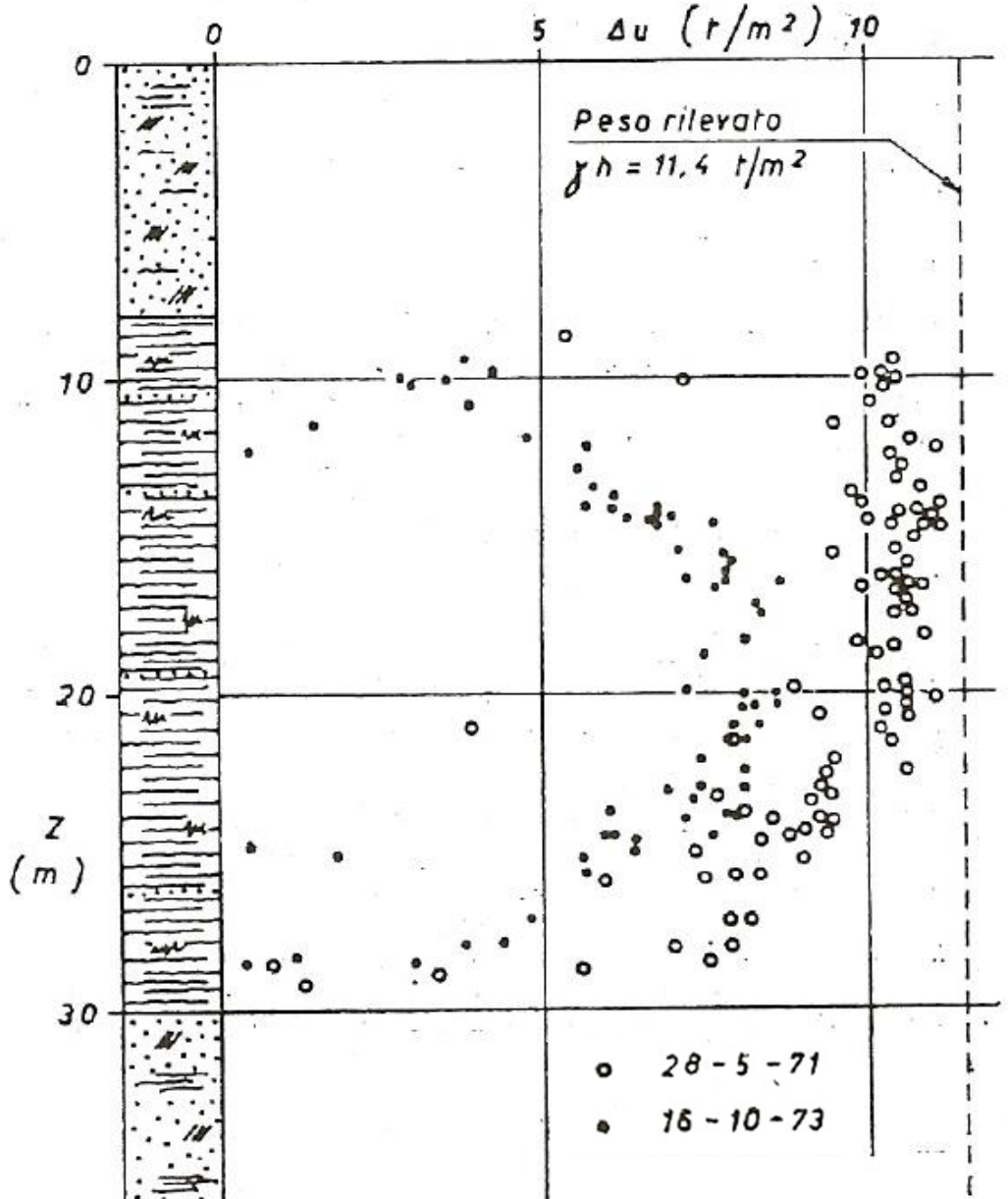
There are three possible explanations:

1. A partial consolidation during the construction stage

2. The conditions are not exactly 1D

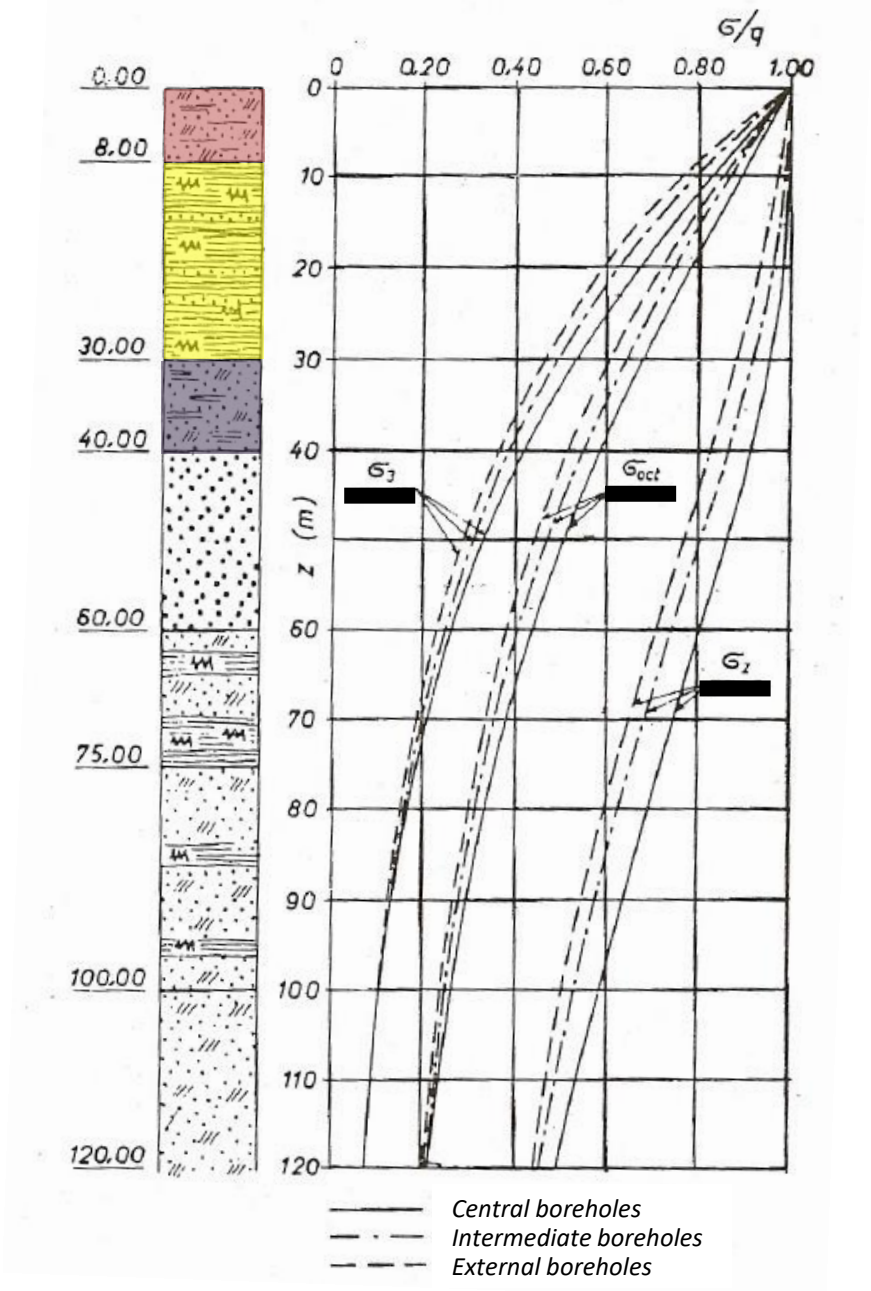
3. Different soil response to undrained loading

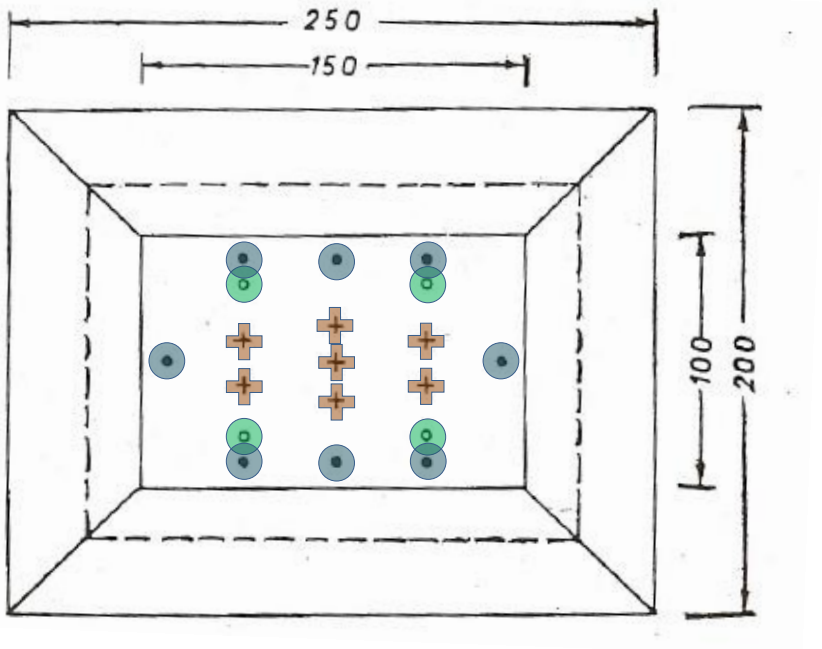
1. A partial consolidation during the construction stage



To be discarded because it does not occur in the upper part of the layer and because of the subsequent consolidation process

2. The conditions are not exactly 1D





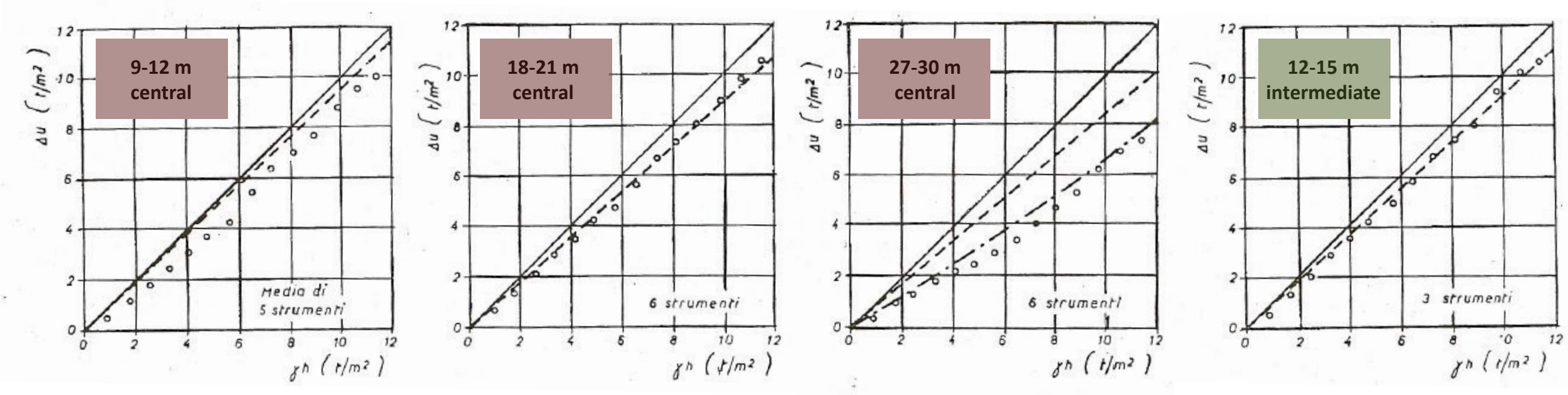
Central boreholes

Intermediate boreholes

External boreholes

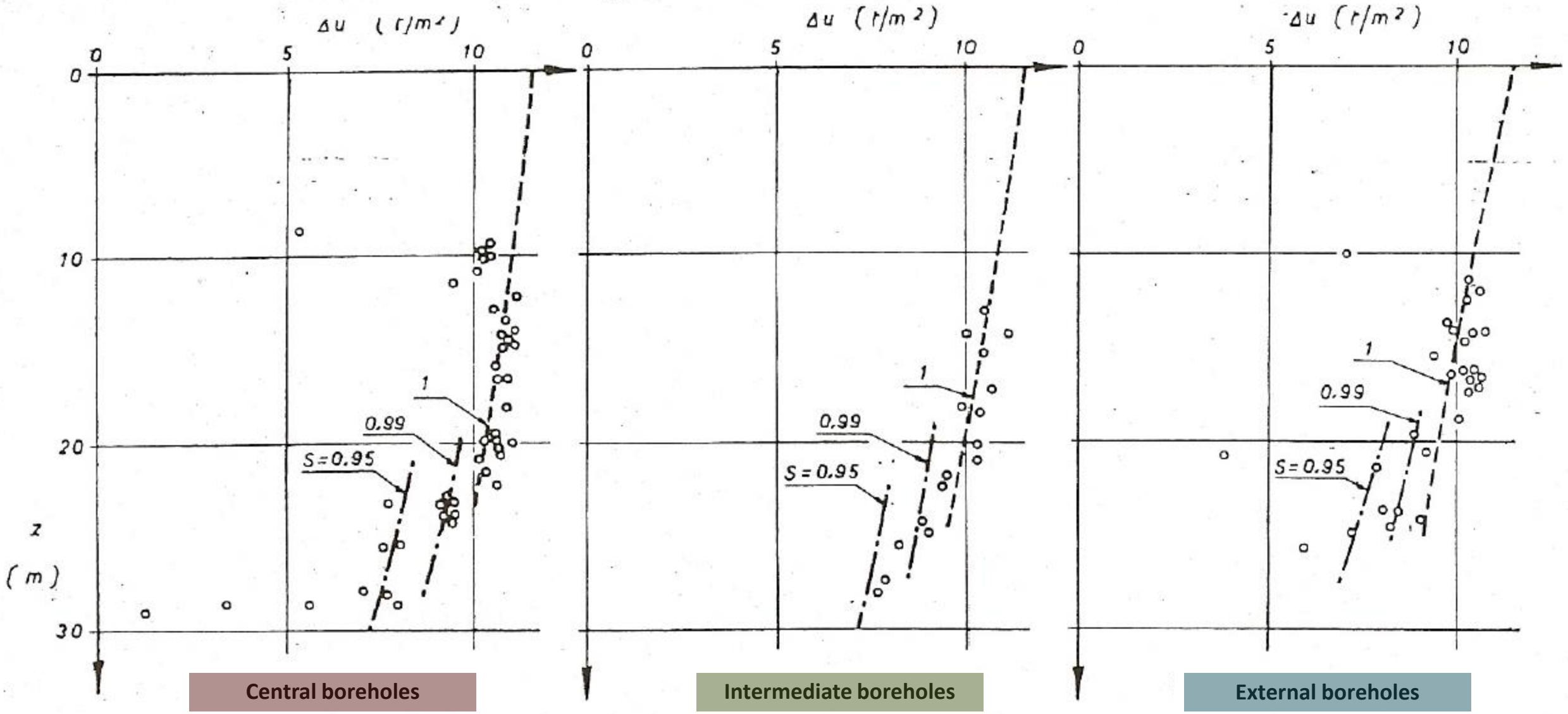
Undrained total stress
induced in the soil
by the test embankment

3. Different soil response to undrained loading



- experimental results
- $\Delta u = \gamma h$
- $\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$ B=1; A=0.7
- B computed for S=0.95 to 0.99; A=0.7

Undrained pore pressure generation at different locations



Central boreholes | **Intermediate boreholes** | **External boreholes**

- *Experimental results*

$$\Delta u = B\left[\Delta\sigma_3 + A\left(\Delta\sigma_1 - \Delta\sigma_3\right)\right]$$

- – – – – $B = 1;\ A = 0.7$
- ——— B *computed using Hill's formula (1948): S = 0.95-0.99 and A = 0.7*

Interpretation of results

(Part 2)

The consolidation process

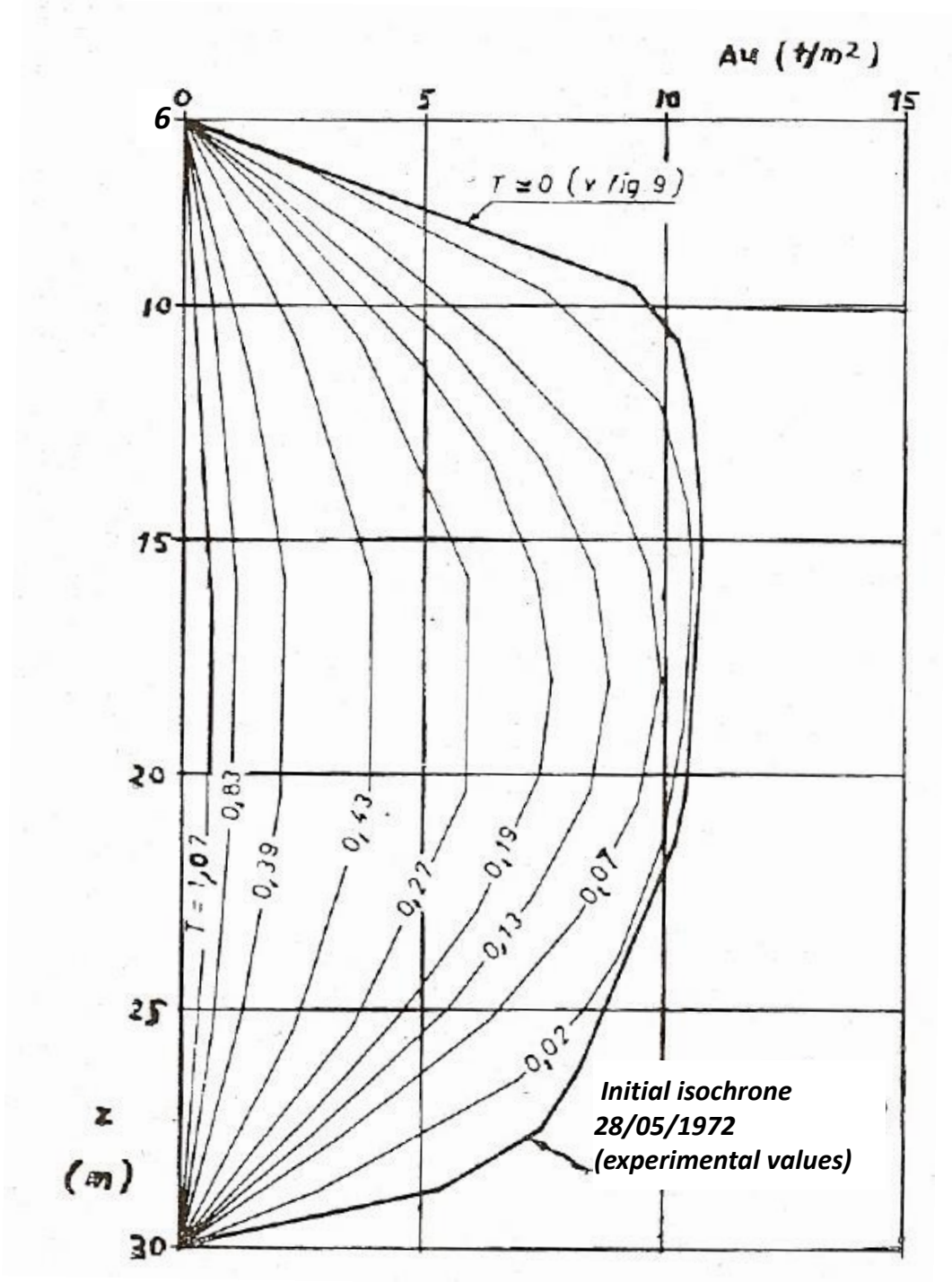
Degree of consolidation in terms of excess pore pressure

$$U = \frac{\int_6^{30} \Delta u_o dz - \int_6^{30} \Delta u(t) dz}{\int_6^{30} \Delta u_o \, dz}$$

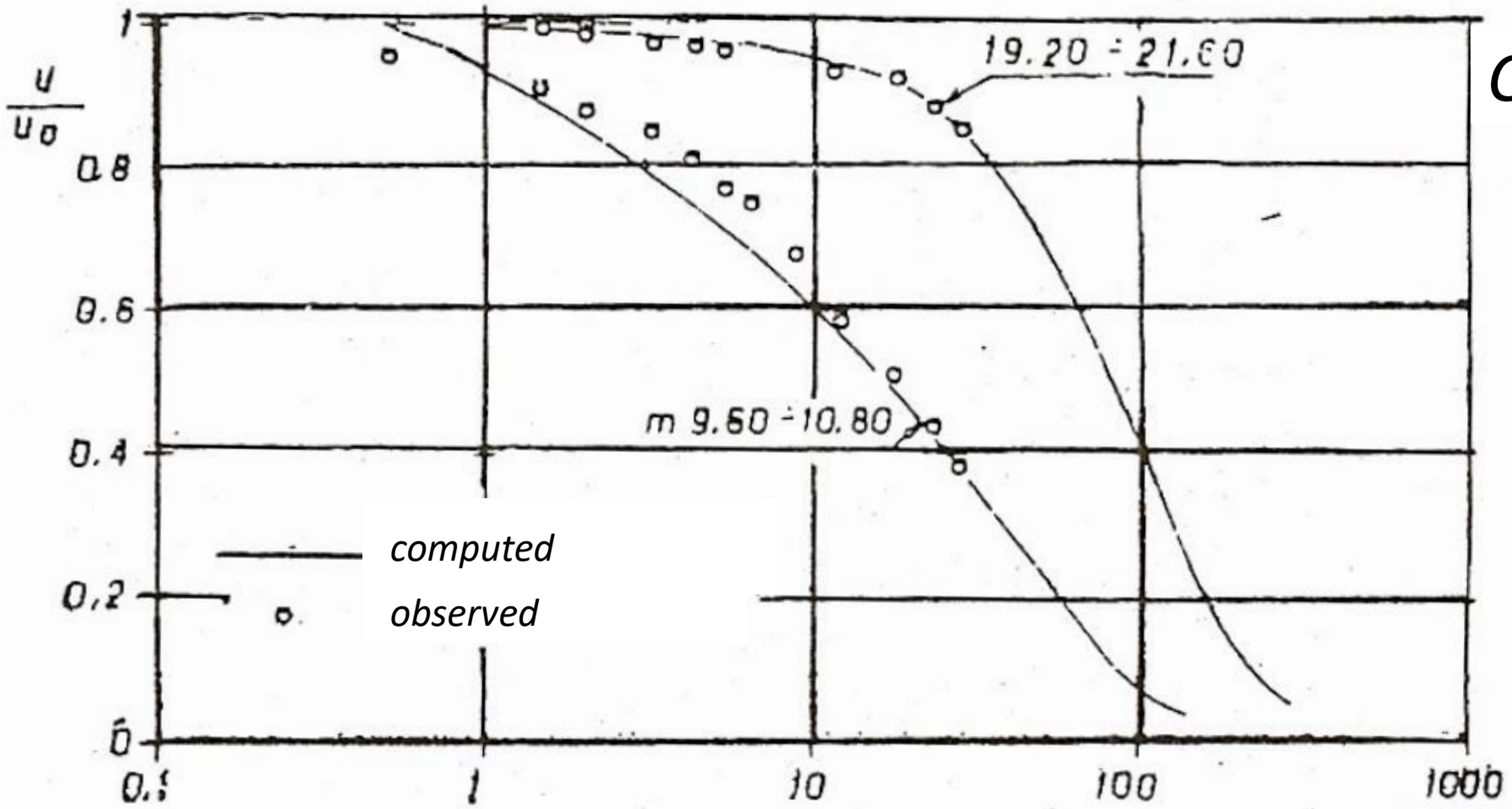
Degree of consolidation in terms of deformations

$$U = \frac{\int_6^{30} \varepsilon(t) dz}{\int_6^{30} \varepsilon(t = \infty) dz}$$

In a linear theory, the two definitions coincide

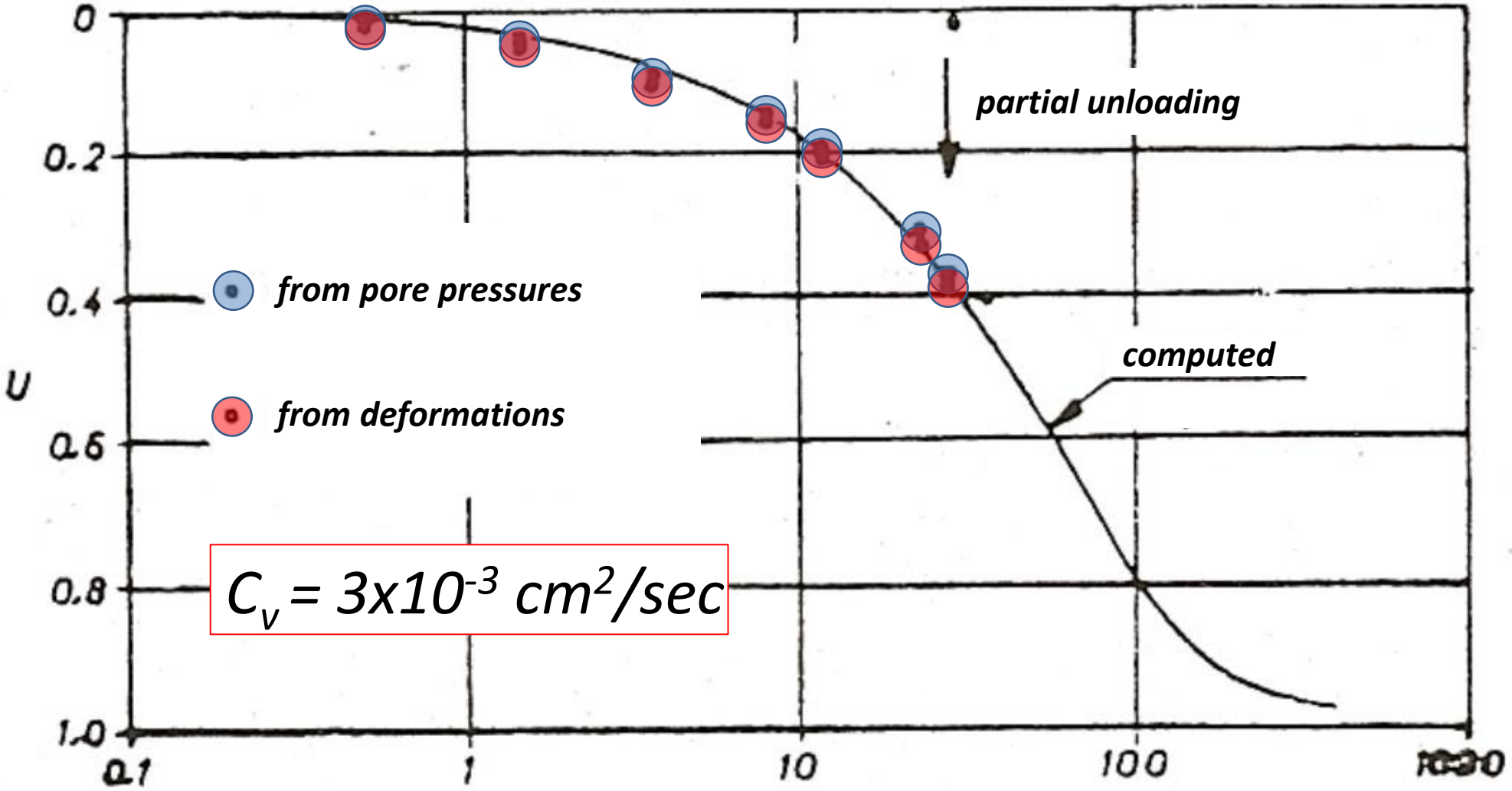


Numerical (actually, graphical!) solution of the consolidation equation assuming as initial isochrone the measured excess pore pressure distribution at the end of embankment construction



$C_v = 3x10^{-3}\ cm^2/sec$

Pore pressure dissipation in two points at the centre and near the boundary of the clay layer



Remind that the average lab value of c_v was $1.3x10^{-3}cm^2/sec$

Lessons learned

1. The choice and installation of the instruments, the execution of the measurements, the timely interpretation of the collected data are essential to the success of a monitoring program. To this aim, a fully dedicated qualified team (or even a qualified person) is absolutely necessary.

2. Duplication of the instrument types and increase of the measuring points is very useful. The cost of instruments is generally a minor fraction of the total cost of the investigation.

3. The back analysis of a consolidation process is easier if based on pore pressure than if based on settlement

Necessity of accelerating the consolidation process confirmed

Sand drains and prefabricated cardboard drains extensively and successfully adopted

But this is another tale!