Behavior of Reinforced Embankment on Soft Ground with and without Jet Grouted Soil-Cement Piles

by

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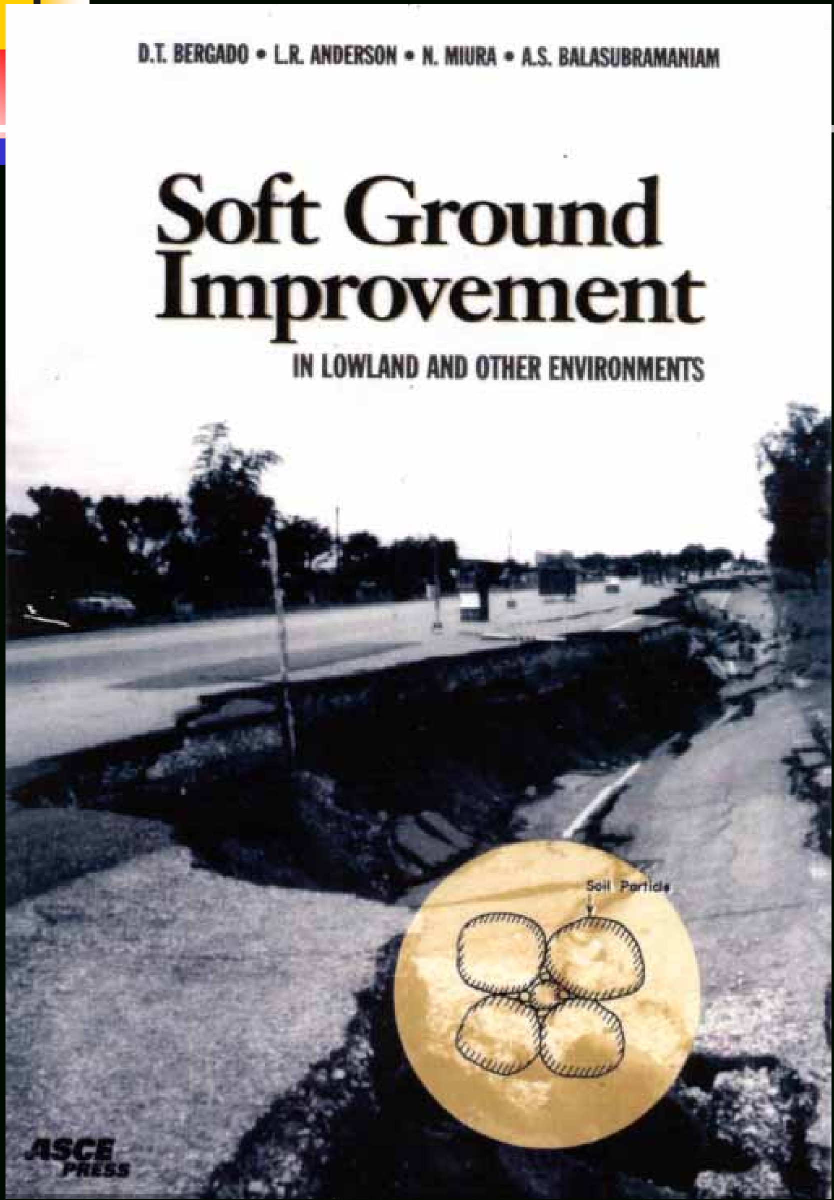
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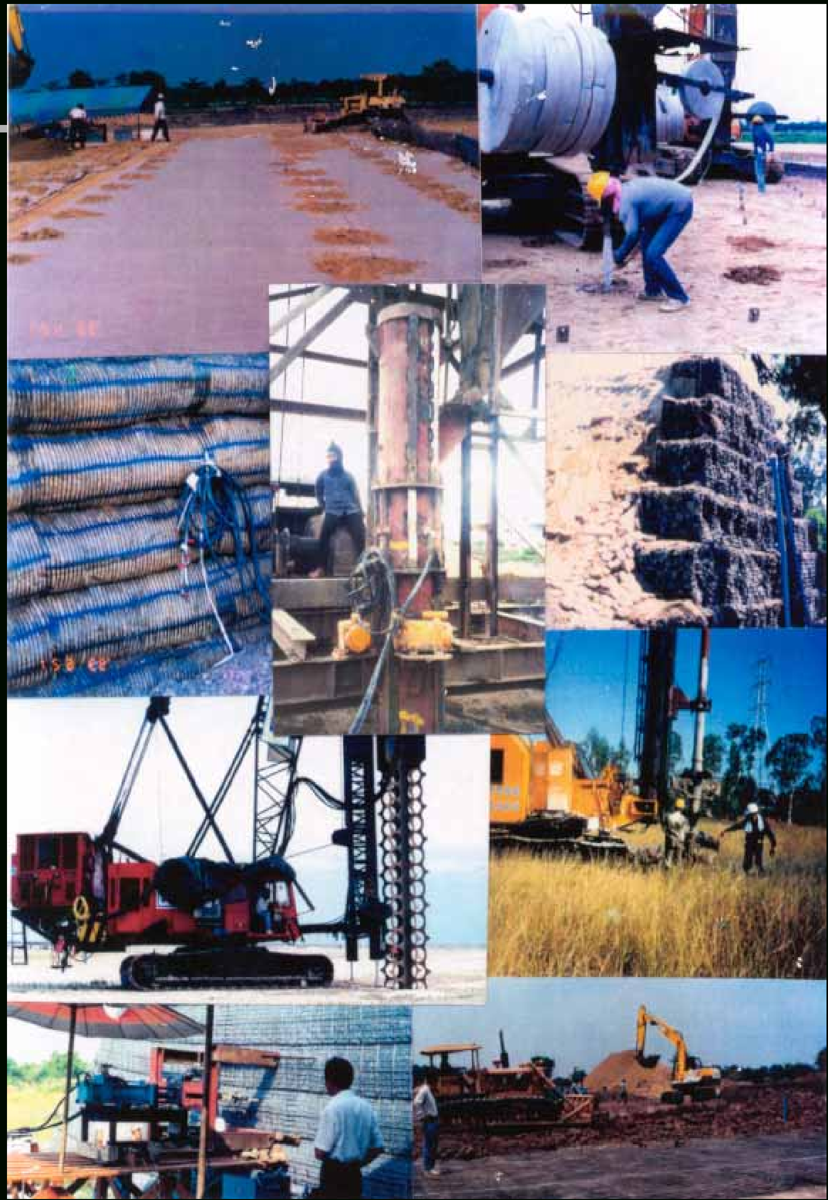
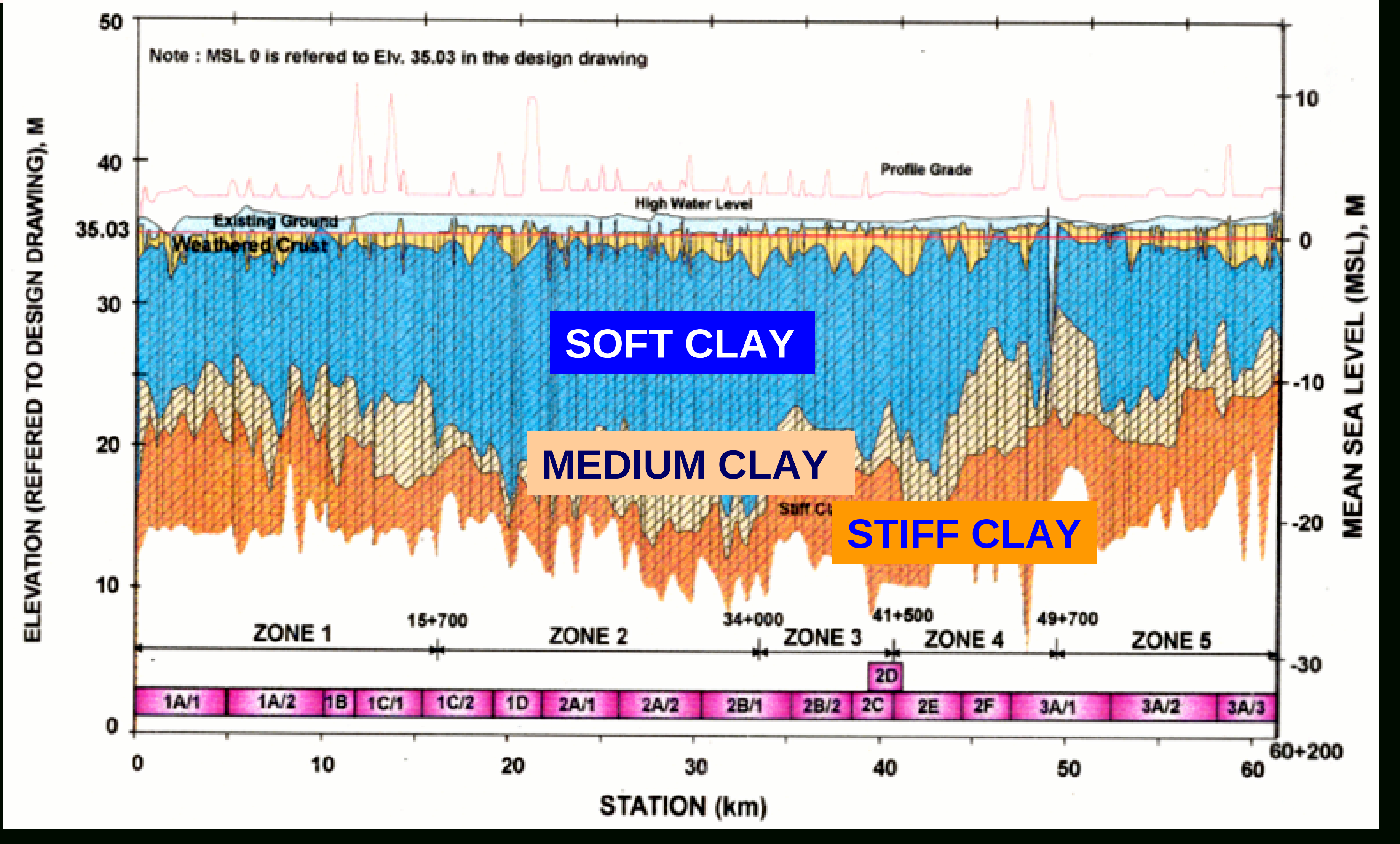
Soft Ground Improvement
IN LOWLAND AND OTHER ENVIRONMENTS
Soil Particle
ASCE PRESS



Soil Profile along Bangkok-Chonburi

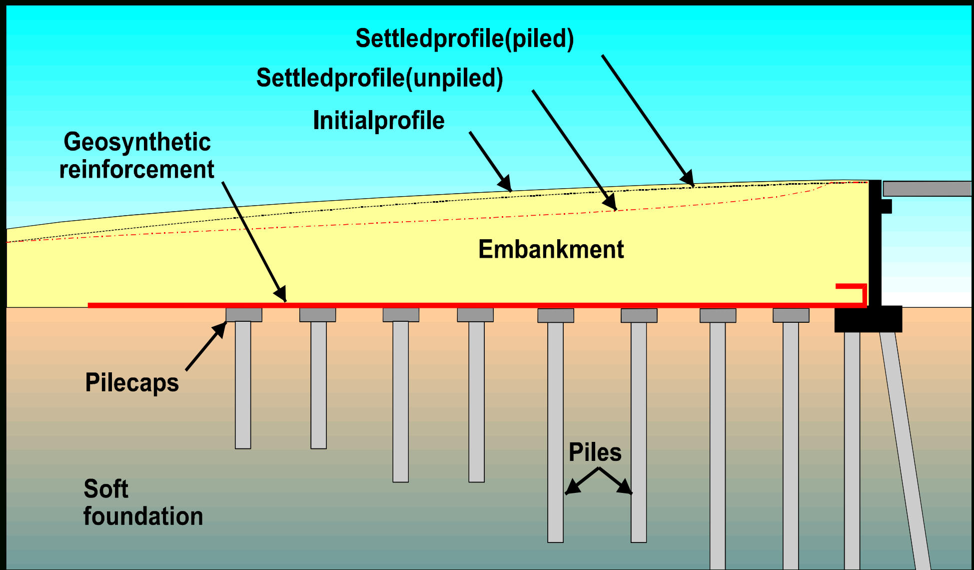


Failure of Embankment on Soft Ground

Problem of Bridge Approach on Subsiding Ground

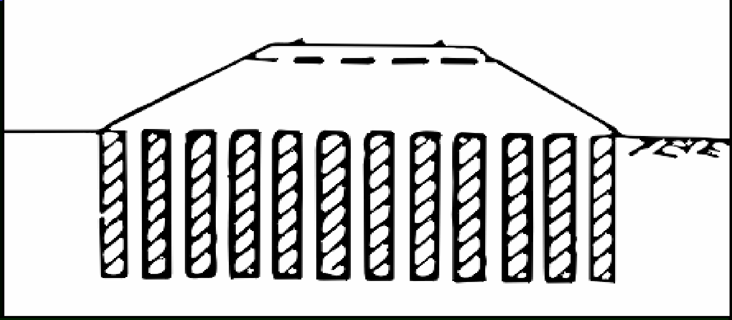
Basal Reinforced Piled Embankments

Transition between non-piled and piled foundations

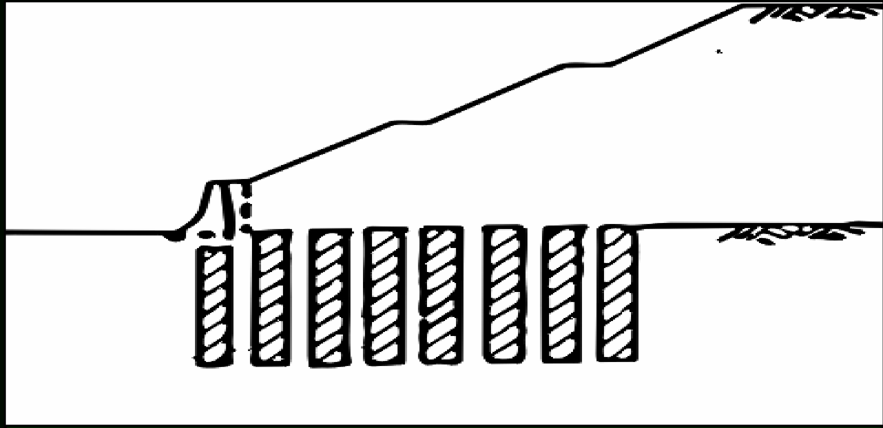


Some Applications of Soil-Cement Piles

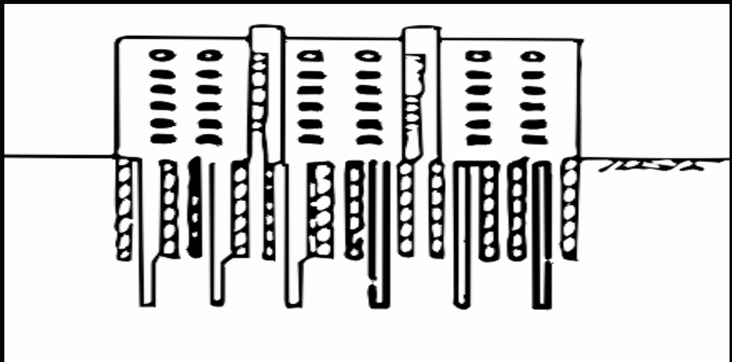
(DJM Research Group, 1984)



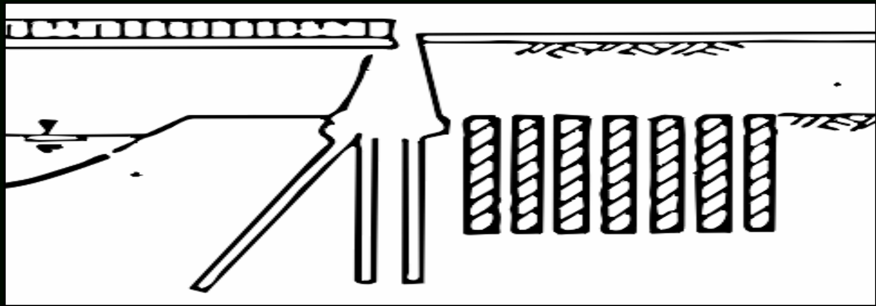
Prevent slope failures and settlement of embankment and structure



Increase stability of slopes



Increase horizontal resistance of structures



Reduce settlement and prevent slope failures of bridge's abutments

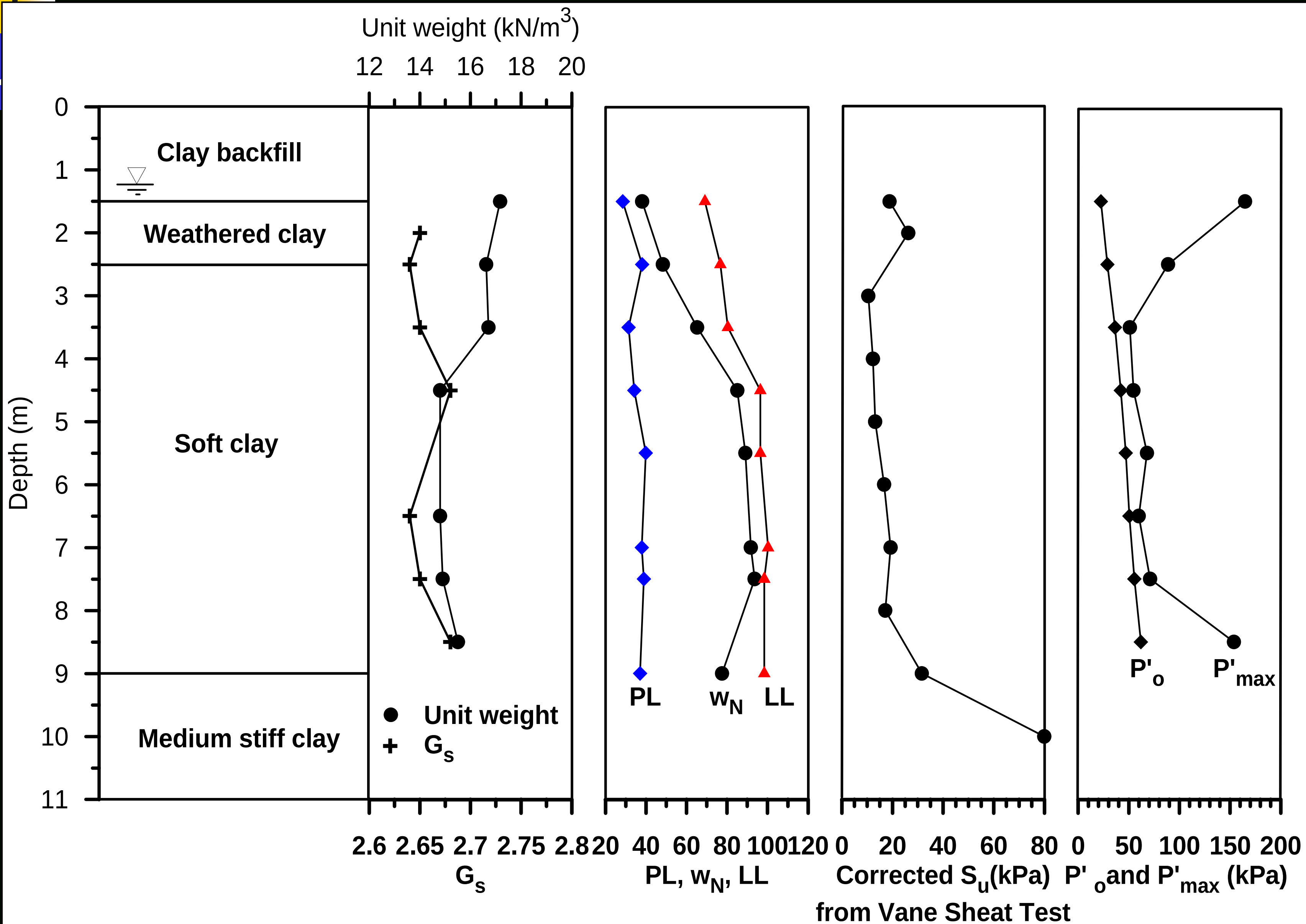
Advantages of Soil-Cement Stabilization

- It can significantly ***increase the strength*** and ***reduce the compressibility*** of soil.
- Soil improvement can be attained at optimum period of ***only 1 month.***
- Cement is **abundant** and cheaper in Asia.
- Cement is **effective** than lime.

Full-Scale Embankment on DMM Piles (Jet grouting)

THE SITE

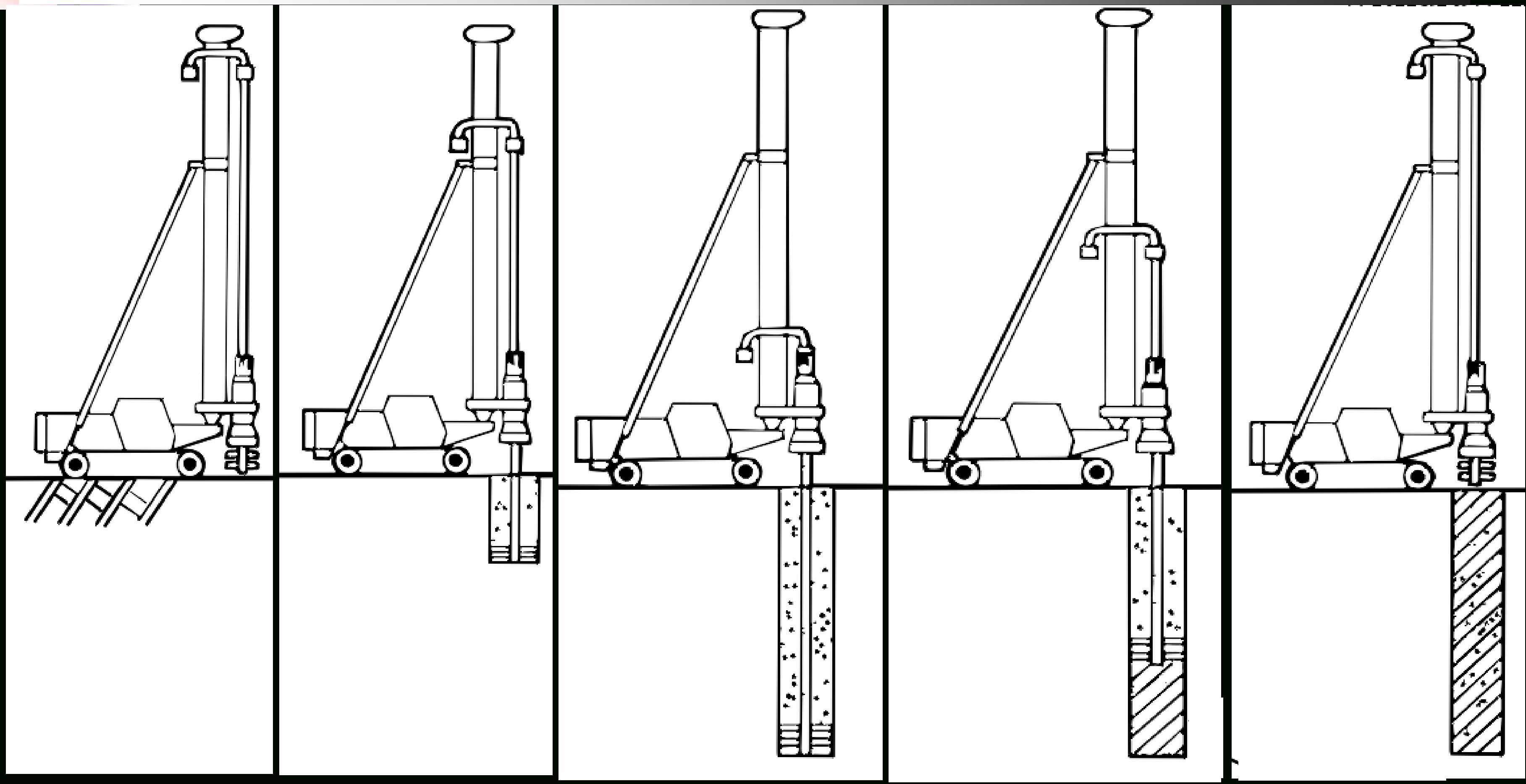
Soil Profile at the Site (Jet grouted piles)



Jet Grouting Machine

Jet pressure = 20 MPa

Sequence of Soil-Cement Piles Installation



(1) Positioning

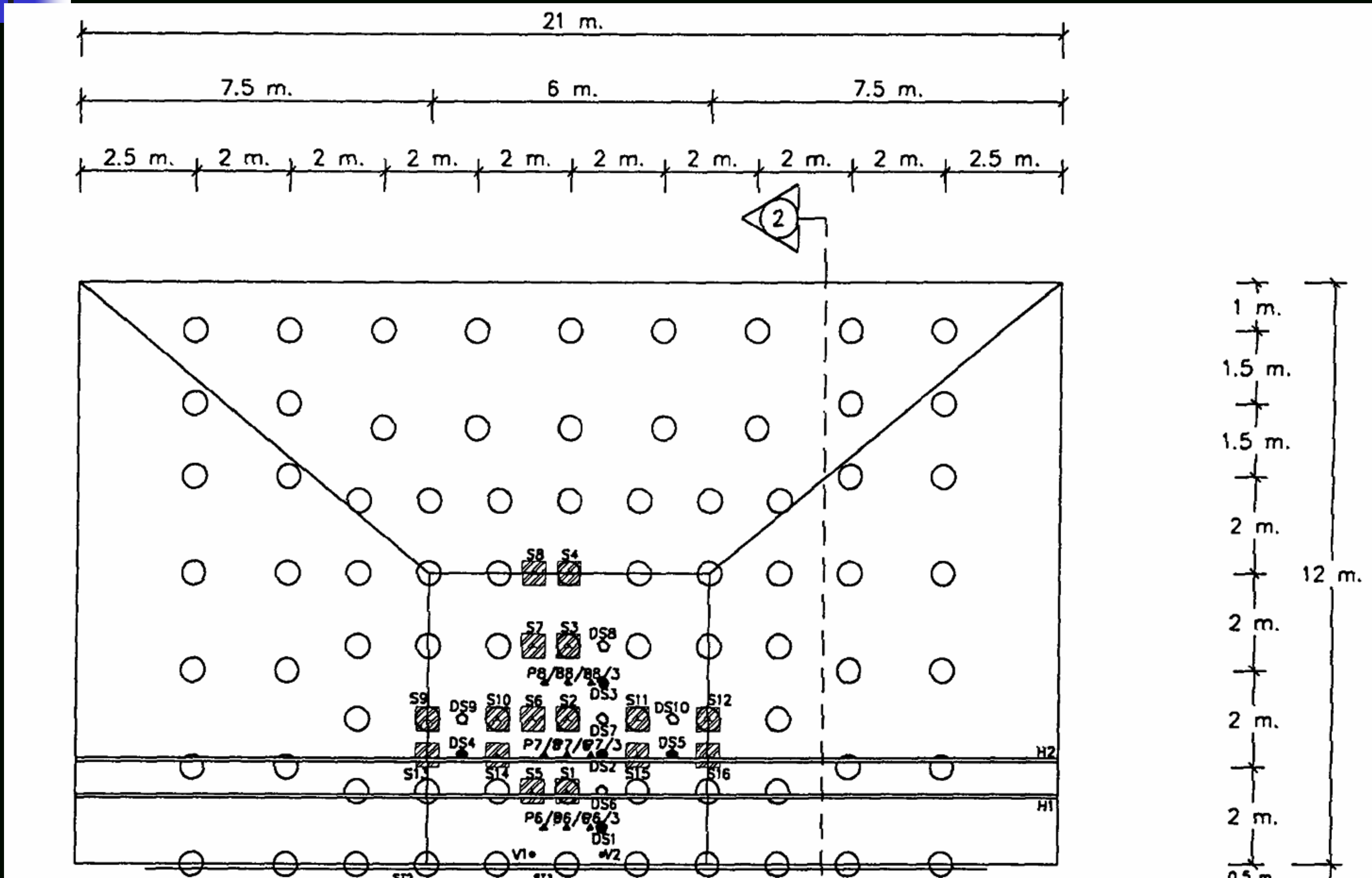
(2) Penetration (Remolding)

(3) Completion of penetration

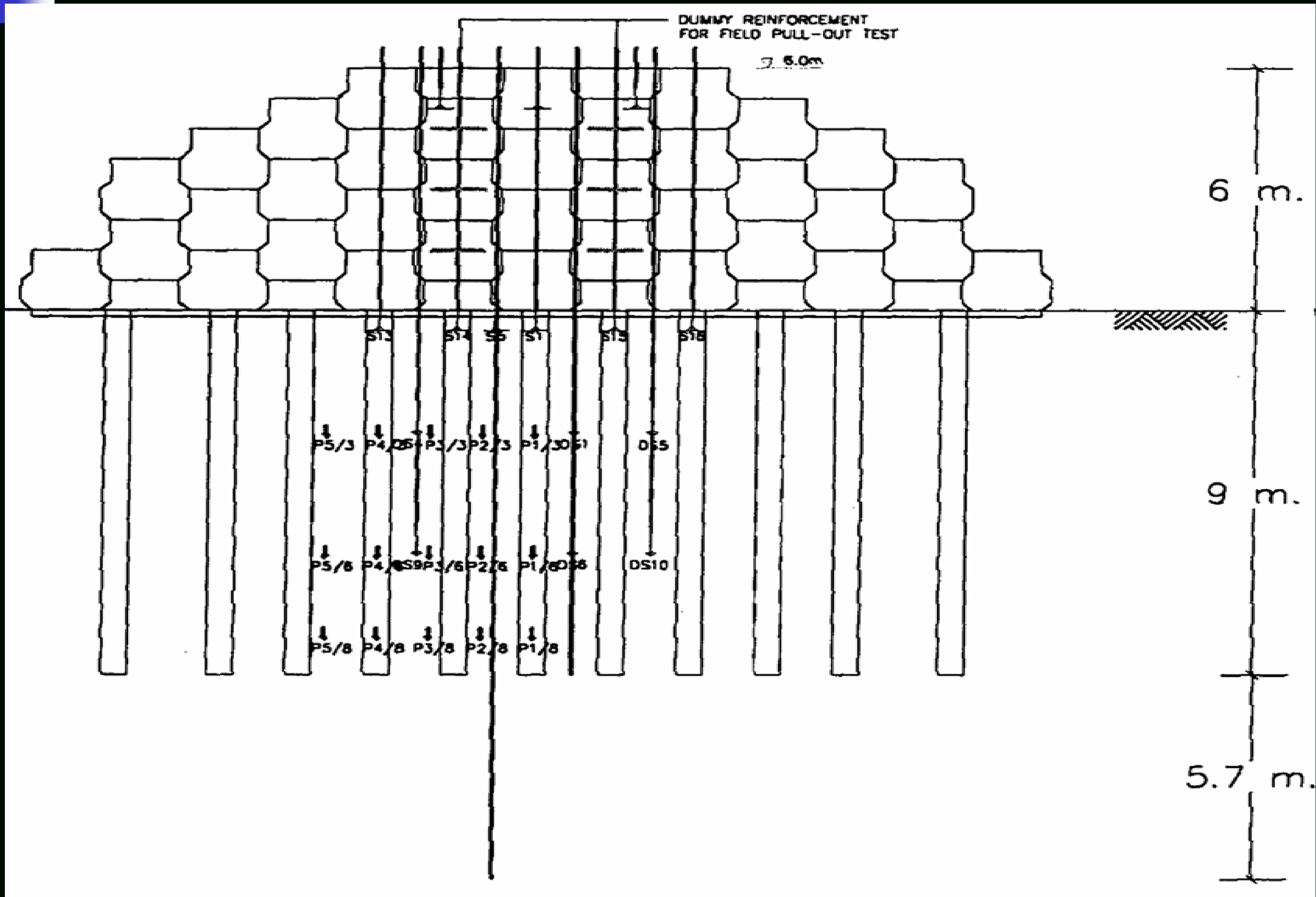
(4) Feeding of cementing agent (withdrawal)

(5) Completion

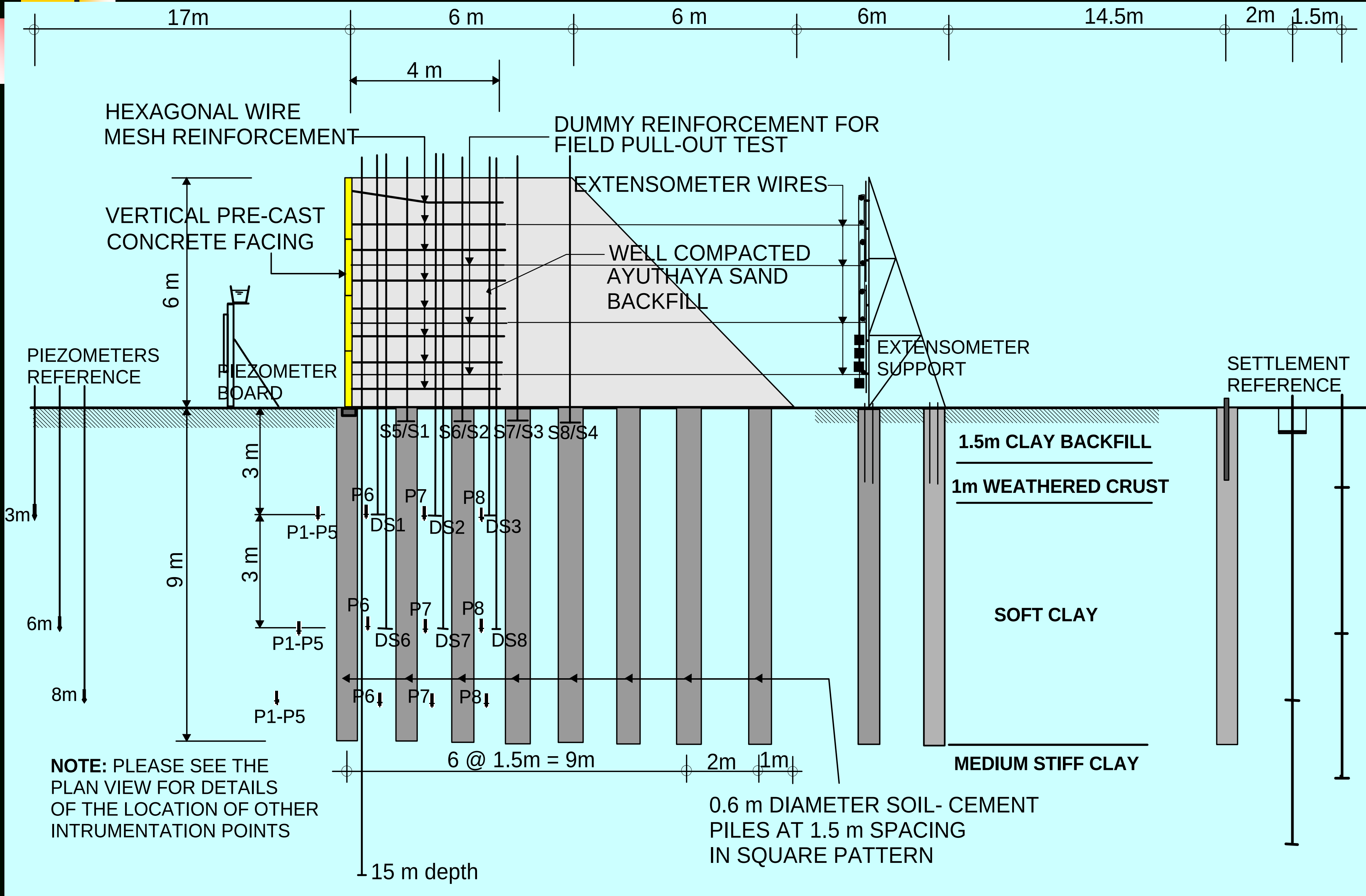
Plan View and Layout of DMM Piles



Front Elevation and DMM Pile Penetration

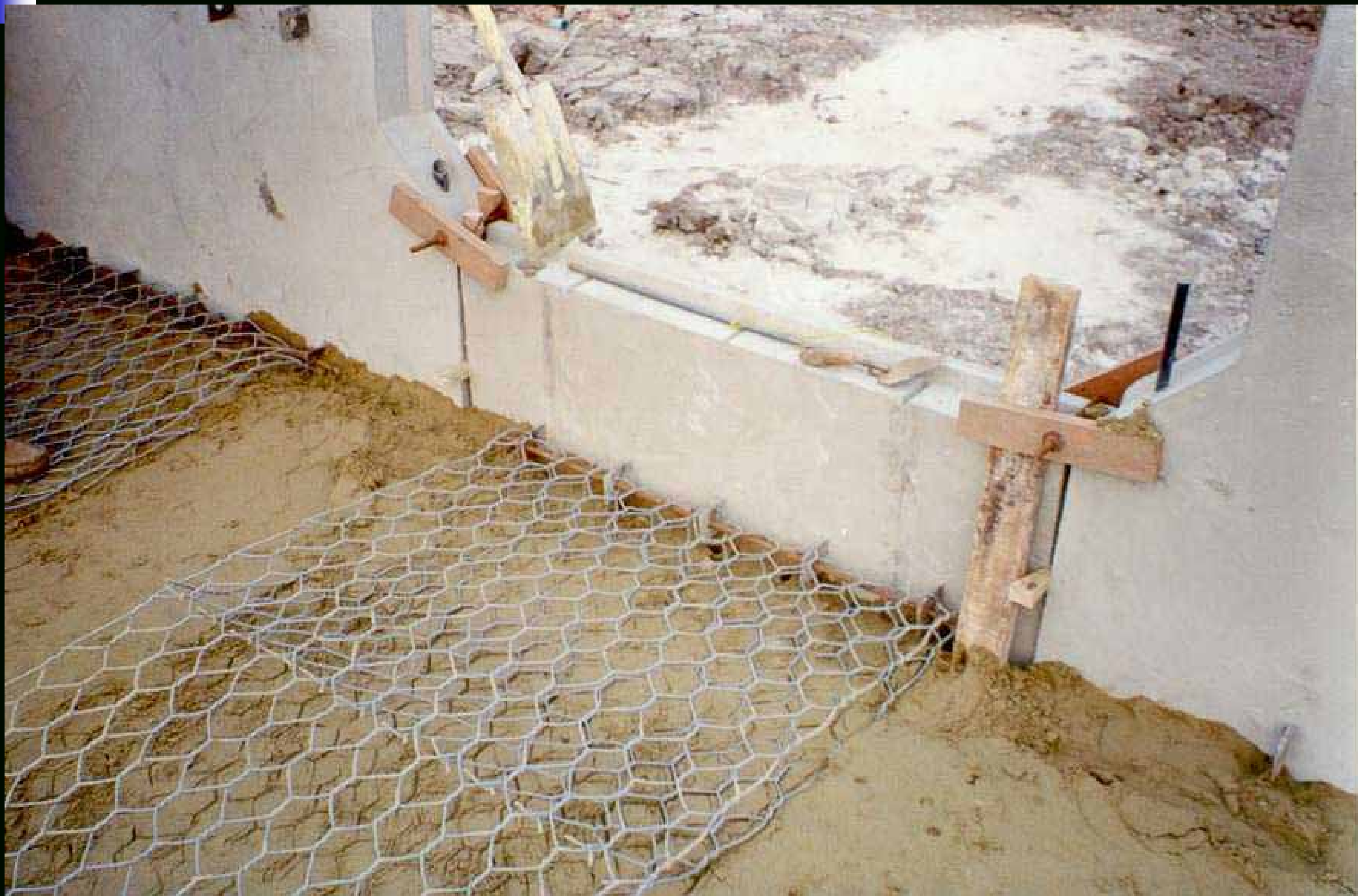


Section thru Center Line

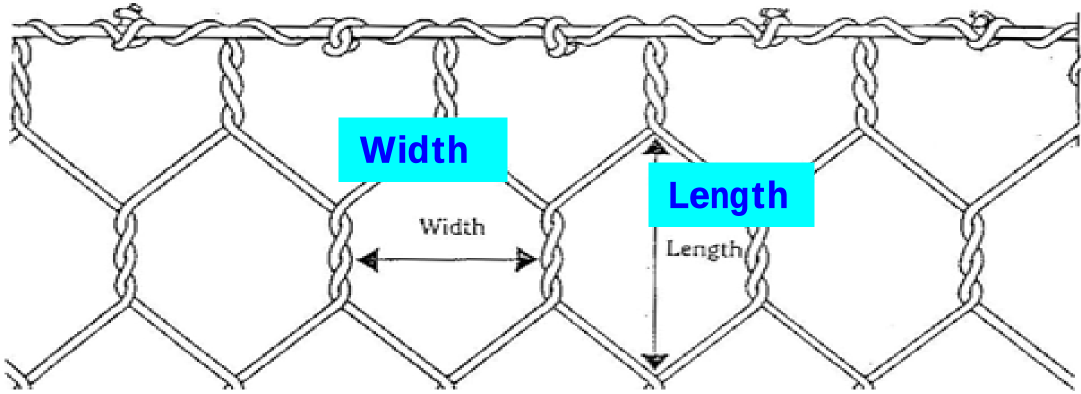


Instrumentations and Laying of Reinforcements

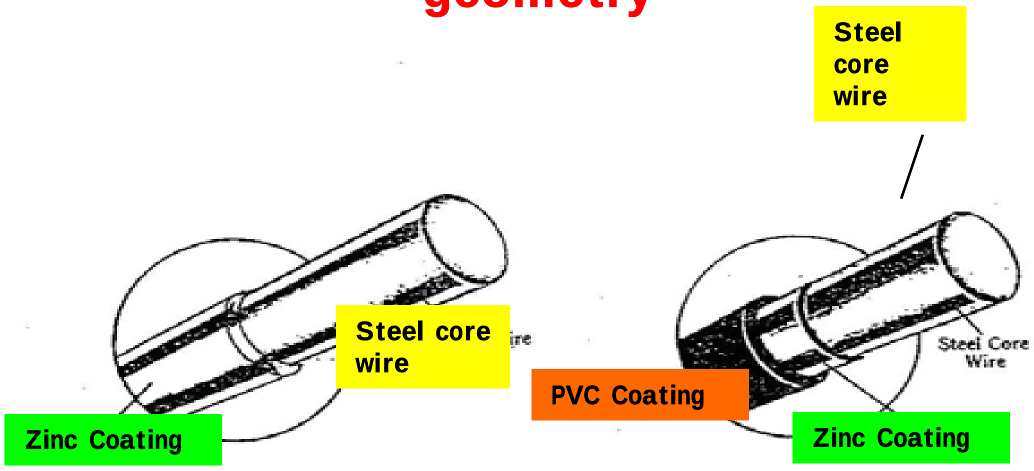
Reinforcement Connection



Hexagonal Wire Mesh

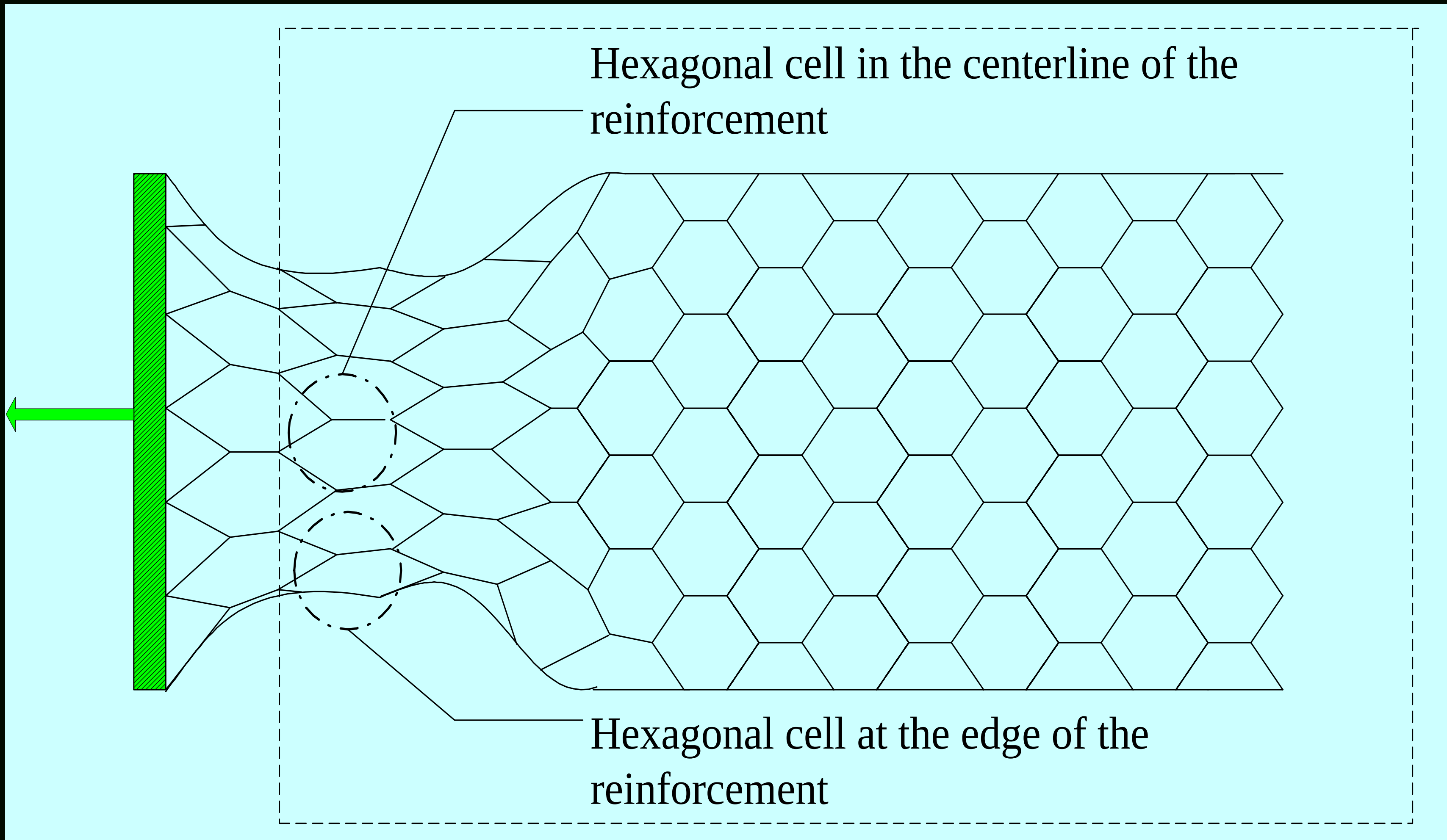


Basic hexagonal wire mesh reinforcement geometry

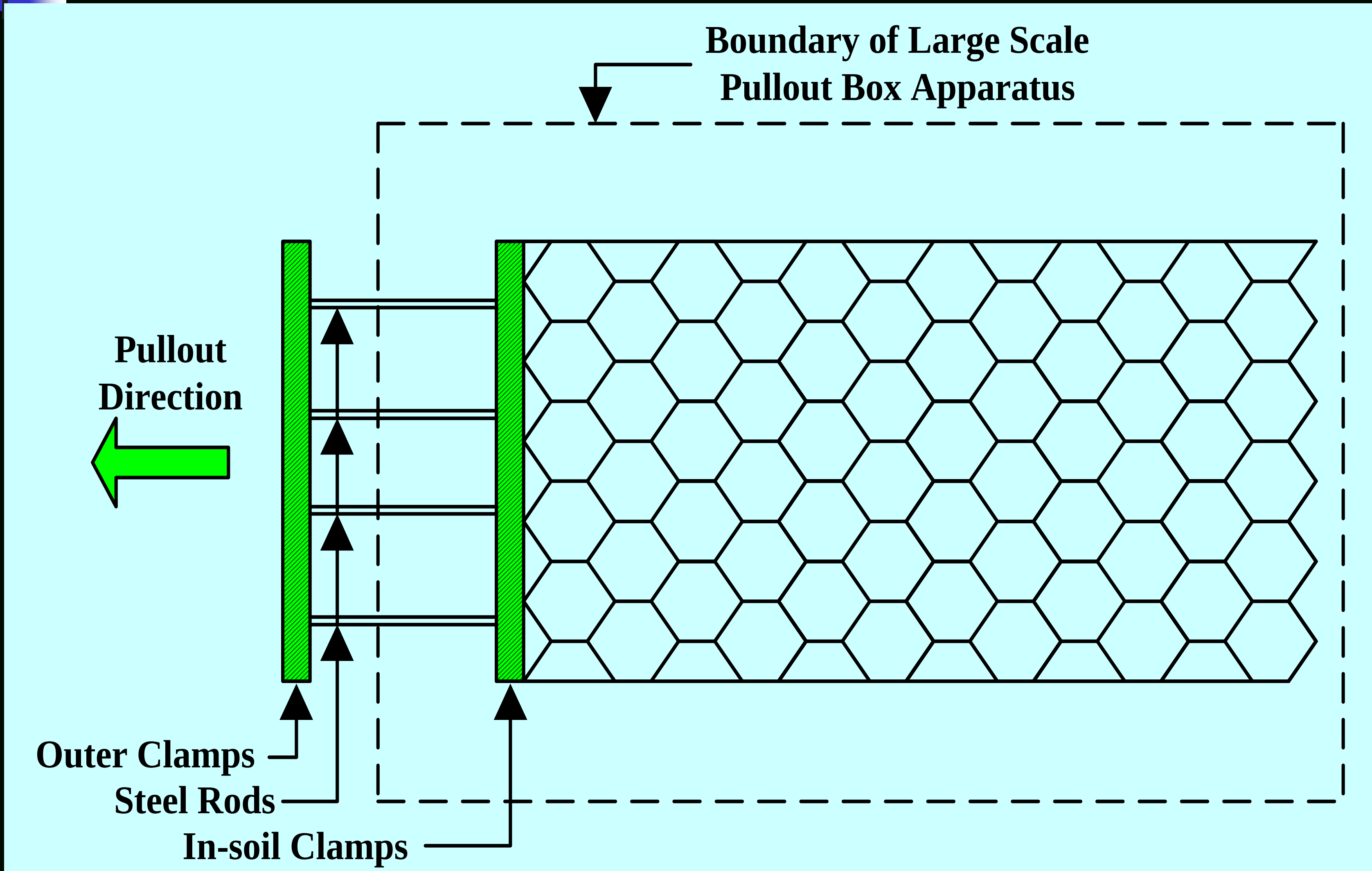


Cross section of different types of hexagonal wire mesh reinforcement

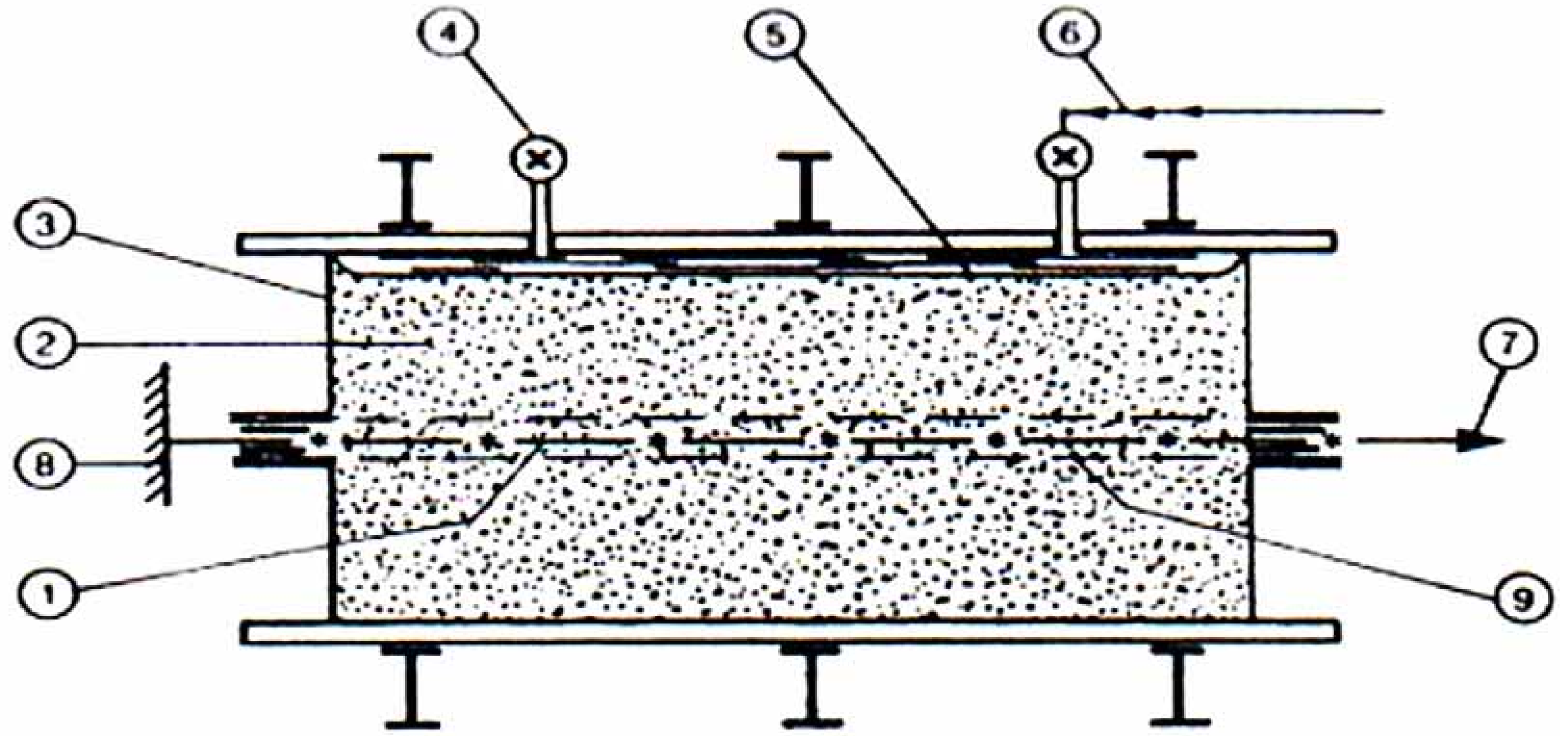
Deformation and Necking Phenomenon of Hexagonal Wire Mesh Reinforcement during Pullout (Conventional pullout test)



Modified Pullout Test Set Up (In-soil Pullout Test)

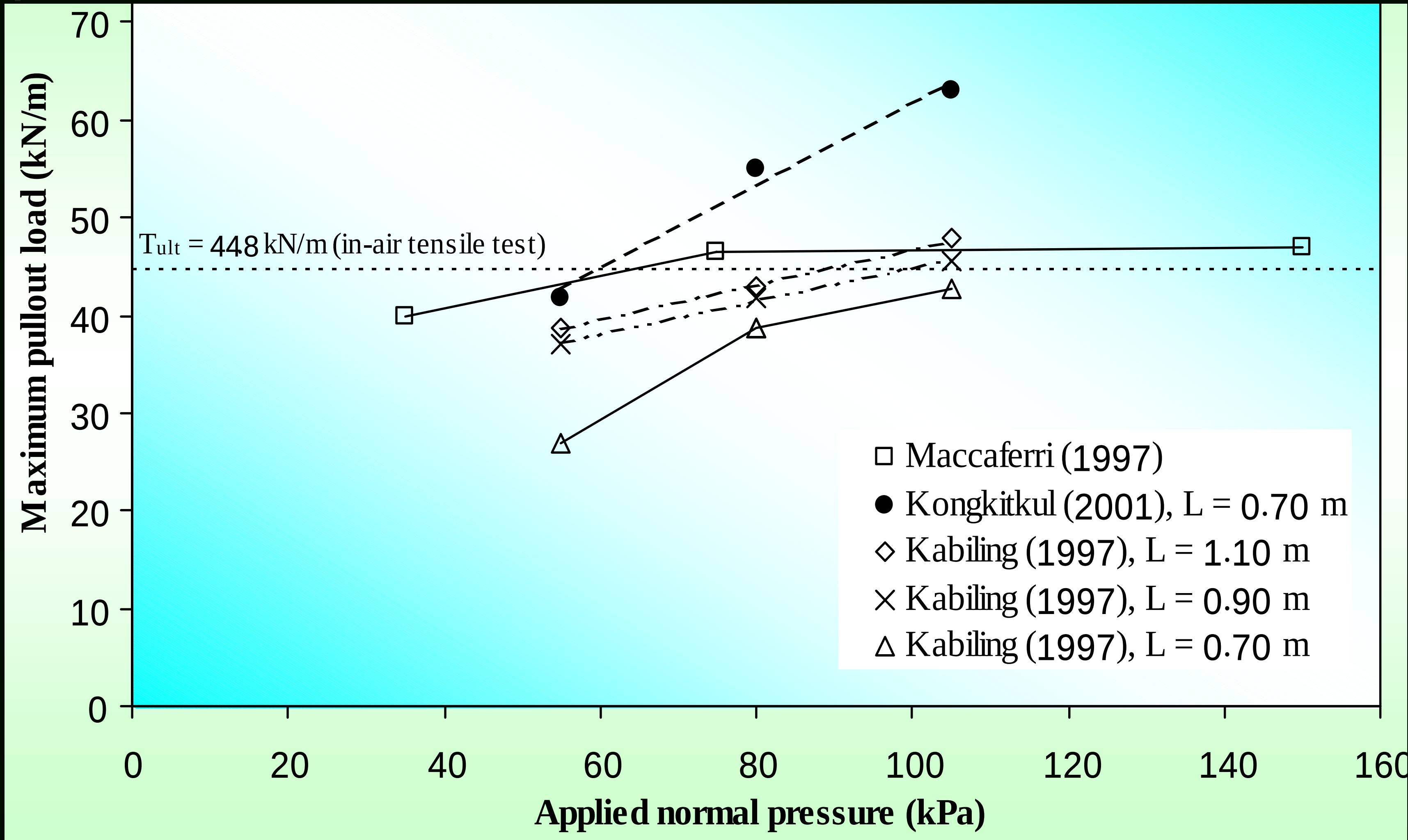


Pullout Test Apparatus (Maccaferri, 1997)



1: Mesh panel
2: Sand
3: Spilt box
4: Safety valve
5: Rubber diaphragm
6: Hydraulic pressure supply
7: Load
8: Anchorage
9: Rubber cloth

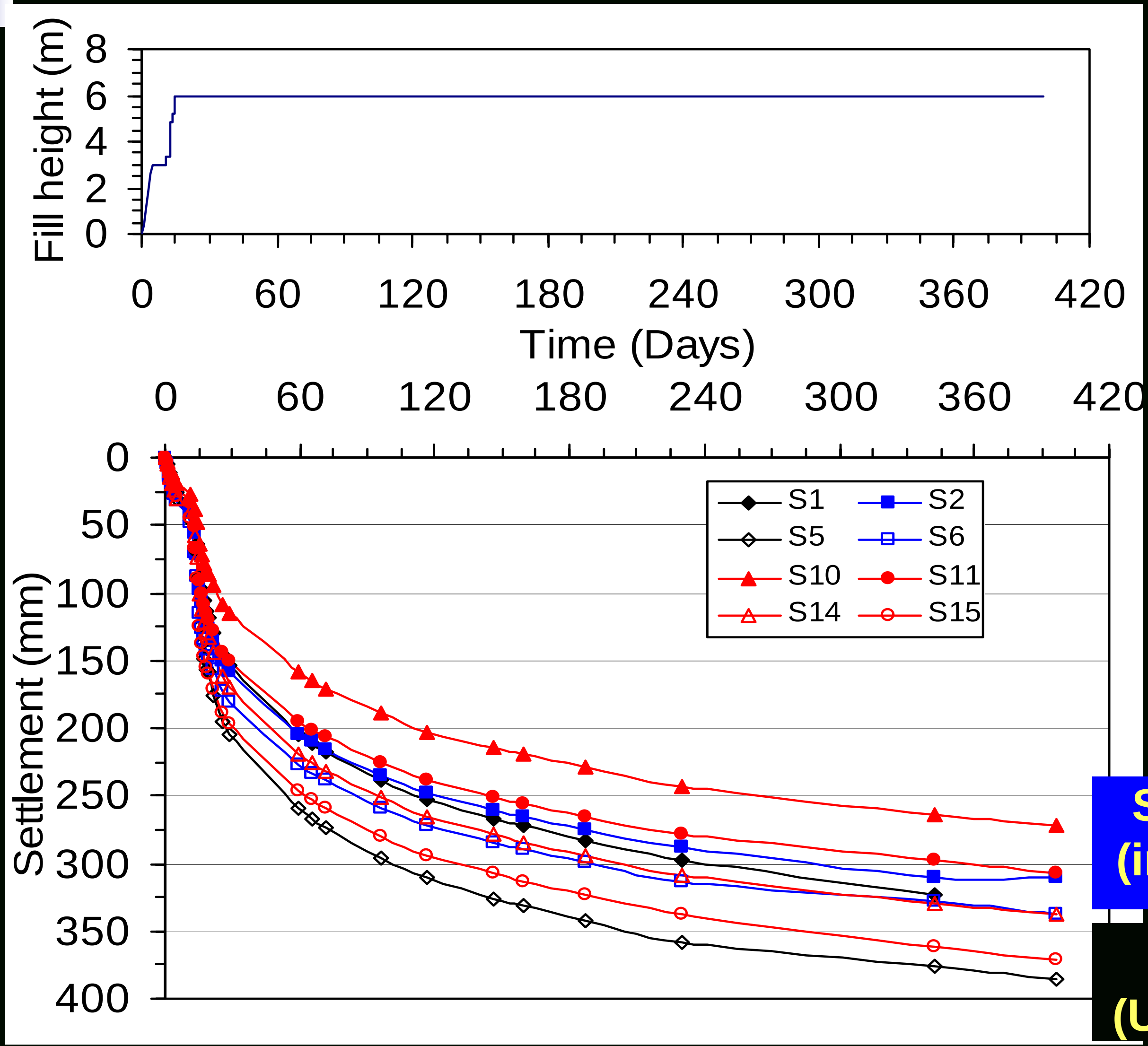
Maximum Pullout Resistance in Various Pullout Test Programs



The Finished 6m High Reinforced Embankment

Surface Settlement

(hollow symbol= "on clay"; solid = "on pile")

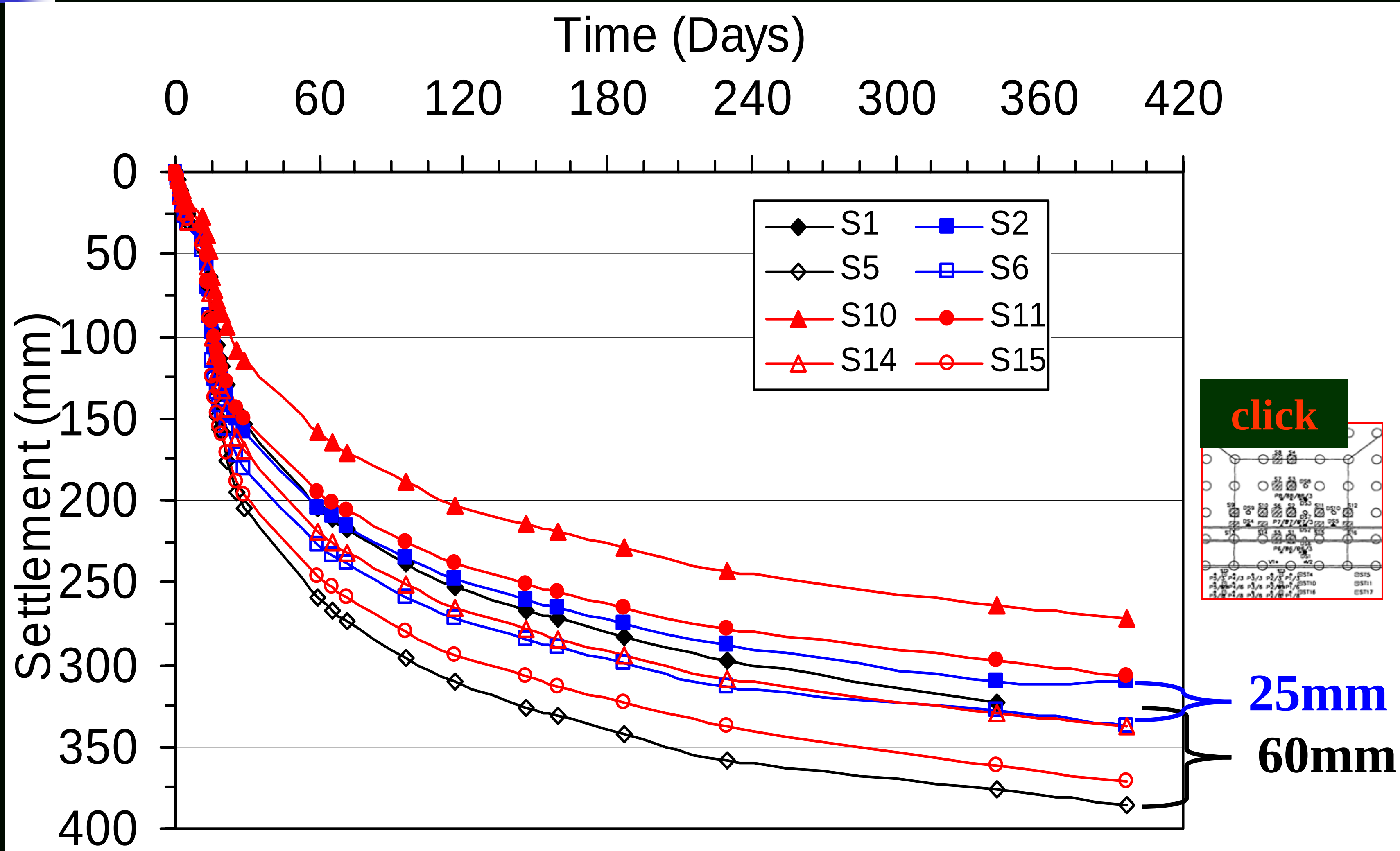


S_p (ave.) =325mm (improved ground)

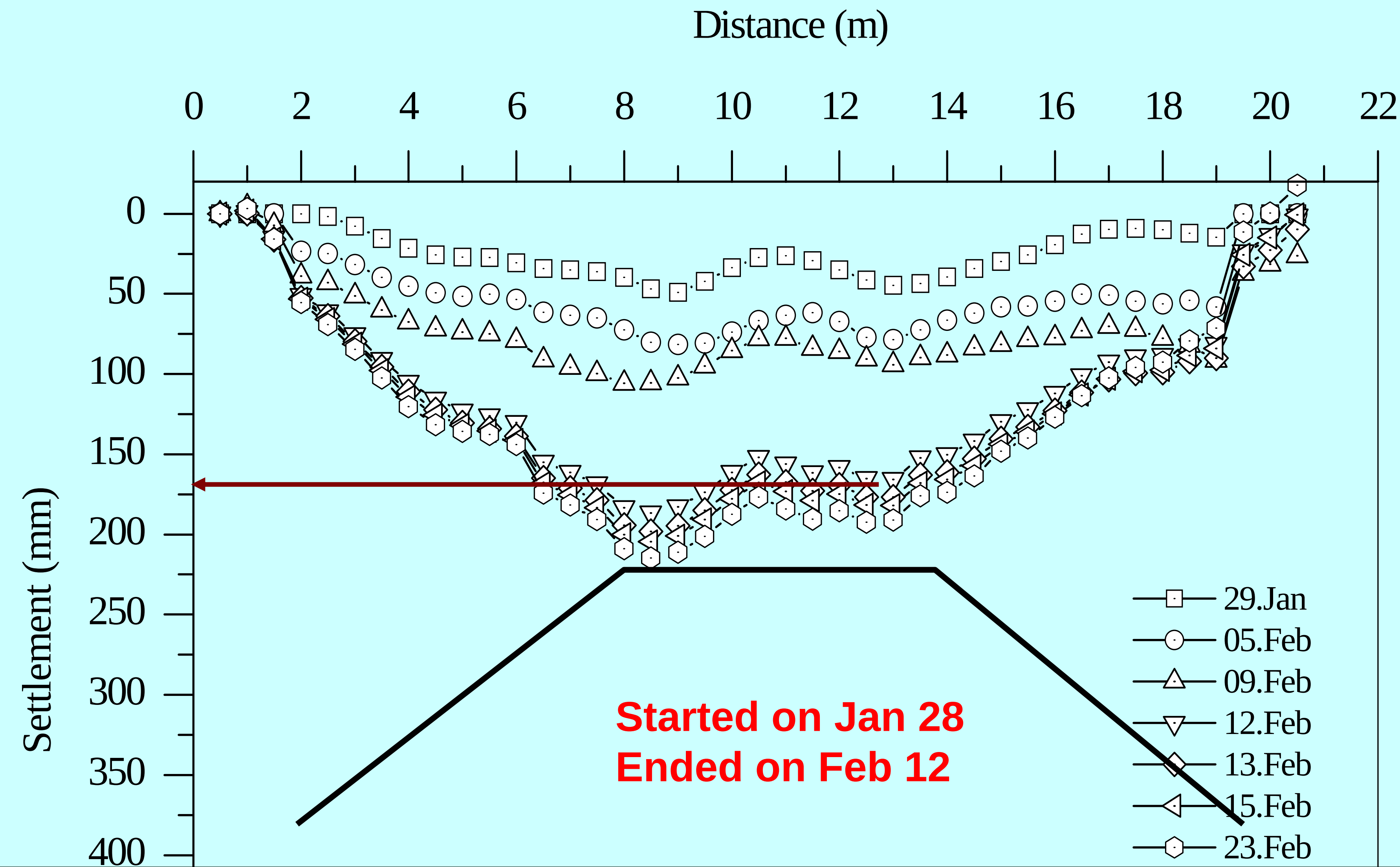
S_p =1200mm (Untreated ground)

Differential Settlement between Soil and Pile

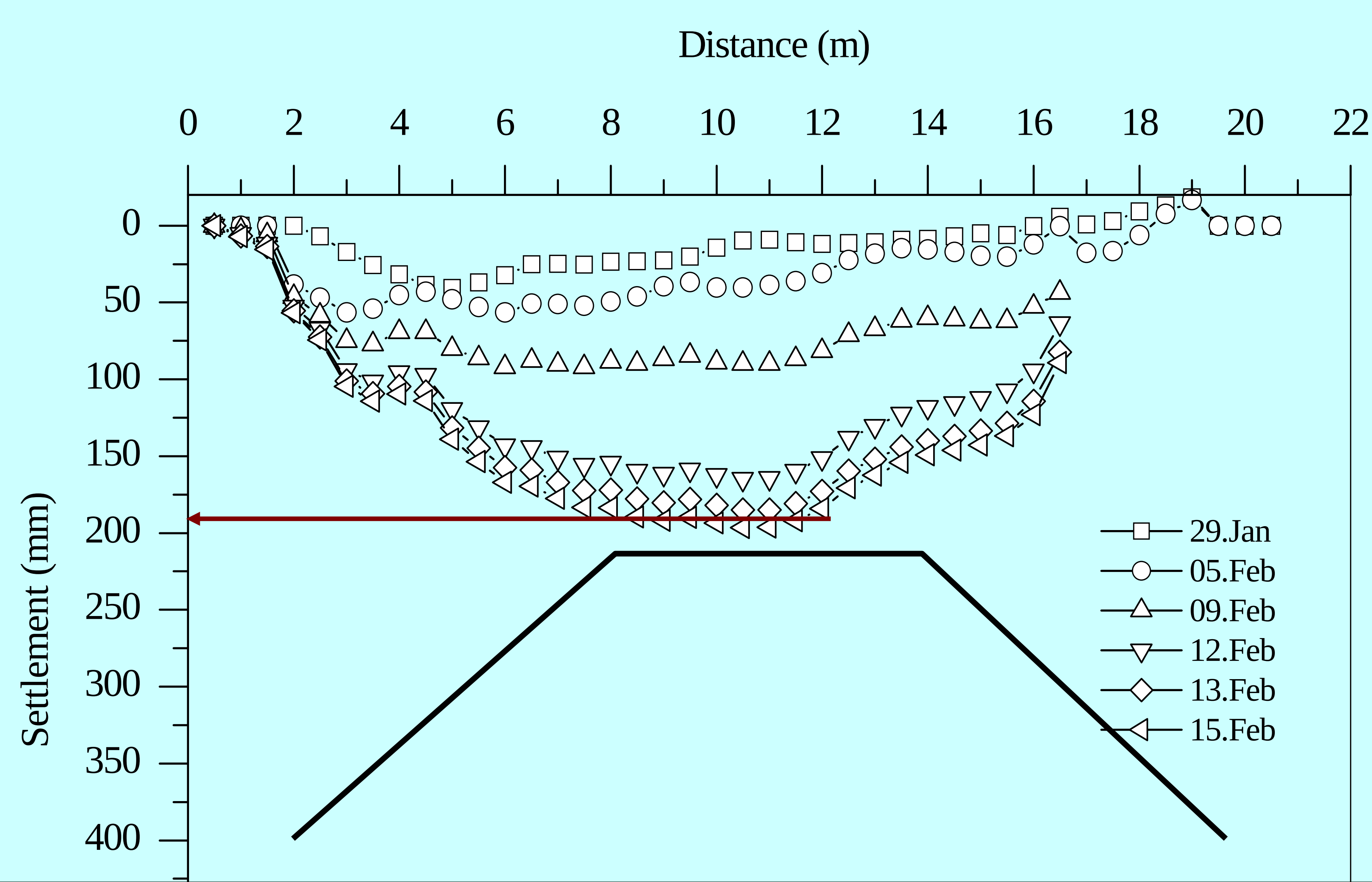
(hollow symbol= “on clay”; solid = “on pile”)



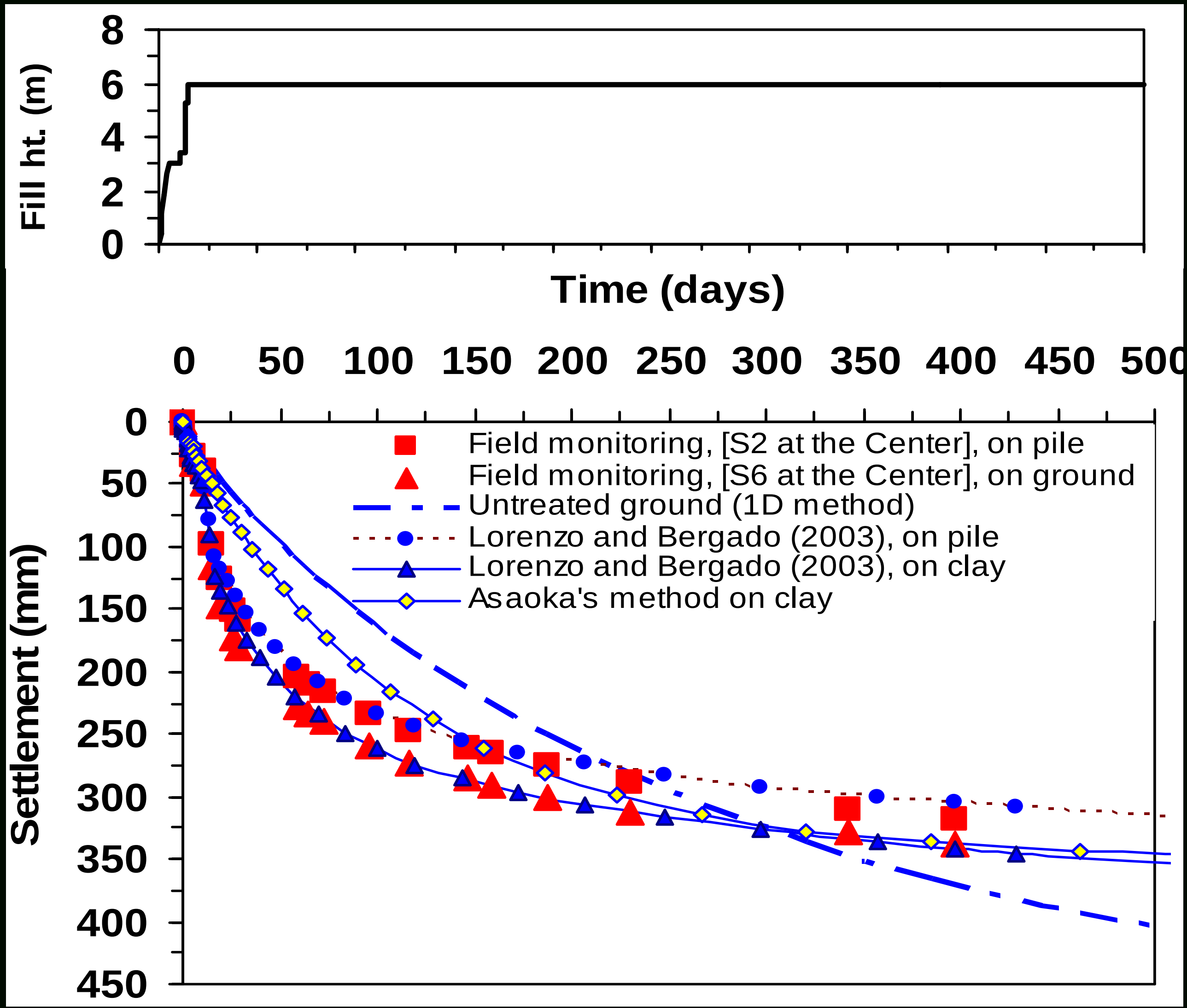
Horizontal Inclinometer H1 (on pile)



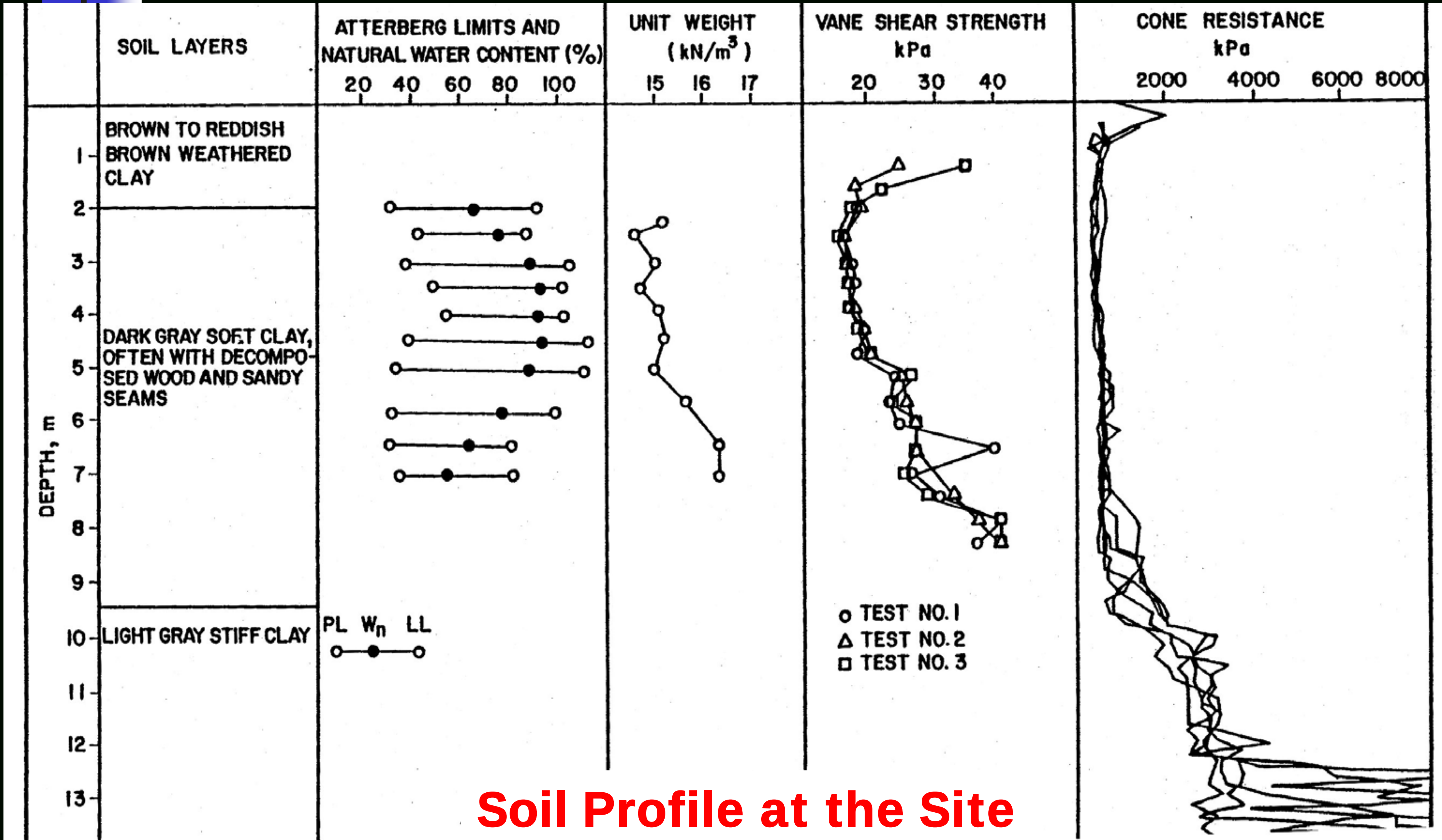
Horizontal Inclinometer H2 (on clay)



Predicted vs. Measured Settlement



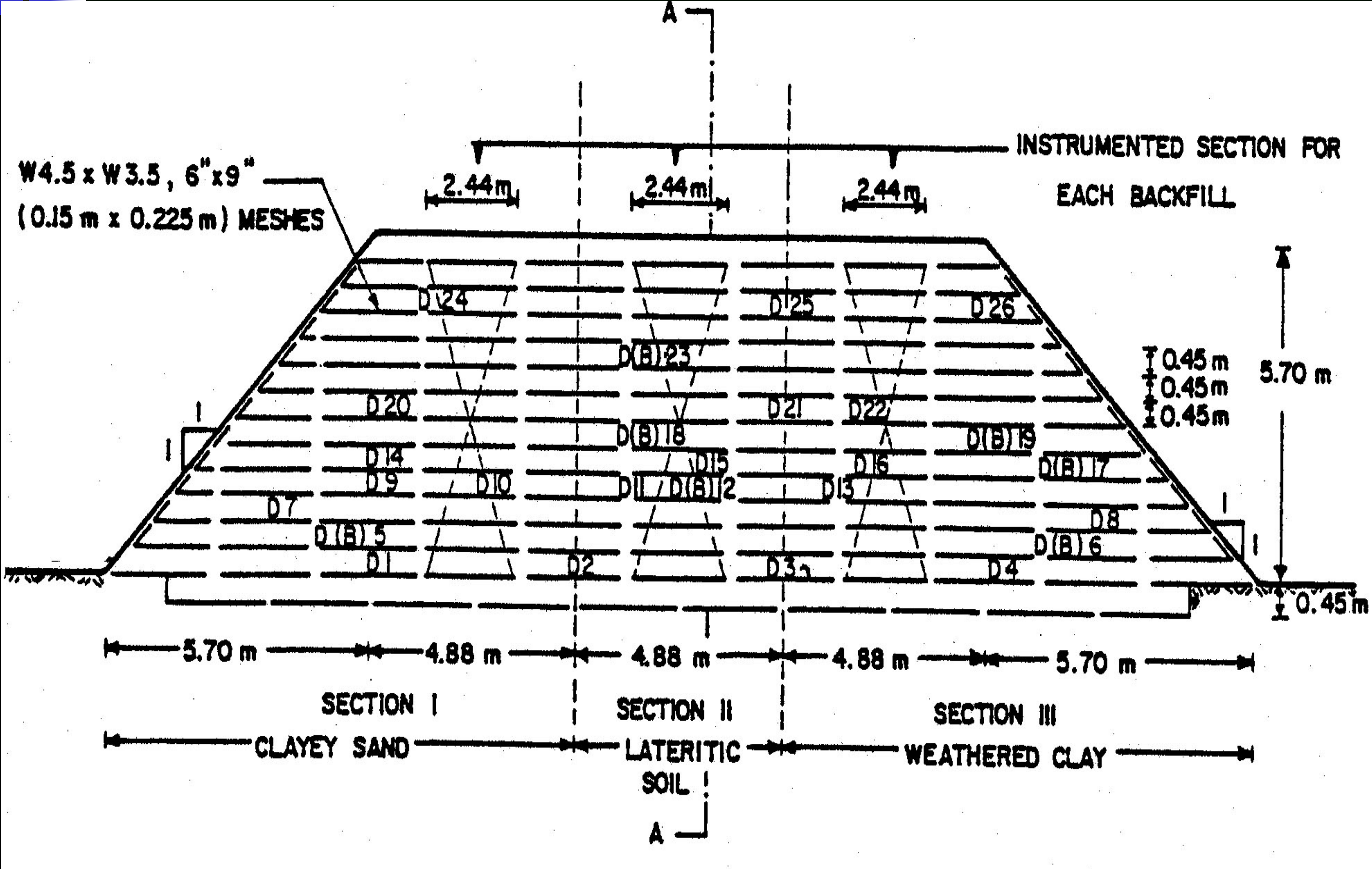
Steel-Grid Reinforced Embankment on Unimproved Ground



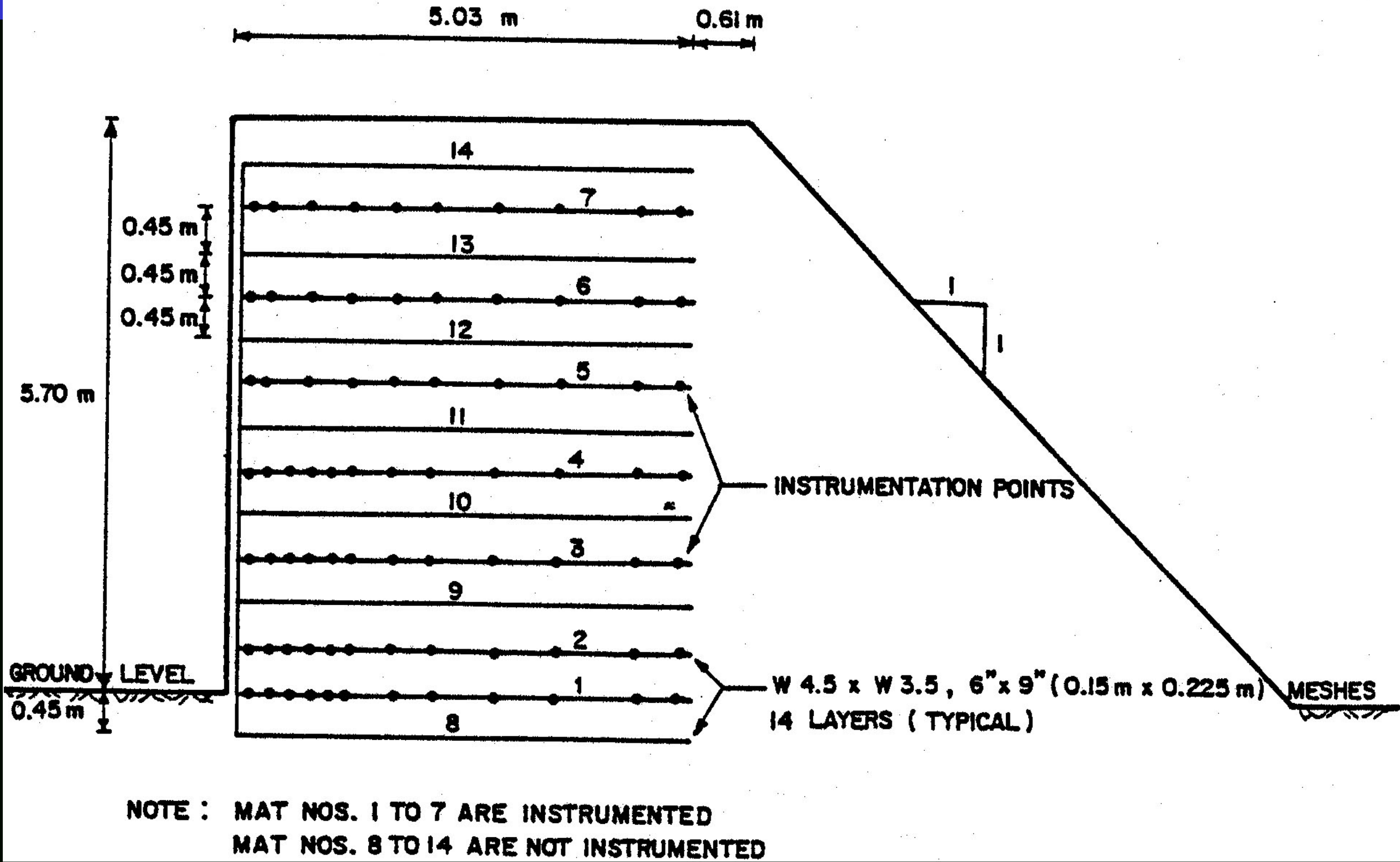
Soil Profile at the Site

Steel-Grid MSE Embankment on Unimproved Soft Foundation

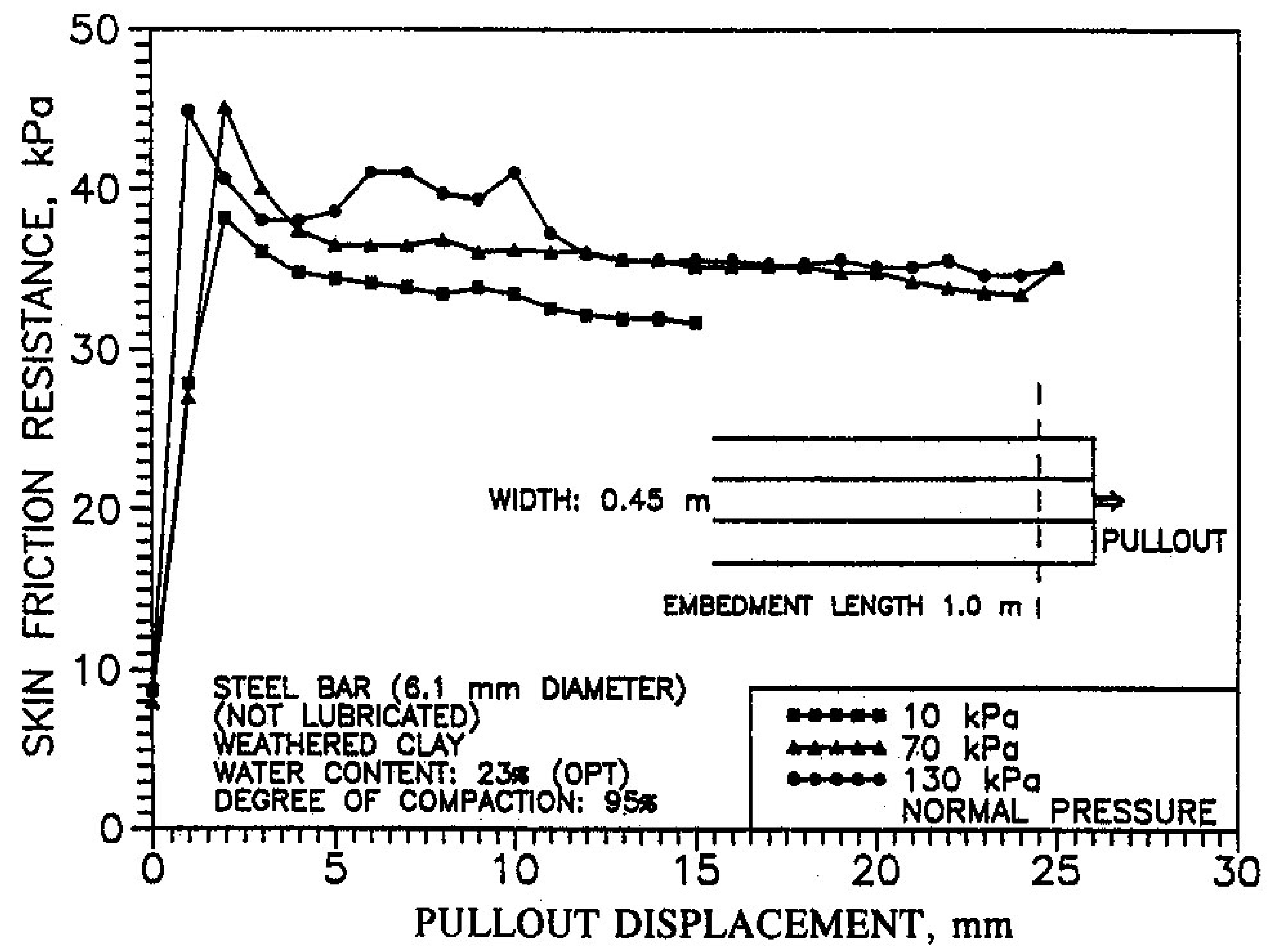
Front Elevation (unimproved foundation)



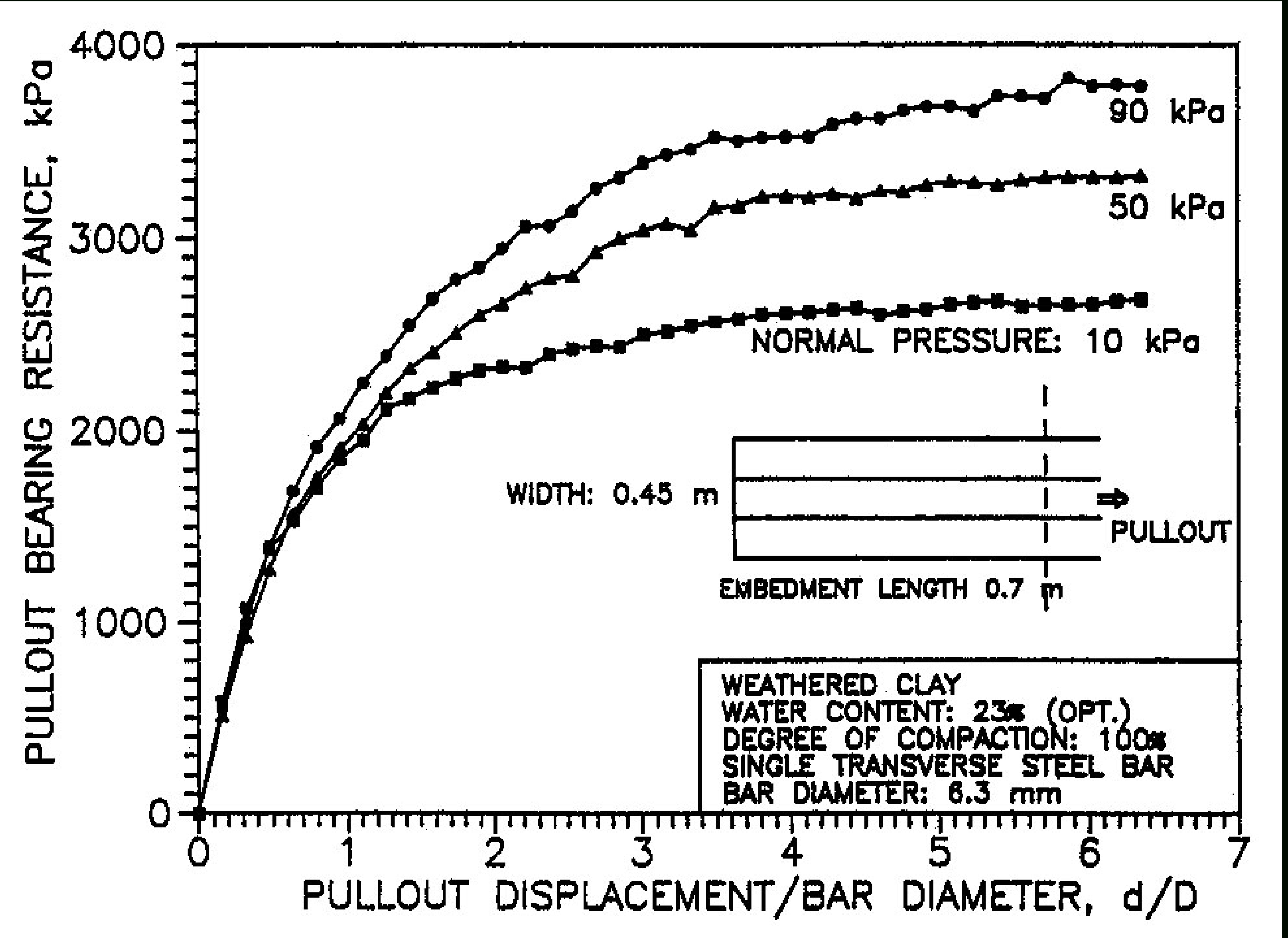
Section View (unimproved foundation)



Pullout Friction Resistance of Steel Grid

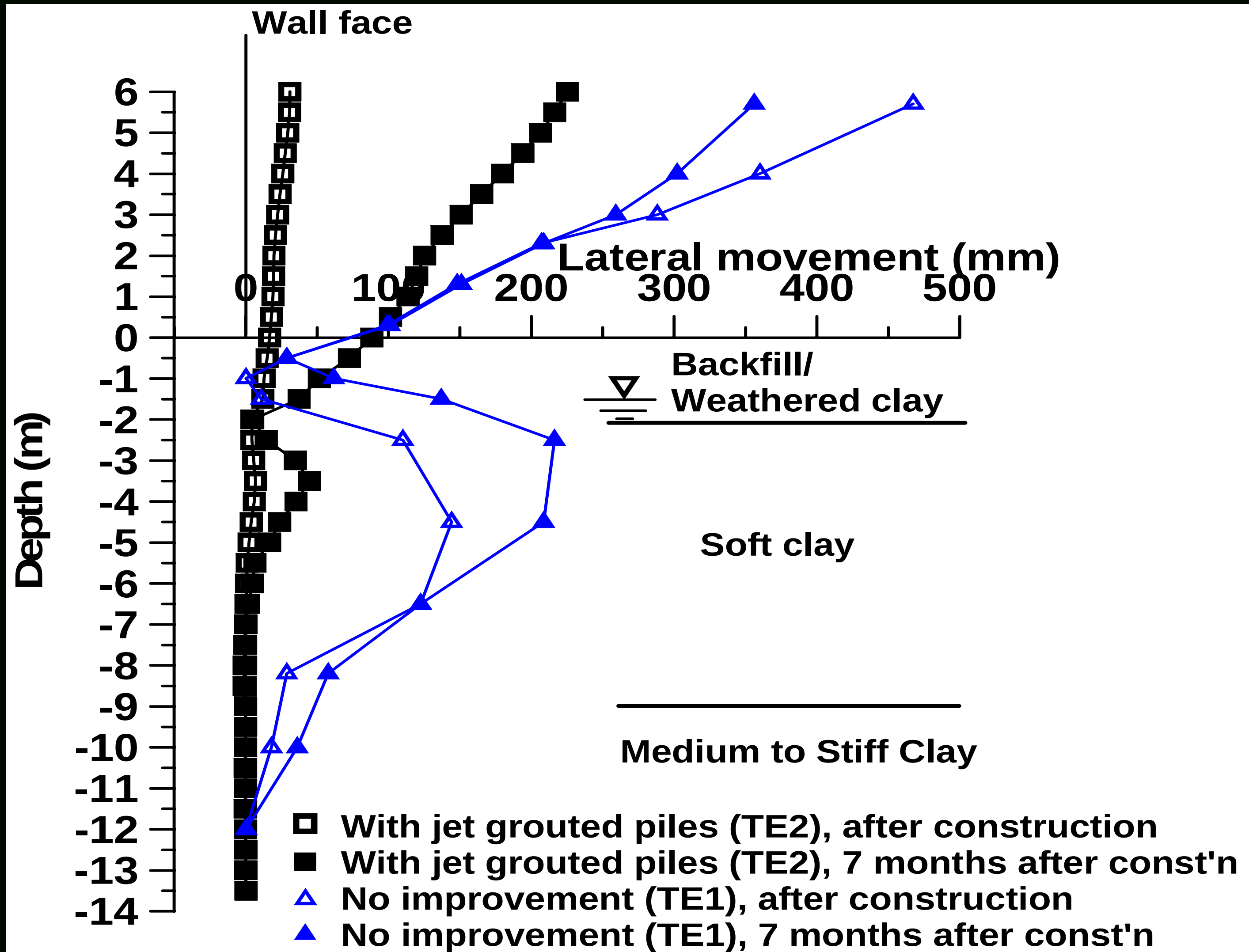


Pullout Bearing Resistance of Steel Grid



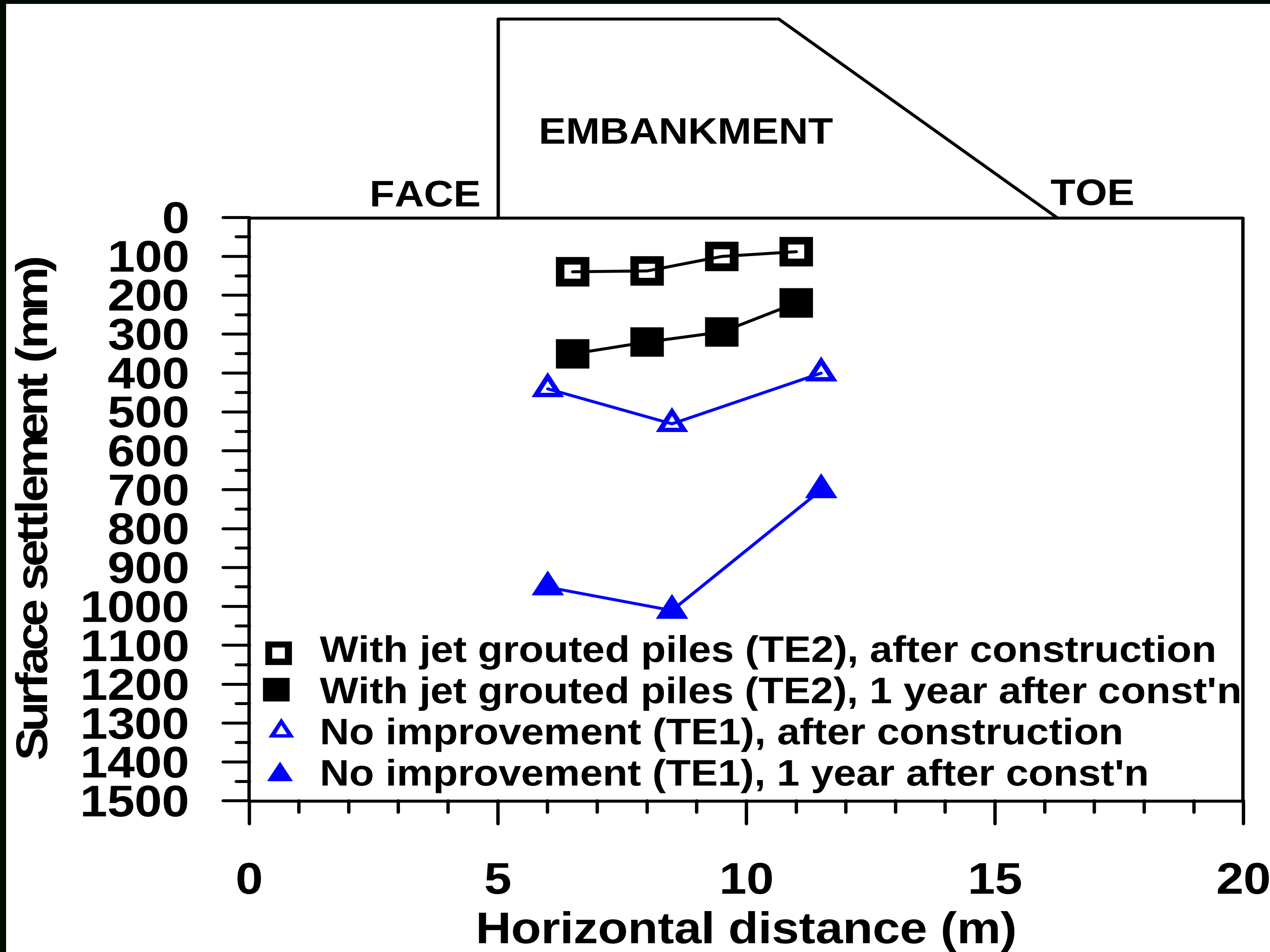
Comparison of Lateral Displacement Profiles

(with and without jet grouted piles)

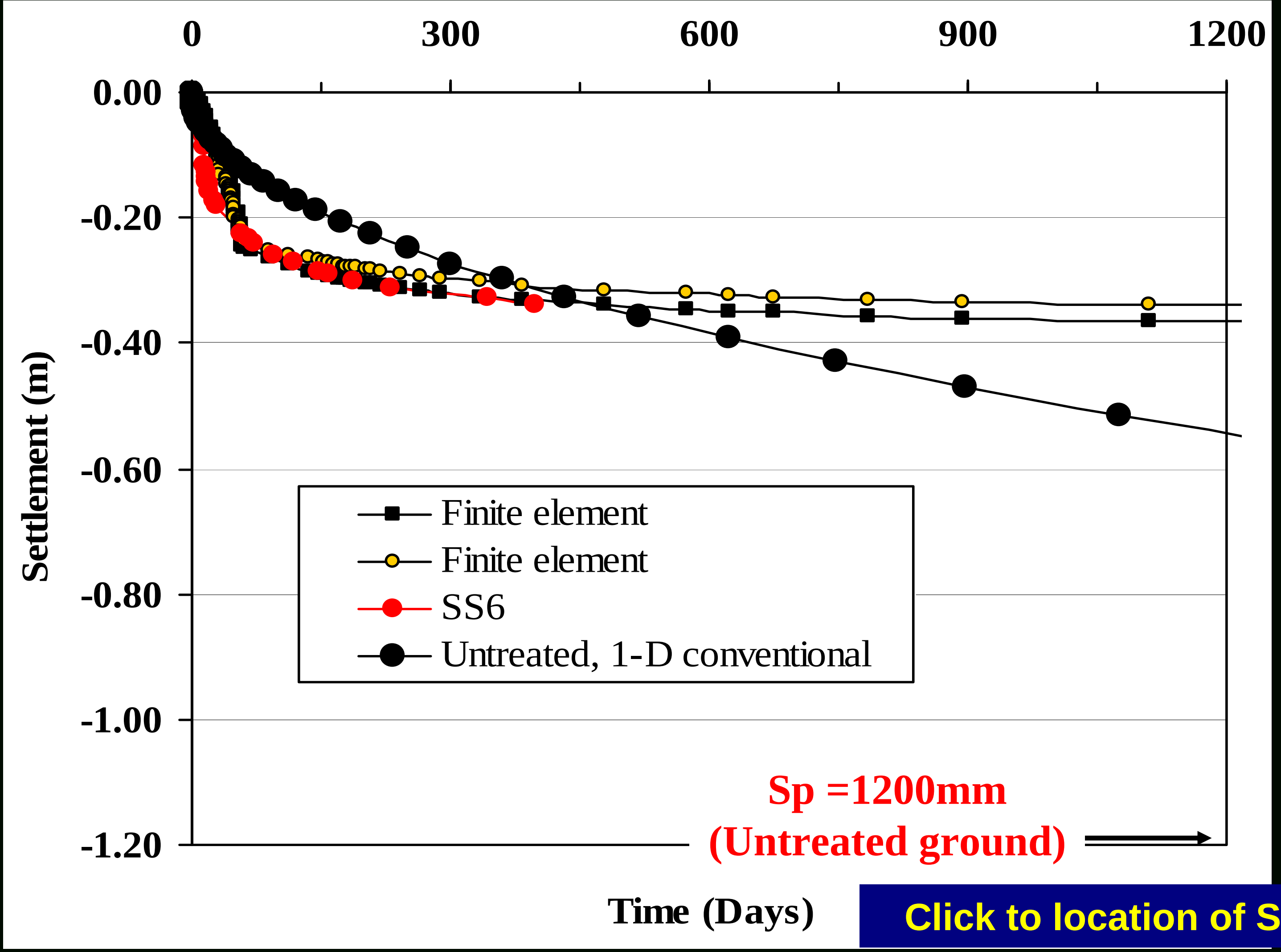


Comparison of Surface Settlements

(with and without jet grouted piles)

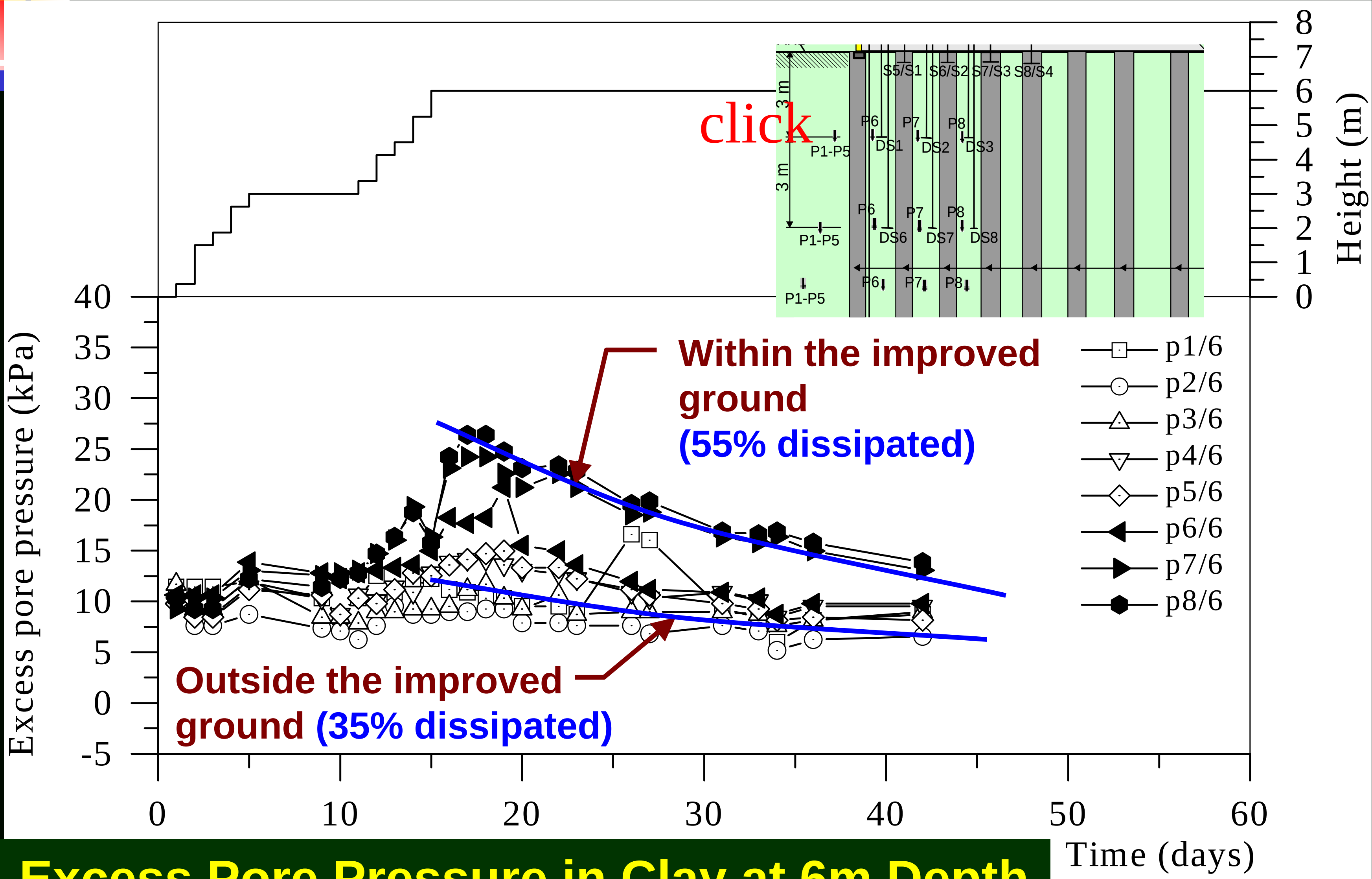


Settlement Reduction and Rate of Settlement



Click to location of SS6

Faster Rate of Consolidation of Improved Ground



Excess Pore Pressure in Clay at 6m Depth

One-Dimensional and Unconfined Compression of Cement-Admixed Clay of Higher Water Content

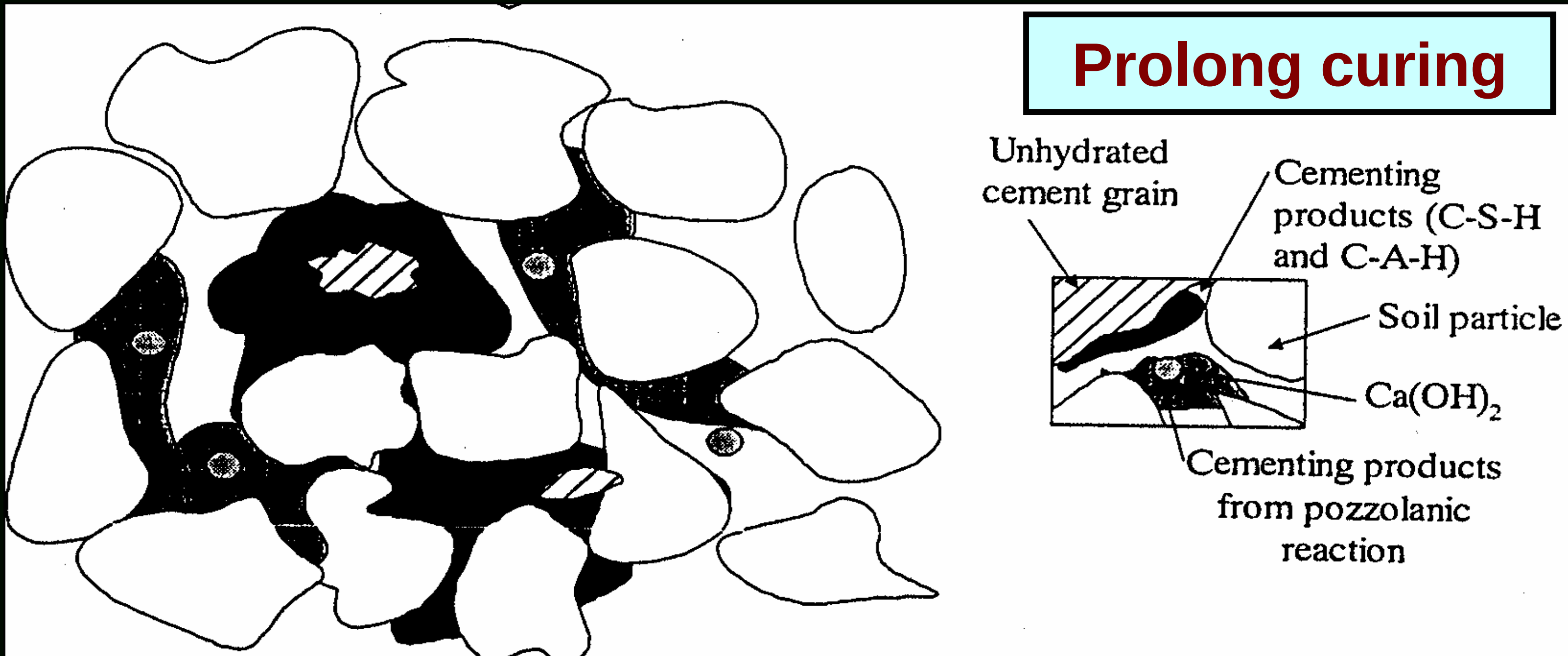
Properties of the Base Clay Bangkok Clay

Properties	Characteristics values
Liquid limit, LL, (%)	103
Plastic limit, PL, (%)	43
Plasticity index, PI, (%)	60
Water content, w (%)	76-84
Liquidity index, LI	0.62
Grain size distribution	
Clay (%)	69
Silt (%)	28
Sand (%)	3
Total unit weight, γ_t (kN/m^3)	14.3
Dry unit weight, γ_d (kN/m^3)	7.73
Initial void Ratio, e	2.2
Color	Dark gray
Activity	0.87 (Normal)
Sensitivity	7.4

Definition of higher water content clay:

A clay that has a natural water content equal to or greater than its liquid limit (LL), or a clay that has been remolded to water content equal to or greater than its LL.

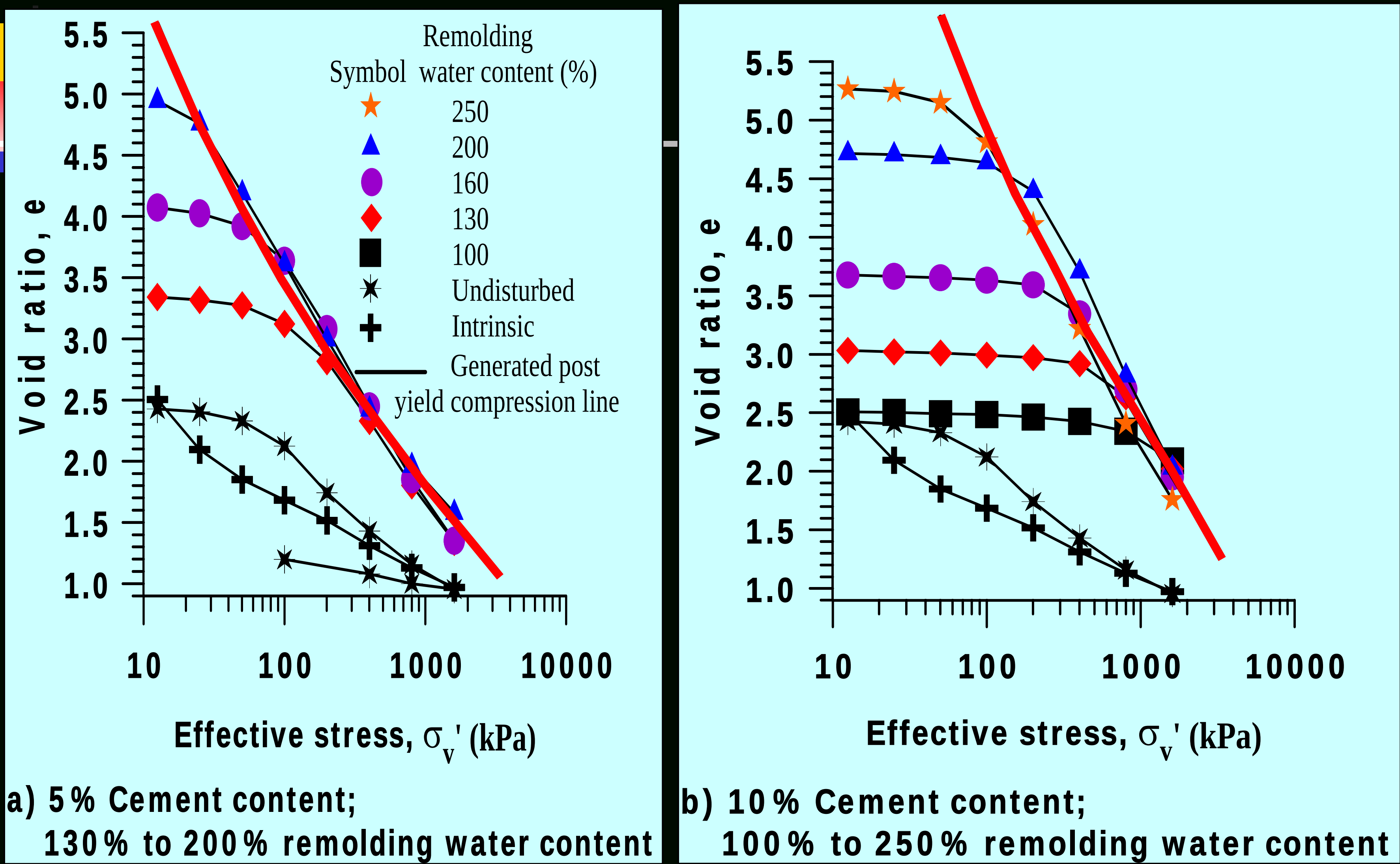
Conceptual Diagram of Cement Stabilized Clay at Higher Water Content



- **Better dispersion of cementing agents/ions within the pores. It is expected to yield higher strength ….**
- **Higher permeability and good drainage ability.**

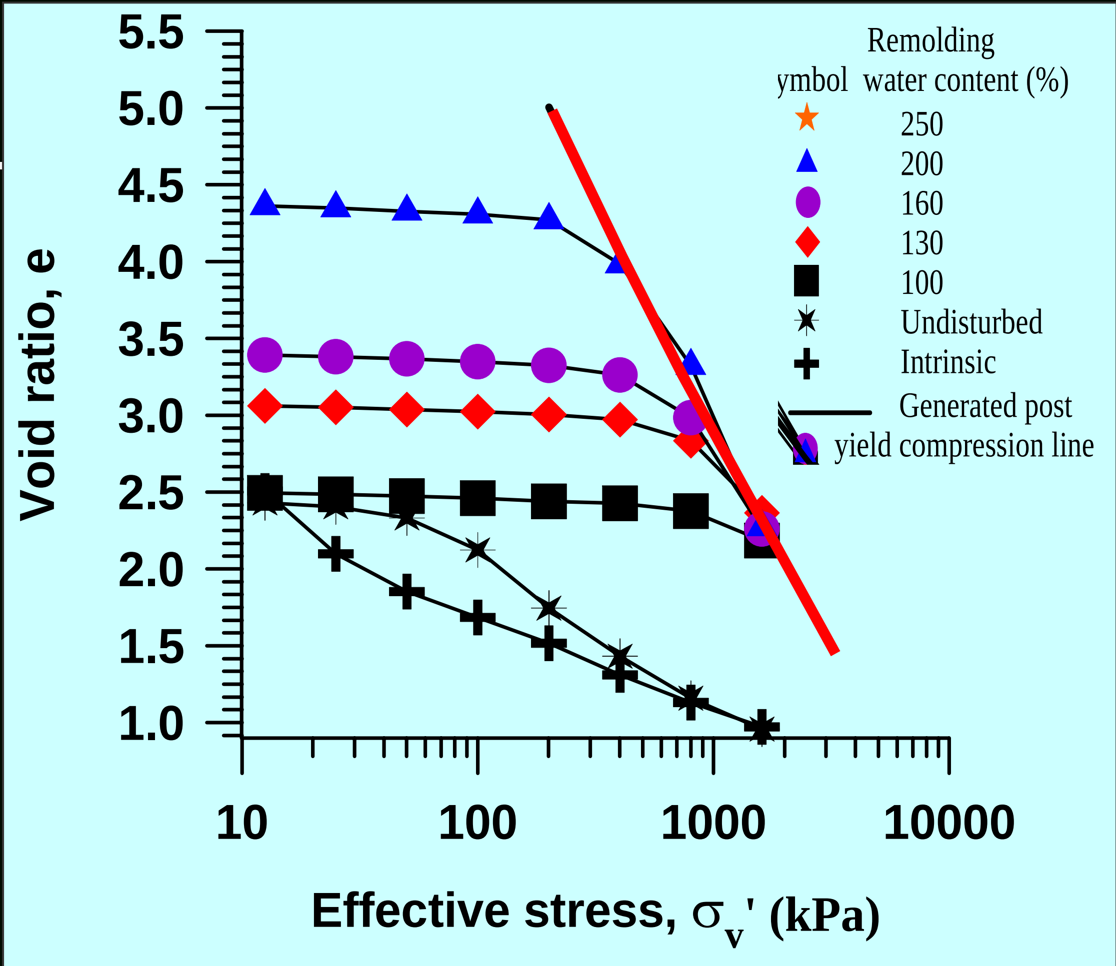
Laboratory Test

- Remolding the base clay at clay water contents from liquid limit (LL) to 2LL.
- Water/cement ratio of slurry of 0.6.
- Curing the specimens directly in the oedometer rings for oedometer tests, and in the PVC mold for UC tests.
- Curing the specimen in the humid room within 7, 14 and 28 days; only 28 days for oedometer tests.



Post-Yield Compression Lines (5% and 10% cement)

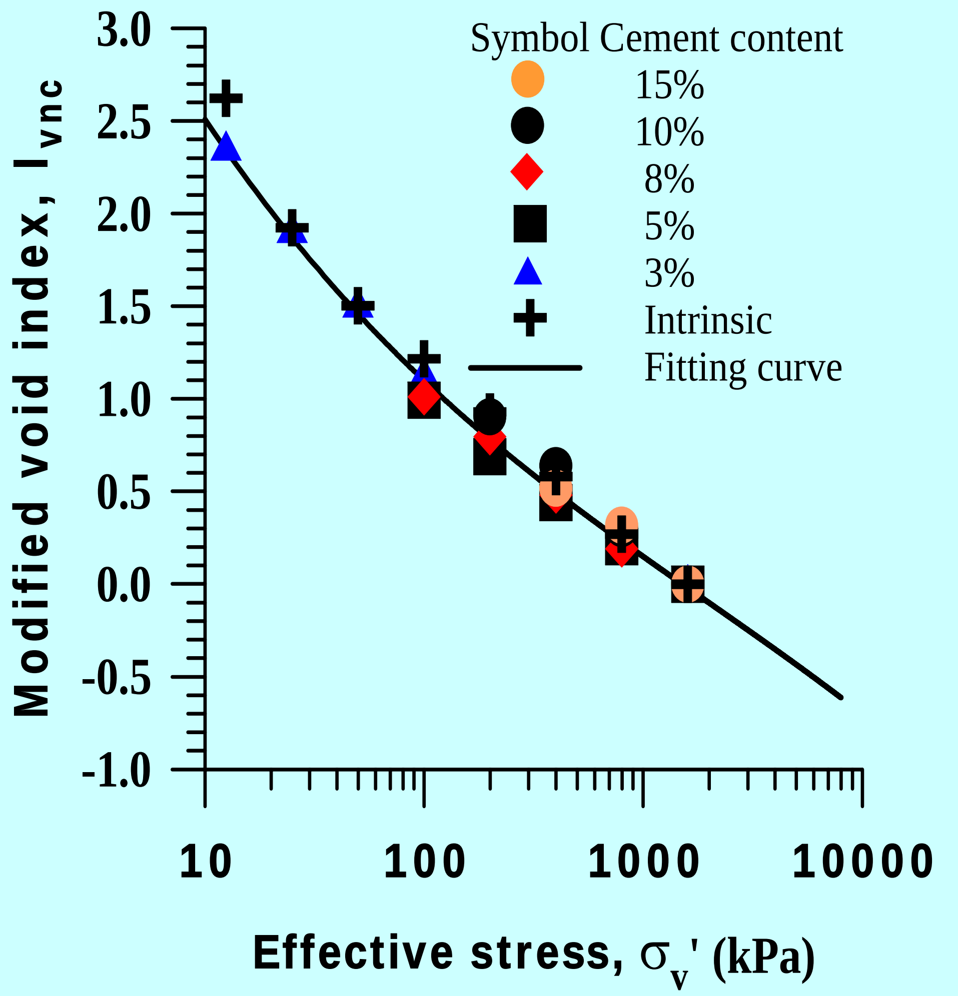
(measured values vs. predicted values)



c) 15% Cement content;
100% to 200% remolding water content

Post-Yield Compression Lines (15 % cement)

(measured values vs. predicted values)



Normalized Post-Yield Compression Curves

- **Normalizing parameter**

$I_{vnc} = (e_t - e_{t,1600})/C^*_{ct}$

where:

e_t = void ratio of treated sample at certain effective stress, σ'_v;

e_{t1600} = void ratio of treated sample at effective stress of 1600 kPa for certain cement content;

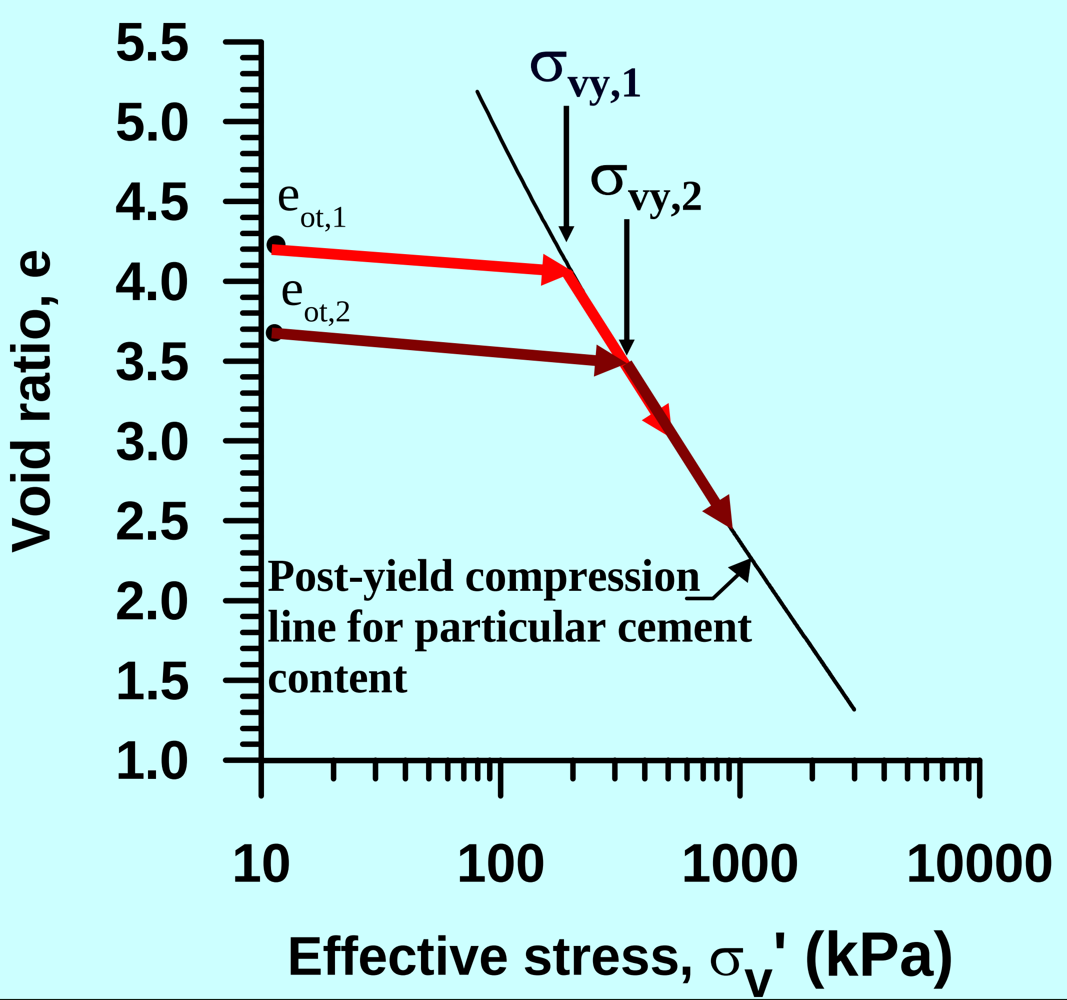
C^*_{ct} = mean slope of the post-yield compression line for certain cement content.

- **Fitted curve**

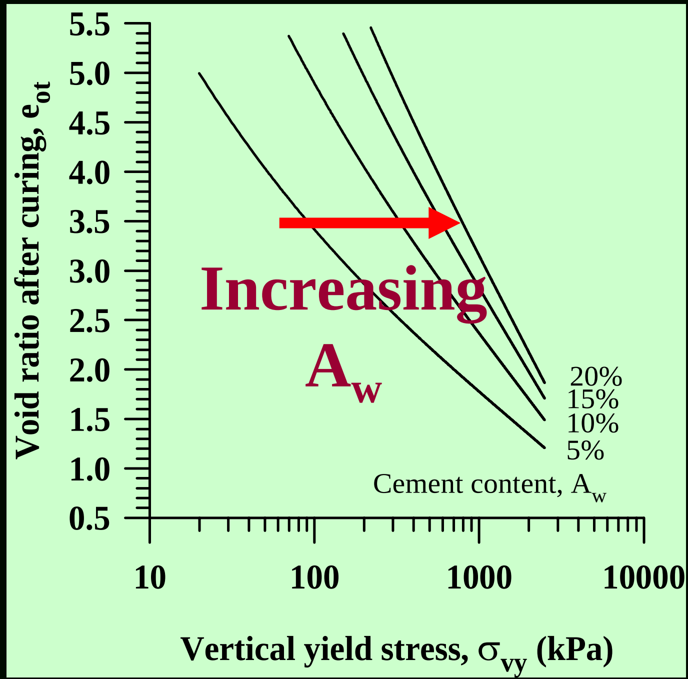
$I_{vnc} = -0.06(\log\sigma'_v)^3 + 0.59(\log\sigma'_v)^2 - 2.76(\log\sigma'_v) + 4.74;$

in similar form of ICL of Burland (1990).

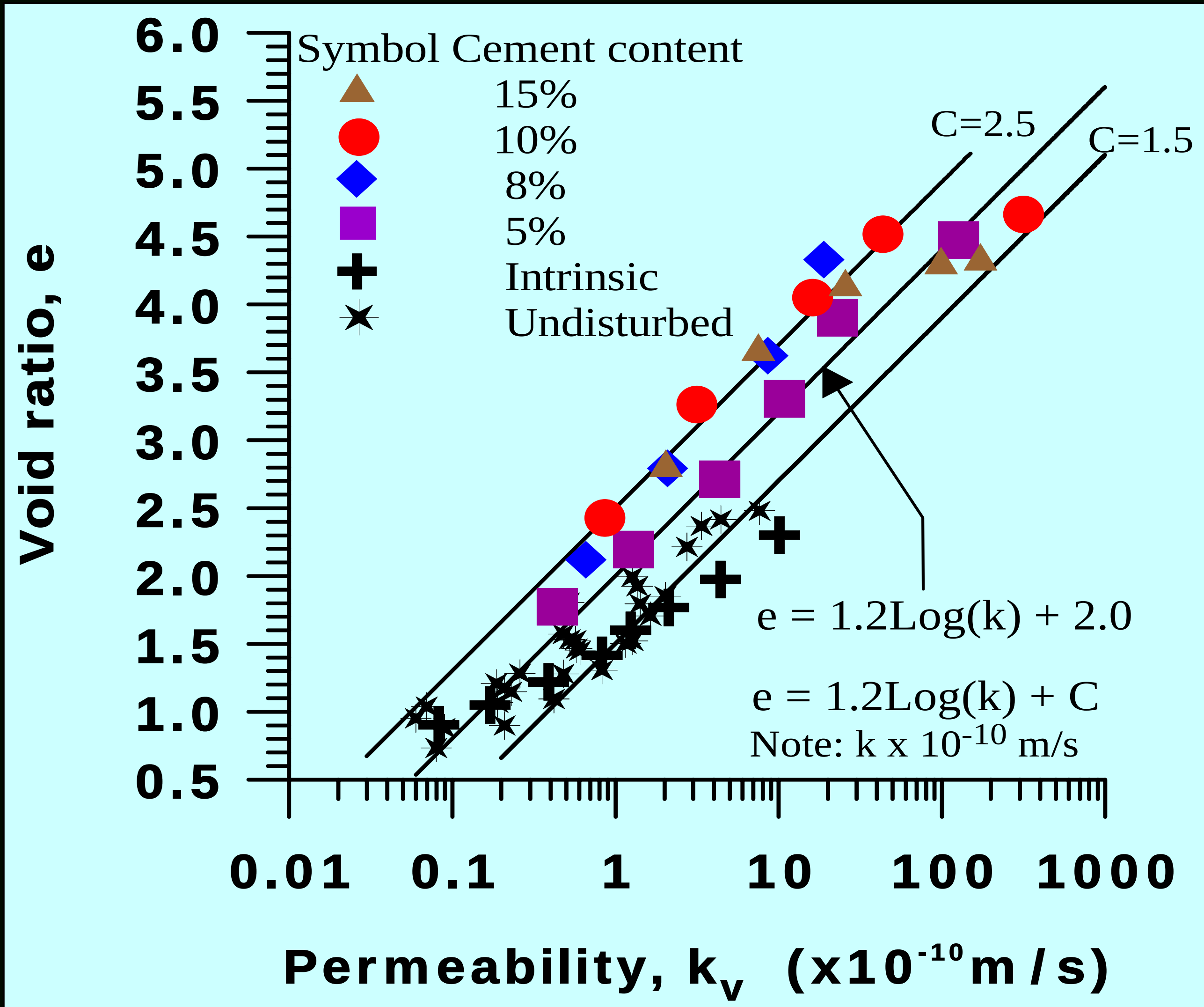
Schematic Diagram for Predicting Compression Line of Cement Treated Clay (curing time: at least one month)



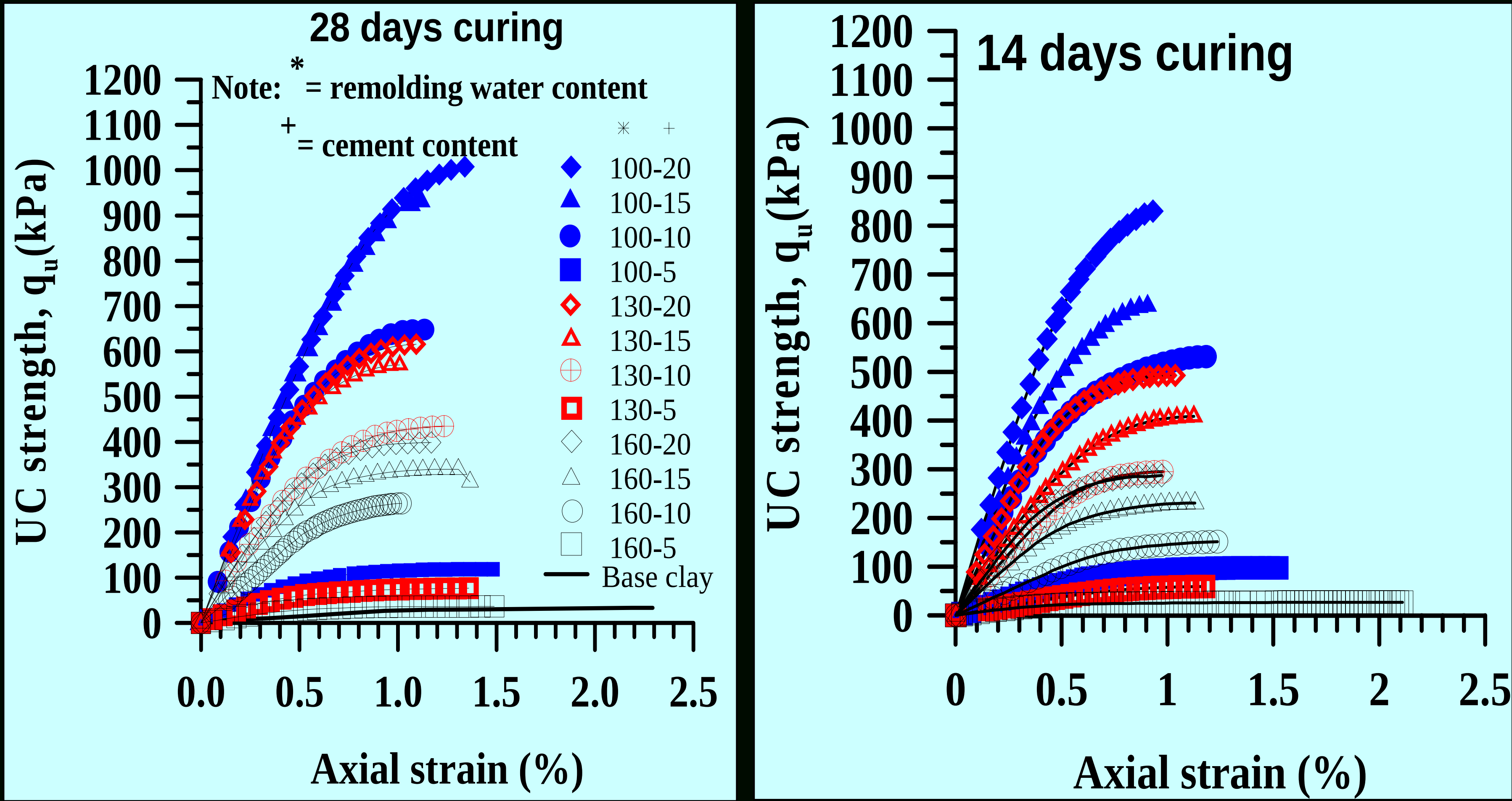
- e_{ot} = initial void ratio after curing;
- σ_{vy} = predicted vertical yield stress.
- Swelling index



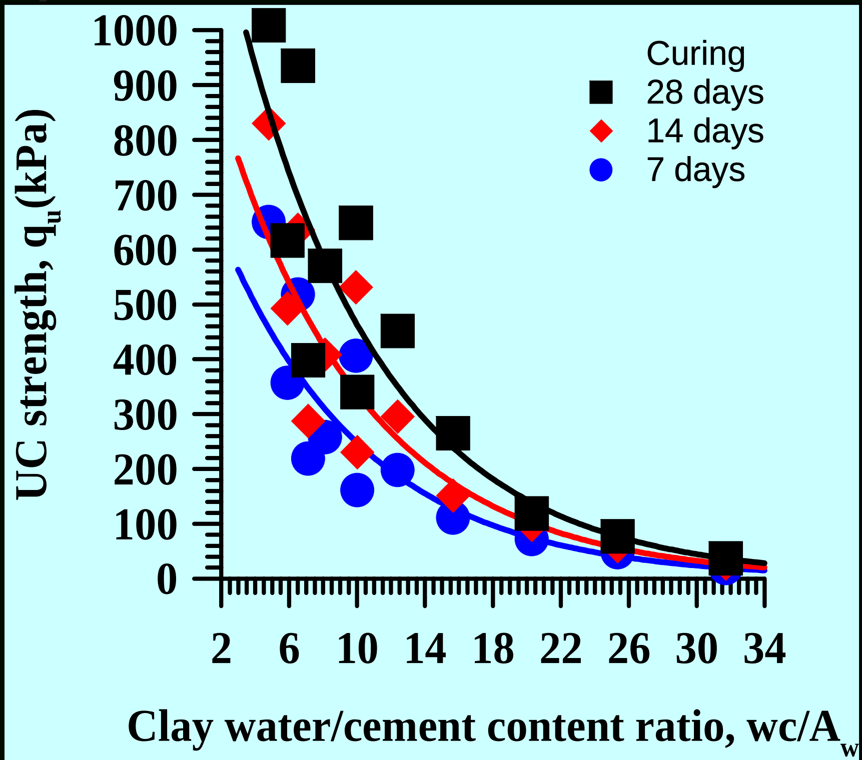
Coefficient of Permeability from Oedometer Test of Untreated and Cement-Treated Soft Bangkok Clay

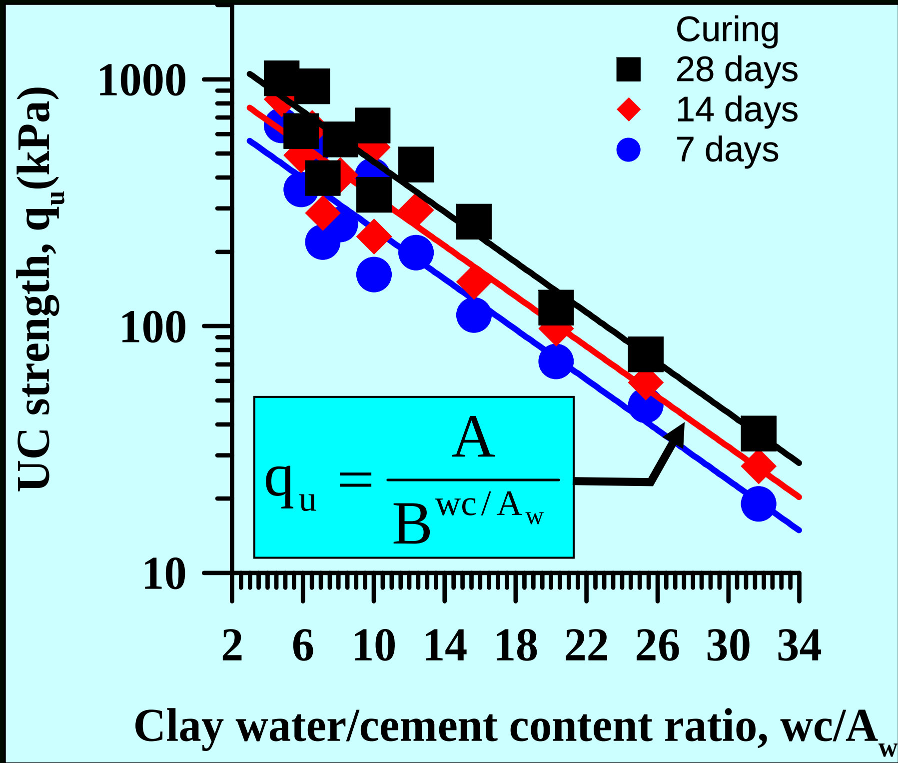


Unconfined Compression Tests



Unconfined Compression Tests *(cont'd)*





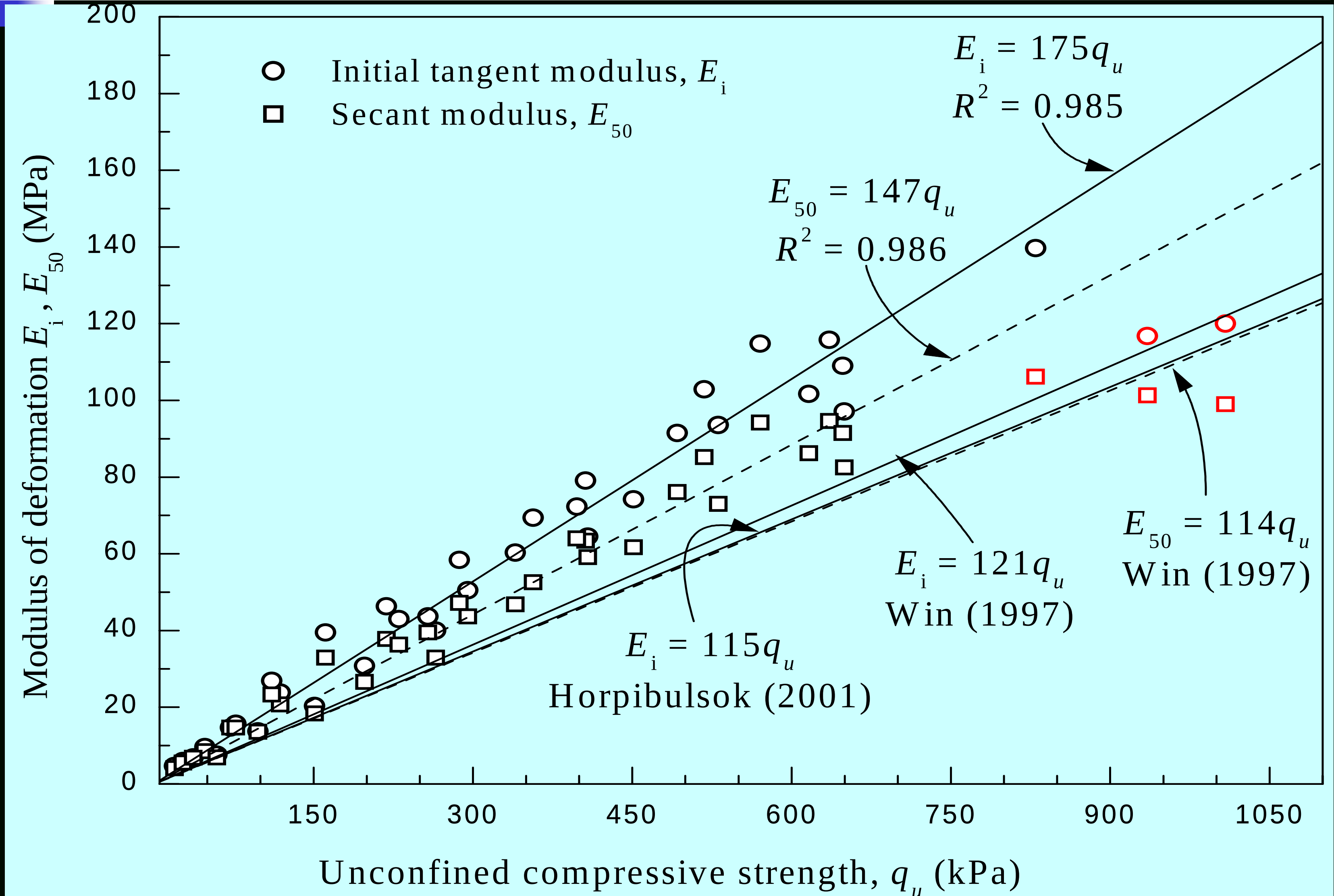
$$q_u = \frac{A}{B^{wc/A_w}}$$

A = f (time, clay type, etc.) = intercept

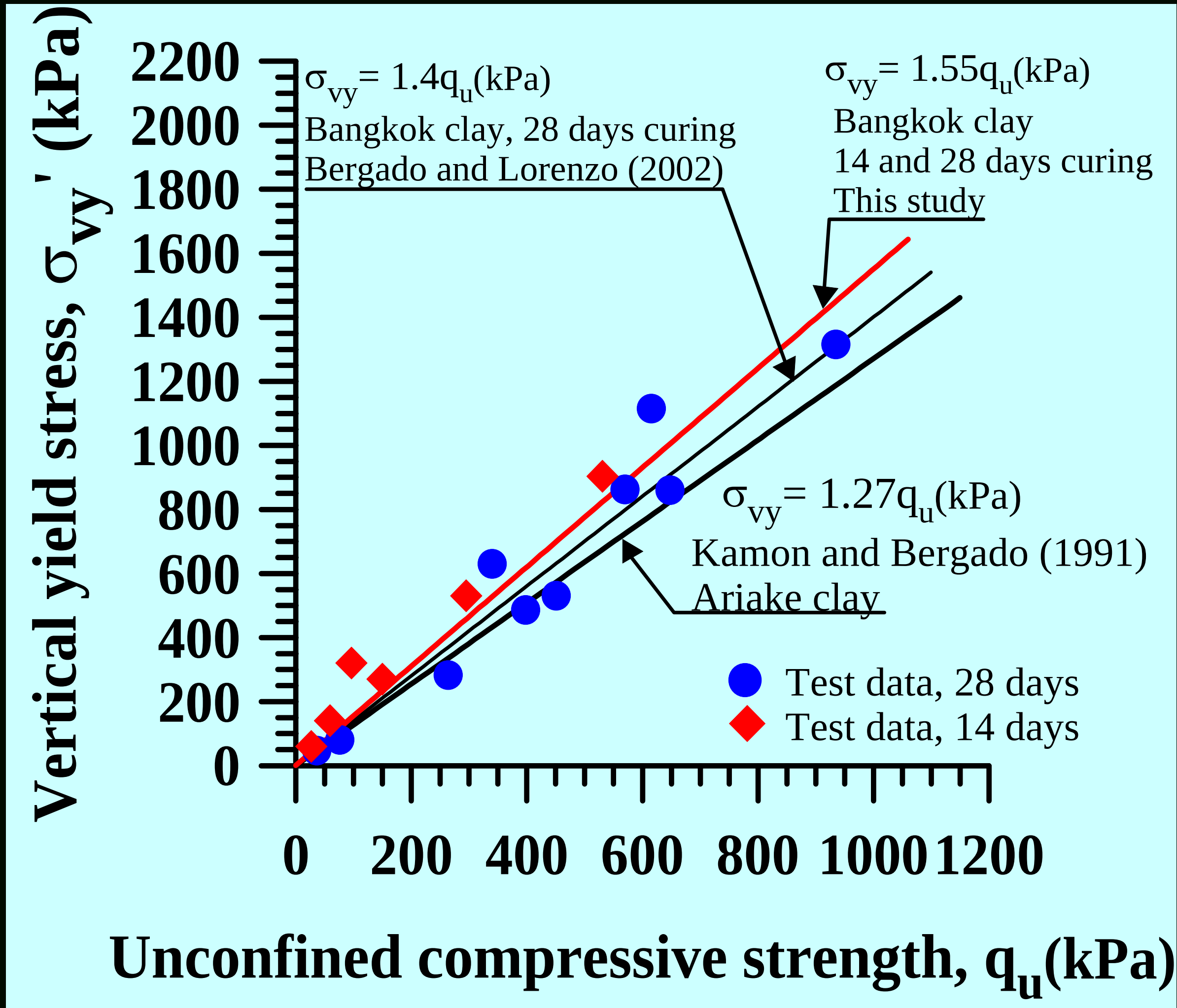
B = f (clay type, etc.) = slope

Modulus of Elasticity versus UC Strength

(Laboratory mix cement-treated Bangkok clay)



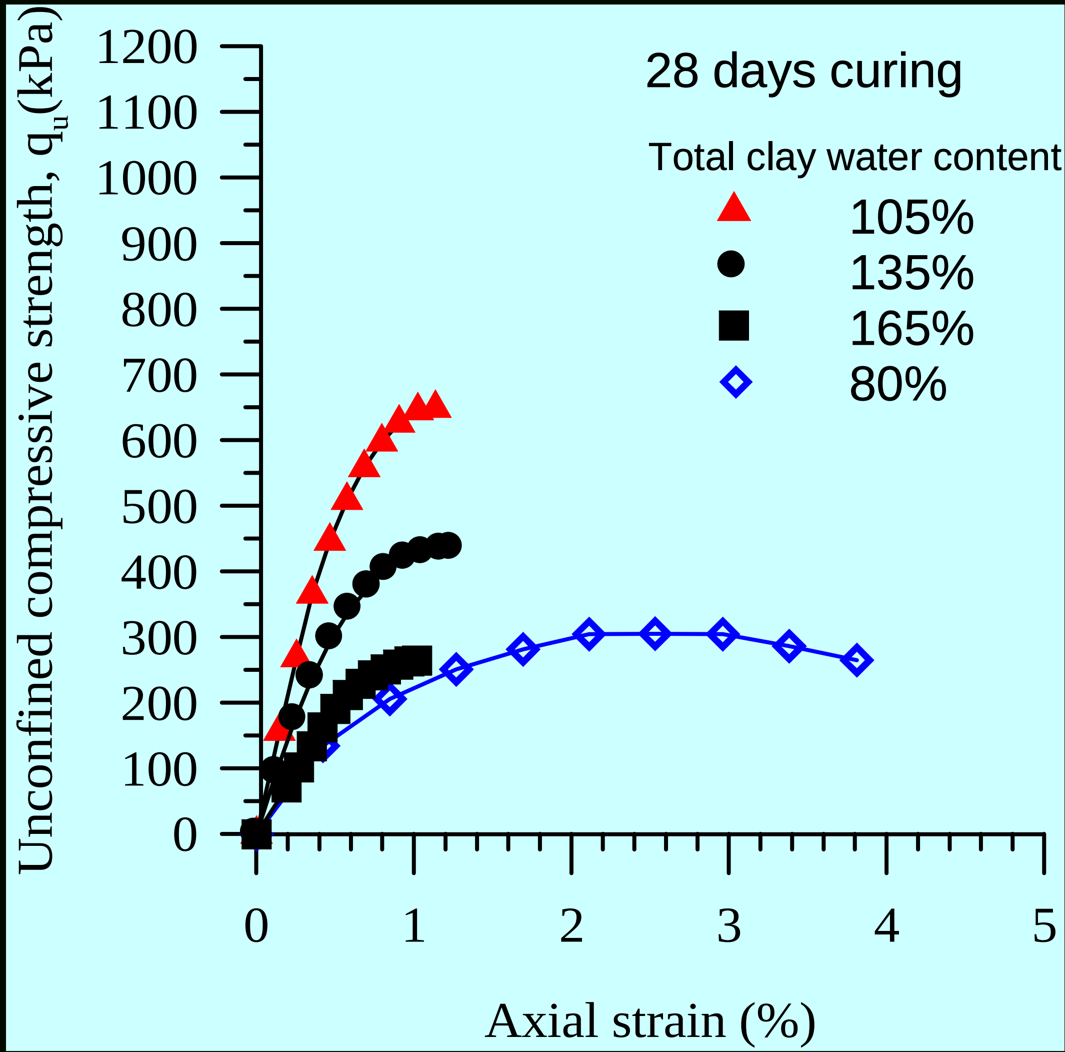
Vertical Yield Stress σ_{vy} versus UC Strength q_u of Cement-Treated Bangkok Clay and Ariake Clay



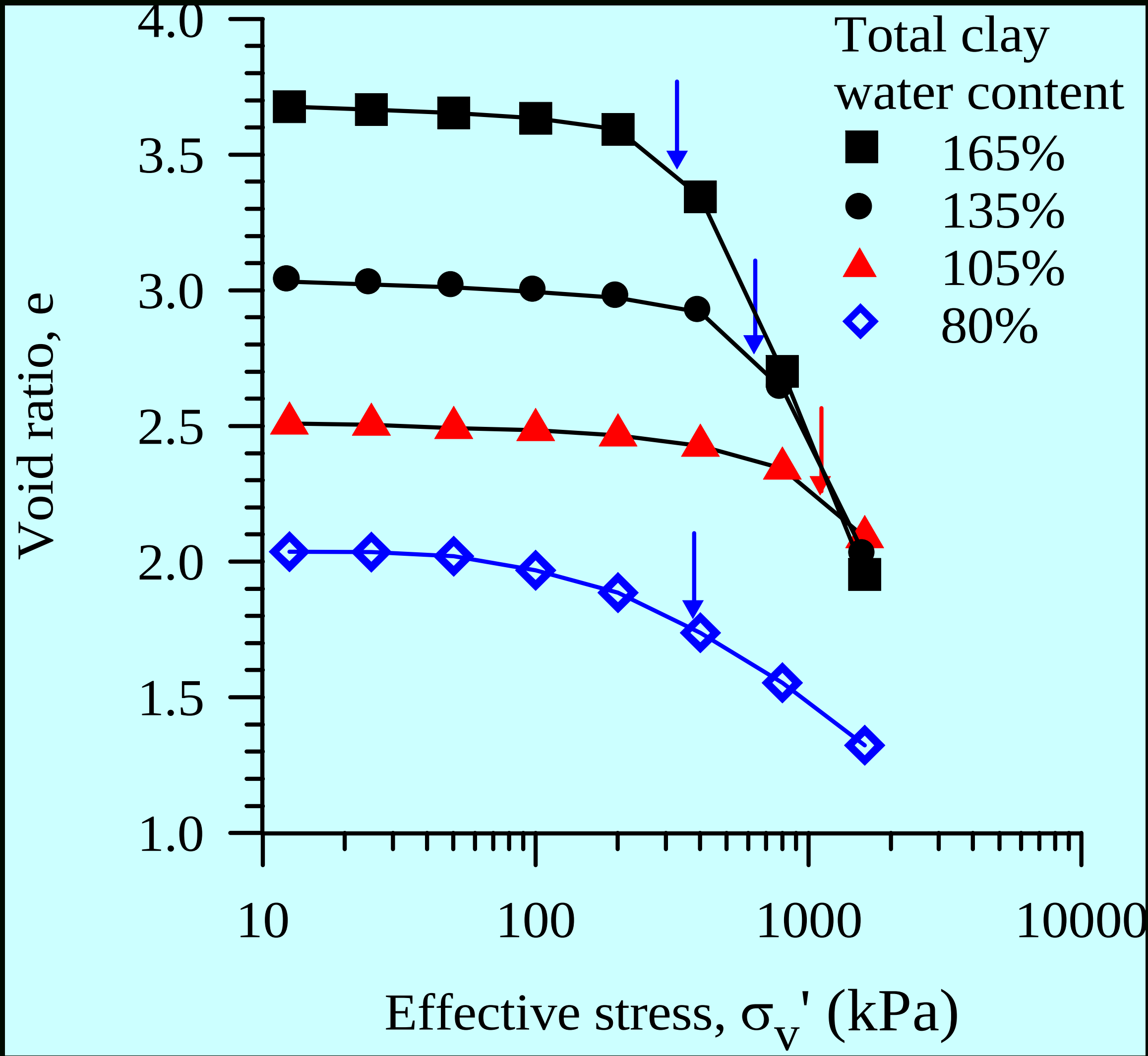
Optimum Mixing Clay Water Content

Optimum mixing clay water content (w_{opt}) is hereinafter defined as the total clay water content (or mixing clay water content) of the clay-cement paste that would give the highest possible improvement in strength of cured cement-admixed clay.

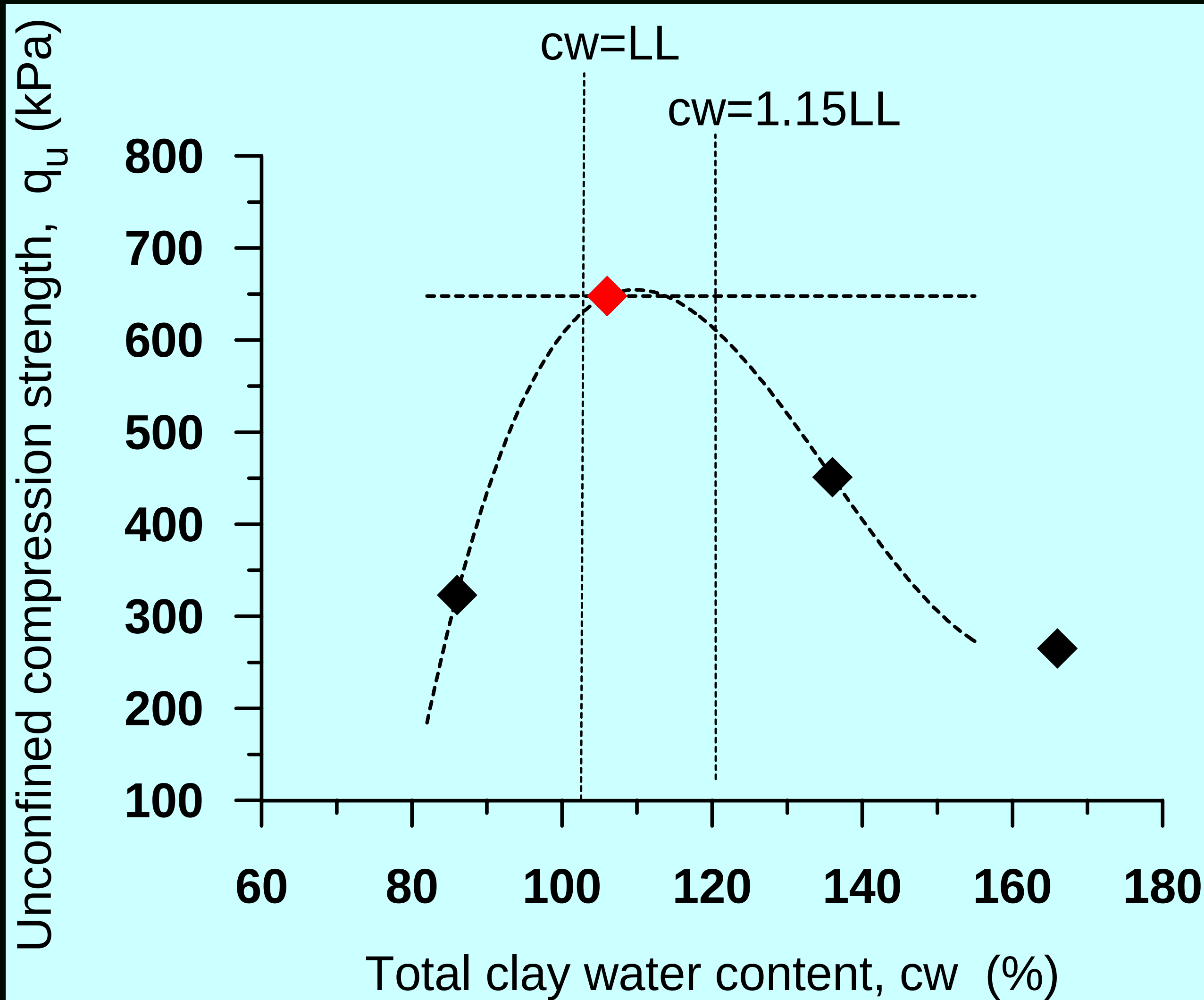
Effect of Mixing Clay Water Content on Unconfined Compression (10% Cement Content)



Effect of Mixing Clay Water Content on 1-Dimensional Compression (10% Cement)



Typical Strength Curve of Cement-Admixed Clay (to get the optimum mixing clay water content)



CONCLUSIONS

1) **Two full-scale reinforced embankments were constructed on soft ground.**

- **The first embankment (TE1), 5.7m high and reinforced with steel-grids, was constructed on unimproved ground.**
- **The second embankment (TE2), 6.0m high reinforced with hexagonal wire reinforcement, was constructed on jet grouted soil-cement piles improved ground.**

CONCLUSIONS *(cont'd)*

2) After embankment construction, the **maximum lateral movements** in the unimproved soft foundation soil was **130mm**, while that of improved foundation soil was only **5mm.**

   Therefore, the installation of soil-cement piles has effected significant increase in the lateral resistance and the bearing capacity of the foundation soil.

CONCLUSIONS *(cont'd)*

3) One year after embankment construction, the maximum surface settlement of TE1 was 1.0m while that of TE2 was only 0.325m. Therefore, the soil-cement pile installation in the soft foundation has also effectively reduced the settlement by at least 70%.

4) Also, one year after construction the unimproved foundation was far from its 90% consolidation, but the soil-cement piles improved ground was already close to its 90% consolidation.

CONCLUSIONS *(cont'd)*

5) The maximum lateral movement of the reinforced embankment on soil-cement piles improved ground was lower than that of reinforced embankment on unimproved foundation.

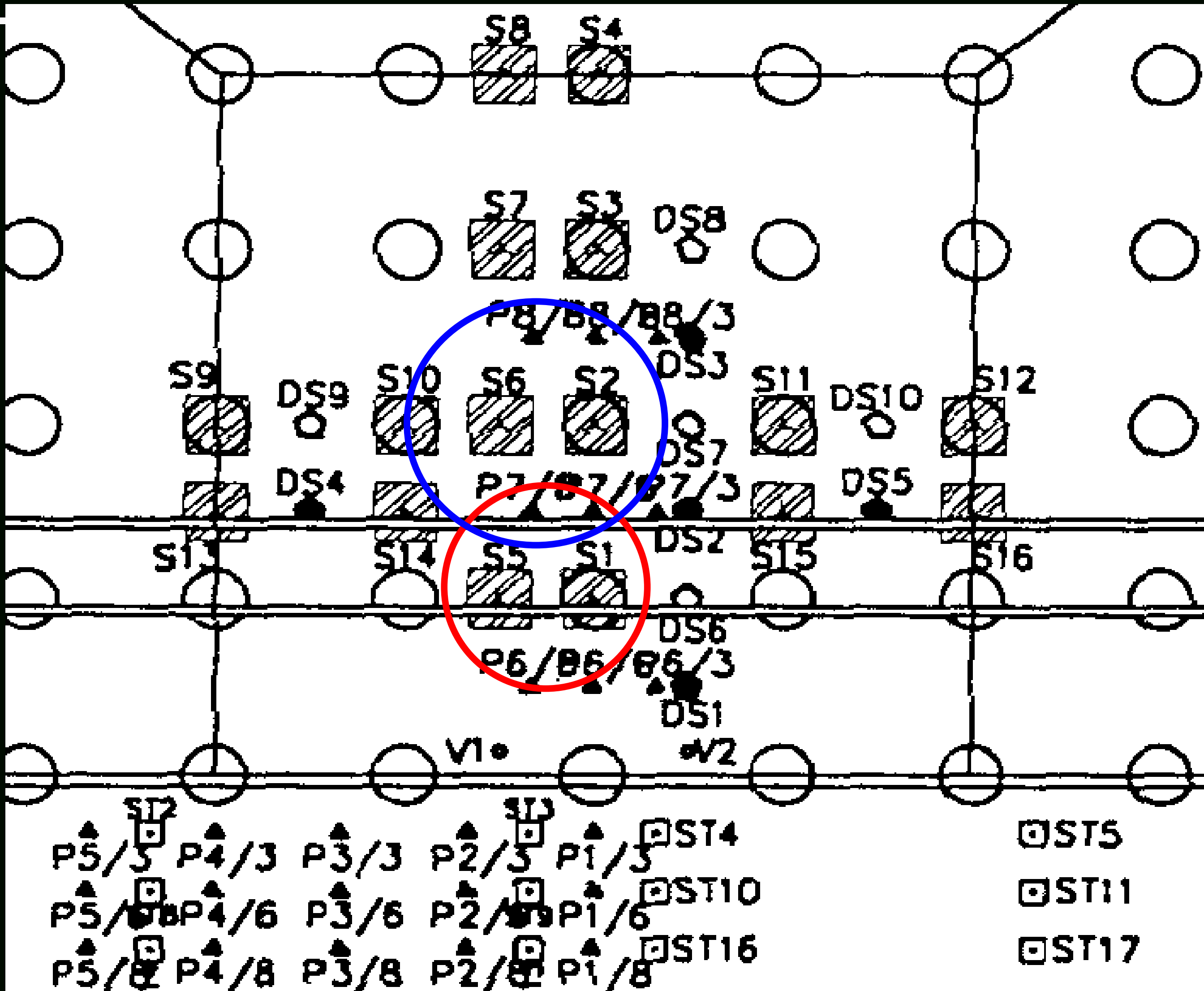
6) The existence of optimum mixing clay water content (w_{opt}) has been proven from the results of UC tests and oedometer tests of cement-admixed clay.

CONCLUSIONS *(cont'd)*

7) w_{opt} was found to fall within liquid limit (LL) up to 1.15LL of the base clay.

8) At optimum mixing clay water content, only 10% cement content by weight is needed instead of 17% in the conventional method to obtain a UC strength of 650 kPa, with consequent 40% cost reduction.

Layout of Settlement Plates



Location of Piezometers