第8回　国際低平地シンポジウム
2012年9月11日～13日　バリ　(三浦記念講演の概要)

バンコク粘土地盤における深層混合処理補強コラム（SDCM）と無補強コラム（DCM）の挙動

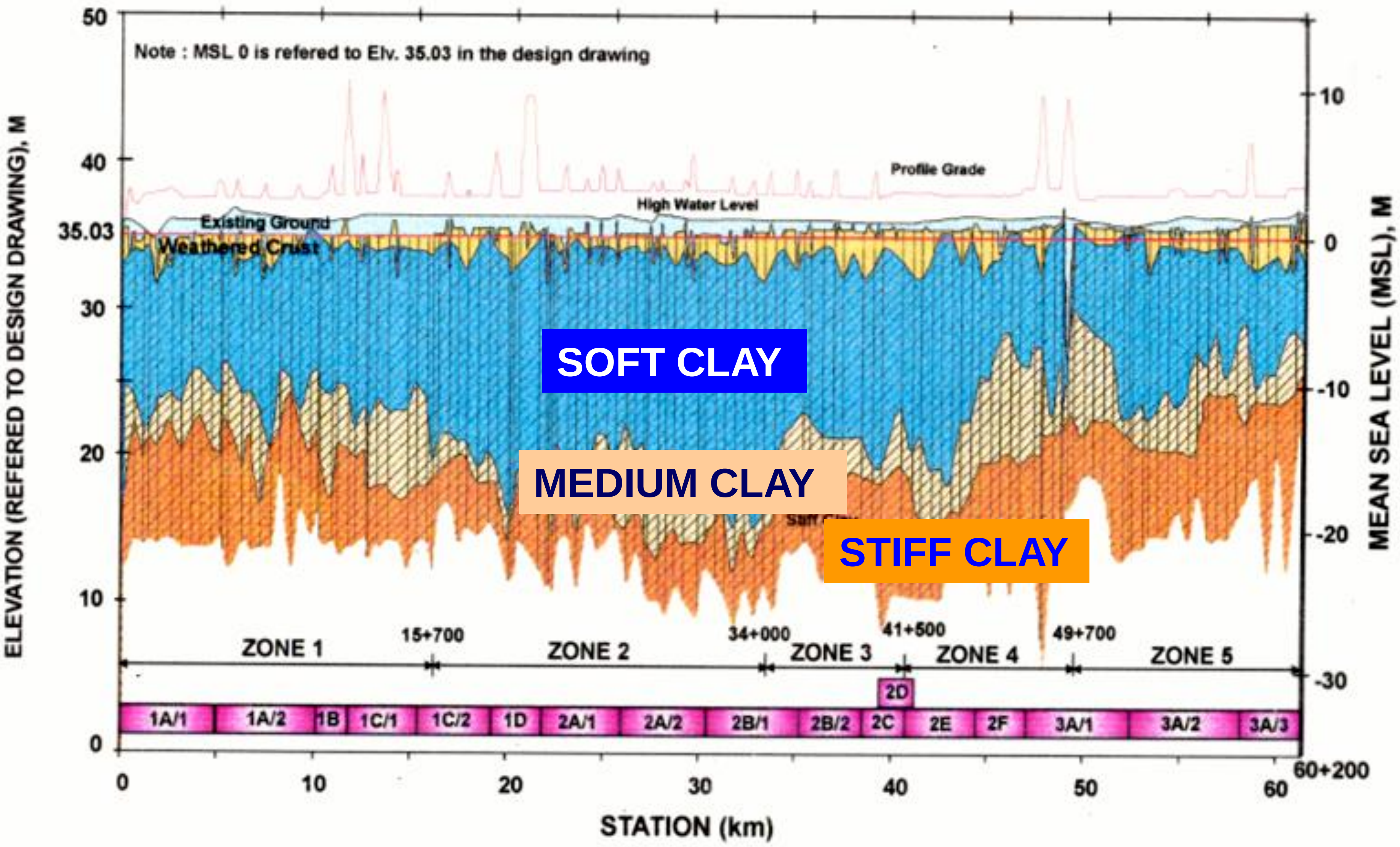
BEHAVIOR OF STIFFENED DEEP CEMENT MIXING (SDCM) AND DEEP CEMENT MIXING (DCM) PILES ON SOFT BANGKOK CLAY

デニス・T・ベルガド教授
アジア工科大学　地盤工学部門　タイ　バンコク

Prof. Dennes T. Bergado

Retired Professor, Asian Institute of Technology, Bangkok, Thailand
Guest Professor, Saga University, Saga, Japan,
Email: dbergado@gmail.com

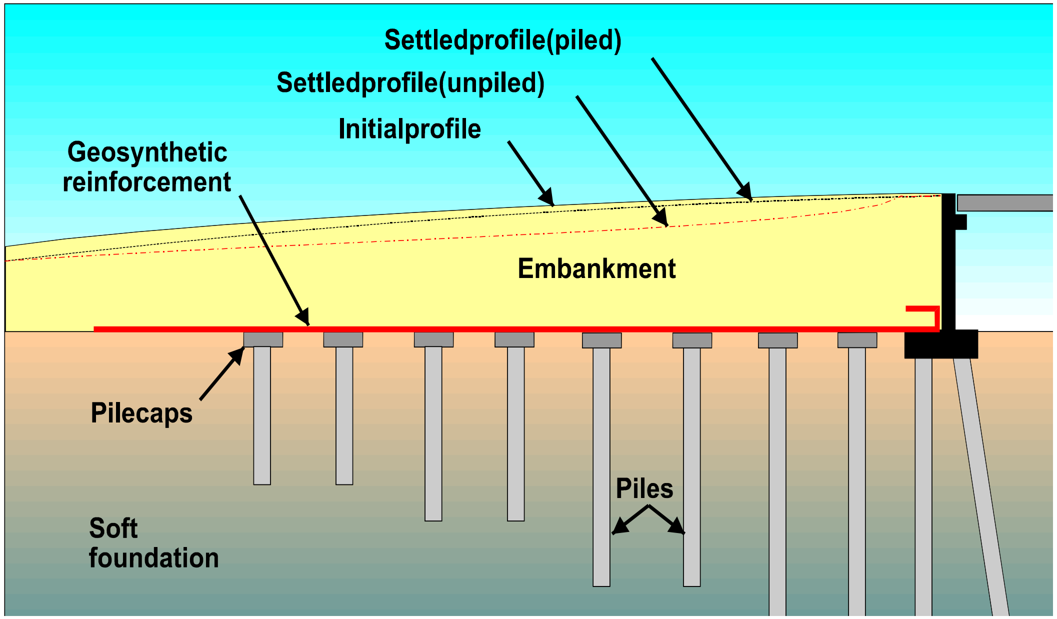
Soft Clay Deposit along Bangkok-Chonburi



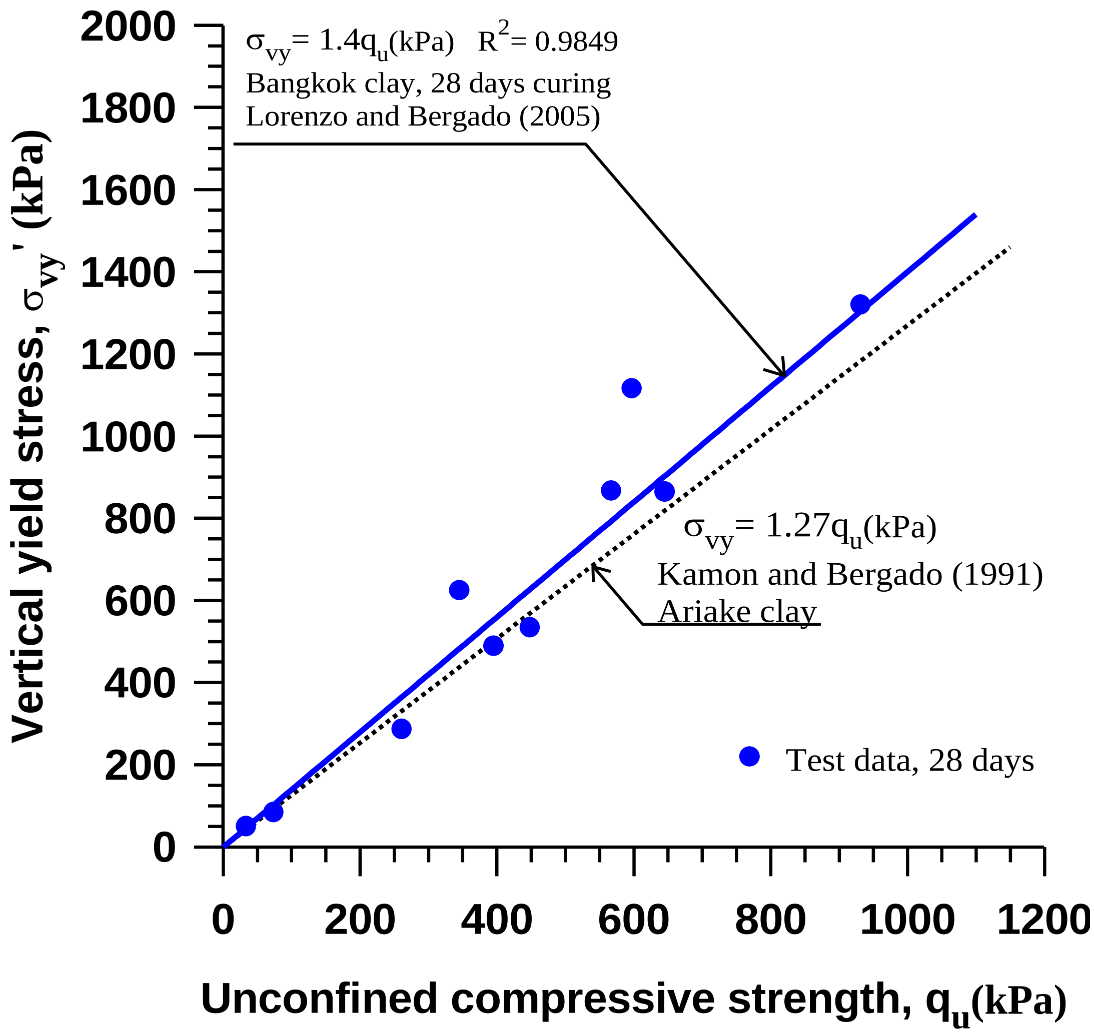
Problem of Bridge Approach on Subsiding Ground

Basal Reinforced Piled Embankments

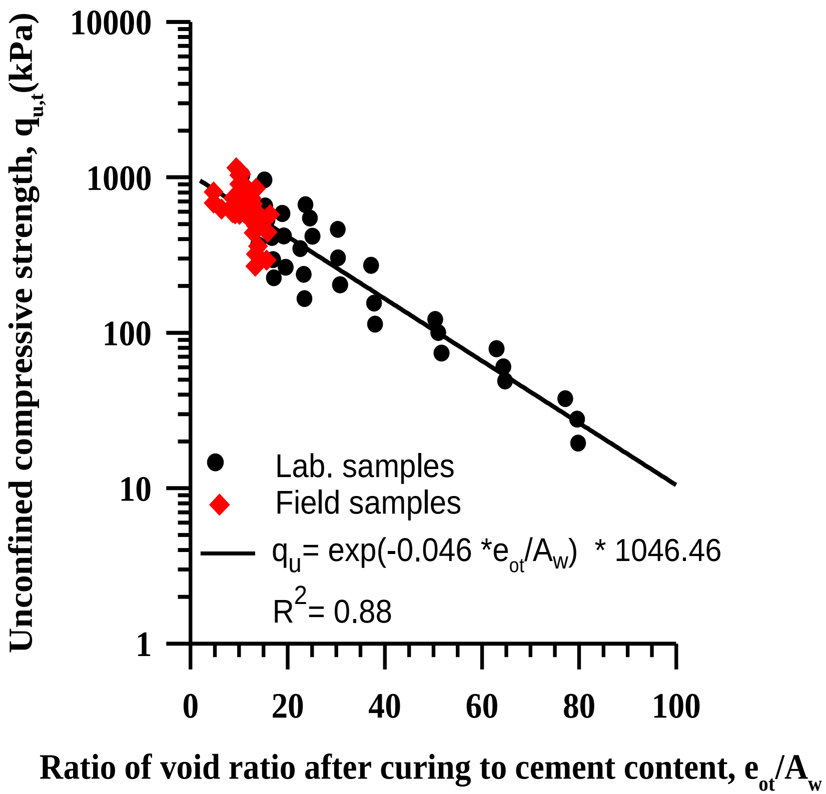
Transition between non-piled and piled foundations

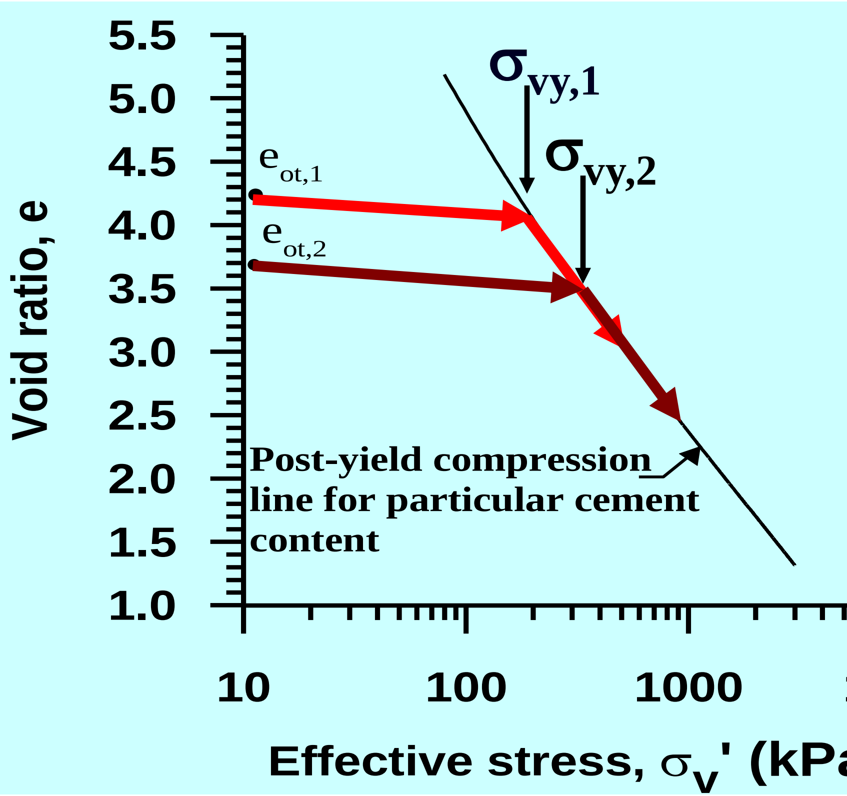


Correlations between σ_{vy} and q_u of Cement-Treated Bangkok Clay and Ariake Clay



Summary:
Prediction of Strength and Compressibility





Unconfined compression **1-Dimensional compression**

Two parameters: (1) after-curing void ratio, e_{ot}
(2) cement content, A_w

Optimum Mixing Water Content

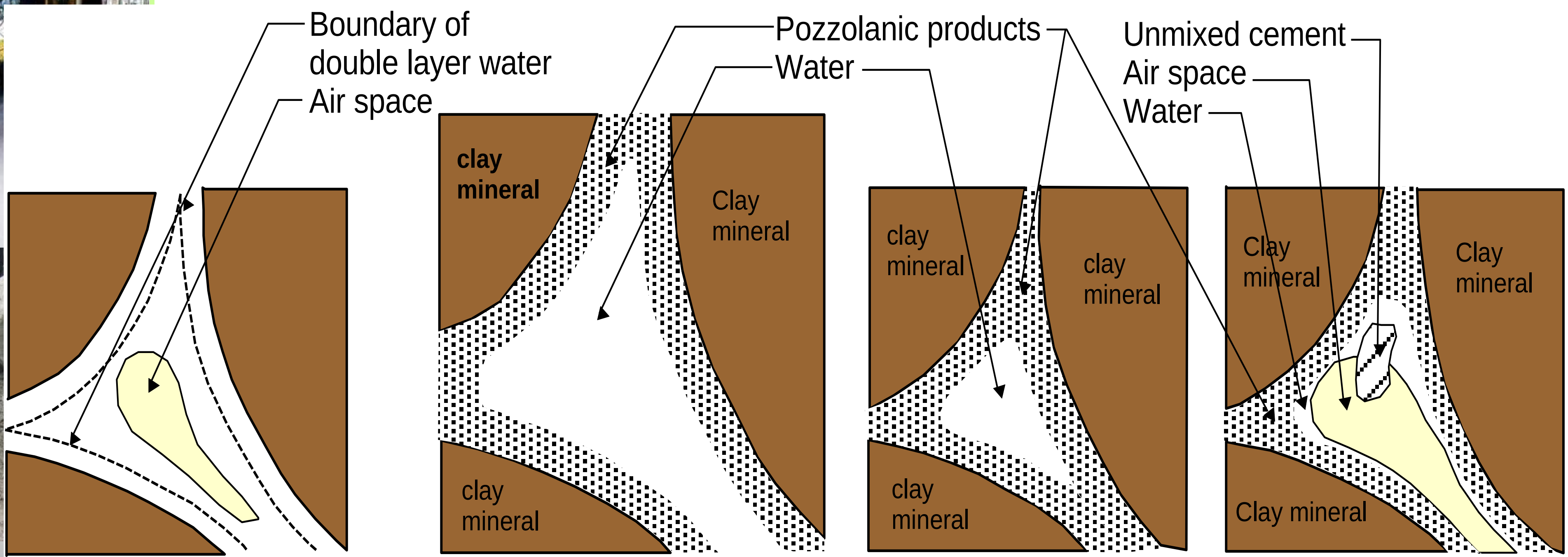


最適な混合含水比

粘土・水分・セメント系の最適混合含水比は、所定のセメント量を混合した試料の養生後の強度が最大となる含水比、と定義

Optimum mixing water content ($C_{w,opt}$) is the total clay water content (or mixing water content) of the clay-water-cement mixture that corresponds to the highest possible improvement in strength of cured cement-admixed clay at a given cement content.

Conceptual diagram of optimum water content



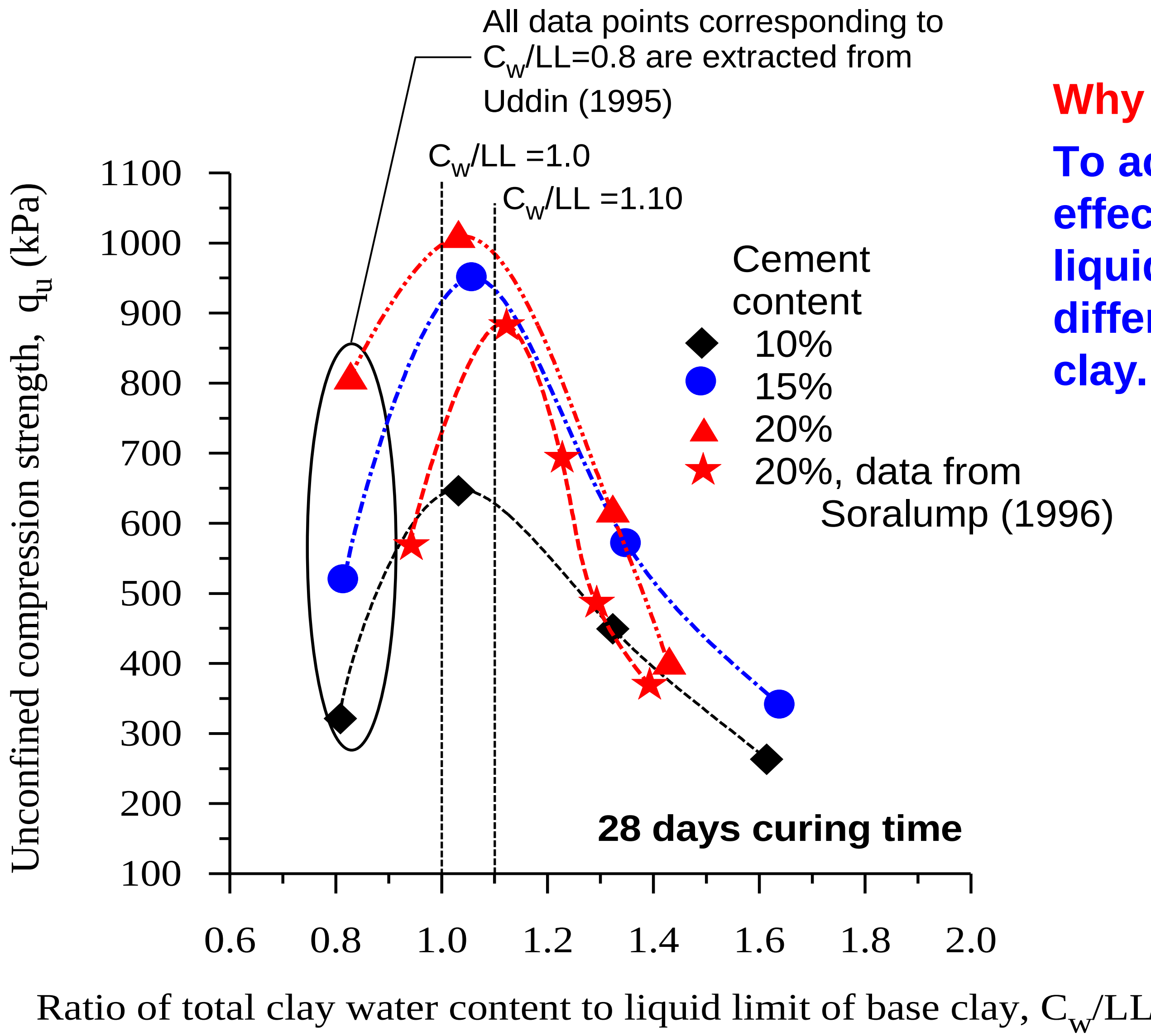
a) Untreated clay

b) High water content (cement-admixed)

c) Optimum water content (cement-admixed)

d) Low water content (cement-admixed)

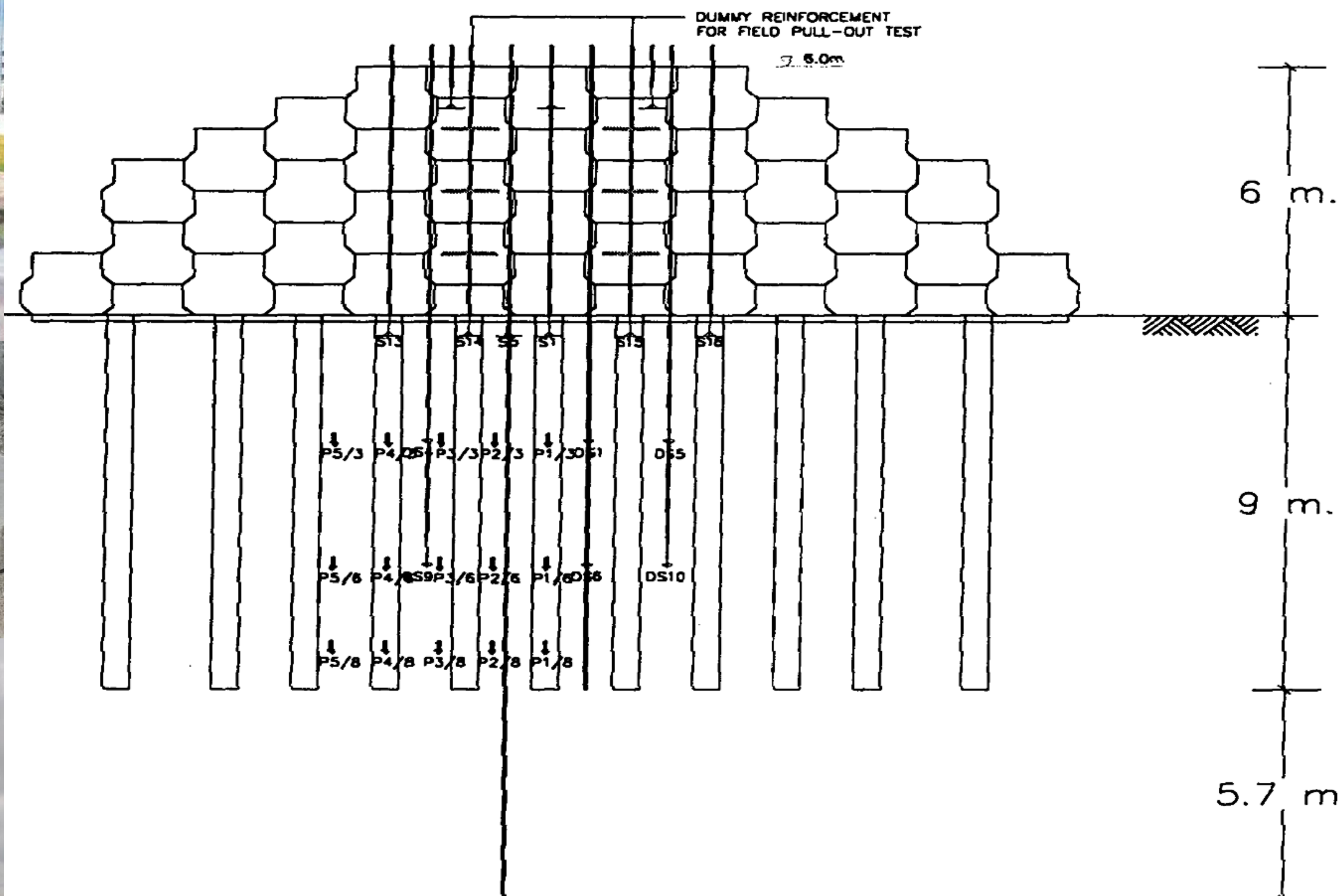
Strength Curve and Optimum Mixing Water Content



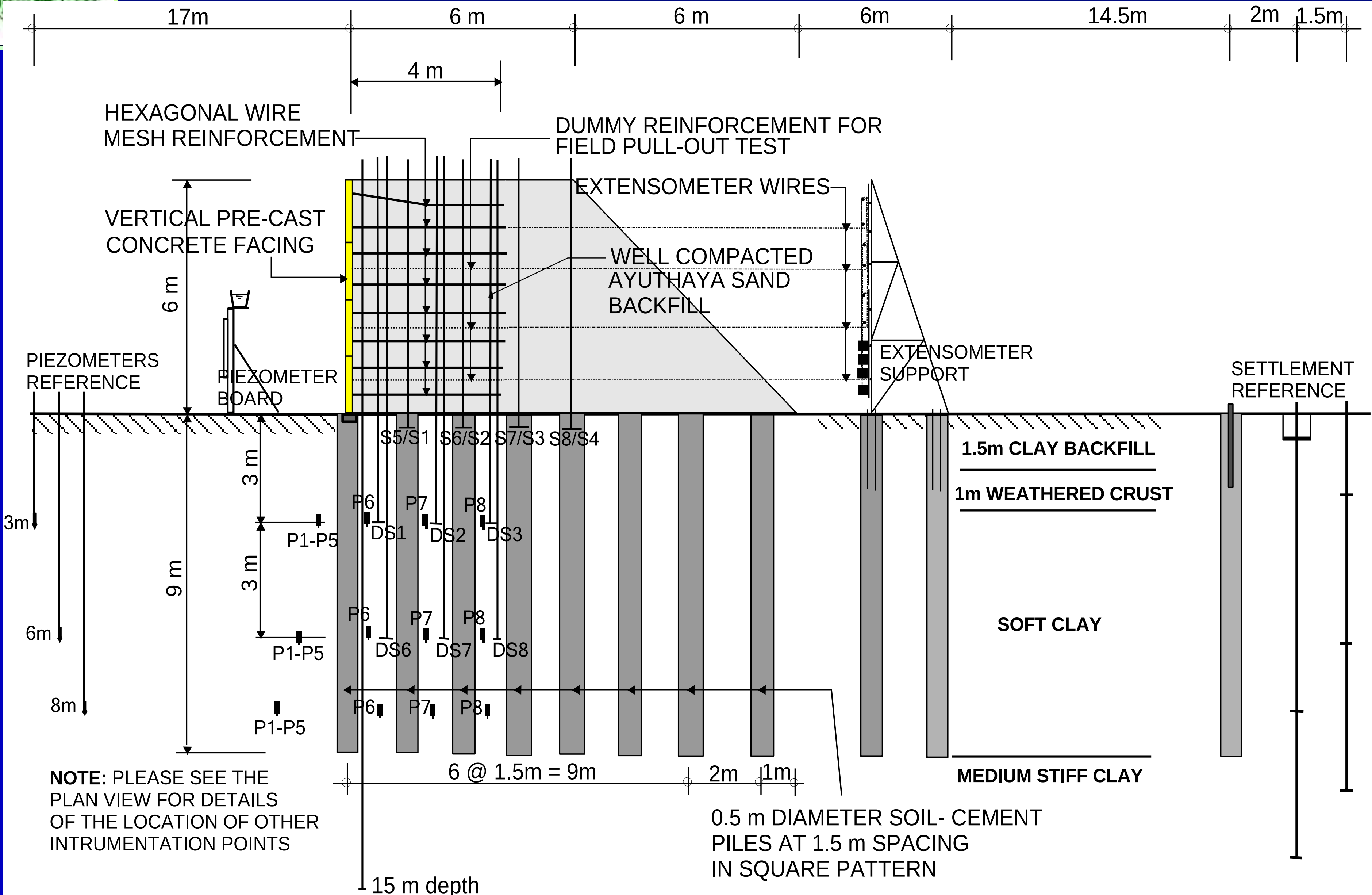
Why C_w/LL?

To account for the effect of varying liquid limits from different types of clay.

Front Elevation and DMM Pile Penetration

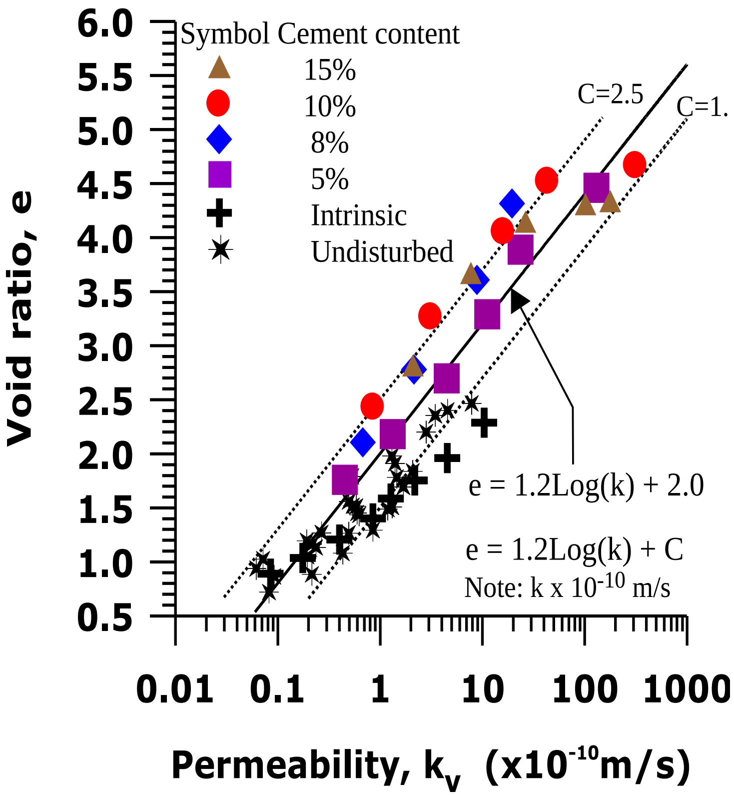


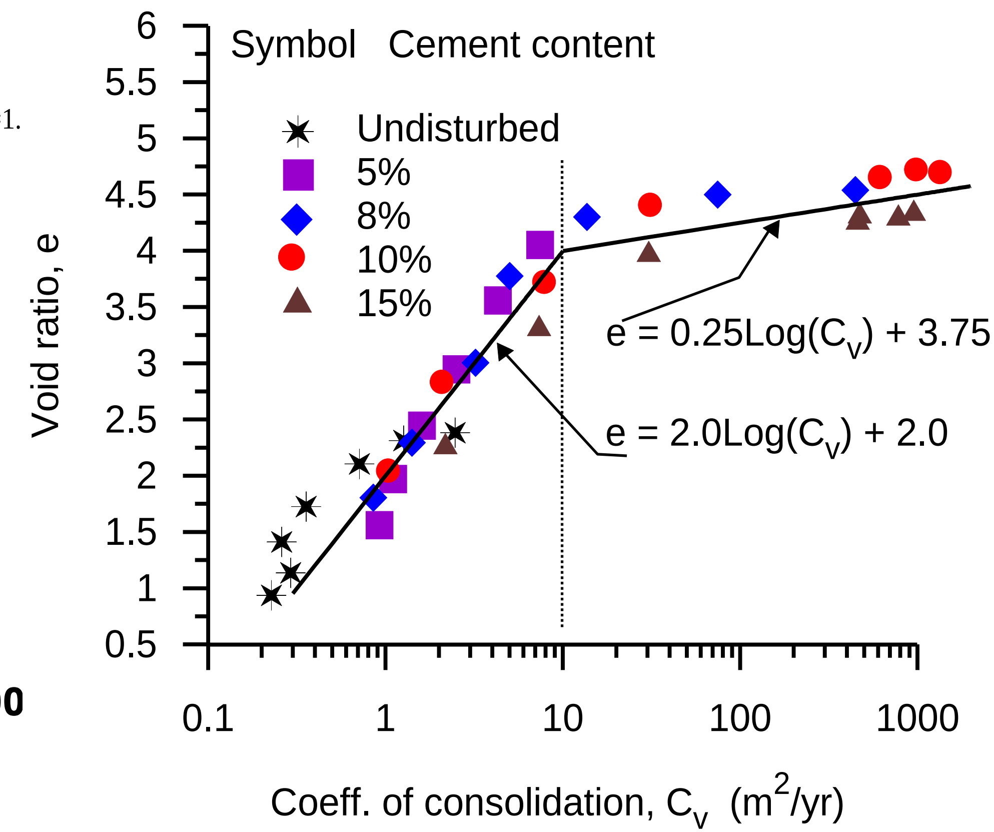
Section thru Center Line



NOTE: PLEASE SEE THE PLAN VIEW FOR DETAILS OF THE LOCATION OF OTHER INTRUMENTATION POINTS

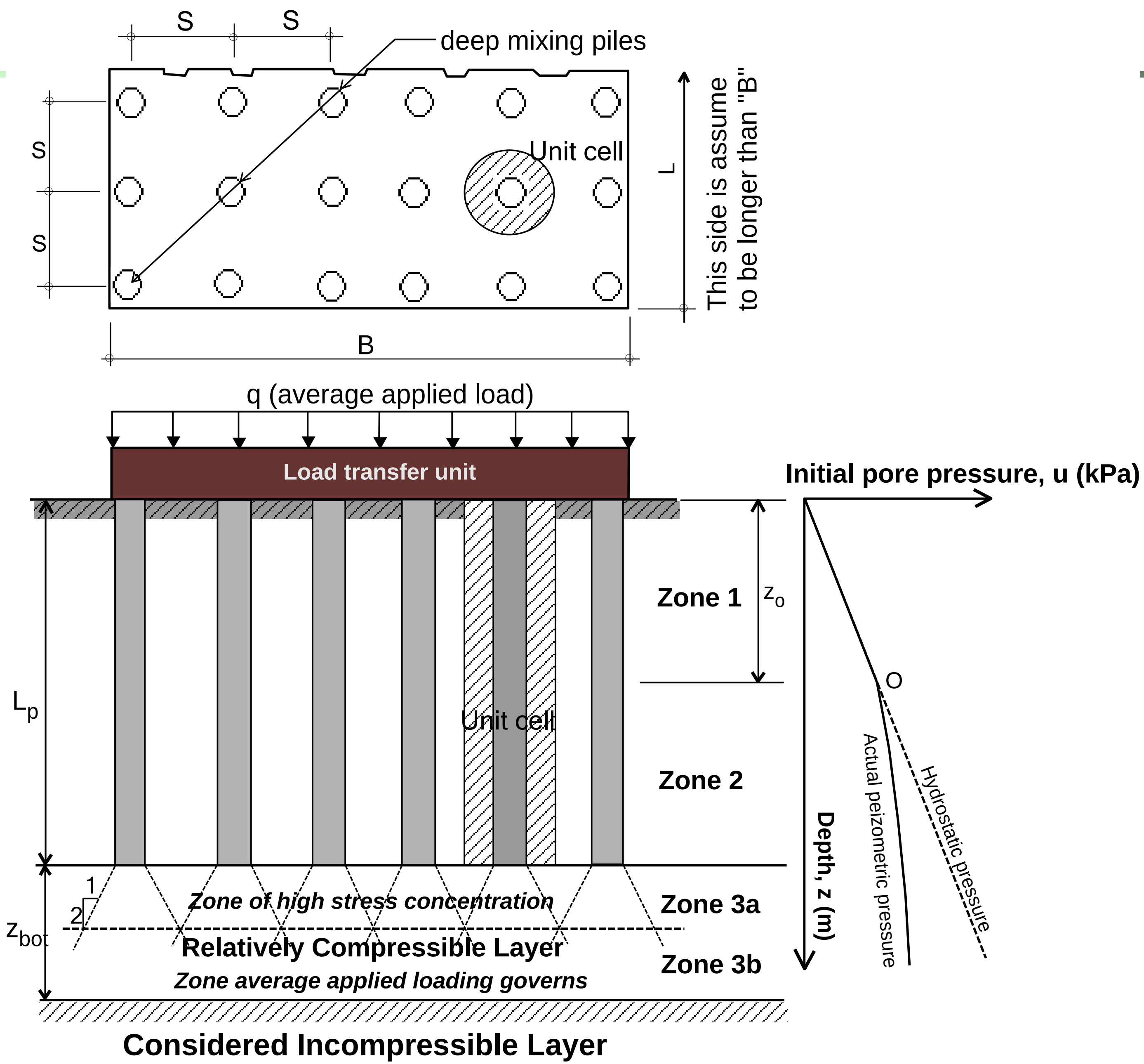
Coefficient of Permeability and Consolidation



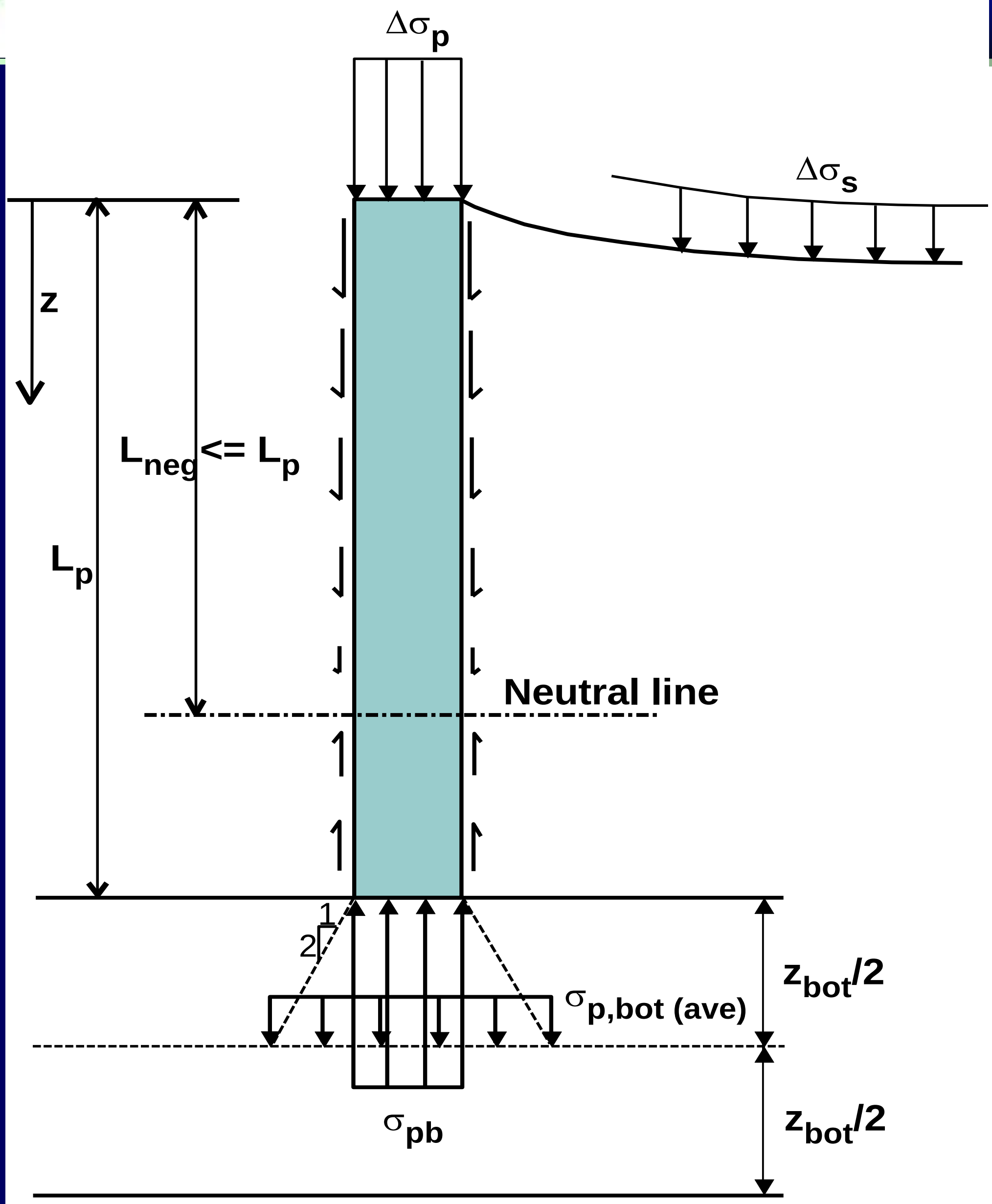


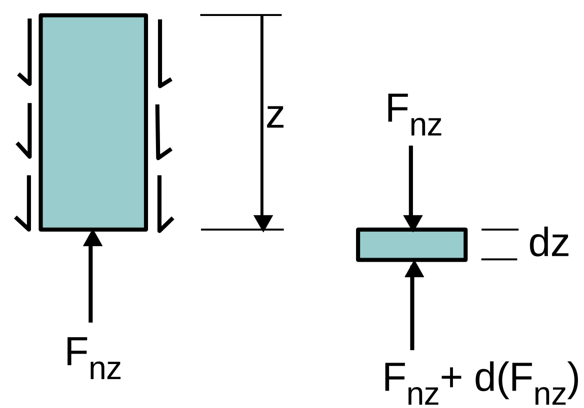
The Finished 6m High Reinforced Embankment

Analytical Model of Deep Mixing Improved Ground



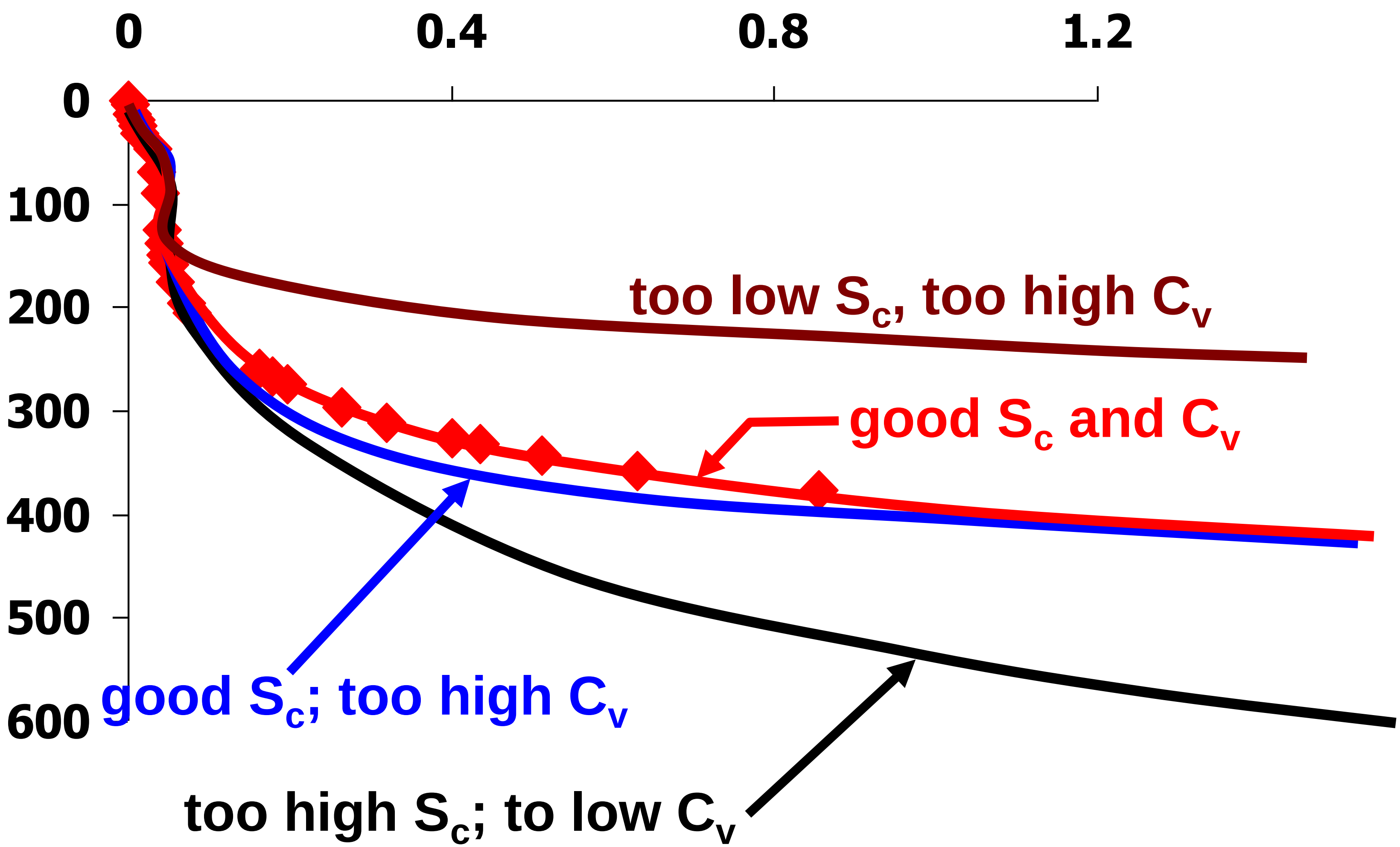
Interaction Mechanism - *Longterm*



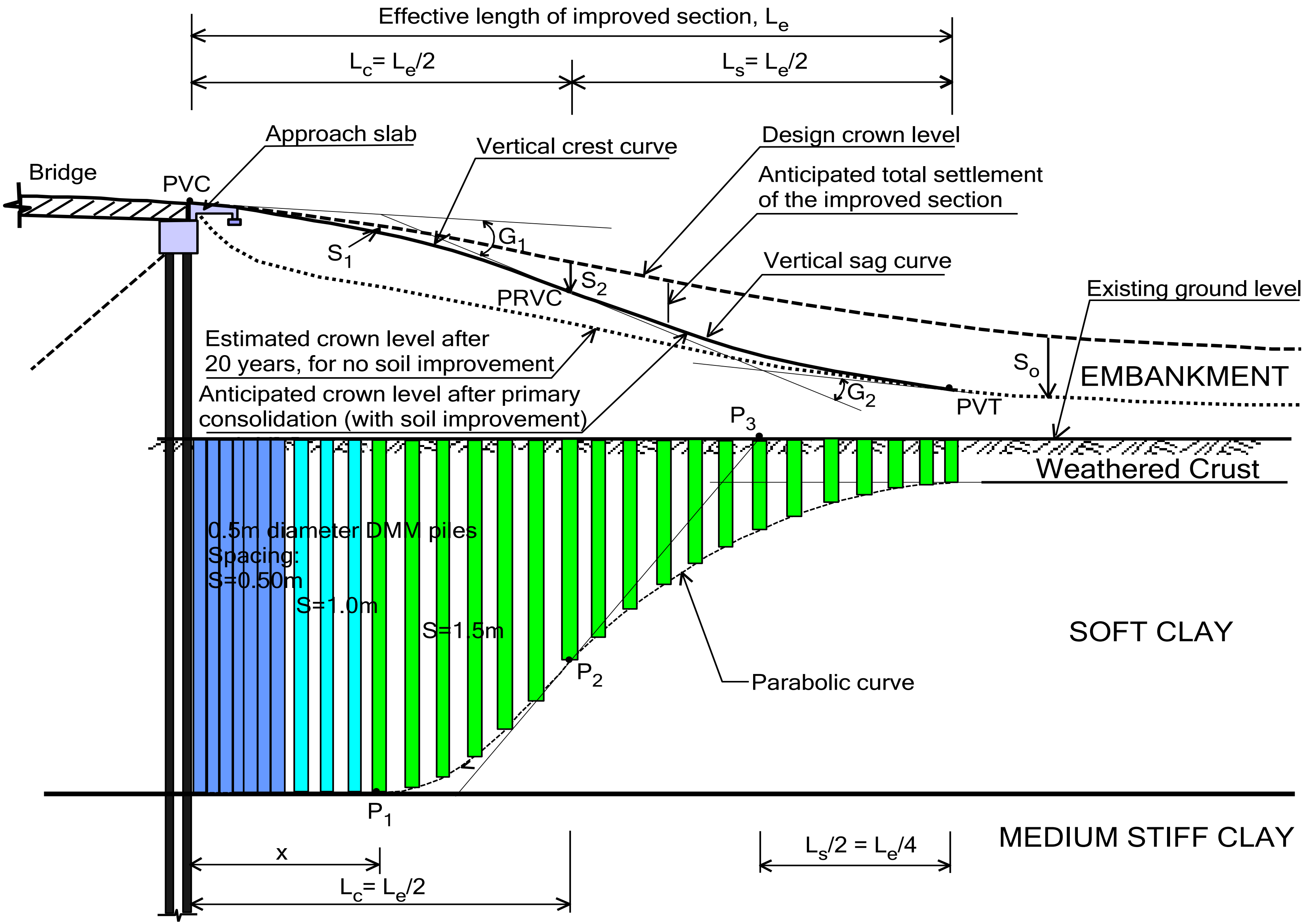


Normal stress on DMM pile induced by the down-drag force of the surrounding soil

Projection of Elastic and Consolidation Settlements and Back-Calculation of Consolidation Properties



Suggested Scheme of Deep Mixing Installation for Bridge Approach Embankment on Soft Clay Ground



無補強コラムDCMの問題

Problems in DCM Pile

せん断強度のばらつき、弱点が発生
せん断強度と変形特性が小さい
予期せぬ破壊が発生
支持力不足と圧縮破壊
周面抵抗と先端支持力の発揮以前に破壊
水平せん断力と曲げ抵抗が小さい

Variability of shear strength

Shear strength is not uniform
Many weak zones such as joints

Low shear strength and stiffness

The unexpected failures often happened
Bearing capacity failures and compression
The bearing failure of DCM pile occurs before its shaft resistance and end bearing are fully mobilized
Low horizontal shear and low flexural resistance

Pile Failure vs Soil Failure

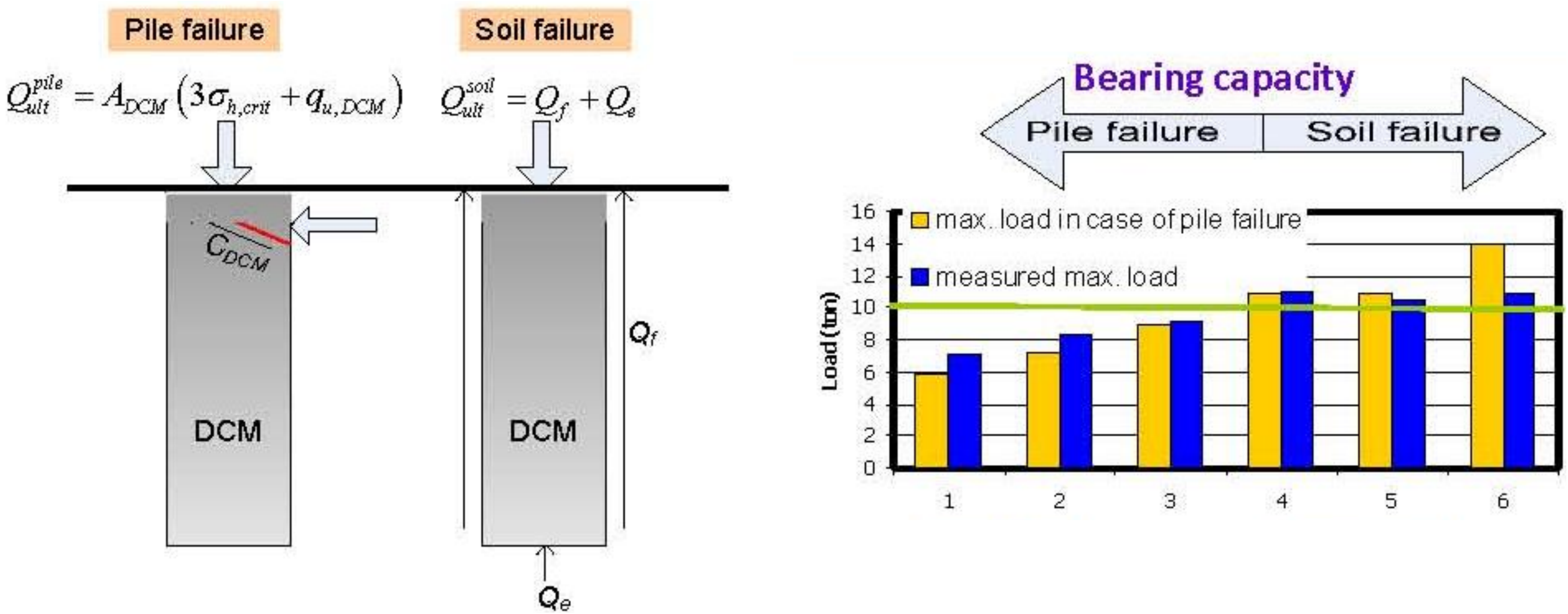
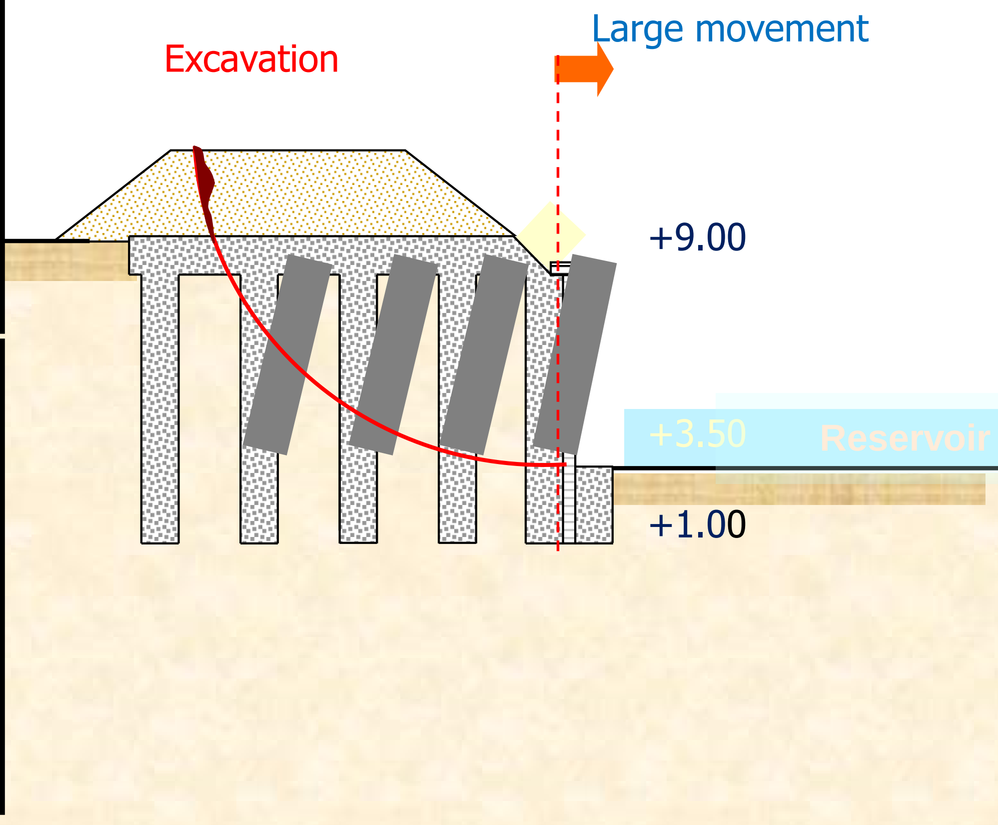


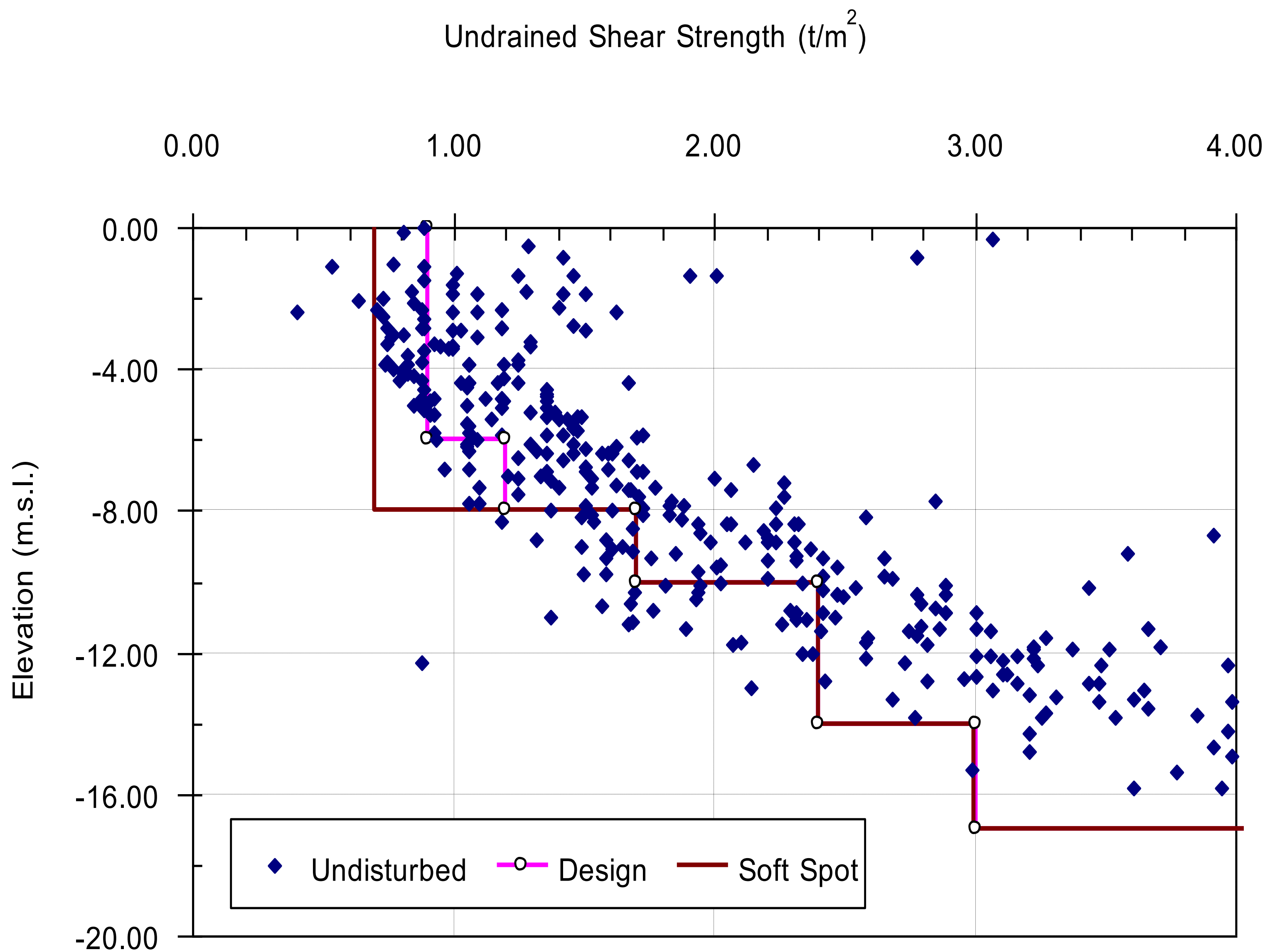
Fig. 1 Low quality of DCM piles on Soft Bangkok Clay (Petchgate et al., 2003)

Application of DCM Pile as Retaining Wall

- DCM pile can maintain compressive stress and resist shear stress but cannot resist flexural stress
- DCM pile has low flexural and tensile strength

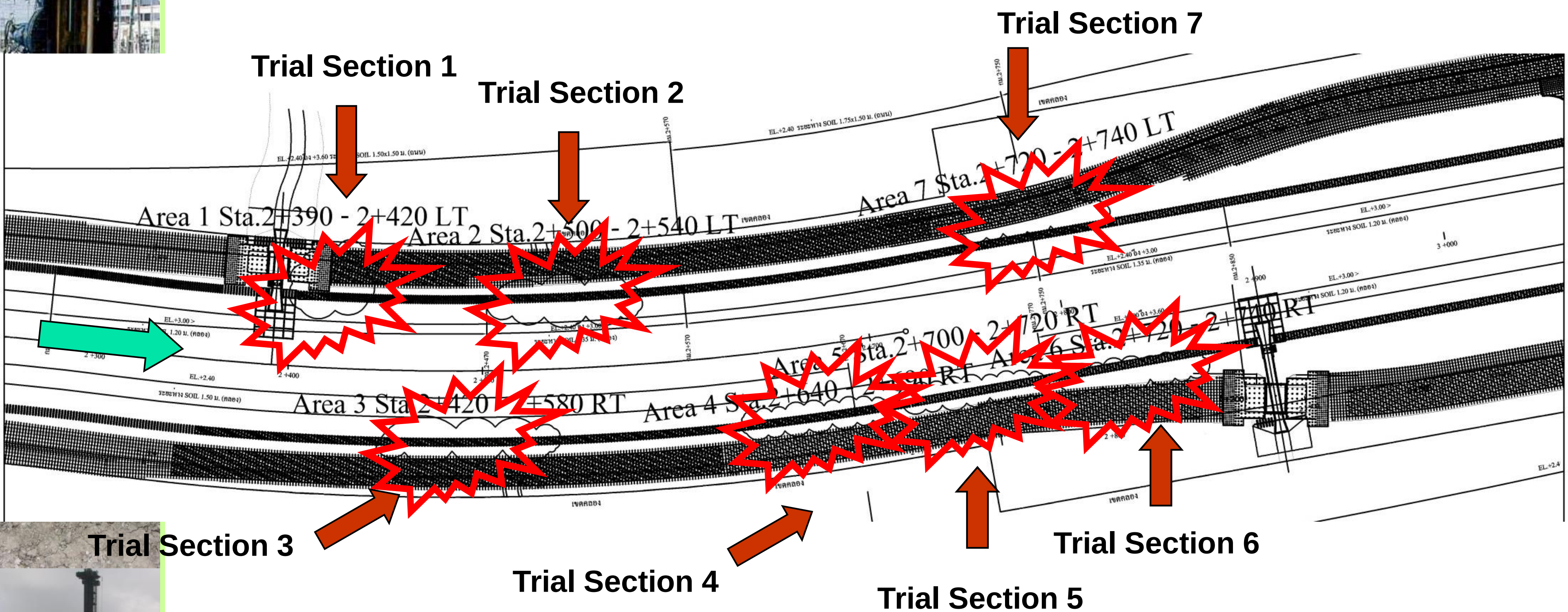


Undrained Shear Strength

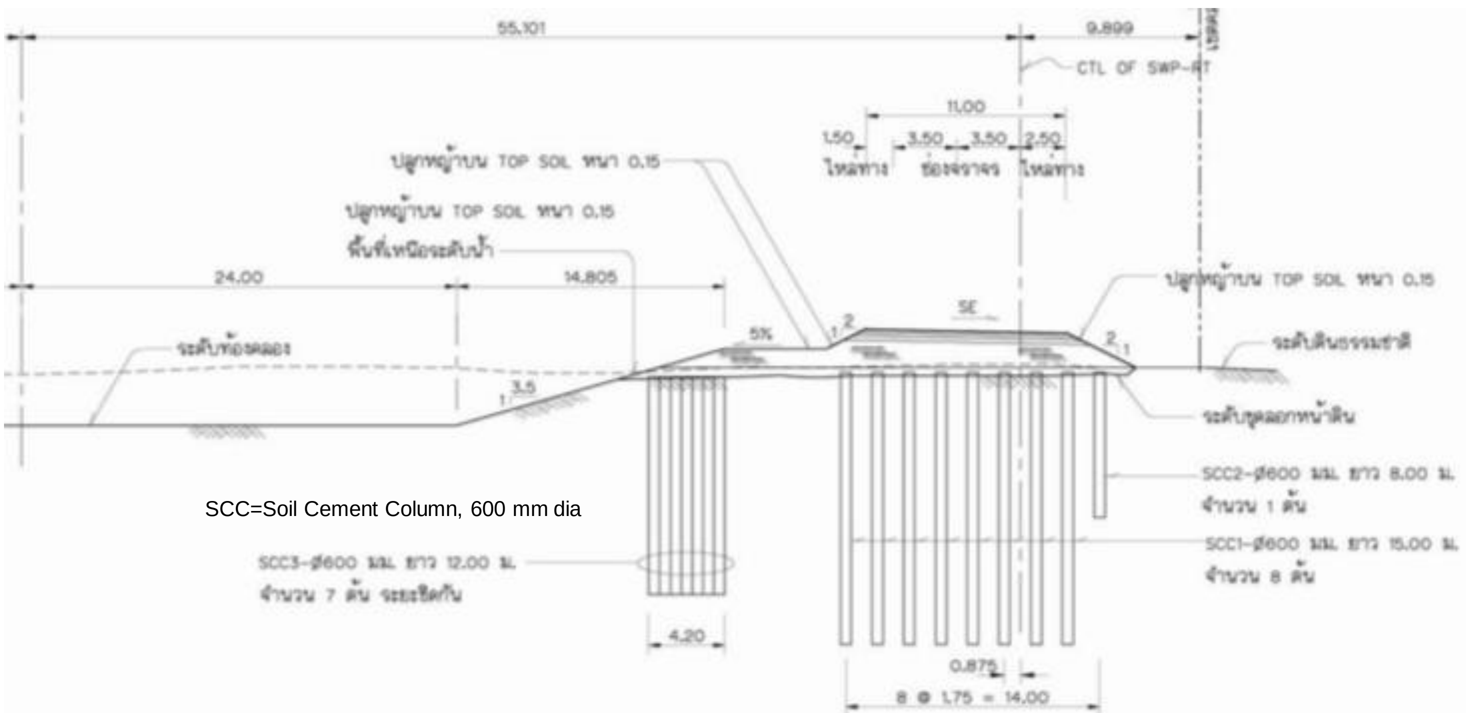


Suvarnabhumi canal : Location of the canal

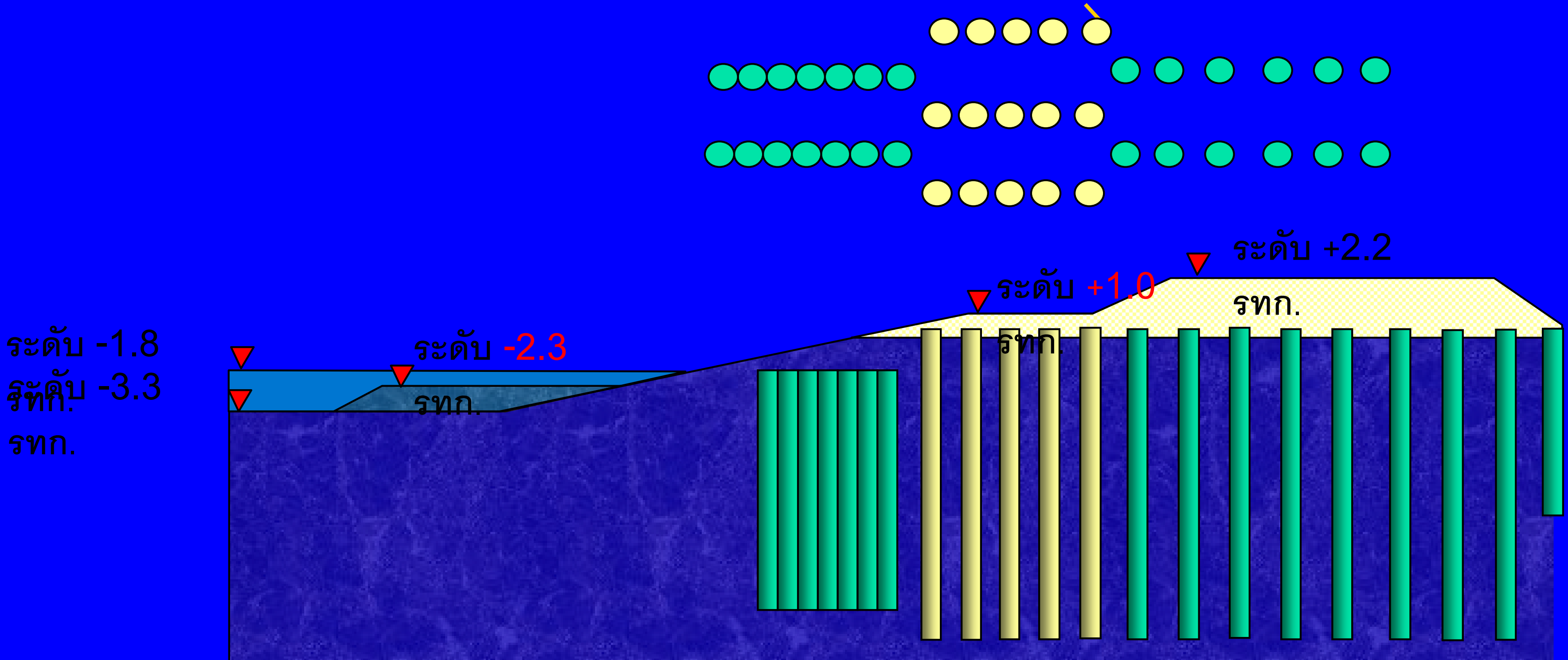
The alignment of Contract 1 Trial section 1 to 7

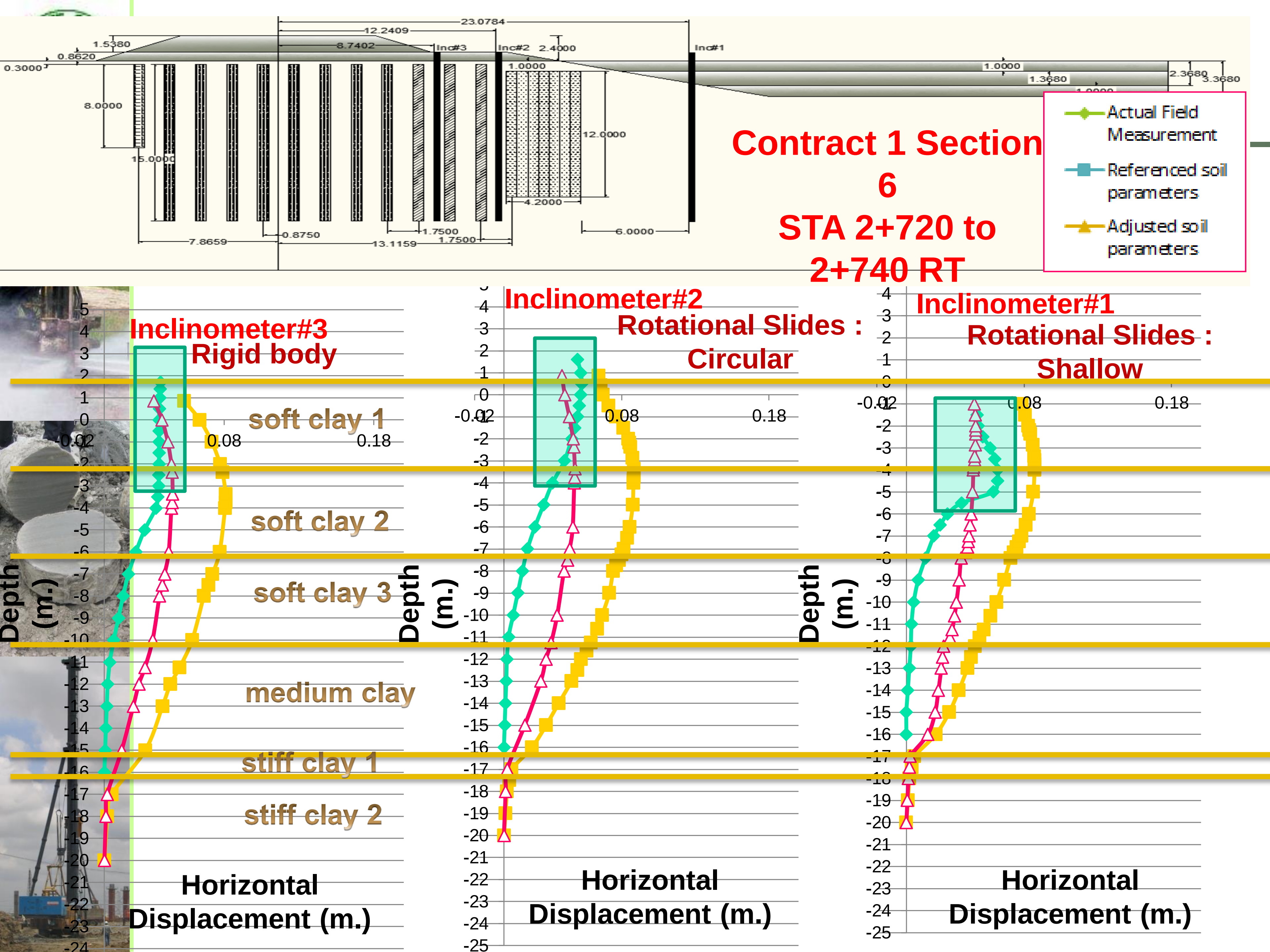


DCM Pile for Slope Protection


55.101
9.899
CTL OF SWP-RT
11.00
1.50
3.50
3.50
2.50
ไหล่ทาง
ช่องจราจร
ไหล่ทาง
ปลูกหญ้าบน TOP SOIL หนา 0.15
ปลูกหญ้าบน TOP SOIL หนา 0.15
พื้นที่เหนือระดับน้ำ
24.00
14.805
ปลูกหญ้าบน TOP SOIL หนา 0.15
SE
5%
ระดับท้องคลอง
ระดับดินธรรมชาติ
3.5
ระดับขุดลอกหน้าดิน
SCC2-Ø600 มม. ยาว 8.00 ม.
จำนวน 1 ต้น
SCC=Soil Cement Column, 600 mm dia
SCC1-Ø600 มม. ยาว 15.00 ม.
จำนวน 8 ต้น
SCC3-Ø600 มม. ยาว 12.00 ม.
จำนวน 7 ต้น ระยะชิดกัน
4.20
0.875
8 @ 1.75 = 14.00

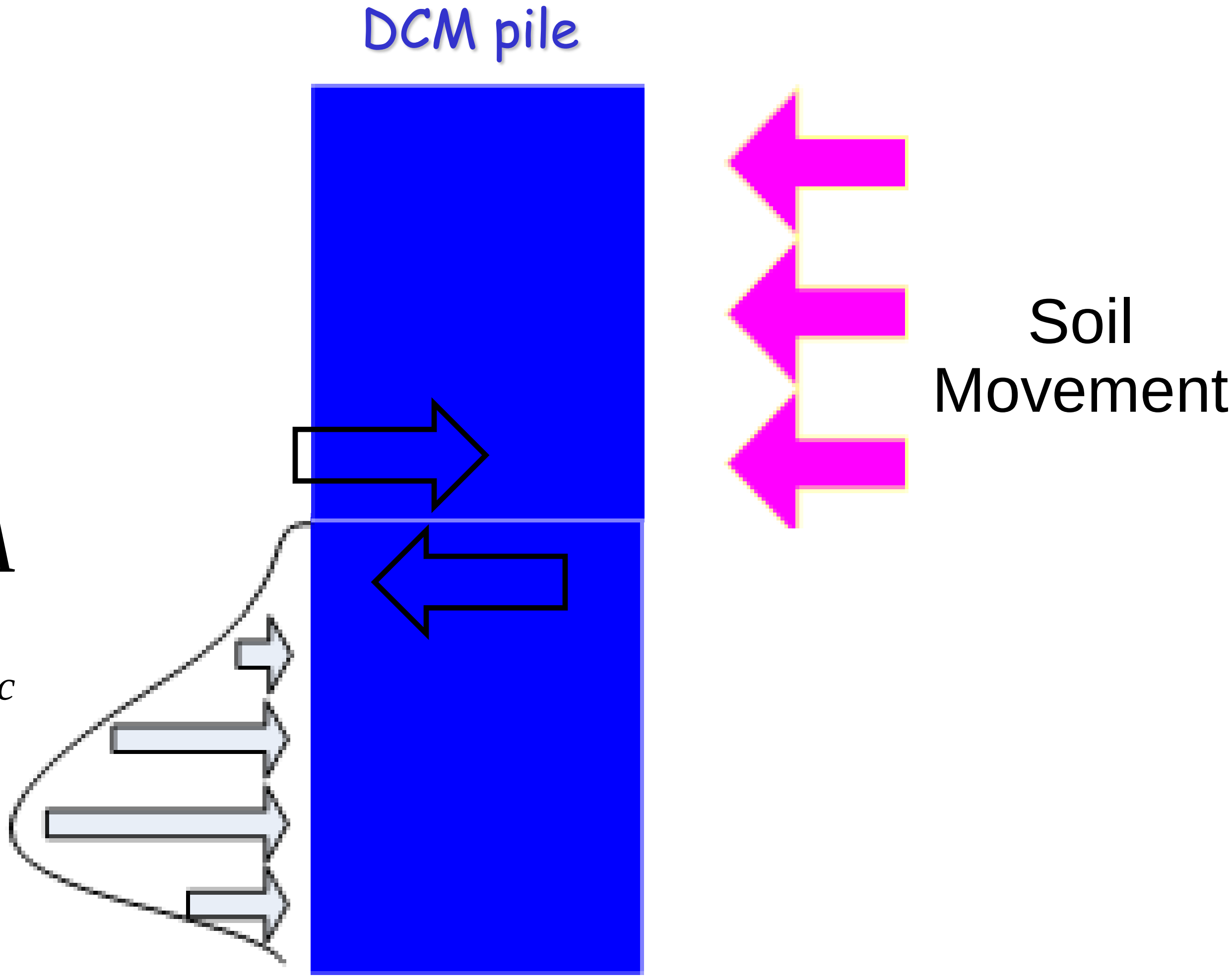

9 August 2007
ระดับ +1.0 รทก.
ระดับ -3.3 รทก.
1 / 3.5
5
ม.


ระดับ +2.2
รทก.
ระดับ +1.0
รทก.
ระดับ -1.8
รทก.
ระดับ -3.3
รทก.
ระดับ -2.3
รทก.



Contract 1 Section 6
STA 2+720 to 2+740 RT
Actual Field Measurement
Referenced soil parameters
Adjusted soil parameters
Inc#3
Inc#2
Inc#1
23.0784
12.2409
8.7402
1.5380
0.8620
0.3000
8.0000
15.0000
2.4000
1.0000
12.0000
4.2000
6.0000
1.0000
1.3680
2.3680
3.3680
7.8659
0.8750
13.1159
1.7500
1.7500
Inclinometer#3
Rigid body
Inclinometer#2
Rotational Slides : Circular
Inclinometer#1
Rotational Slides : Shallow
soft clay 1
soft clay 2
soft clay 3
medium clay
stiff clay 1
stiff clay 2
Depth (m.)
Horizontal Displacement (m.)
-0.02
0.08
0.18

Shear Failure



$$S = \tau A$$

$$S = \frac{1}{4}\sigma_c$$

DCM and SDCM

DCM Pile

Variability of shear strength

Low strength and stiffness

- **DCMコラム：せん断強度のばらつき と圧縮強度と剛性が小さい**

- **SDCM：プレキャストコンクリート杭を挿入 支持力の増加、横抵抗力の増加、水平変形量の縮小**

SDCM Pile

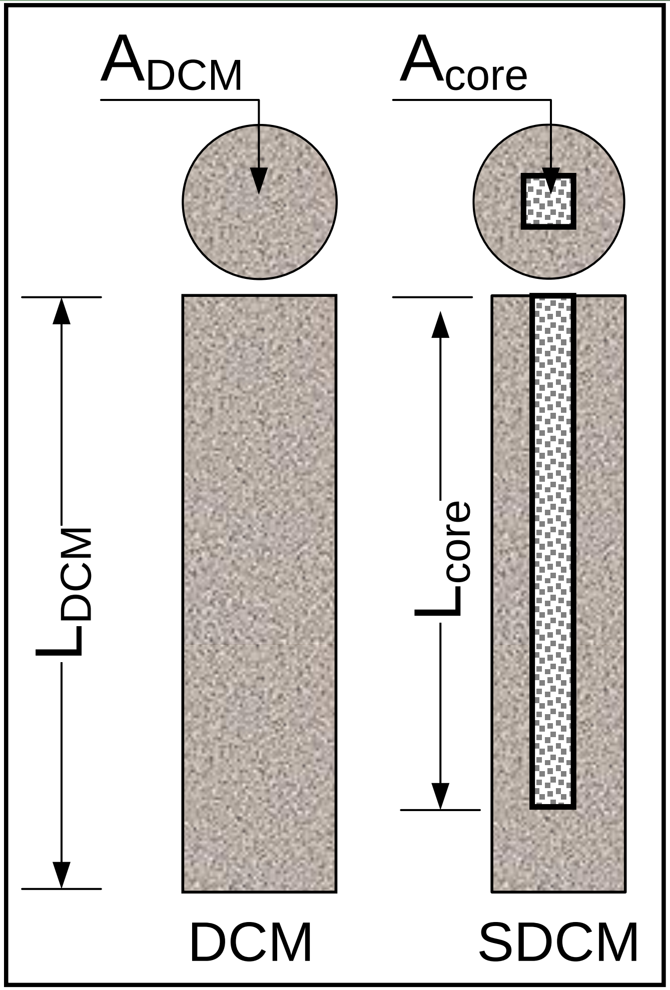
Composite pile

Insertion of a precast concrete core pile

Increase bearing capacity

Increase lateral resistance

Reduce deformation



Area ratio $= A_{core}/A_{DCM}$

Length ratio $= L_{core}/L_{DCM}$

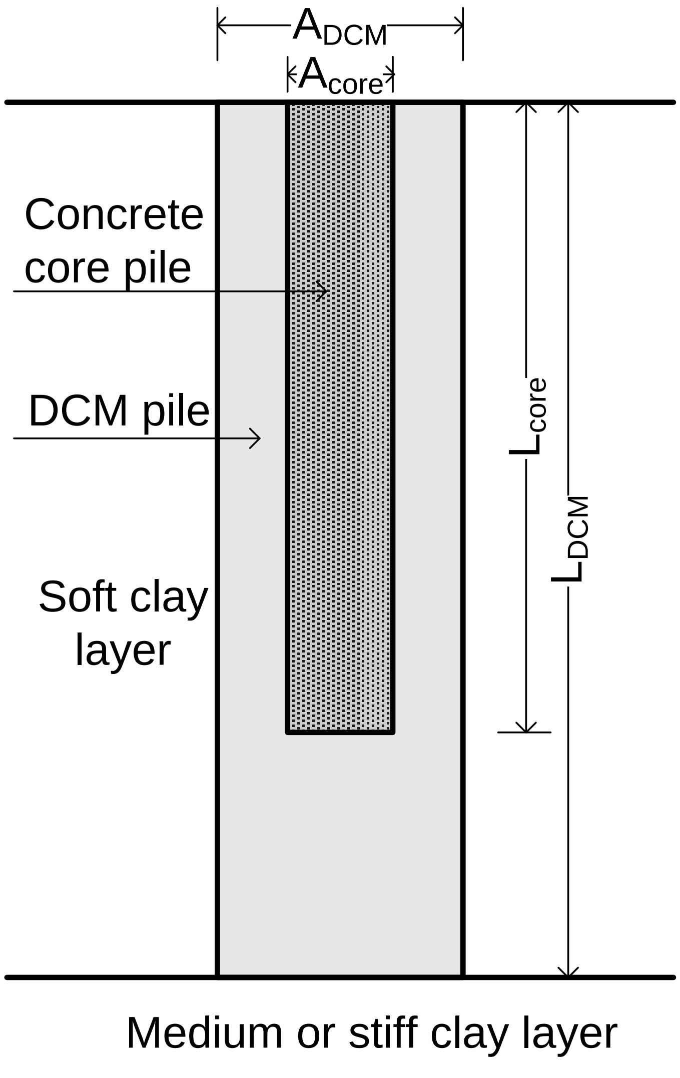
Construction of SDCM Piles

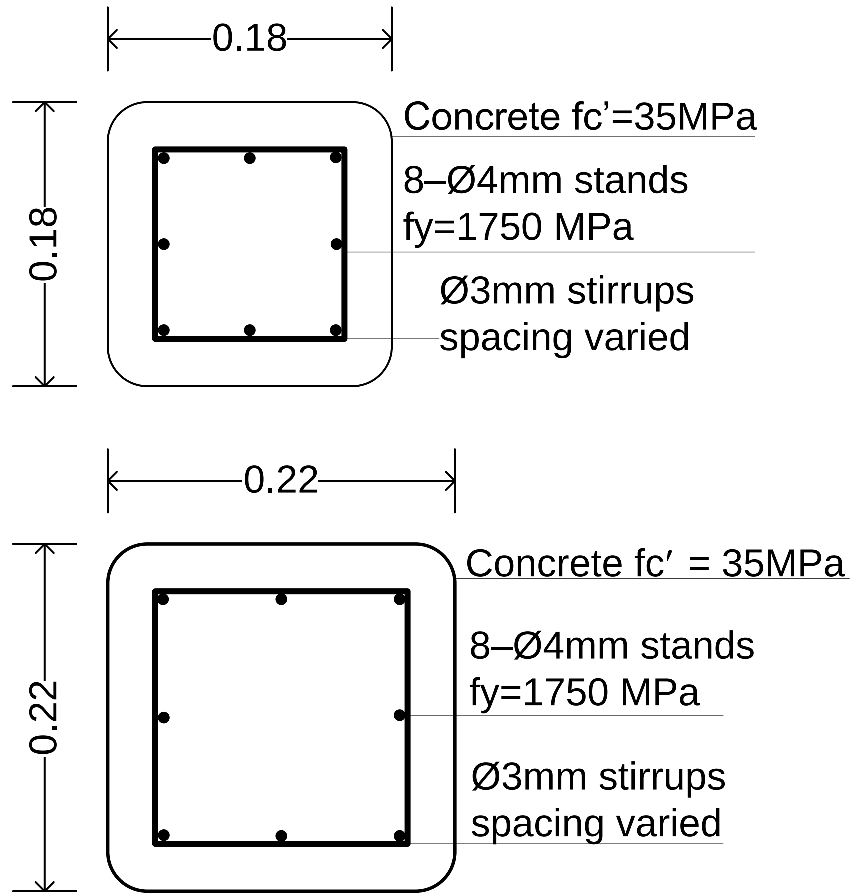
Insertion of prestressed concrete pile.

No pushing force due to very low fiction

Curing time in-situ for 80 days.

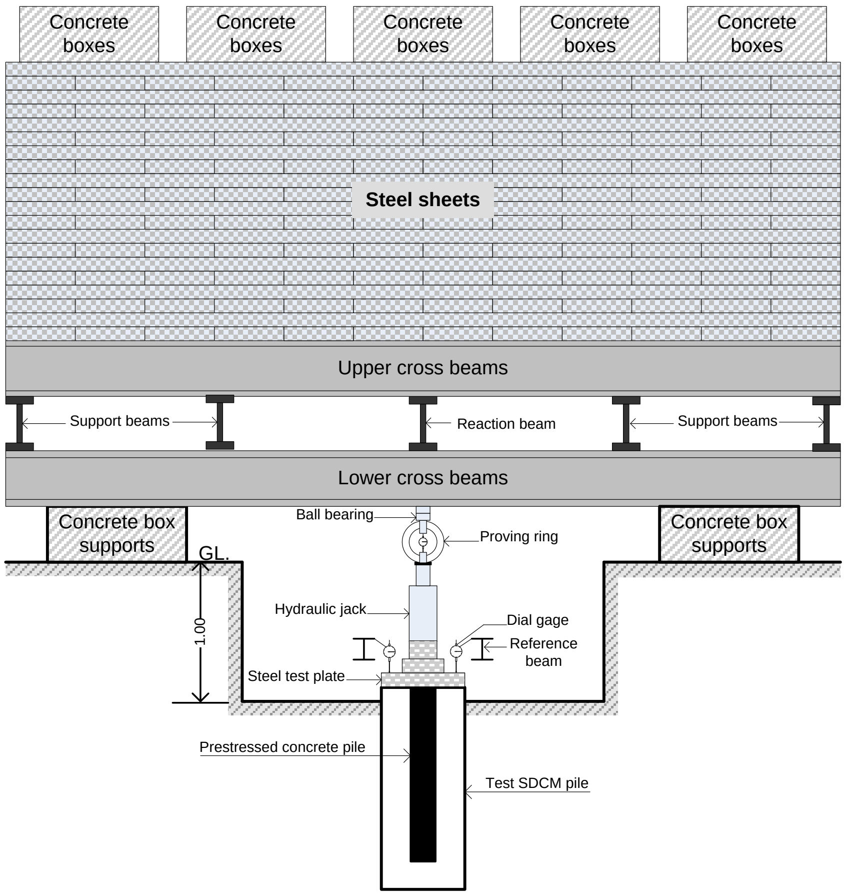
Full Scale Load Test





Prestressed concrete core pile

Axial compression piles



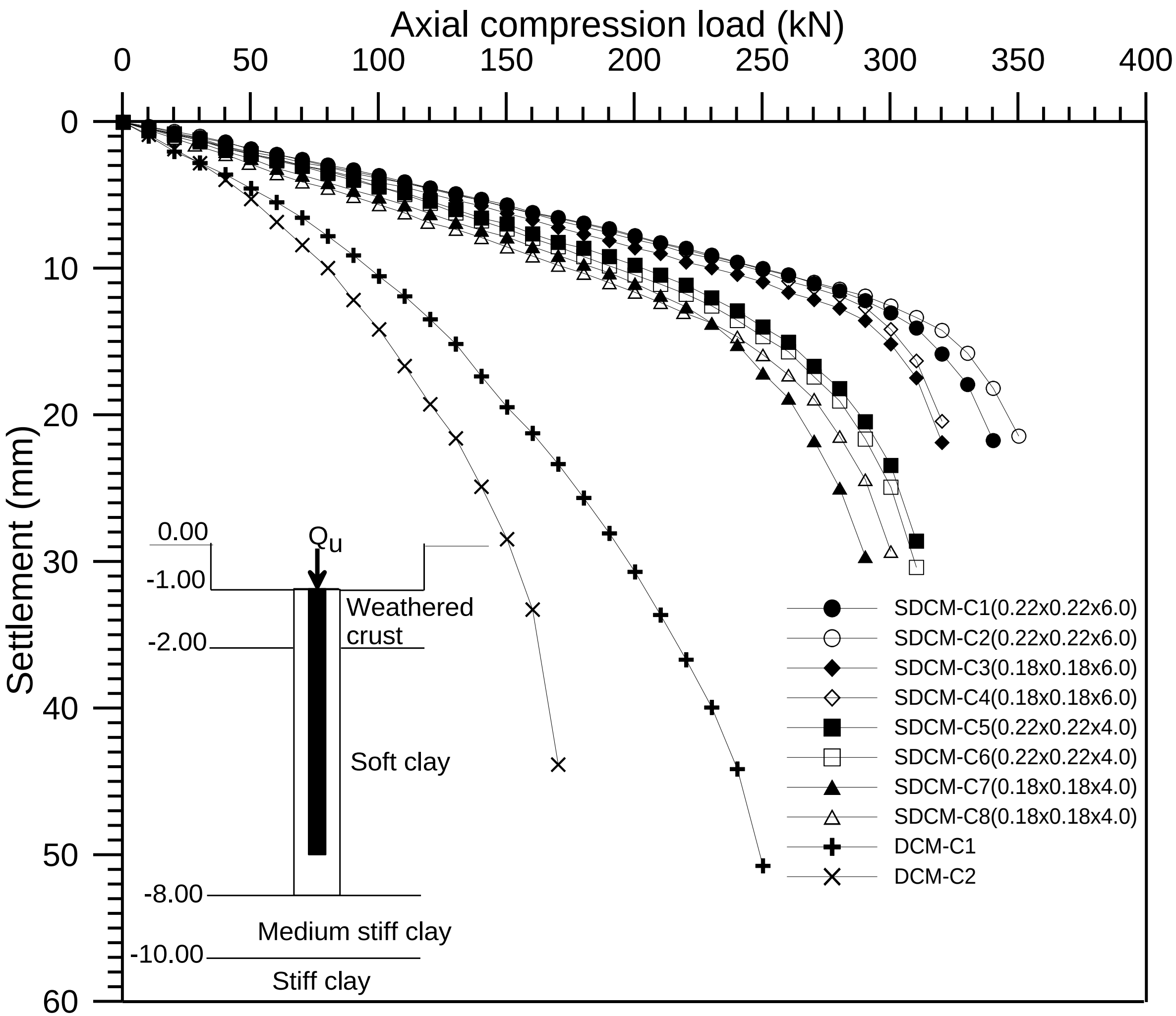
28 Cases

Different core size: 0.18, 0.22, 0.26, 0.30 m.

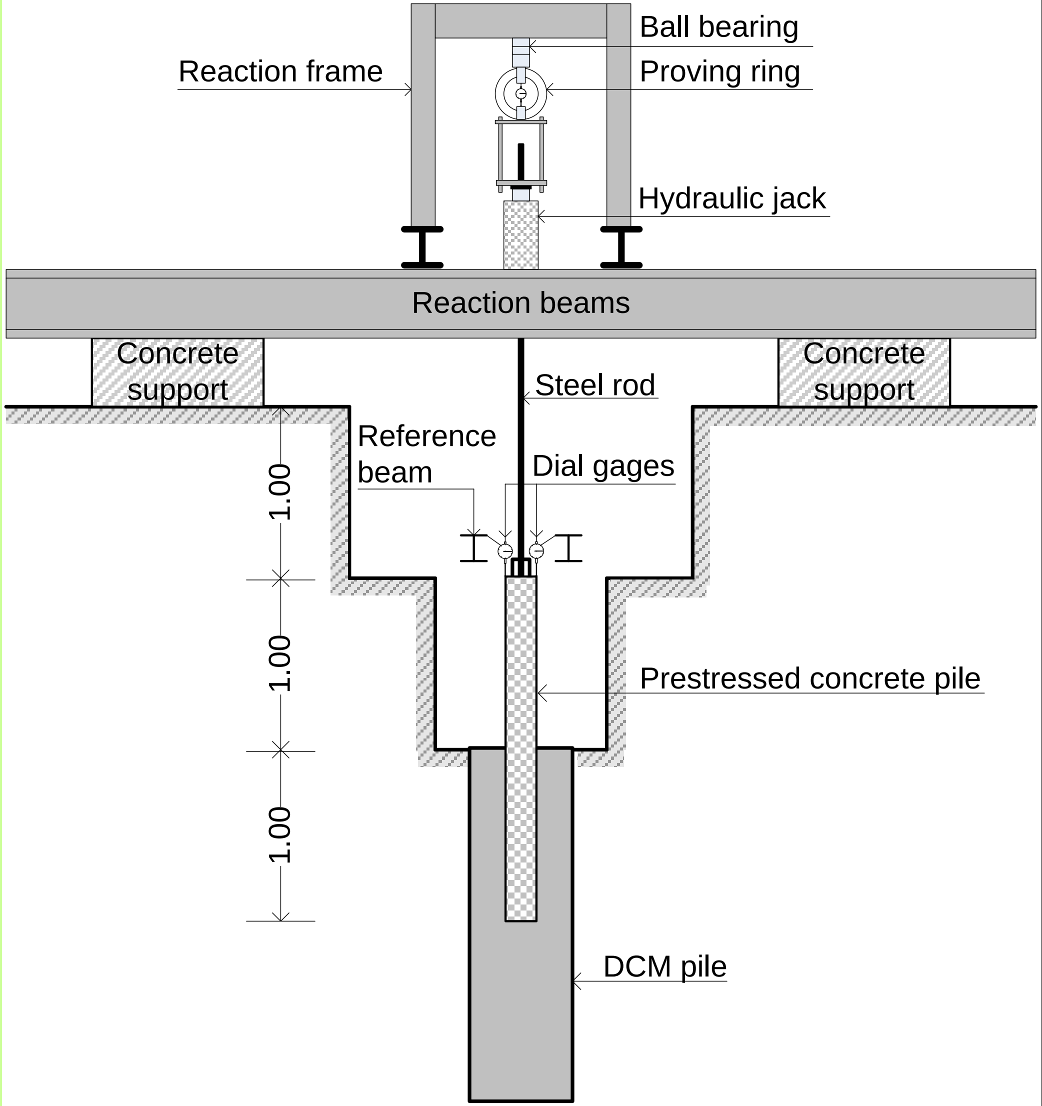
Different length: 1.00, 2.00, 3.00, 4.00, 5.00, 6.00, 7.00 m.

Based on the tangent method by Butler and Hoy (1977).

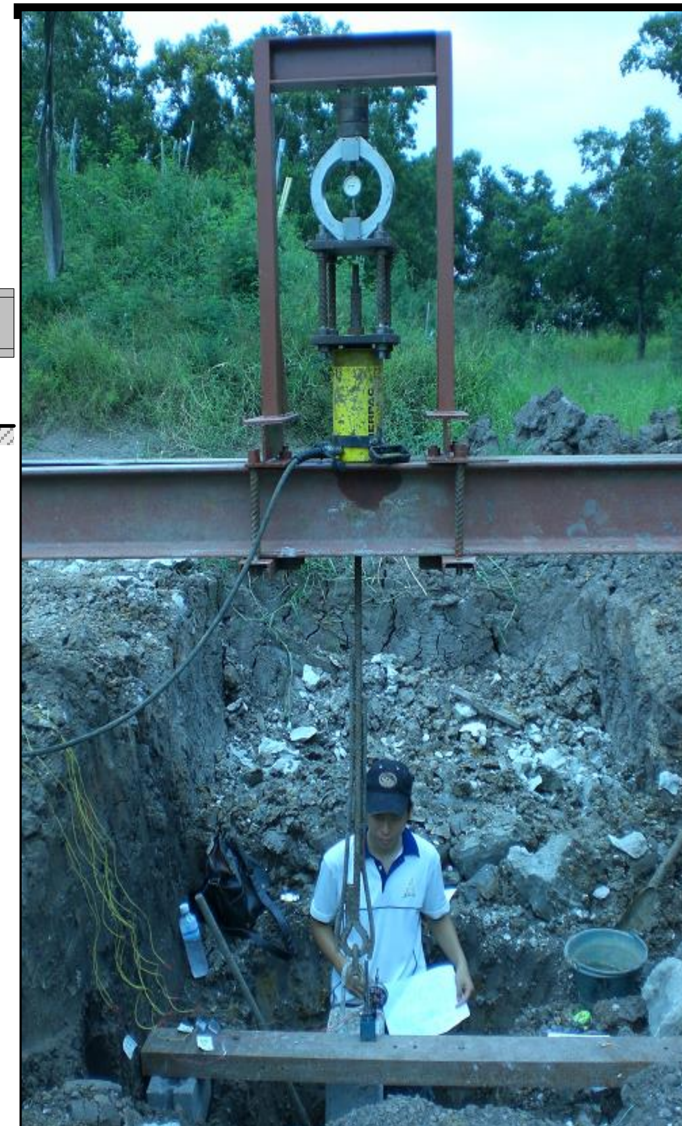
Axial compression piles



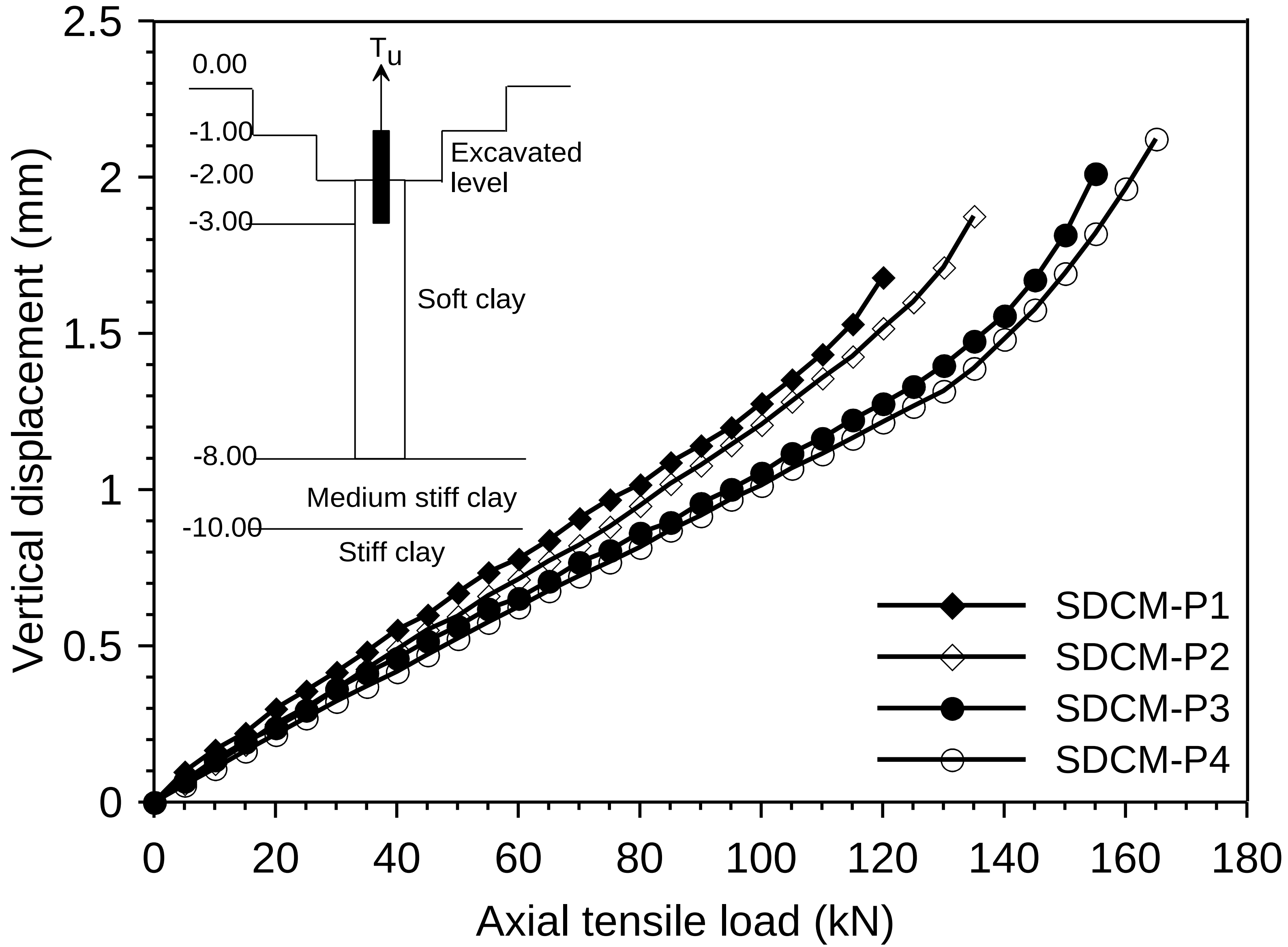
Full Scale Load Test



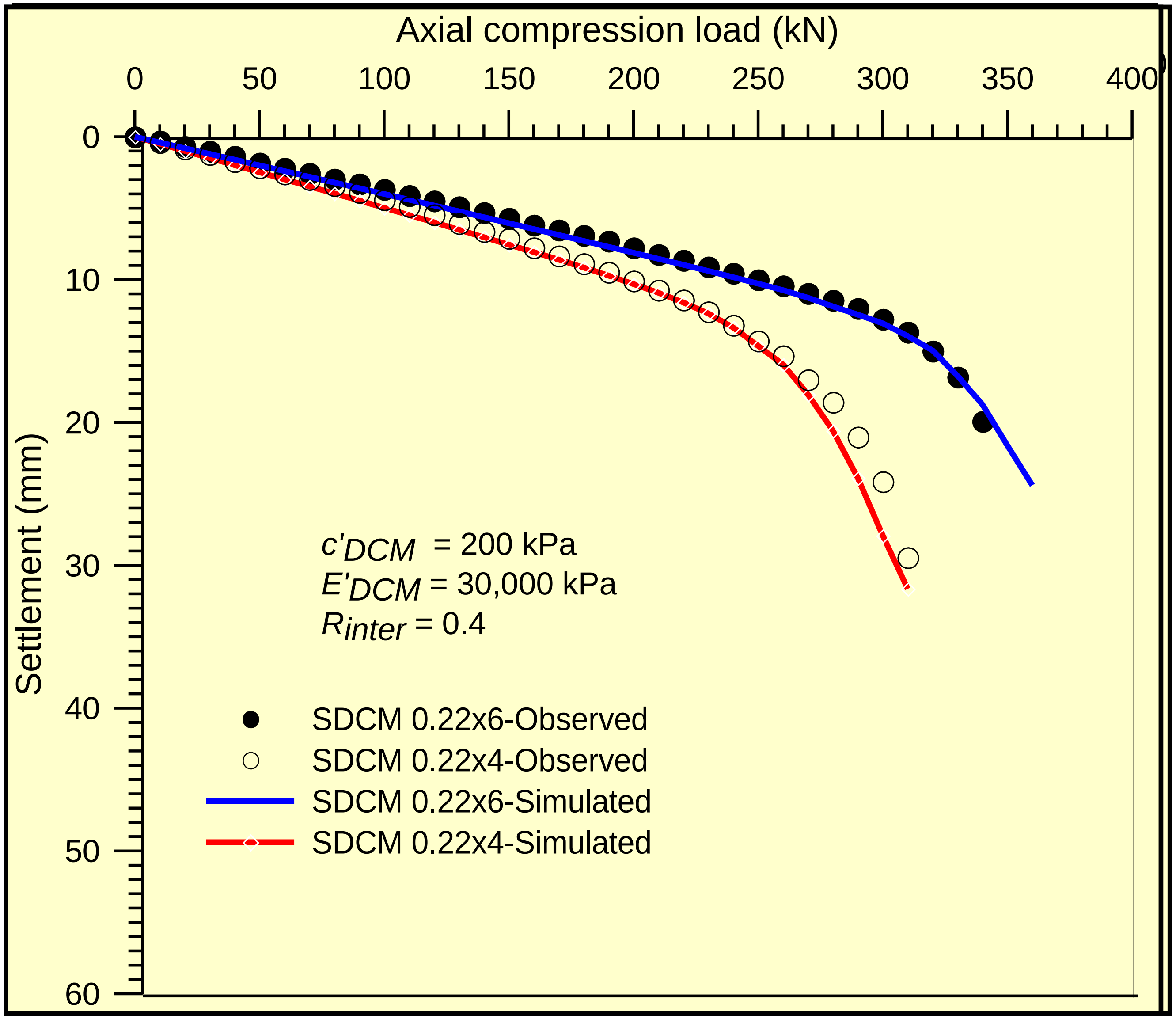
Pull out test



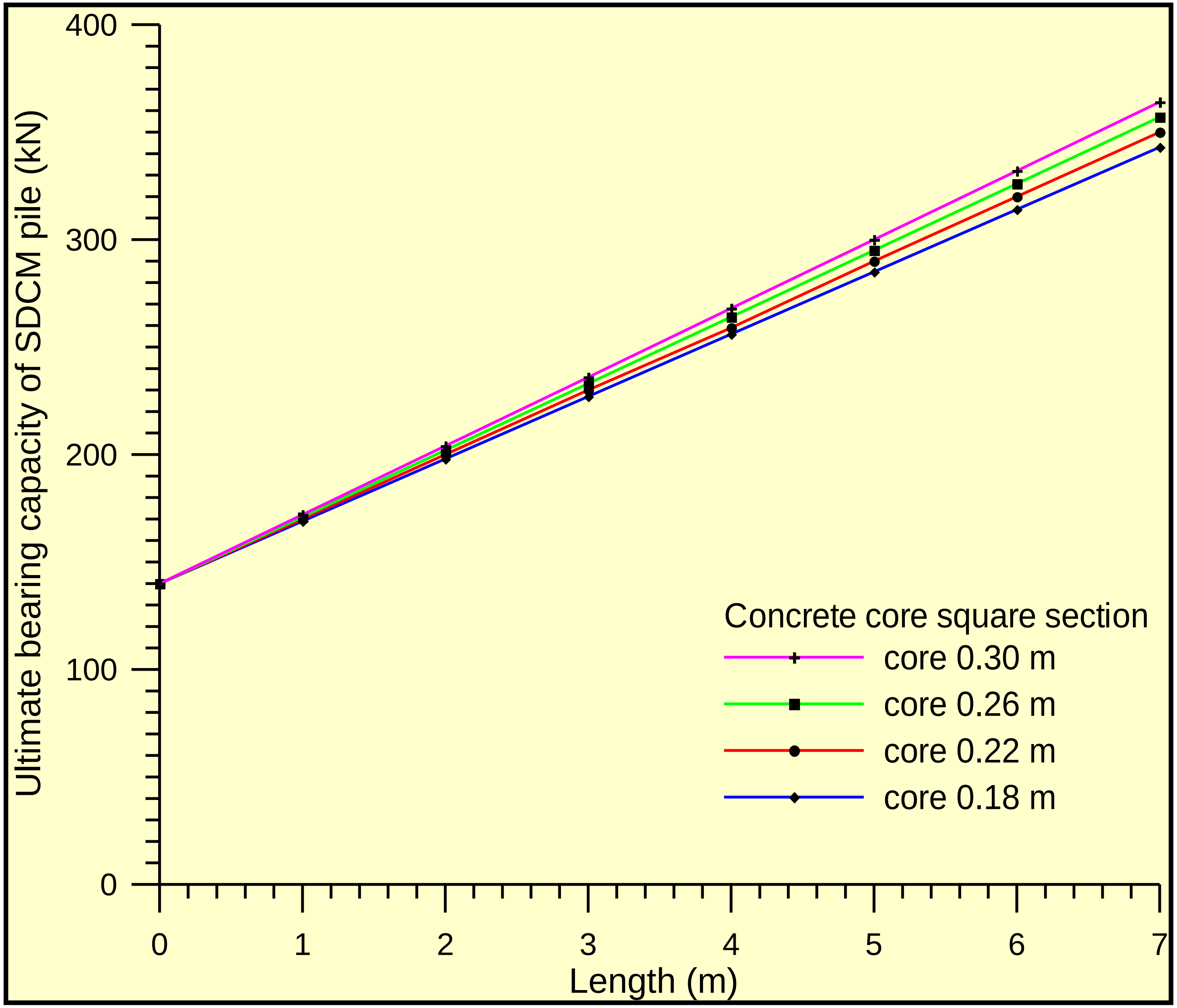
Full Scale Pile Load Test



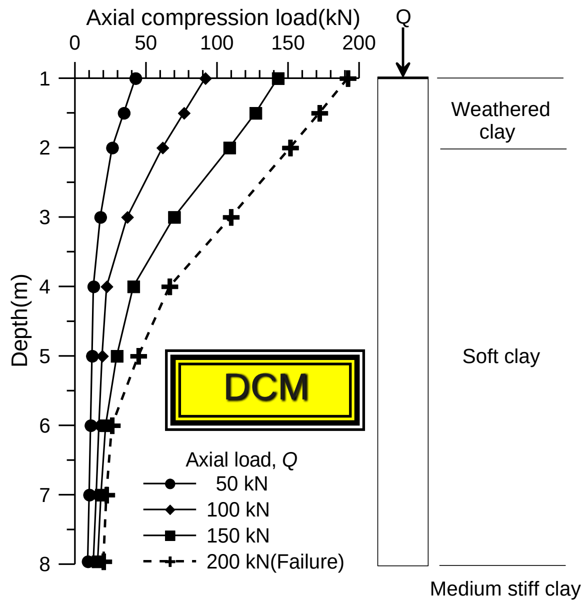
Back-Calculated of Axial Compression DCM/SDCM Pile

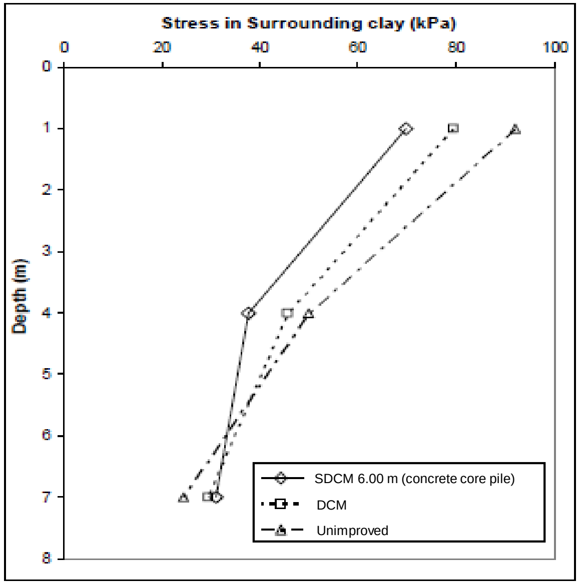


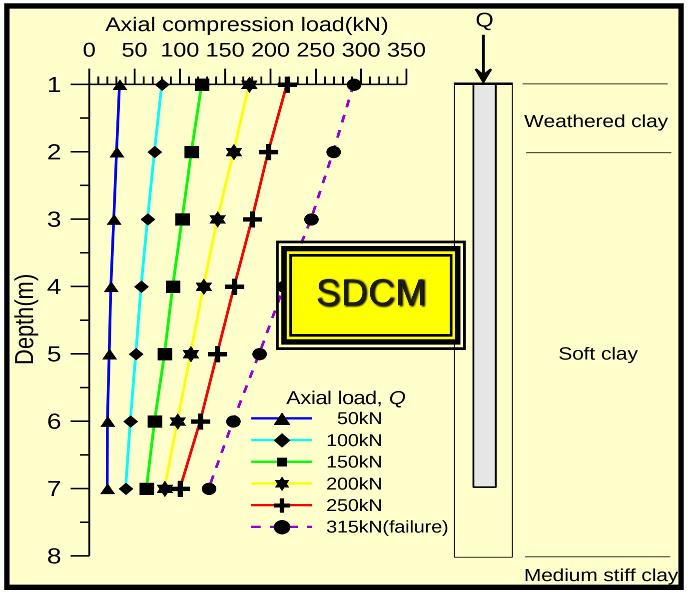
Effect of Length of Concrete Core Piles



Load Transfer DCM/SDCM Piles/Surrounding Ground







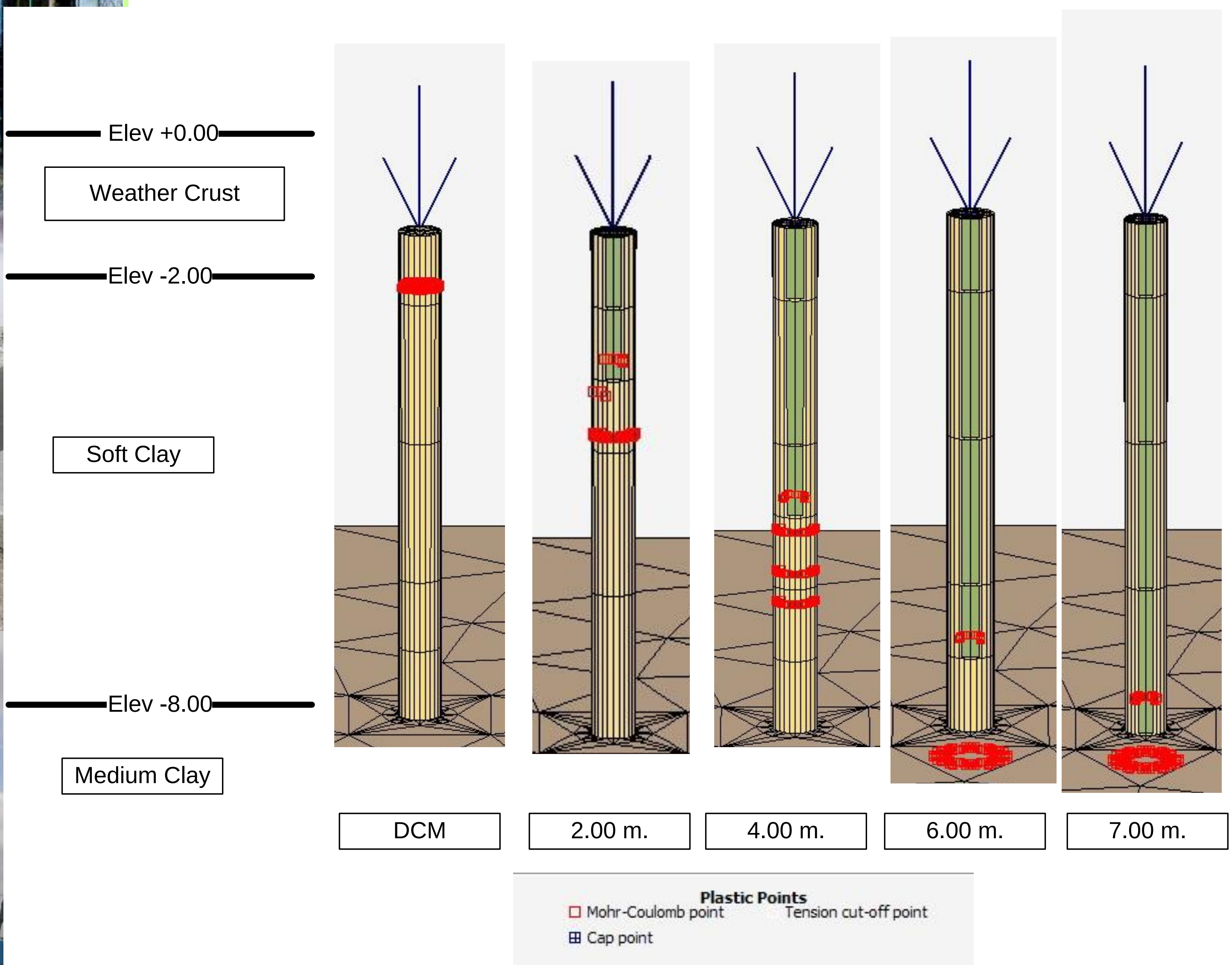
Failure Mode

1. The plastic points are the stress points in a plastic state. (Brinkgreve and Broere, 2006)

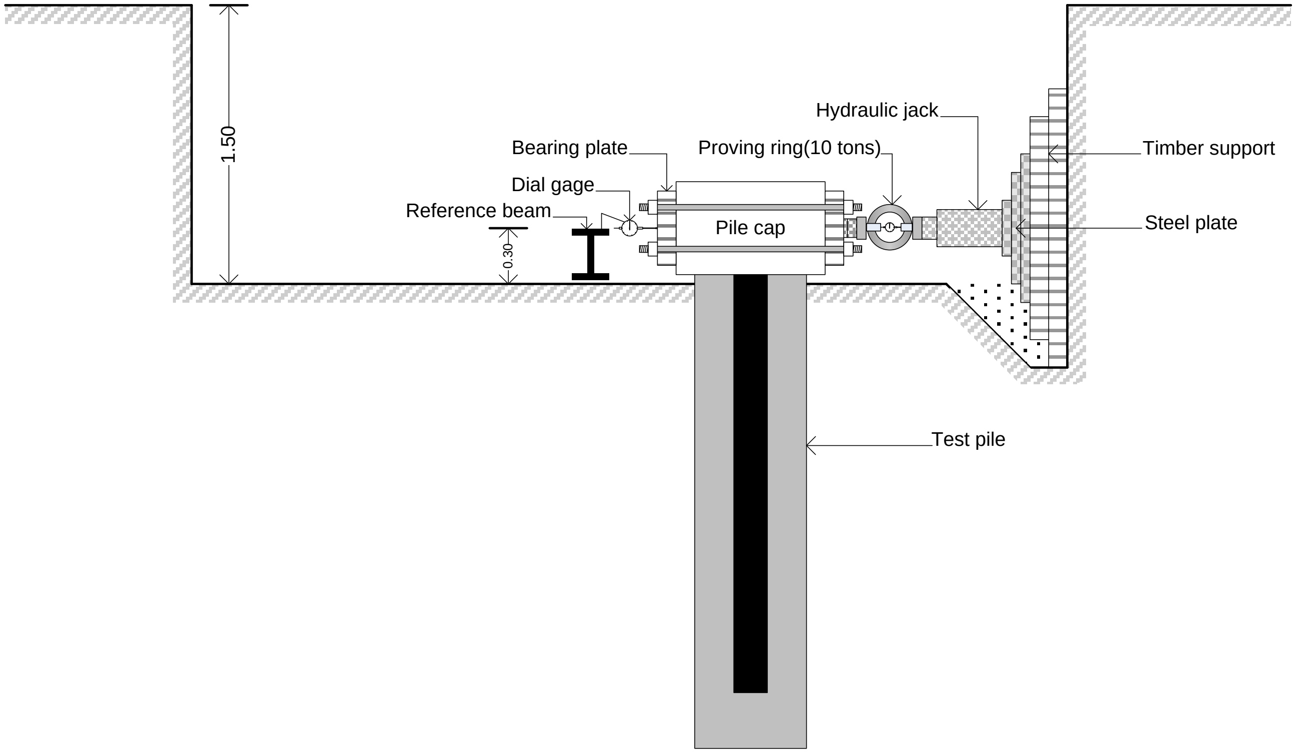
2. The relative shear stress gives an indication of the proximity of the stress point to the failure envelope. (Brinkgreve and Broere, 2006)

   The relative shear stress is defined as: $$\tau_{rel} = \frac{\tau^*}{\tau_{\max}}$$

Failure Mode (Plastic Points)



Lateral Piles

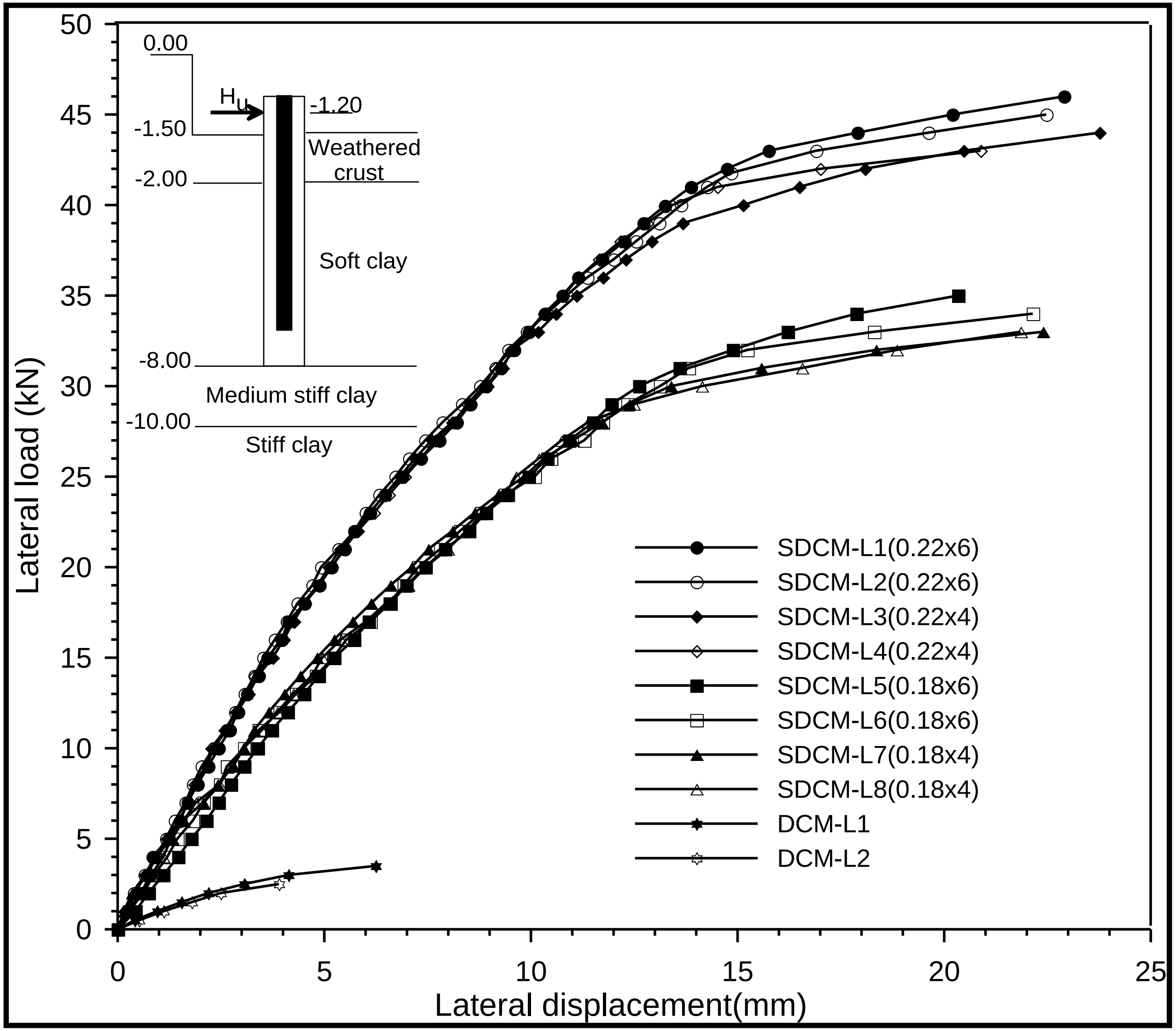


28 Cases

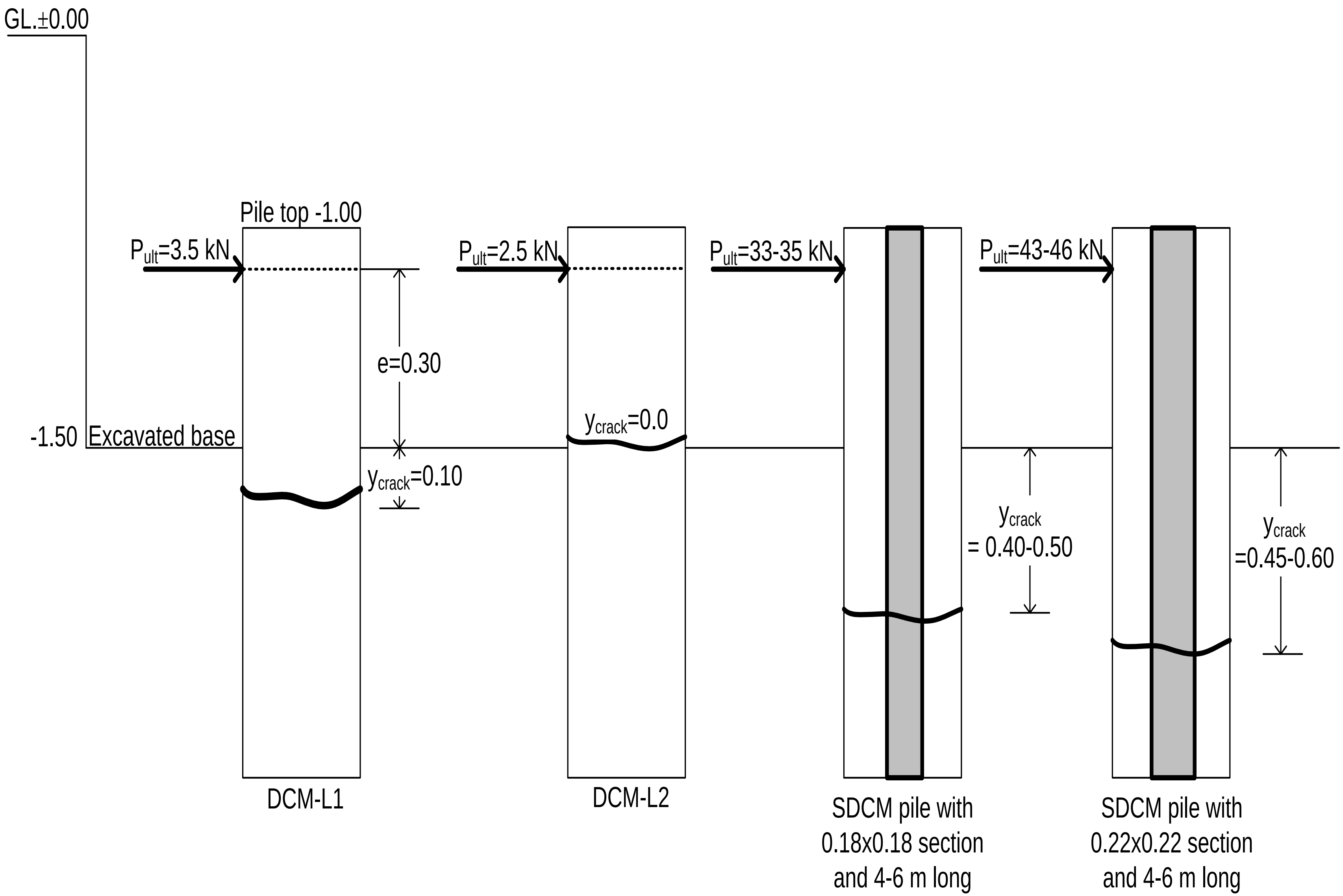
Different core size:
0.18, 0.22, 0.26, 0.30 m.

Different length:
1.00, 2.00, 3.00, 4.00, 5.00, 6.00, 7.00 m.

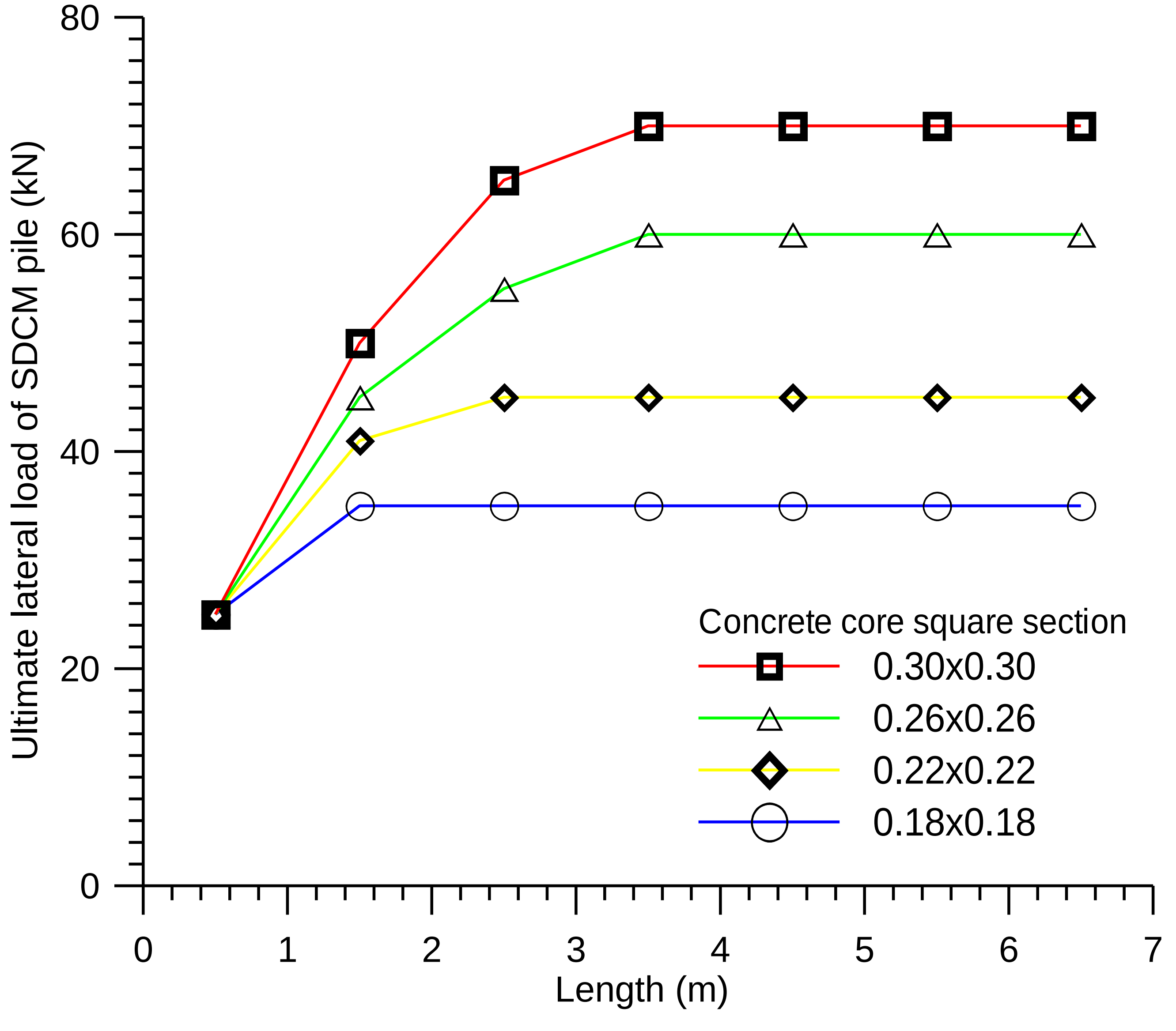
Lateral Piles



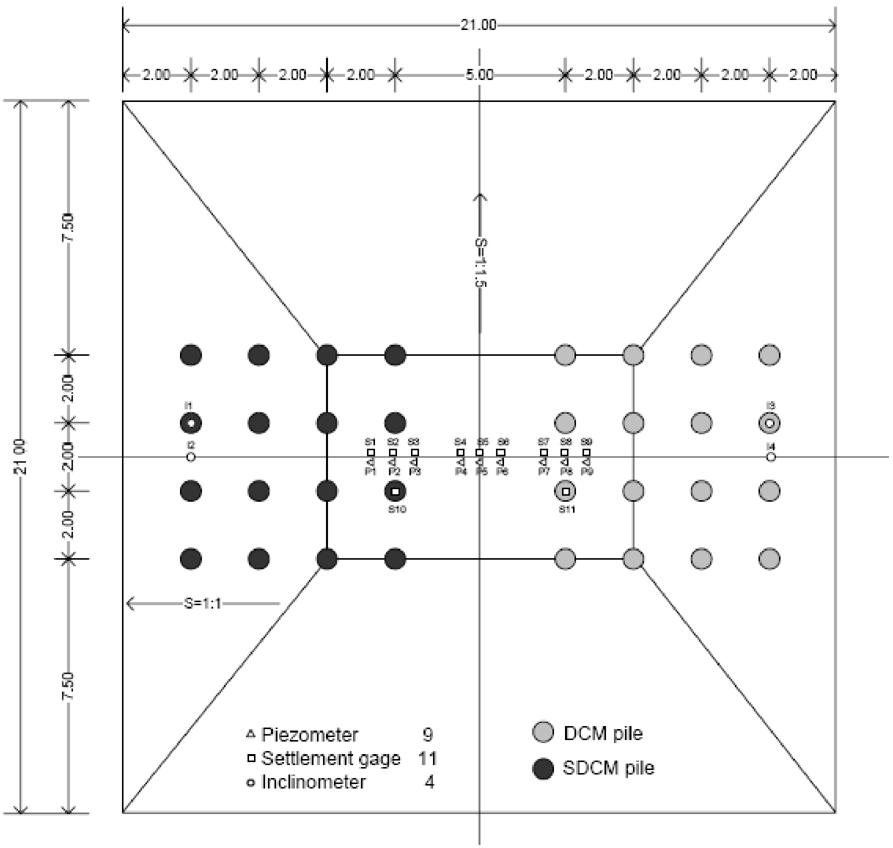
Lateral Load Test Results

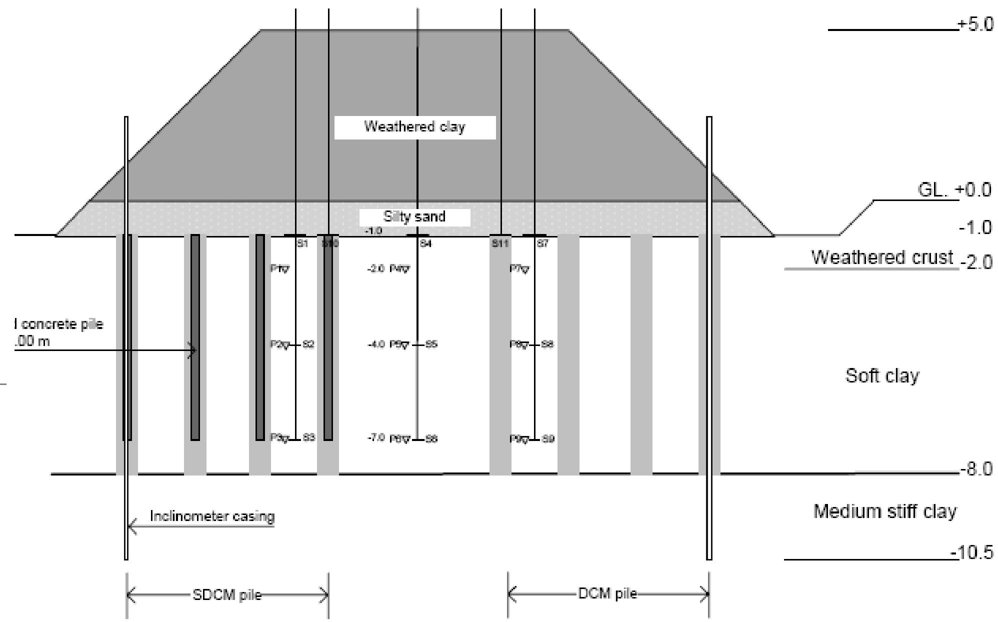


Lateral Pile Simulations (SDCM)



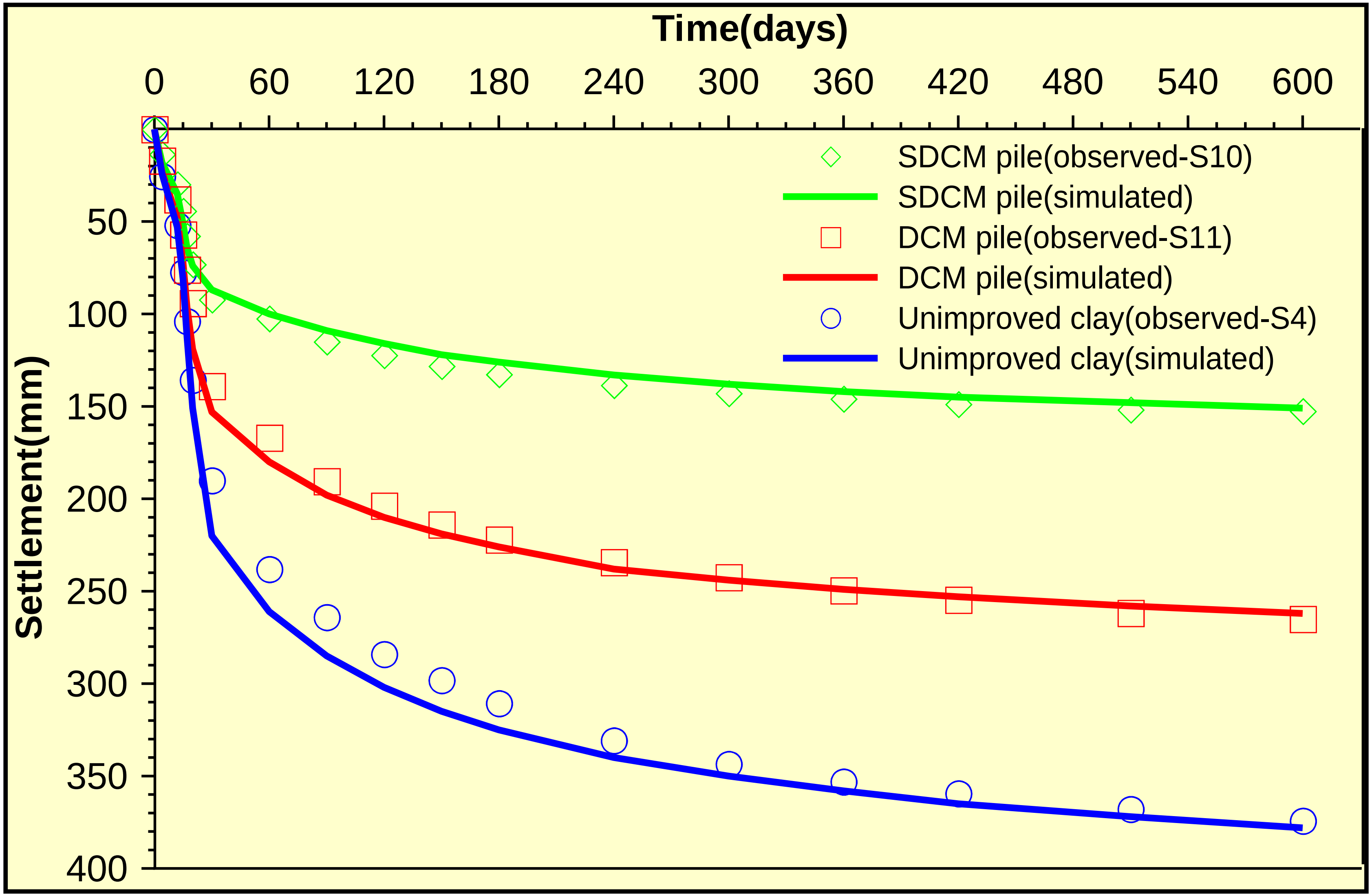
Embankment



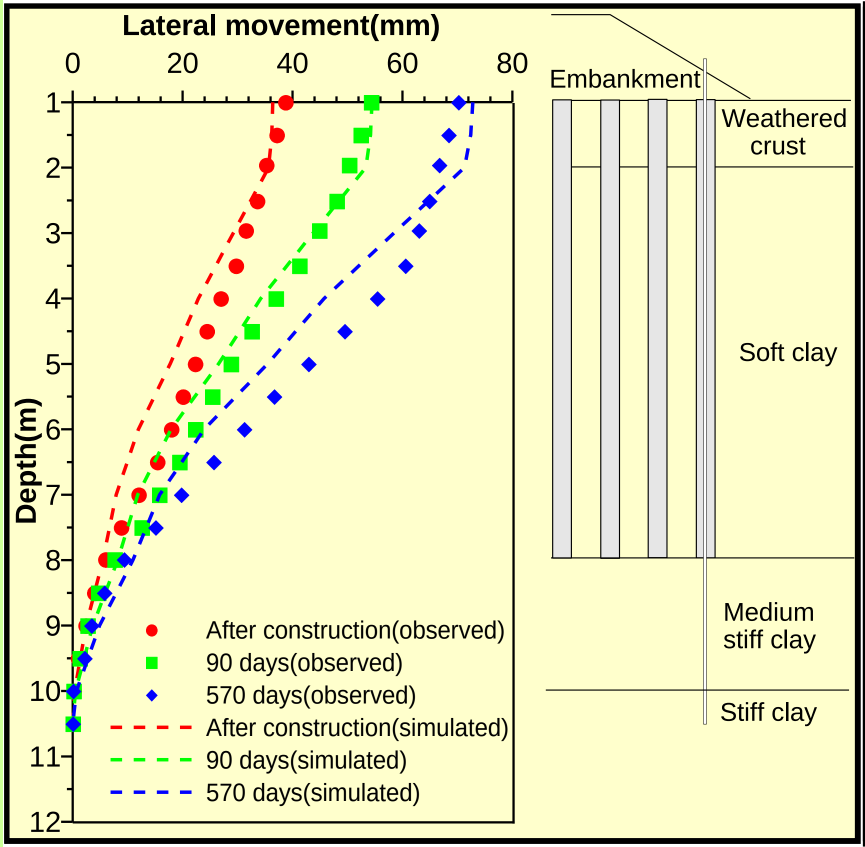


16 SDCM piles and 16 DCM piles

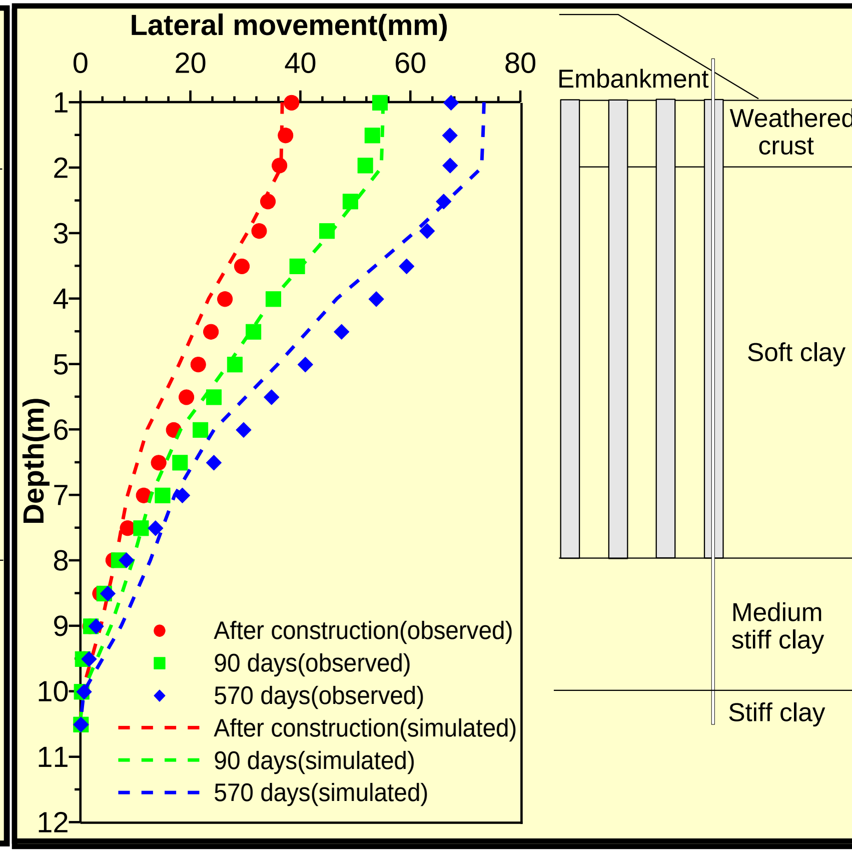
Embankment


Time(days)
0
60
120
180
240
300
360
420
480
540
600
Settlement(mm)
50
100
150
200
250
300
350
400
SDCM pile(observed-S10)
SDCM pile(simulated)
DCM pile(observed-S11)
DCM pile(simulated)
Unimproved clay(observed-S4)
Unimproved clay(simulated)

Lateral Movements DCM/Surrounding Ground

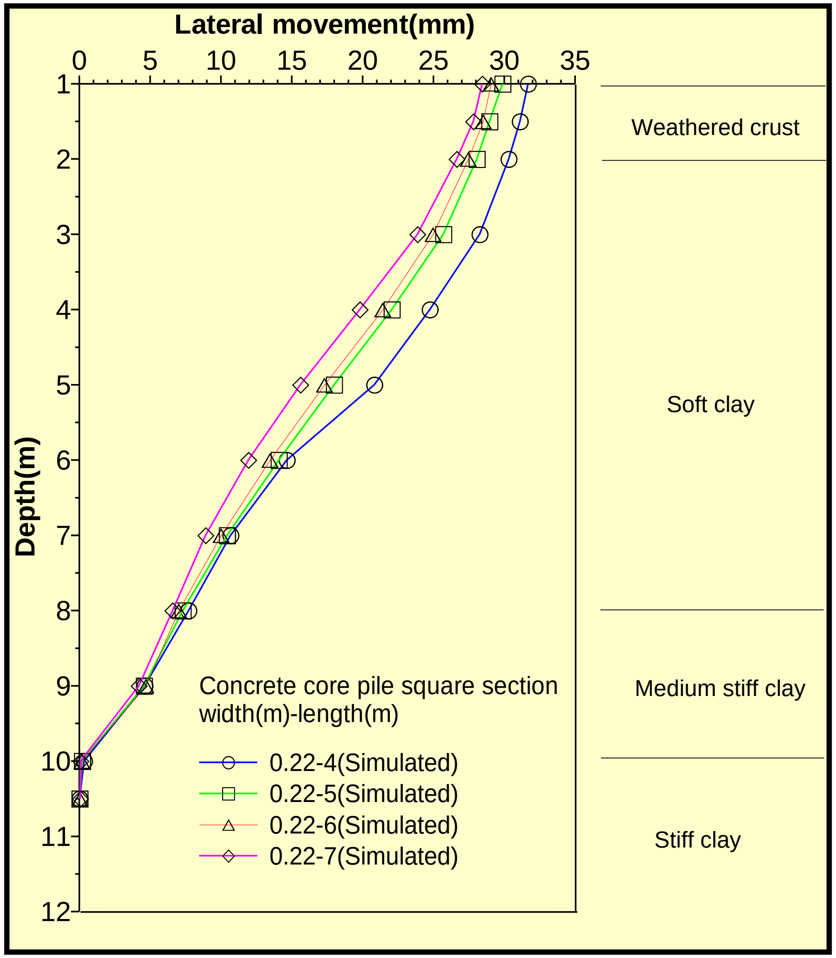


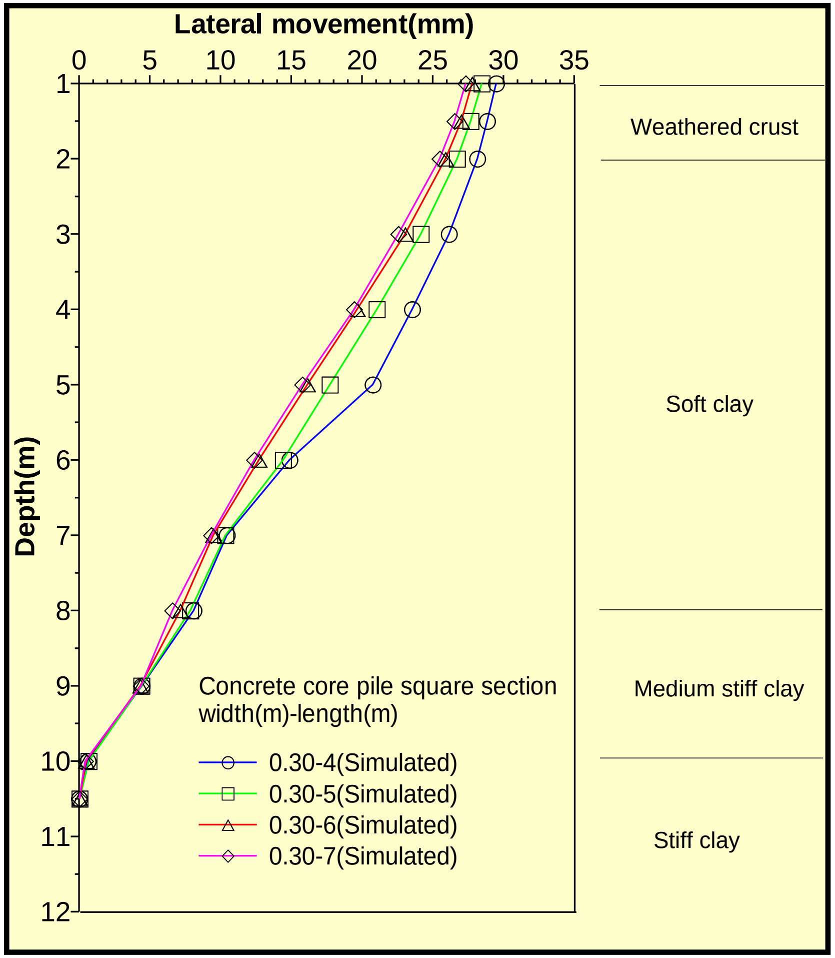
DCM Pile



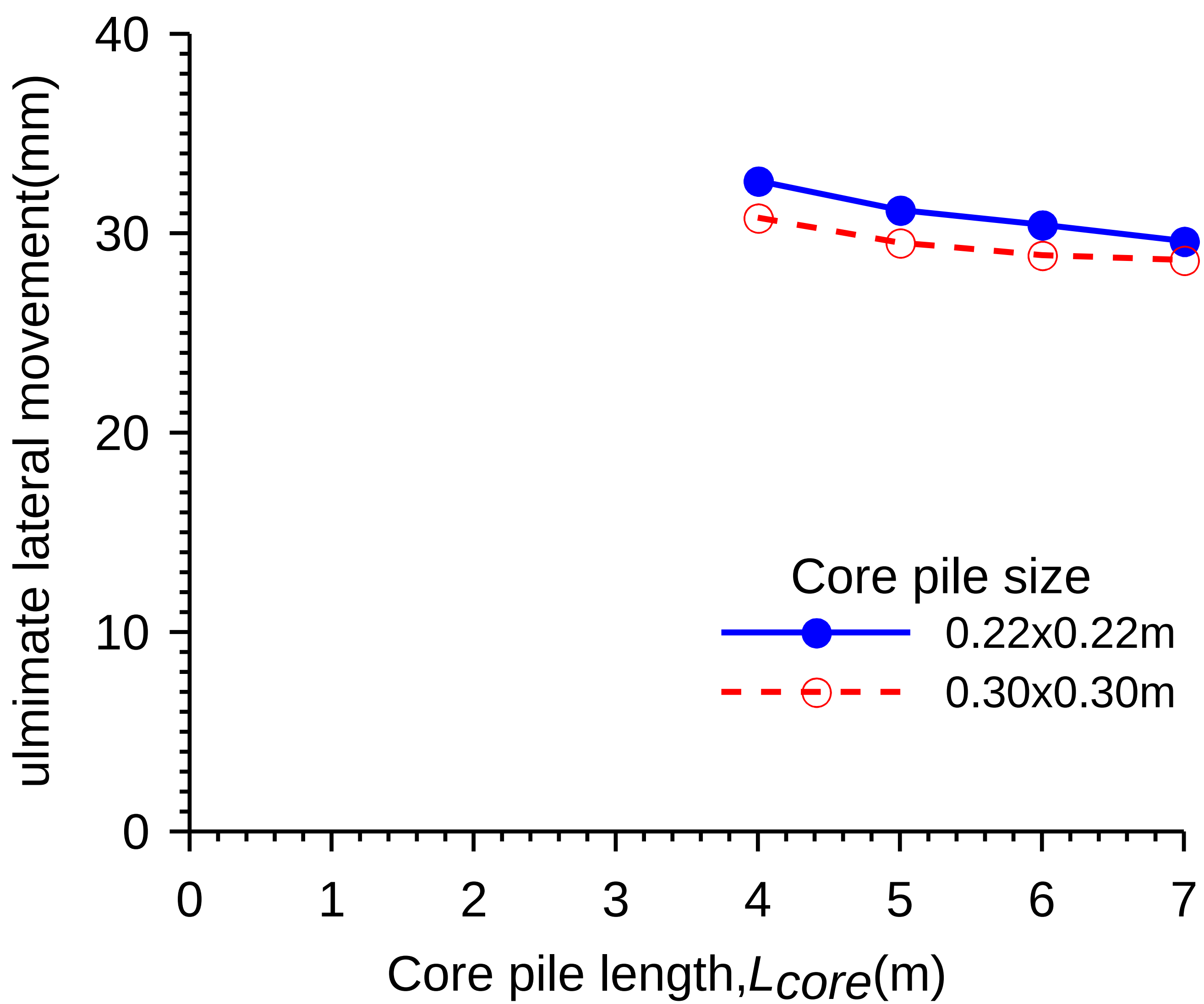
Surrounding DCM

Lateral Movements of SDCM Piles





Lateral Movements vs Concrete Core Pile Sizes





CONCLUSIONS

結論 （1）

圧縮材としてのセメント･粘土混合物の特性

- •DCM-C1 :粘着力300kPa、ヤング率60,000kPa
- •DCM-C2：粘着力200kPa、ヤング率40,000kPa
- •SDCM:　粘着力200kPa　ヤング率30,000kPa

1) Axial Compression of DCM and SDCM Piles

- **The cement-clay cohesion C_{DCM} were 300 kPa and 200 kPa for DCM C-1 and DCM C-2, respectively.**
- **The cement-clay modulus, E_{DCM}, were 60,000 kPa and 40,000 kPa for DCM C-1 and DCM C-2, respectively.**
- **The slightly different results reflect the construction quality control in the field tests.**
- **For the SDCM pile, the corresponding value for C_{DCM} and E_{DCM} were 200 kPa and 30,000 kPa, respectively.**

CONCLUSIONS 結論（2） セメント混合物の圧縮特性

強度効果:L_{core}/L_{DCM}がA_{core}/A_{DCM} より大
DCM:最大荷重はトップ1mで生じ、4mまでに減少、最大強度の10%で先端まで達する。破壊はトップで発生
SDCM:トップでは最大強度の90%で先端まで
コンクリートコア長さ2m:先端強度は最大強度の30%まd漸減
長さ7m:同じく70%まで漸減

2) Axial Compression of DCM and SDCM Piles

- **Increasing the length ratio, L_{core}/L_{DCM}, has dominant effect than increasing the sectional area ratio, A_{core}/A_{DCM}.**
- **For the DCM pile, the maximum load developed at the top 1m and rapidly decreased until the depth of 4m from the pile top and constant load of 10% of the ultimate load until the tip of DCM pile. Thus, the failure takes place at the top in the case of DCM pile.**
- **The axial load at the top of SDCM comprised 90% of ultimate load and linearly decreased to the tip to 70% and 30% of ultimate load corresponding to 2m and 7m of concrete core pile length, respectively.**



CONCLUSIONS　結論(3)　水平抵抗

DCMの水平抵抗 Tcore:計算値は50kPa

SDCMの水平抵抗 T_{SDCM} :計算値は5000kPa

SDCMの横抵抗最大値は断面積比に比例的3.5mより長い場合は効果は低減

SDCM3.5mより長い場合:破壊は曲げモーメント(長い杭の破壊)で発生

3.5mより短い杭の場合:周辺地盤の破壊に依存

3) Lateral Loading of SDCM Piles

- For the SDCM pile, the corresponding values for T_{core} and T_{DCM} obtained from the simulation were 5000 kPa and 50 kPa, respectively.
- The ultimate lateral load of SDCM pile increased with increasing sectional area because it increased the stiffness of the pile but the length of concrete core pile did not increase the ultimate lateral load capacity when using the lengths longer than 3.5m.
- For the SDCM pile with lengths longer than 3.5m, the failure occurred by bending moment (long pile failure) while the short pile failed by surrounding soil failure.

CONCLUSIONS

実規模盛土による載荷試験



コンクリートコアが長いとSDCMおよび周辺地盤の鉛直変位は低減
コンクリートコアが4～6mでは長さに応じて沈下は直線的に減少、6～7mでは効果減
コア長が長くなると水平変位は小さくなる
断面積比に応じて水平変位は減じる
盛土の水平変位を抑制するにはコンクリートコアは4m以上にとることが望ましい

4) Full Scale Embankment Loading of SDCM Piles

- **The longer core pile can reduced the vertical displacement of SDCM pile and the surrounding soil.**
- **The settlement reduced linearly with increasing lengths of concrete core piles from 4 to 6m but slightly reduced from 6 to 7m core pile length.**
- **The longer the lengths, the lower the lateral movements.**
- **The bigger sectional areas also reduced the lateral movements.**
- **The concrete core pile should be longer than 4 m in order to reduce the lateral movements of the embankment.**

THANK YOU!!!