Wick Drains and Piling for Cai Mep Container Port, Vietnam, and the true cost of 5 cent per foot

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Amsterdam

May 27, 2016

Fellenius, B.H. and Nguyen, M.H., 2013. Wick Drains and Piling for Cai Mep Container Port, Vietnam. ASCE GeoInstitute Geo-Congress Oakland, March 3-6, 2013. In Sound Geotechnical Research to Practice, State of the Art and Practice in Geotechnical Engineering, ASCE, Reston, VA. Armin W. Stuedlein and Barry R. Christopher, eds., Geotechnical Special Publication, pp. 445-462.

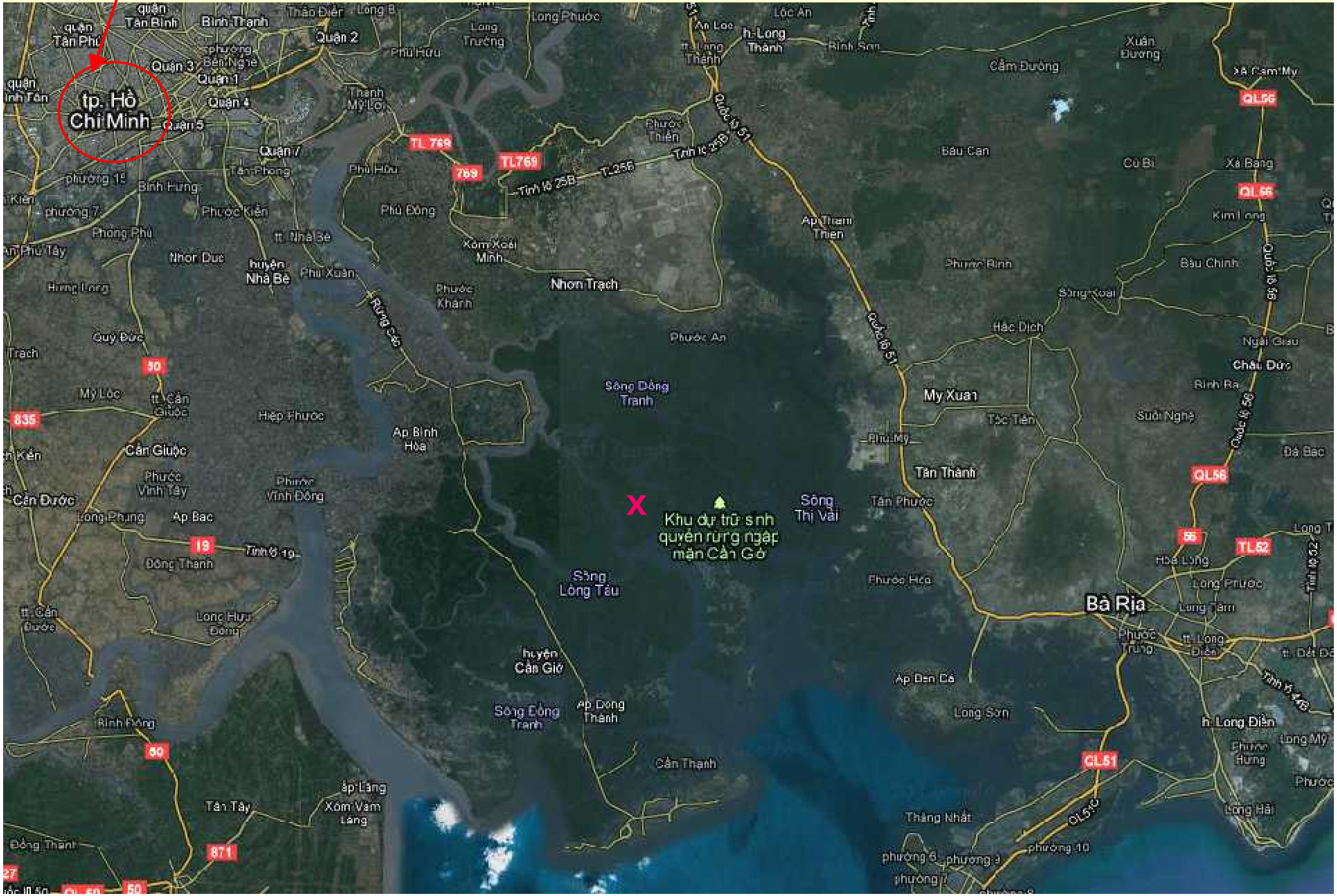
Paper #217 amongst those for download.

The Mekong


CHINA
MYANMAR
Dien Bien Phu
HANOI
Haiphong
TRUONG SON
Nam Dinh
LAOS
Gulf of Tonkin
Hainan (China)
Vinh
South China Sea
Quang Tri
Hue
Da Nang
THAILAND
VIETNAM
Pleiku
Qui Nhon
CAMBODIA
Nha Trang
Da Lat
Andaman Sea
Gulf of Thailand
Bien Hoa
Ho Chi Minh City
Phan Thiet
Chau Doc
Vung Tau
Can Tho
Ca Mau
Soc Trang
Mekong River

The General Area

Saigon/HoChiMinhCity




Thi Vai Port
Cai Mep Port
Image © 2011 GeoEye
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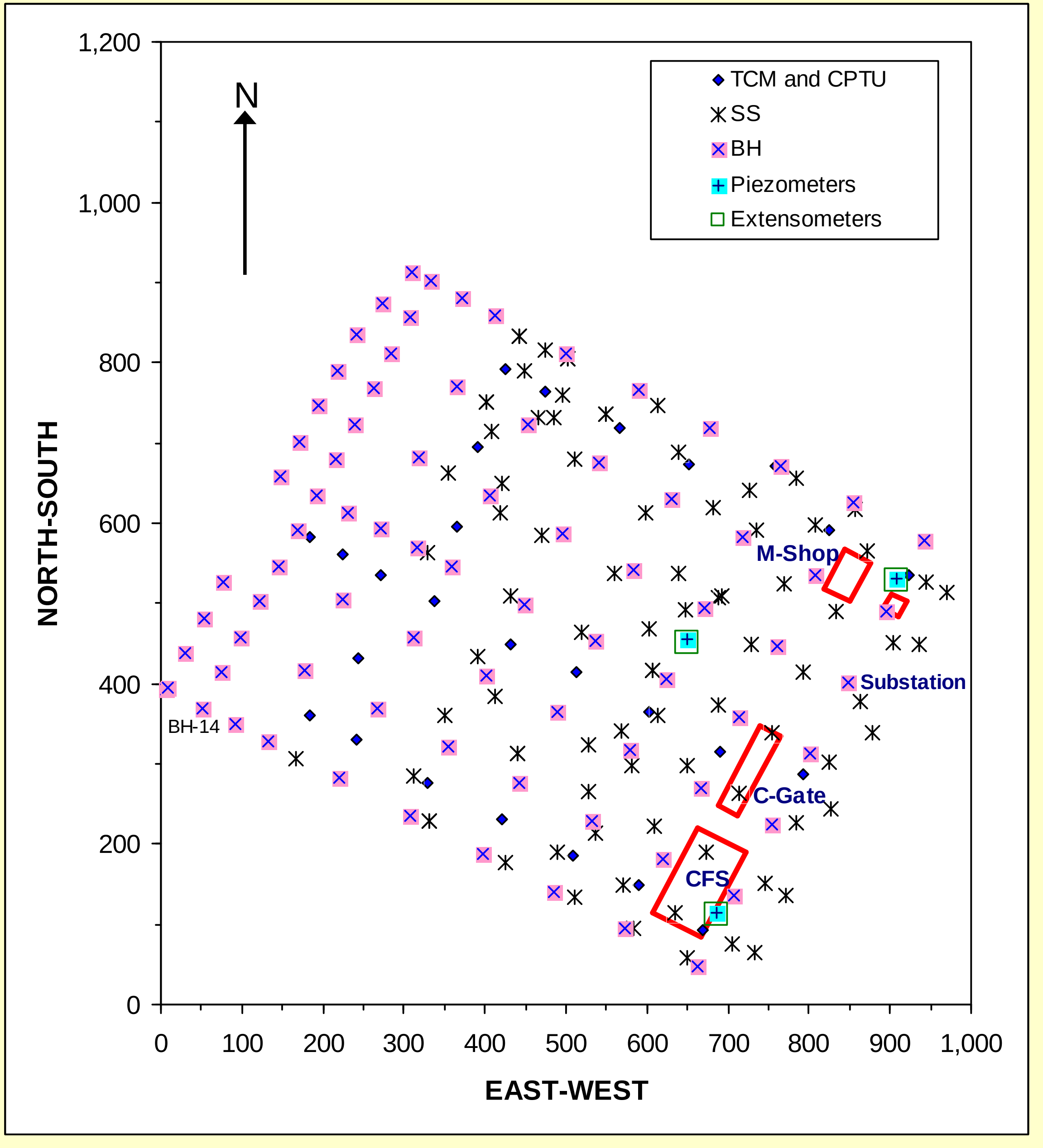
Artist View

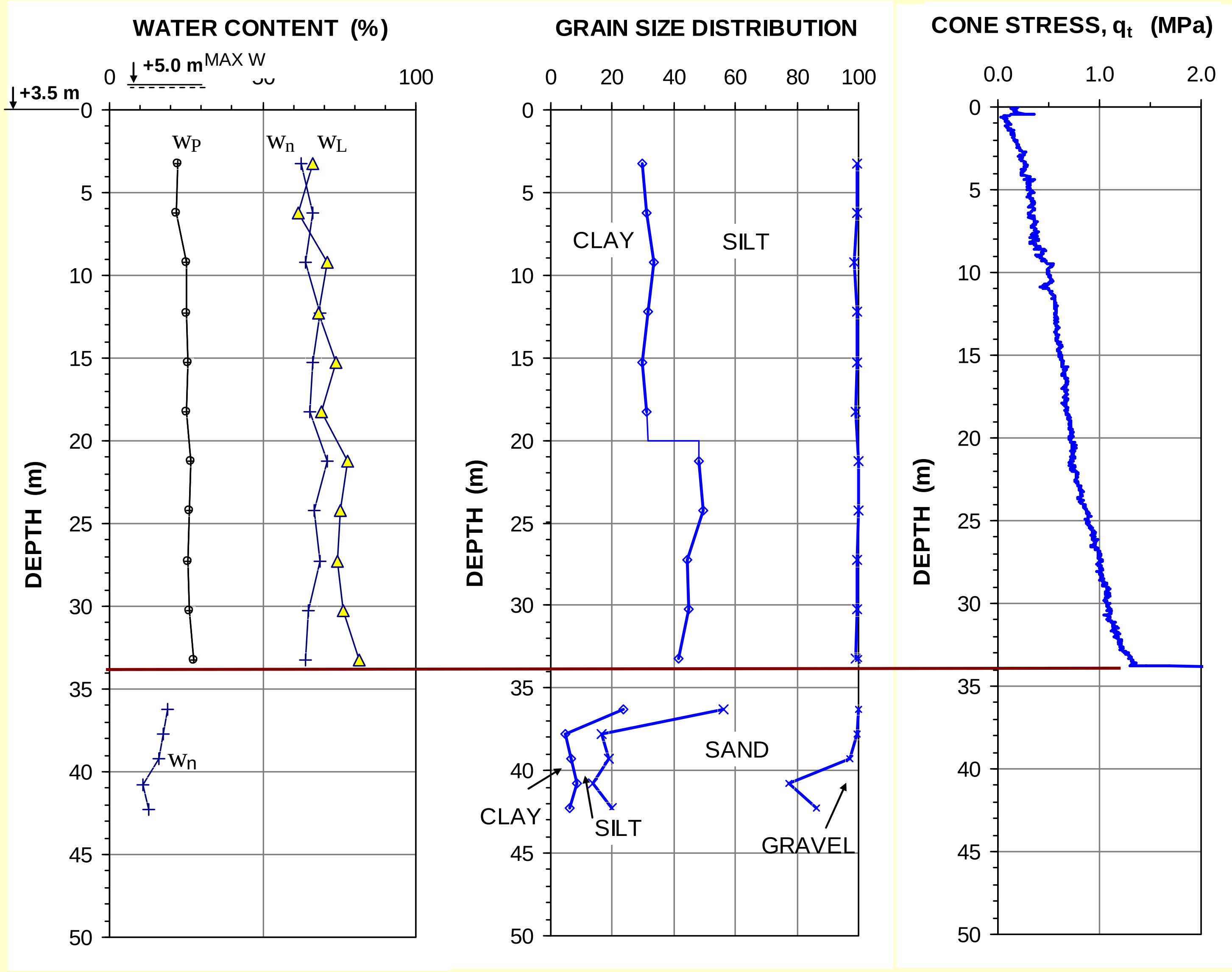

Cai Mep International Container Terminal
- ODA/Saigon Port – APM/SSA
Downstream
Tan Cang - Cai Mep Container Port
Saigon Port/PSA Container Port
Thi Vai – General Cargo Port
Upstream

The site of the new container facility extends over an 800 m by 600 m area along the Thi Vai River

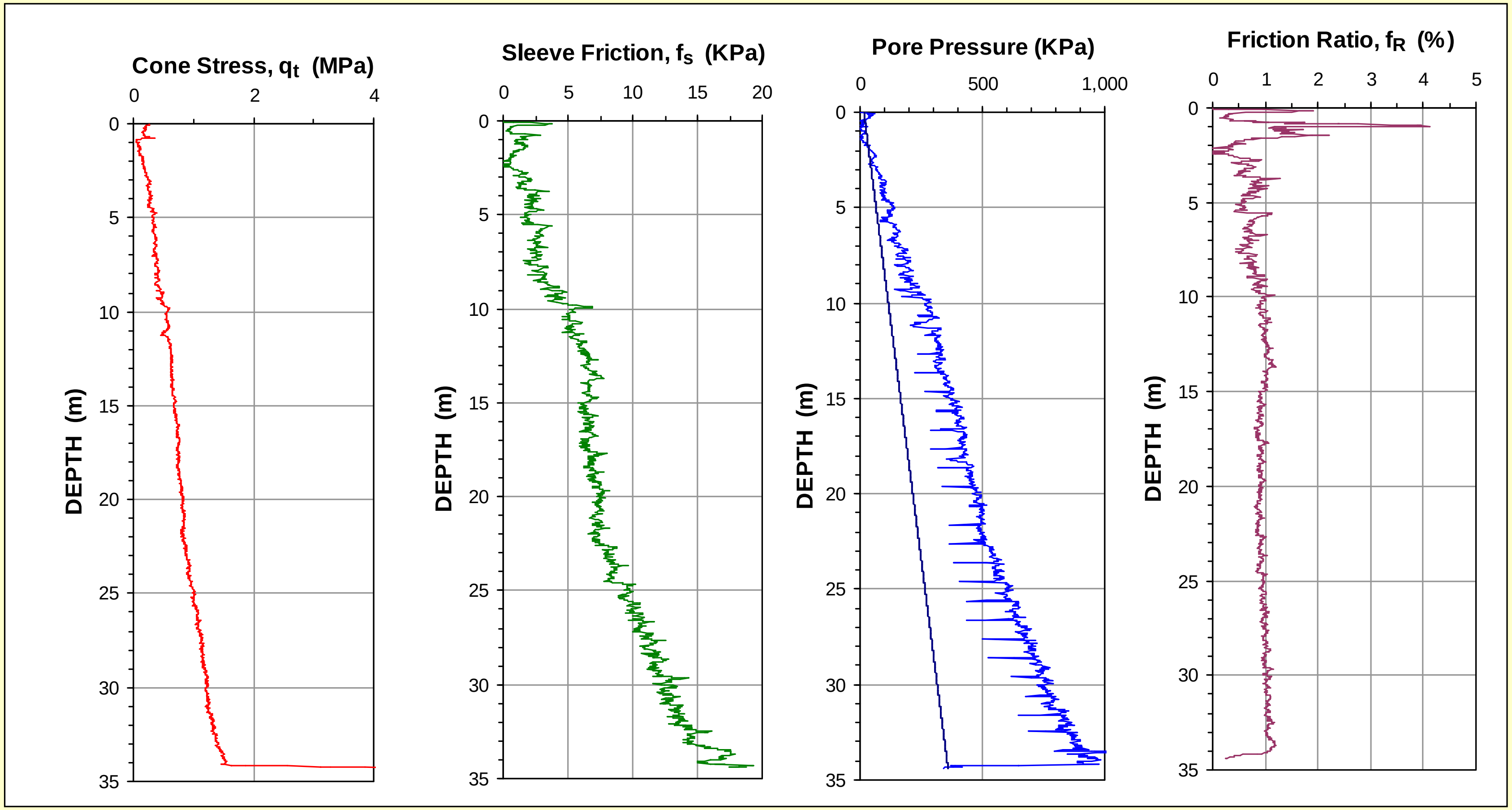
Locations of Buildings, Boreholes, and Settlement Points



Soil Profile

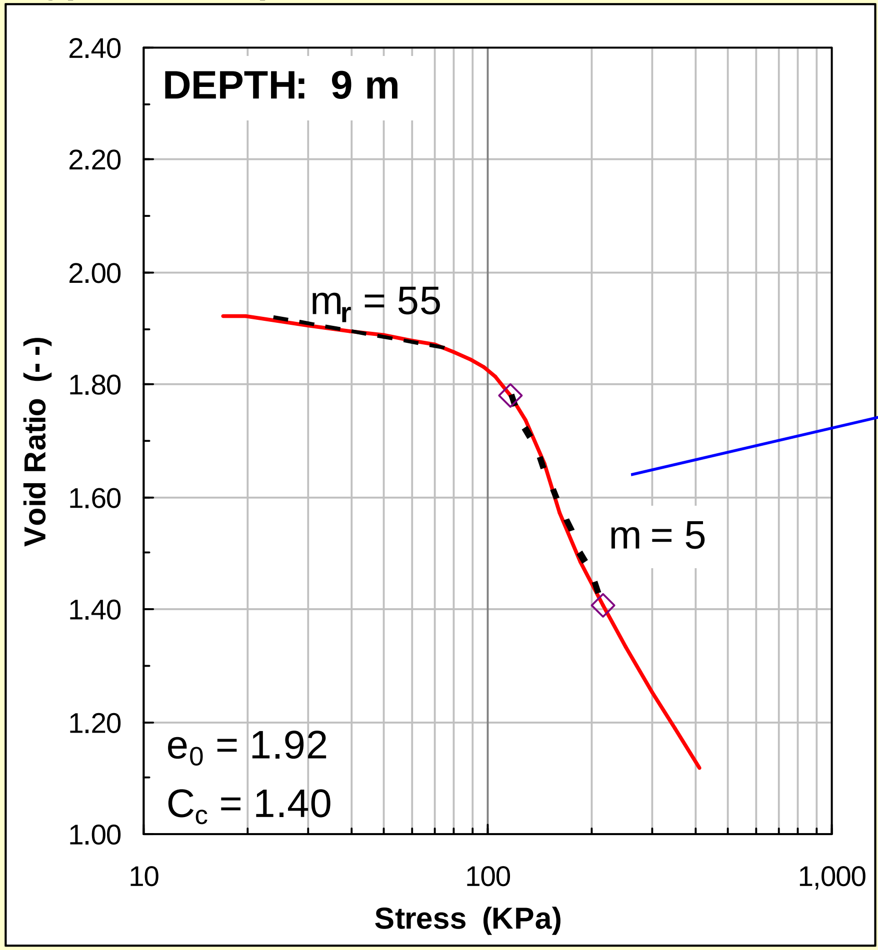


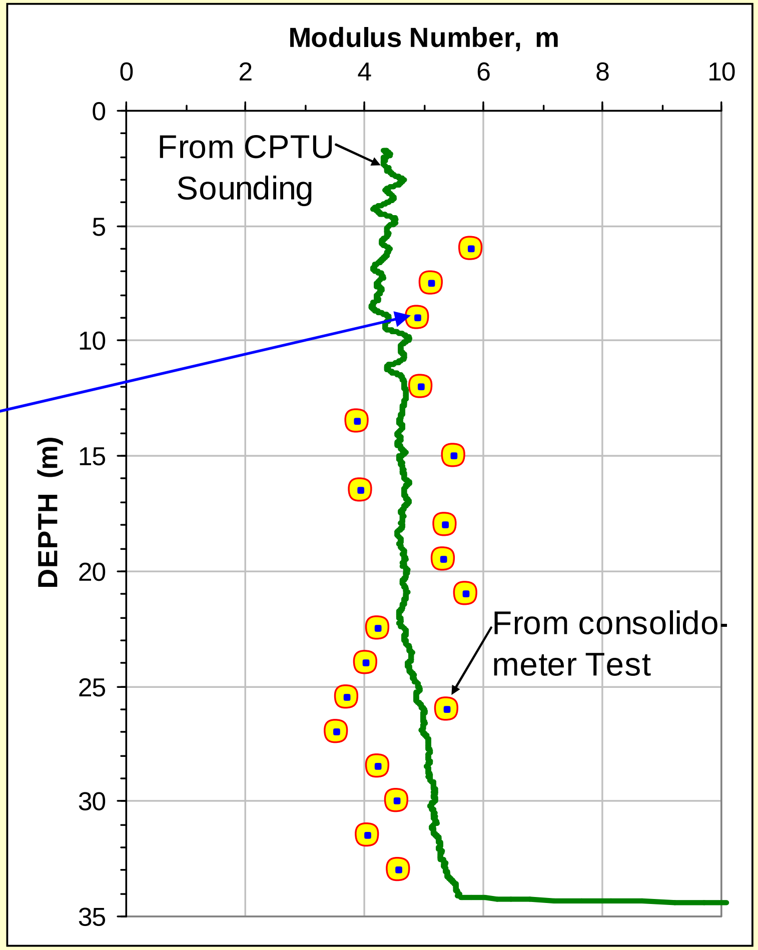
CPTU Sounding Results

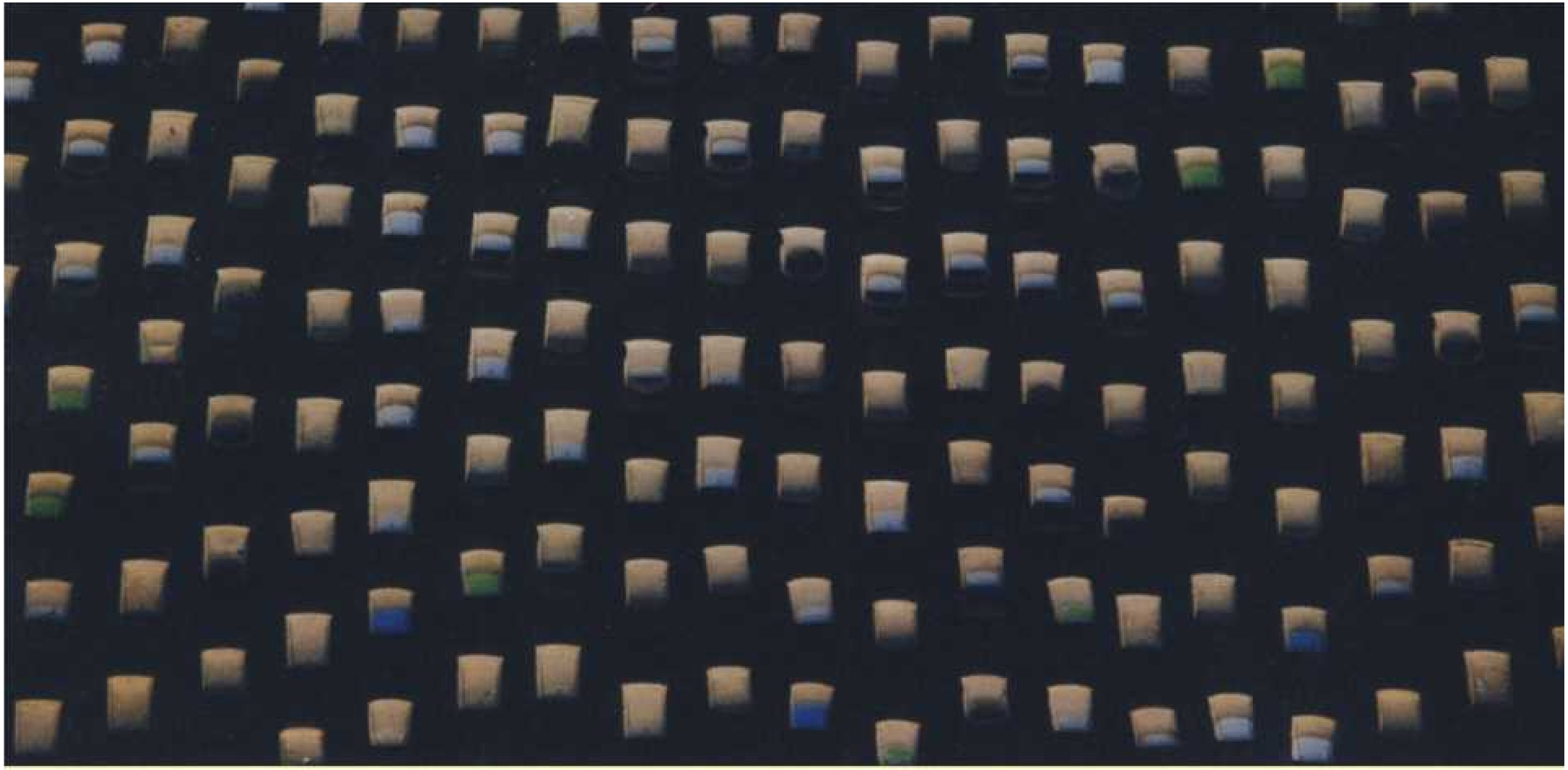


Results from a large series of consolidation tests show the soil to be very compressible, normally consolidated

Typical example of results







Risk for flooding in the area is real and the inundation can be severe, as illustrated by the flooding of the Fall of 2011. The above shows an areal photo of a Honda factory parking lot in Bangkok (October 2011).

The highest water level expected at the site is Elev. +4.0 m, which level is about 0.5 m above the ground surface. Therefore, the ground elevation will be raised by **about 2.0 m** to Elev. +5.5 m in order to avoid flooding and to create a suitable foundation surface.

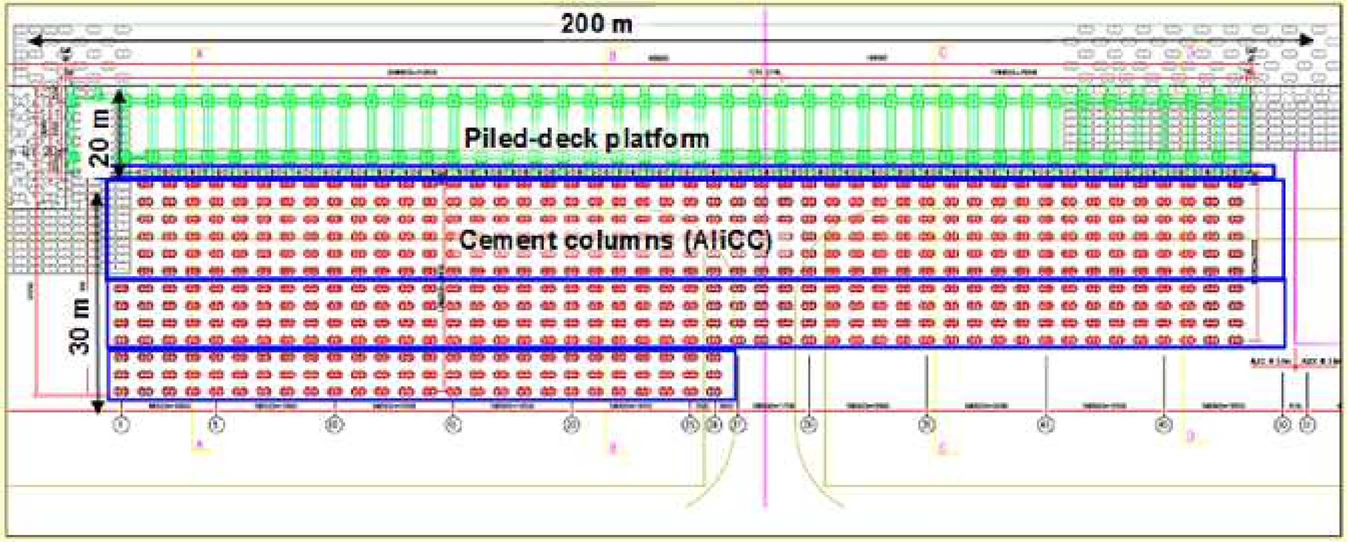
Because of the thick very compressible clay and silt layer, the thick fill needed for raising the land (≈2+ m final height) will cause significant settlement, which would continue for a very long time. To shorten that time, vertical drains (**wick drains**) were installed to 37 m depth across the site (in some places into the sand, in other places, a bit of the clay was left between the drain tip and the sand). Moreover, a temporary surcharge was added raising the surface to Elev. +8 m through Elev. +10 m, i.e., an **<u>additional</u>** 2.5 m to 4.5 m of fill height.

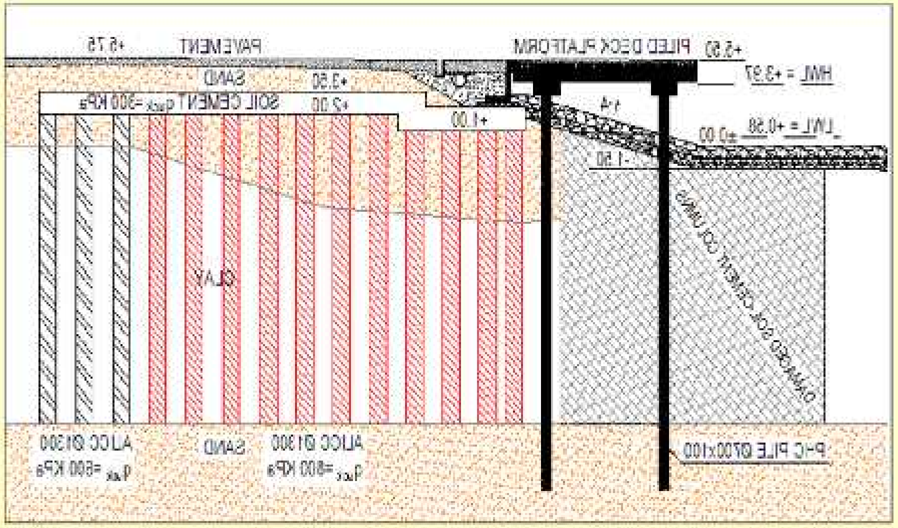
Raising the ground near the sloping shore line (and dredging outside the shore line) had consequences

Downstream view of the first cracks that appeared at Thi Vai site along the riverbank (April 5, 2010)

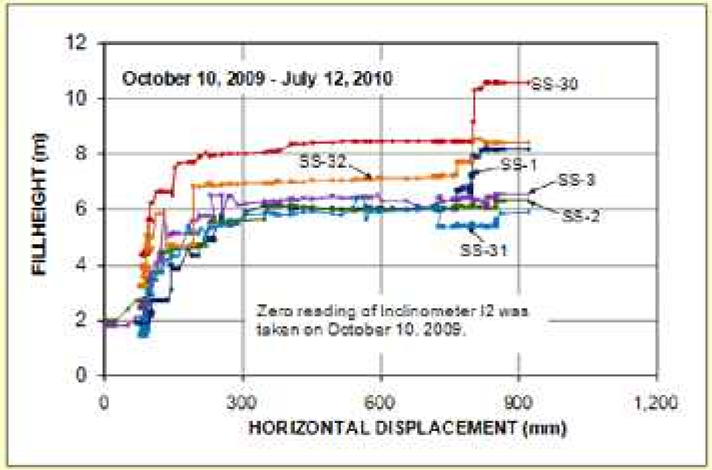
Slope failure on July 12, 2010, viewed upstream

Remedial Solution

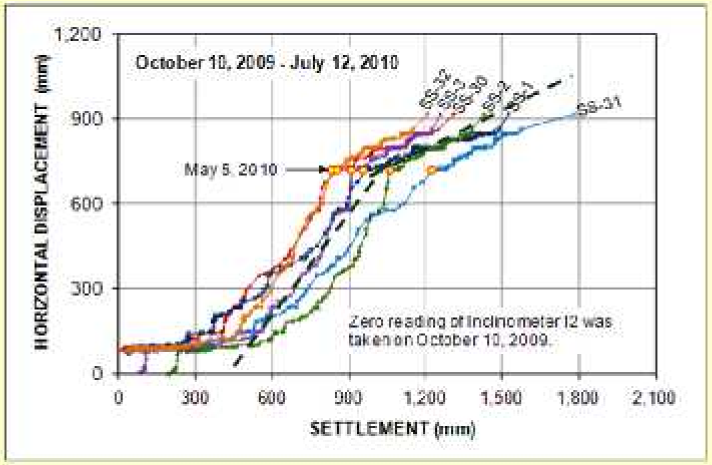




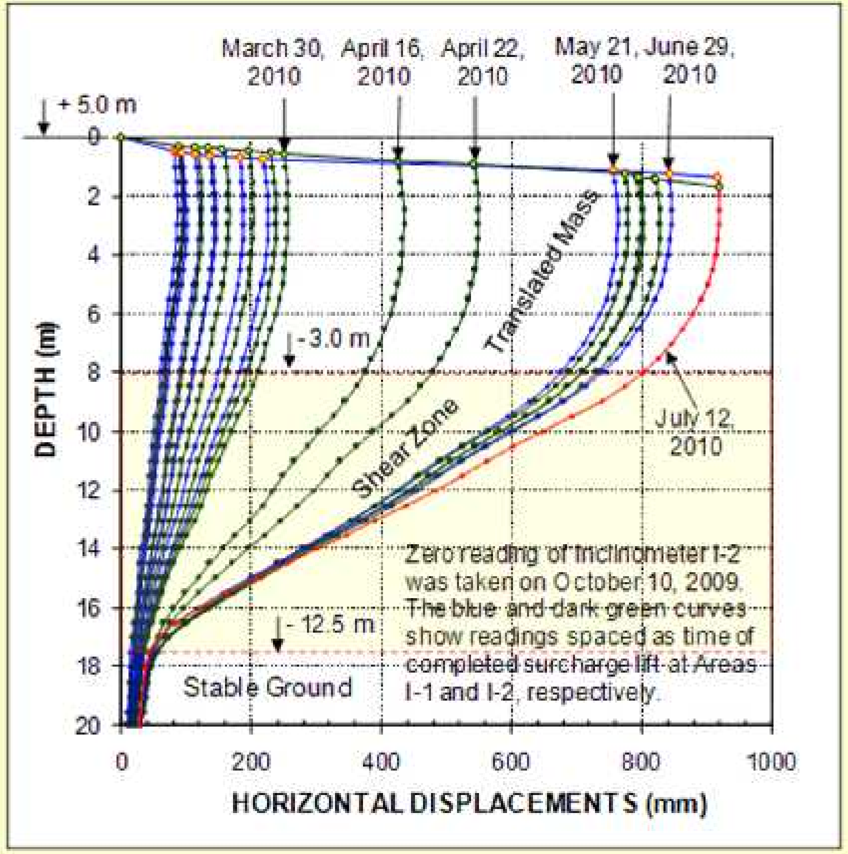
OBSERVATIONS



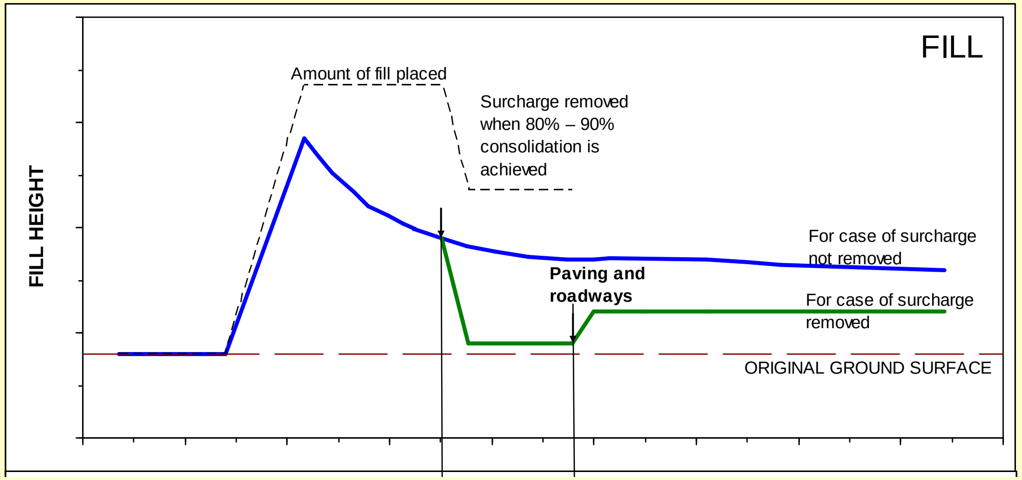
Fill Height vs. Horizontal Displacement



Horizontal Displacement vs. Surface Settlement

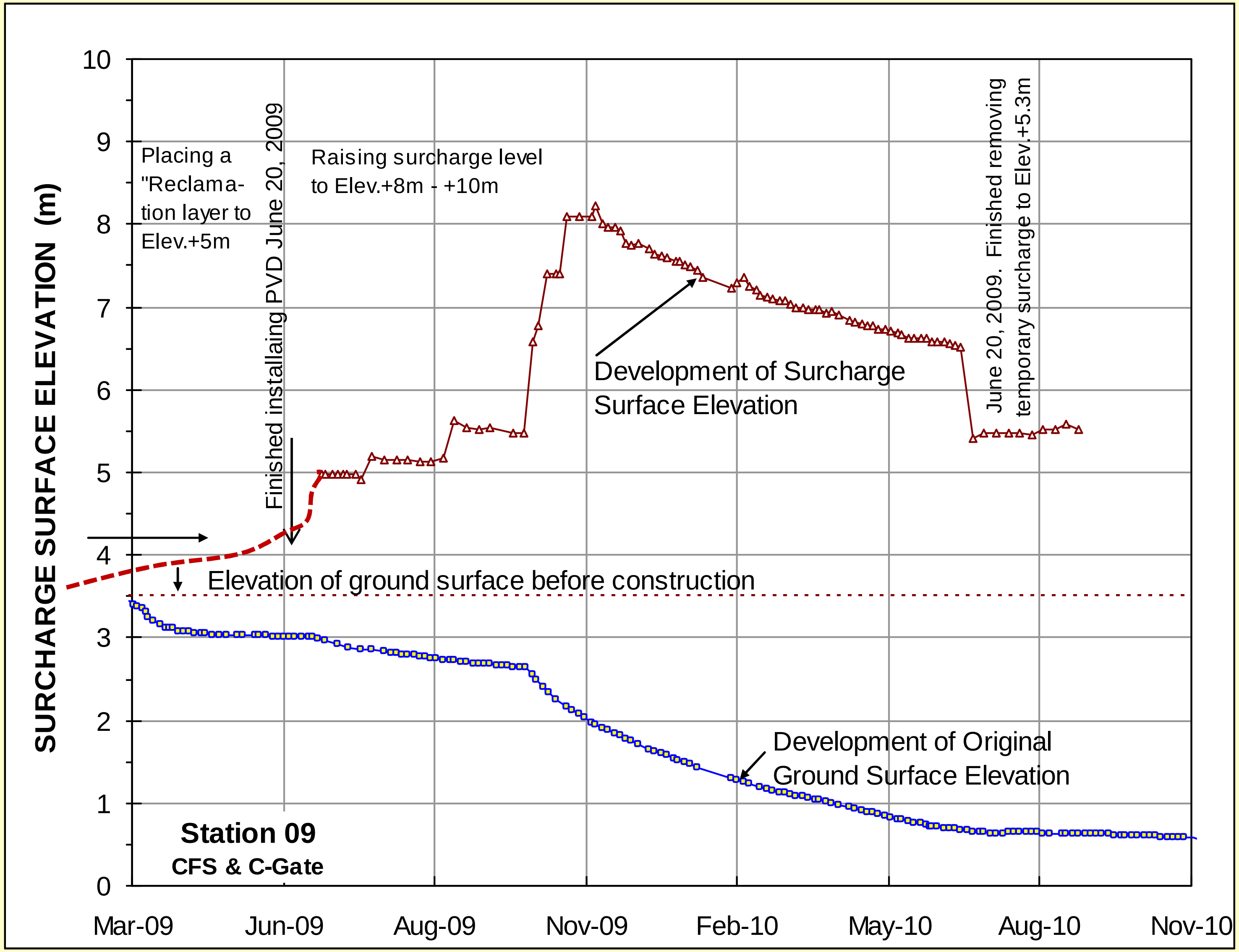


Principle of the wick drain and surcharge soil improvement scheme

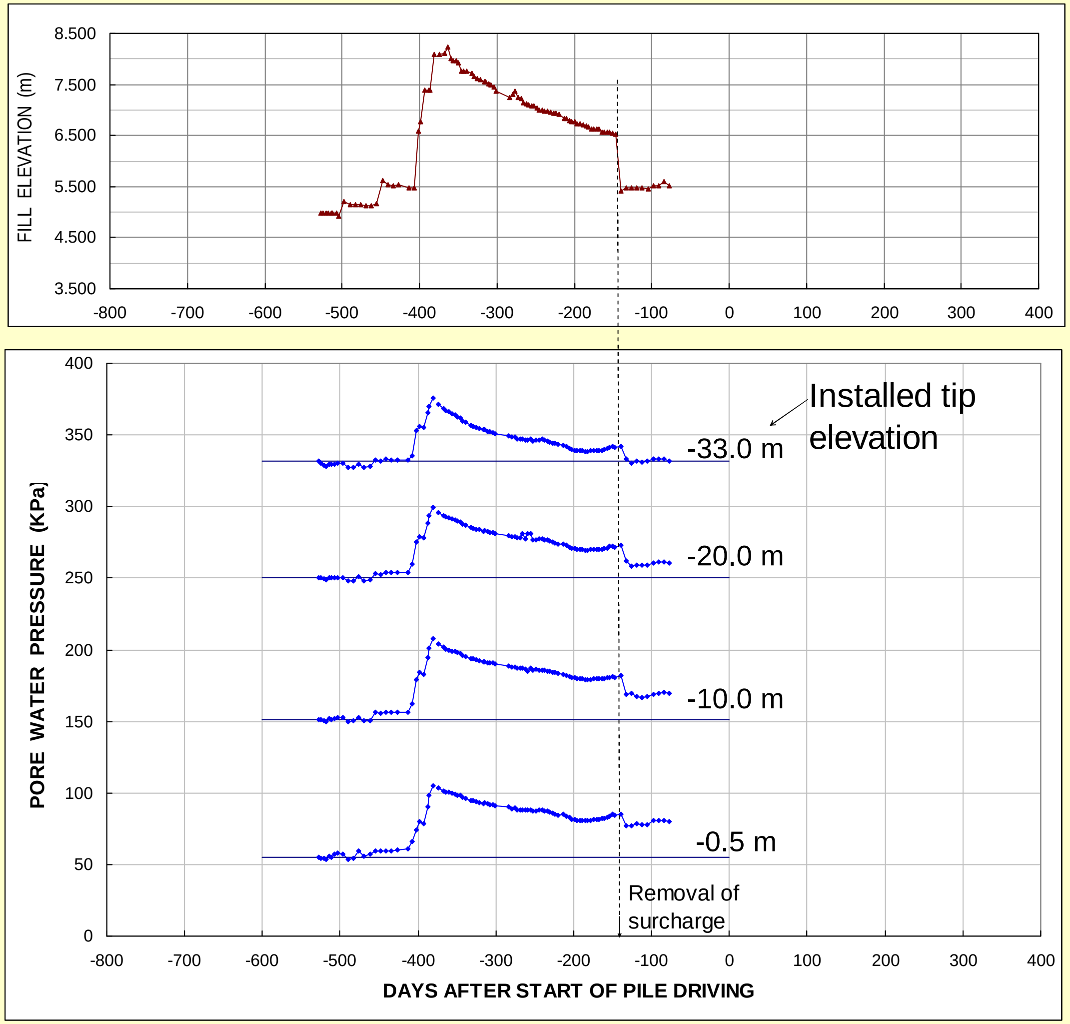


The wick drain used for the project was a 100 mm wide and 3 mm thick consisting of a corrugated, 0.15 mm thick, plastic core wrapped with a synthetic filter.

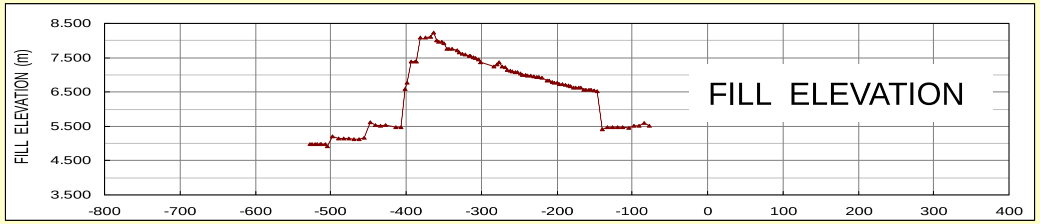
Fill height and ground surface settlement until one month before start of driving piles for the building foundations



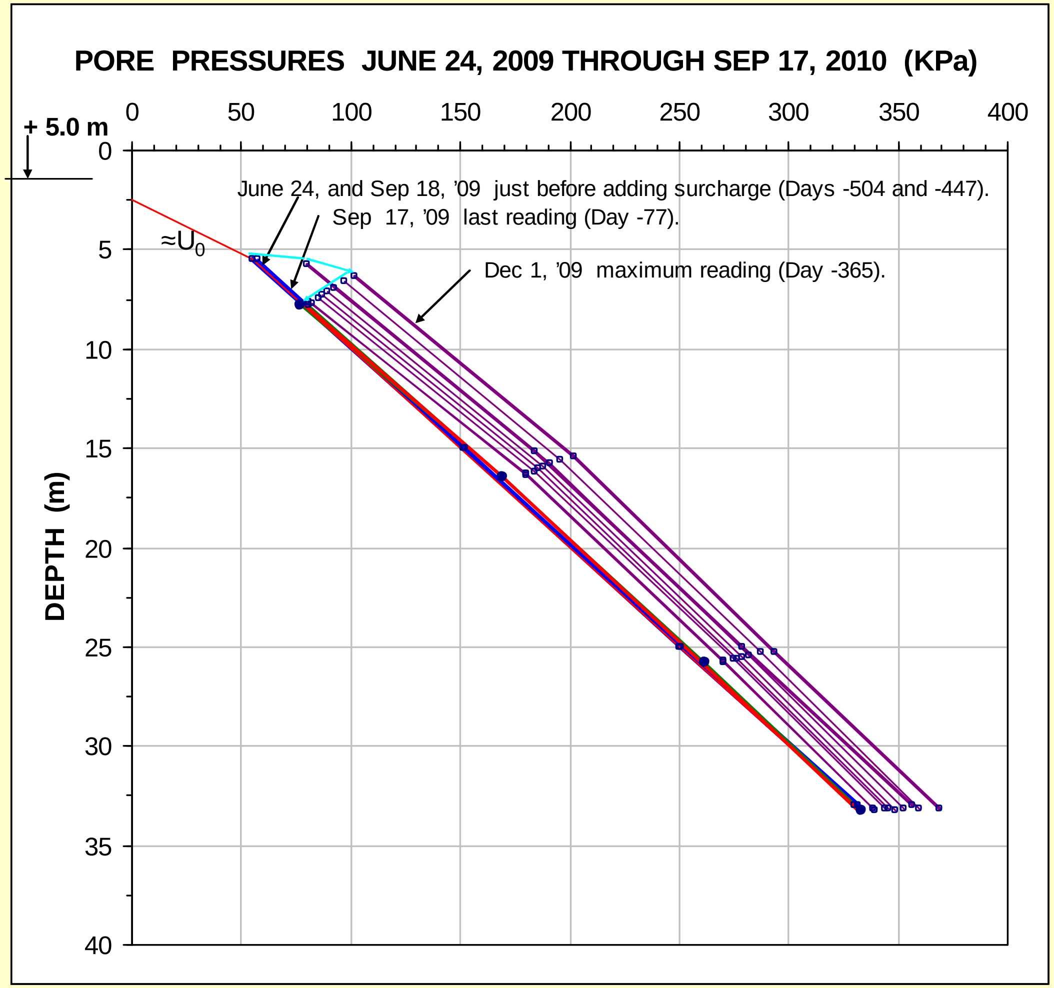
Fill height and pore pressures measured June 24, 2009, through September 17, 2010 (Days -527 and -77) at the CFS building



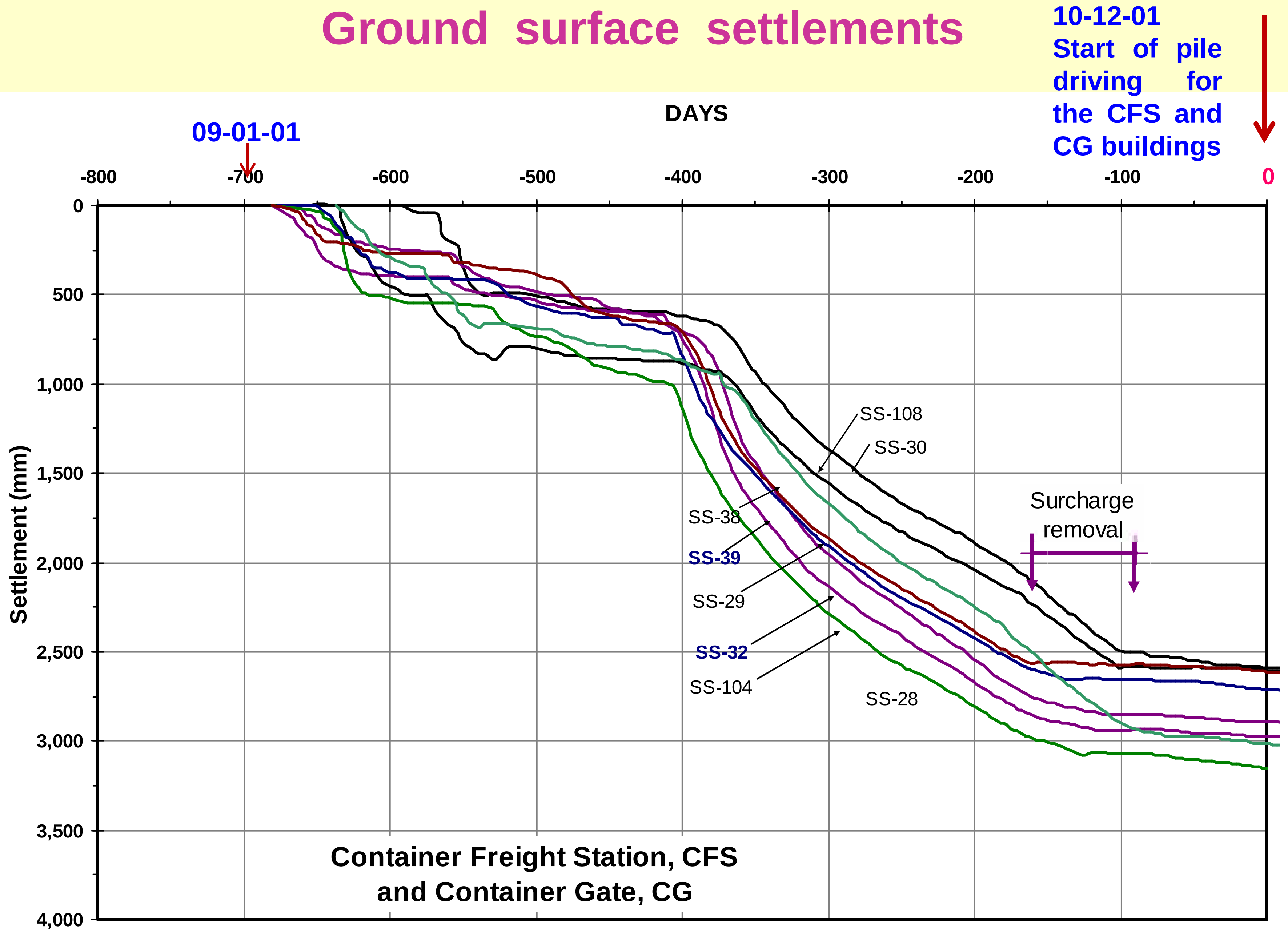
The tip elevations are per original installed depth. The <u>settlement of the piezometer tips is not included</u>.



Distribution with depth of the pore pressures at the CFS building



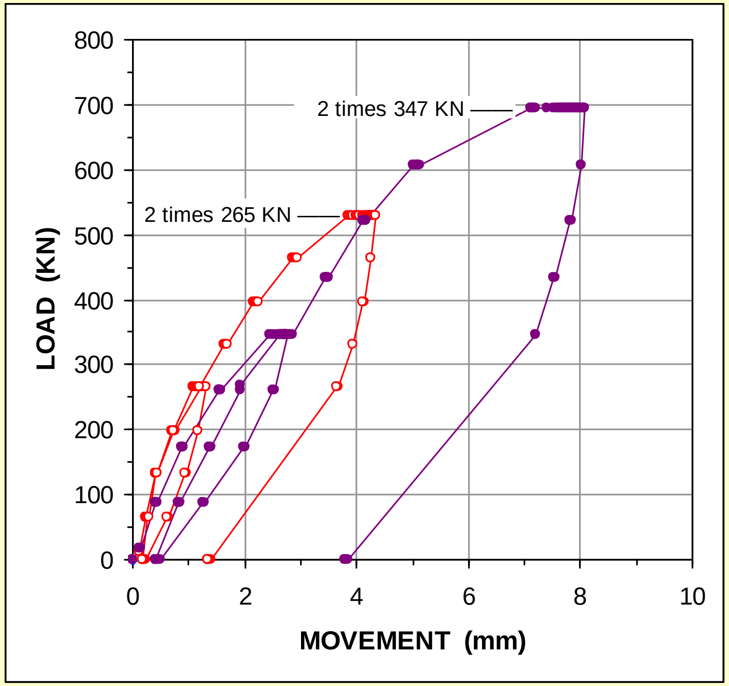
Ground surface settlements



View on October 4, 2011, taken from the south-east end of CFS building showing some of the about 1,680 piles driven for the CFS.

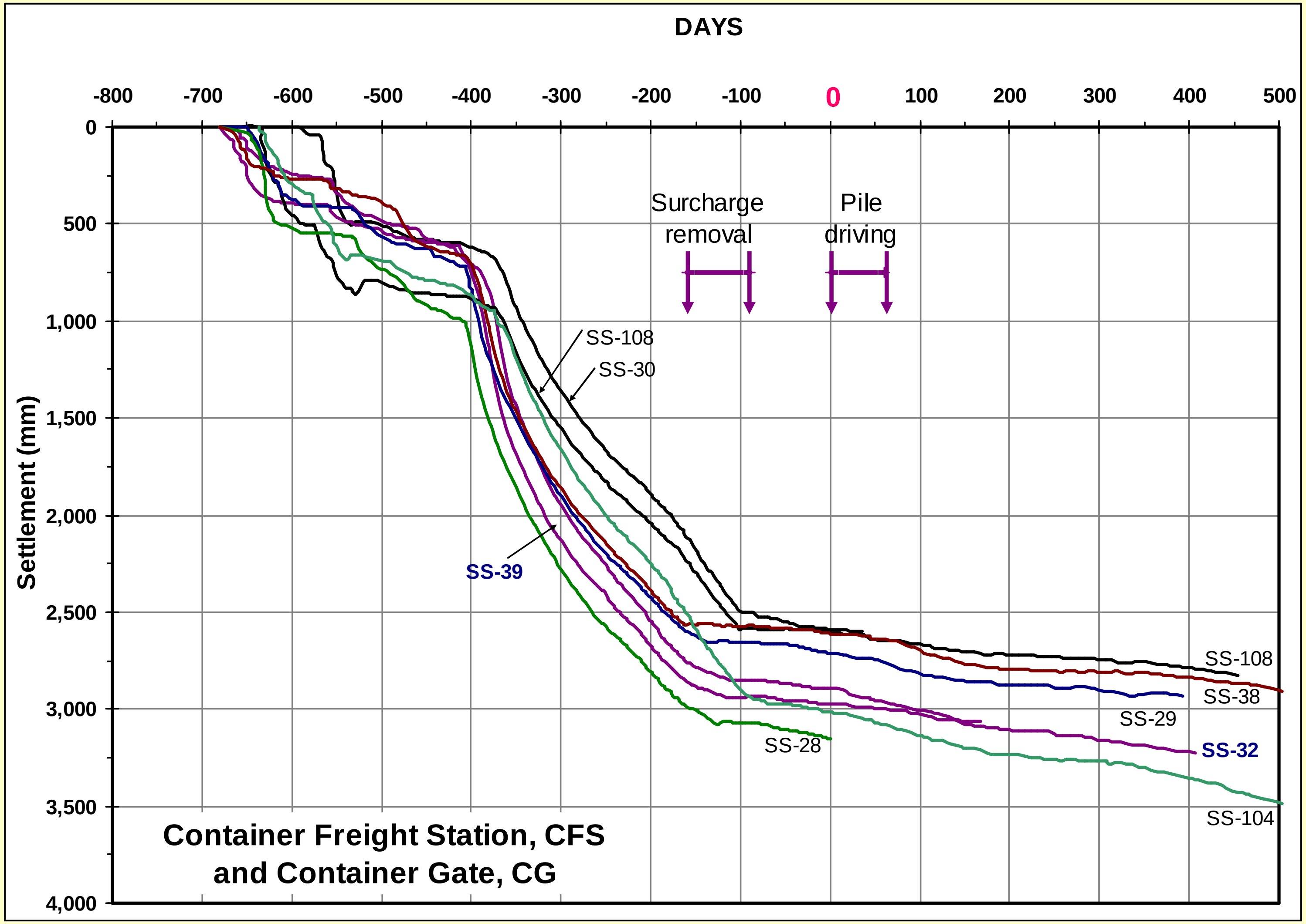
The building foundations were placed on precast, ordinary reinforced, concrete piles with a square 400 mm cross section made up by 10-m segments spliced in the field by welding steel end-plates together. For Buildings CFS and CG, the piles were driven to **28 m** and **18 m** depth, respectively. The intended working loads were 347 KN for the CFS building and 265 KN for the other buildings. One pile at each building was subjected to a static loading test. The test piles were not instrumented, and the test schedule included unloading/reloading cycles and varying load hold durations. Therefore, the test results have very limited use for the design beyond showing that the pile capacities were adequate.

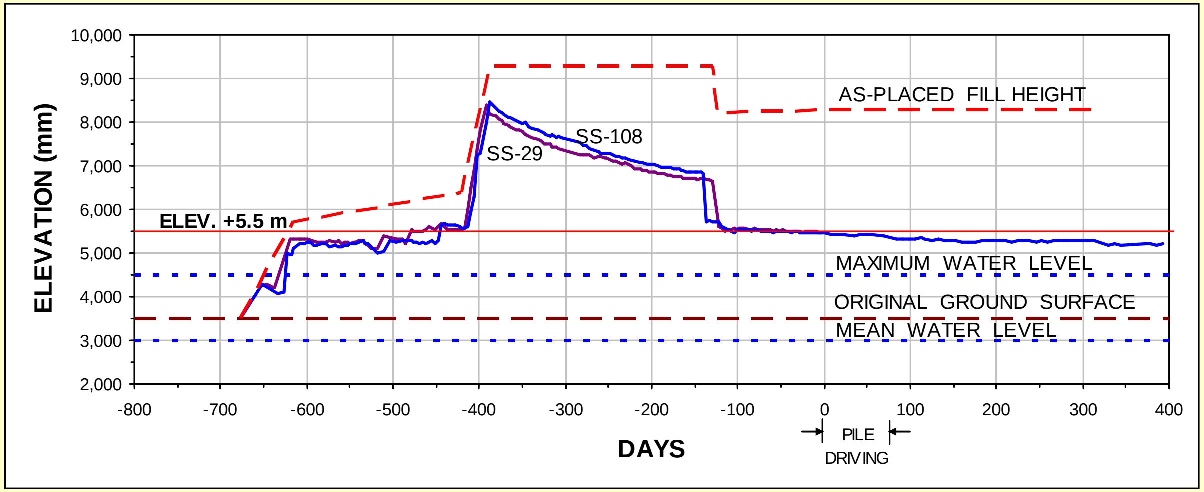
The static loading tests (CFS and CG) were carried out in September 2010, nine months after pile driving

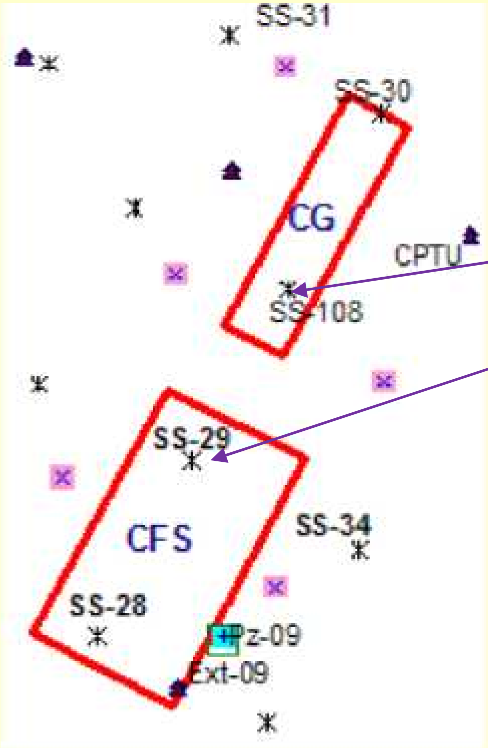


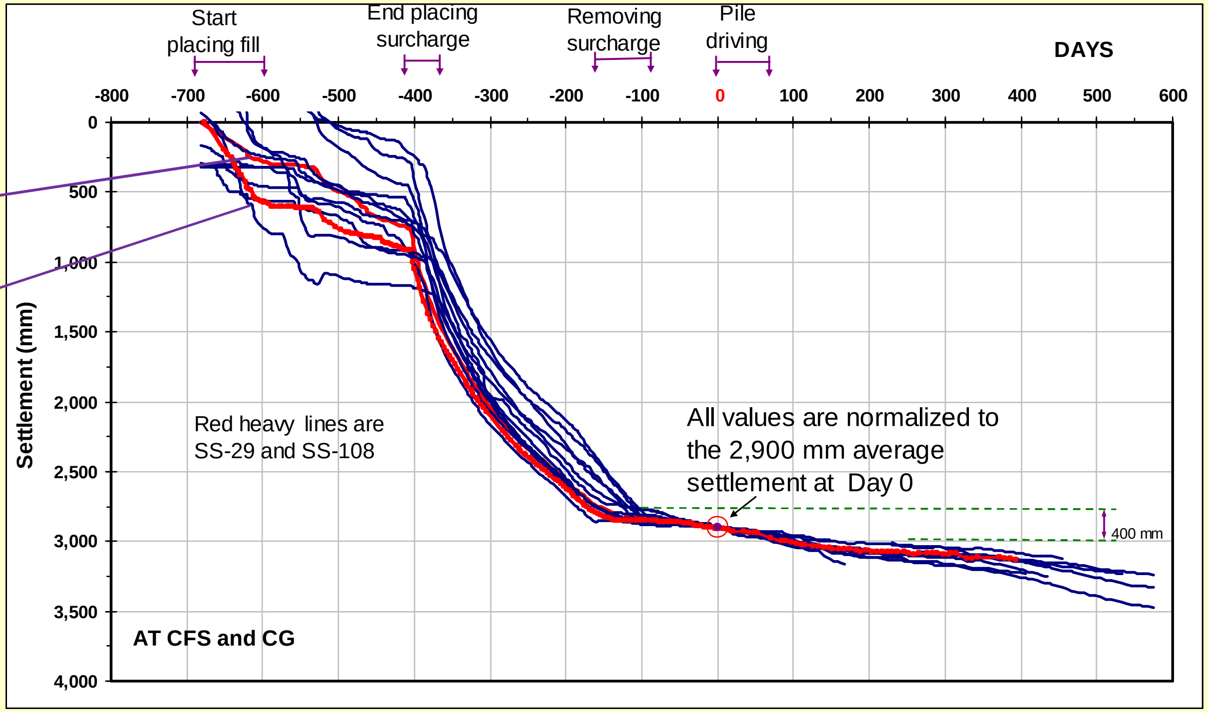
Load-movement curves from static loading tests at CFS and CG buildings

The below figure shows the settlements measured by the SS-plates at or near the buildings until November 15, 2011. The zero date is December 1, 2010, the day of the start of the pile driving for the CGS building. Driving was completed on January 24 at the CG building.



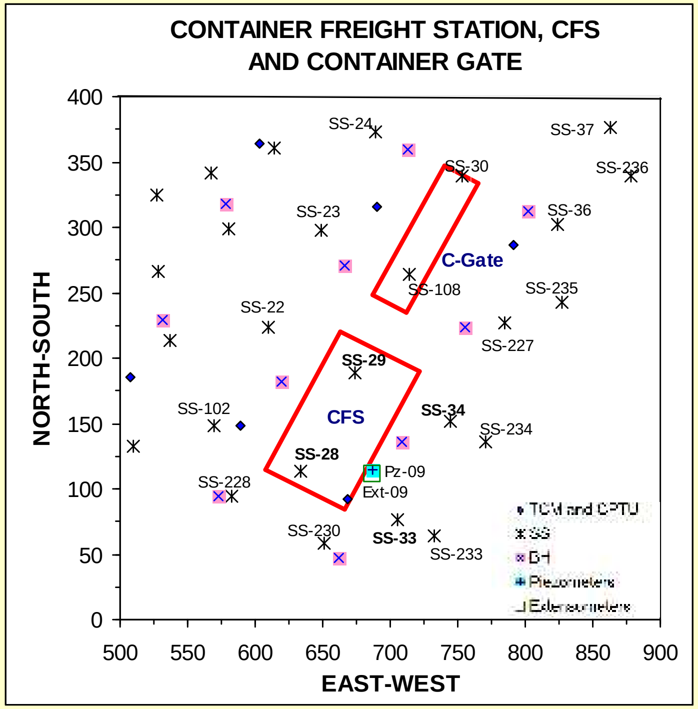

ELEVATION (mm)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
AS-PLACED FILL HEIGHT
SS-108
SS-29
ELEV. +5.5 m
MAXIMUM WATER LEVEL
ORIGINAL GROUND SURFACE
MEAN WATER LEVEL
-800 -700 -600 -500 -400 -300 -200 -100 0 100 200 300 400
DAYS
PILE DRIVING

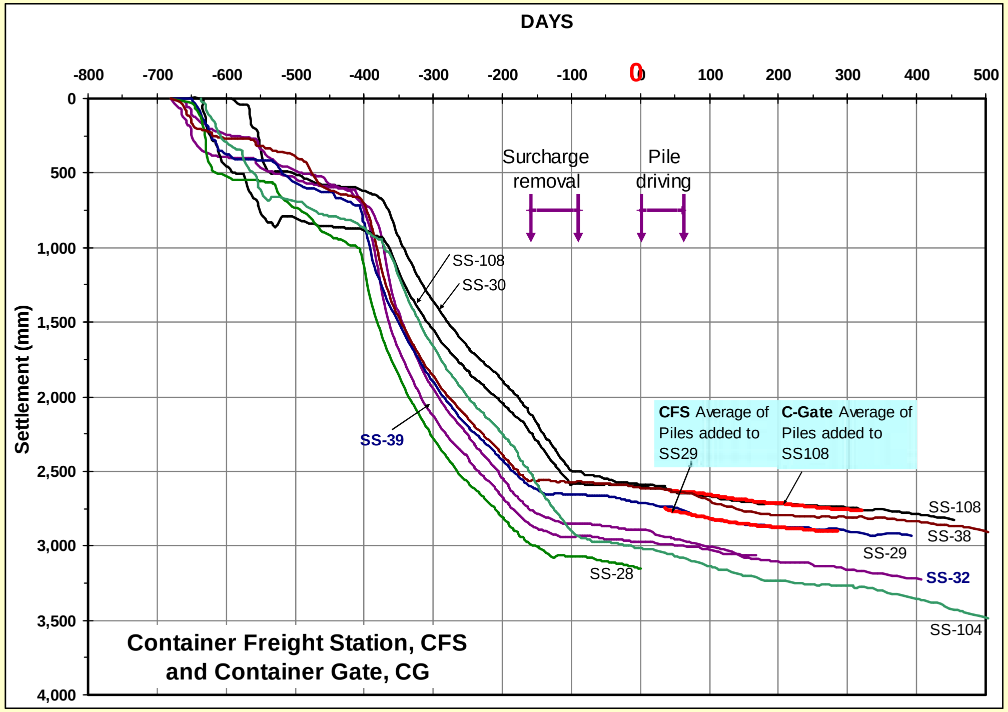

SS-31
SS-30
CG
CPTU
SS-108
SS-29
CFS
SS-34
SS-28
Pz-09
Ext-09


Start placing fill
End placing surcharge
Removing surcharge
Pile driving
DAYS
-800 -700 -600 -500 -400 -300 -200 -100 0 100 200 300 400 500 600
Settlement (mm)
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
Red heavy lines are SS-29 and SS-108
All values are normalized to the 2,900 mm average settlement at Day 0
400 mm
AT CFS and CG

Settlement plate values at the building locations
Not set to common settlement at Day 0

Now, showing also the measured pile-head settlement

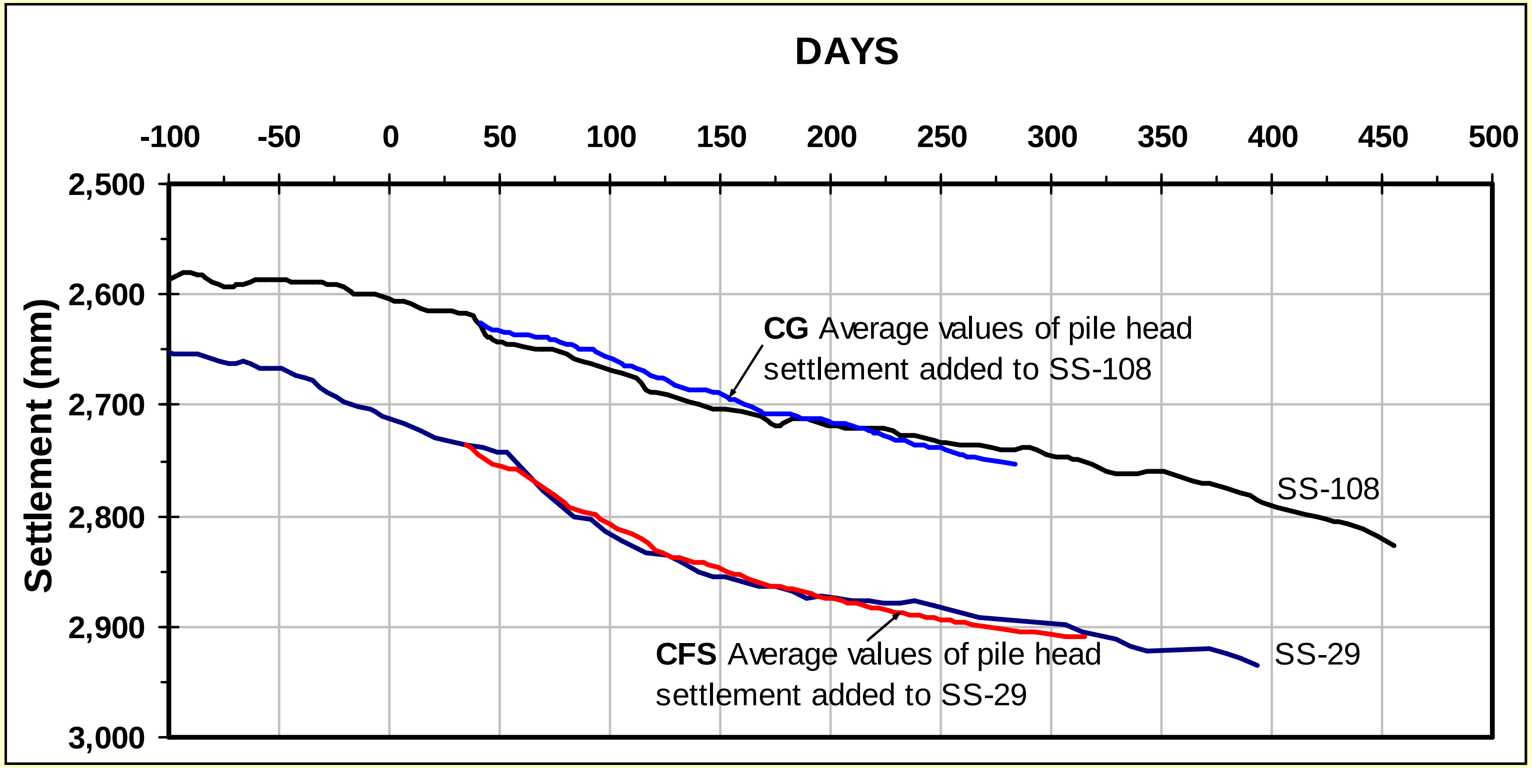




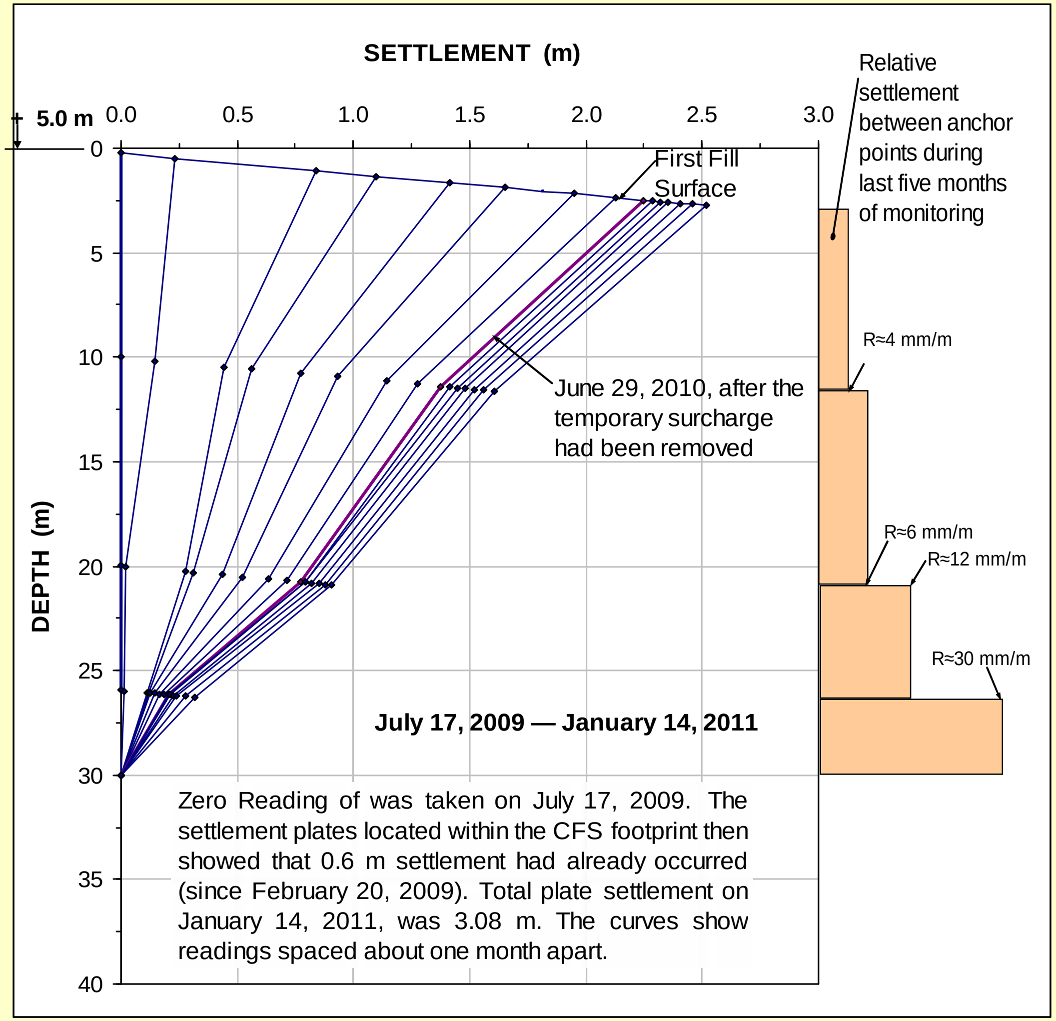
Container Freight Station (CFS) and Container Gate (CG)

Settlements of ground surface and pile heads

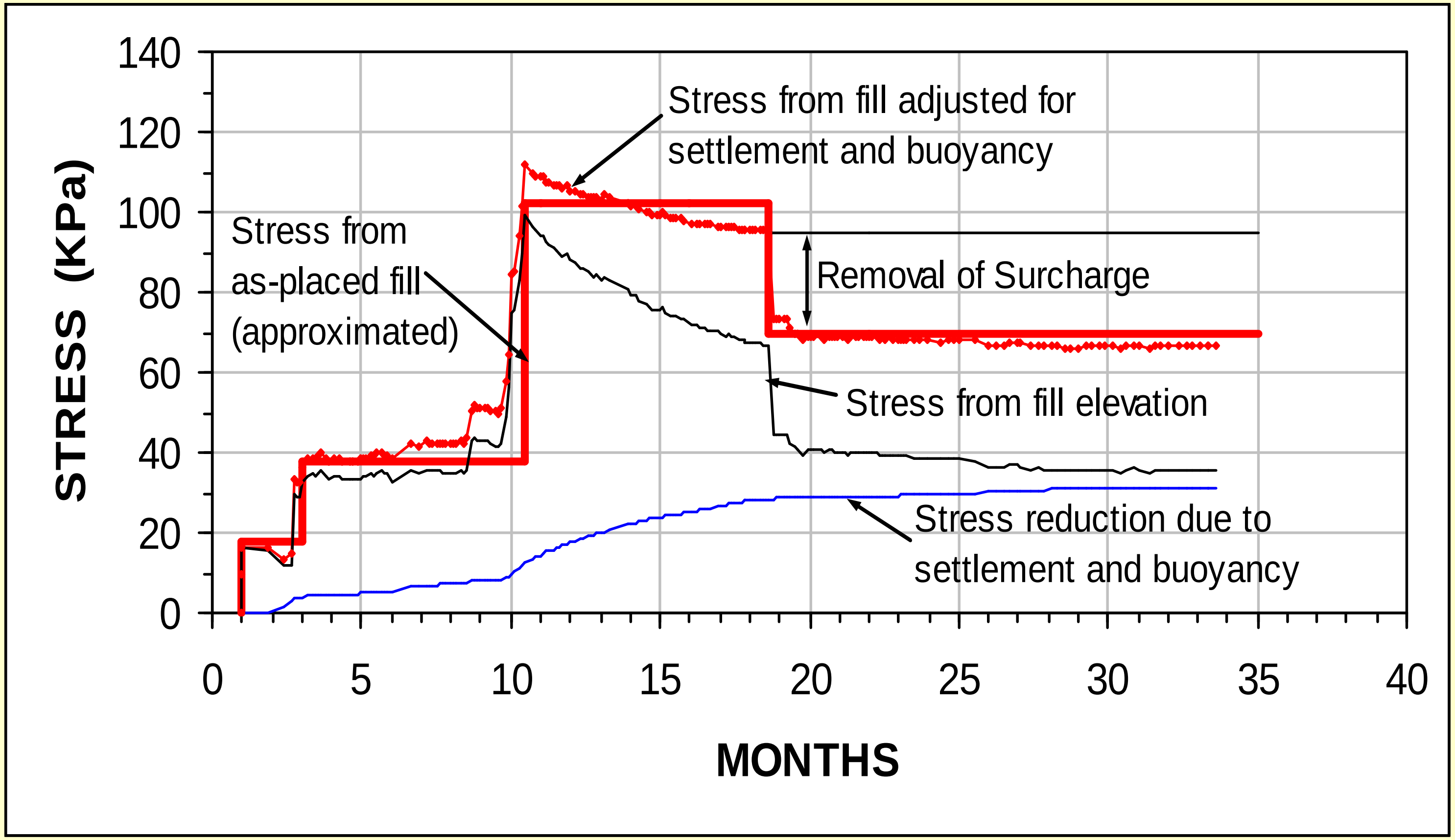
Settlements measured for SS-plates and 28 m long piles at the CFS and CG buildings until November 15, 2011



Settlement distribution measured in an extensometer station (multi-anchor points) outside the CFS building **during 18 months:** from July 17, 2009 (one to three months after start of placing fill) through January 14, 2011, one month after piles were driven near the location of the extensometer station.



Fill height and settlement – Measurements used as input to analysis

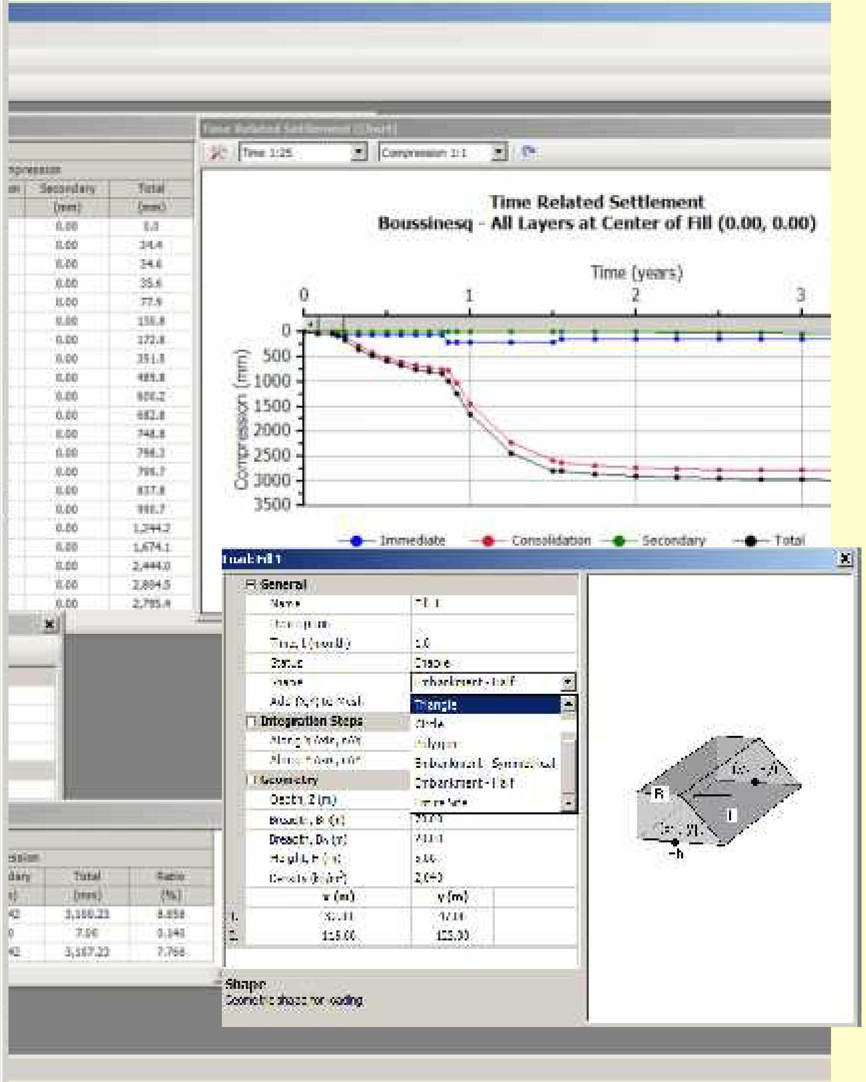


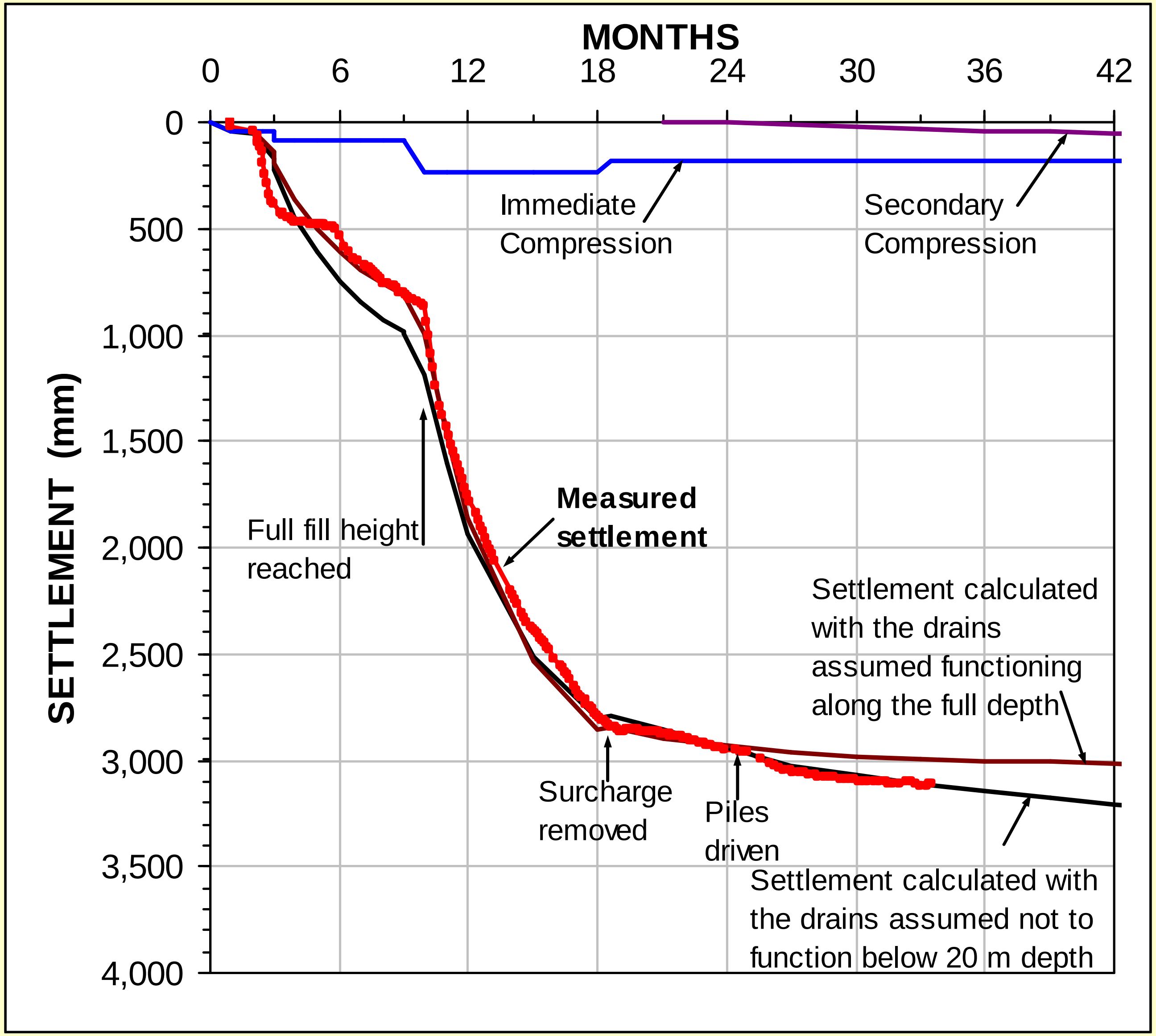
UniSettle4 input and results
[www.info@unisoftLtd.com]

Soil Layer: Clay & Silt to 35m

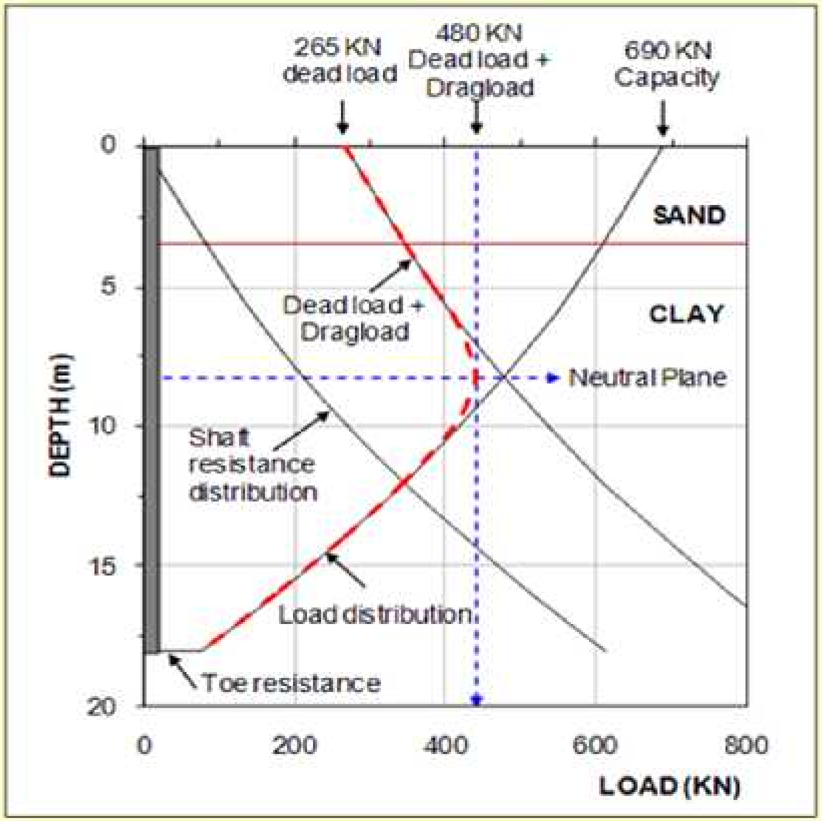
General	
Name	Clay & Silt to 35m
Type	
Description	Drains to full depth
Label	
Thickness (m)	35.00
Depth (m)	35.00
Z Steps (m)	4.00
Layer Interpolation	Use layer average values
Density (kg/m^3)	1,600
Initial Void Ratio, e_0	1.790
Compressibility	
Method	Janbu j and modulus number
Stress Exponent, j	0.0 - Peat, clay, and silt
Preconsolidation Parameter	Use preconsolidation margin,...
Preconsolidation Margin, $\Delta\sigma'$ (kPa)	13.0
Immediate Comp. Modulus Number, m_i	150.0
Immediate Recomp. Modulus Number, m_{ir}	1,200.0
Virgin Modulus Number, m	5.0
Recompression Modulus Number, m_r	50.0
Seconday Compression	
Secondary Compression Index, C_α	0.01000
Start of Consolidation, t_1 (years)	1.00
Duration of Consolidation, t_{90} (years)	1.00
Report Period, t_r (years)	20.00
Drainage	
Drainage Type	Horizontal only
Coefficient of Consolidation, c_h (m^2/s x10^{-8})	4.583
Time to 90% Consolidation, t_{h90} (years)	0.75
Unloading Consolidation Factor, c_{hr}	1.00

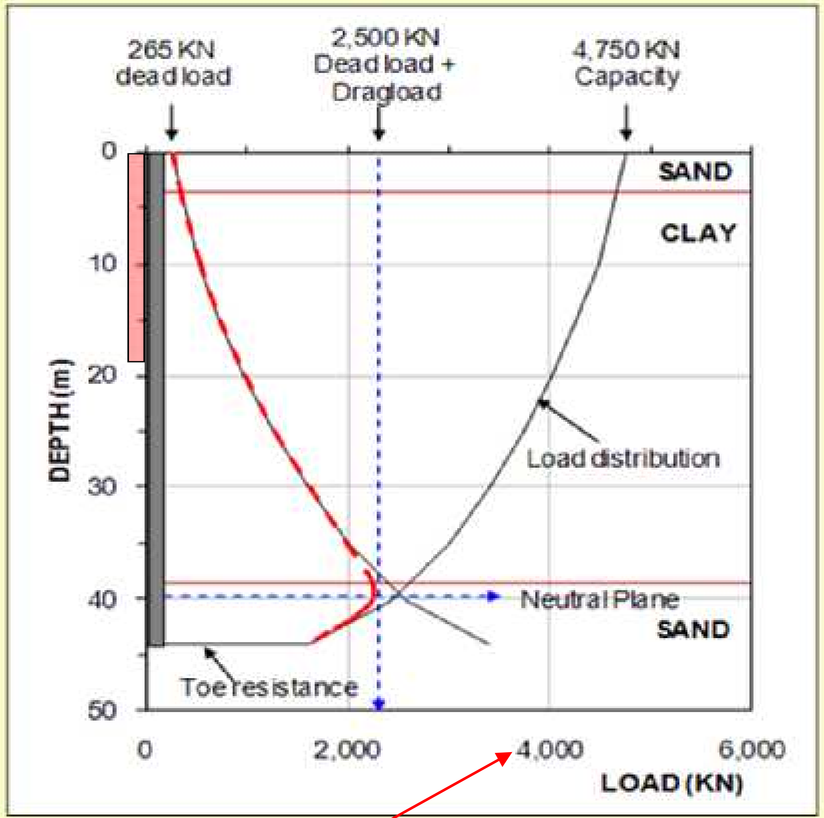
Preconsolidation Parameter
Select preconsolidation parameter. Overconsolidation ratio, OCR, or preconsolidation margin, $\Delta\sigma'$.




MONTHS
0
6
12
18
24
30
36
42
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
SETTLEMENT (mm)
Immediate Compression
Secondary Compression
Full fill height reached
Measured settlement
Settlement calculated with the drains assumed functioning along the full depth
Surcharge removed
Piles driven
Settlement calculated with the drains assumed not to function below 20 m depth

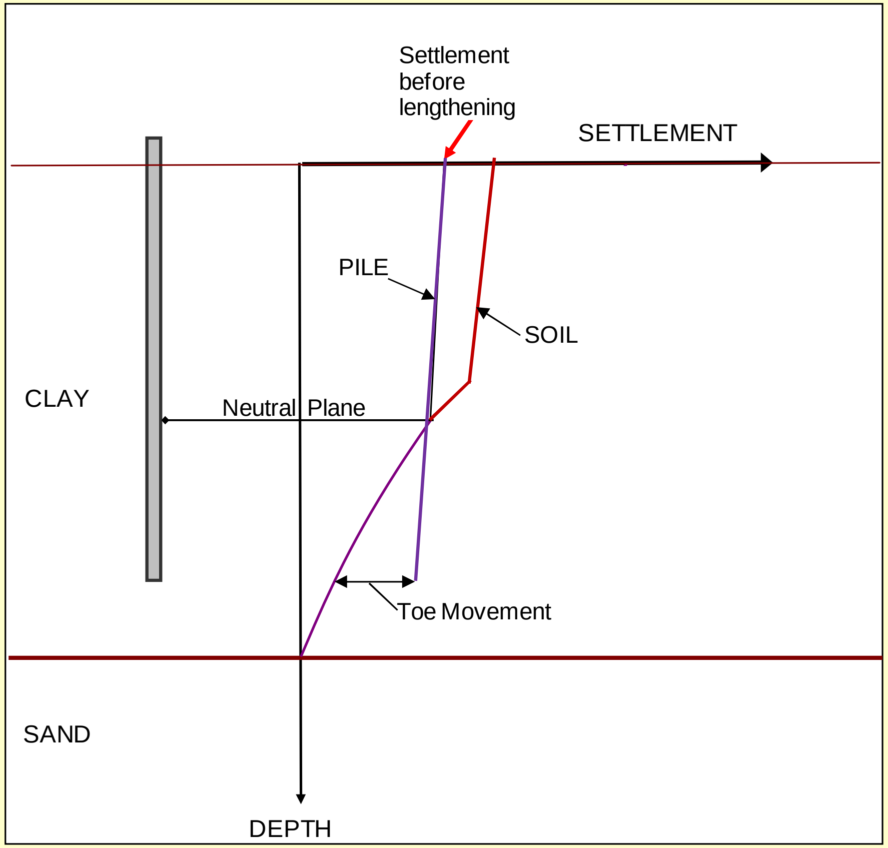
Analysis of the 18 m long pile and after lengthening to 44 m



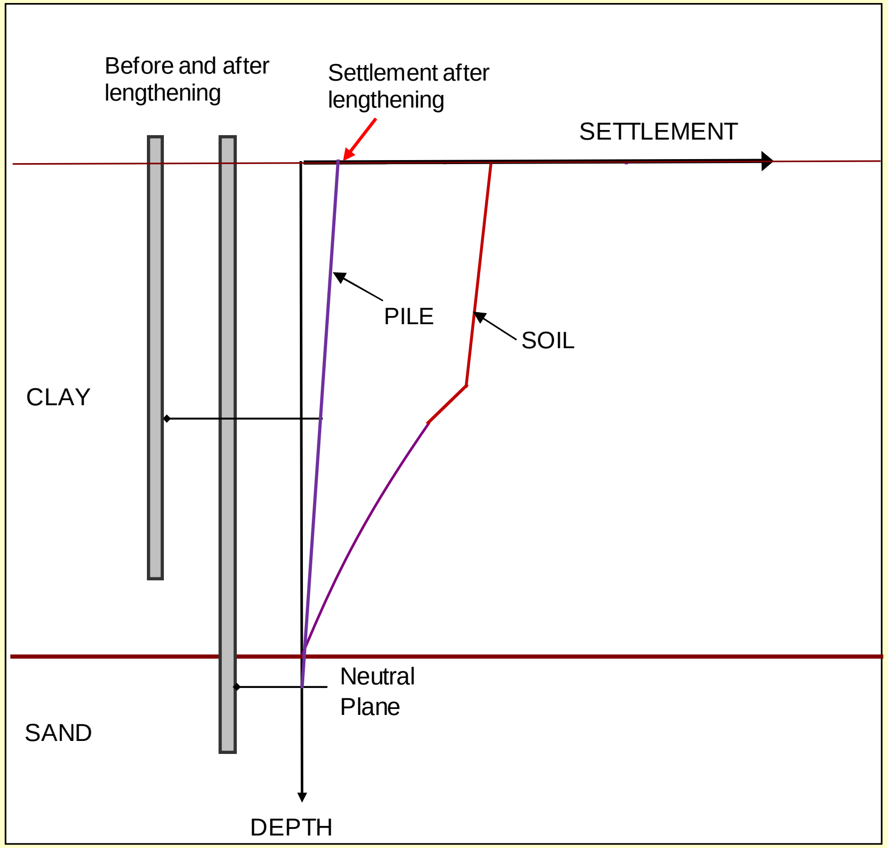


N.B. Different Scale

Settlement before lengthening

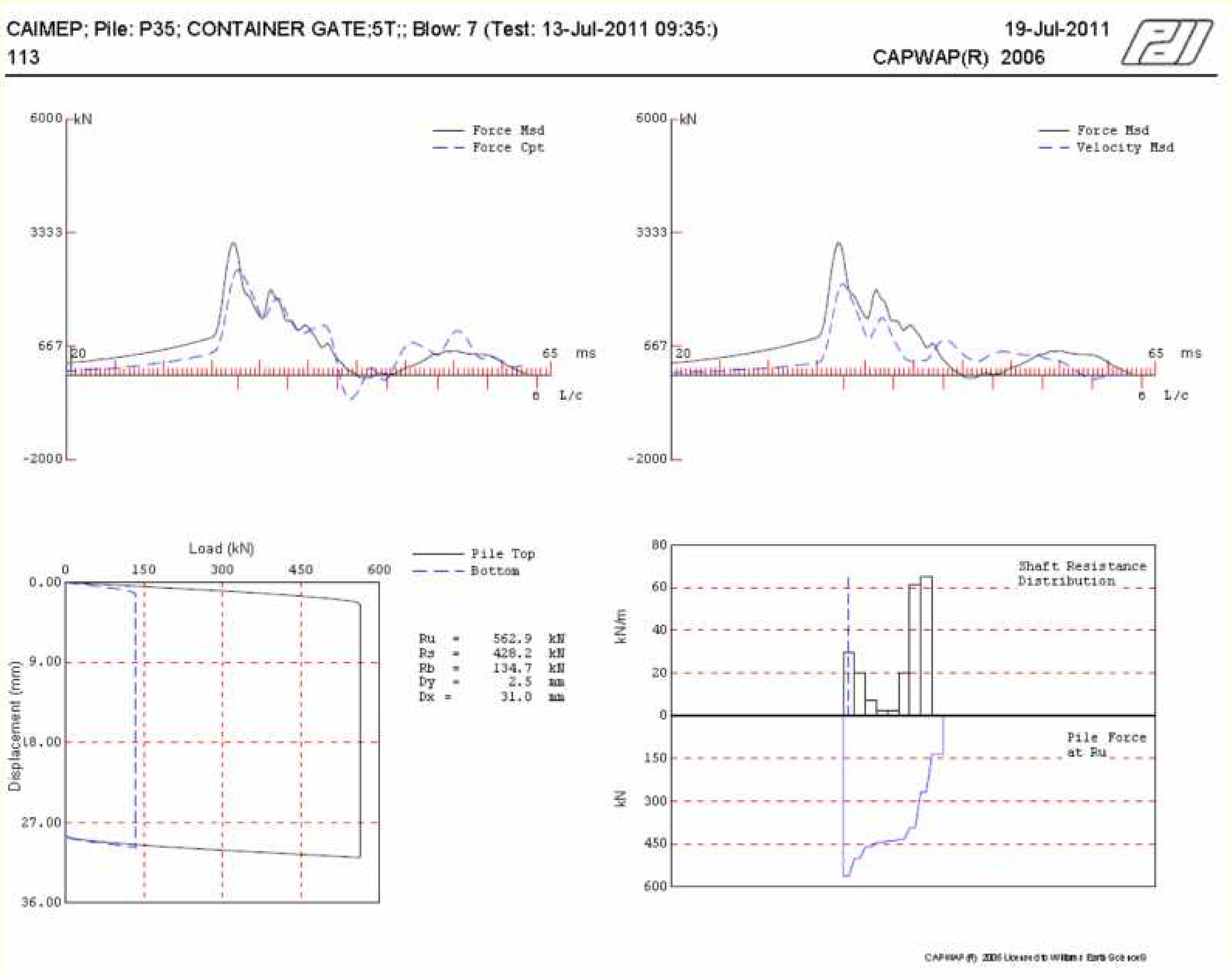


Settlement after lengthening



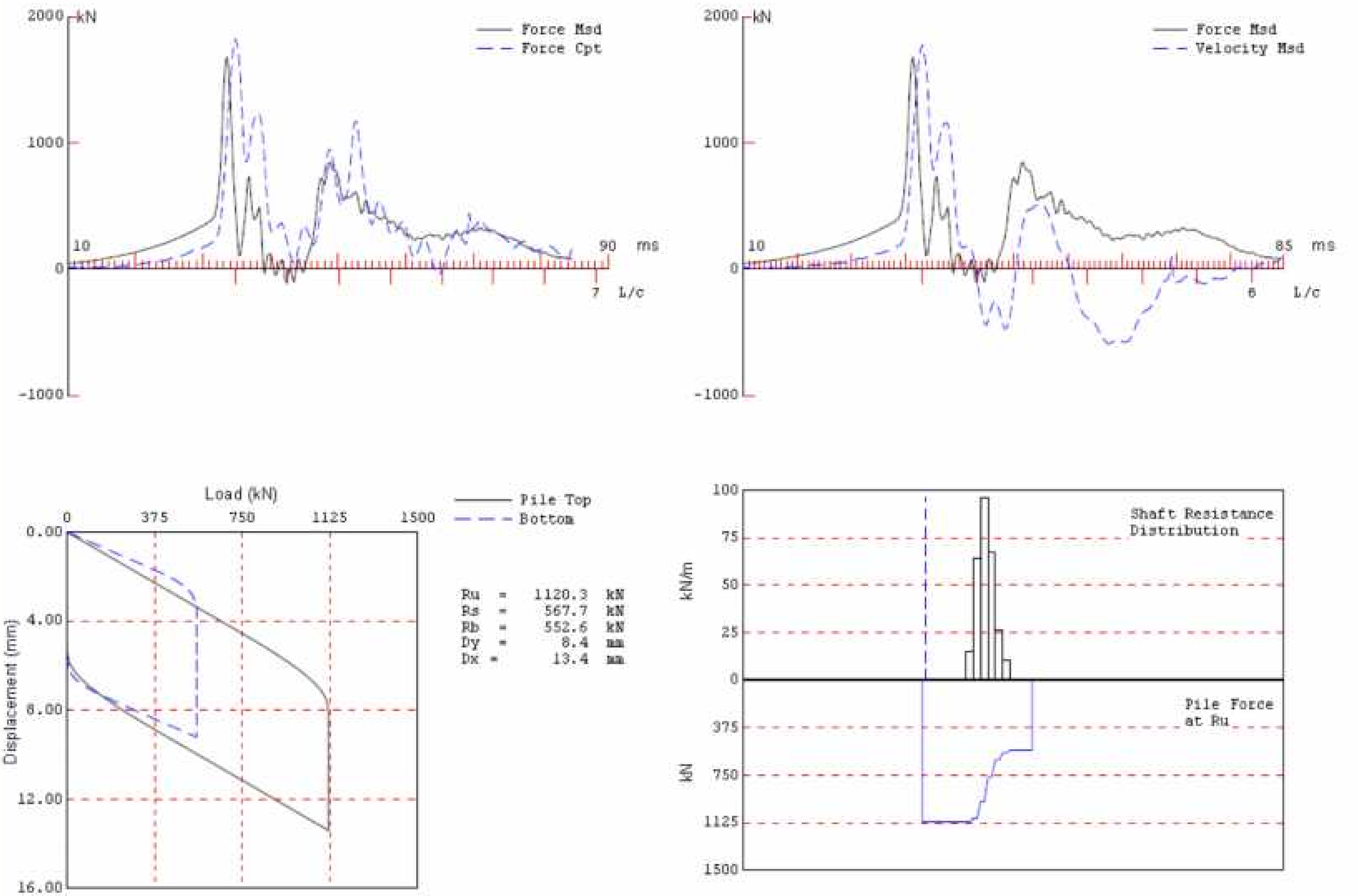
View on October 4, 2011, taken from the south end of CFS building showing some of the about 750 piles driven for the CFS building. In the background, lengthened piles are being driven for the CG building.

Photos from the driving of piles with extension


CAIMEP; Pile: P35; CONTAINER GATE;5T;; Blow: 7 (Test: 13-Jul-2011 09:35:)
113
19-Jul-2011
CAPWAP(R) 2006
Force Msd
Force Cpt
Force Msd
Velocity Msd
kN
ms
L/c
Load (kN)
Displacement (mm)
Pile Top
Bottom
Ru = 562.9 kN
Rs = 428.2 kN
Rb = 134.7 kN
Dy = 2.5 mm
Dx = 31.0 mm
Shaft Resistance Distribution
kN/m
Pile Force at Ru

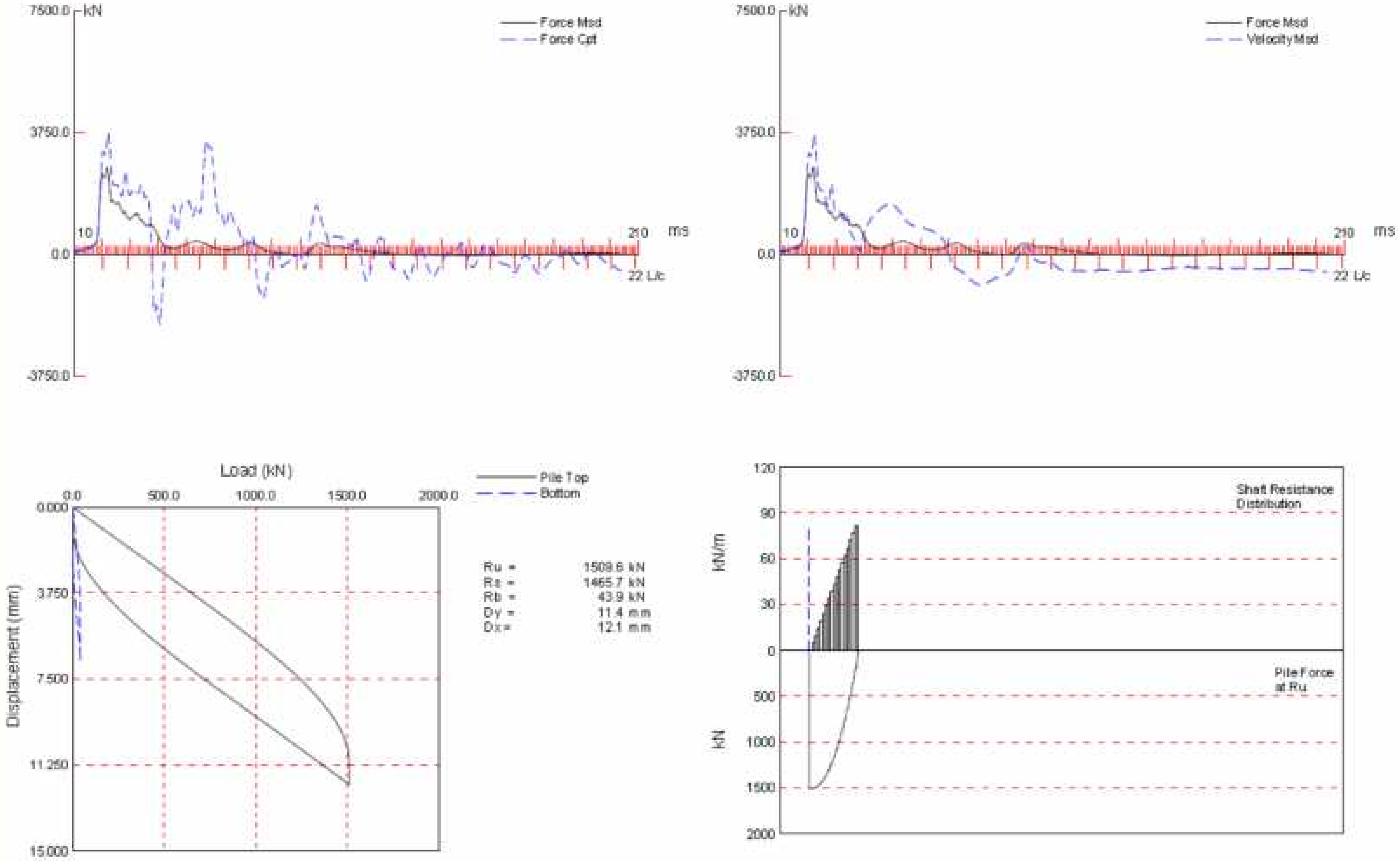
CAIMEP; Pile: P11; CFS;5T;; Blow: 5 (Test: 12-Jul-2011 16:29:)
113

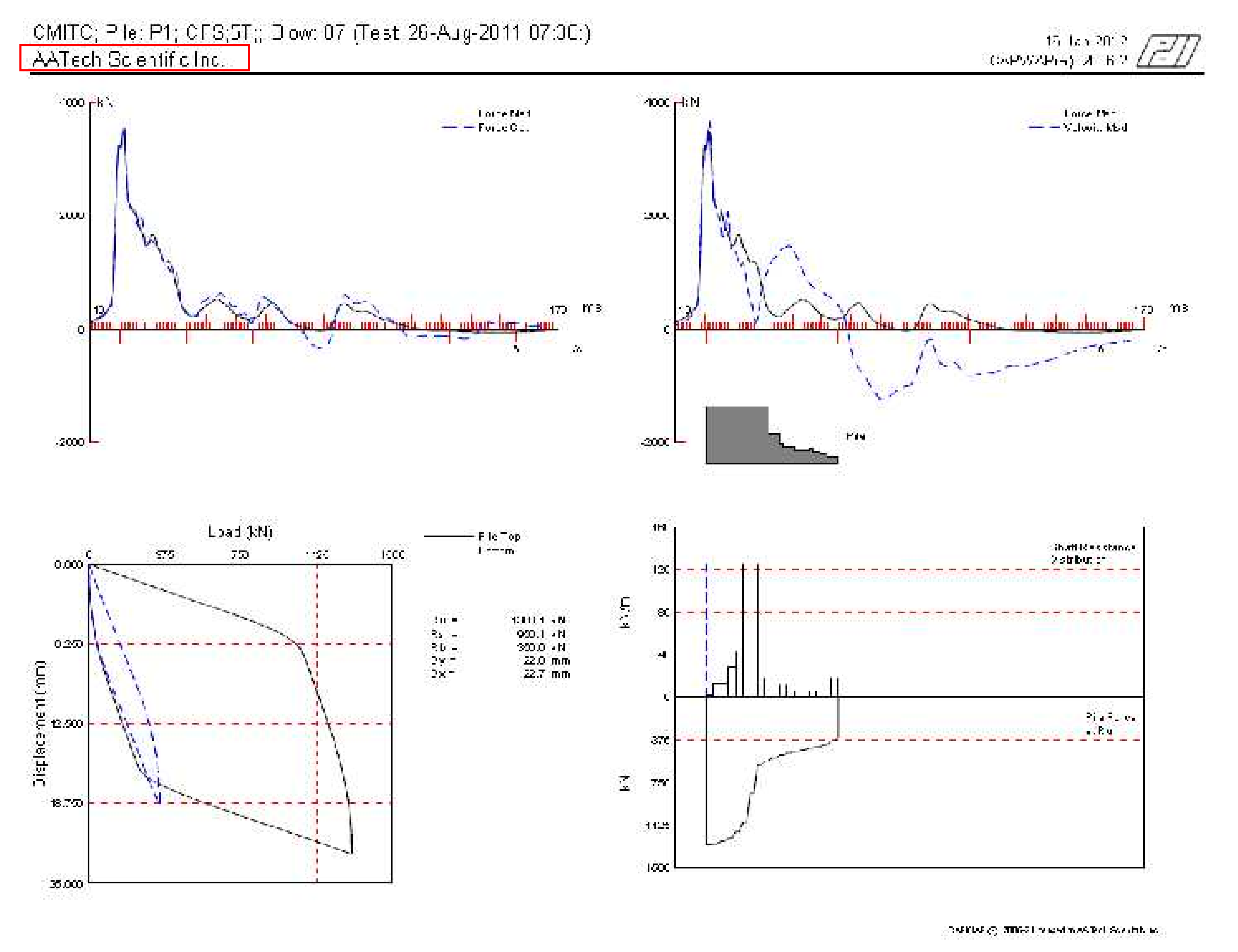
19-Jul-2011
CAPWAP(R) 2006

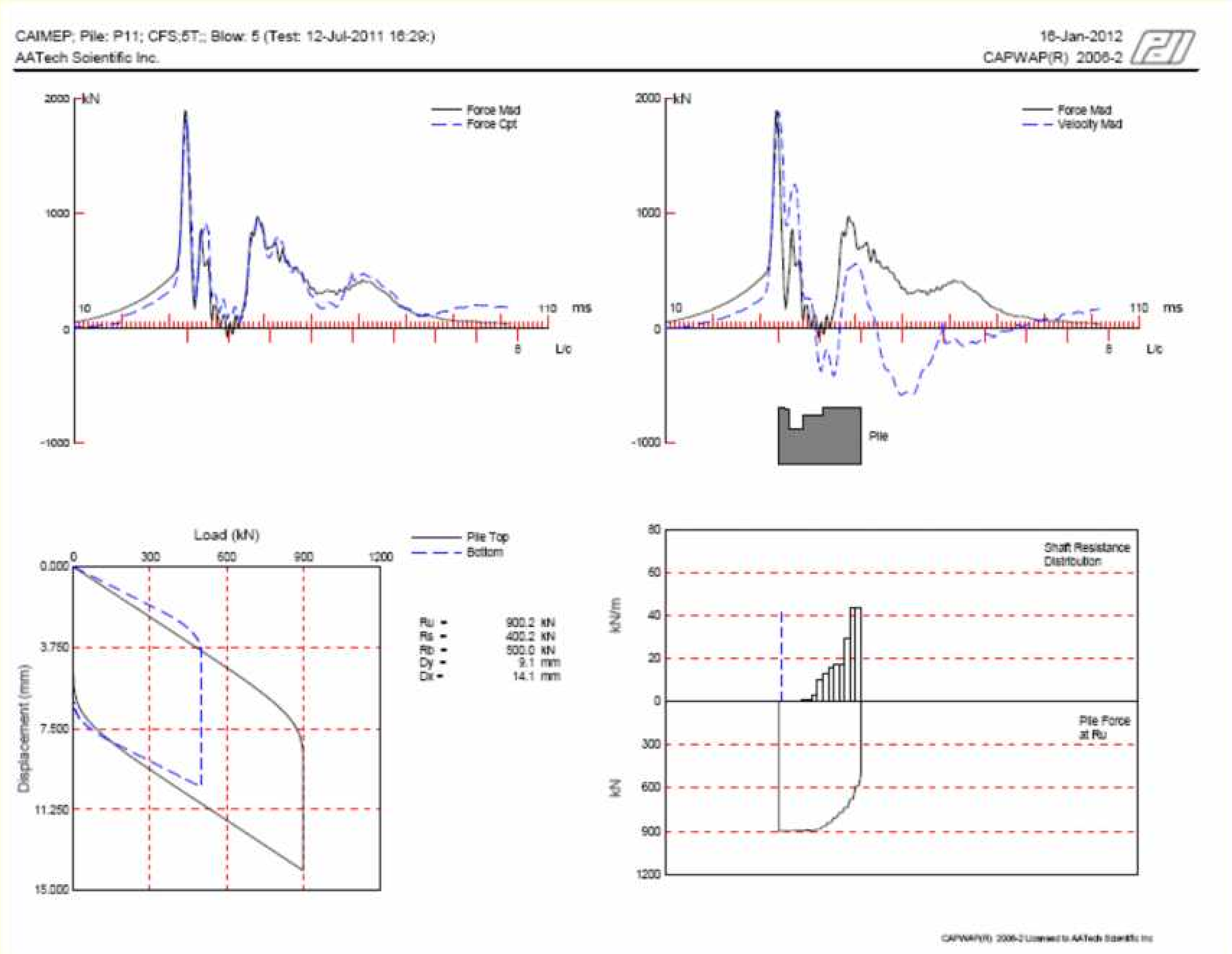


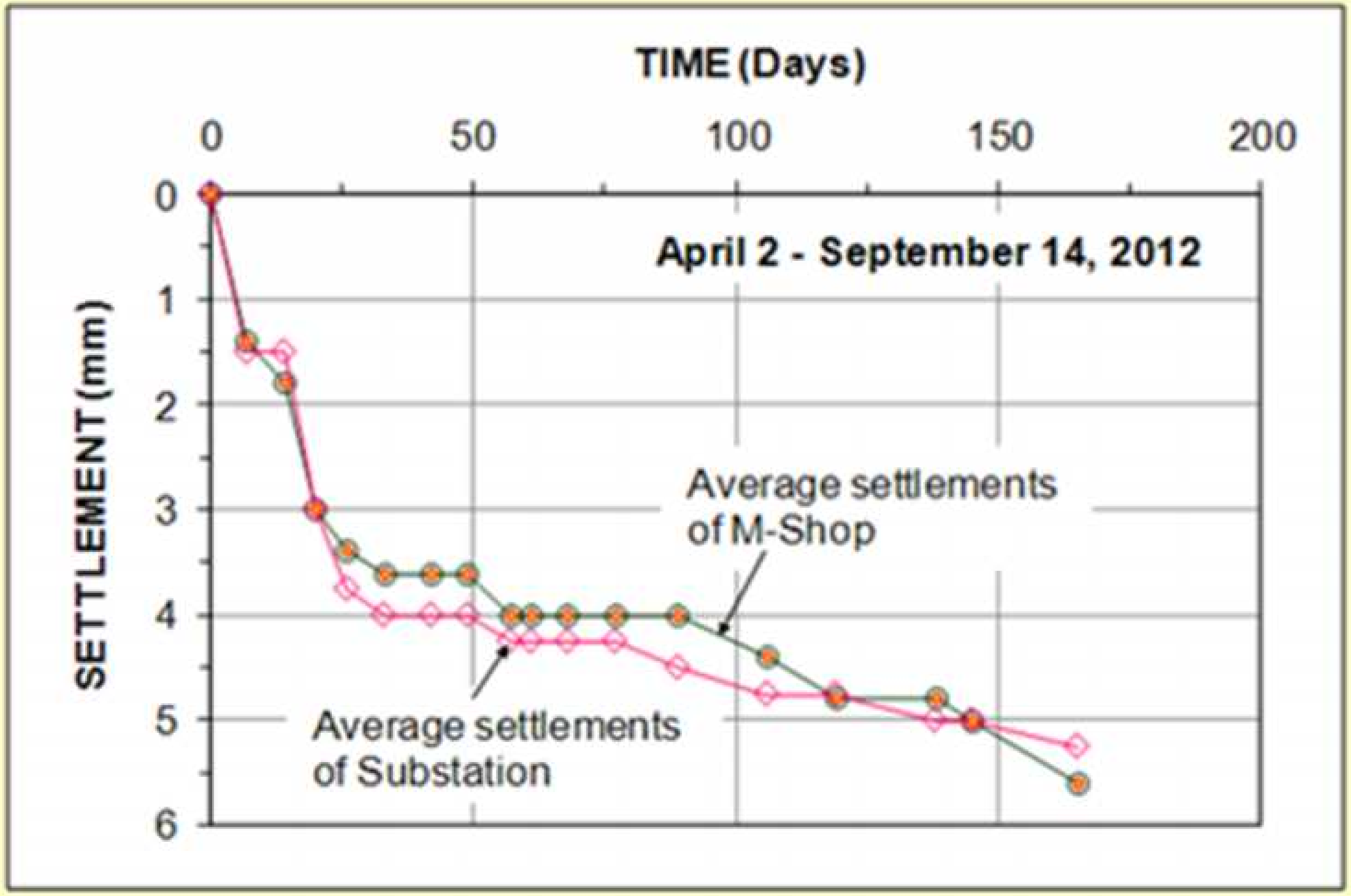
Cai Mep International Container Terminal; Pile: P1; CFS;5T;; Blow: 87 (Test: 26-Aug-2011 07:38:)
113

31-Aug-2011
CAPWAP(R) 2006 DEMO




CMITC; Pile: P1; CFS;ST;; Blow: 07 (Test: 26-Aug-2011 07:30:)
AATech Scientific Inc.
Load (kN)
Displacement (mm)
22.0 mm
22.7 mm
Pile


CAIMEP; Pile: P11; CFS;5T;; Blow: 5 (Test: 12-Jul-2011 16:29:)
AATech Scientific Inc.
16-Jan-2012
CAPWAP(R) 2006-2
Force Msd
Force Cpt
Velocity Msd
kN
ms
L/c
Pile
Load (kN)
Pile Top
Bottom
Displacement (mm)
Ru = 900.2 kN
Rs = 400.2 kN
Rb = 500.0 kN
Dy = 9.1 mm
Dx = 14.1 mm
Shaft Resistance Distribution
Pile Force at Ru
kN/m
kN
CAPWAP(R) 2006-2 Licensed to AATech Scientific Inc



Settlement of M-Shop and Substation buildings constructed on the lengthened piles

CONCLUSIONS

The most probable cause to the continued consolidation below about 20 m depth is that large soil stresses have squashed the wick drains preventing the drains from functioning properly.

The consequence is that the overall area and the piles will continue to settle even if no new fills are placed.

The problem with the settling piled foundations can be (and was hopefully) resolved by lengthening the piles to bring the neutral plane (the depth to the settlement equilibrium) into the non-settling sand below the clay.

It is not realistic to install new and better drains or arrange, say, for vacuum treatment to get the consolidation to occur quickly. The site will have to live with continuing to add fill to compensate for excessive settlement, which will in turn add consolidation. And, to suffer the maintenance actions that regularly will be required for non-piled foundations.

The monitoring scheme was designed to confirm that the wick drain method worked. When the measurements showed that the method did not work, the method became very much inadequate, and it could not be of any assistance for selecting a solution to the problem. Every monitoring programme should have redundancy and be designed to resolve issues should the design show to be unsuccessful. How to resolve the question "what if we're wrong?" should always be kept in mind and kept foremost in the planning of a monitoring programme.

Thank you for your attention