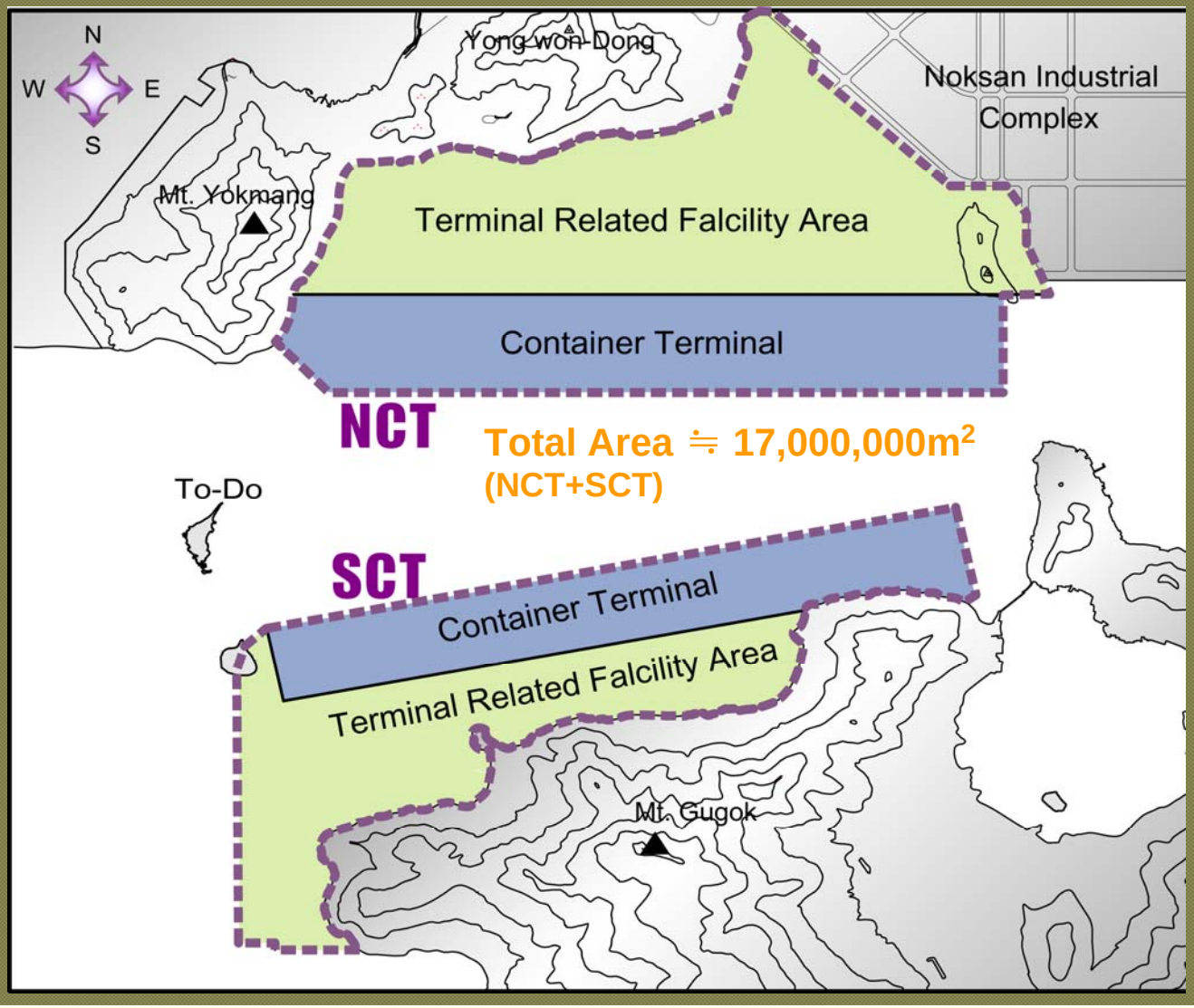
Experience from the performance of ground improvement in thick marine clay deposit

Location of the Busan New Port

Close-up view of BNP site (on the satellite photograph)

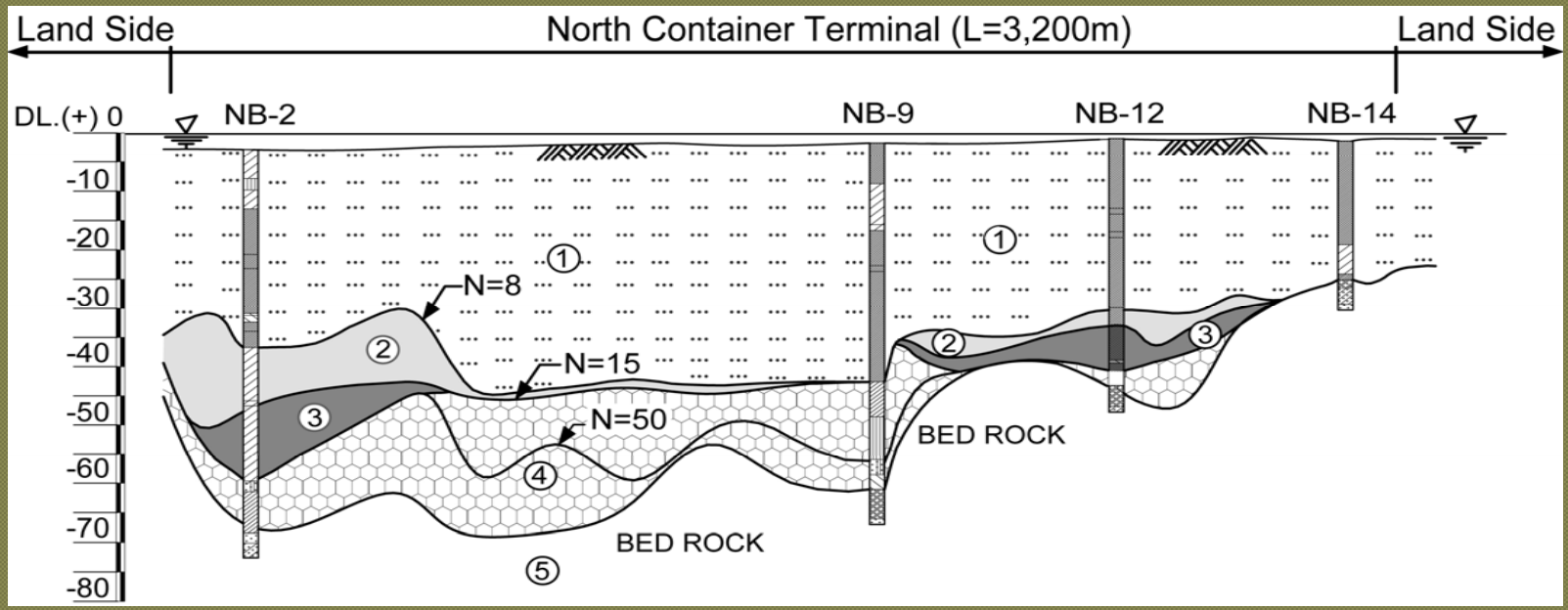
Terminal and their related facility areas of BNP

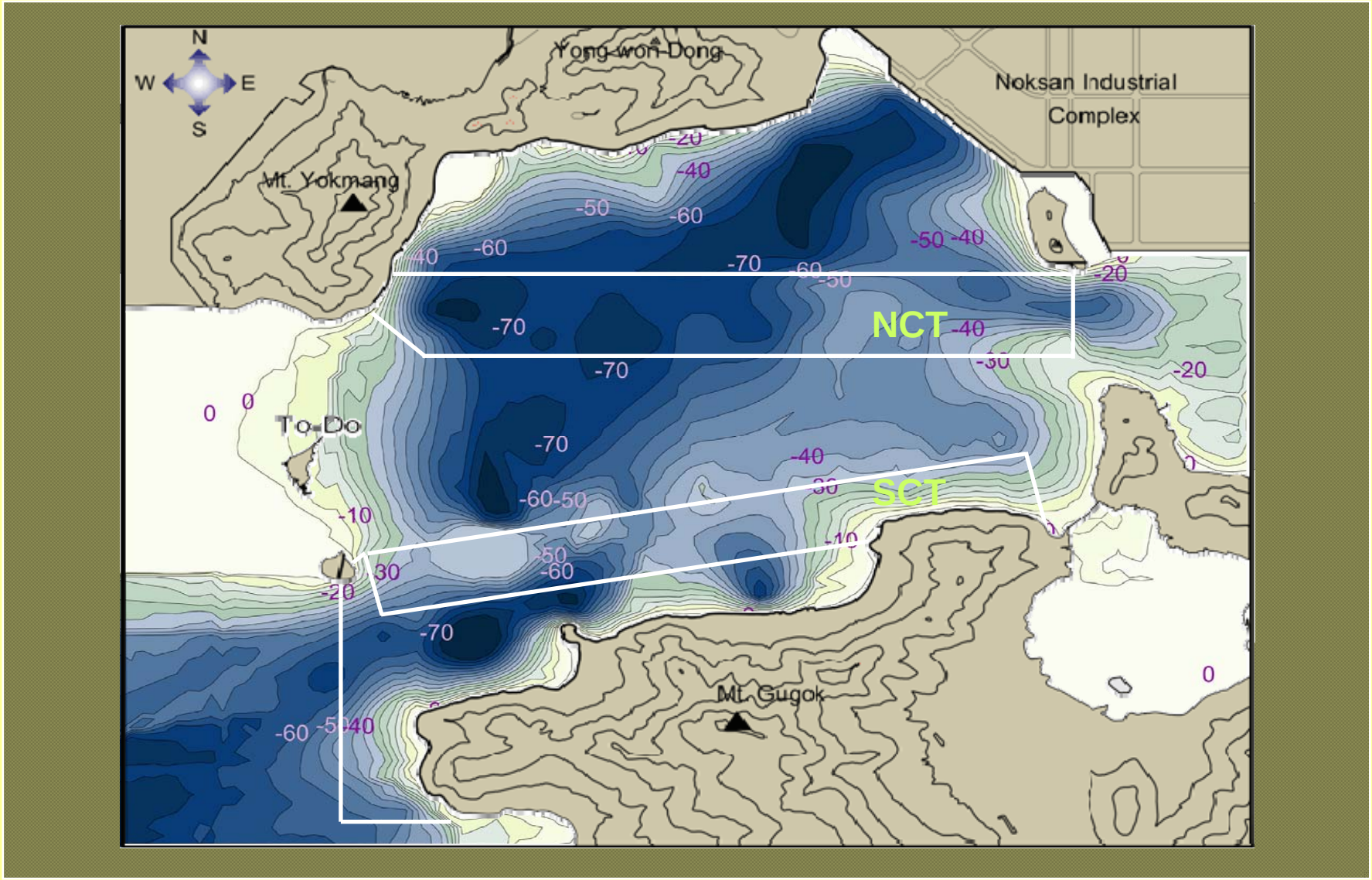


Field and laboratory tests

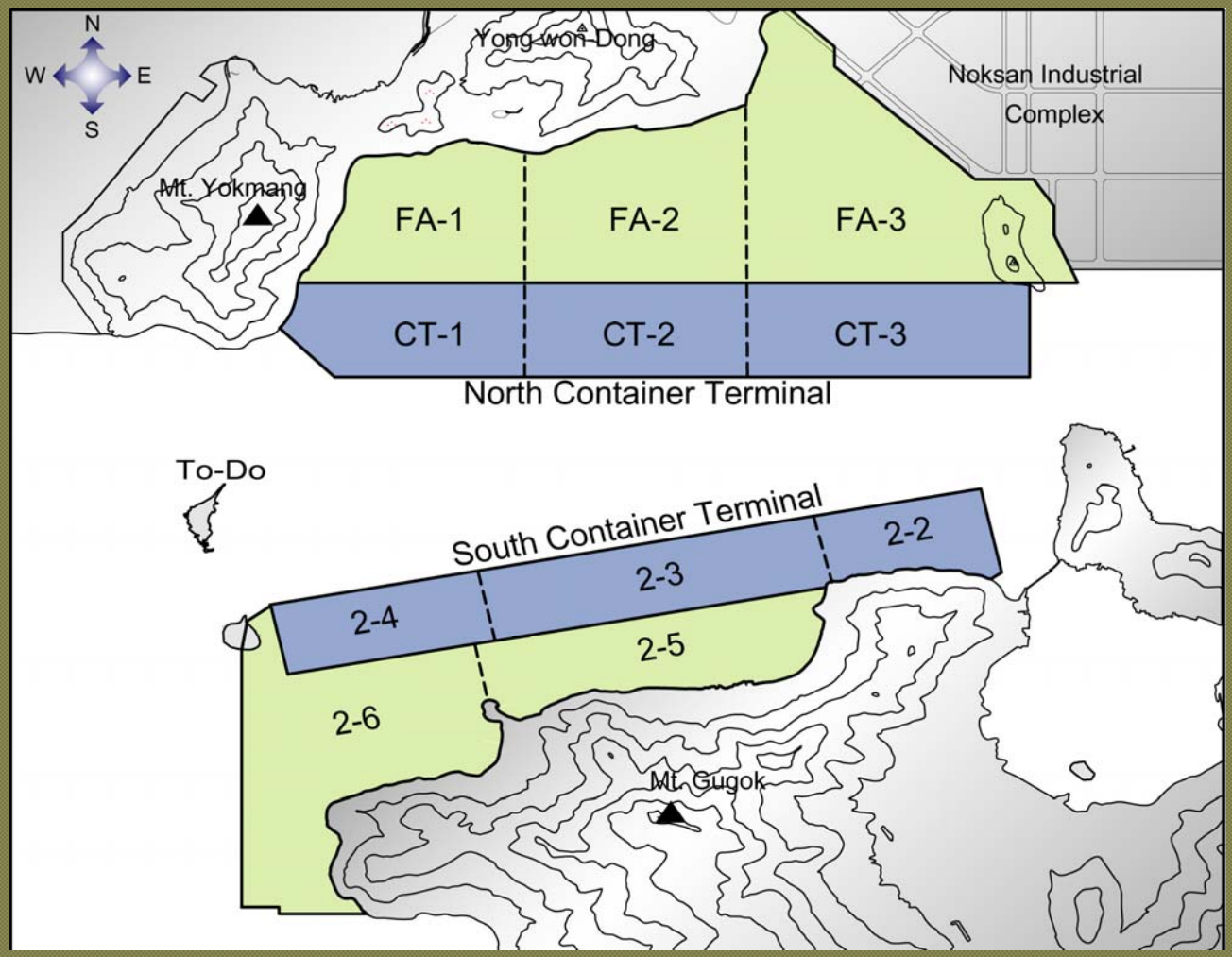
Field Test	Quantity
Exploratory boring	257
CPT(piezocone)	84
Vane shear	108
Pressuremeter	18

Laboratory Test	Quantity
Natural moisture content	969
Sieve analysis	969
Atterberg limit	828
Consolidation	566
Unconfined compression	503
Triaxial compression	610



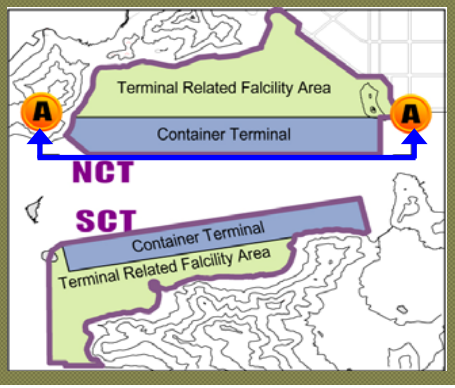

N
W
E
S
Yong-won-Dong
Noksan Industrial Complex
Mt. Yokmang
NCT
To-Do
SCT
Mt. Gugok
-20
-40
-50
-60
-70
0
-10
30

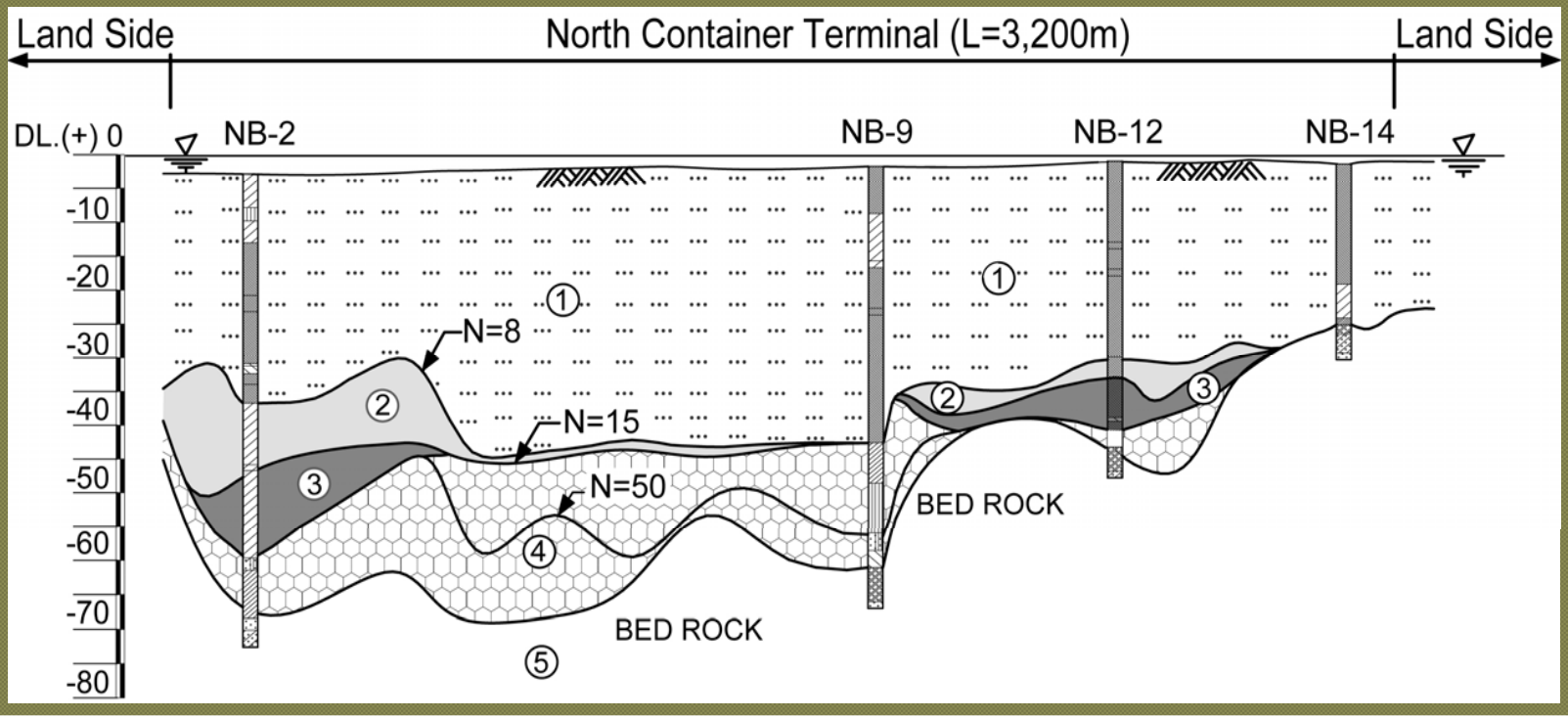
Horizontal zoning Based on subsoil conditions



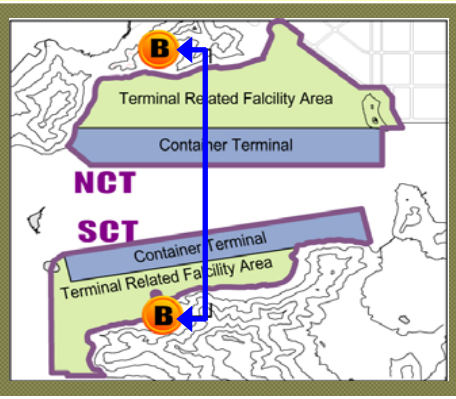
Container Terminal Area Terminal Related Facility Area

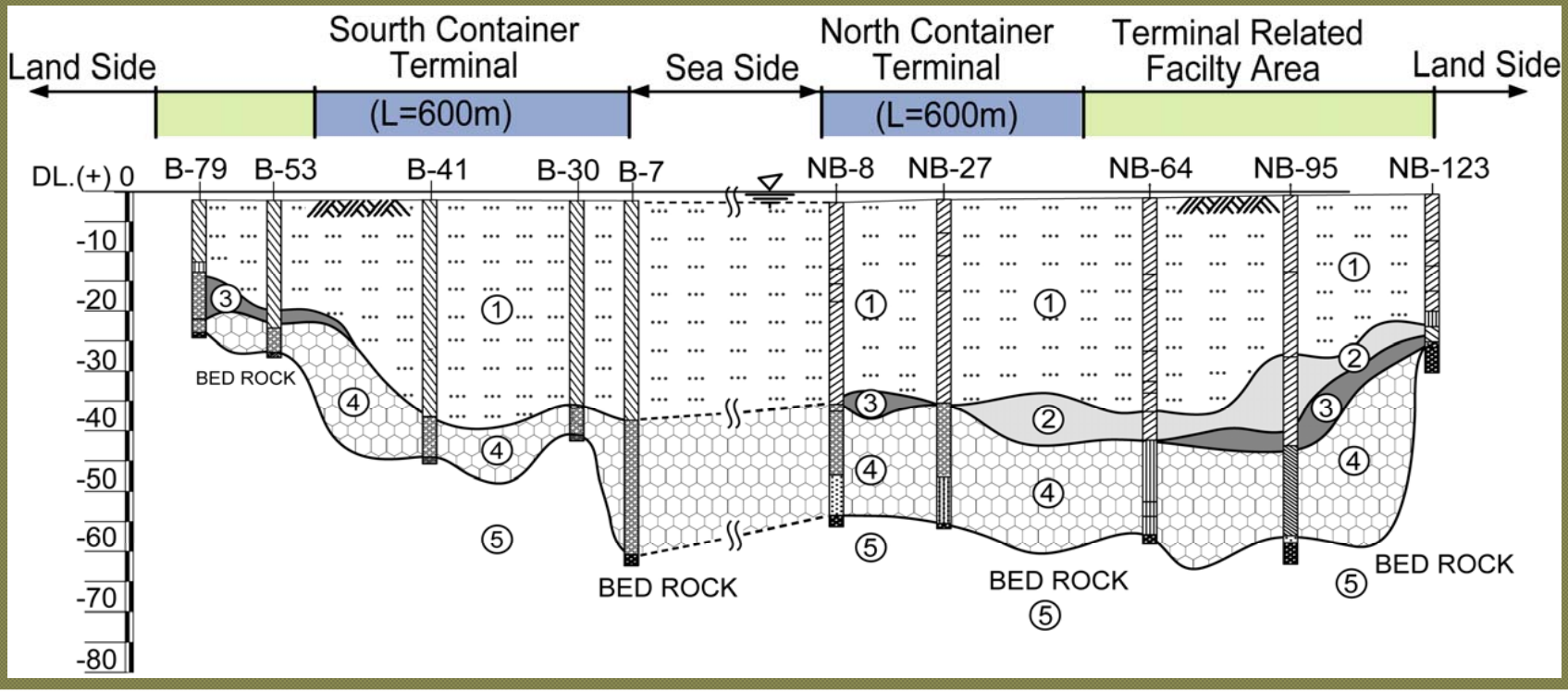
Profile of subsoil (section A-A)





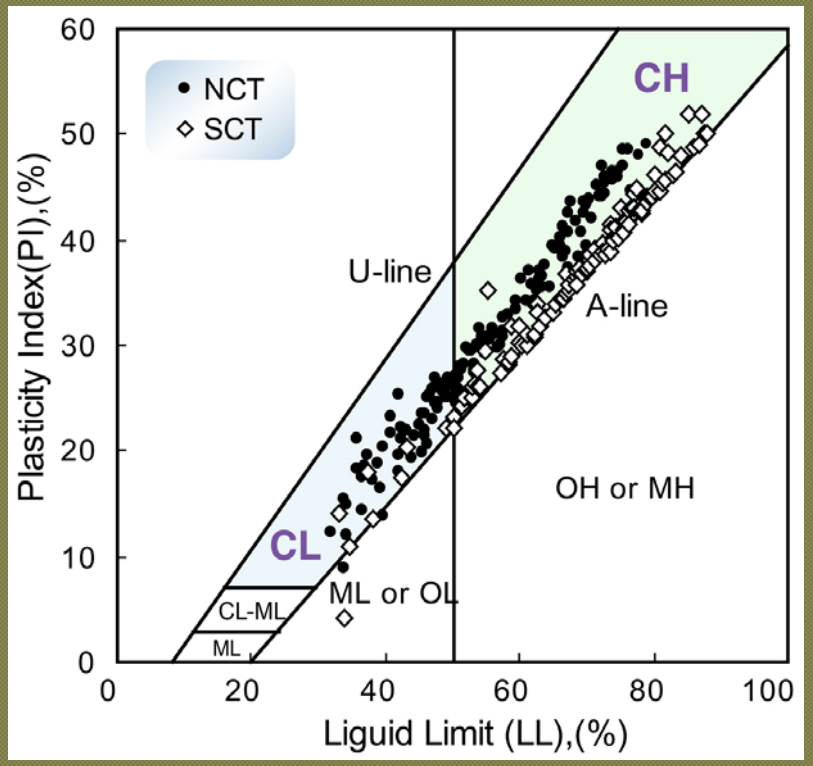
Profile of subsoil (section B-B)



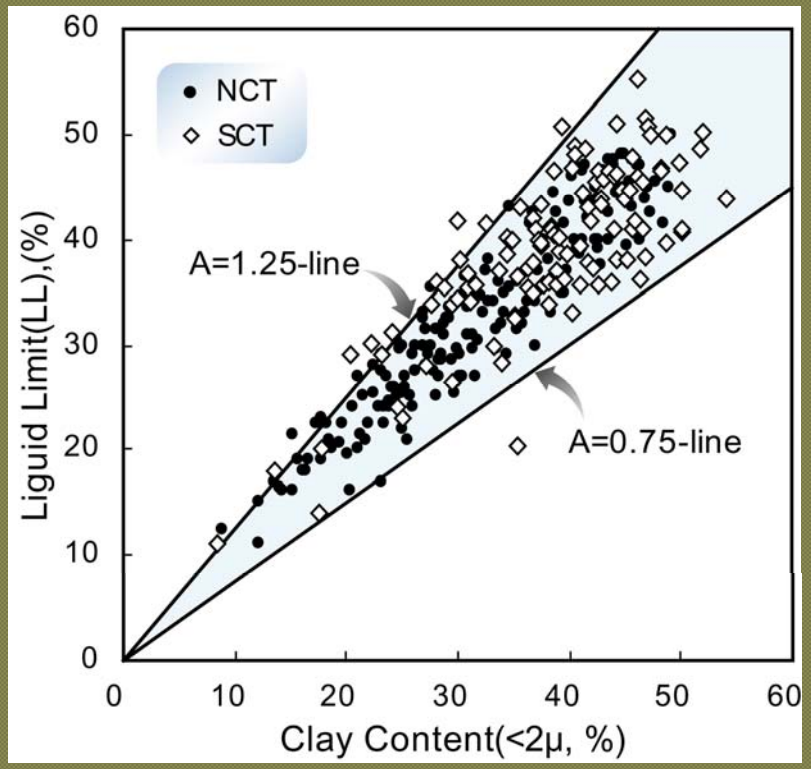


Plasticity chart & activity

Plasticity chart

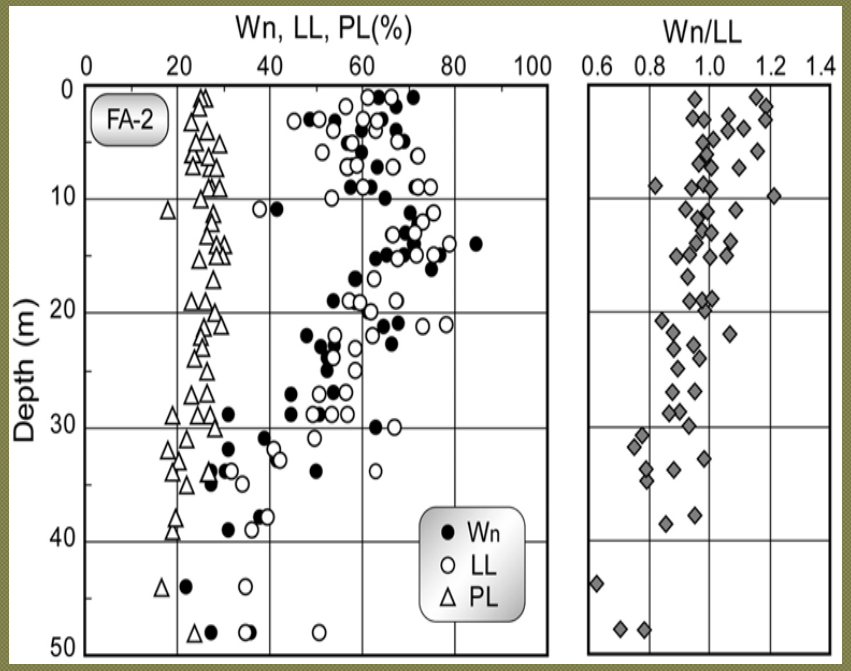


Activity

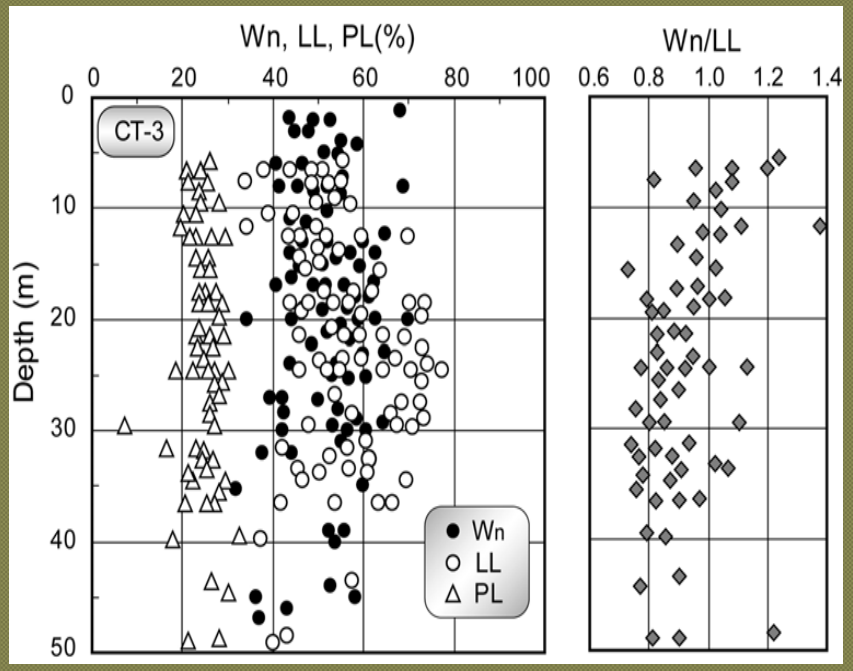


Atterberg limits with depth

FA-2

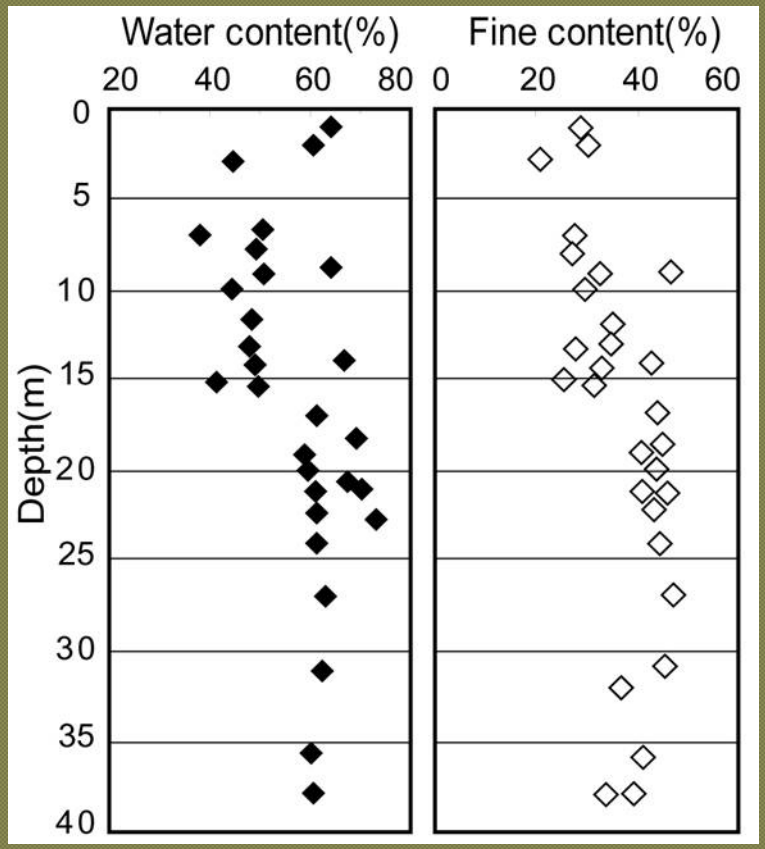


CT-3

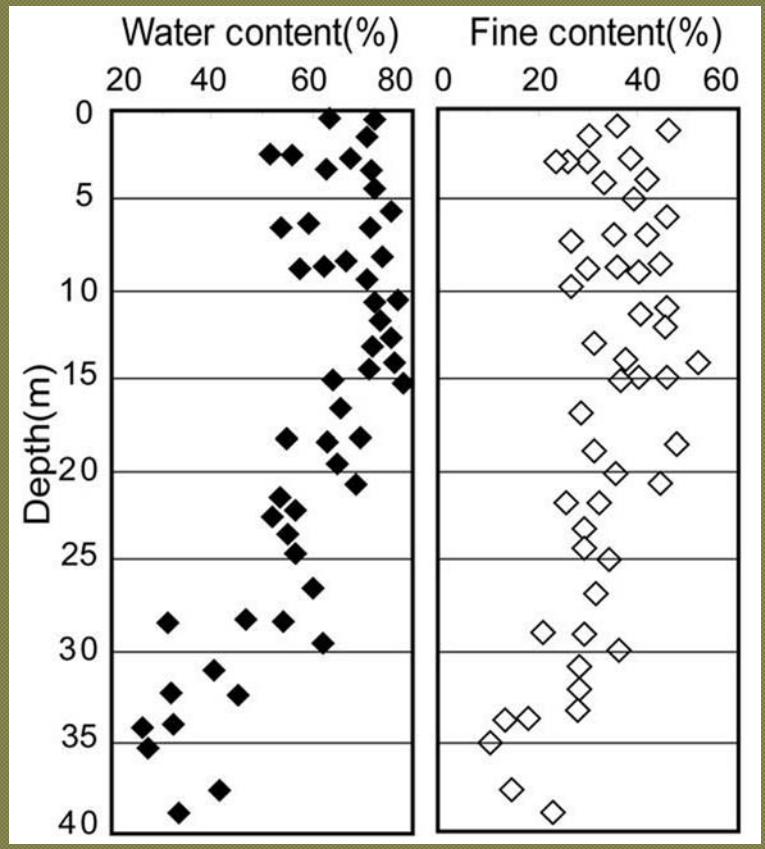


Variation in water content and fine content

CT-2

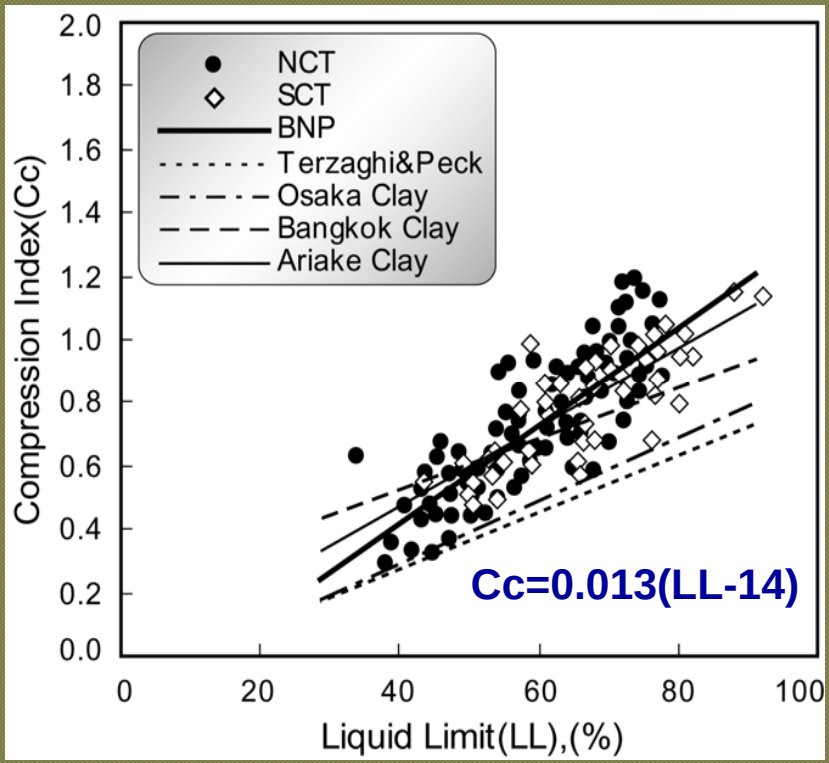


FA-1

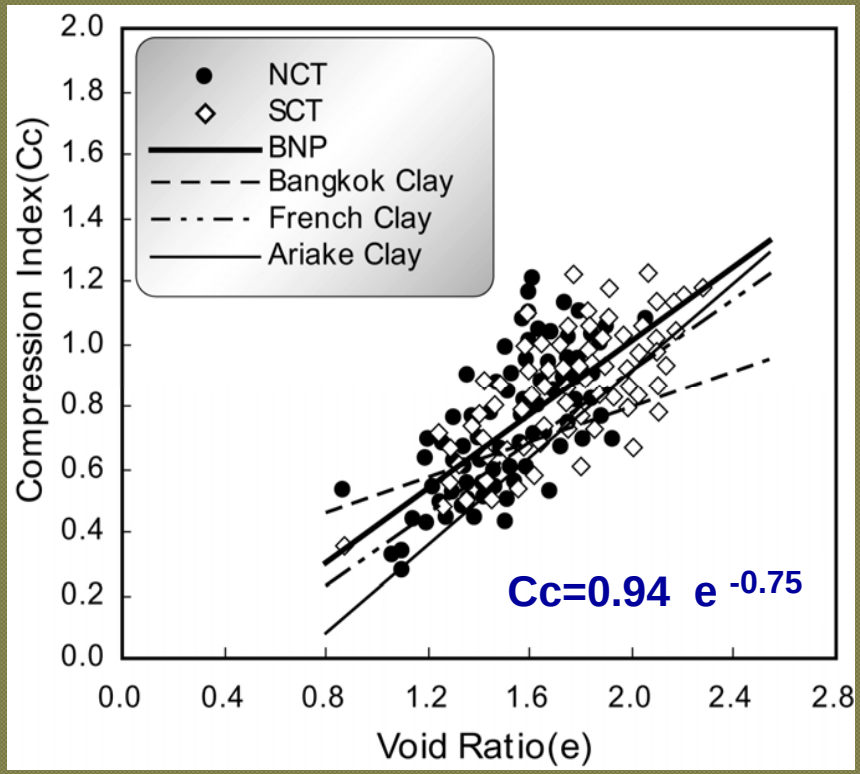


Compression Indices with LL and e

Cc - LL

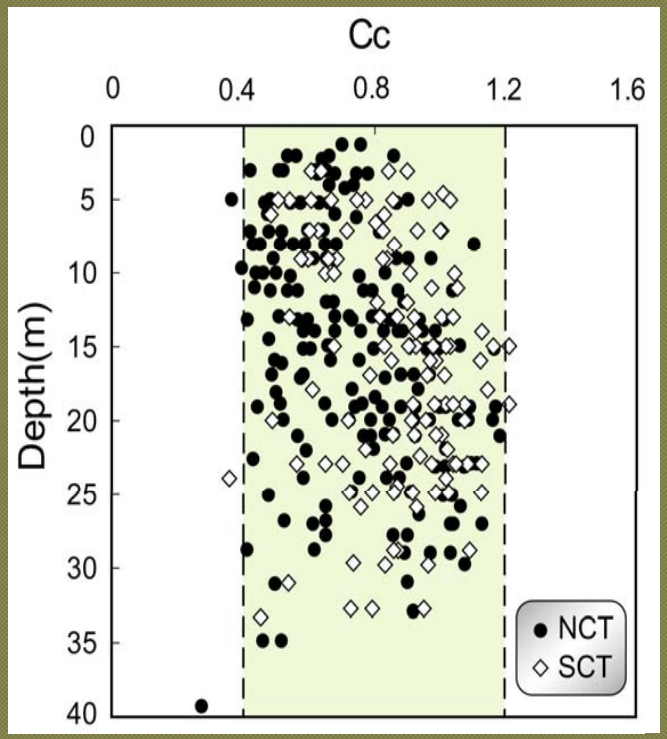


Cc - e

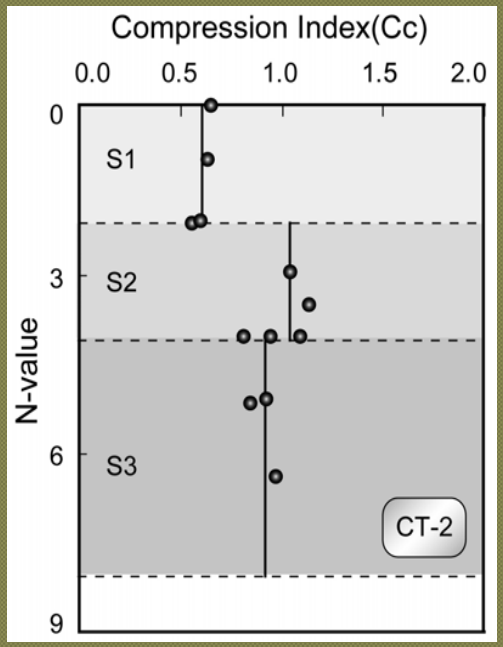


C_c values obtained from NCT & SCT sites

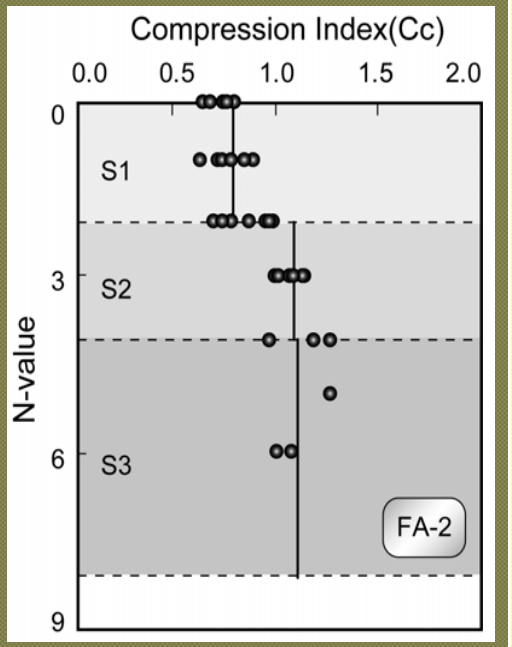
NCT+SCT



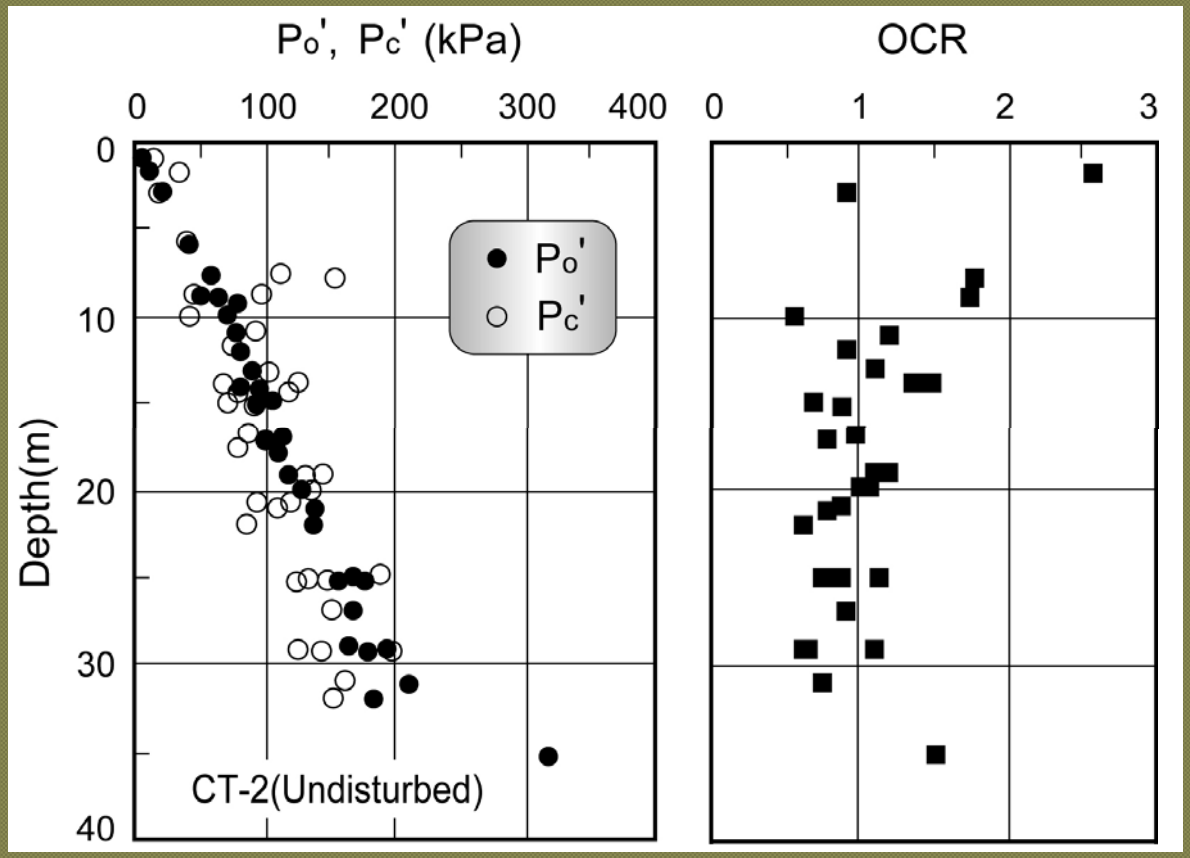
CT-2



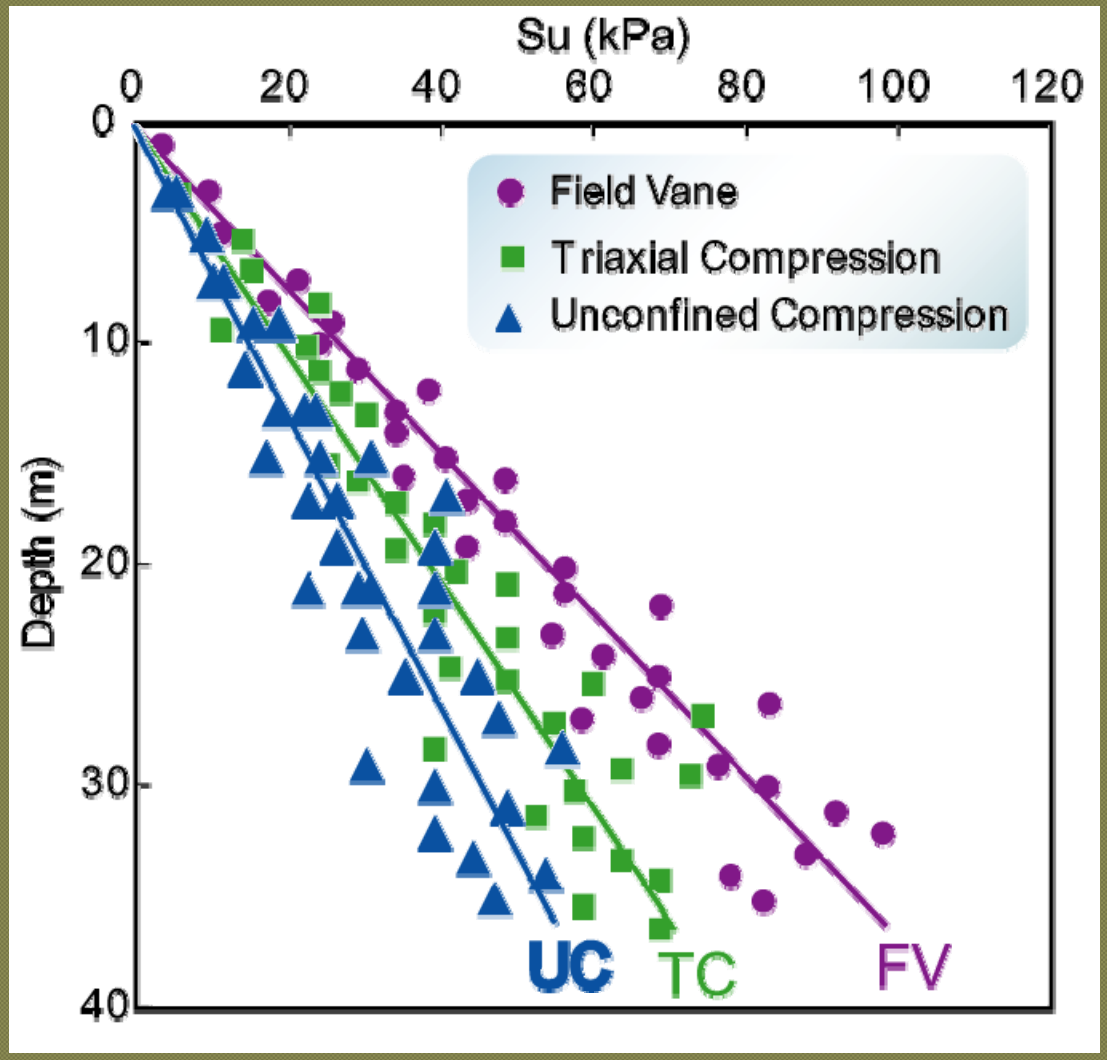
FA-2



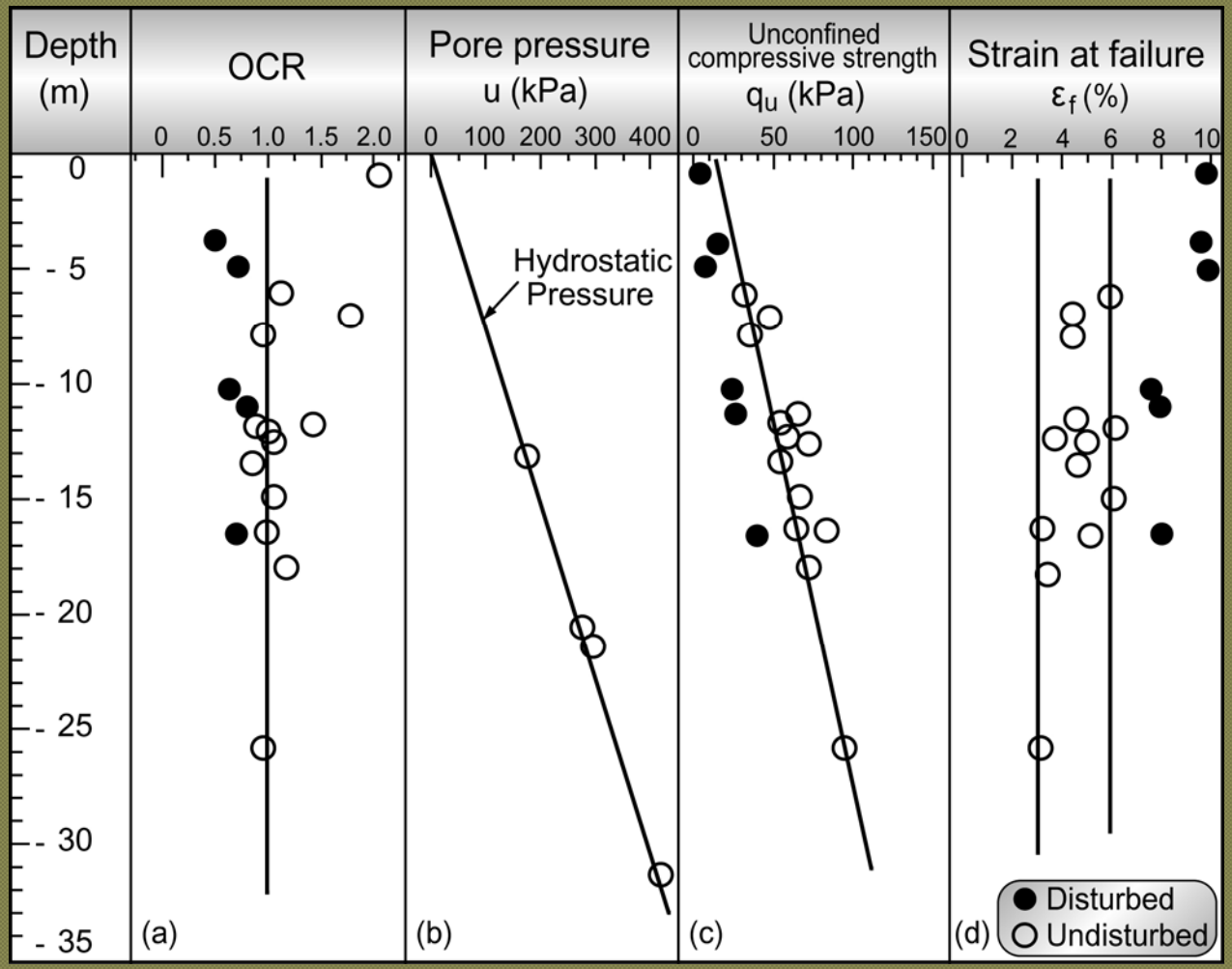
Po´, Pc´ and OCR values with depth



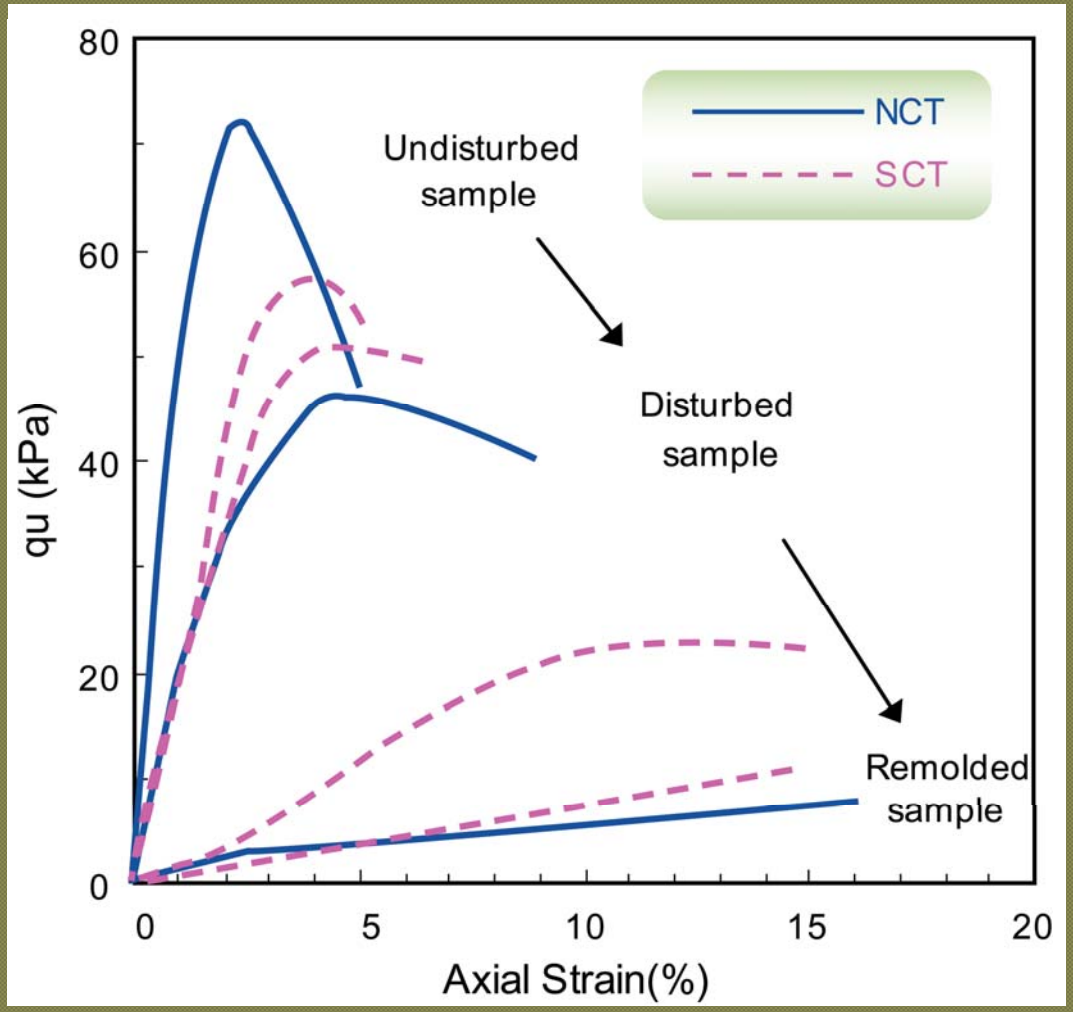
Su obtained from different test devices



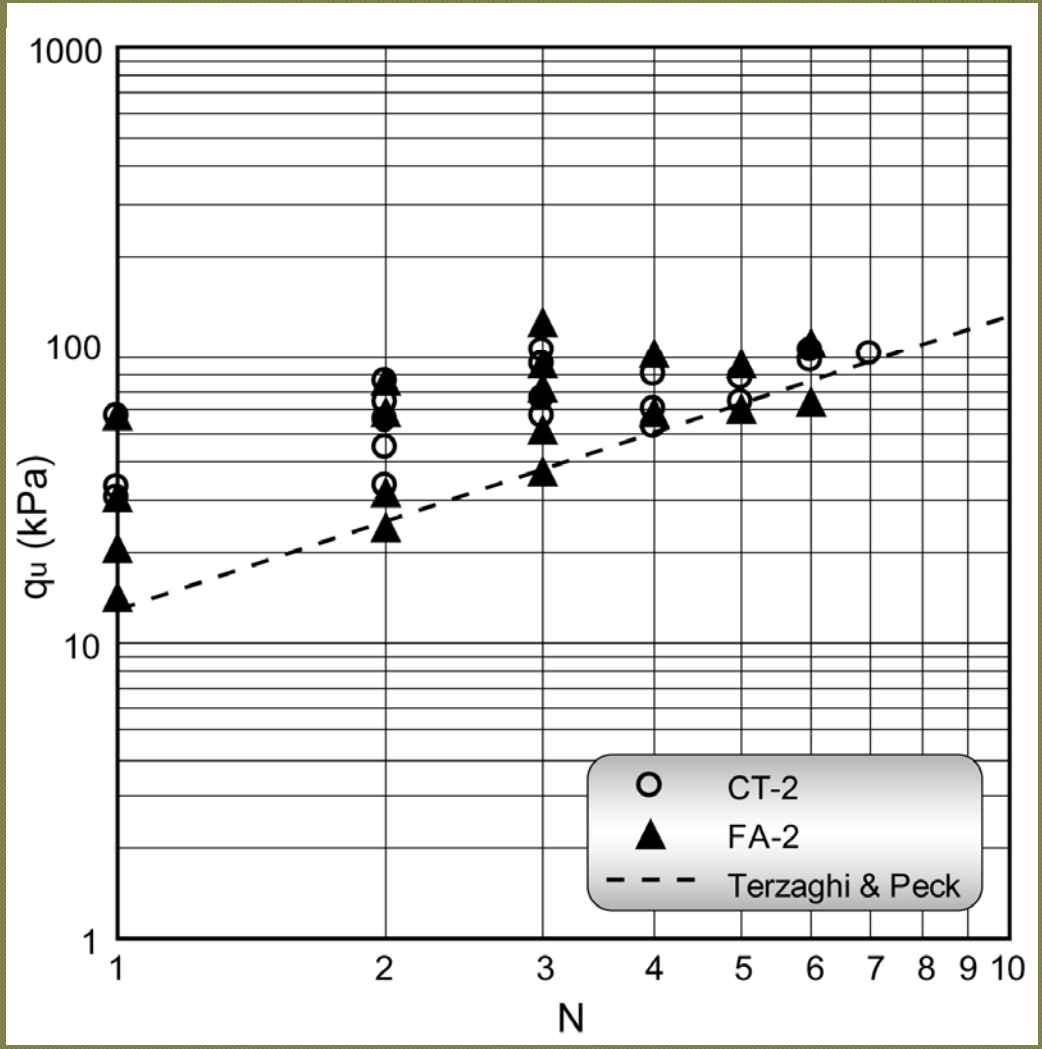
Variation of OCR, u, q_u and ε_f



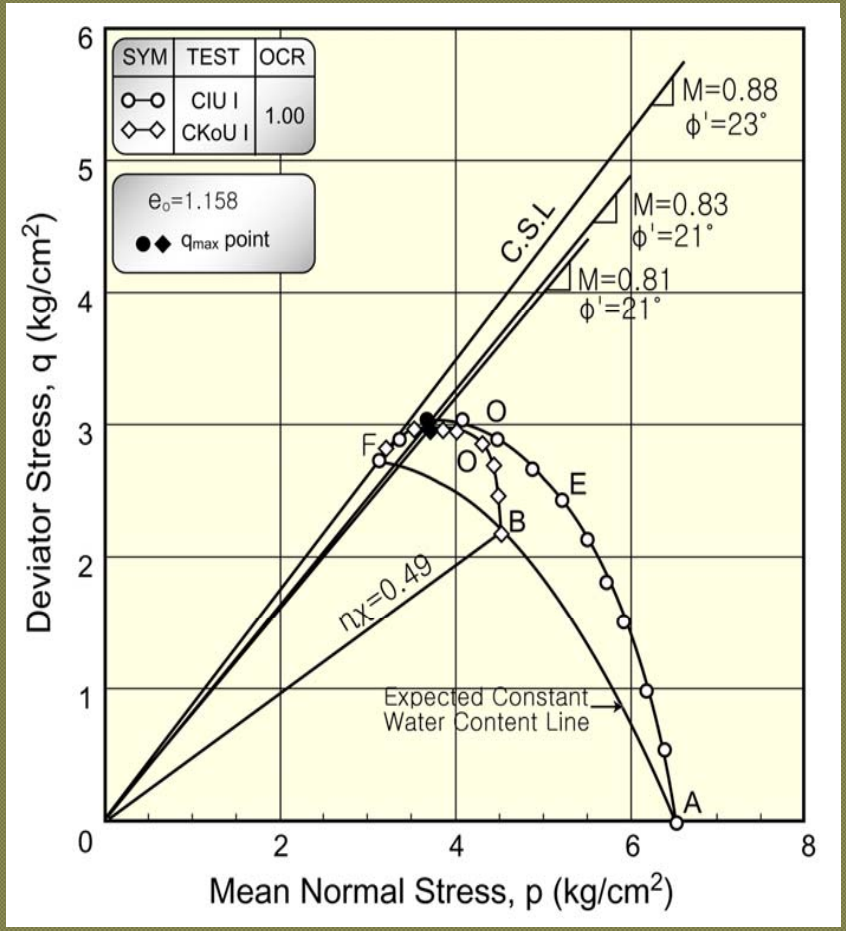
q_u and axial strain in NCT & SCT regions

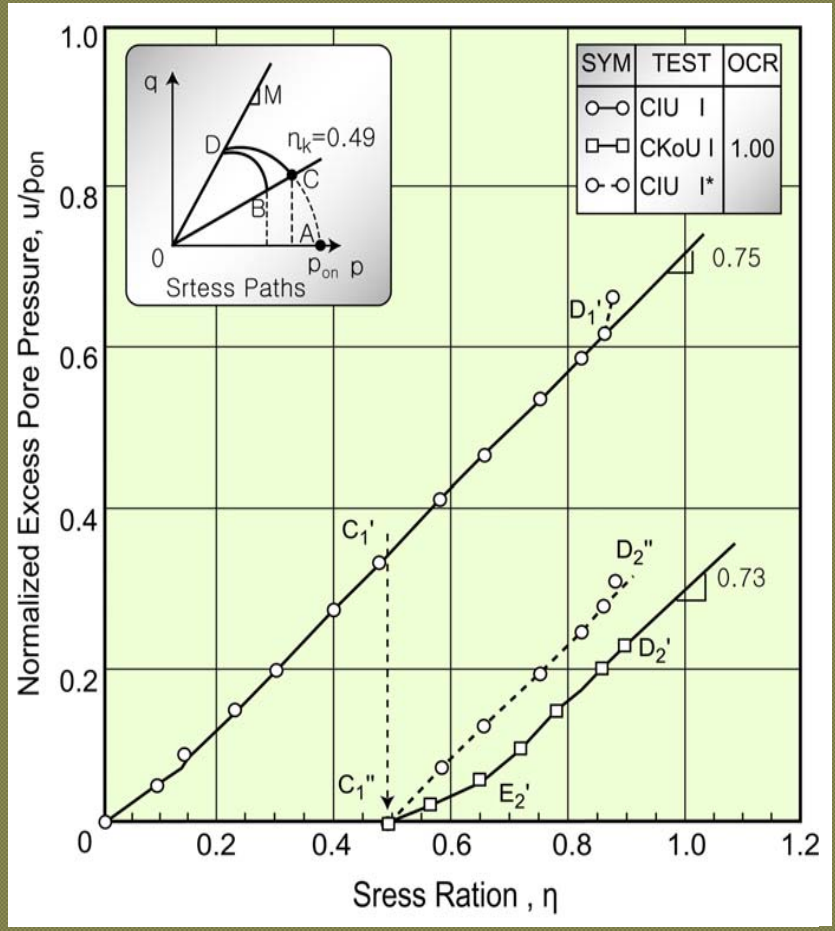


Relationship between qu and N values



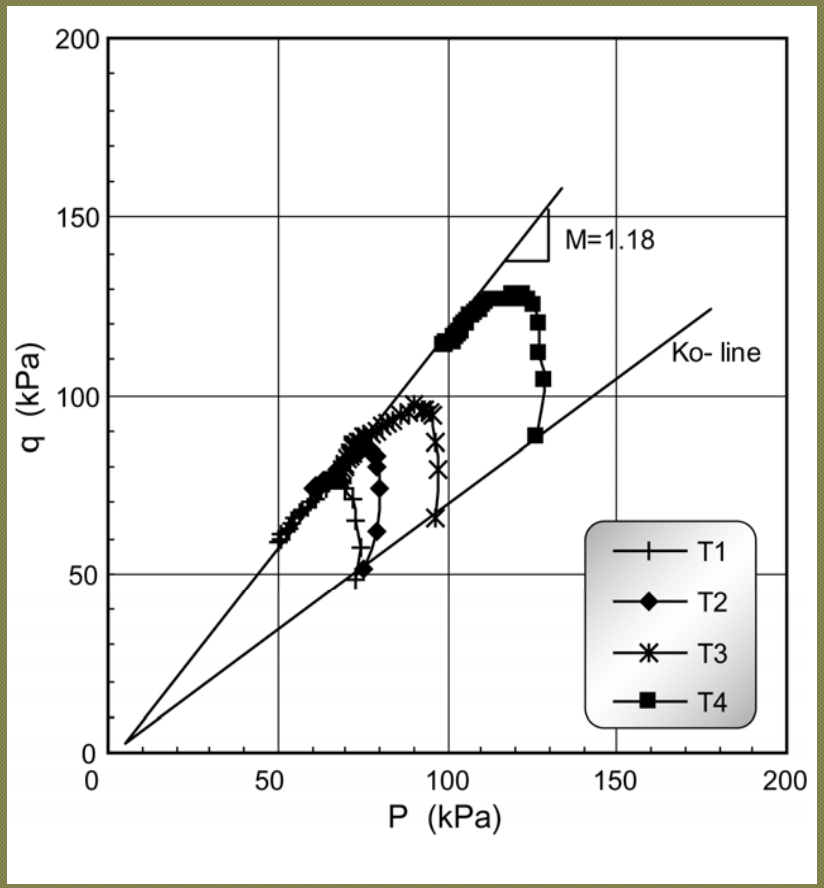
u/p_{on} vs. q/p relationship from N.C. Bangkok clay

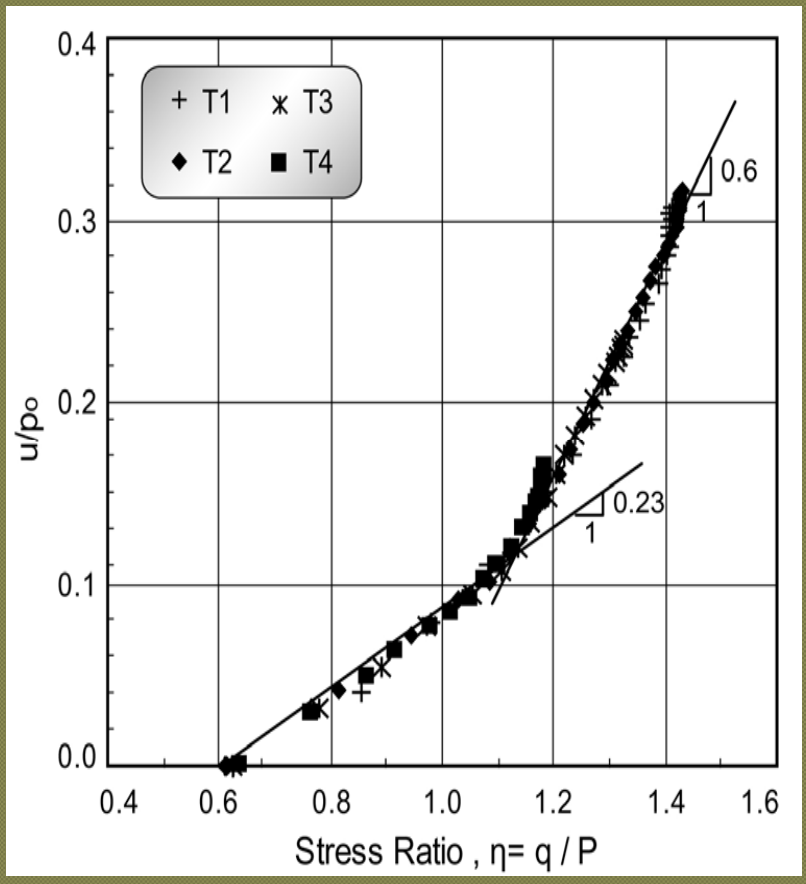




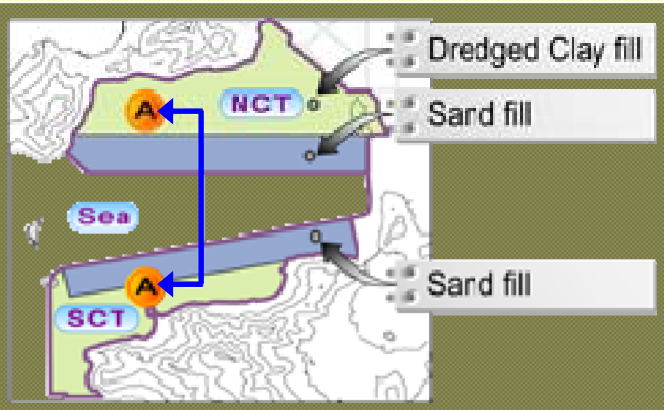
(Kim, S.R.,1991)

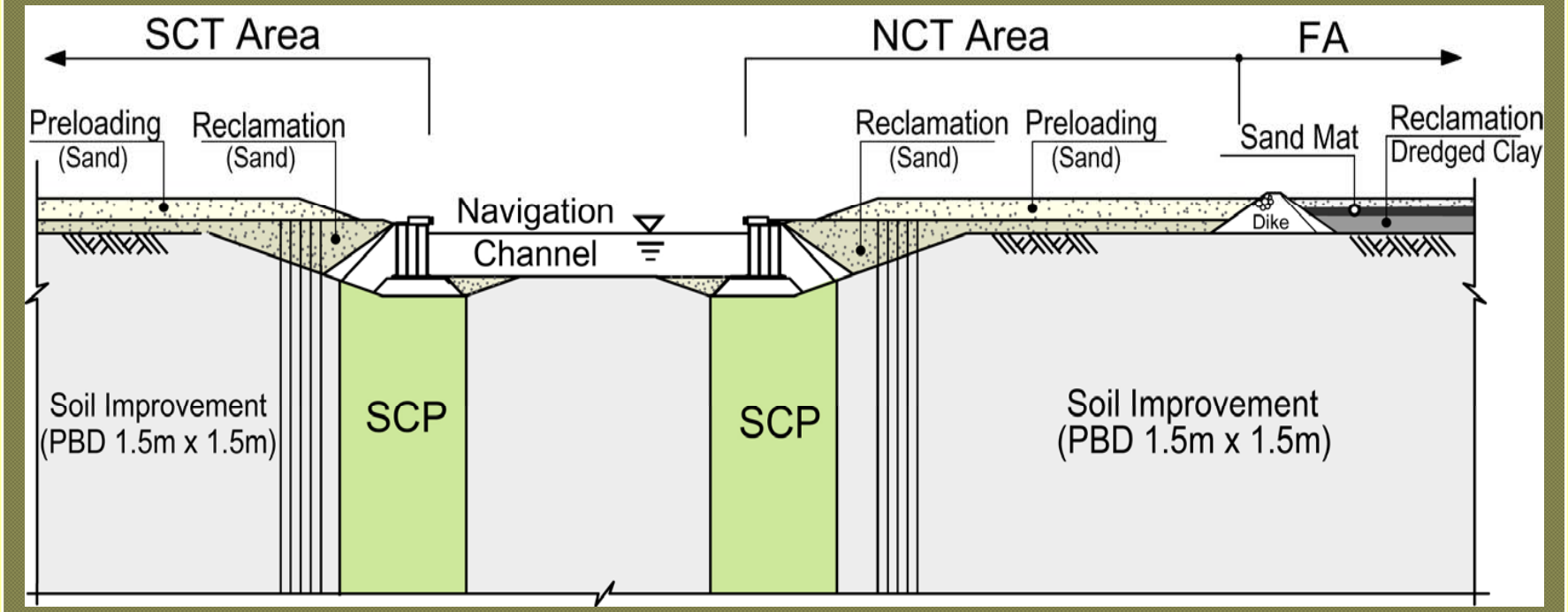
u/p_{on} vs. q/p relationship from CKoU tests



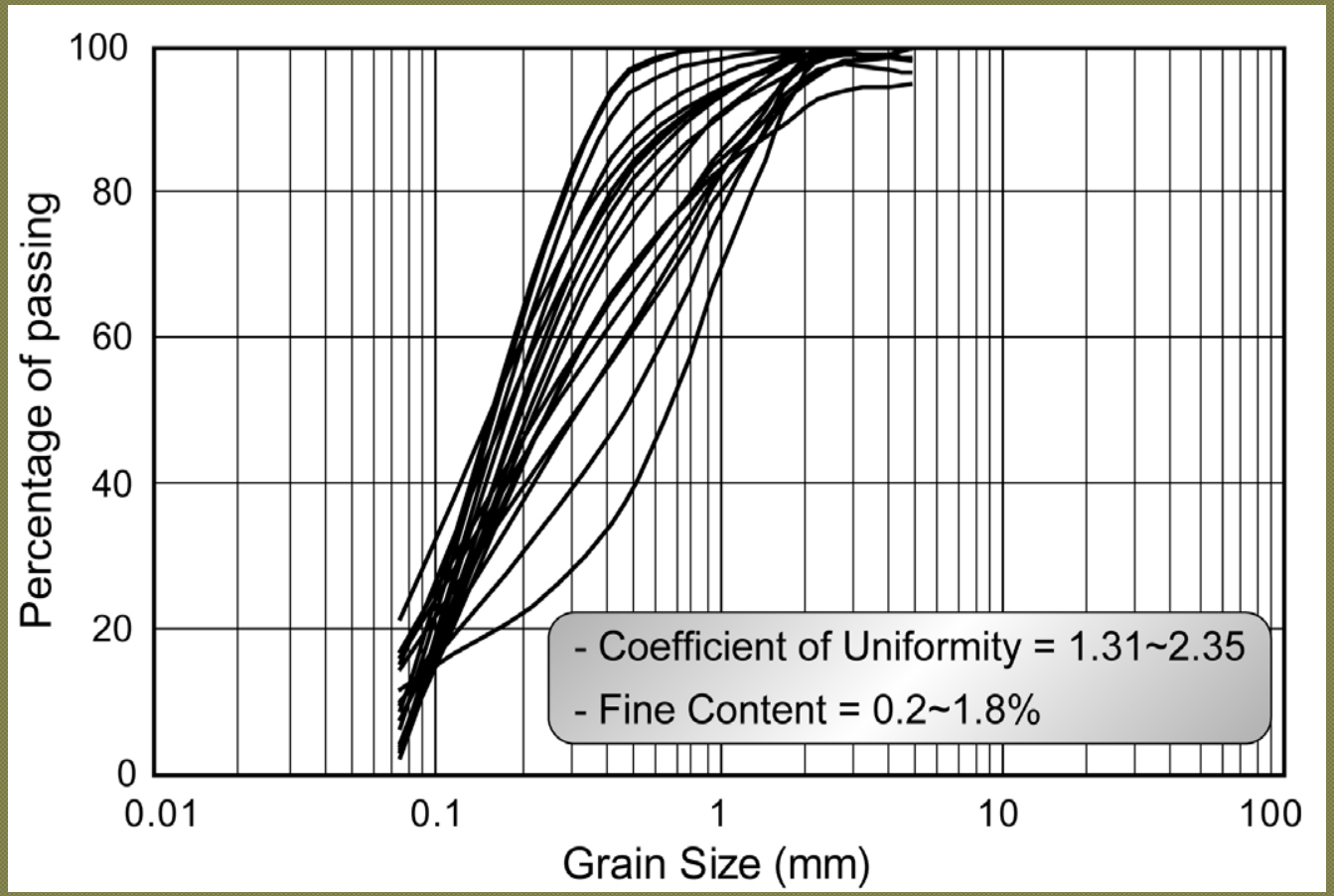


Typical section of BNP after reclamation

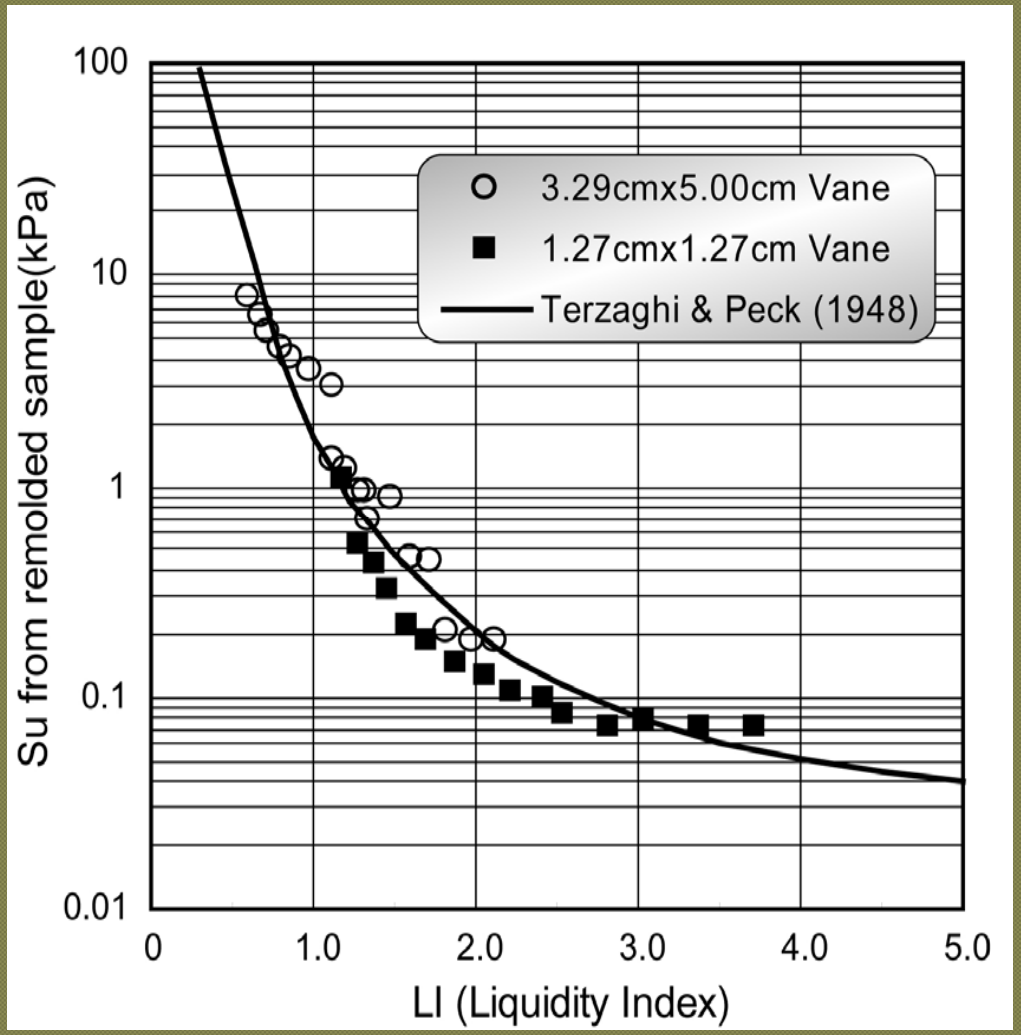




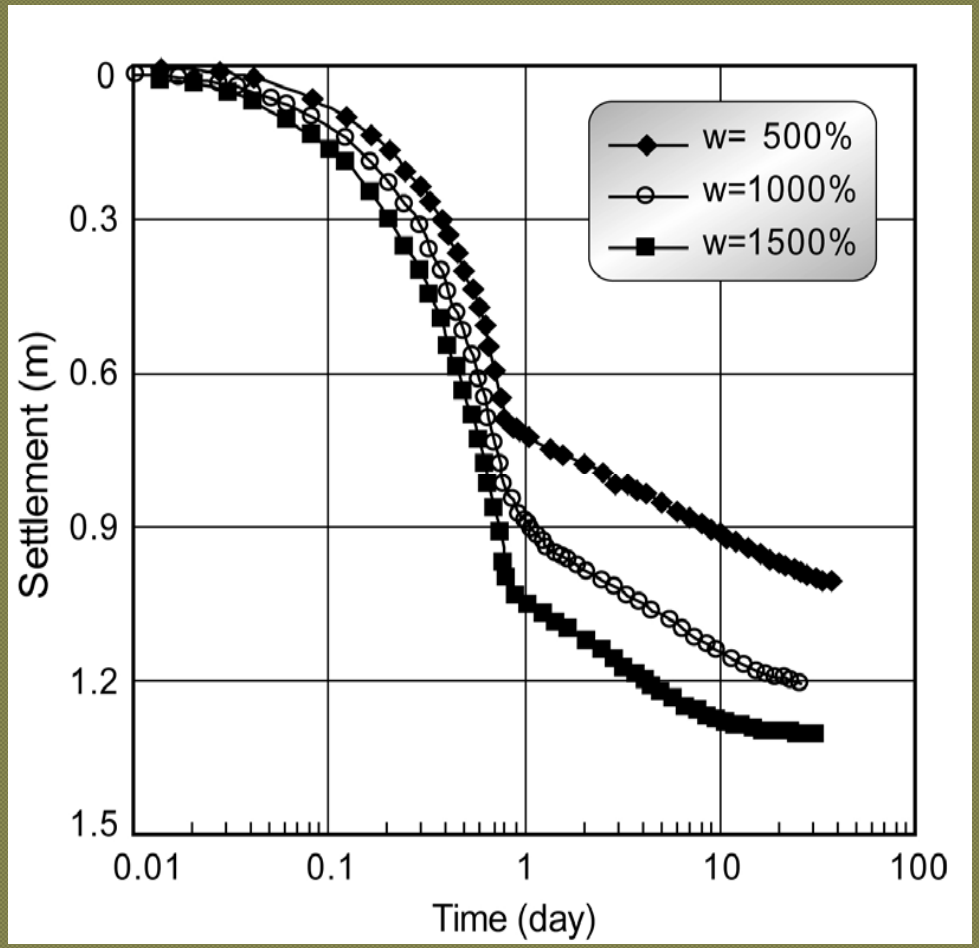
Grain size distribution of sand fill material



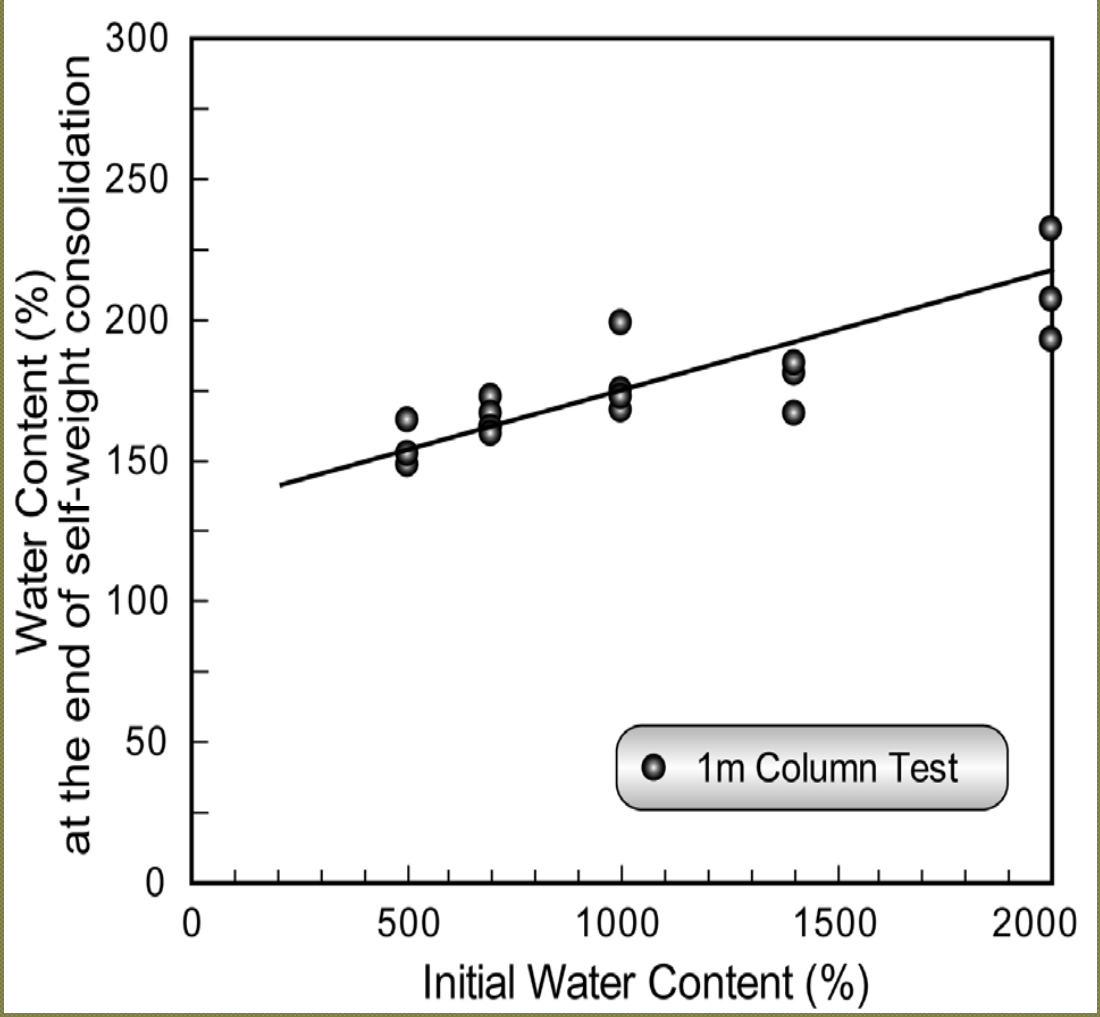
Su of remolded clay with liquidity index



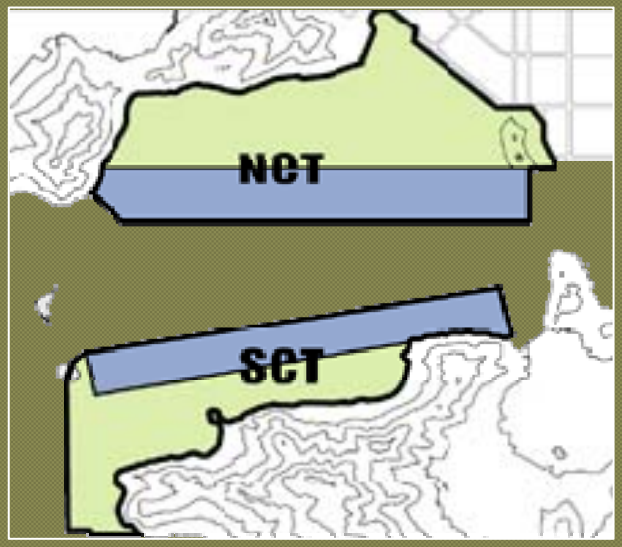
Settlement curves of clay particles with time



Effect of initial water content



Design loads and allowable settlements

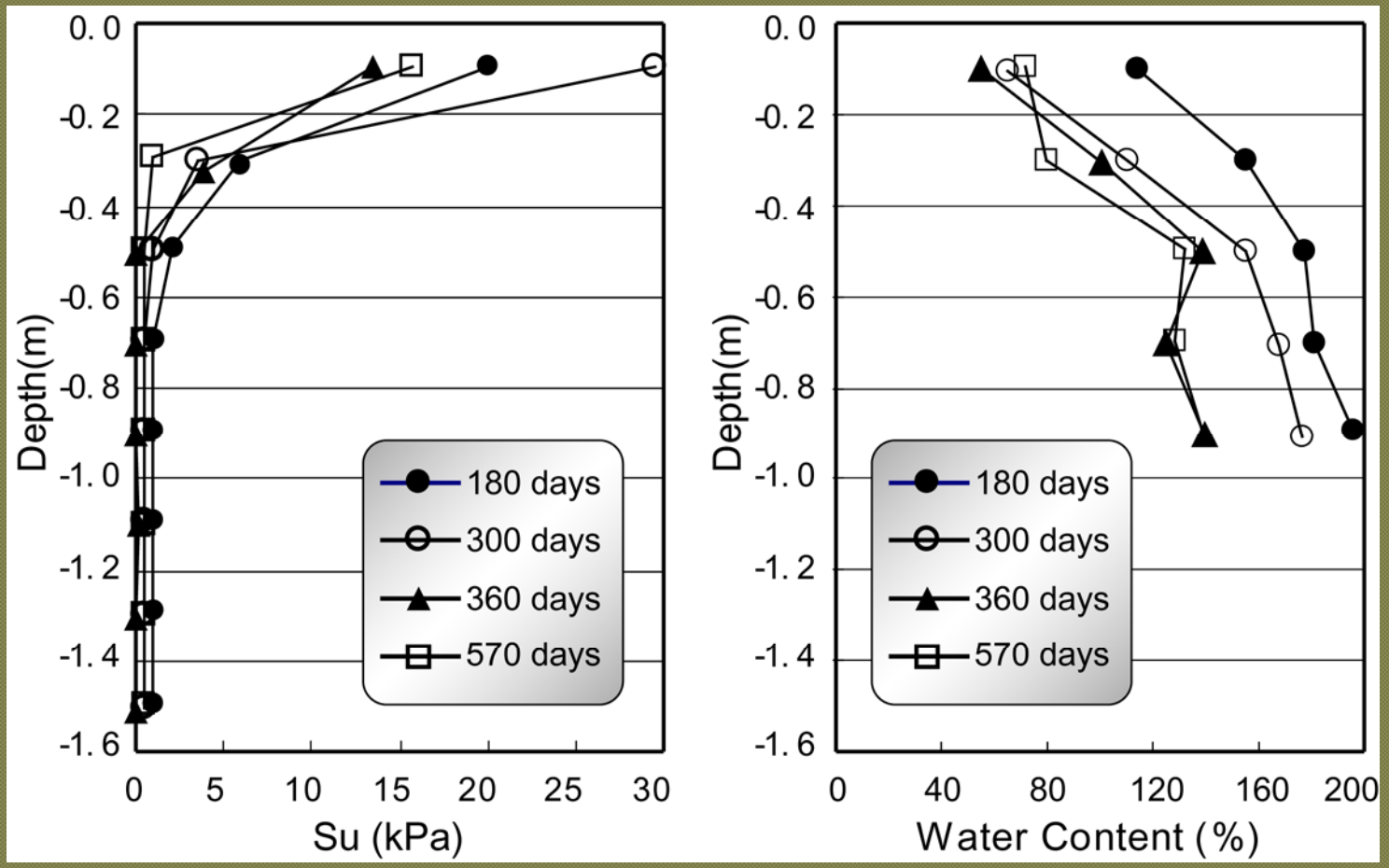


Container Terminal Area

Terminal Related Facility Area

Location	Operation load (kPa)	Allowable settlement (cm)
Container Terminal Area	30	10
Terminal Related Facility Area	15	30

Su & ω of dredged clay after application of PTM

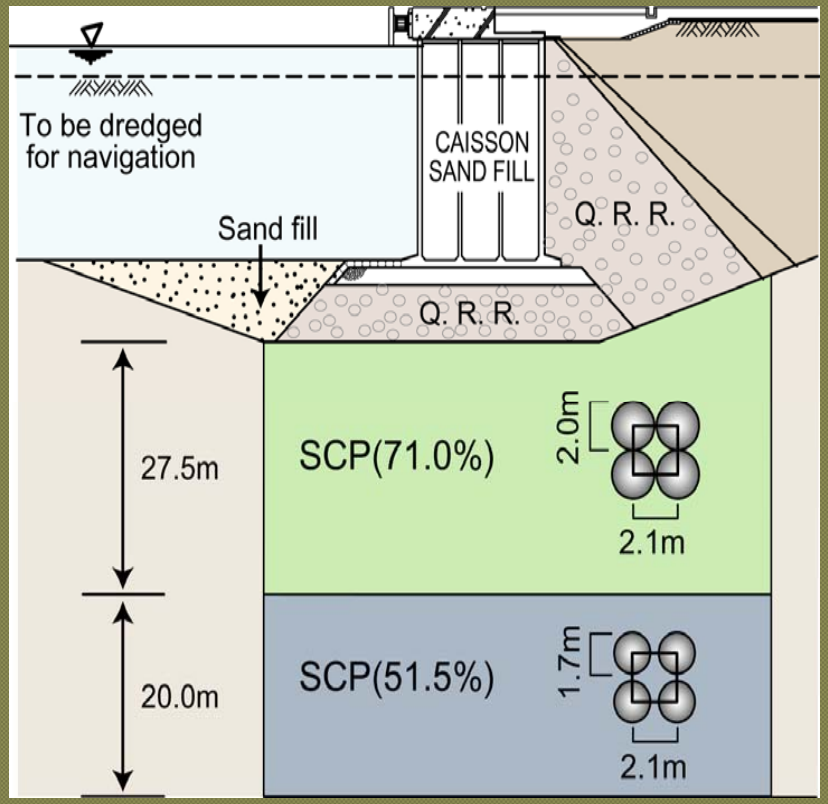


(After Lee, Y.N. & Lee, S.W., 2003)

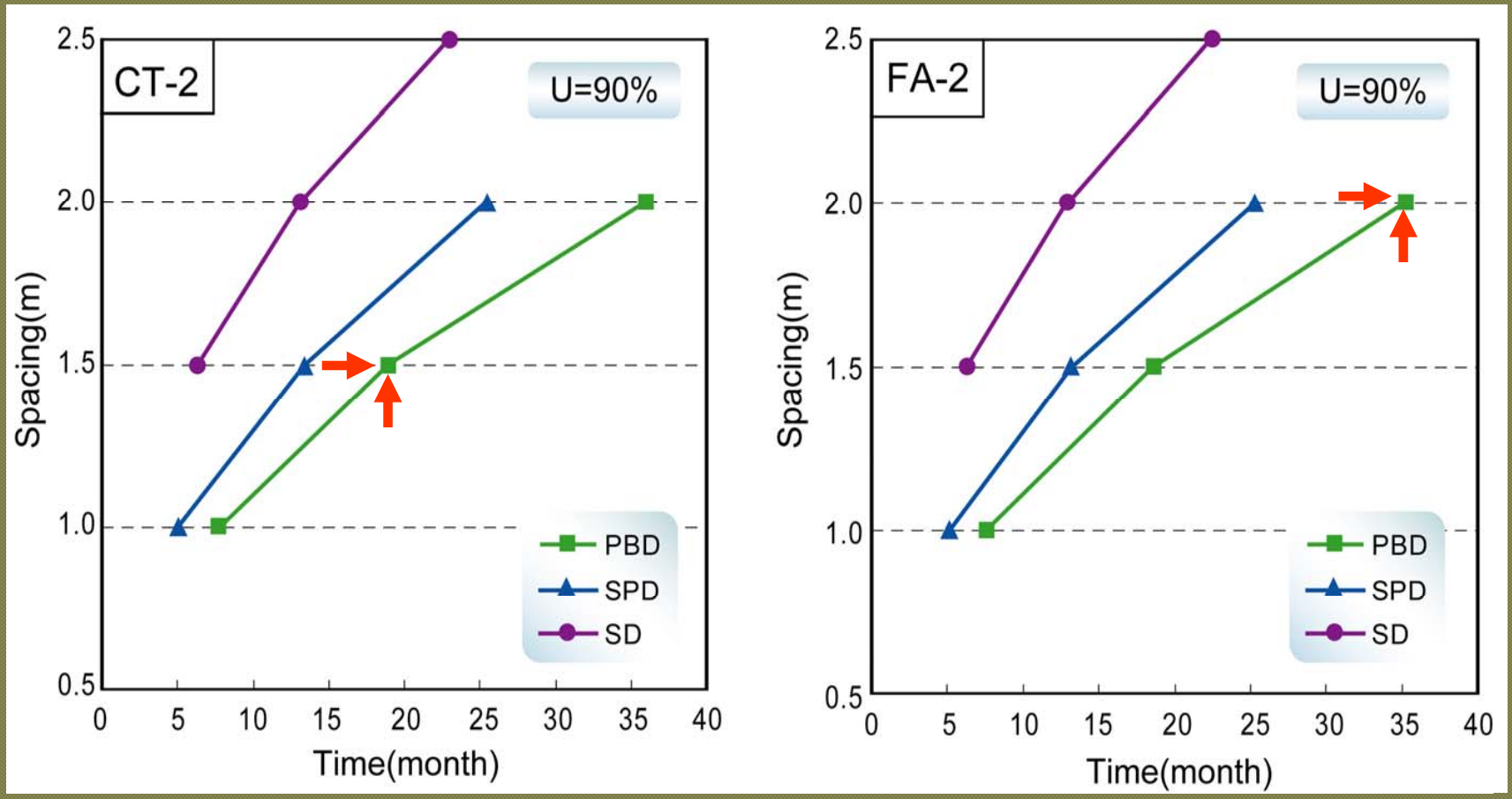
Onsite placement view of bamboo matting

- Surface treatment method of dredged clay

Typical section of quay wall foundation



Consolidation times with drain spacing



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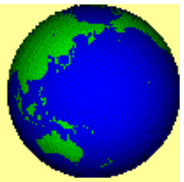
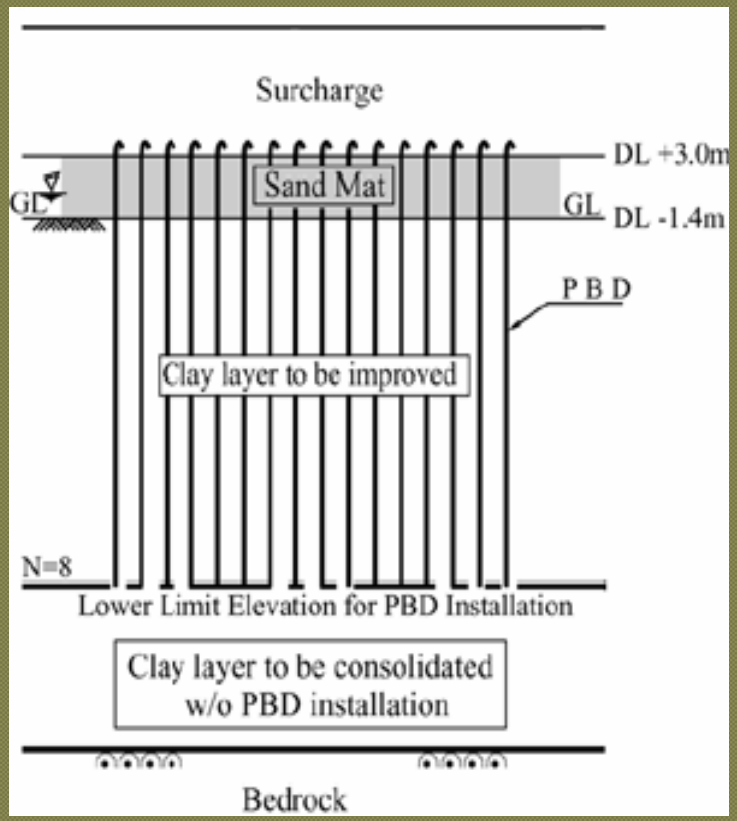
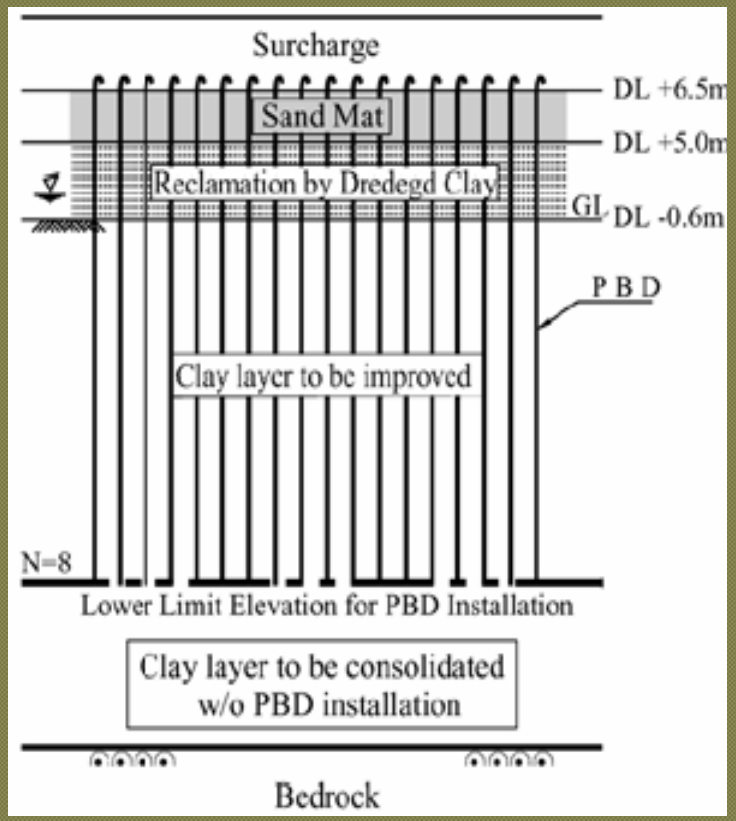


Schematic profiles of PBD installation

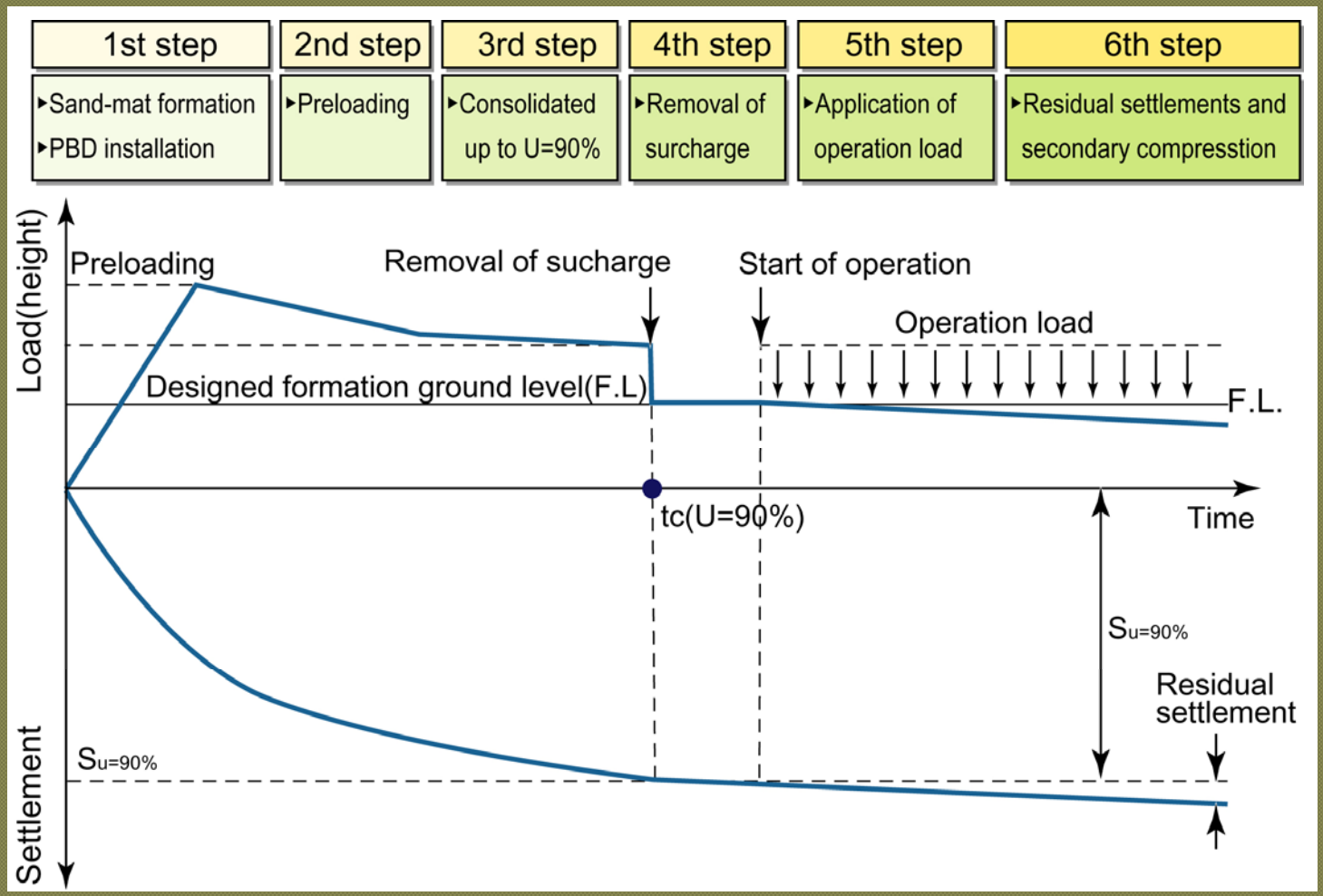
CT-2



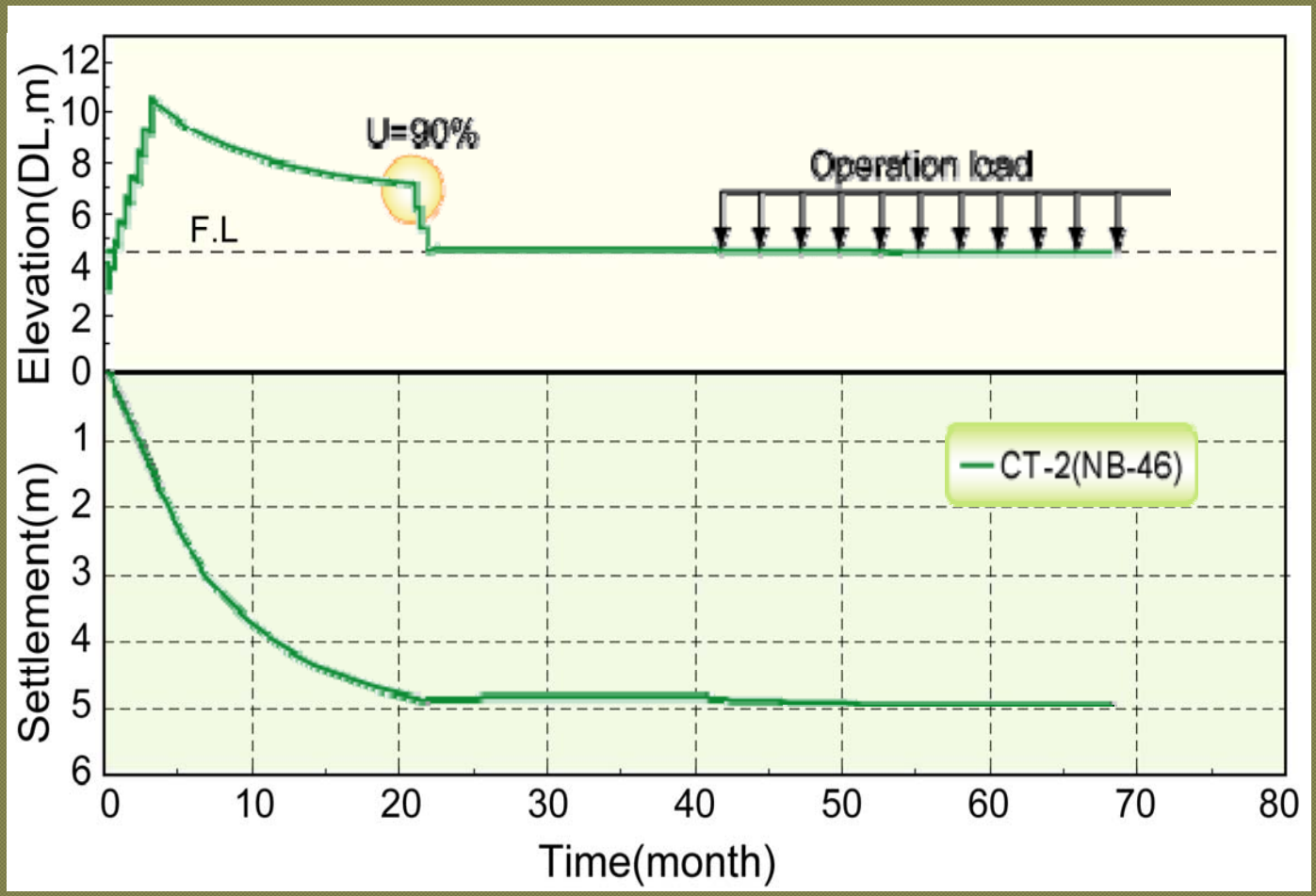
FA-2



Construction steps and settlement curve (CT-2)



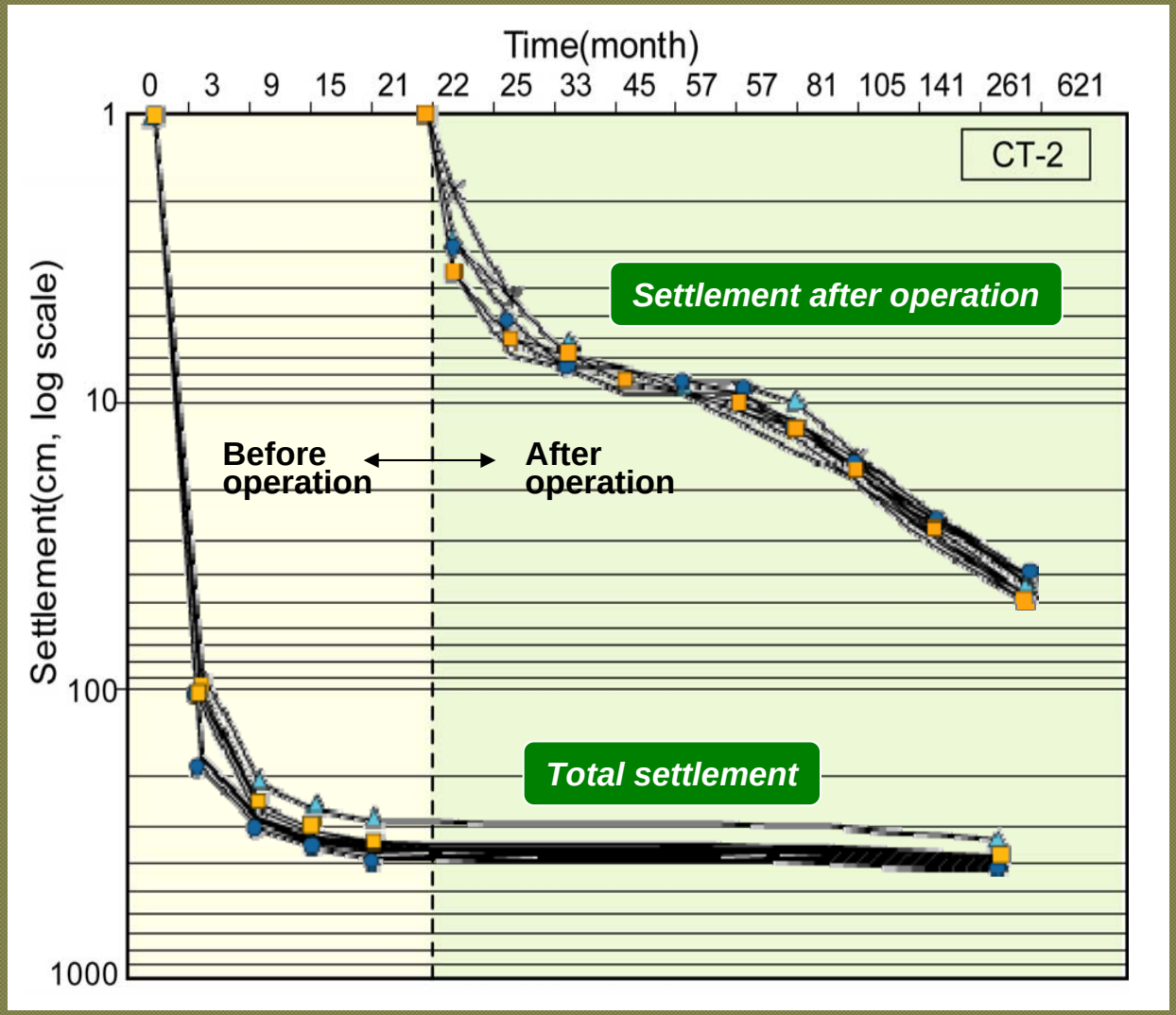
Typical settlement curve (CT-2)



Expected amount of settlement in NCT area

Description		Settlement (cm)		
		CT-1	CT-2	CT-3
Before Operation	U=90%	80~560 (400)	390~570 (490)	80~480 (350)
After Operation	Allowable Settlement	10	10	10
	Settlement w/o PBD	0~26 (14)	0~17 (9)	0~22 (5)
	Secondary Settlement	22~50 (33)	32~47 (40)	3~45 (29)
	Sub Total	57	59	44
Total Settlement		**457**	**549**	**394**

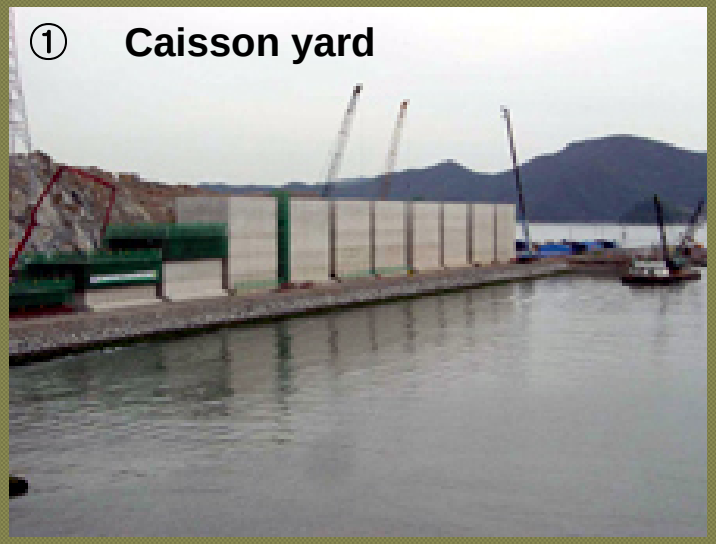
Settlements before and after operation



Installation process of caissons for quay wall

SKIP

① Caisson yard



② Transportation of caisson

③ Placement of caisson

④ Preloading of caissons

① Caisson yard

SKIP

② Transportation of caisson

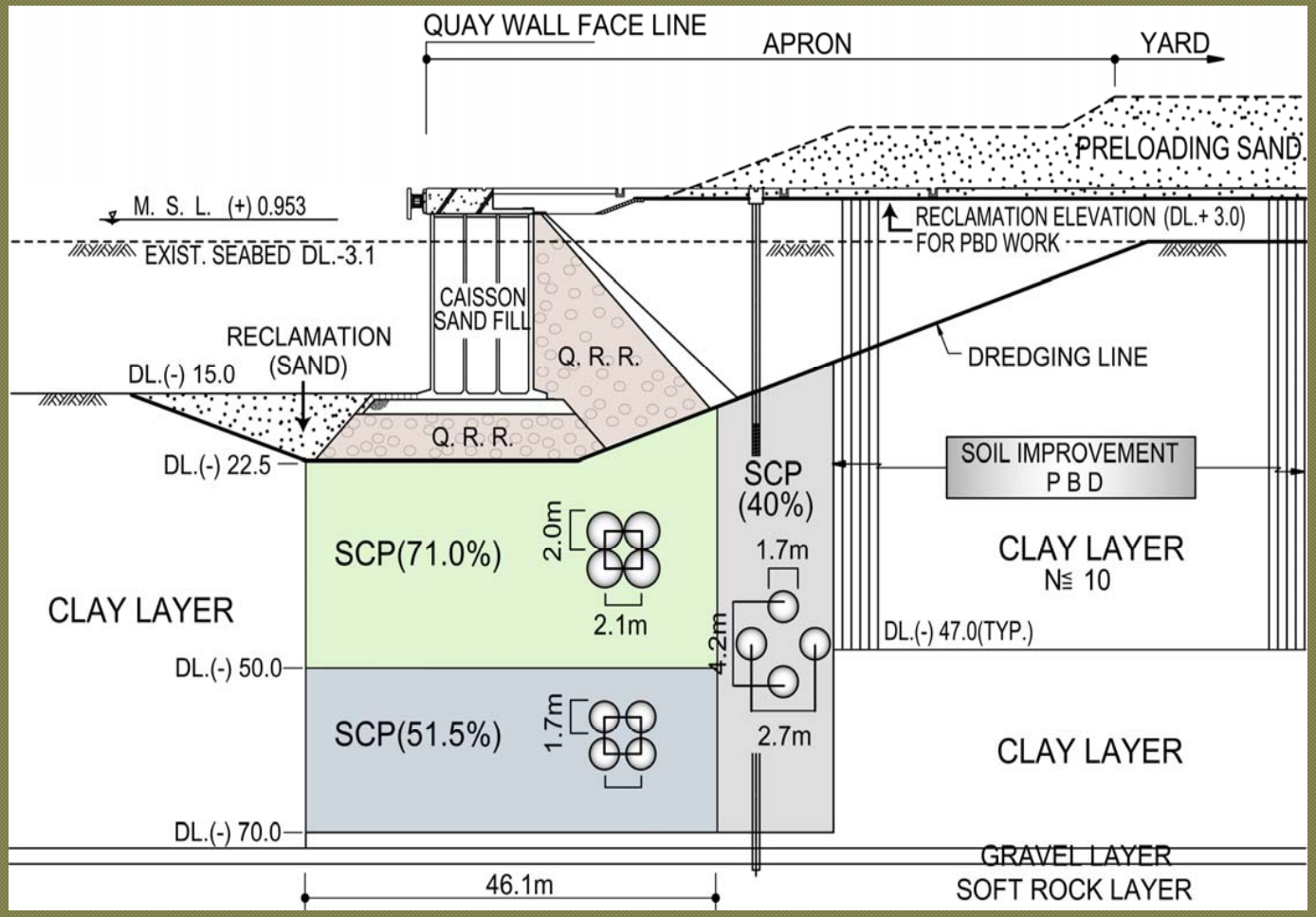
SKIP

③ Placement of caisson

SKIP

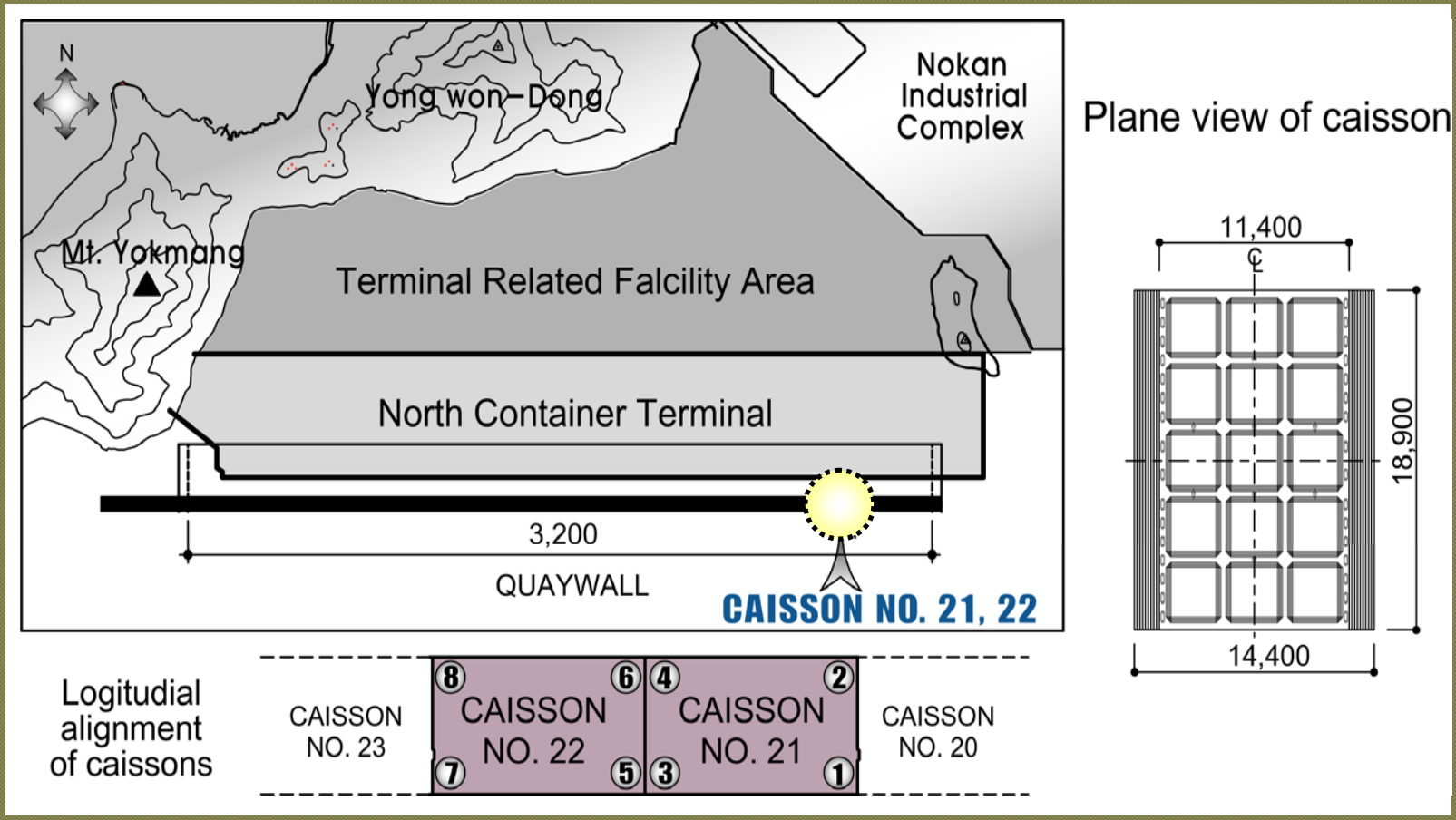
④ Preloading of caissons

Typical cross section of quay wall foundation

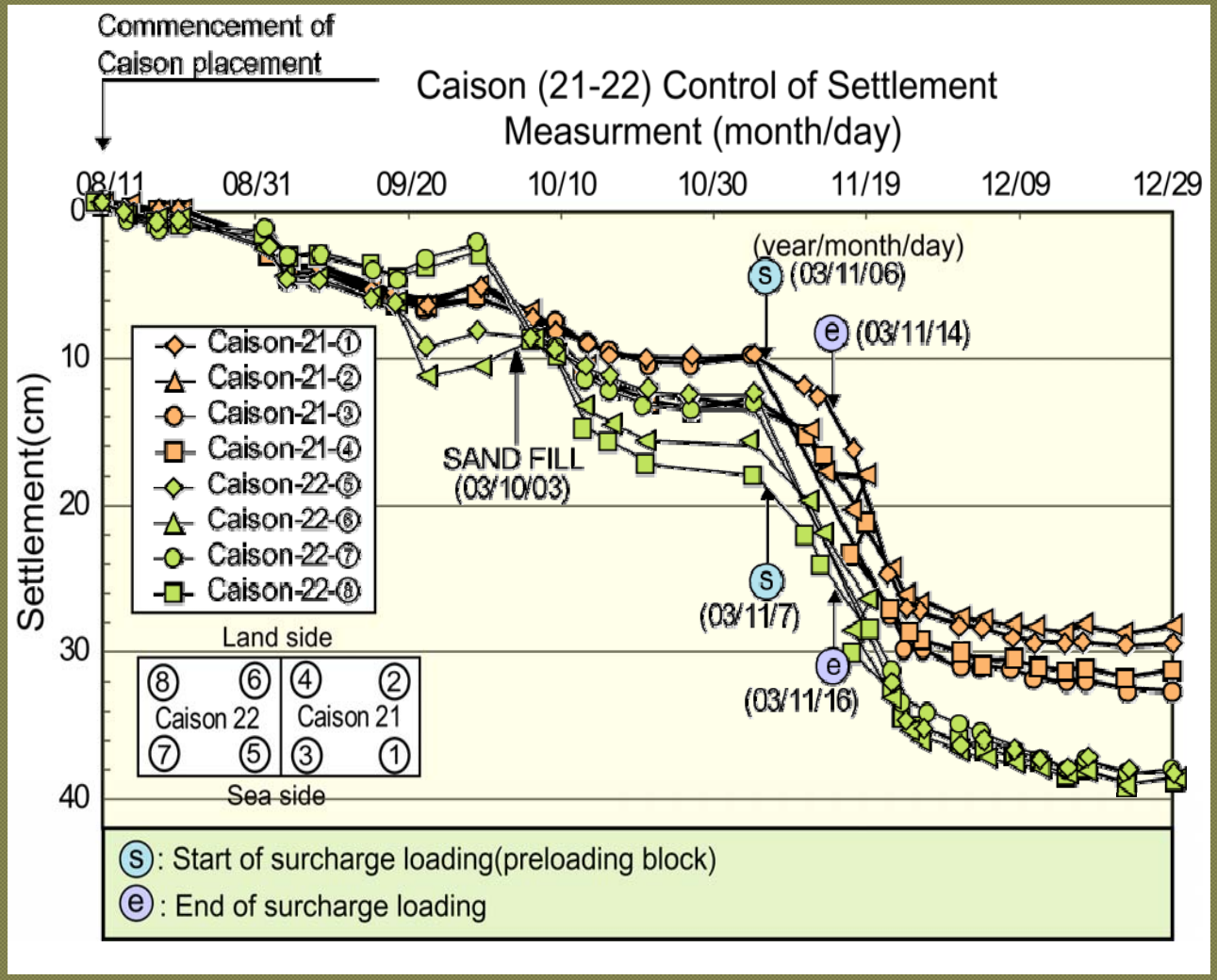


Location of caissons for actual settlement observation

Caisson No.21 & 22 in NCT



Settlement-time histories of caisson 21 & 22



Amount of settlements at each construction stage

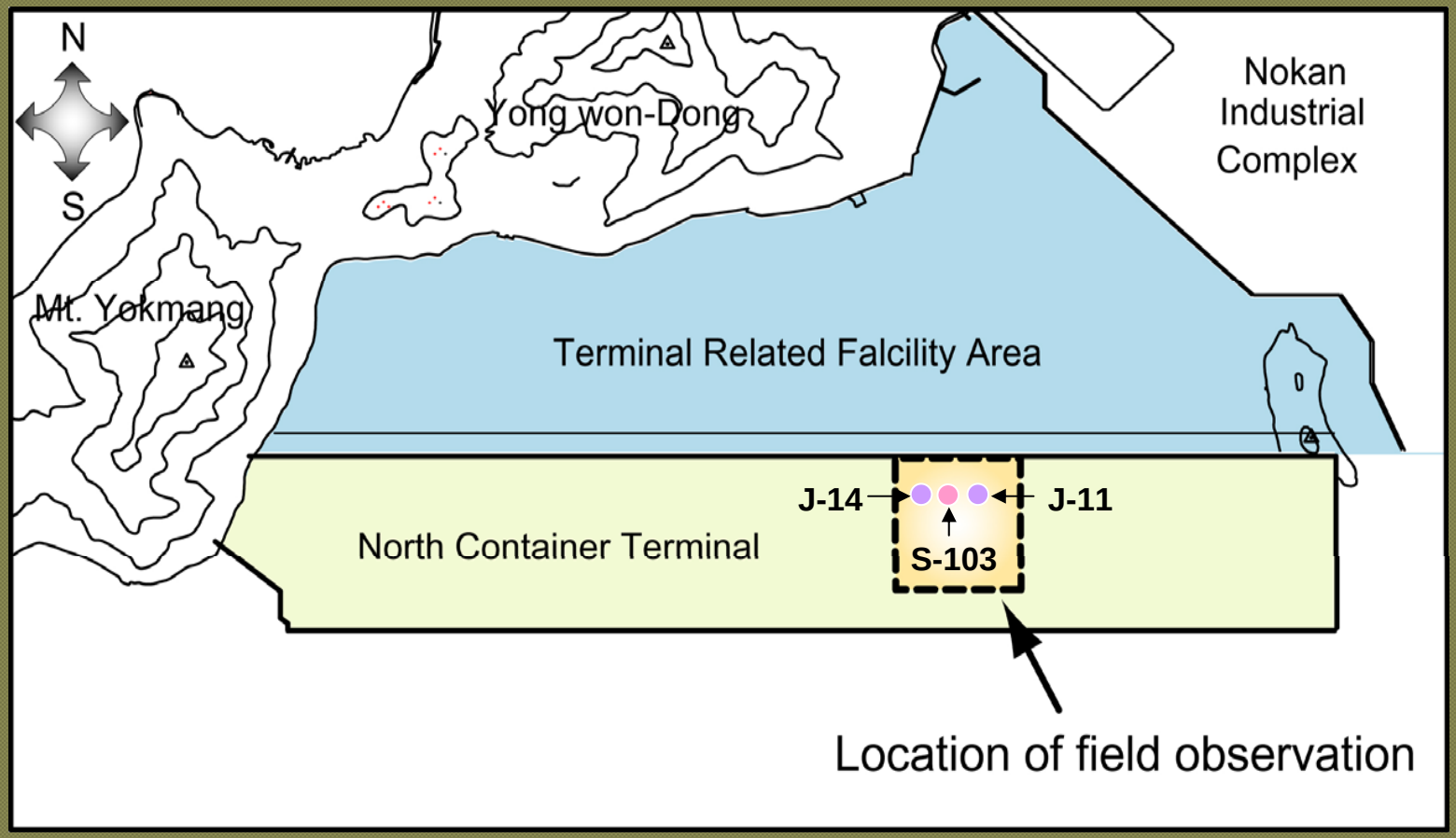
Caisson No.		Caisson placement	Start of surcharge loading	End of surcharge loading	Start of stabilized settlement	t=140days
No. 21	t	0	89	97	105	140
	△S (cm)	0	10.0~12.2 (13.0)	16.6~21.0 (19.0)	26.3~29.7 (28.0)	28.3~32.6 (30.5)
	$\triangle S/\triangle S_{140}$ (%)	0	43	62	92	100
No. 22	t	0	88	95	105	140
	△S (cm)	0	12.8~18.2 (16.0)	22.2~24.5 (23.0)	33.4~35.2 (34.5)	37.9~38.6 (38.3)
	$\triangle S/\triangle S_{140}$ (%)	0	42	60	90	100

t = elapsed time after caisson placement (day)

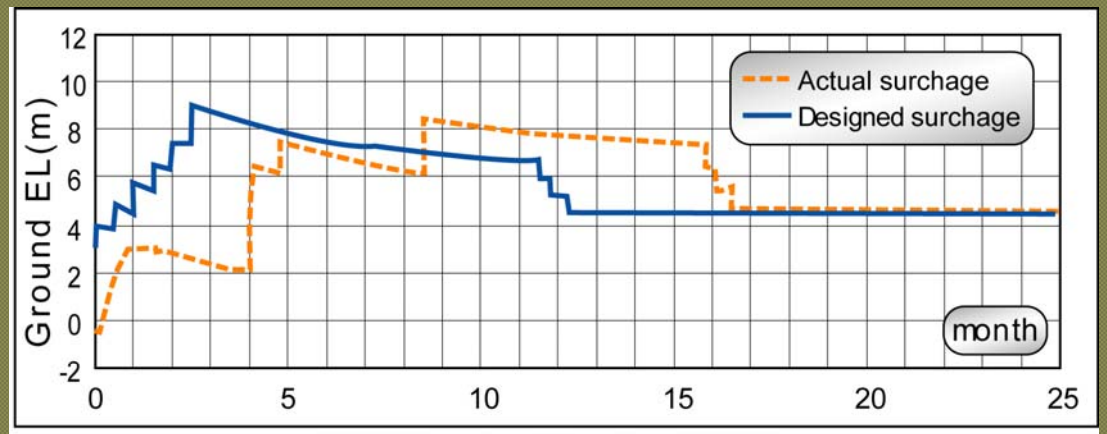
△S = accumulated settlement; ( ) denote average values

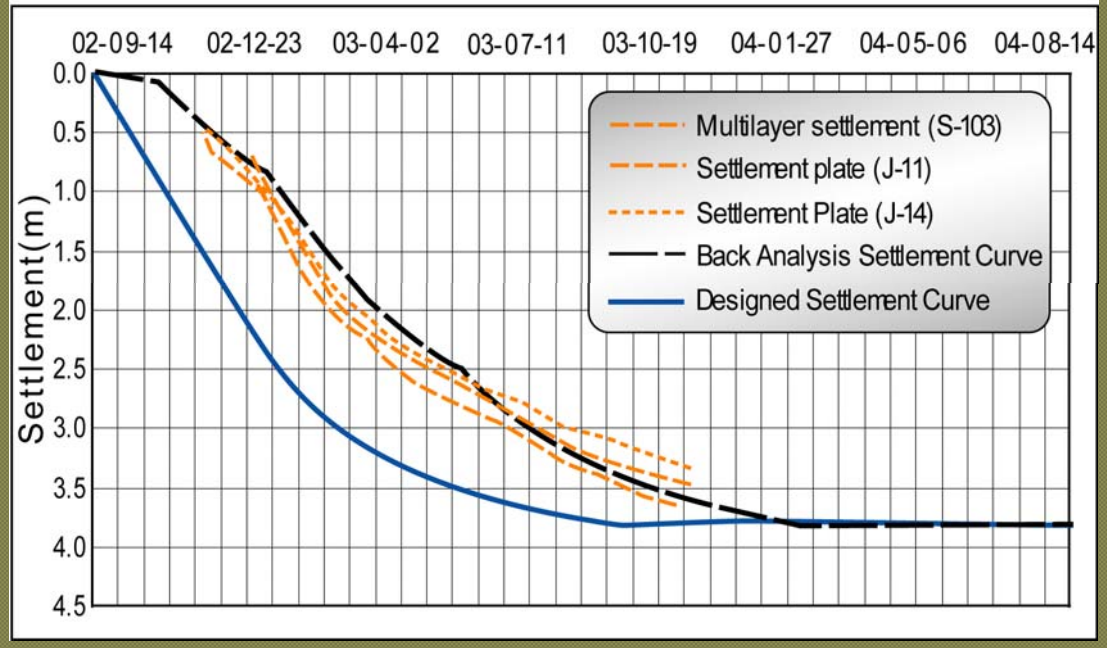
$\triangle S/\triangle S_{140}$ = settlements ratio with respect to reference settlement at 140 days

Location of field observation in CT area of NCT

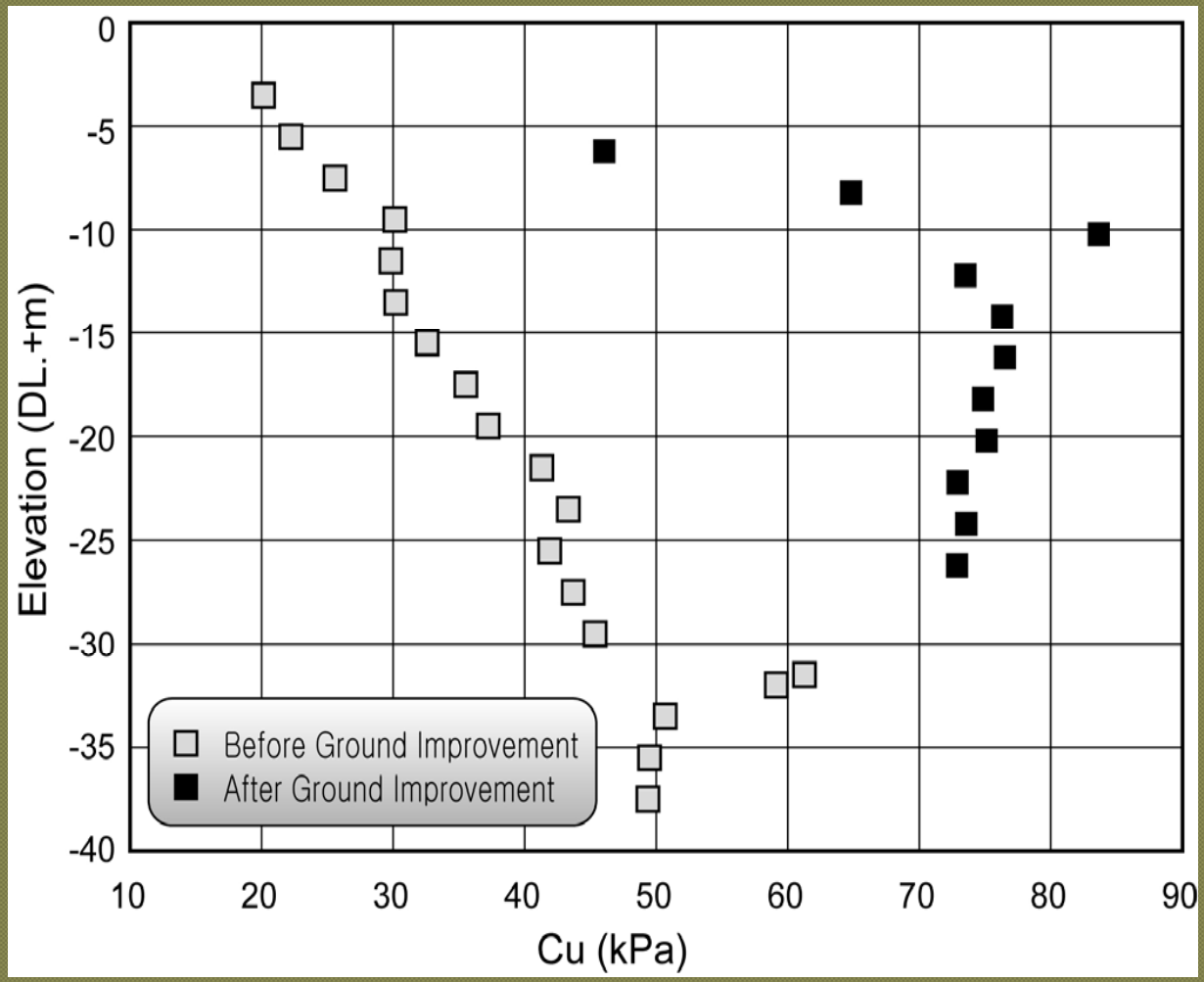


Surcharge-settlement-time history (CT, NCT)





Ground improvement effects on shear strength



Some construction photographs

SKIP

- Construction progress of the site

General view of the site (2002/05/30)

SKIP

General view of the site (2002/08/23)

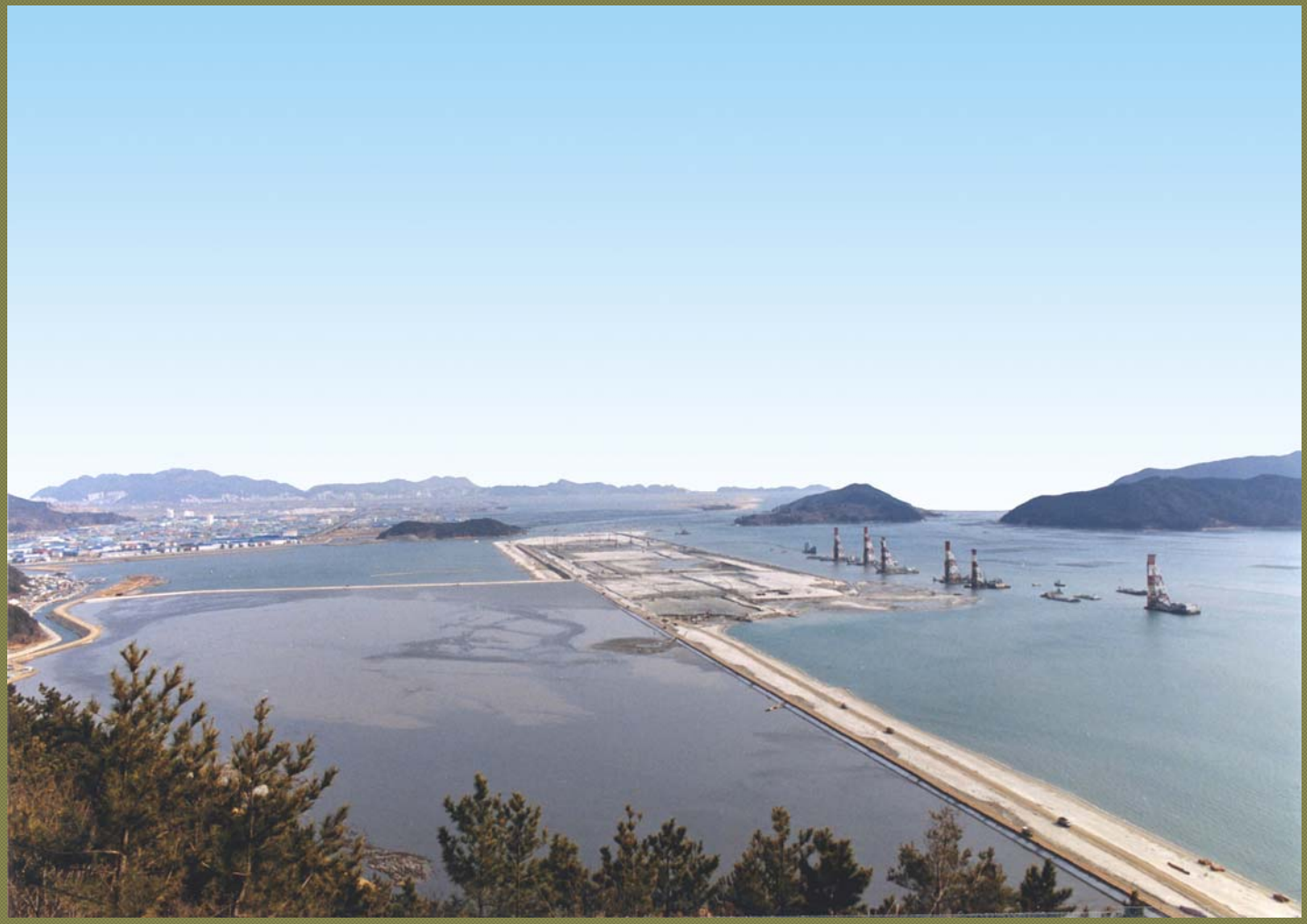
SKIP

General view of the site (2002/10/12)

SKIP

General view of the site (2003/02/24)

SKIP



General view of the site (2003/09/06)

SKIP

General view of the site (2004/03/08)

SKIP

Photograph of BNP site from the satellite

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Concluding Remarks

1. About 80% of the BNP area is covered with a very thick (> 40m),sensitive, young, and normally consolidated soft clay. Deepest rock formation is encountered at a depth of about 75m from the seabed.

2. Index and engineering properties have a strong location-dependence. Careful sub-zoning along vertical and horizontal directions is necessary. However, w_n/LL does not seem to be influenced much by location.

Concluding Remarks

3. Sandwich-type of bamboo matting can successfully be used for the surface treatment of dredged clay layer.

4. Sand compaction pile (SCP), 2m in diameter at 2m intervals in a rectangular pattern is evaluated to satisfy the foundation requirement of 30,000kN caissons for the quay wall.

Concluding Remarks

5. 1.5m X 1.5m (for the CT area), 2.0m X 2.0m (for FA area) patterns of PBD installation are considered the most cost effective and reliable ground improvement method for the BNP.

6. Monitored data from the areas strengthened by SCP and PBD are agreeing with the predicted values within an acceptable range.

Concluding Remarks

7. Estimated amount of settlement prior to opening the NCT is about 3.3~4.9m. About 0.6~0.7m of settlement is expected to take place during 50 years of operation.

8. 70~80% of the secondary settlement is expected to develop within the first five years. Which indicates that a manageable maintenance scale against the amount of long-term settlement shall need to be implemented.

Bird's-eye view of the Busan New Port (2011)

Review