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Vacuum Preloading for Soil Improvement and Land Reclamation Projects

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Outline

- Background & Principles
- Methods and Case Studies
- Performance Evaluation
- Recent Developments

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Why Vacuum Preloading

- Up to 80 kPa of surcharge can be applied quickly on any soft ground without causing stability problems – THE most cost-effective method for land reclamation using soft fill materials.
- It is more economical compared with fill surcharge.
- Water can be collected and treated if the ground is contaminated.

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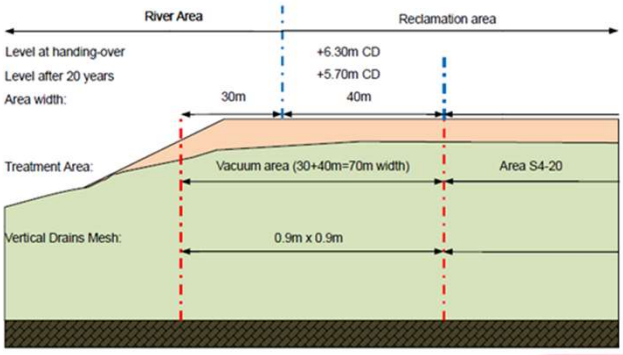
Why Vacuum Preloading

- It can be used as either a consolidation or soil stabilization method.



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After Herve (2015)

Vacuum preloading for land reclamation

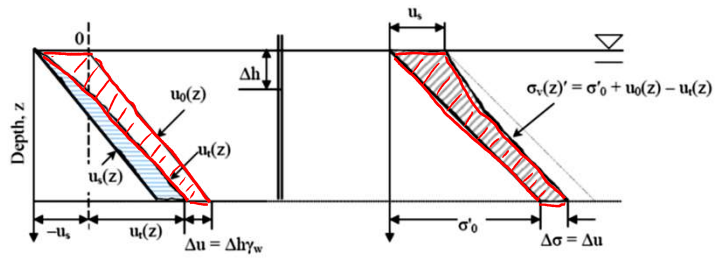
When there is a shortage of sand fill for land reclamation, excavated and dredged soil becomes an economical solution. In this case, vacuum preloading is the most suitable method for soil improvement.

More than **190 km²** of land has been reclaimed for the **Tianjin Port** in Tanggu using clay slurry

Port of Brisbane

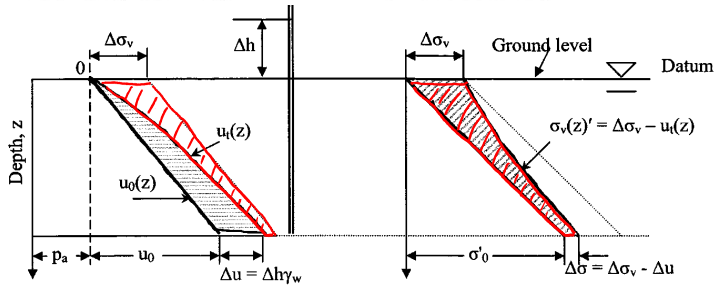
Channel maintenance dredging materials consisting of river muds capped with sand was used. The thickness of the fill was up to 9 m. The seabed compressible clay was over 30 m.

Principles



Pore water pressure change — Effective stress change

Vacuum



Pore water pressure change — Effective stress change

Fill surcharge

PRESENT METHODS

- With membrane
- Without membrane

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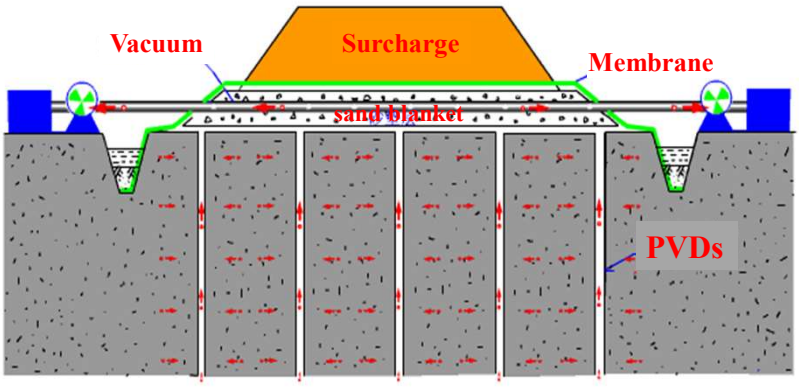
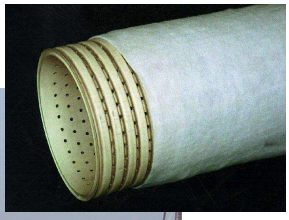
Membrane Methods: VC or VC + Surcharge



Placement of sand blanket and installation of vertical drains



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Placement of corrugated flexible pipes

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Installation of 2-3 layers of membrane

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Placement of a protection layer on top of the membranes

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Application of vacuum pressure

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Application of vacuum and fill surcharge together

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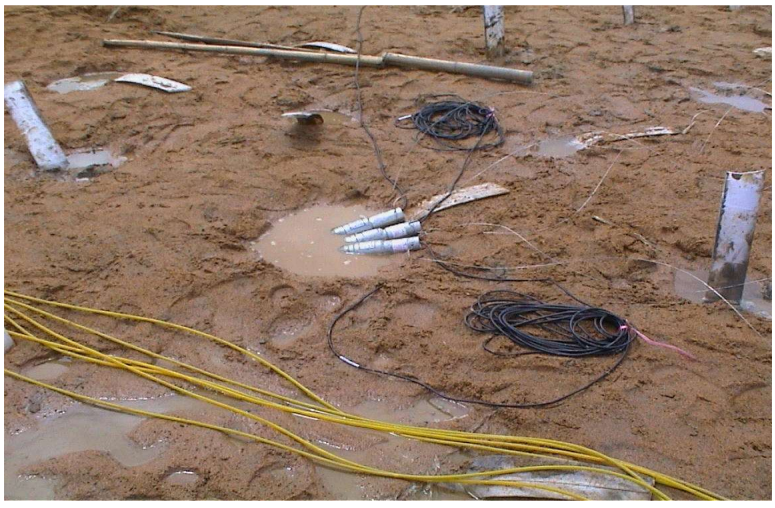

Installation of instruments for field monitoring

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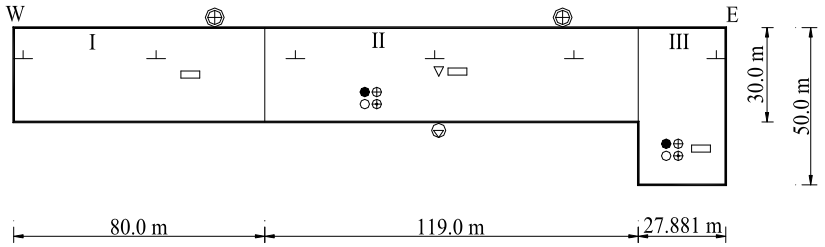
Case Study: A Storage Yard using Combined Vacuum and Fill Preloading (Yan & Chu, 2005)



Settlement gauge

PWP transducer

Multi-level gauge

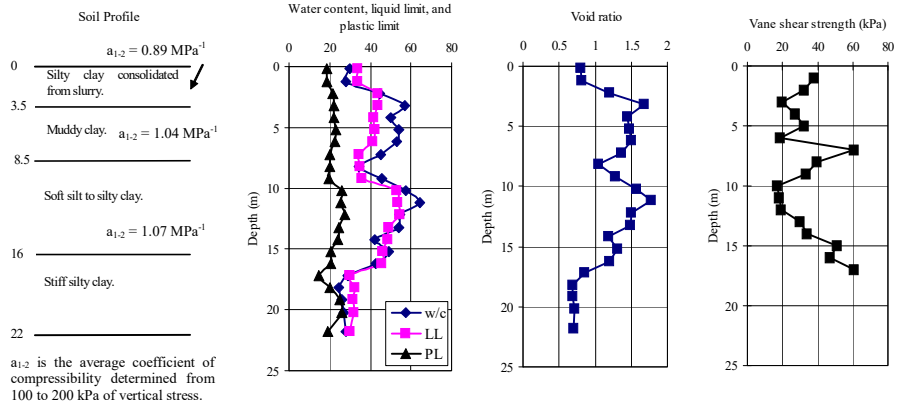
Borehole

Field vane

Inclinometer

Piezometer

Soil Profile and Soil Properties



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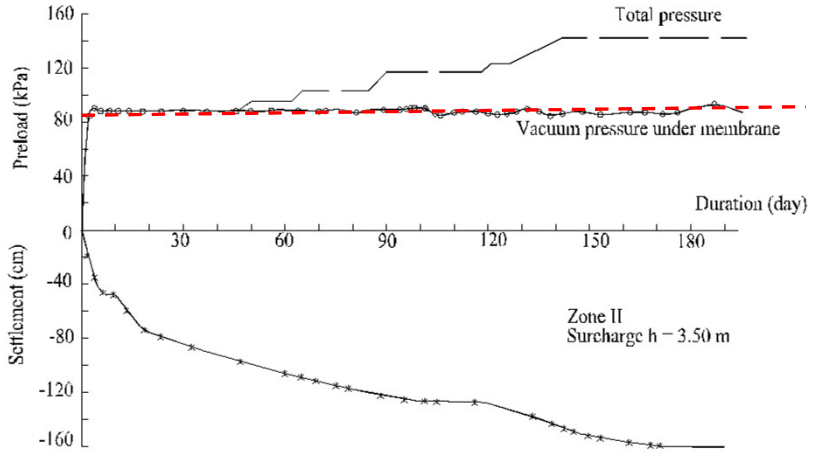

Loading History and Ground Settlement

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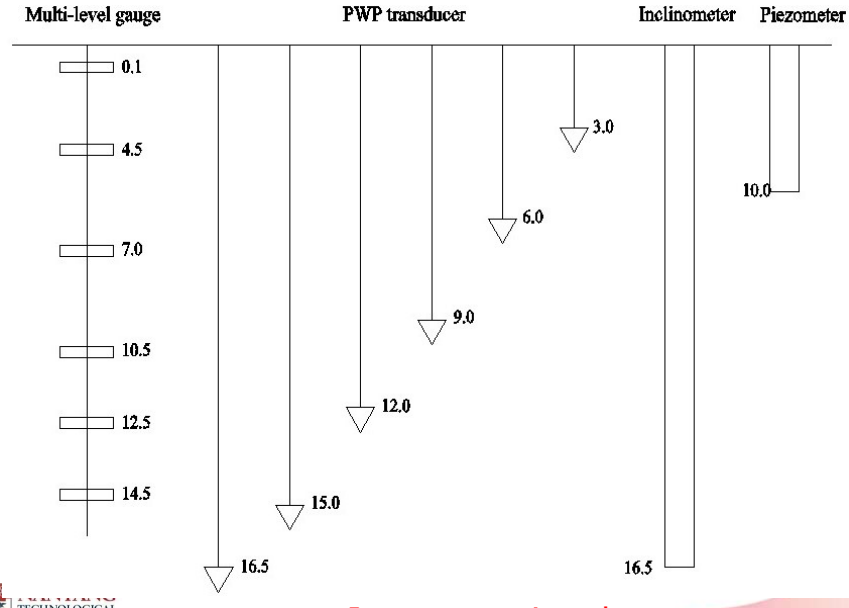

Instrumentation plan

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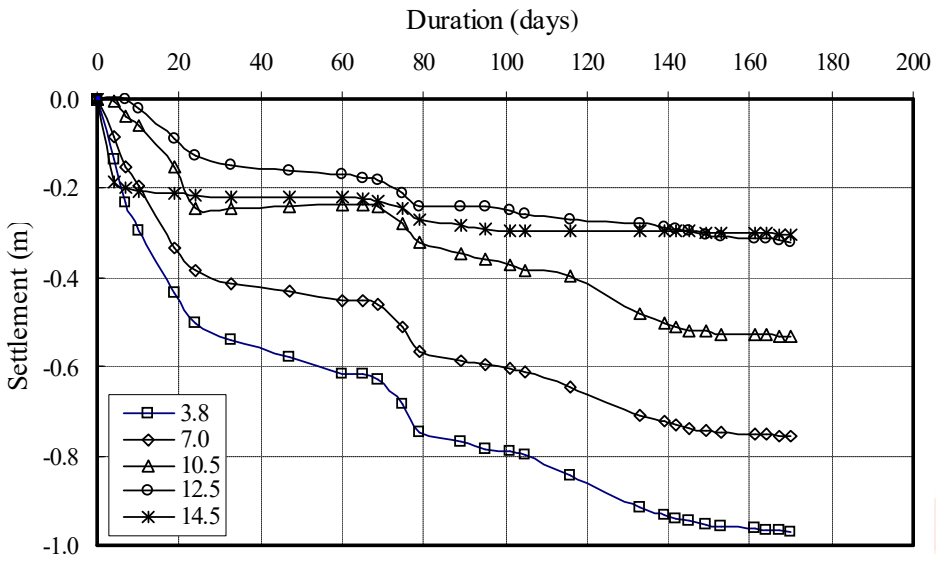

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Settlement measured at different depth versus time

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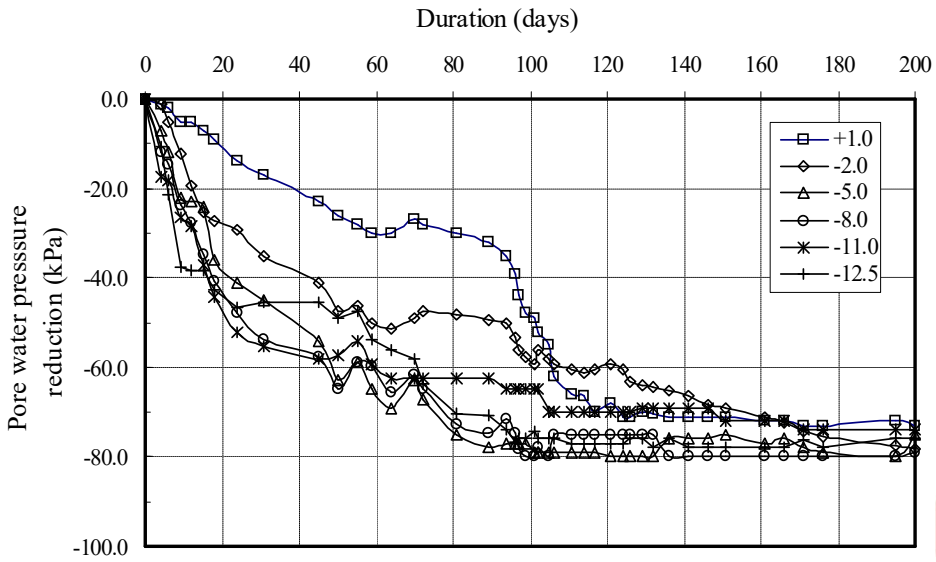

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Pore pressure reduction at different depths versus time

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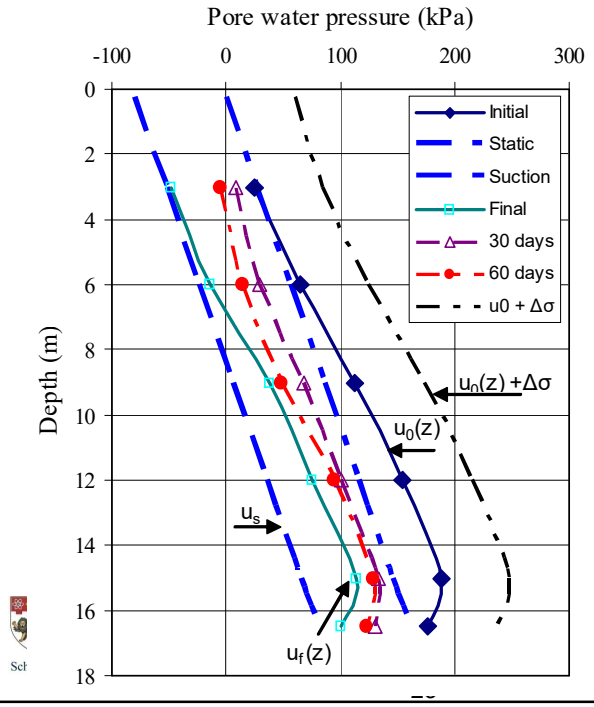
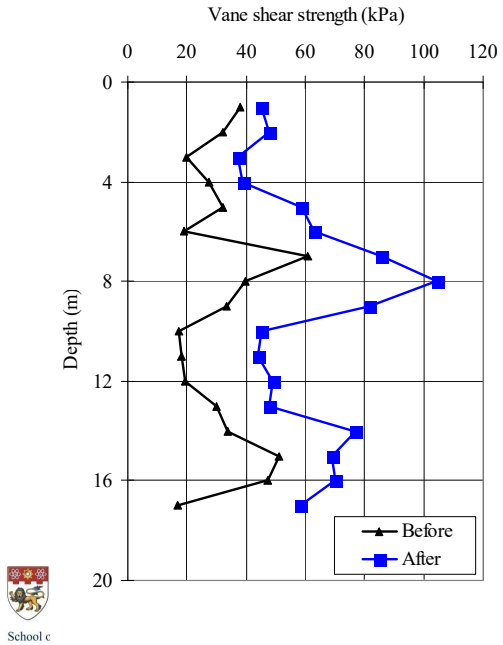


Pore water pressure variation versus depth profiles

DOC based on settlement = 87%

DOC based on pore pressure = 82%



Field vane shear profiles

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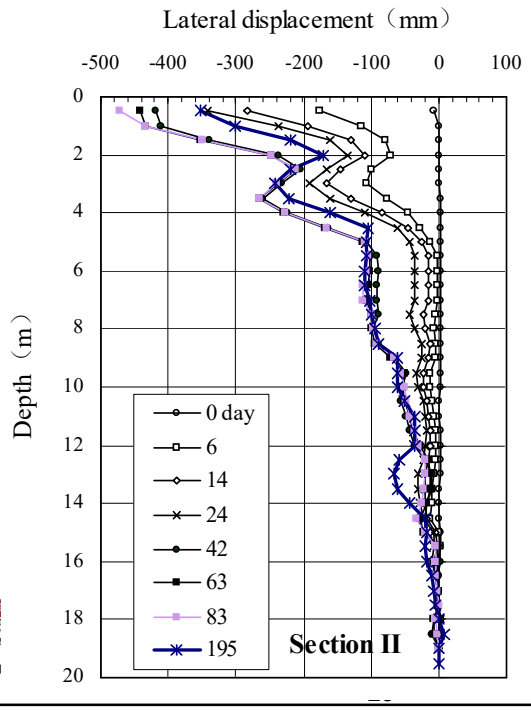

Lateral displacement

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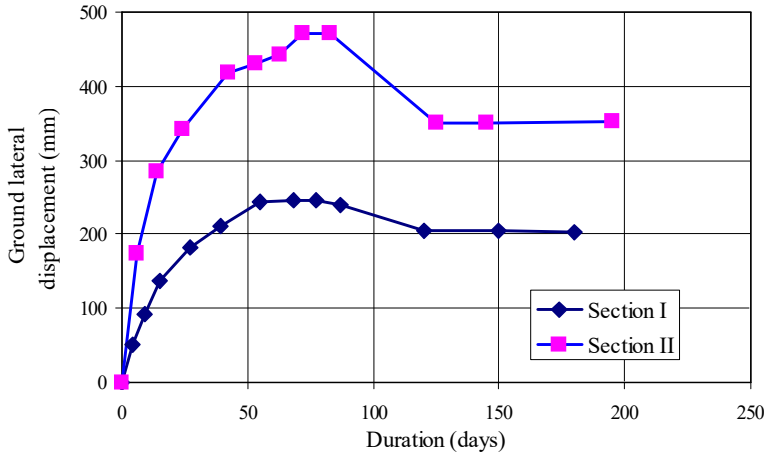
Combined loading can reduce lateral displacement



Ground lateral displacement versus time curves

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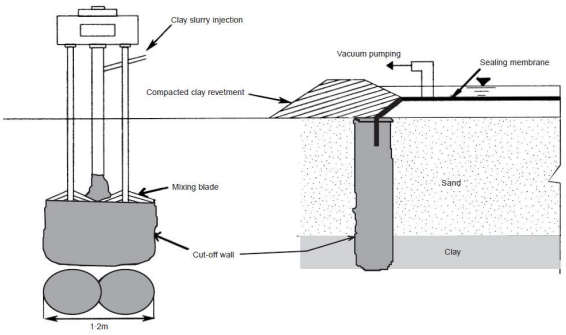
Effect of lateral displacement

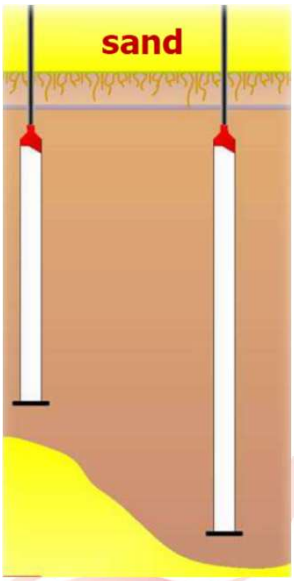
Use of cutoff walls for sandy layer over soft clay



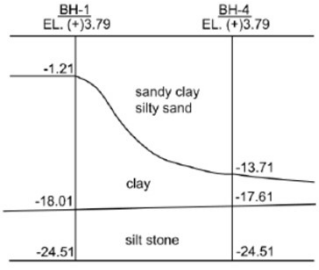
After Tang and Shang (2000)

Membraneless method

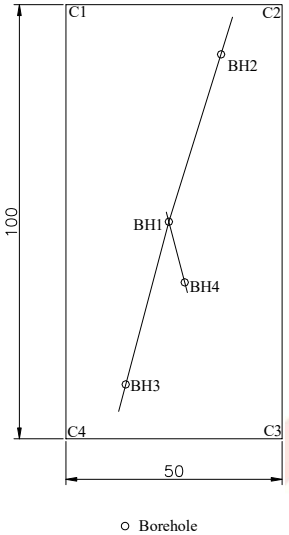
When the use of a cut-off wall is too expensive or not feasible, PVD with plastic sleeve or a direct connection of PVD to vacuum tube may be used.



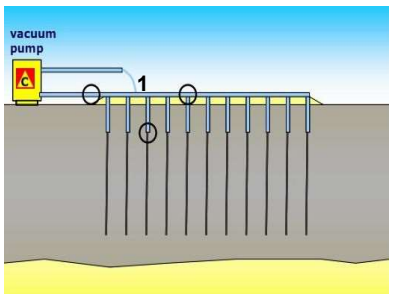
Case Study: Soil Improvement at Tuas Singapore



Project Location and soil profile



Membraneless VC method



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Installation of PVD with tubes

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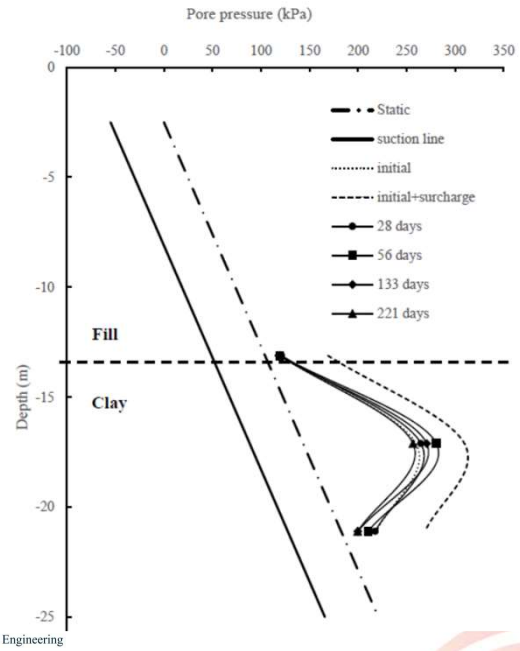

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Summary on membraneless VC

- Great saving on cutoff wall.
- Requires very detailed SI data which may be difficult for large scale implementation.
- For the same reason, there can be short circuits in the VC system and affect the VC performance.
- The installation is time consuming.
- The vacuum pressure achieved is normally 60 kPa or lower.

Degree of Consolidation Calculation

- Based on settlements
- **Based on Pore water pressures**

Methods for Calculating DOC

- Normally based *settlement* monitored:

  $DOC = S(t)/S_{ult}$

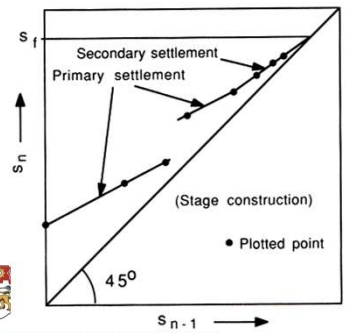
  Different methods for estimating S_{ult} has been adopted (Asoaka, Hyperbolic, and Zeng et al.).

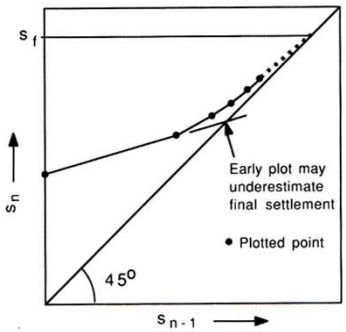
- **Based on *pore water pressure* (PWP)** monitored.

  Can be done easily using the following method.

Asaoka's method

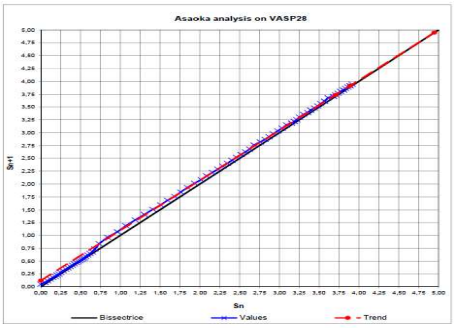
Note: The results of Asaoka's method is affected by the time interval used (the larger the Δt, the smaller the S_f) and the secondary settlement. **Early plot (with DOC<70%) may not be reliable.**

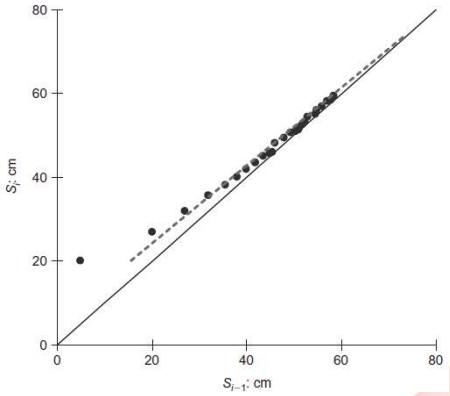




After Holtz et al. (1991)

Ultimate settlement prediction?





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Chu et al (2009)

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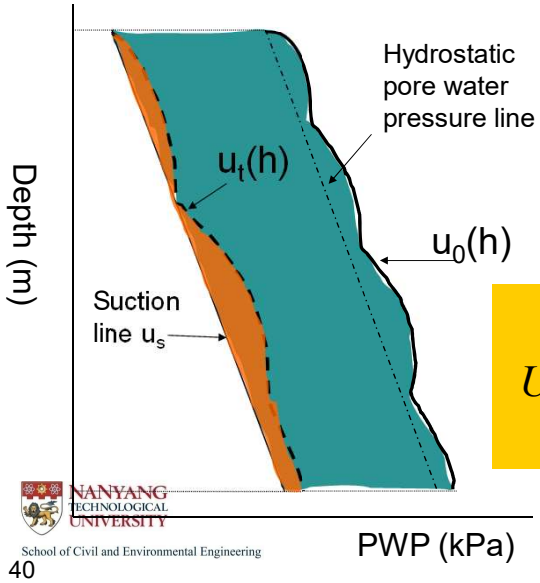
Calculation of DOC using PWP



After Chu and Yan (2005)

$$U_{avg} = 1 - \frac{\int [u_t(h) - u_s] dh}{\int [u_0(h) - u_s] dh}$$

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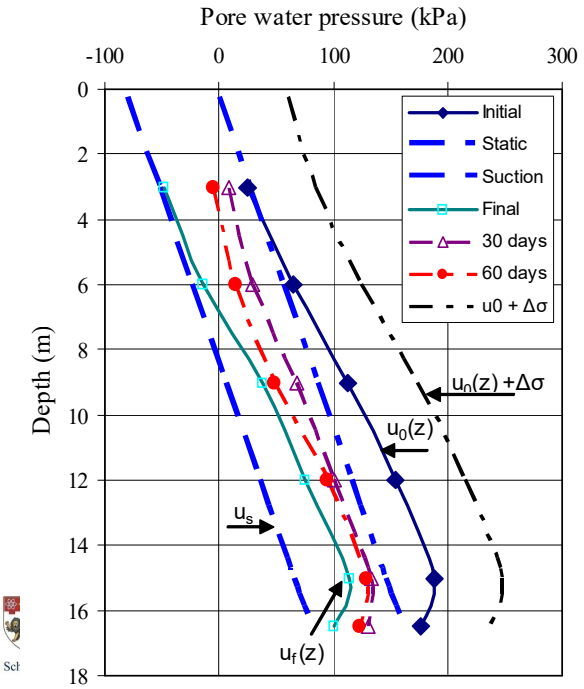

Pore water pressure variation versus depth profiles

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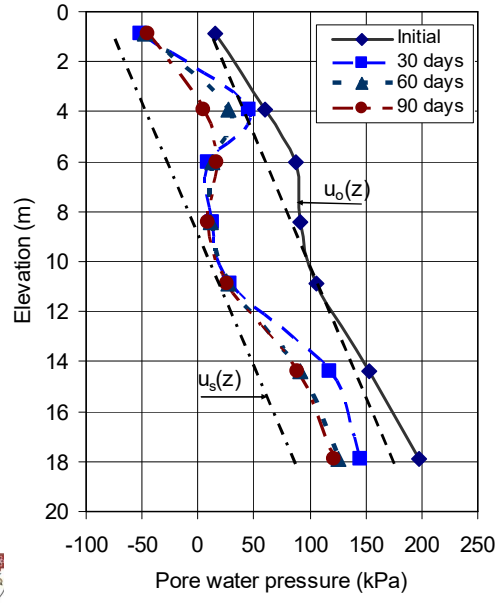

Case II:

PWP Distribution Profiles in a oil storage yard (after Chu et al. 2000)

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DOC Calculated using PWP and Settlement

Degree of consolidation (DOC)	Based on settlement data				Based on pore water pressure data			
	30	60	90	End	30	60	90	End
Case I	-	-	87%	-	-	-	82%	-
Case II	45%	80%	88%	**95%**	38%	73%	84%	**92%**

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Why DOC_PWP is smaller than DOC_Settlement?

- It is related to how PWP and settlement are measured. When limited instruments are used, instruments will be placed to measure the largest settlement and PWP.
- **Settlement is measured at a surcharge lower than specified.**
- When DOC (pwp) is more than 85%, the difference tends to be small.

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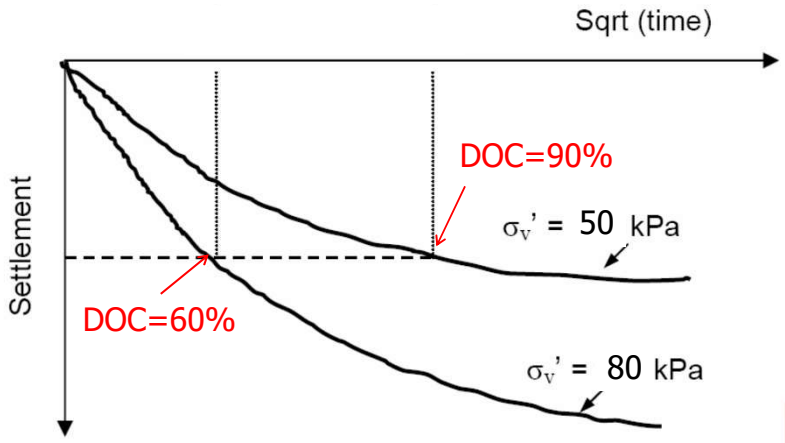
Settlement changes with consolidation pressure



Recommendations

- As both settlements and PWPs are measured, DOC should be calculated using both settlement and PWP data.
- For vacuum preloading project, PWPs have to be used to evaluate the vacuum pressure applied. Hence, the use of PWPs to evaluate DOC is an essential step.
- A difference between DOC evaluated using settlement and PWP data is understandable as long as a good explanation can be given.

RECENT DEVELOPMENTS

for the use of vacuum preloading of clay slurry fills for land reclamation

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Use of dredged soft soil

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Difficulties in the use of soft soil/ slurry for land reclamation

- **Major difficulty:** The top surface is too soft for workers and machines to go on top to carry out soft improvement work.
- **Key technical challenge:** ***how to form a working platform??***
- **Method to use:** ***the one with the lowest unit cost!***

Land reclamation and soil improvement method for soft fills

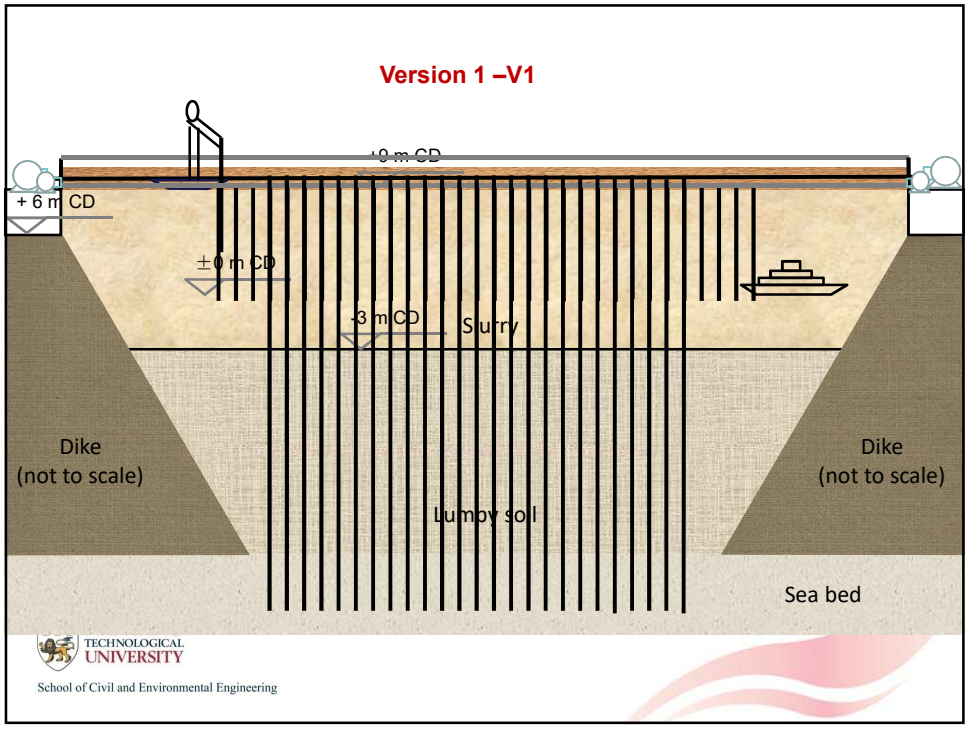
Version 1 –V1

Fill materials:

- ***Grabbed lumpy soil for below -3 mCD***
- ***Clay slurry or sand for above -3 mCD***

Soil Improvement Method: Use two rounds of Vacuum preloading (VP):

- ***R1: Use special VP to consolidate the top 4-5 m of slurry fill to form a working platform***
- ***R2: Use conventional VP to improve the whole soft fill layers and the soft seabed soils***


Version 1 –V1
+ 6 m CD
±0 m CD
-3 m CD
Slurry
Dike
(not to scale)
Dike
(not to scale)
Lumpy soil
Sea bed
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Installation of PVD over slurry
Courtesy of Prof Yan
Courtesy of Prof Cai
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Vacuum with membrane, but without sand blanket

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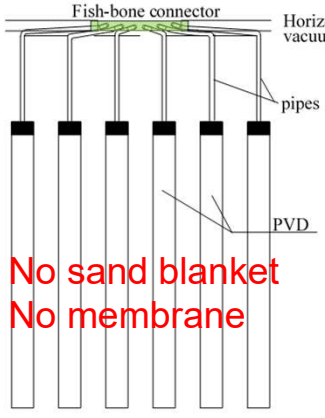
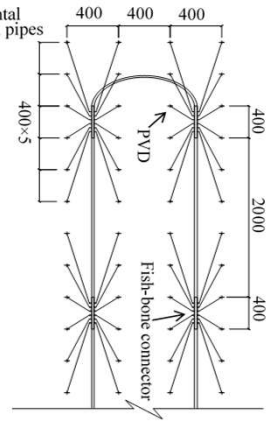
Fish-bone vacuum preloading (FBVP) without membrane



No sand blanket
No membrane



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Guo, Chu, et al, (1916); Sun et al. (2017)

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Summary

- Vacuum preloading causes an inward lateral movement. Thus, the pressure can be applied instantly without causing any instability problem.
- There are two methods to apply vacuum pressure: with or without the use of membranes. Each has its own advantages and disadvantages.
- Vacuum preloading is applied by reducing the pore water pressure in the soil through the application of a vacuum pressure. The preloading value can only be assessed by measuring the vacuum pressure in the soil. Thus, it is essential to monitor both settlements and pore water pressures in the soil and use both sets of data to estimate the degree of consolidation achieved.
- The key for consolidation of clay slurry is the formation of working platform. A cost-effective method to use two rounds of vacuum preloading is suggested.

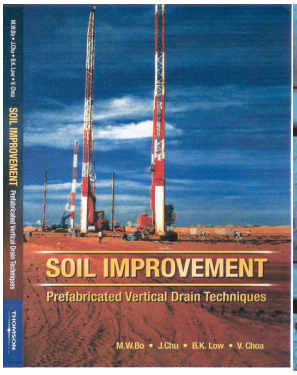
17TH International Conference on
Soil Mechanics & Geotechnical Engineering

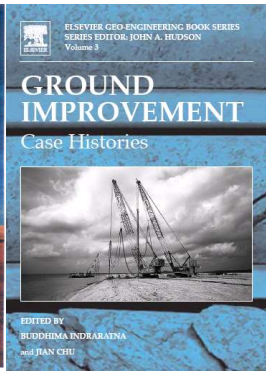
State of the Art Report

Construction Processes
Procédés de Construction

Jian Chu
Nanyang Technological University, Singapore
Serge Varaksin
Menard, France
Ulrich Klotz
Zublin International GmbH, Germany
Patrick Mengé
Dredging International n.v., DEME, Belgium

Chu, J. Varaksin, S. Klotz, U. and Mengé, P. (2009). "Construction Processes." *State-of-the-art Report, 17th International Conference on Soil Mechanics and Geotechnical Engineering*, Alexandria, Egypt, 5-10 Oct. Vol. 4, pp. 3006-3135 (130 pages).





Chapter 4

Prefabricated vertical drains

J Chu and VR Raju

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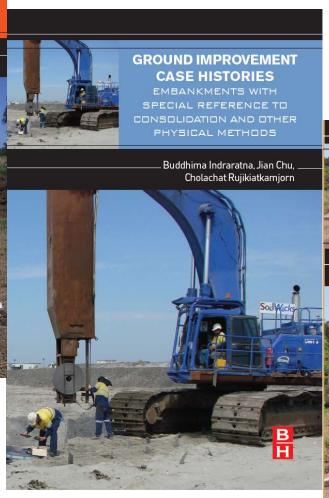
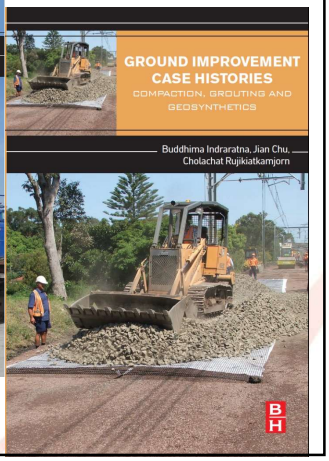
Ground Improvement

3rd Ed, by Krisch and Bell (2013)





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3. Chu, J., Bo, M. W., Chang, M. F., and Choa, V. (2002). "The consolidation and permeability properties of Singapore marine clay." *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, Vol. 128, No. 9, 724-732.
4. Chu, J., Bo, M. W., and Choa, V. (2004). "Practical considerations for using vertical drains in soil improvement projects." *Geotextiles and Geomembranes*, Vol. 22, 101-117.
5. Bo, M. W., Chu, J., Choa, V. (2005). "Changi East Reclamation and Soil Improvement Project." Chapter 9, In *Ground Improvement – Case Histories*, Eds. B. Indraratna and J. Chu, Elsevier, 247-276.
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