Vacuum consolidation

Design and case studies

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Supporters

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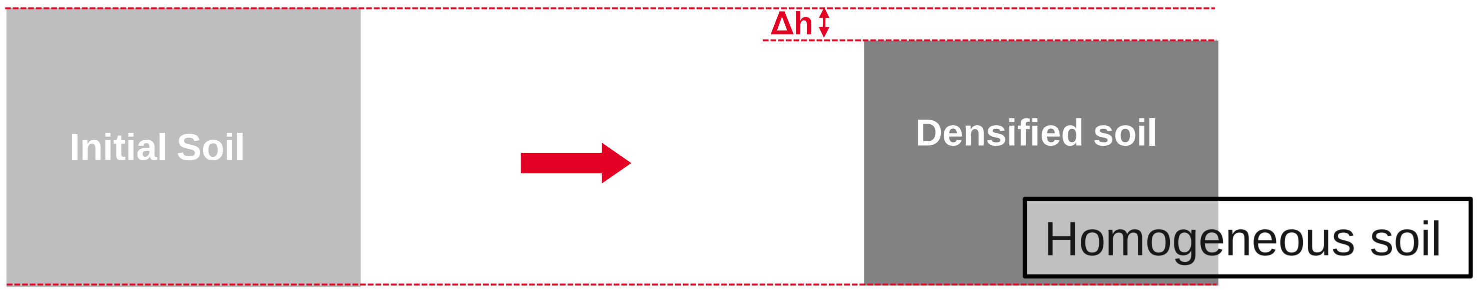
Introduction

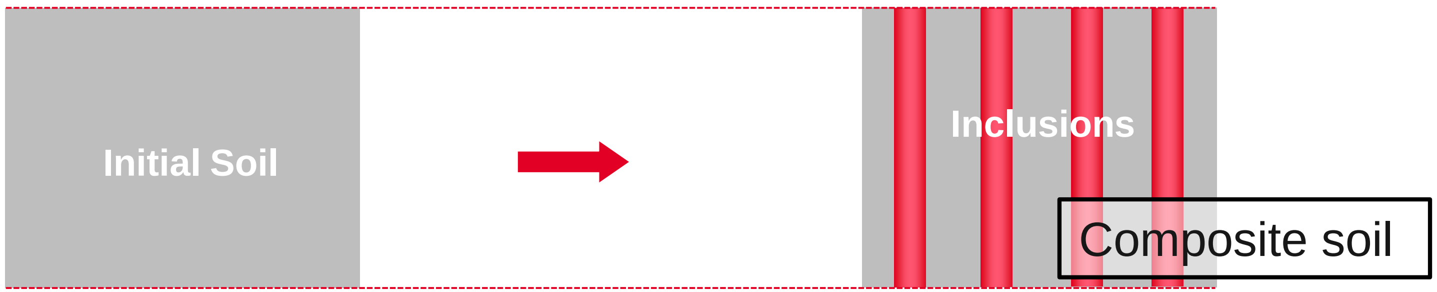
Ground improvement techniques

- Densification by direct action on the soil structure

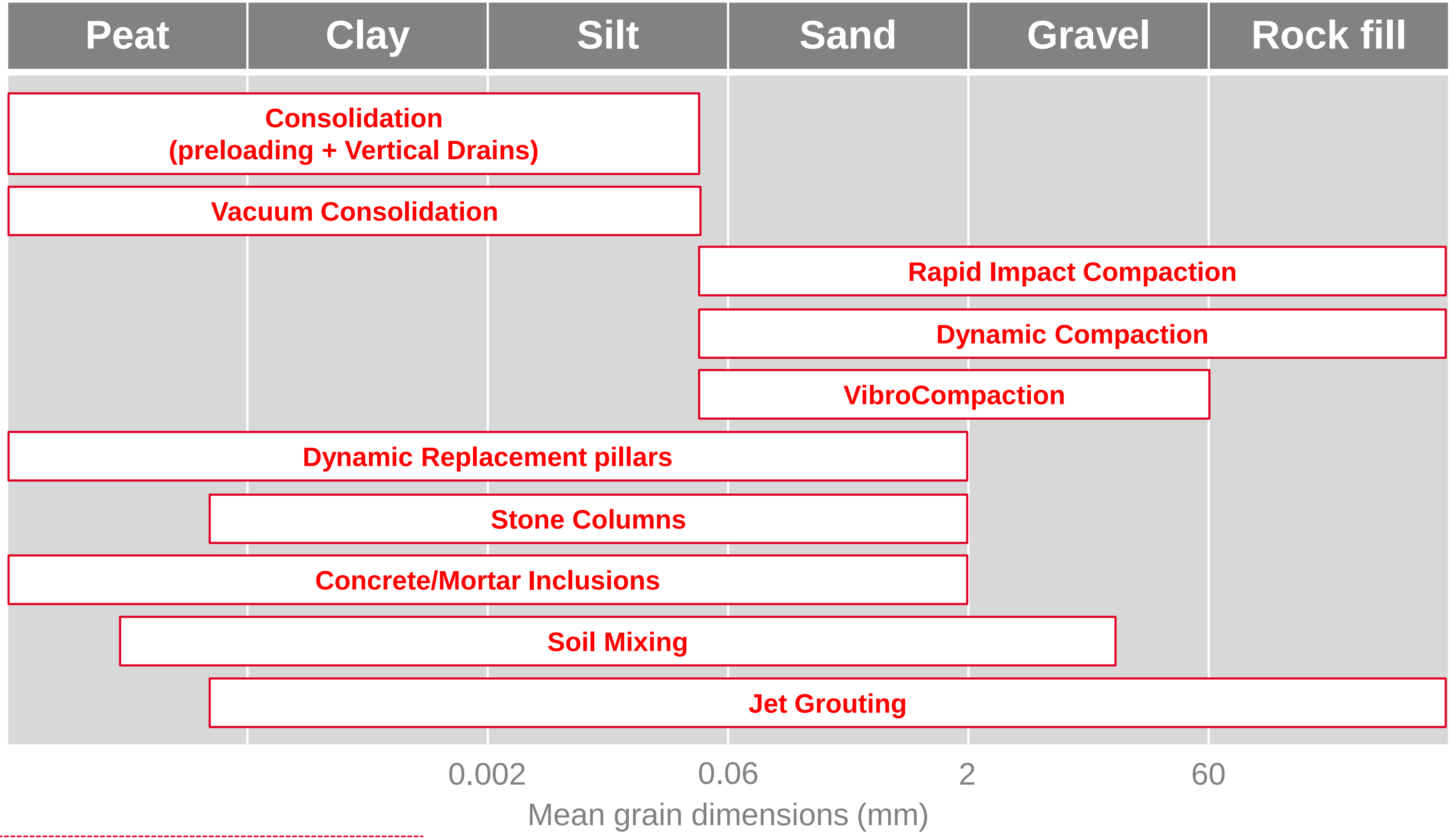


Ground reinforcement techniques

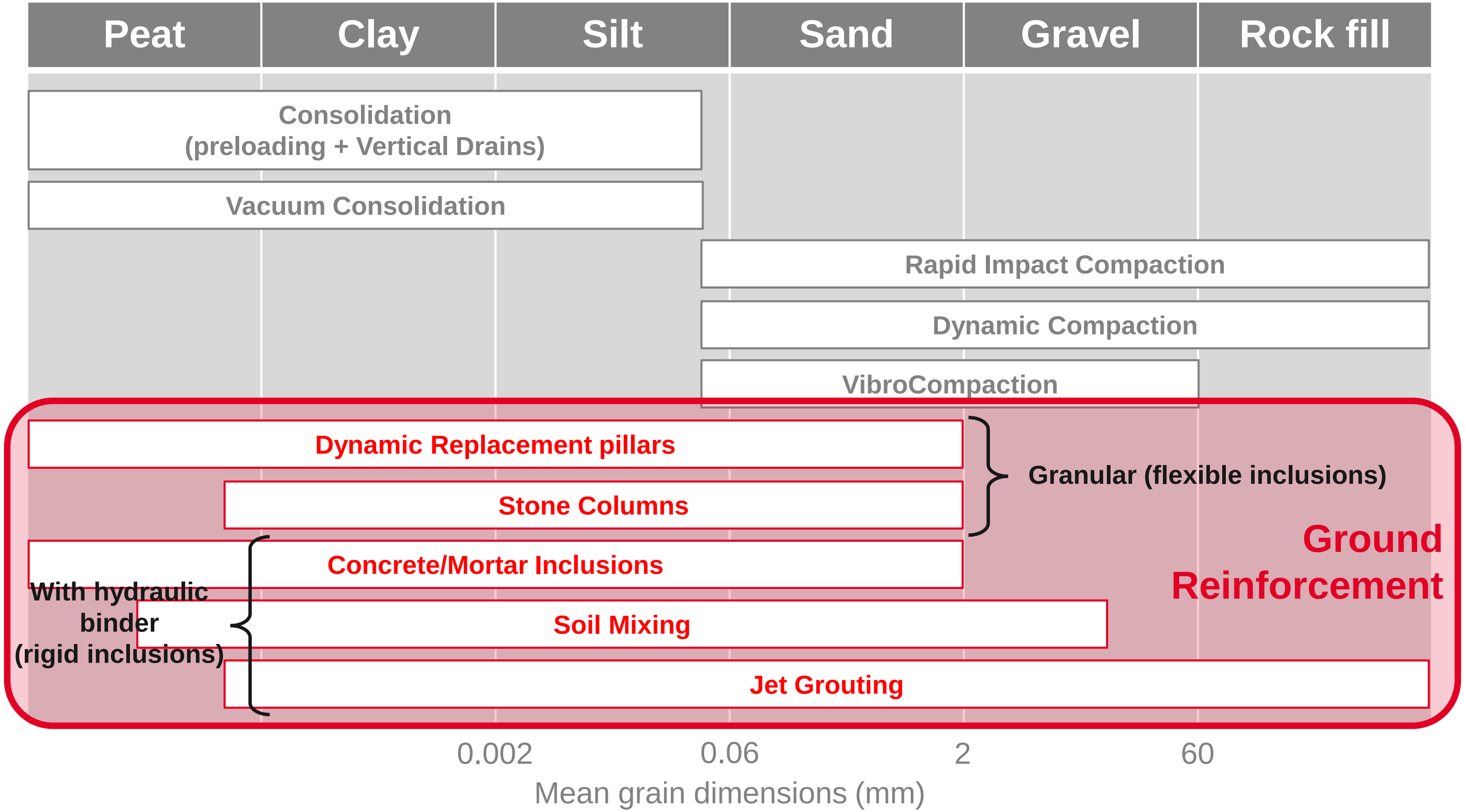
- Global improvement of performance by installation of inclusions



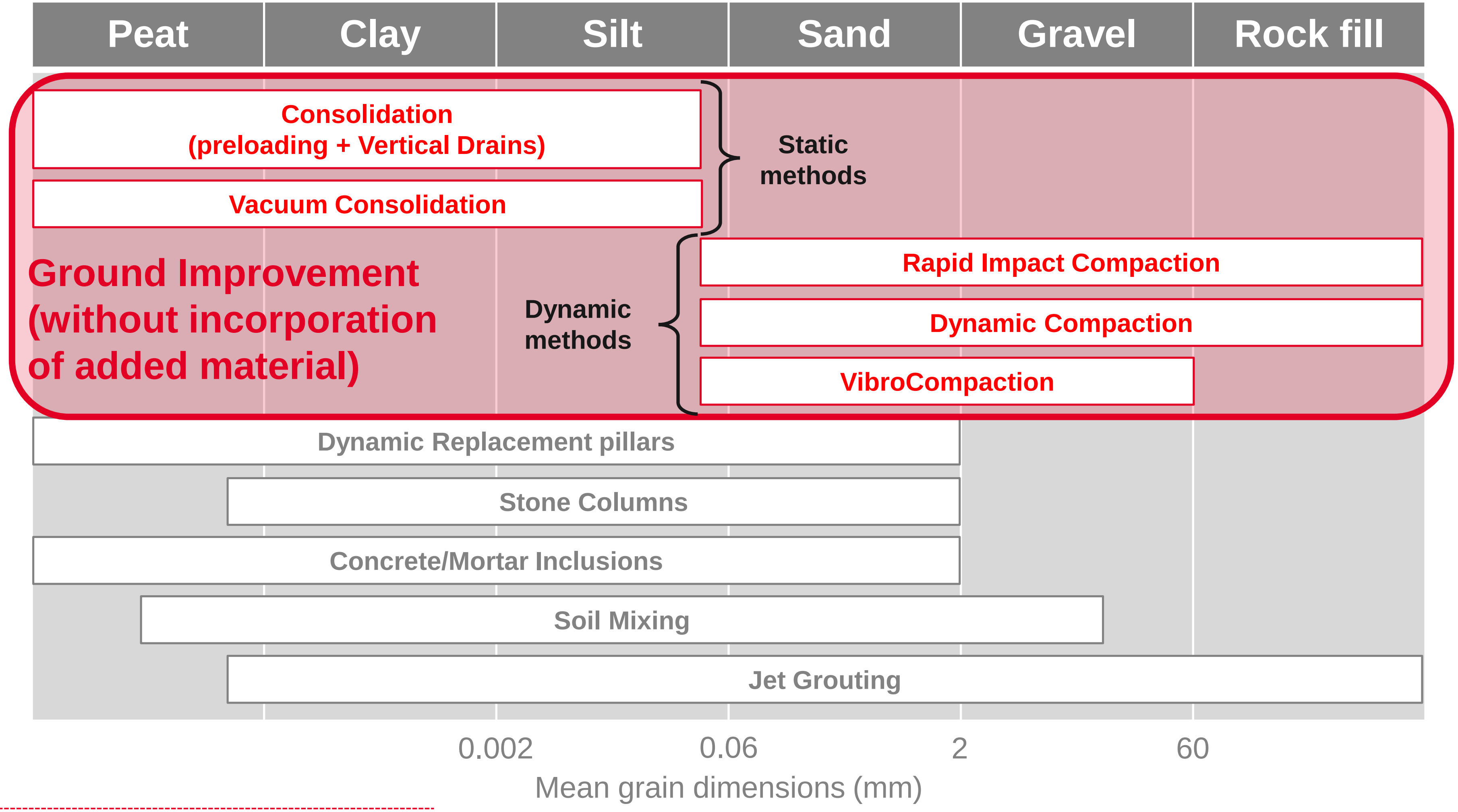
Introduction



Introduction



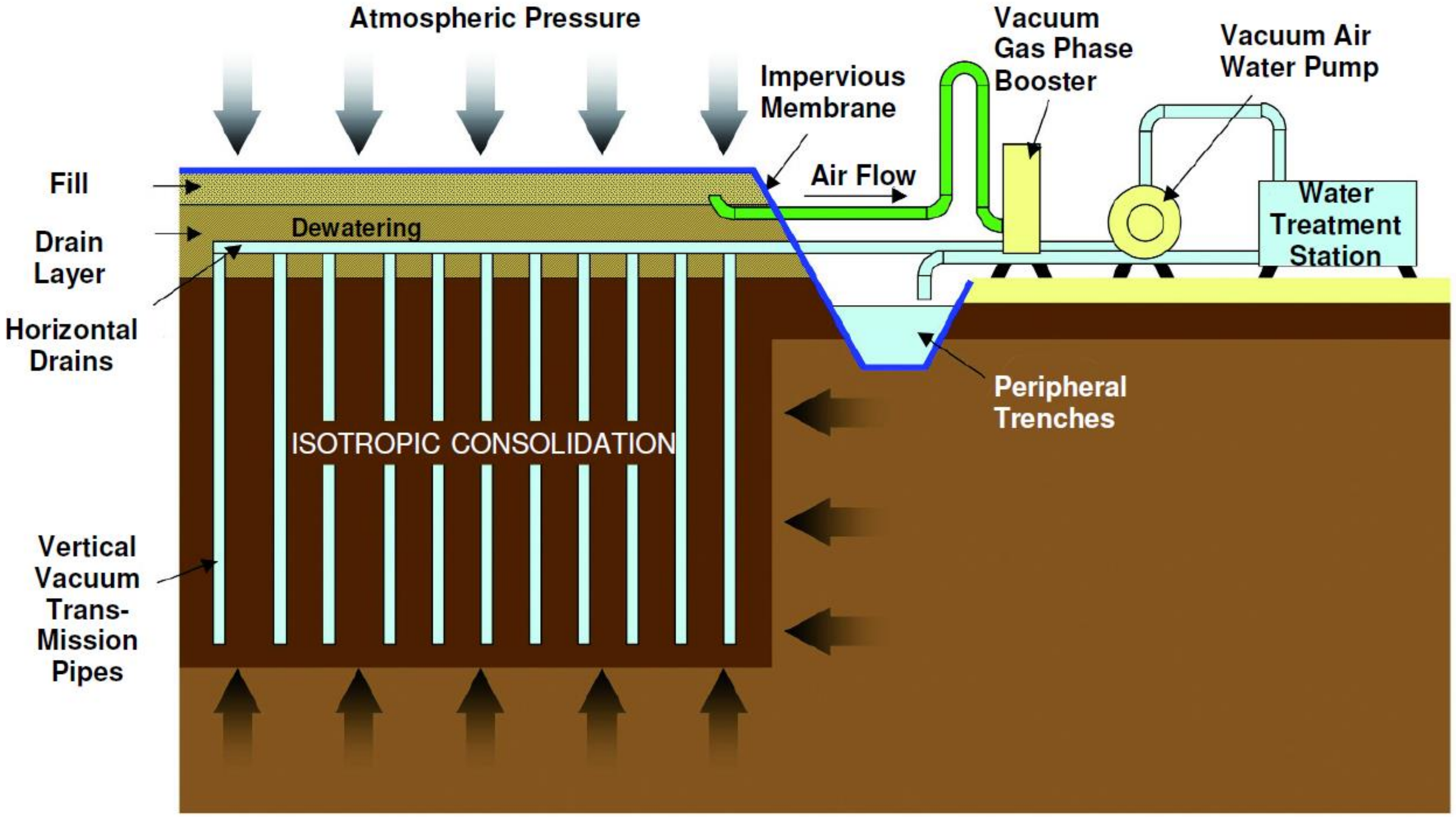
Menard Vacuum System

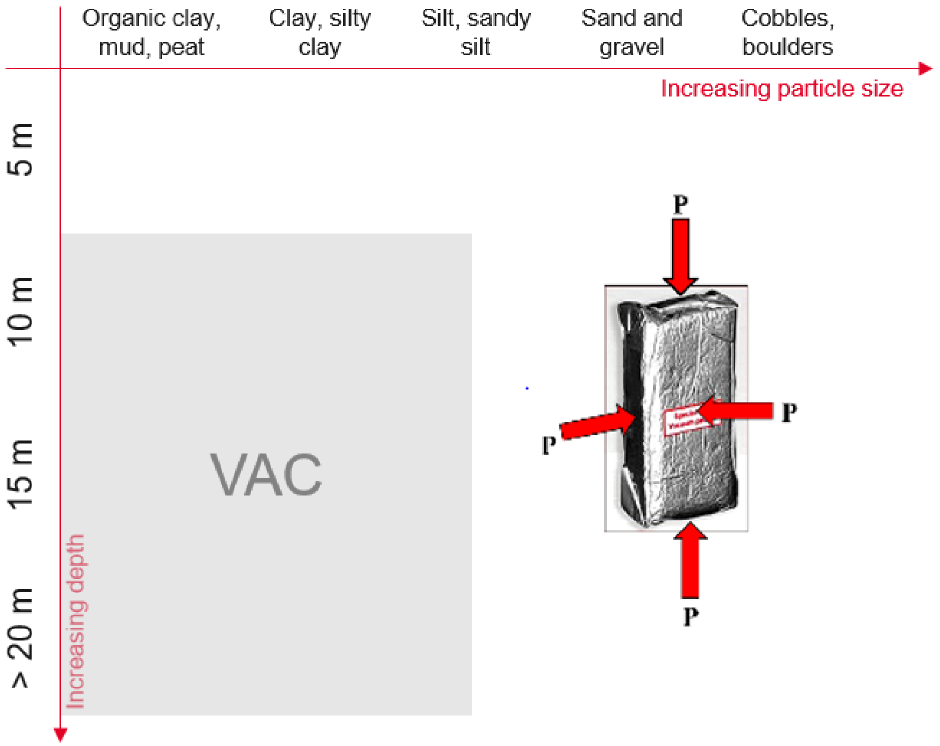


02

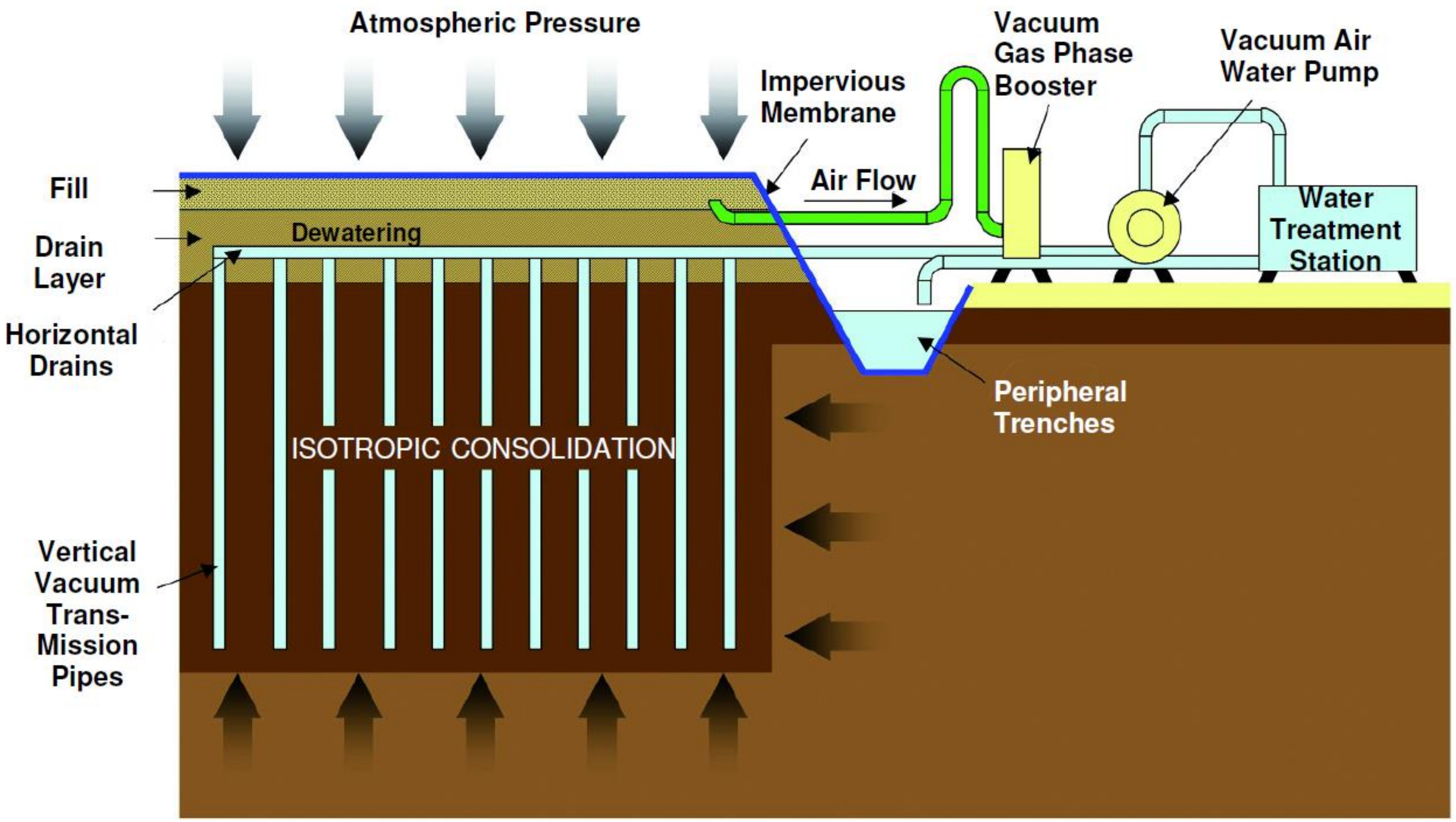
Menard Vacuum Consolidation

Menard Vacuum Consolidation



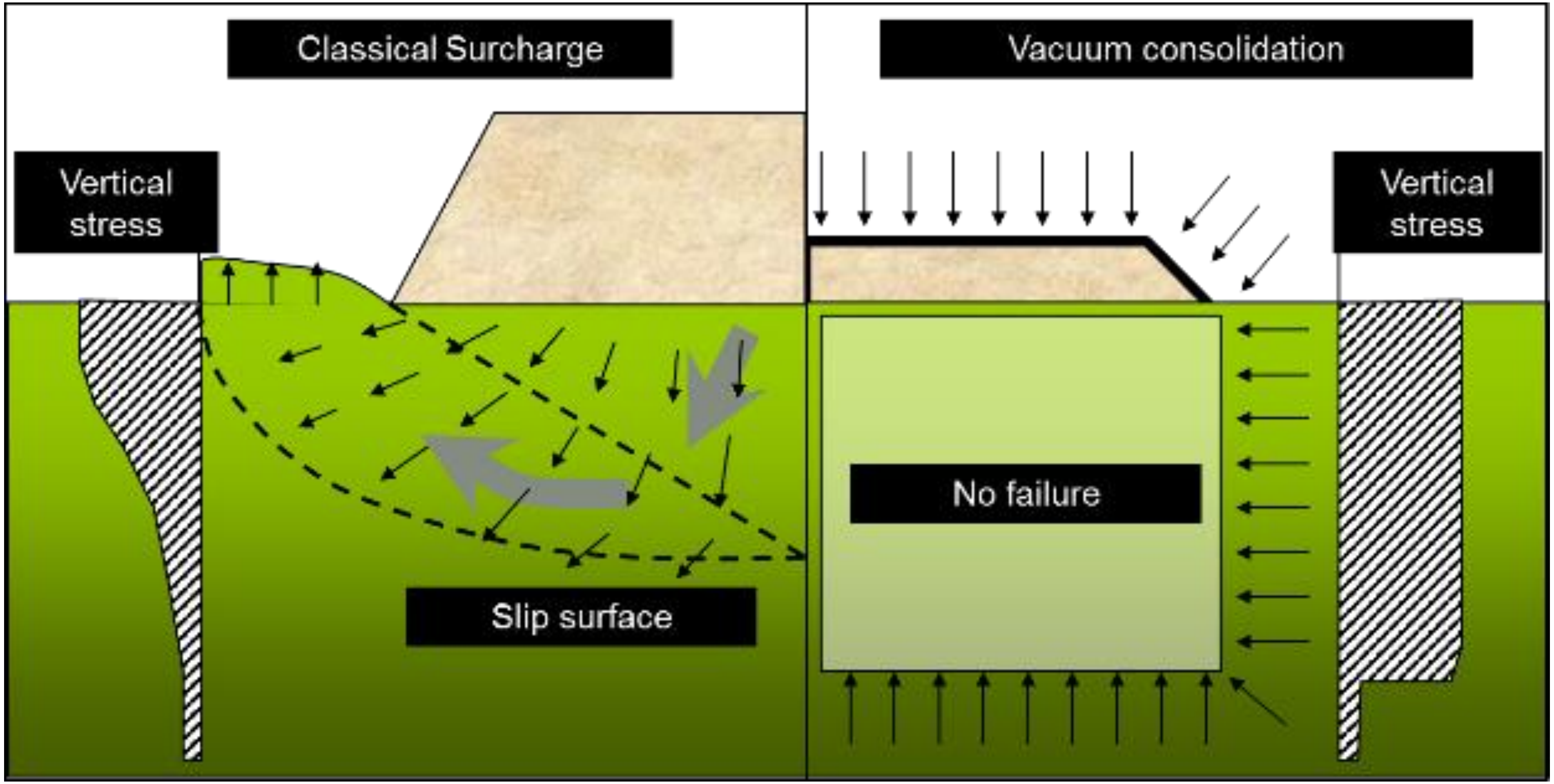


Menard Vacuum Consolidation



The air and water pumping system is installed and creates vacuum in the soils below the impervious membrane equivalent to a depression **between 60 and 80 kPa**, depending on the global efficiency of the system.

Menard Vacuum Consolidation



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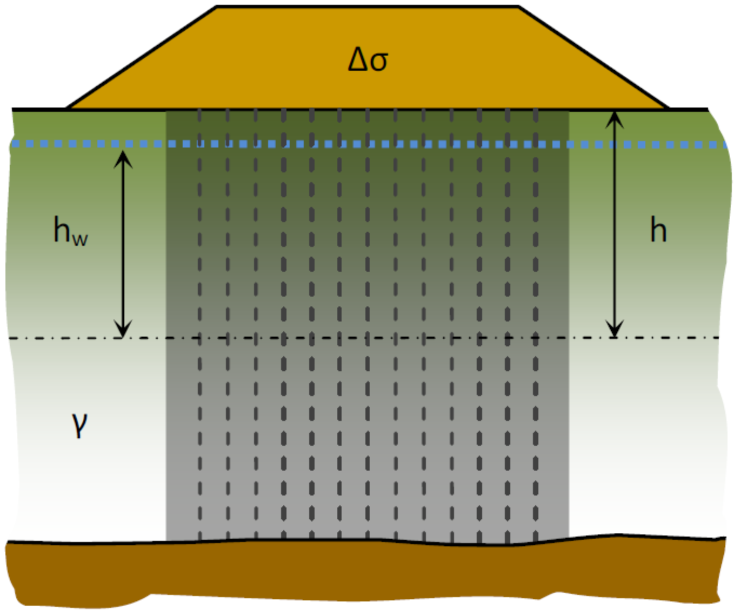
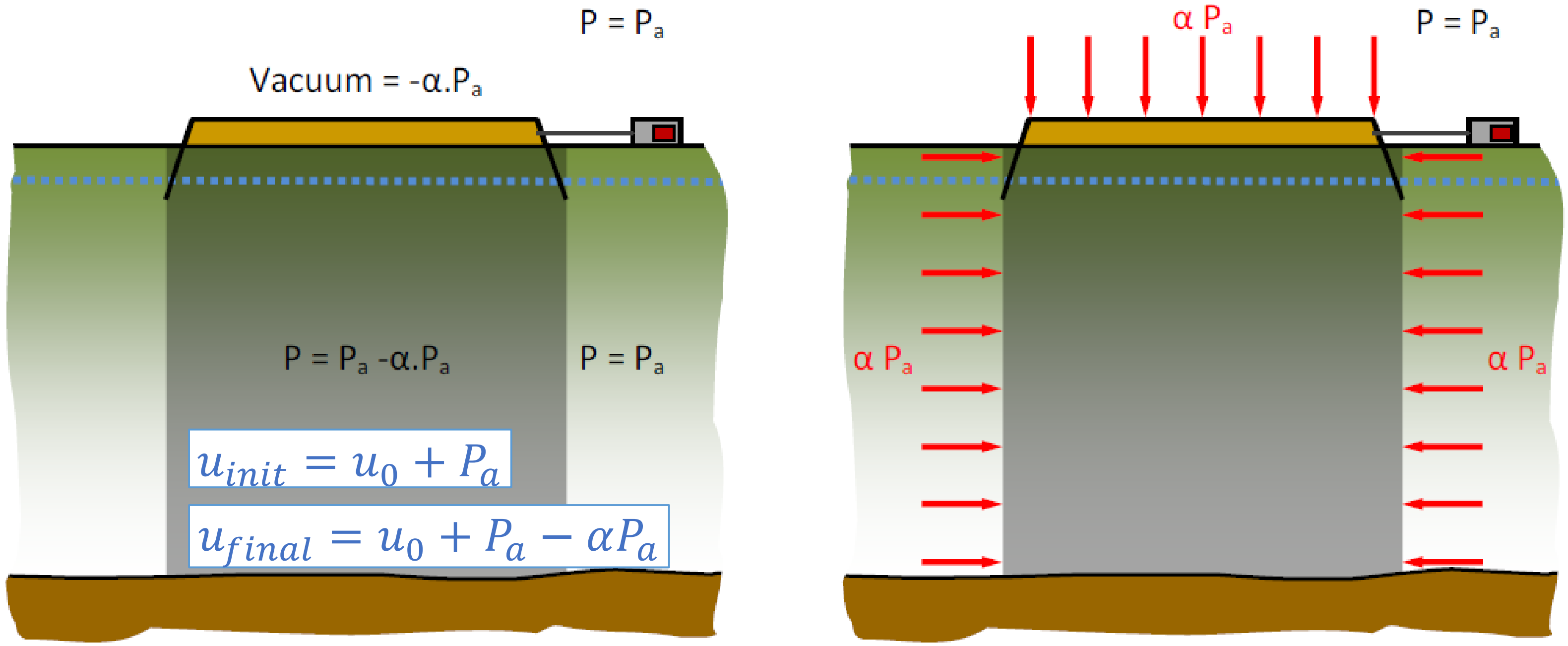
Menard Vacuum Consolidation

Classical preloading



Vacuum preloading



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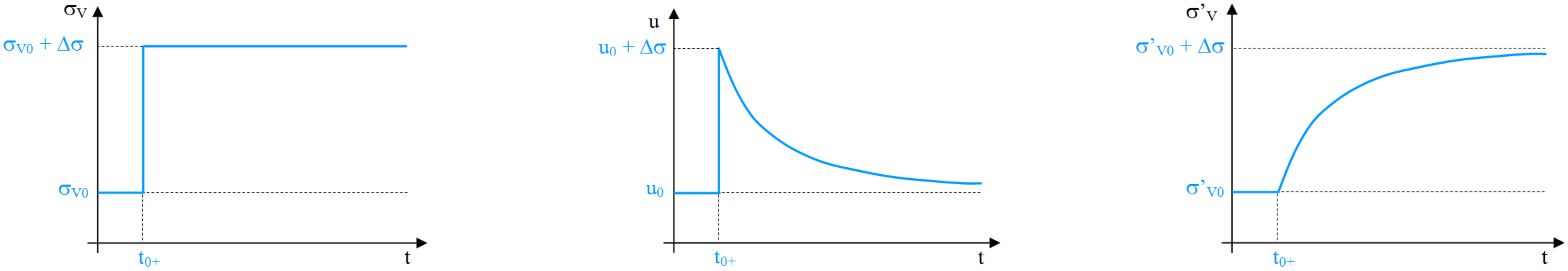
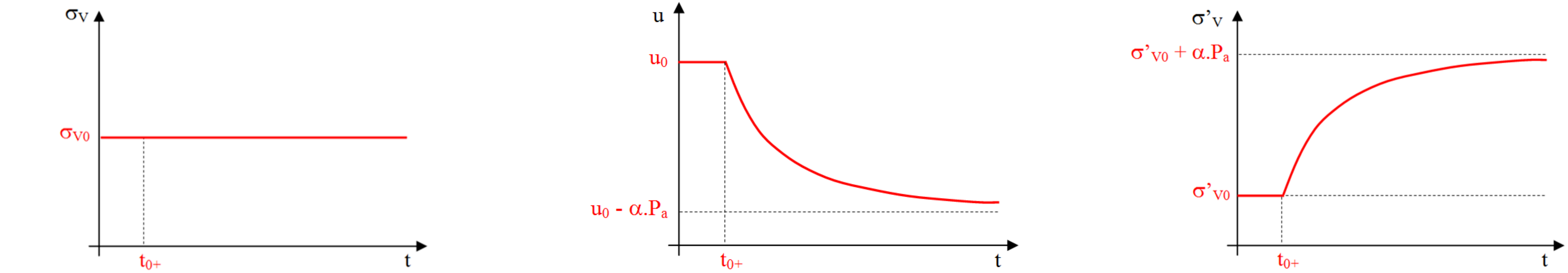
Menard Vacuum Consolidation

$$\sigma' = \sigma - u$$

Classical preloading



Vacuum preloading

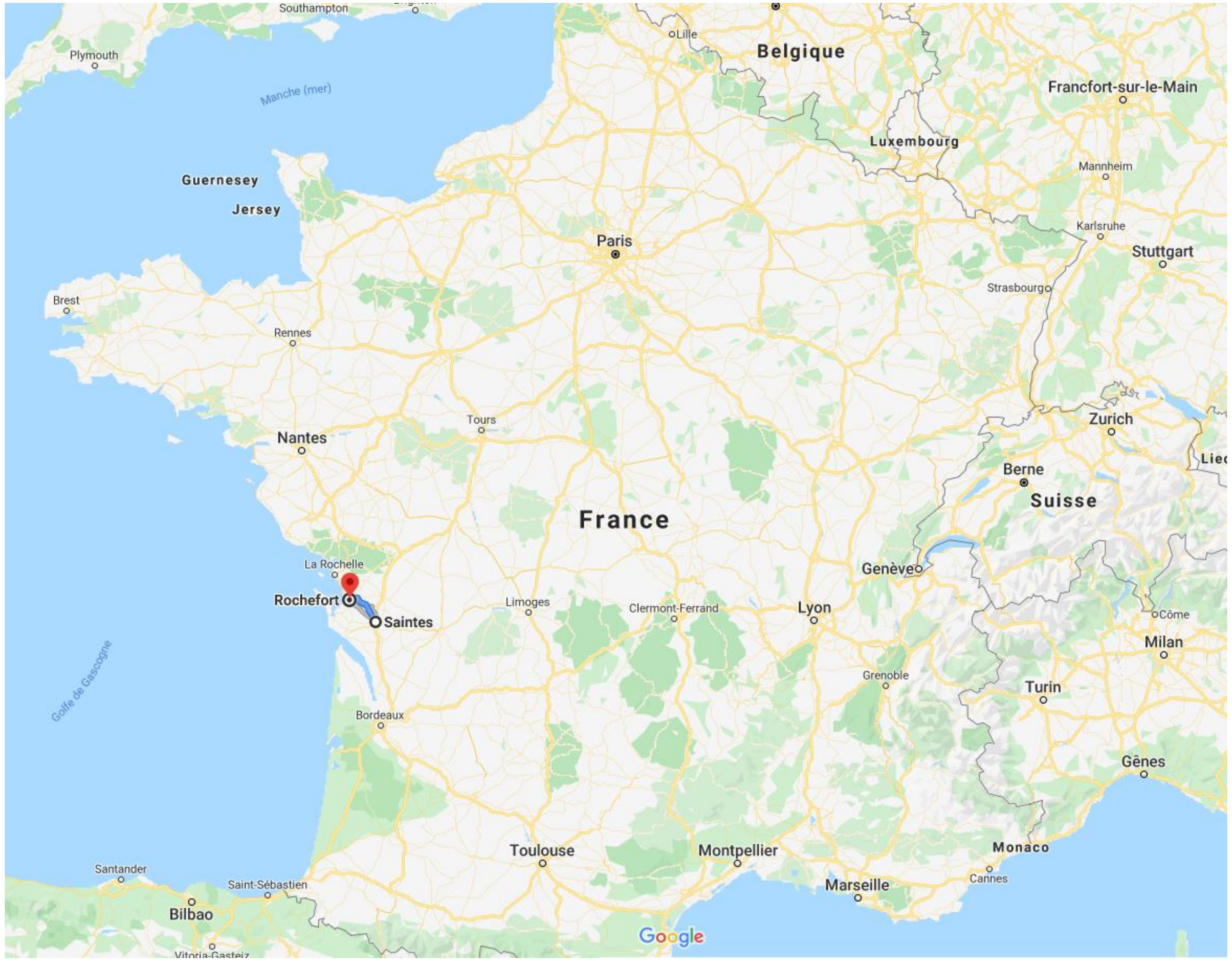


03

Case study #1

A837 Highway in France (1993)

A837 Highway (1993-1994)



- A837 project (1993-1994) – Rochefort to Saintes

Total length of section : 37,5 km
10 km go through marshy zones with fill from 2,0 m to 8,0 m high

- Current sections

Classical preloading with vertical drainage

Prefabricated band drains (10 cm)
Grid : from 1,00 to 1,60 m
Depth : from 10 to 25 m

- Critical sections (bridge access embankments)

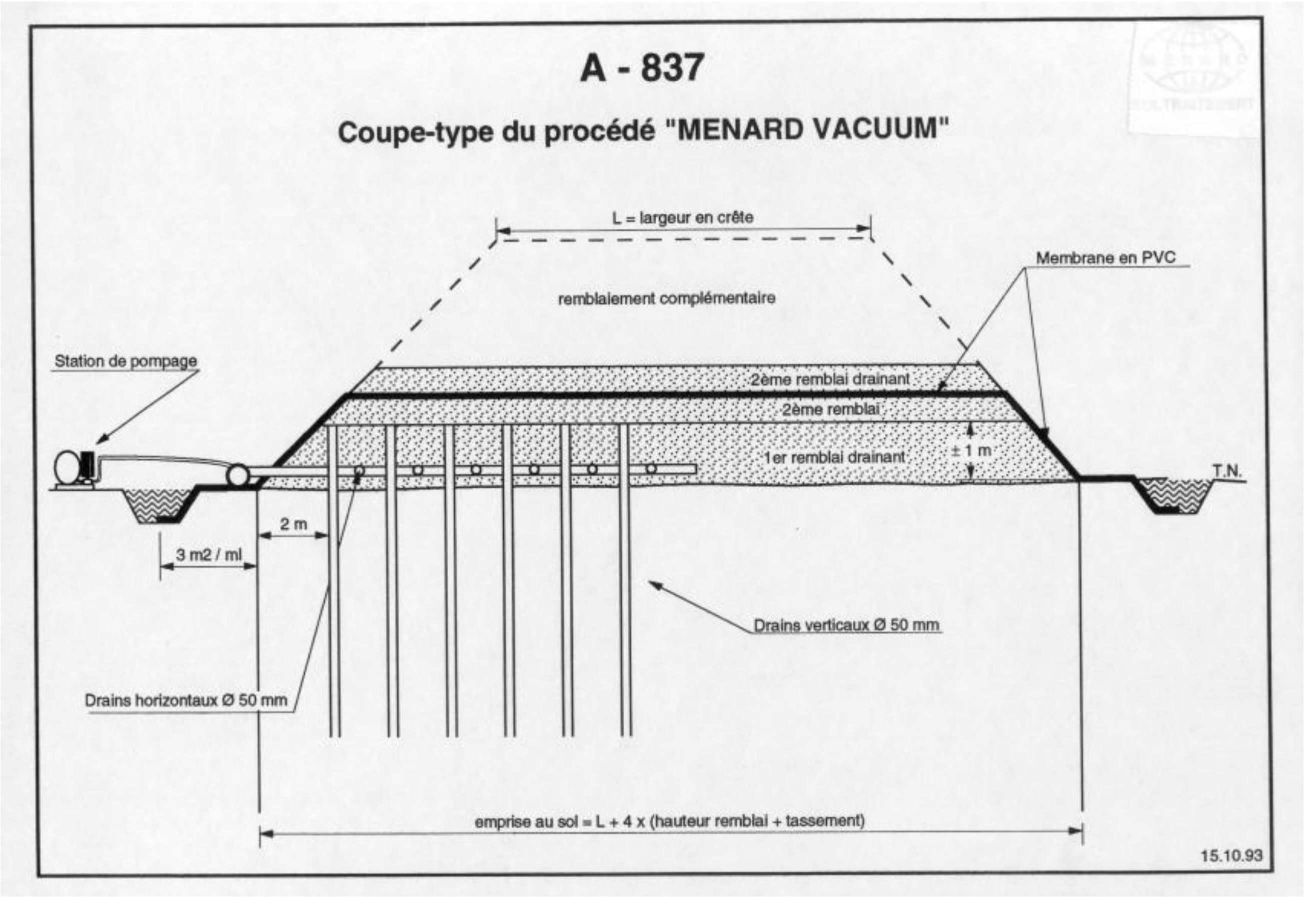
Menard Vacuum Technique as an alternative solution to preloading+drains+stone columns+berms

Soil conditions and technical specifications

Section	(1) Tonnay Charente	(2) Boutonne	(3) Agnet
Thickness of soft soil	18 to 26 m	4 to 13 m	4 to 20 m
Height of fill above ground level	2 m	5 to 8 m	6 m
Settlement criterion	**10 cm after 30 years**		

	Undrained Shear Strength **Su**	Void ratio **e**	Compression index **Cc**	Swelling index **Cs**	Creep index **Cαe**	Coeff. of vertical consolidation **Cv**	Coeff. of horiz. consolidation **Ch**
Soft clay	15 kPa	1,99	1,24	0,079	0,068	10^{-7} m²/s	7 x 10^{-7} m²/s

Sequence of works



- Placing a free drainage sand blanket (0,5 to 1,0 m thickness) in order to provide a suitable working platform
- Installation of vertical drains
- Installation of an horizontal drains network
- Installation of monitoring
- Excavation of trenches
- Installation of membrane
- Connection of drainage system to the pumps and beginning of pumping
- Add fill (to reach the final level and to compensate the expected settlement)

Installation of vertical drains and horizontal drains

Preparation of peripheral sealing trenches

Installation of membrane

Monitoring of consolidation – Settlement plates and piezometers

Connection of drainage system to the pumps and beginning of pumping

Some pictures

Tonnay Charente swamp area with 2 m high fill on membrane

Boutonne River crossing (One zone is simply under vacuum, the other one is already filled)

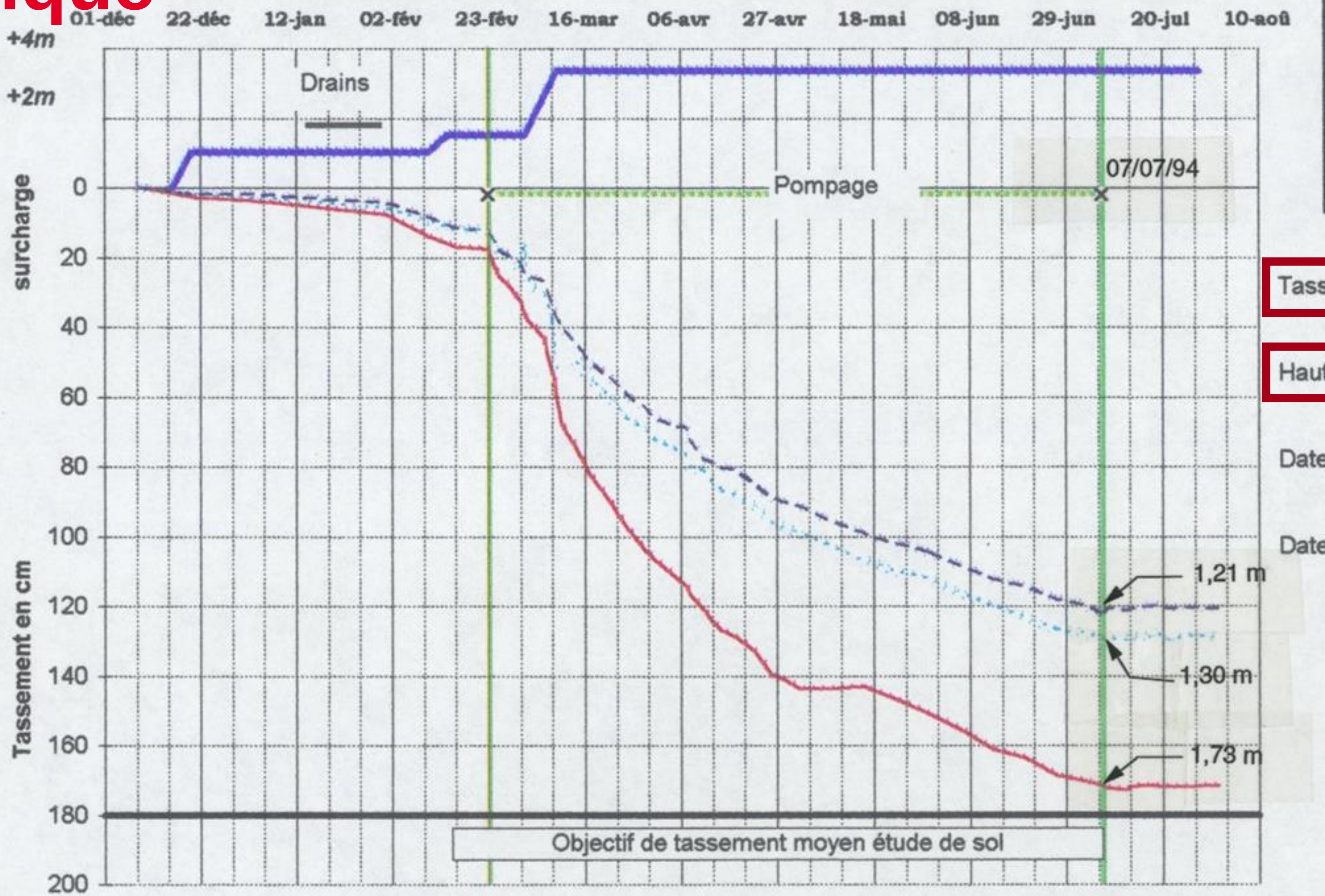
Results

With Menard Vacuum Consolidation, no more temporary surcharge.

The fill is placed directely on the membrane under vacuum up to final elevation increased only by the height of expected settlement during consolidation.

Historique

A 837 Saintes Rochefort Travaux préparatoires
Marais de Tonnay Charente Zone Daurade RD 911 profil 248,5



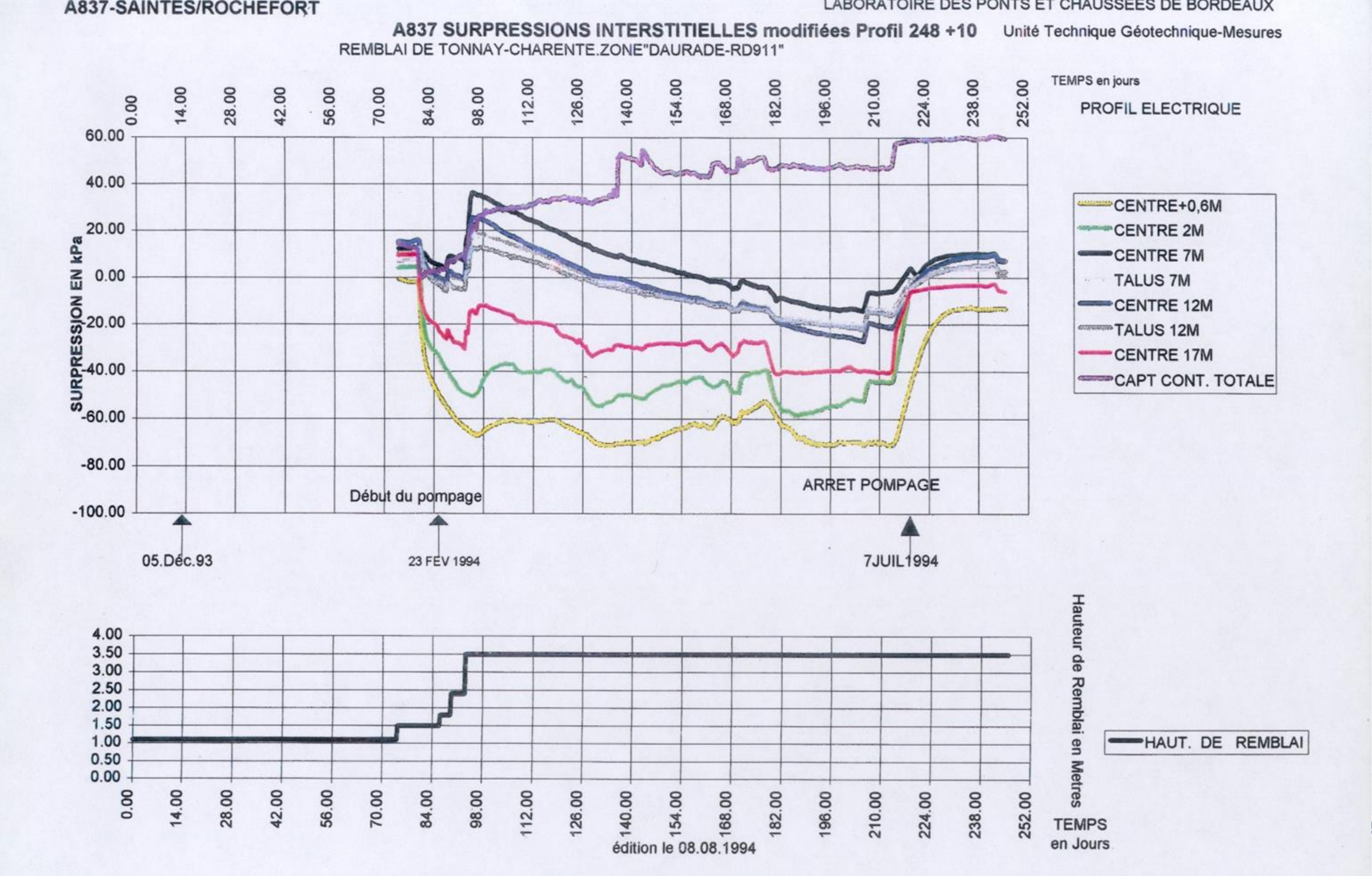
profil	profondeur de sol compressible	
248,5 a	18,6 m	
248,5 g	18,7 m	
248,5 d	18,6 m	
Hauteur de remblai		

Tassement prévu étude de sol 1,80 m

Hauteur totale de remblai : 3,70 m

Date de début de pompage 23/2/94

Date de fin de pompage 7/7/94


A837-SAINTES/ROCHEFORT
LABORATOIRE DES PONTS ET CHAUSSEES DE BORDEAUX
A837 SURPRESSIONS INTERSTITIELLES modifiées Profil 248 +10
Unité Technique Géotechnique-Mesures
REMBLAI DE TONNAY-CHARENTE.ZONE"DAURADE-RD911"
TEMPS en jours
PROFIL ELECTRIQUE
0.00
14.00
28.00
42.00
56.00
70.00
84.00
98.00
112.00
126.00
140.00
154.00
168.00
182.00
196.00
210.00
224.00
238.00
252.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
SURPRESSION EN kPa
CENTRE+0,6M
CENTRE 2M
CENTRE 7M
TALUS 7M
CENTRE 12M
TALUS 12M
CENTRE 17M
CAPT CONT. TOTALE
Début du pompage
ARRET POMPAGE
05.Déc.93
23 FEV 1994
7JUIL1994
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Hauteur de Remblai en Metres
HAUT. DE REMBLAI
TEMPS
en Jours
édition le 08.08.1994

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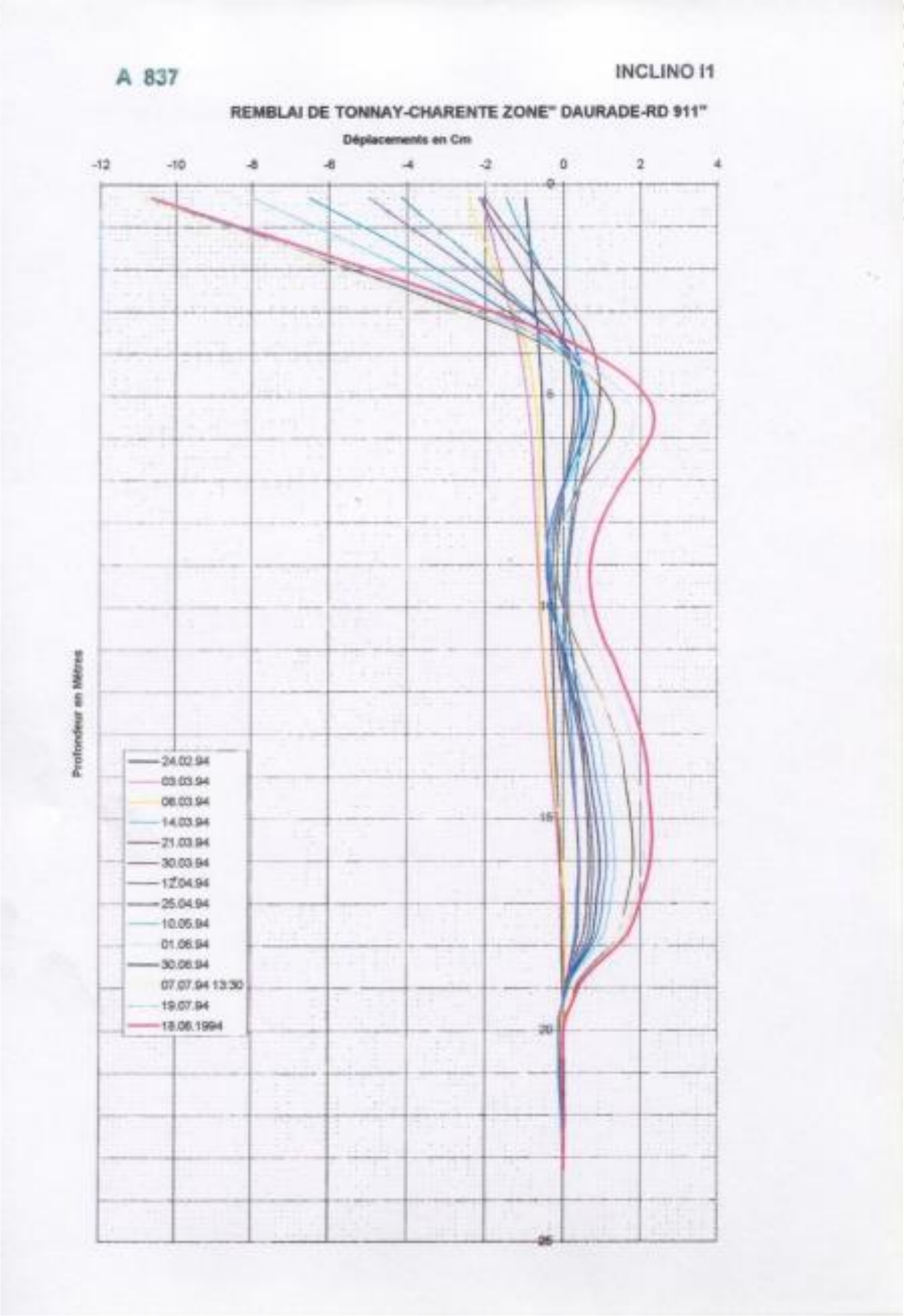
Inclinometer results

The embankment is on the left; there is a 10 cm inwards horizontal displacement due to horizontal consolidation.



Conclusions

Advantages of Menard Vacuum solution

- Quicker embankment construction without any circular failure risk (6 to 9 months instead of 18 months)
- No more lateral berm
- Decreased volume of earthmoving (no more temporary surcharge)
- Better control of settlement with time

04

Case study #2

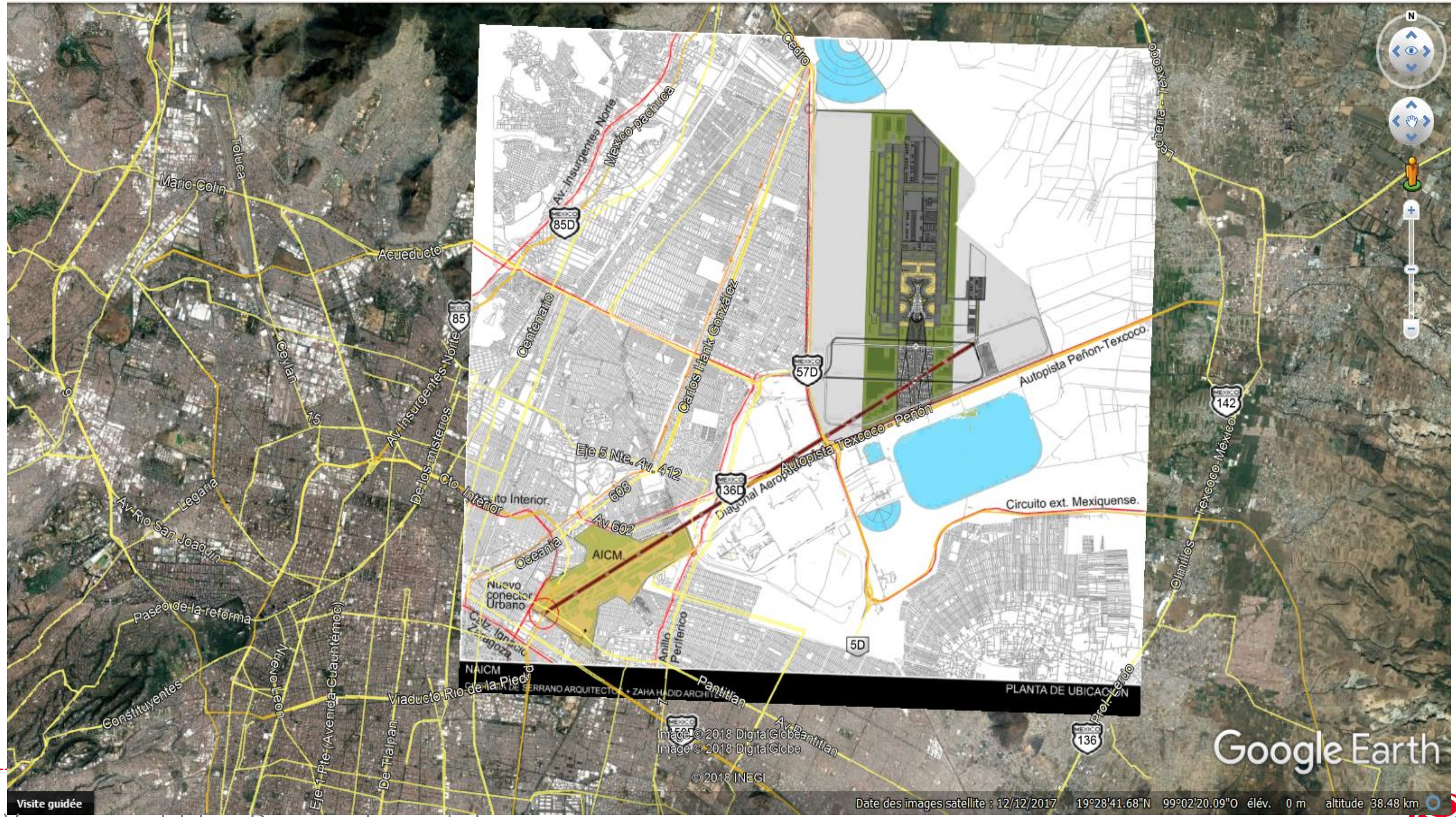
New Mexico City Airport (2018)

The New Mexico City International Airport (NAICM)

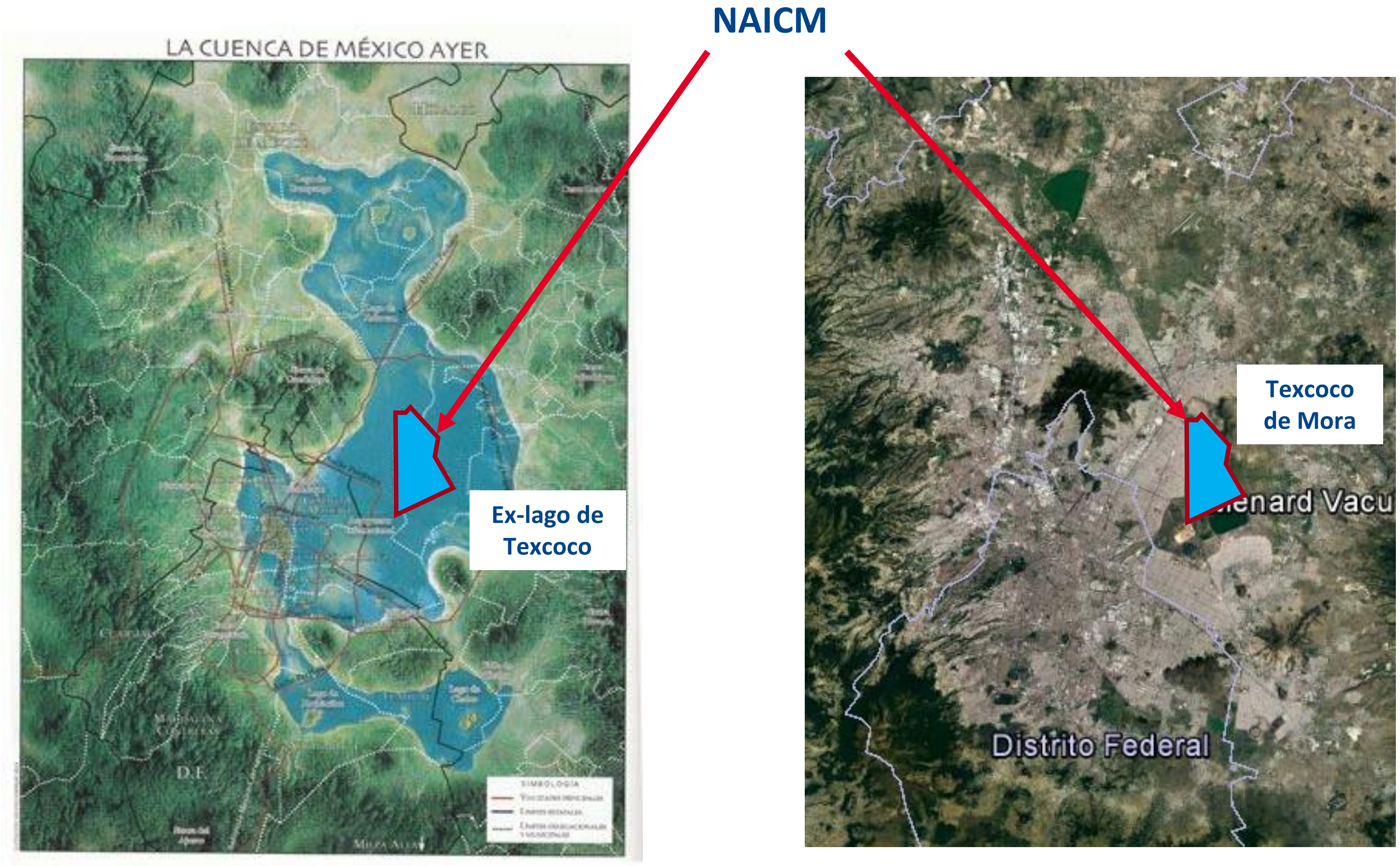
The NAICM was partially built when it was abruptly canceled in late 2018 after a popular consultation. Instead, the current Federal government of Mexico plans to build an international airport at Santa Lucía Air Force Base north of the city.

1st phase in operation: October 2020
Total area: 4 430 hectares
X-shaped terminal: 743,000 m^2
Runways: 3
Passengers per year: 68 millions

Soil conditions



Soil conditions



Soil conditions

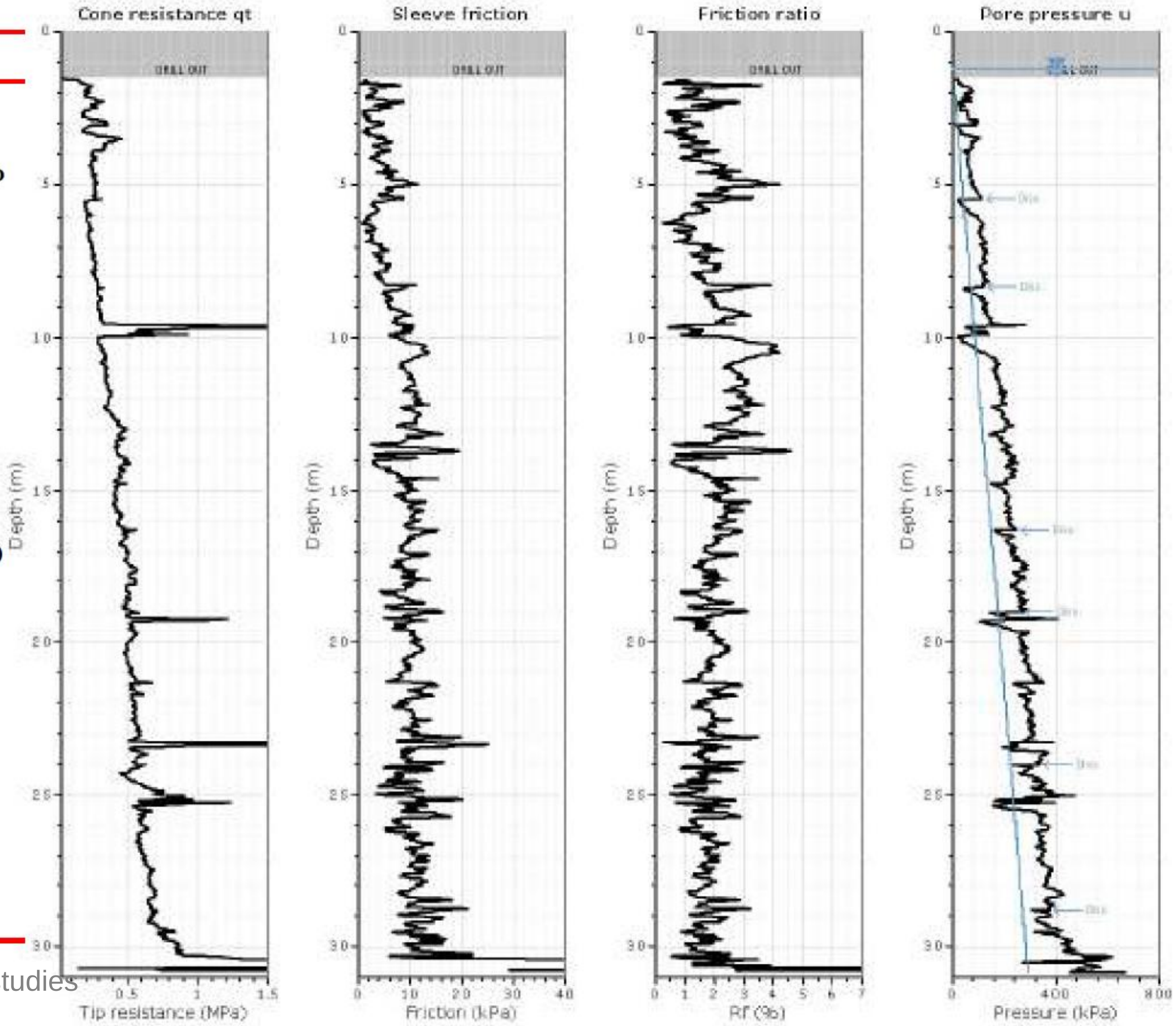
Plataforma de Tezontle

NAF ~ 1.10 m

Hundimiento reg prom ~ 24 a 32 cm/año

FAS (Formación arcillosa superior) con intercalaciones de arenas y cenizas volcánicas) Arcillas CH

Capa dura (CD)



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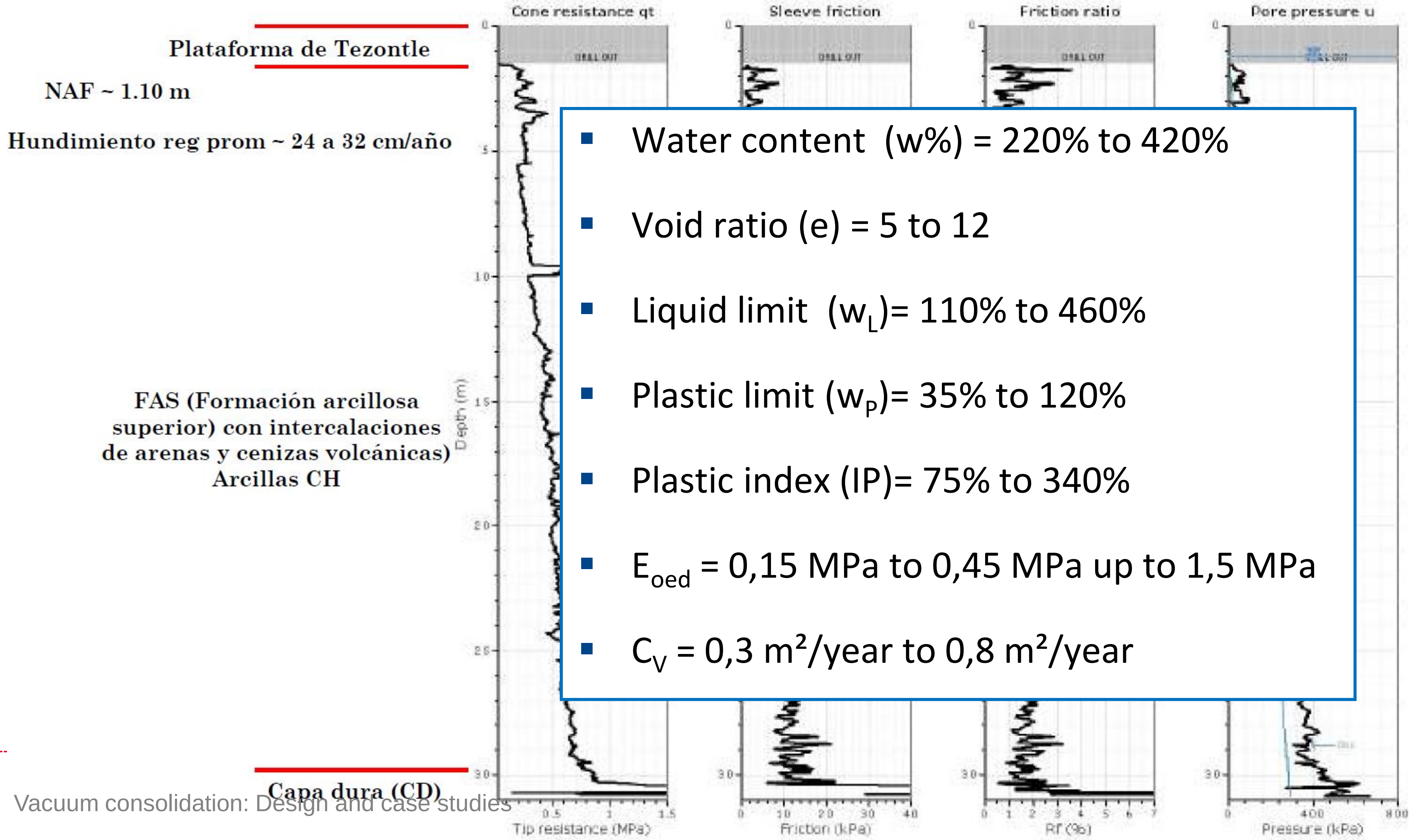
Soil conditions



- Water content (w%) = 220% to 420%
- Void ratio (e) = 5 to 12
- Liquid limit (w_L)= 110% to 460%
- Plastic limit (w_P)= 35% to 120%
- Plastic index (IP)= 75% to 340%
- E_{oed} = 0,15 MPa to 0,45 MPa up to 1,5 MPa
- C_V = 0,3 m^2/year to 0,8 m^2/year

Ground improvement works

Prefabricated Vertical Drains and Prelaoding under Runway II

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Prefabricated Vertical Drains and Prelaoding under Runway II

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Ground improvement works

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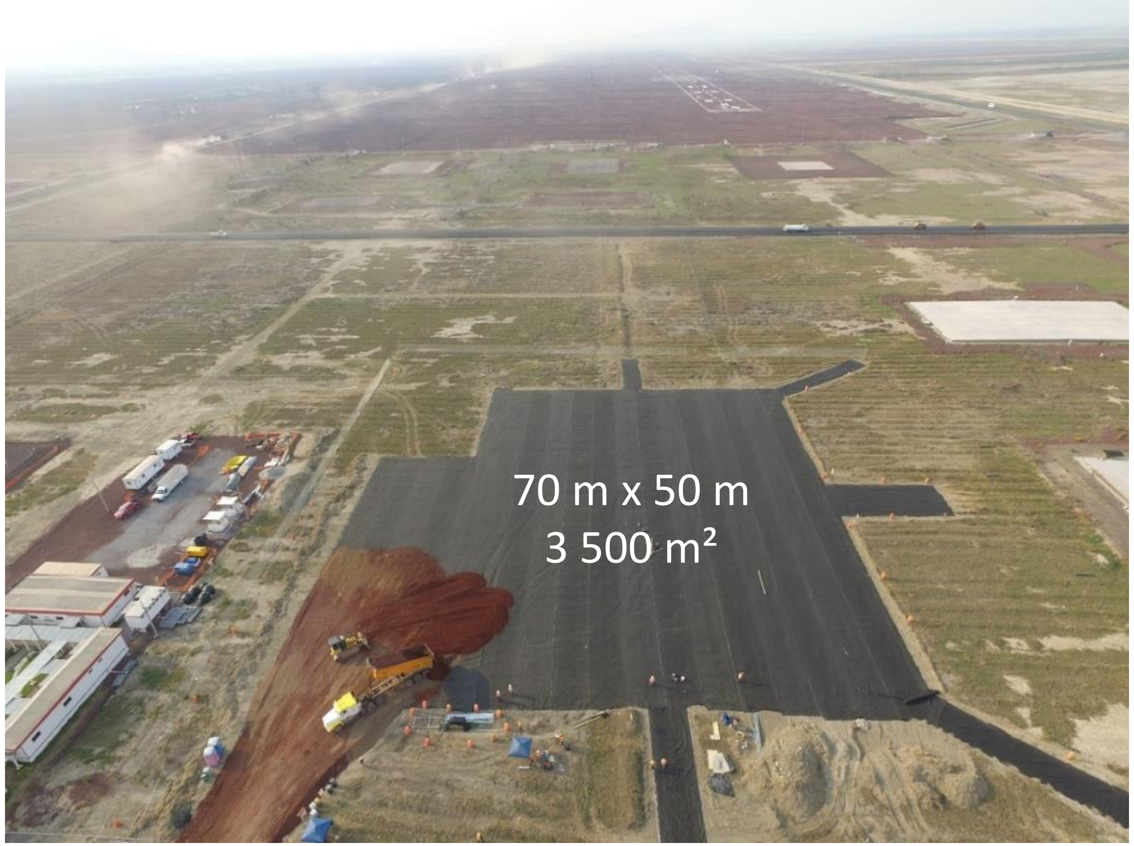
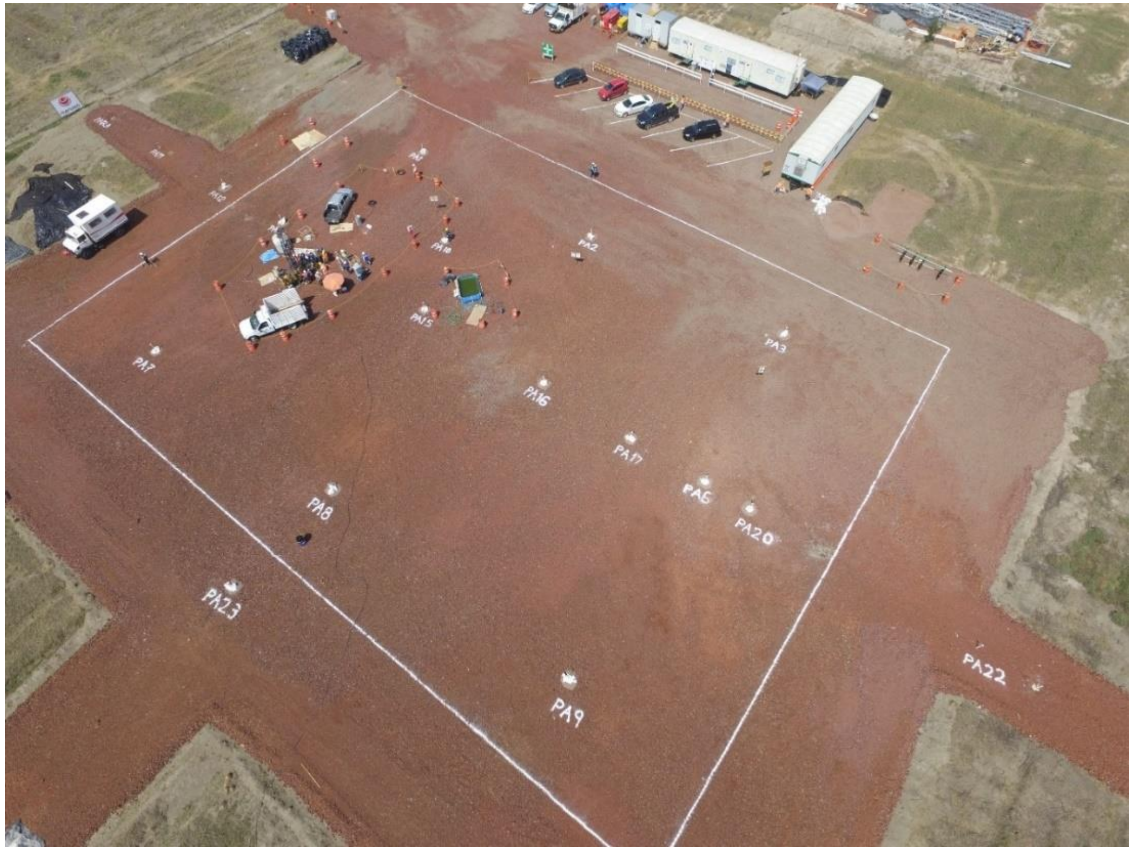
Menard Vacuum Trial Area - Execution

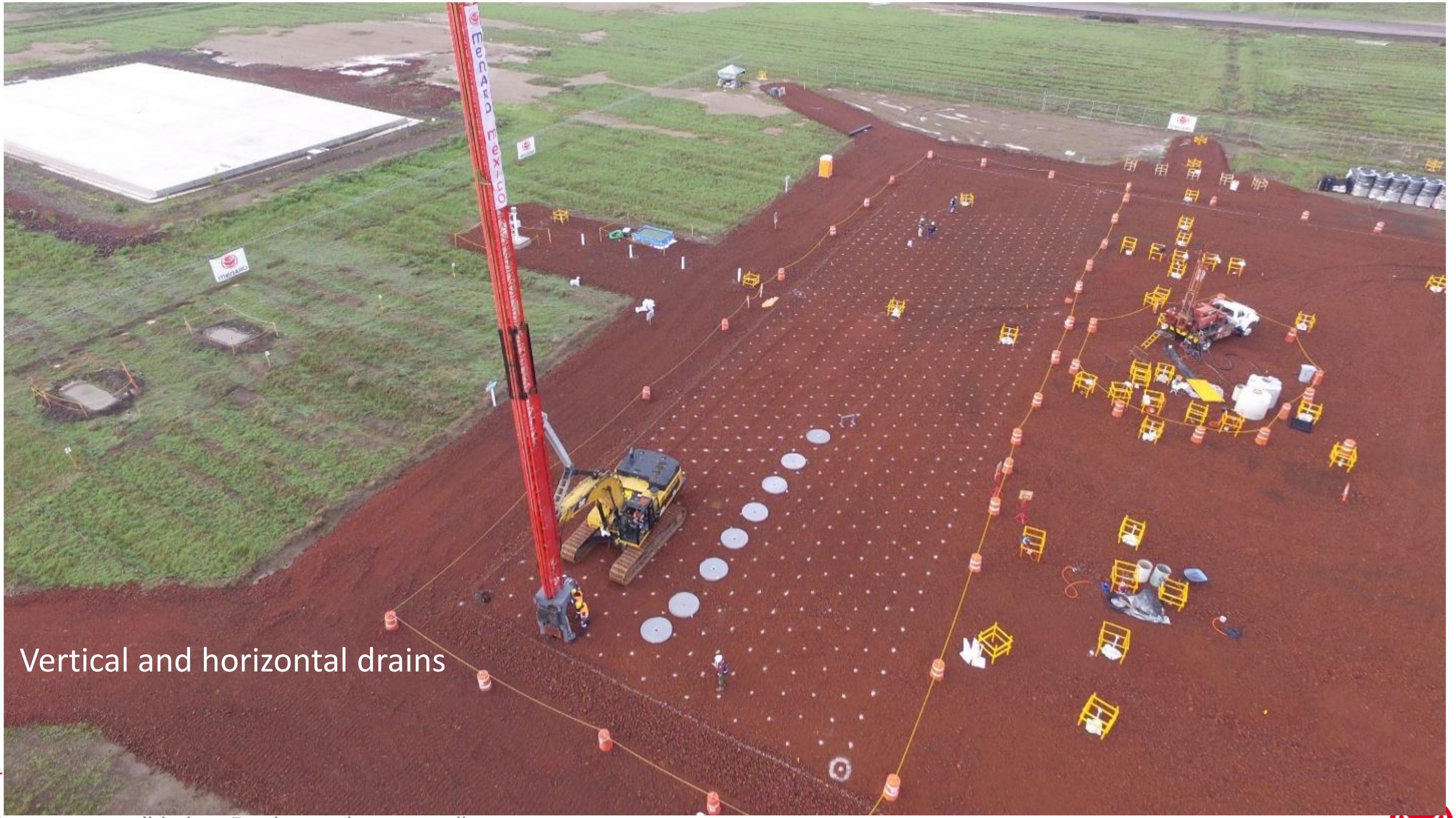


Working platform
0,5 m + 0,5 m = 1 m of “tezontle” (13,7 kN/m³)



Monitoring installation

Menard Vacuum Trial Area - Execution



Menard Vacuum Trial Area - Execution

Before Vacuum

After beginning of Vacuum

Menard Vacuum Trial Area - Execution

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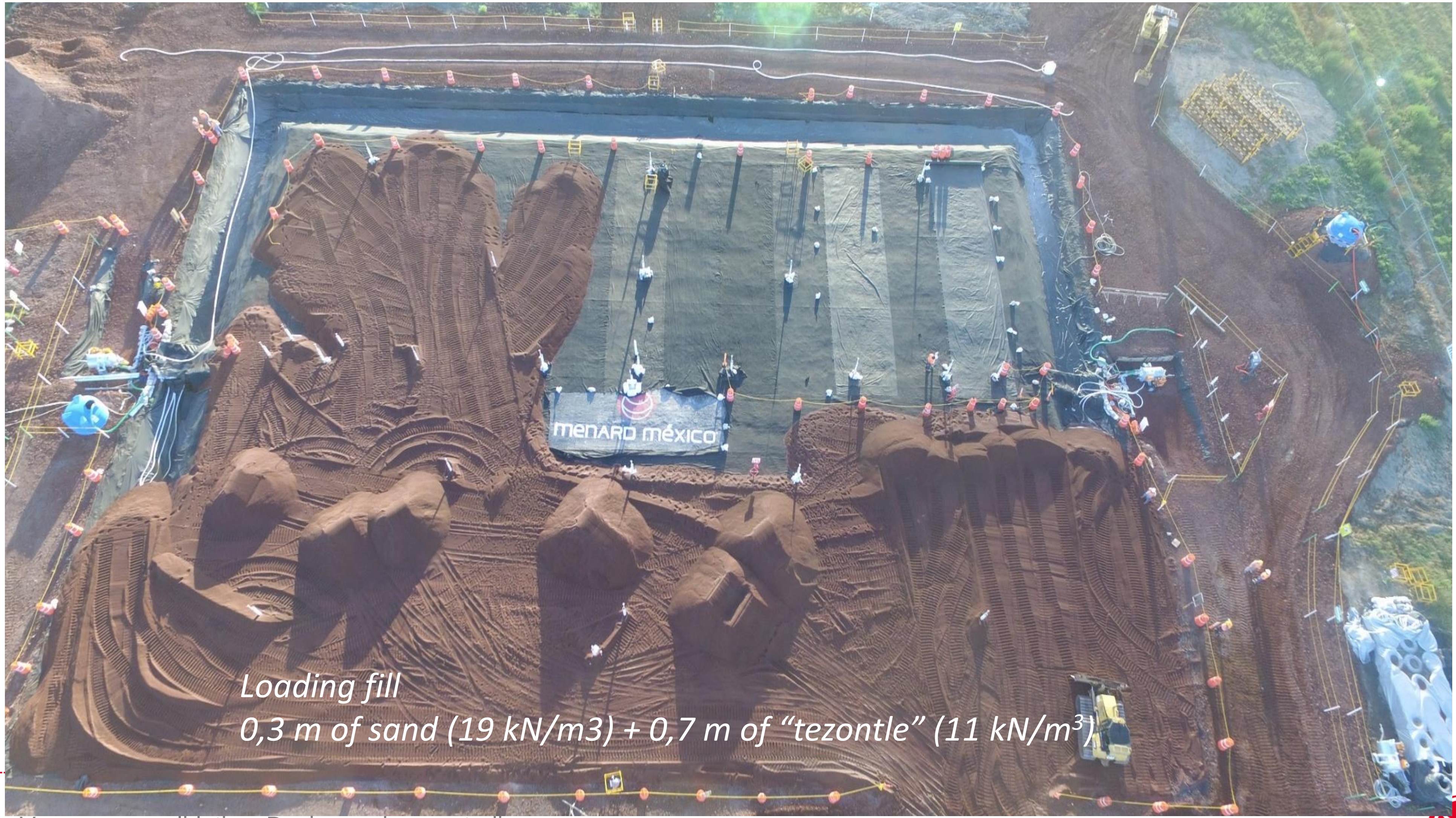
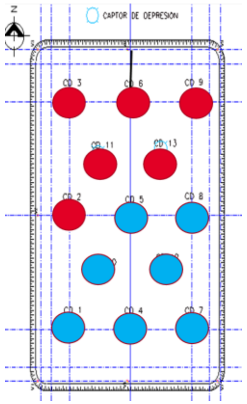
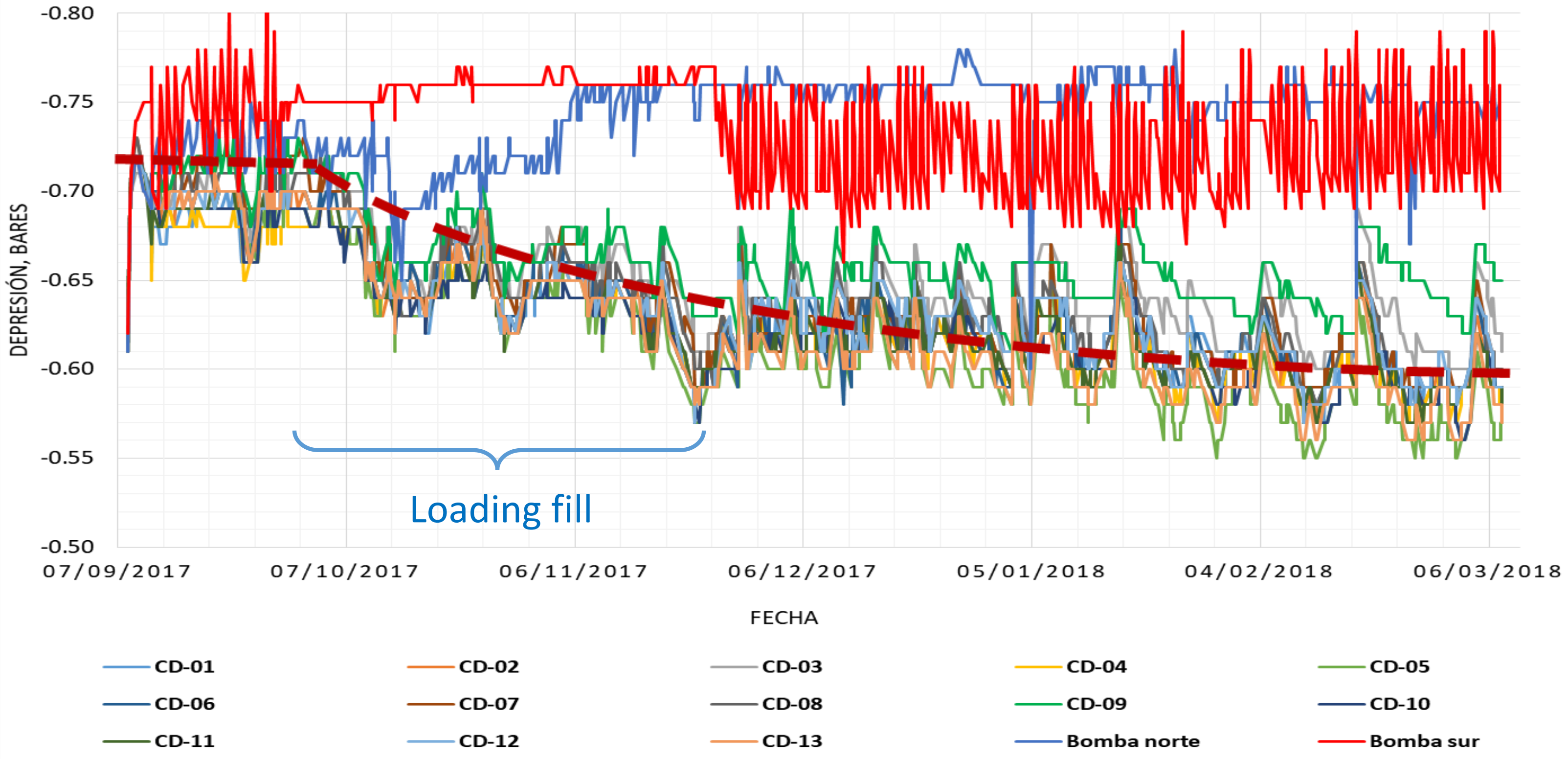
Menard Vacuum Trial Area - Execution



Results – Vacuum Pressure



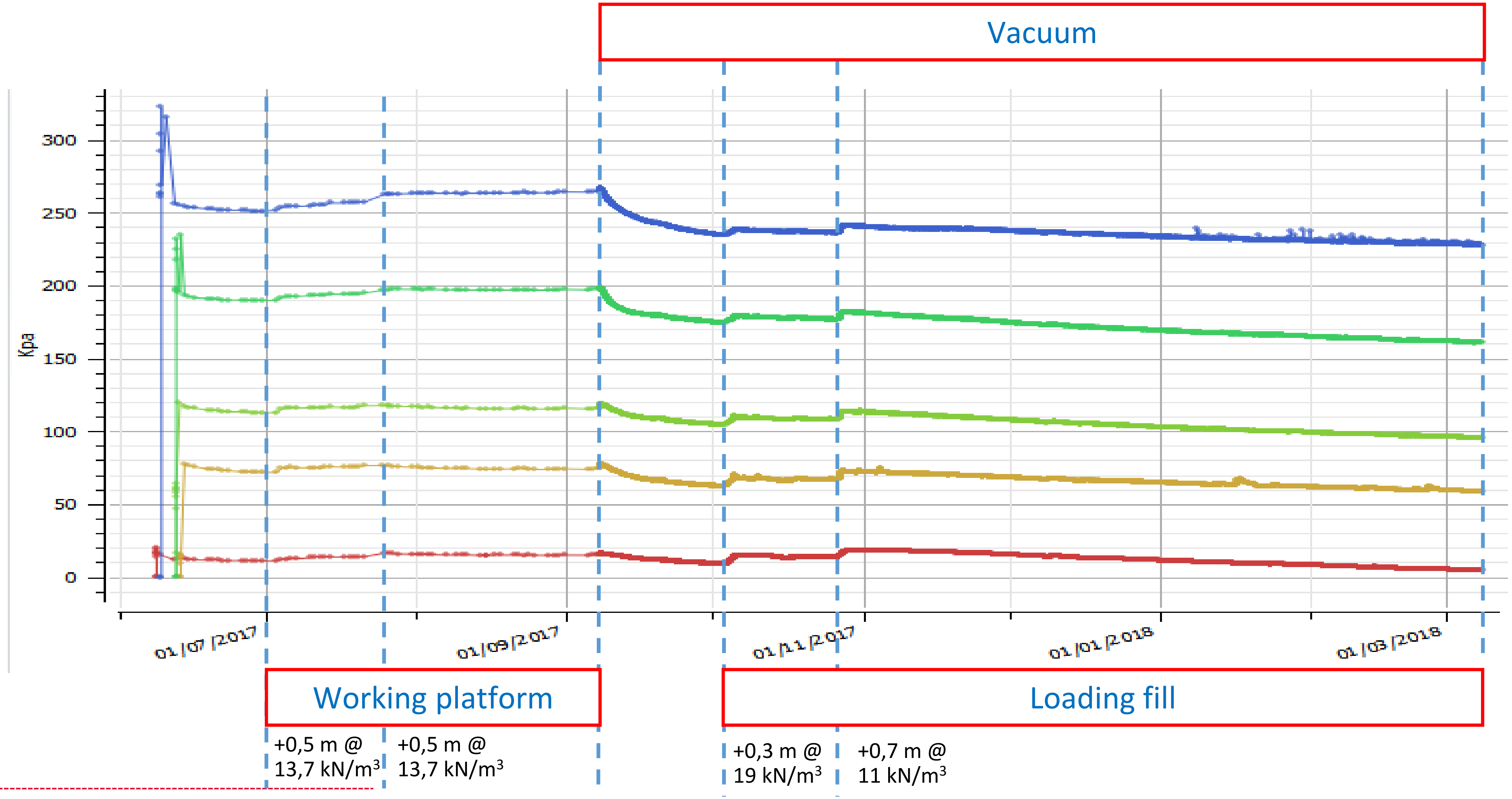


Atmospheric pressure = **78 kPa** at the Texcoco Lake (2228 m a.s.l)

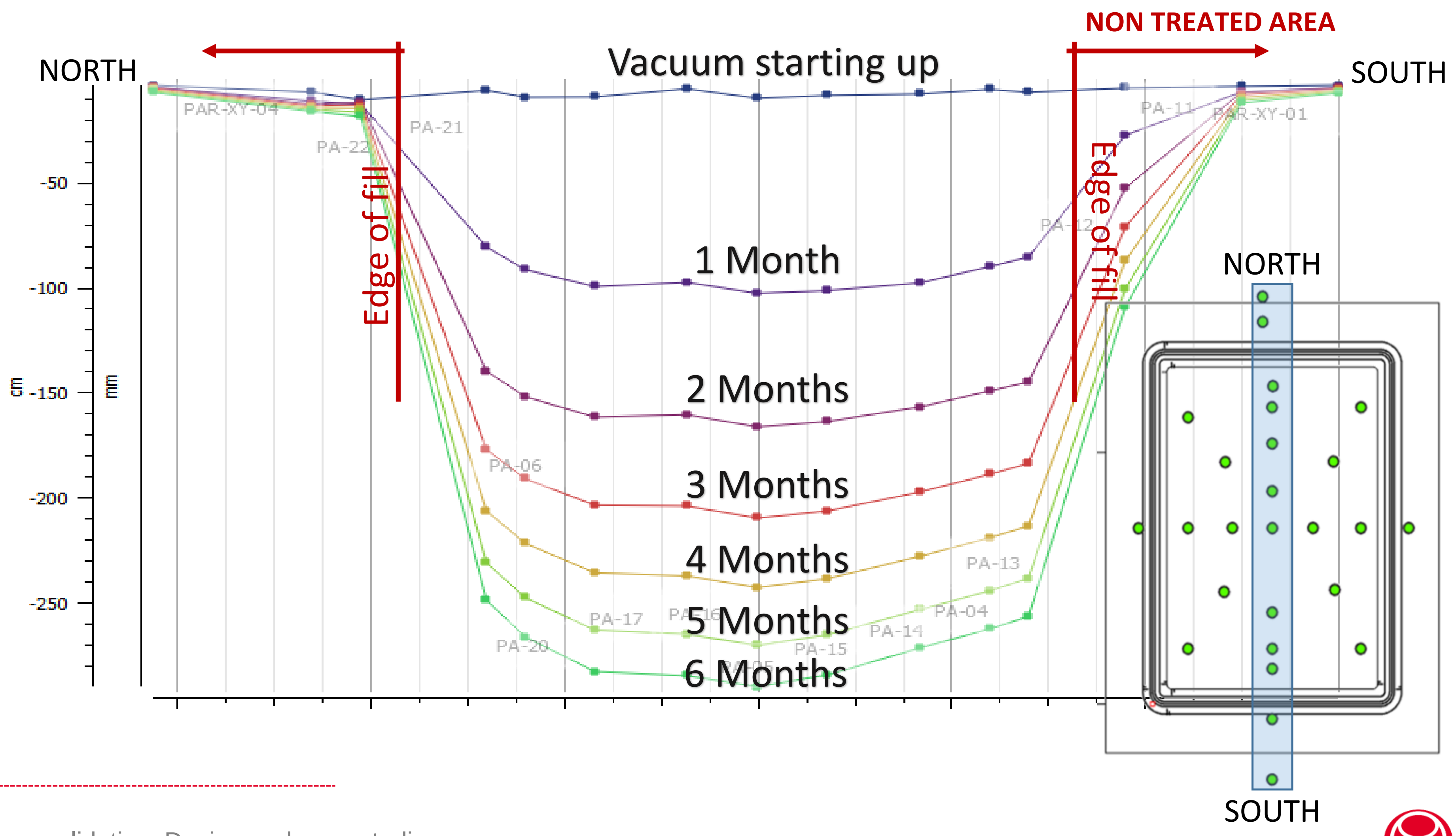
Vacuum pressure = **72 kPa** in the soil at the beginning

Vacuum pressure = **60 kPa** in the soil after 6 months

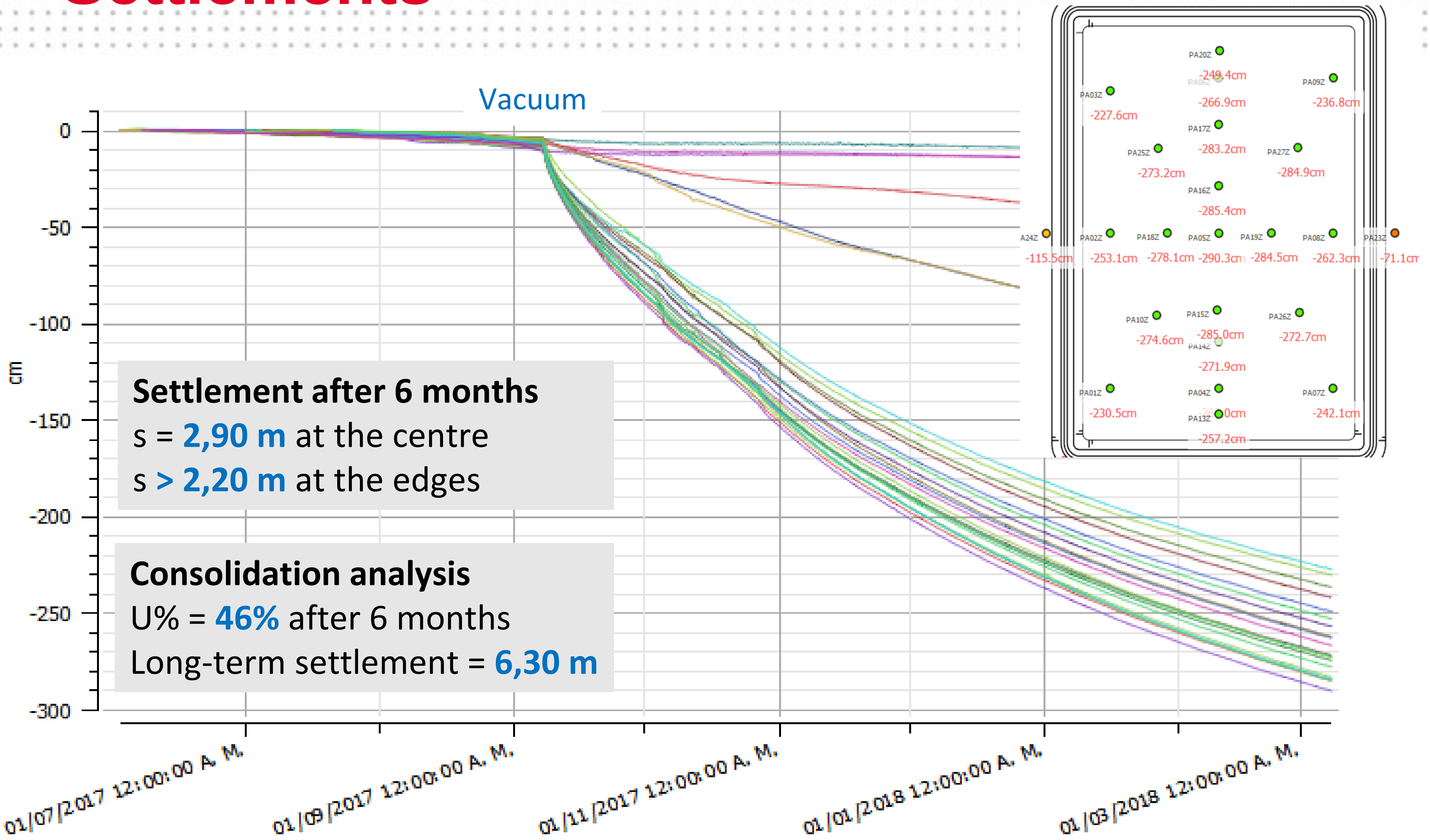
Results – Pore Water Pressures



Results – Settlements



Results – Settlements



Settlement after 6 months

s = **2,90 m** at the centre

s **> 2,20 m** at the edges

Consolidation analysis

U% = **46%** after 6 months

Long-term settlement = **6,30 m**

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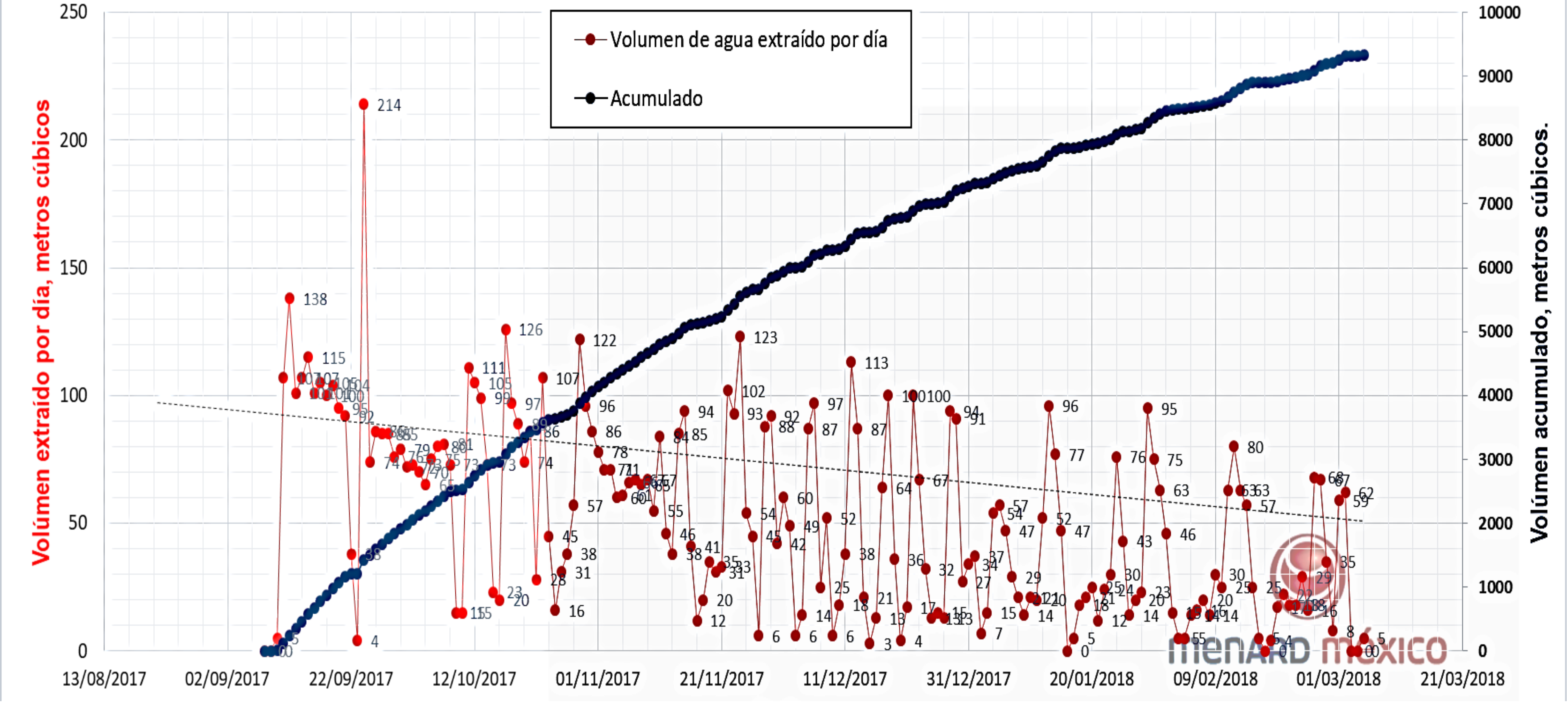
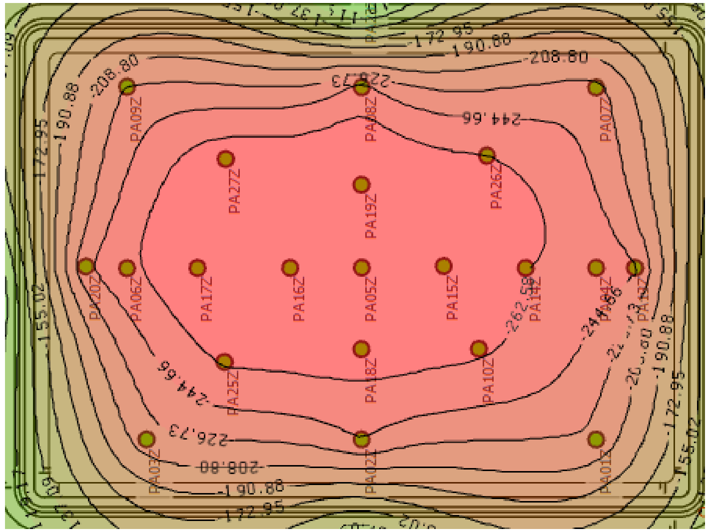
Results – Settlements and extracted water

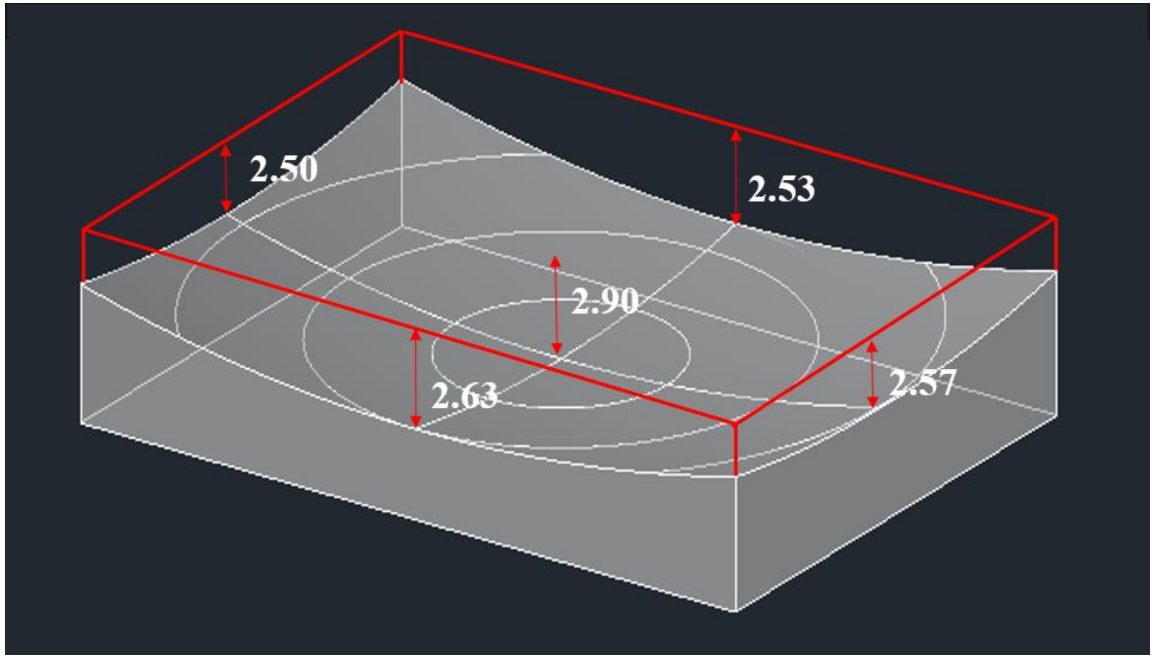


Volume of extracted water

V_{water} = 9 353 m^3

Results – Settlements





Volume of extracted water

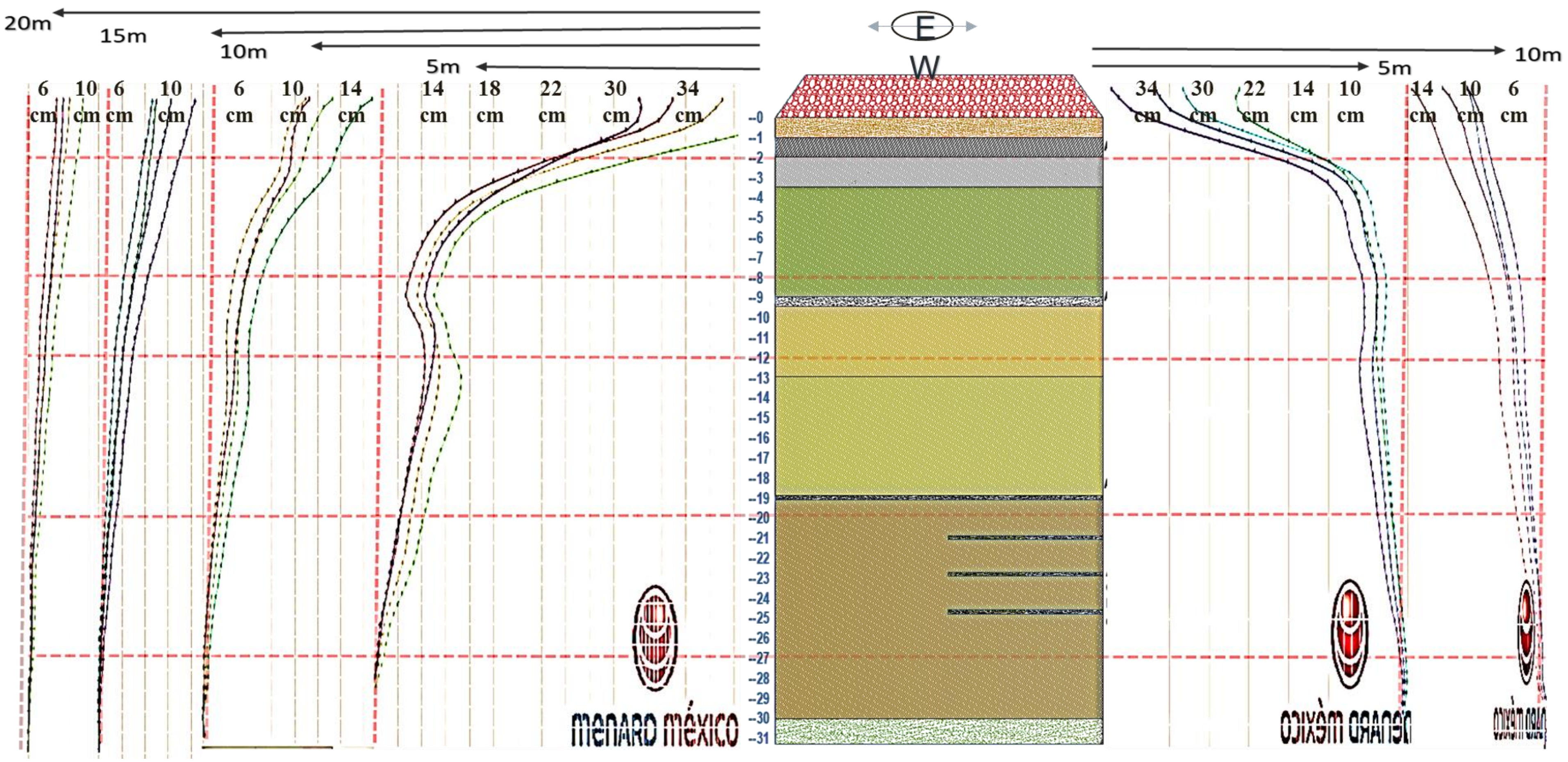
V_{water} = **9 353 m³**

Volume of settlement

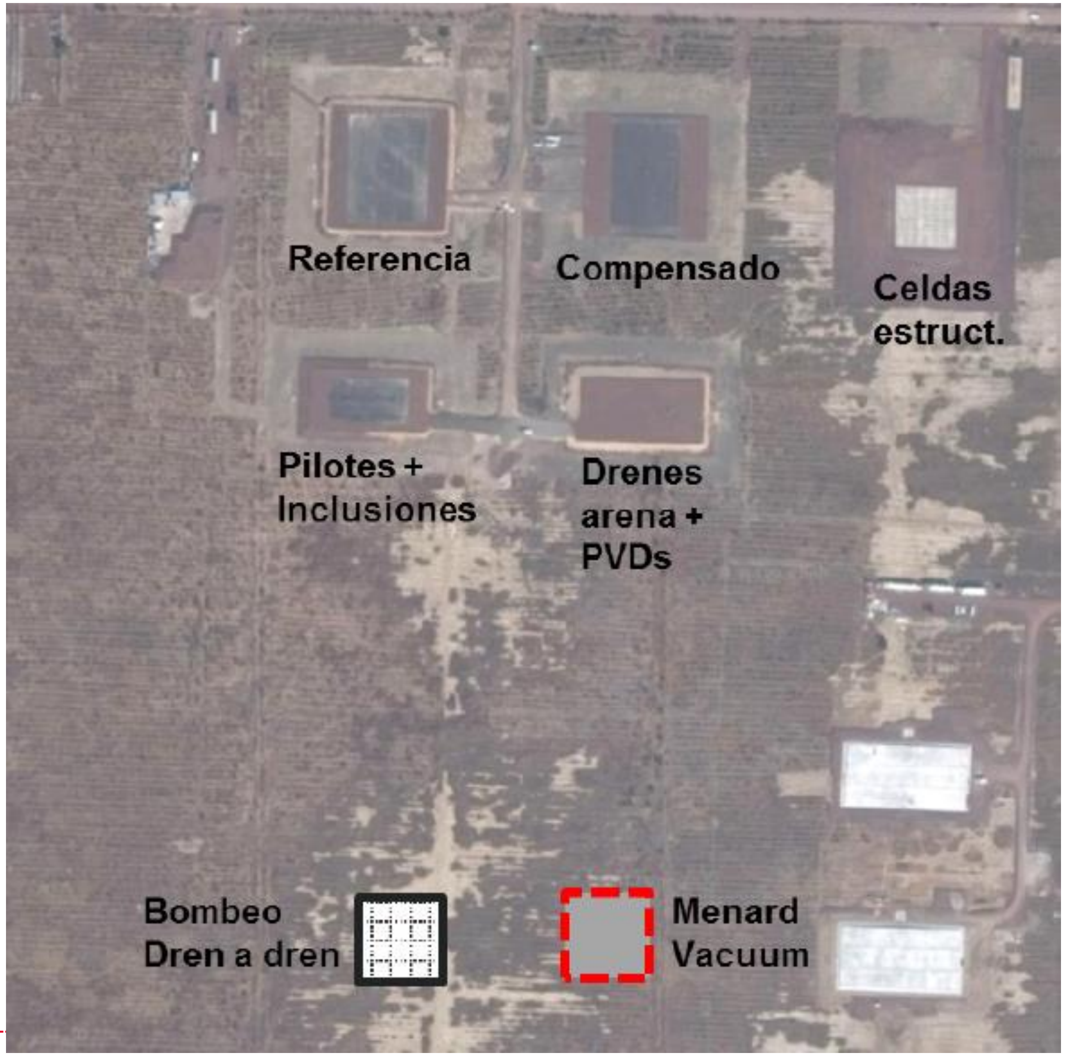
$V_{settlement}$ = **9 628 m³**

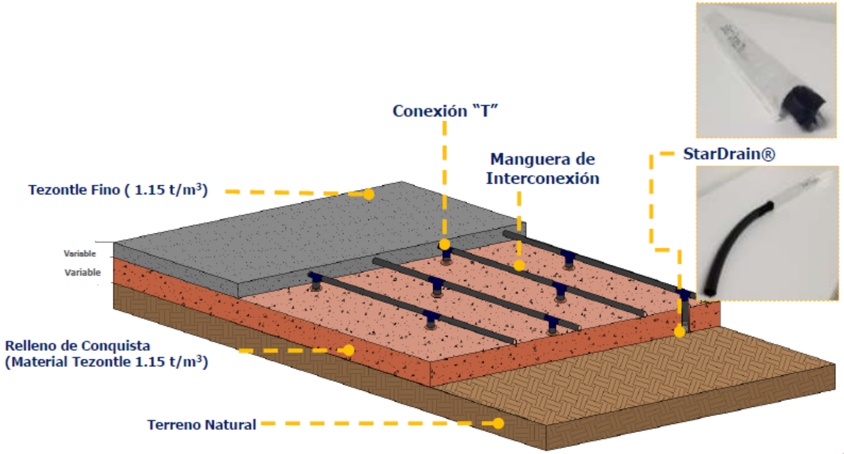
The amount of extracted water is equal to the total settlement. Menard Vacuum Consolidation method has nothing to do with dewatering.

Results – Lateral displacements

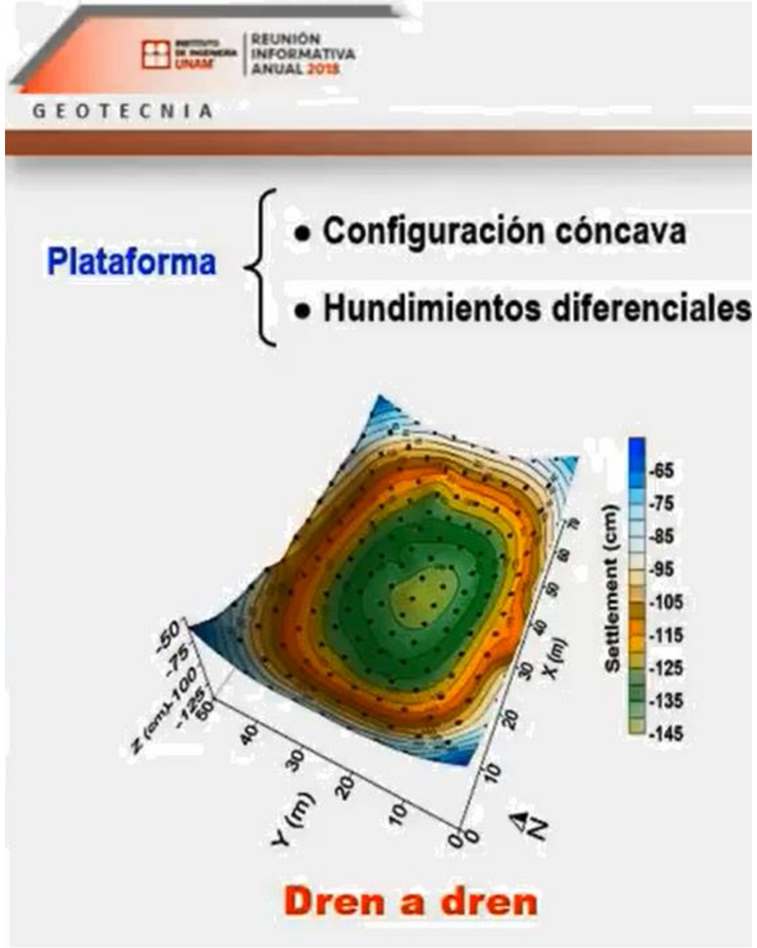


Menard Vacuum Trial Area vs Drain to Drain Trial Area





Menard Vacuum Trial Area vs Drain to Drain Trial Area



Differential settlements along the transverse centerline

Fig.10 summarizes data obtained from the horizontal inclinometer. Curves evidence isochronic settlement profiles that have almost symmetrical shapes and trends similar to that exhibited by traditional embankments. The differential settlements between the center and the boundaries of the embankment are influenced by the inward movements of the lateral boundaries caused by vacuum. Boundary settlements vary linearly with the corresponding ones detected at the centre. Along the transverse centerline a ratio equal to 0.6 between lateral and central settlements was observed: this value is practically coincident with that predicted by the elastic theory for traditional embankments.

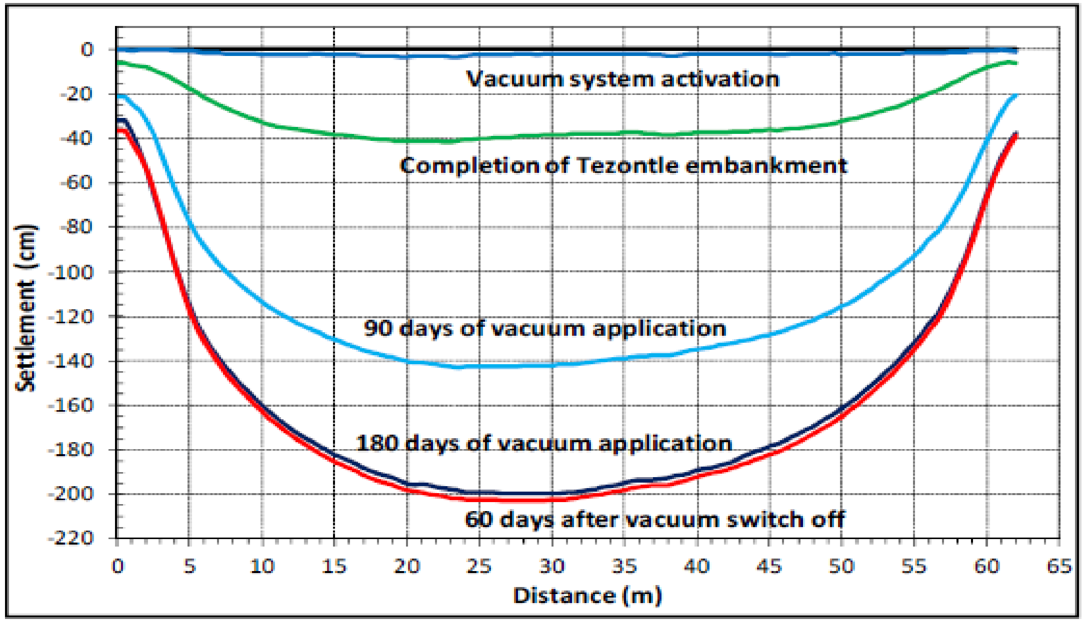


Fig 10 – Time history of settlements measured by horizontal inclinometer

Settlements
2,00 m at the centre
1,20 m at the edges

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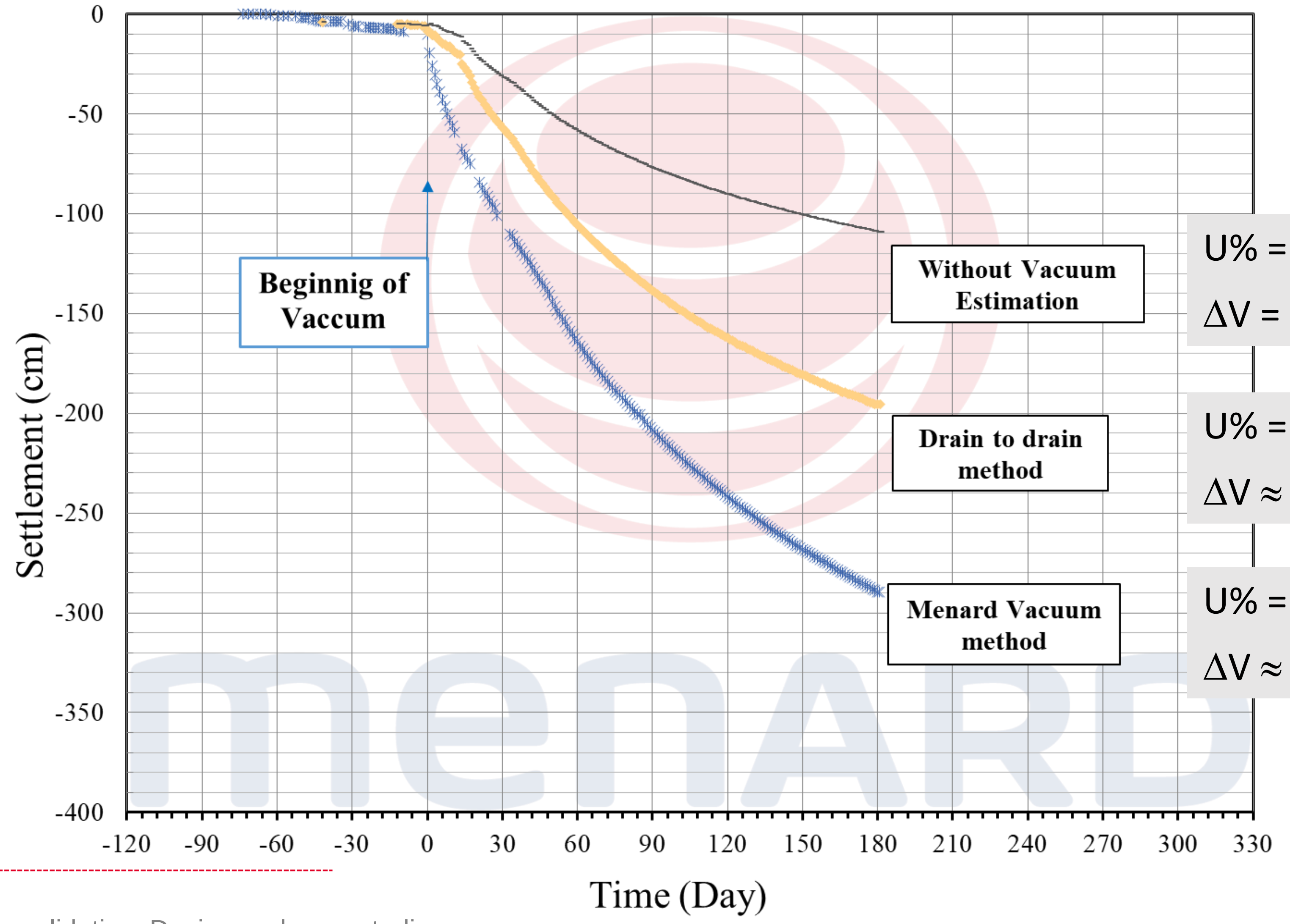
Menard Vacuum Trial Area vs Drain to Drain Trial Area



U% = 46%

ΔV = 0 kPa

U% = 46%

ΔV ≈ 27 kPa

U% = 46%

ΔV ≈ 60 kPa

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Drain to Drain method
1,98 m in 6 months
Menard Vacuum
2,90 m in 6 months

Bibliography

Cognon, J.M. (1991). La consolidation atmosphérique. Vacuum consolidation. *Revue Française Géotechnique, n°57, pp. 37-47*

Ghionna, V.N. et al. (2018). Vacuum preloading with drain to drain method for the New International Airport of Mexico City. *DFI-EFFC International Conference on Deep Foundations and Ground Improvement*, Rome, Italy.

Juarez Velazquez, L.D. and Cirion Arana, A. (2018). Vacuum Consolidation with impervious membrane Soil Improvement System (Atmospheric Consolidation System). Test panel case study made for Mexico's New International Airport (NAIM) in Texcoco, Mexico. *XXIX Reunión Nacional de Ingeniería Geotécnica*, León, Mexico

05

Conclusions

Conclusions

Vacuum consolidation is an effective means for improving highly compressible soft soils.

- The Vacuum Consolidation method uses the site atmospheric pressure to pre-load an impermeable soil in order to anticipate long-term surface deformations and to “prepare” the soil to withstand the future service loads.
- Vacuum consolidation can yield an effective equivalent preload of about 3 to 5 m of conventional surcharge;
- Vacuum consolidation allows to accelerate the consolidation process as compared to conventional stage-loading because it reduces drastically the risk of failure;
- It can be easily combined with classical preloading;
- As compared to classical preloading, the Vacuum pressure acts homogeneously throughout the soil mass, without any reduction in depth or width.