

Introduction

The French A837 tollway connects the Atlantic façade in la Rochelle to the Paris -Bordeaux main axis. Following the path of the Charente River, the road crosses a predominantly flat area near Rochefort with three marshlands identified as main sources for large amplitude settlements after fill placement:

- the Tonnay Charente marshland crossing 2 canals and with an average of 20 meters of compressible normally consolidated clay, divided in 3 distinct areas,
- the Boutonne river where a four arches bridge will require 7 meters height access embankments,
- the Agnet, consisting of a narrow 20 meters deep thalveg valley with alluvial deposits.

The objective of the Menard vacuum consolidation treatment (MVC), patented, was to enable fast construction of the road embankments and reduce post-construction settlement to within acceptable limits.

Although part of a private construction project, implementation of the MVC was closely monitored by the geotechnical section of the French Highway Authority (SCETE Bordeaux) as well as by an independent geotechnical consultant (SORES) for additional instrumentation and follow up.

Geotechnical conditions

Although the soil conditions were variable across the various sites, the subsoil generally consisted of soft, normally consolidated clay with the following characteristics:

Area	Tonnay-Charente	Boutonne	Agnet
Average depth (m)	$16.5 < D_{ave} < 22.1$	$8.3 < D_{ave} < 13.2$	8.3
e_0 (void ratio)	$1.03 < e_0 < 2.22$	1.5	$1.88 < e_0 < 2.33$
C_c (compression index)	$0.33 < C_c < 1.24$	$0.30 < e_0 < 0.8$	$0.99 < e_0 < 1.07$
C_s (recompression index)	$0.035 < C_s < 0.079$	$0.035 < C_s < 0.08$	$0.07 < C_s < 0.08$
$C_{\alpha e}$ (secondary consolidation)	$0.019 < C_{\alpha e} < 0.068$	$0.01 < C_{\alpha e} < 0.032$	0.045
C_h ($10^{-3} \text{cm}^2/\text{sec}$) (coefficient of horizontal consolidation) [ratio $C_h / C_v = 7$]	$3.9 < C_h < 7$	1.4	2
C_u (kPa)	$17 < C_u^1 < 75$	$15 < C_u < 28$	$13 < C_u < 25$

Table 1 : Design Soil parameters

Principle

The basic procedure of MVC consists in removing atmospheric pressure from a confined sealed medium of soil to be consolidated and maintain the vacuum during a pre-determined period of time as illustrated below.

¹ C_u , increasing with depth

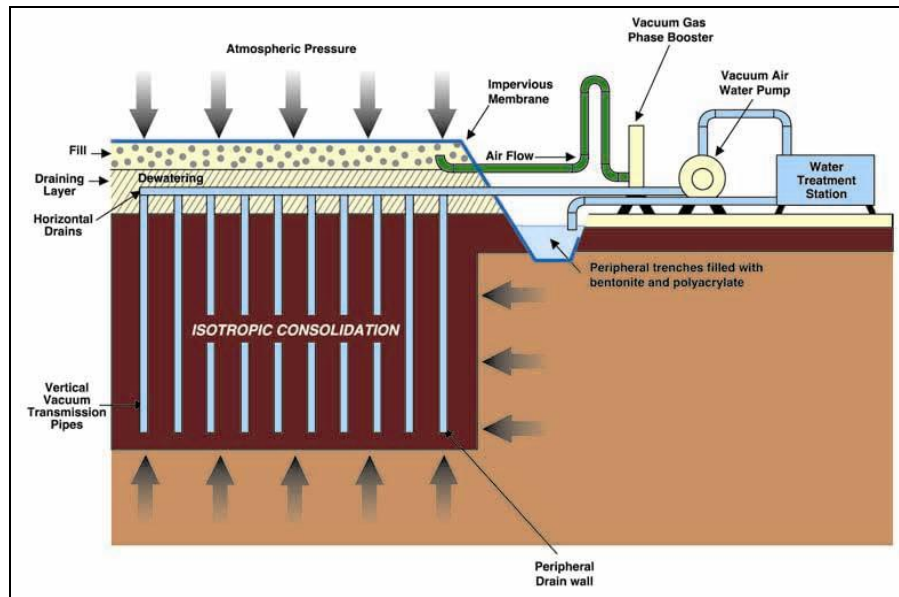


Fig. 1 - Menard Vacuum system (MVC) typical cross-section

Technological problems associated with this method include:

- maintain an effective drainage system under the membrane that expel water and air throughout the whole pumping duration,
- keeping a non water saturated medium below the membrane
- maintain an effective level of vacuum - preferably at 30% of the atmospheric pressure,
- maintain a leak proof system in particular at the pumps / membrane connections and over the whole membrane area,
- anchoring and sealing of the system at the periphery,
- Reducing lateral seepage towards the vacuum area.

Design

The preliminary steps associated with the MVC design are summarized below (see table 1 for case history values):

1. starting with initial soil report and lab results, compute the settlement at 30 years $S_{30,0}$ under the embankments weight, adding both primary and secondary settlements
2. re-iterate as necessary the previous calculation taking into account the additional height of fill to compensate for previously computed settlement $S_{30,i}$; the design settlement value S_{30} is the limit of the converging progression; the corresponding embankment weight is Δh
3. based on a design depressurization level of 80kPa during vacuum application, compute the primary settlement $S_{\infty, MVC}$ (100% primary consolidation settlement under the load associated with the embankment height and the vacuum effect) – the secondary settlement is neglected here since vacuum will only be applied over 6 months or less

4. define a consolidation rate (average) target as: $U_{ave}\% = S_{30} / S_{\infty, MVC}$
5. design the vertical drainage pattern so that $U_{ave}\%$ takes place in 3 months

Monitoring

During the consolidation period it is then necessary to calibrate the settlement objectives on the basis of the on-going vacuum parameters – see fig 2 for a description of a typical instrumentation profile:

- check the actual depressurization level using vacuum gauges placed in the draining fill (below the membrane and above the water table)
- record the on-going settlement at the surface (settlement sensors) at fixed time interval and use the Asaoka method to find out:
 - the empirical final settlement value under the combined effect of (vacuum + full embankment height)
 - the in-situ coefficient of radial consolidation C_r
- compare the settlement targets and re-evaluate the consolidation rates objectives using a consolidation program
- Monitor the settlement of the various layers using multi-point settlement gauges as shown on Fig 5.

Tollway section	Tonny Charente			Boutonne		Agnat
	West Daurade	Daurade RD 911	RD 911 St Louis	Right Bank	Left Bank	
DESIGN DATA						
Road elevation above GL	1.70m	1.55m	1.85m	7.55m	5.25m	5.90m
Computed 30years settlement, S_{30}	2.56m	1.80m	1.55m	2.10 m	2.35m	2.00m
Total Height of Embankment	4.26m	3.35m	3.40m	9.35m	7.57m	7.90m
Estimated settlement with vacuum, $S_{\infty, MVC}$	3.75m	3.02	1.88m	2.30m	2.50m	2.43m
Consolidation rate target, $U_{ave}\%$	68%	60%	82%	90%	94%	85%
Vacuum transmission pipes grid (drainage)	1.5m square grid			1m square	1m square	1.35m square
CONSTRUCTION MONITORING						
Asaoka final settlement	2.47m	1.81m	1.10 – 1.90m	1.60m	1.34m	1.09m
Achieved settlement	2.18m	1.65m	1.10 – 1.80m	1.52m	1.15m	1.03m
Achieved consolidation rate (PPG)	69%	75%	67%	-	83%	76%
Achieved settlement compared to calculation	89%	96%	101 – 114%	105%	90%	²

² Further to the steep geometry of the subsoil, no TASS analysis could realistically be carried out.

In addition to the previous measurements, pore-pressure gauges (PPG) placed in the sub-soil will record the evolution of pore-pressure dissipation during the consolidation process – see fig 3.

The PPG readings taken at different elevations can also be plotted on a pore-pressure vs. depth diagram, as on fig 4. The ratio of consolidation at a given time hence corresponds to the ratio of the area between line AD and the actual monitoring curve to the area defined by ABCD.

Finally, inclinometers are installed for qualitative interpretation. The fact that soil contraction occurs near the surface seems in accordance with the higher drainage characteristics nearer to the drainage platform. The values measured are relatively small – less than 100mm – as compared to what would have occurred during consolidation with only the embankment weight (the vacuum and the embankment weight tend to balance each other actions).

Post-construction monitoring

Fig 6 shows the long term expected settlement at 30 years based on post-construction settlement data on the Agnet area gathered from the end of the work until 2003 (2250 days). The slope of the settlement curve in log (t) coordinates indicate a secondary settlement in line with the initial expectations and the analysis of the settlement versus log t curve shows that a total settlement between 90 and 110 mm should be expected after 30 years of operation for the highway.

Conclusion

This paper highlighted the different quality control measures performed during a Menard vacuum job to monitor the consolidation process.

Further to the construction of the toll way, long term monitoring of road settlement have been generally satisfactory, with an average settlement of less than 100mm in the first 6 years.

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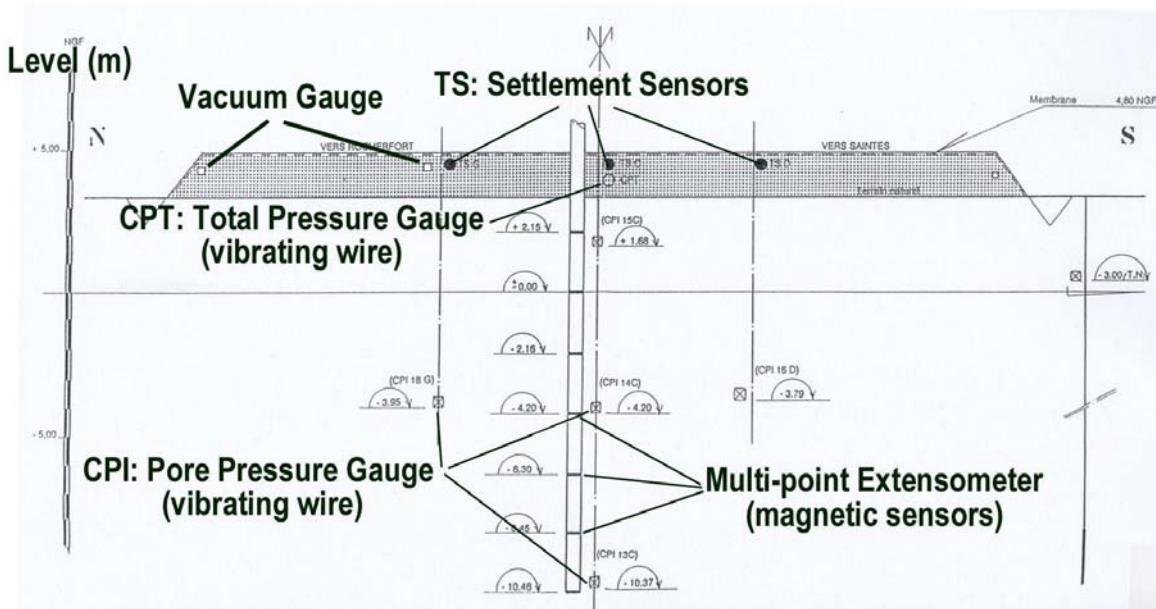


Fig 2 : Typical Instrumentation Profile

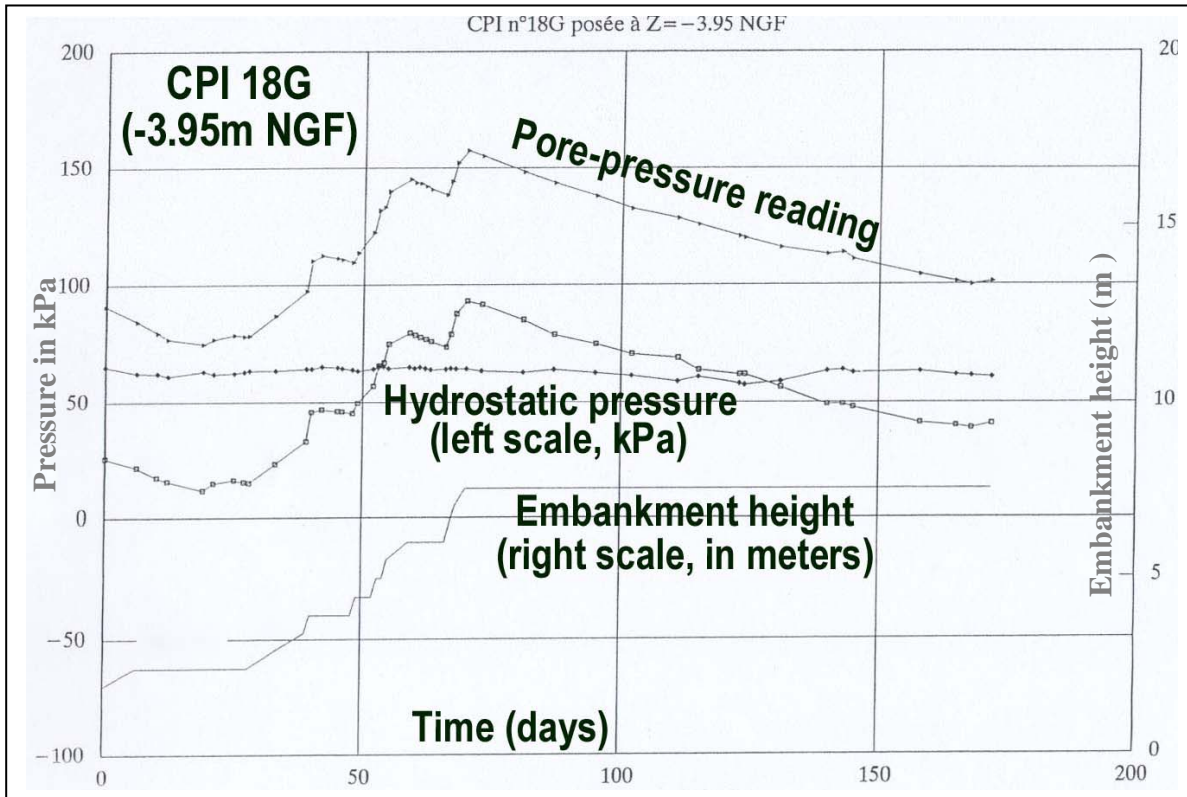


Fig 3 : Typical Piezometer Readings versus time (here Piezometer No CPI18G located at elevation -3.95 NGF) – Embankment height is also indicated for information

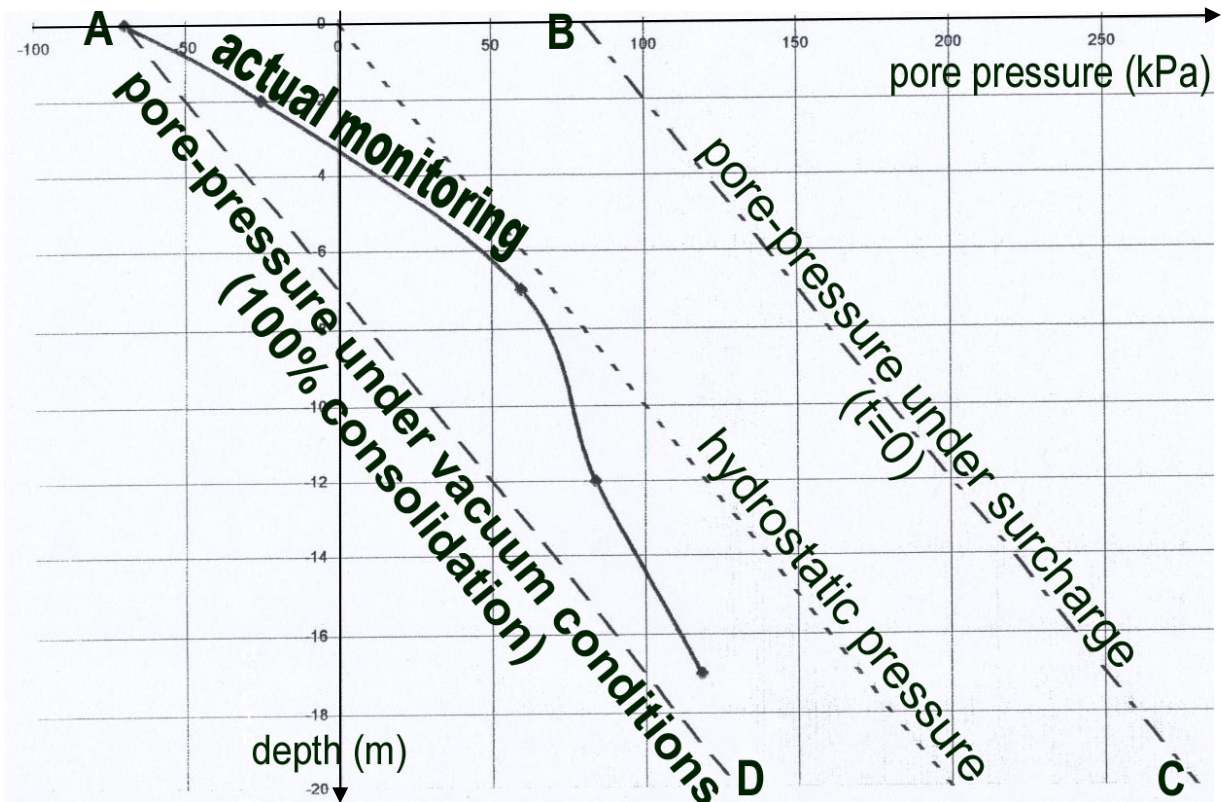


Fig 4 : Monitoring of Pore Pressure versus depth – Theoretical curves are dashed

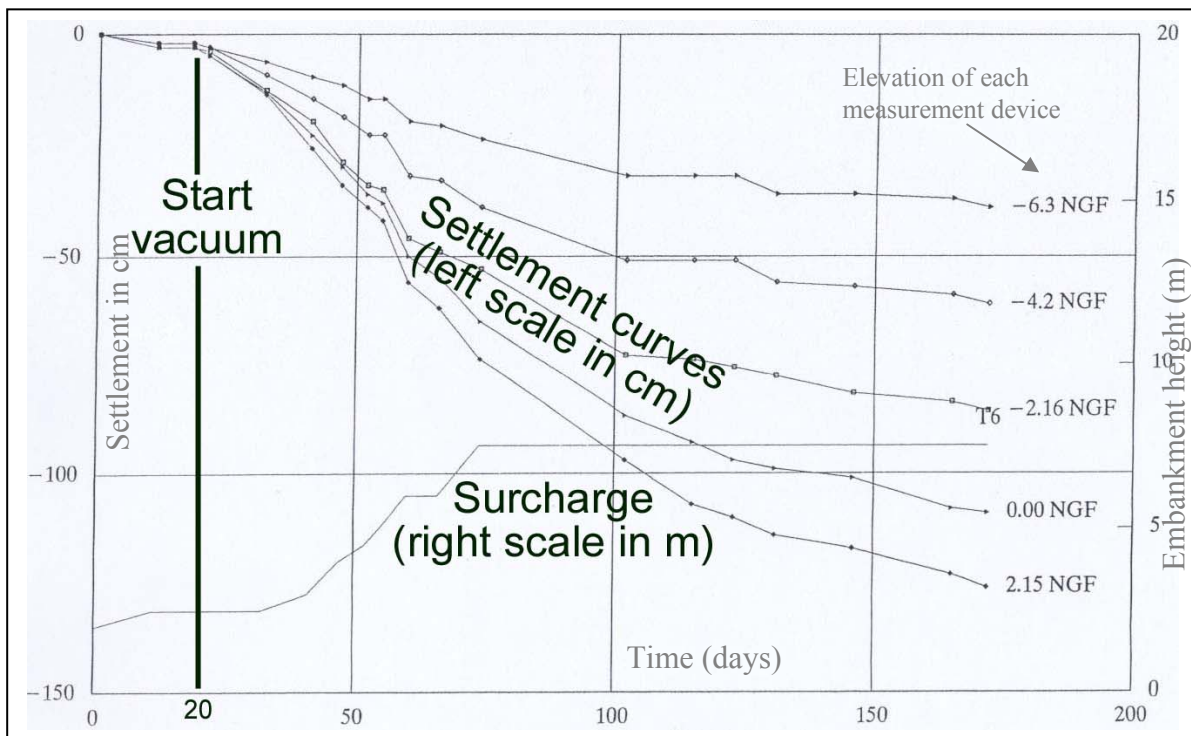


Fig 5 : Typical Multidepth Settlement Gauge Reading -

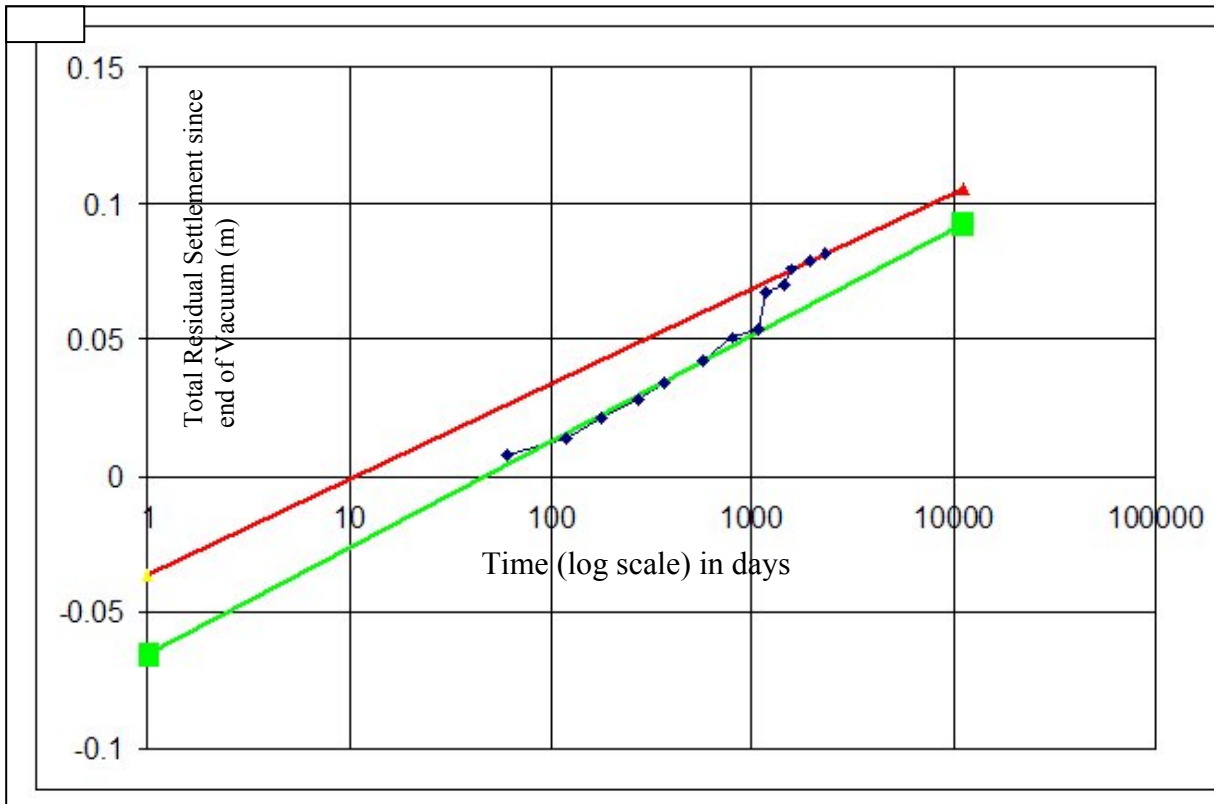


Fig 6 : \log_{10} (time) - Residual Settlement after end of Vacuum Consolidation curve (Red line is the linear regression based on last three points – green curve is linear regression based on initial 8 points)



Tonnay Charente site during vacuum



Boutonne River site during vacuum