Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-814

Geotechnical design of a lock with thin-wall chambers and embankments made of silt treated with hydraulic binders on Canal Seine Nord Europe project.

Rémy Mattras, Luc Boutonnier,
Egis Groupement ONE, remy.mattras@egis-group.com, luc.boutonnier@egis-group.com

Véronique Berche,
SCSNE, veronique.berche@scsne.fr

ABSTRACT: The Canal Seine-Nord Europe project, a large-scale navigable waterway over 100 km long designed to connect the Paris basin to the navigable network of northern France and Europe, will ultimately facilitate a modal shift of part of the highway traffic in this region. The construction of the canal will also constitute the largest earthworks project in France in the coming years, involving several tens of millions of cubic meters of excavation and fills. Under the initiative of SCSNE and the design engineering offices, the canal and lock design focused on reusing local material resources to minimize the environmental impact of the works. The use of "limons des plateaux", a silty-loess formation widely present along the canal route, allowed for the optimization of the lock chamber structures, which reach a maximum height of 25 meters, reducing the amount of concrete required for the stability of the structure by leveraging the high mechanical properties of these materials after treatment with hydraulic binders. This article outlines the various stages in the design of these structures, whose construction is yet to come:

- Identification of the silt resources along the canal route through geotechnical surveys,
- Laboratory characterization of the behavior of treated silts under different stresses, with additional soil mechanics tests over varying durations and maturation conditions (up to 12 months, with partial immersion):
  o Evolution of characteristics post-implementation,
  o G/Gmax degradation curve of the material,
  o Cyclic fatigue phenomenon under the impact of lock chamber filling and emptying cycles,
- Confirmation of the laboratory-measured characteristics with an experimental structure and embankment,
- Integration of this data into the soil-structure design studies of the project

KEYWORDS: Canal Seine Nord Europe, lock, treated silt, hydraulic binders, soil mechanics, cyclic behavior

1 INTRODUCTION

The design of locks with thin-wall chamber walls and embankments made of treated silt is an innovative solution that optimizes the lock structure by taking advantage of the high mechanical properties of the treated silt fills. This paper presents the field and laboratory investigations that were carried out to validate this solution and ensure its technical robustness in preparation for the upcoming construction works.

We found no example in the literature of a similar design for lock structures. In the North of France, the treated silt good mechanical properties are well known, in road or motorways projects, to ensure embankment stability, stiff embankment near bridges abutments or for use as subgrade layer (LCPC-SETRA 2000). The use of soil treatment and cemented soils is moreover developing in dams and levee projects with research projects as DigueELITE (Nerincx et al., 2018) and an update of ICOLD documentation (ICOLD, 2024).

2 FUNCTIONAL CHARACTERISTICS

The Canal Seine Nord Europe, a major regional development project combining technical performance, environmental respect, and safety, is set to connect Compiègne, in the Oise department, to Aubencheul-au-Bac, in the Nord department, by 2032. This large-gauge canal, 107 kilometers long and 54 meters wide, is a key link in the Seine–Escaut waterway, which will connect the French network to 20,000 kilometers of European waterways. It will thus promote the development of river transport—an environmentally friendly solution for freight transport—and enhance the competitiveness of production and the attractiveness of the regions.

Figure 1. Overview of CSNE location

This major construction project represents an investment of more than 5 billion euros, financed by the European Union, France, and local authorities, which oversee the Société du Canal Seine-Nord Europe (SCSNE), the public entity responsible for its implementation.

The Canal Seine-Nord Europe is a Class Vb waterway according to the European Conference of Ministers of Transport classification, with dimensions designed to accommodate the navigation of a projected vessel type in the form of a pushed convoy with the following characteristics:

- Length 185 meters ;
- Width 11.40 meters ;
- Loaded draught : 3 meters ;
- Deadweight tonnage 4,400 tons.

To adapt to the topography encountered along the canal route and optimize the excavation volumes as well as the travel time for navigation, the project involves the construction of 6 "Vb class" locks. The highest locks on the route feature a maximum drop height of over 25 meters in the northern section (locks of Marquion-Bourlon and Oisy le Verger).

The high locks are monolithic structures consisting of three main structural elements:

- The chamber, which corresponds to the main section of the lock, with a length of 195 meters and a width of 12.50 meters.
- The upstream and downstream heads, which are sufficiently rigid to allow the operation of the lock gates. The heads are connected to the chamber by the continuous reinforced concrete base slab.

The locks also feature auxiliary structures shown in the diagram below:

- Saver basins and aqueducts designed to conserve water resources during lockage operations,
- A pumping station ensuring the hydraulic continuity of the canal.

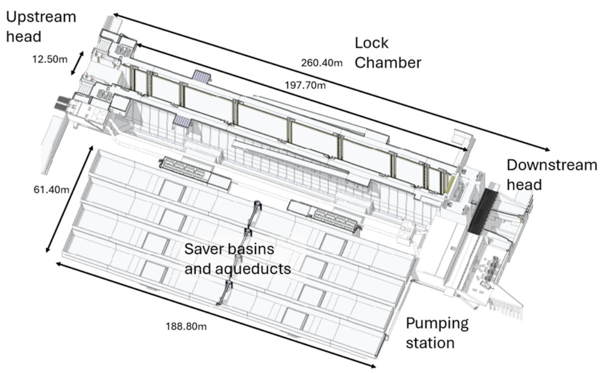

Figure 2. The different parts of CSNE locks

The lock structure is designed for a lifespan of 100 years, which represents approximately 1 million filling and emptying cycles. Each filling and emptying cycle imposes a cyclic load on the structure. The durability of the wall chamber's seals requires limiting the displacement at the head of the wall to 20mm under the effect of water pressure during each cycle.

3 DESIGN METHODOLOGY

The design approach followed by the project owner and the design engineer to optimize the lock structures is described below, considering silt resource availability.

3.1 *Evaluation of material resources*

The first step consisted in identifying the available material resources compatible with use as backfill treated with hydraulic binder.

The materials sought are silty plateau loams, sufficiently homogeneous, free of organic matter, with a thickness adequate to allow for "industrial" extraction during the construction works.

The analysis of the canal excavation project identified 7 spoil areas meeting these criteria, spread along the canal route and located at a reasonable distance from the lock construction sites (these 7 sites are located in localities of Noyon, Ercheu, Catigny, Sermaize, Ytres, Marquion, Sauchy Lestrée). The following surveys were conducted at these 7 sites:

- 32 core drilling boreholes
- 64 large diameter auger boreholes
- 16 mechanical shovel pits
- 1,200 samples, equating to 17,800 kg of materials collected
- Over 1,000 physical identification tests in the laboratory (moisture content, granulometry, plasticity index, shrinkage limit, organic matter content)

The consideration of the site survey results, and the parallel design studies led to the selection of the Sauchy Lestrée site for the supply of silts for the Marquion-Bourlon lock, a 25-meter-high lock located in the north section of the canal.

The materials found at this site consist of silty loams (Methylene Blue Value MBV generally lower than 2) with an ochre color, and more clayey loams (Methylene Blue Value MBV generally higher than 2.3) with a brown color, with a thickness generally greater than 5 meters and a sufficient volume for the lock construction works. Additionally, these silty loams have a moisture content and organic matter content compatible with the needs of the construction site.

3.2 *Laboratory characterization of treated silts*

The second step involved characterizing the mechanical behavior of the treated silty loams in order to define the design parameters for the lock embankments.

The parameters sought during the laboratory tests are described below. These tests were conducted for different maturation durations (7, 28, 90, until 720 days) and under different moisture conditions (endogenous or submerged).

The soil mechanics tests were carried out under a range of confining stresses corresponding to those expected in the future structure: with a maximum embankment height of around 35 m, i.e. a maximum vertical stress of approximately 700 kPa, the confining stresses tested ranged between 50 and 500 kPa.

- **Suitability for treatment,** using standard testing methods in the field of earthworks (uniaxial compressive strength UCS, and secant modulus measurements Ec). These simple tests confirmed the compatibility of the soils with the treatment made of lime (noted CaO) and hydraulic binders (noted LHR), as well as the formulation selected for the treatment: 1% CaO, 5% LHR, moisture content wOPN+1, compaction 98% OPN. These tests also allowed for the definition of the evolution of basic characteristics (UCS/Ec) over time and with varying hydraulic binders dosages, as shown below:

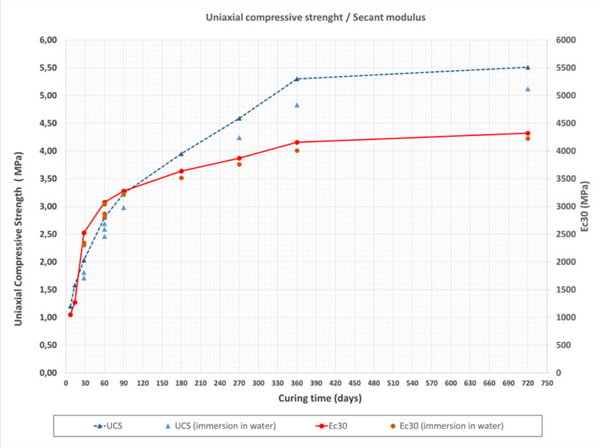

Figure 3. Variation of the uniaxial compressive strength and secant modulus with curing time (courtesy Cerema)

- **Shear strength (c/phi)** measured under different conditions (drained, undrained, cyclic) and various levels of stress compatible with the expected stresses in the future embankments. These tests allowed for the definition of the resistance assumptions to be considered for the embankment design. An example test series obtained after a curing period of 90 days under endogenous or submerged conditions is shown below. The curves below highlight the peak and plateau strengths of the treated silts after a curing period of 90 days, as well as the corresponding strain levels.

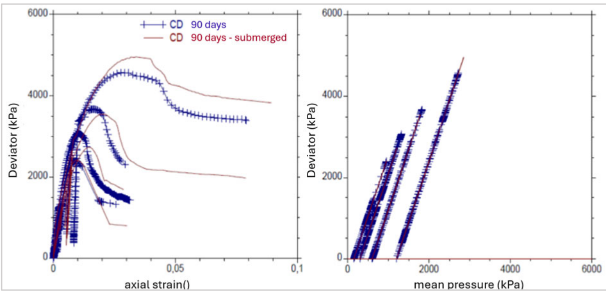

Figure 4. Example of triaxial test on treated loam, 90 days curing (courtesy Cerema)

- **Variation of the modulus of elasticity** with deformation: measured using resonant column tests, and cyclic triaxial tests. An example test series obtained after a curing period of 90 days under a confining pressure of 500 kPa is shown below.

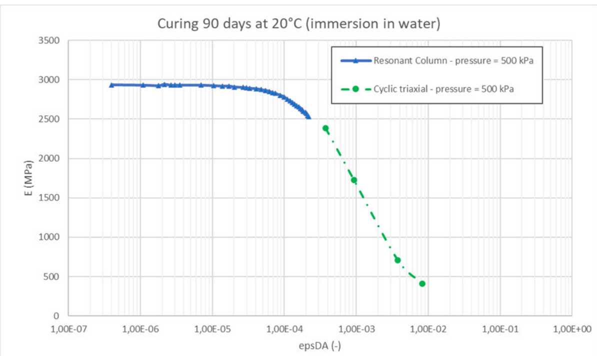

Figure 5. Variation of the elastic modulus with deformation (courtesy Cerema)

- **Long-term evolution** of the characteristics of treated loams, including the characterization of the fatigue of treated loams under the effect of cyclic loading due to lockages, as well as the effect of aging of the treated loams due to their own weight. An example of fatigue test series obtained after a curing period of 270 days under a confining pressure of 50, 100 and 200kPa, with cyclic loading of 0.4 Hz is shown below.

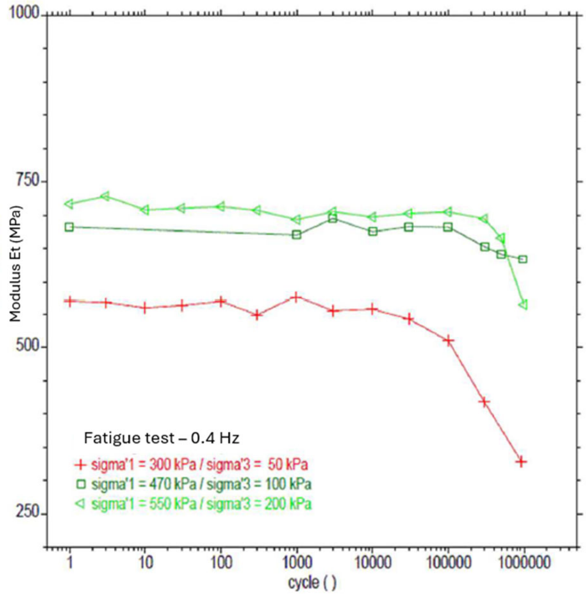

Figure 6. Variation of the elastic modulus with cycling loading, 1 million cycles (courtesy Cerema)

The consideration of the test results led to the definition of the calculation assumptions used for the design of the Marquion lock, incorporating a safety margin on the measured parameters.

3.3 *Confirmation of performance achievement on experimental site: Marquion Demonstrator*

The testing program was supplemented by an experimental construction site aimed at validating, in the field, the results obtained in the laboratory.

The Marquion demonstrator is an experimental embankment made of treated silty loam, 5 meters high, constructed in horizontal layers of 25 to 30 cm in thickness, and built against a vertical concrete wall.

The pictures below show the geometry of the treated loam embankment, and the concrete wall, and an overview of the demonstrator after completion.

Carried out in parallel with the design studies, the Marquion demonstrator made it possible to:

- Define implementation and compaction methods for embankments made of treated loam,
- Ensure the monolithic nature of the treated loam mass built in successive layers,
- Measure the performance achieved in treated loam embankments under real construction conditions, using various tests: in-situ measurements (Menard pressuremeter, membrane dilatometer, cross-hole drilling), and sampling for geotechnical laboratory testing,
- Monitor the evolution of these performance characteristics over a two-year period following construction

The tests carried out between 2021 and 2023 thus confirmed the achievement on site of the performance levels measured during the laboratory testing phase.

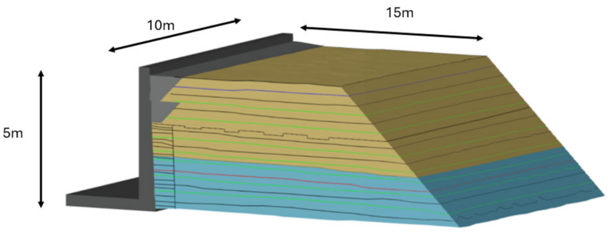

Figure 7. Geometry of the demonstrator of Marquion (courtesy SB Valérian)

Figure 8. Overview of the demonstrator of Marquion after completion (courtesy SB Valérian)

3.4 *Design of the Structure and Treated Loam Embankment*

The design of the chamber walls and the treated loam embankment was carried out using soil-structure finite element modeling on Plaxis 2D.

The image below illustrates an example of the geometry considered for the 2D finite element modeling.

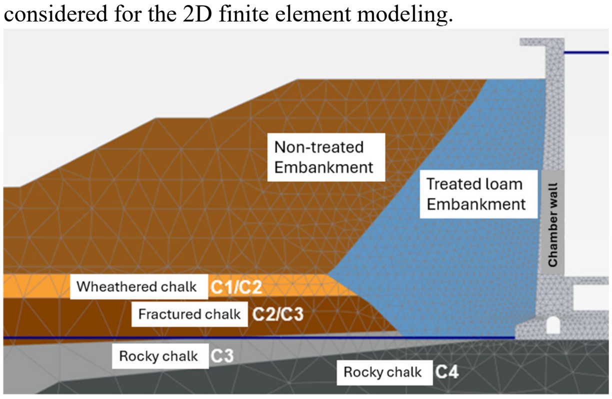

Figure 9. Geometry used for 2D finite element modeling

Due to the limited track record with this type of design and the potential variability in the quality of treated loam on-site, the calculation is performed within a range, considering two sets of parameters:

- Set of parameters 1: lower value of the elastic modulus in the treated loam. This set is used for checks related to the chamber wall structure: internal design of the reinforced concrete and verification of the wall displacement criterion (20mm at the top). A low value of distorsion ($Gamma_{0.7}=2.10^{-5}$) is considered to increase actions on the structure.
- Set of parameters 2: upper value of the elastic modulus in the treated loam. This set is used for checks related to the strength of the treated loam embankment (limiting the plastified zones). A mean value of distorsion ($Gamma_{0.7}=3.10^{-4}$) is considered, according to soil mechanics results.

For each set of parameters, the design takes into account the evolution of the treated loam characteristics for the different stages of the structure's life:

- Construction phase: strength gain of the treated loams with time after filling work,
- Service phase: consideration of the nominal characteristics of the treated loams,

  End of service life: consideration of degraded characteristics. The aging tests conducted over a period of 2 years did not reveal any significant creep phenomenon for the treated loam within the expected range of stress in the structure. However, exploratory calculations carried out using a high reduction coefficient (up to 5 and even 10) showed that any potential long-term creep phenomenon is not likely to compromise the performance of the structure.

Table 1. Calculation parameters for service checks

Parameters Service	Elastic modulus – HSS law (MPa)		Shear strength	
	G0 / E0	Eur / E50	Friction angle Φ' (°)	Cohesion c' (kPa)
Set 1: for structure design	*G0=400* *E0=960*	*Eur=600* *E50=300*	*30*	*400*
Set 2: for treated loam design	*G0=1250* *E0=3000*	*Eur=2500* *E50=1250*	*30*	*400*

Table 2. Calculation parameters for end-of-life checks

Parameters End of life	Elastic modulus – HSS law (MPa)		Shear strength	
	G0 / E0	Eur / E50	Friction angle Φ' (°)	Cohesion c' (kPa)
Set 1: for structure design	*G0=200* *E0=480*	*Eur=300* *E50=150*	*30*	*200*
Set 2: for treated loam design	*G0=625* *E0=1500*	*Eur=1250* *E50=625*	*30*	*200*

The modelling performed mainly aimed to:

1. Simulate the behaviour of the lock wall and the lock chamber, and to estimate the deformations of the structure during construction and then in service under the effect of cyclic lock-filling loads,
2. Estimate the interaction parameters between the lock chamber structure and the soil for use as assumptions in the civil engineering models:
   - Loads within the structures,
   - Reaction moduli and stress state at the soil–structure interface.
   - These data were integrated into the civil engineering design studies of the lock chamber.
3. Verify the design of the treated silt embankments, using mechanical properties adjusted based on the laboratory tests carried out as part of the specific testing programme : plastified zones of treated loam were limited to few percents of the global volume of embankment, and soil distortion was checked to remain allowable according to laboratory results.
4. Verify the stresses in the foundation soils.

4 CONCLUSIONS

The design of the Marquion-Bourlon lock with thin chamber walls and treated loam embankments is an innovative technical solution that optimizes the reinforced concrete structure of the lock by using loams available near the construction site.

The project owner and the design engineer implemented a comprehensive design approach, including a specific laboratory testing program, validated by the completion of the experimental construction site.

The design assumptions were thus validated step by step, confirming the robustness of the technical solution.

Construction of the Canal Seine-Nord Europe structures began in 2024 and will continue until 2032.

5 ACKNOWLEDGEMENTS

The authors would like to thank all the people involved in this testing and design process started in 2020:

- Esiris company in charge of the site survey and first identification laboratory tests,
- NGE and VINCI (Terélian) companies in charge of suitability for treatment tests,
- CEREMA (laboratory of Aix en Provence) in charge of soil mechanics tests,
- LMDC (laboratory of INSA Toulouse) in charge of aging tests,
- SPIE BATIGNOLLES VALERIAN company in charge of the construction of Marquion Demonstrator.

6 REFERENCES

LCPC-SETRA (2000). Traitement des sols à la chaux et/ou aux liants hydrauliques. Application à la réalisation des remblais et des couches de forme. Guide technique.

SETRA (2007). Conception et réalisation des terrassements – Guide technique. Fascicule 1 : études et exécution des travaux, Fascicule 2 : organisation des contrôles, Fascicule 3 : méthodes d'essais.

Nerincx N., Bonelli S., Mercier F., Cornacchiolo F., Fry JJ., Herrier G., Richard JM., Puiatti D., Tachker P. (2018). Digueelite overflow resistant lime treated soils for dikes and earthdams. Innovation Awards – R. 29. CIGB, 26ème congrès des grands barrages, Vienne, Juillet 2018.

ICOLD (2024). Committee on cemented material dams. Cemented material Dams: Design and Practice. Cemented soil dams. Version 15/03/2024

Bufalo M, Berche V, Mattras R, Queste O (2024), Monolithic Character of treated soil embankments: Optimization of compaction modes, bonding of layers and mechanical performances – Colloque Digues 2024, March 2024.