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Some case histories from tunnelling projects in the Parisian region

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ABSTRACT: This paper presents key lessons from recent underground works carried out for the Grand Paris Express project in France, highlighting three case studies presented in the literature. The first examines a 32-meter-deep excavation supported by diaphragm walls with five levels of struts, comparing three analysis models: Winkler-type, 2D finite element (FE), and 3D FE. Displacement measurements from fiber optics and strain gauges validate the results. The second case involves the construction of France's deepest metro station (56 meters), using traditional tunneling methods with strict displacement constraints. Predicted displacements from 2D and 3D FE models are compared to actual settlement measurements. The final case explores machine learning techniques for predicting ground settlements in urban tunneling, using input data such as ground settlement and TBM parameters, continuously refined with geotechnical data. These case studies provide insights into the magnitudes of observed settlements, the solutions developed to mitigate them, and the effectiveness of modeling and predictive techniques. This paper brings literature references of underground works carried out in France that can be useful for Brazilian designers working in analogous conditions.

1 INTRODUCTION

The Grand Paris Express is an ambitious infrastructure project in the Paris region, involving the creation of four new metro lines - 15, 16, 17, and 18 - along with extensions to existing ones. Approximately 200 kilometers of new tunnels will be excavated by the end of the project, and about 70 new stations will be constructed. The work began in 2015, with completion expected by 2030.

Excavation works are carried out in challenging conditions within densely populated areas where strict performance criteria are imposed. The underground space composed by layered sedimentary deposits, is already congested, and the new tunnels and stations interact with existing structures (parking lots, other metro stations and tunnels, building foundations, sewers). Compliance with tight displacement limits is mandatory to ensure safety and prevent disturbances to neighboring structures, which are often sensitive.

In this context, design and construction techniques push the boundaries of state-of-the-practice. Advanced modeling is essential to predict ground response, while precise instrumentation and monitoring systems track the actual behavior of the ground and surrounding structures. Continuous comparison between measured and predicted data enables ongoing refinement of the design.

This paper presents three case histories on deep excavations in the area, highlighting the specific challenges, ground conditions, modeling techniques used, and a comparison with the measured behavior.

2 OVERVIEW OF THE CASE HISTORIES

This paper compiles the publications of Nejjar et al. (2022), Cahn et al. (2024), and Richa et al. (2024) related to works recently concluded in the Parisian region.

Nejjar et al. (2022) presents a detailed numerical back analysis of the fully monitored 32-meter-deep excavation supported by diaphragm walls with five levels of struts, at Fort d'Issy-Vanves-Clamart.

Cahn et al. (2024) presents the case of the deepest metro station of France (Saint-Maur-Créteil, 56 meters depth), with caverns built using traditional tunneling methods and strict displacement constraints due to interaction with a nearby existing station.

Richa et al. (2024) explores machine learning techniques for predicting ground settlements for parts of the metro 14 and 15. The input data used are ground settlement measurements, TBM parameters, and estimated geotechnical profile and properties.

Figure 1 presents the location of the quoted case histories in the context of the Grand Paris Express

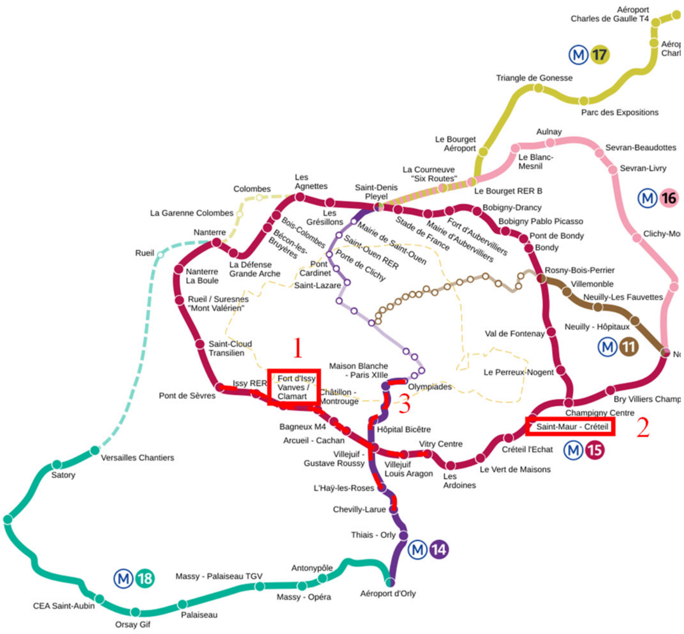

Figure 1 – Location of the presented case histories in the context of the Grand Paris Express. (1) Nejjar et al. (2022); (2) Cahn et al. (2024); (3) Richa et al. (2024)

3 CASE 1: DEEP EXCAVATION WITH HIGHLY INSTRUMENTED RETAINING WALLS

The case presented by Nejjar et al. (2022) regards the station Fort d'Issy-Vanves-Clamart, which is a 32m depth excavation supported by propped diaphragm walls in very dense urban area (Figure 2). The case stands out due to the availability of comprehensive monitoring data, including wall monitoring through fiber optics (wall displacements and estimation of bending moments), use of strain gages to evaluate prop loads, and earth pressure-cell transducers to evaluate actual earth pressures. The availability of the data allowed for an understanding of the actual soil-structure interaction mechanisms taking place and the comparison to the designed-modelled phenomena.

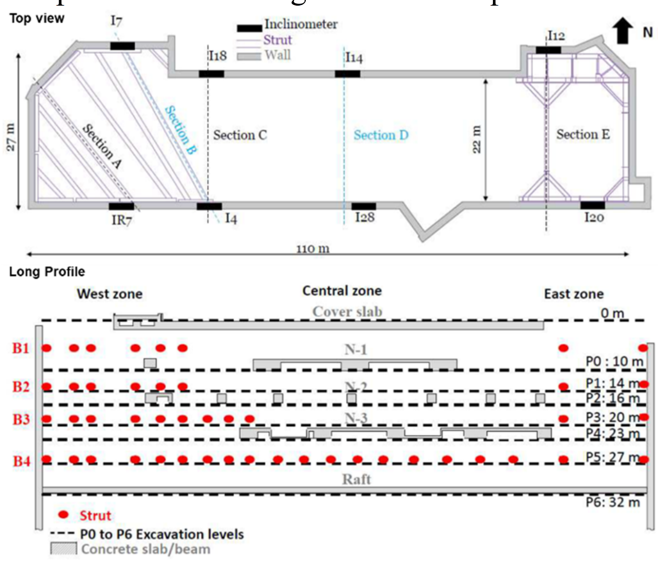

Figure 2 – Top view and longitudinal profile of the Fort d'Issy-Vanves-Clamart station (Nejjar et al, 2022)

Ground conditions are typical of the Parisian basin. The ground investigation campaign included Ménard pressuremeter tests (as usual in French practice), logging, laboratory triaxial tests and geophysical tests (cross holes), aiming at an assessment of shear moduli at small strains. The combination of tests representative of different strain domains enabled the adjustment of the deformability parameters of the ground in the calculation through back analysis and comparison with the real deformations in the soil. Table 1 presents some parameters used in the design and allows for a comparison between Ménard type modulus E_M (assessed using standard pressuremeter tests) and G_0, shear modulus at small strains, assessed using geophysics. On this subject, more recent research has shown that pressuremeter tests including unload and reload loops are an interesting tool to characterize ground shear moduli at small strains as well as its decay as a function of strain level (Lopes et al, 2024). This is especially true for fine ground (such as the Plastic Clays) for which analytical solutions are available.

Table 1 – Design ground parameters for the Fort d'Issy-Vanves-Clamart station

Ground	E_M MPa	G_0 MPa	$\gamma_{0.7}$	φ' °	c' kPa	K_0
Backfill	6	175	9.5E-05	29	0	0.52
Limestone	25	600	9.0E-05	35	20	0.43
Plastic clay	40	117	1.1E-04	17	10[1]	0.85
Meudon marl	100	670	1.5E-04	25	30	0.58
Chalk	170	950	1.3E-04	35	40	0.43

(1) Cu = 120 kPa

Figure 3 presents the cross-section with geotechnical profile for the Fort d'Issy-Vanves-Clamart station.

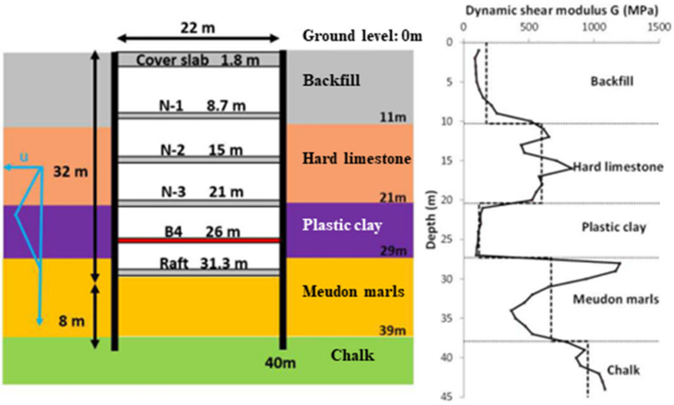

Figure 3 – Cross-section with geotechnical profile for the Fort d'Issy-Vanves-Clamart station (Nejjar et al, 2022)

It should be noted that it is current practice in France to use simplified subgrade reaction method (SRM) to model retaining walls of various sizes (from simple to very complex projects). The method is very well established in the country since the 80's and finds great respect between practitioners because of its simplicity and robustness. The local experience, and several comparisons between measurement and modelling, have historically enabled do establish reliable correlations between Ménard pressuremeter modulus and the horizontal subgrade reaction modulus. For simple cases, the method yields more reliable results than what can be achieved using 2D or 3D finite element models, for the simple reason that it is much easier to parameterize (direct correlation with Ménard modulus), and less complex to carry out (no interface laws nor advanced constitutive modelling). This is not true for more complex cases, like very deep excavations with several strut levels, where the SRM method is unable to model the stress redistribution within the ground. The quoted work of Nejjar et al (2022) confirms this statement.

The back analysis was conducted using both 2D and 3D finite element models (FEM), which were then compared with a simplified subgrade reaction method (SRM), frequently employed by designers. The goal of this comparison was to understand the real differences in accuracy and have a better appreciation of the domain of applicability of each one. Figure 4 presents the three levels of modelling complexity adopted.

Figure 5 presents a comparison between calculated and measured earth pressures using earth pressure cells installed in the diaphragm wall panels. As quoted by the authors, At the initial state, earth pressure at rest, based on K_0, is consistent across numerical models. However, in the hard limestone, measured pressures at cells C1 and C2 are lower than expected, likely due to wall installation effects causing in-situ stress unloading. In the Meudon marls, cell C4 measurements align with expectations due to high confinement at depth, minimizing unloading effects. Conversely, in the plastic clay, measured pressures at cell C3 are close to active earth pressure, suggesting disturbed conditions at the trench face.

At the final stage, FEM-2D and FEM-3D models accurately predict earth pressures at C1 and C2 in the hard limestone, while SRM underestimates stresses, likely due to its inability to model arching effects. In the Meudon marls, cell C4 shows higher measured pressures than predicted, possibly due to a shallower-than-modeled interface between the Meudon marls and the chalk. For the plastic clay, cell C3 measurements remain lower than predicted by all models, with pressures limited to active earth pressure levels. Given the initially low measurements at this cell, a further reduction in pressure was anticipated.

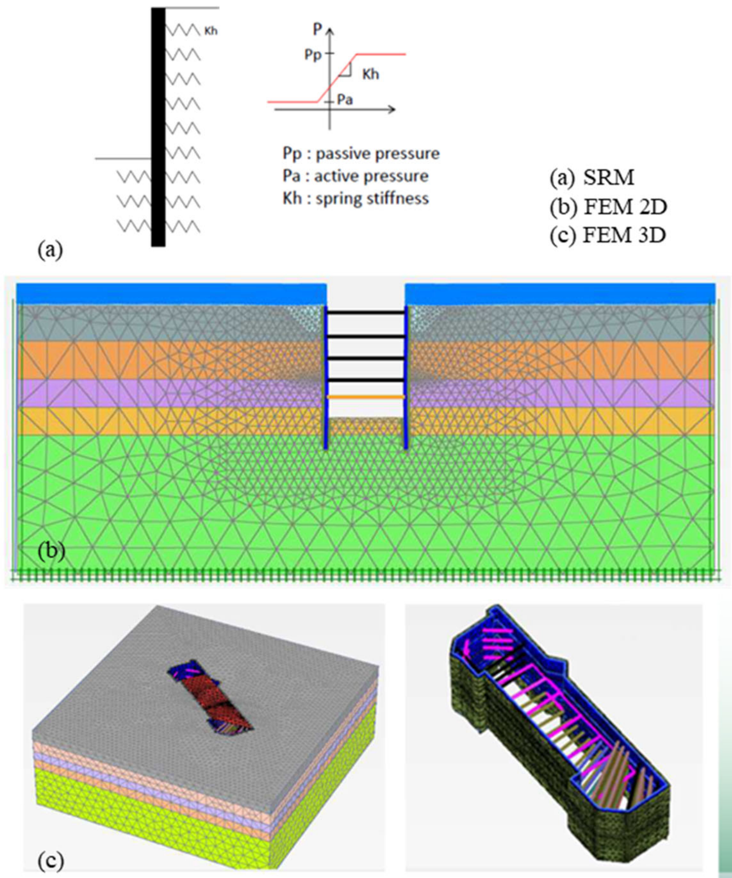

Figure 4 – Three modelling approaches used for the Fort d'Issy-Vanves-Clamart station. (a) Subgrade Reaction Method (SRM); (b) 2D Finite Element Method; (c) 3D FEM

Figure 6 shows a comparison between wall displacements and bending moments assessed with the different methods as well as measurements using fiber optics. All prediction methods are satisfactory in this point of view.

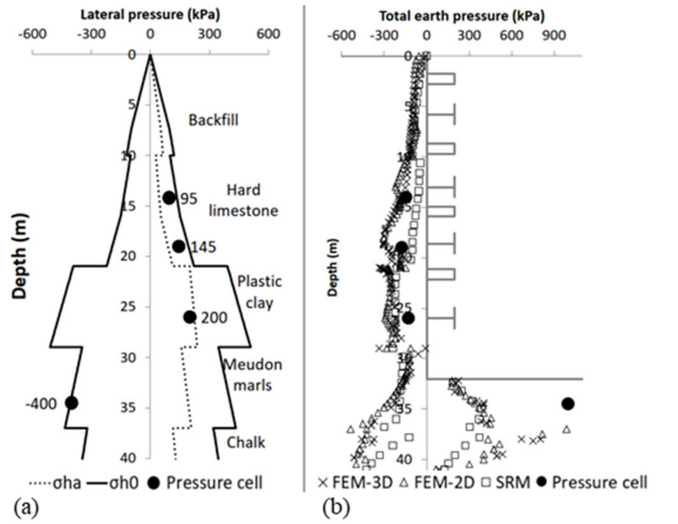

Figure 5 – Comparison between calculated and measured earth pressures. (a) initial measured earth pressure, (b) final earth pressure profile

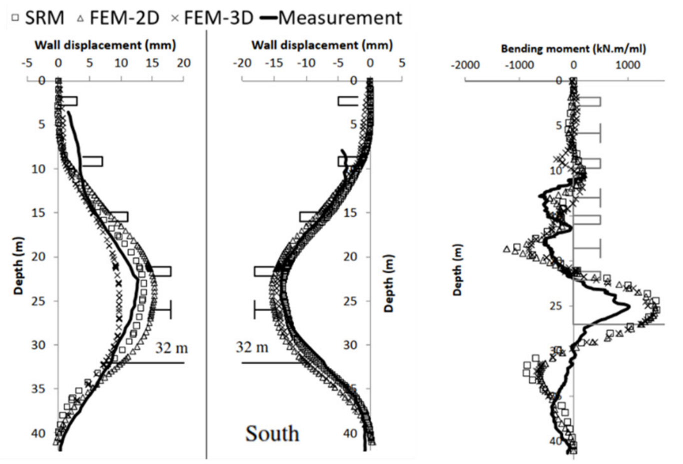

Figure 6 – Comparison between displacements and bending moments measured and predicted using SRM, 2D and 3D FEM

Figure 7 presents the settlement though obtained behind the retaining with the numerical models and compares it to a measurement point on the ground. Few measurement points were available on the surface due to the high density of buildings on the area. The few measurements points available show that predictions using 3D FEM tend to underestimate the ground settlement. Nejjar (2019) states that one of the possible reasons is that the presence of buildings with different types of foundations (sometimes unknown) was not taken into account. More recent research (El Arja, 2020) has shown that the settlement though behind the walls can be governed by ground contractive volumetric deformations in the ground, which require a constitutive model accounting for a hardening law and a flow rule to be captured.

One of the key lessons learned is that this study confirms that the simplified soil-structure interaction captured by SRM can provide results as accurate as advanced FEM modelling regarding the wall displacements. This is possible due to a relevant choice of the deformation modulus suitable for the targeted strain range.

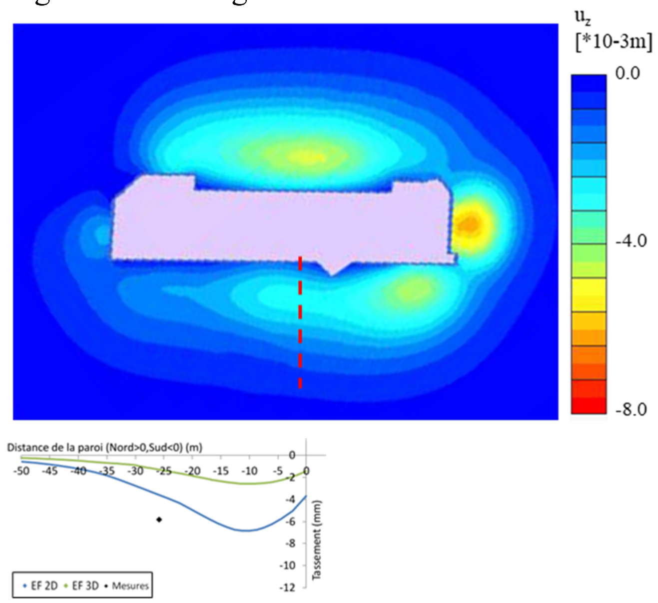

Figure 7 – Modelled settlement through and comparison between 2D, 3D FEM and measurements (Nejjar, 2019)

However, SRM is not able to capture all significant components of strutted retaining walls for very deep excavations. SRM relies on independent horizontal springs and neglects arching effects that can develop in the ground. Thus, SRM can underestimate the props loads, up to -40 % in the present study, especially for deep excavation phases in contrasted layered soils (limestones and clays, for example).

The use of strain gauges in the struts enabled to confirm the temperature variations have an important effect on the prop load. All methods of evaluation of the prop-wall stiffness (using SRM, 2D or 3D FEM) were efficient, except for props positioned at wall panels located at angular spots, for which 3D model is most appropriate.

Another key takeaway from the present back-analysis is that it confirms that the behavior of highly overconsolidated clays such as the Parisian Plastic Clay shall be modelled in drained conditions: the timescale for the excess pore pressure dissipation is small compared to the works timescale, which is mainly due to the type of loading (shearing). This is a recurrent question for which designers are challenged: for highly overconsolidated clays, undrained cohesion can be important, leading to low horizontal pressures on the walls, and thus economical design. Swapping from hundreds kPa of undrained cohesion to only a few kPa of drained cohesion has an important impact on design and is generally a source of discussions that can put the designer under pressure.

Another important lesson learned regards the fact the matching only the displacement criteria on a back analysis is not sufficient to ensure that other outcomes are also matched, such as earth pressures, prop loads or settlement though. For very deep propped excavations, the limitations of SRM shall be taken into account regarding ground arching effect, having an important impact on prop. The limitations of usual constitutive models regarding the prediction of the settlement though shall be recognized.

4 CASE 2: TRADITIONAL TUNNELING FOR A DEEP UNDERGROUND STATION

The paper by Cahn et al. (2024) discusses the construction of France's deepest metro station, Saint-Maur-Créteil (deepest point at 56 meters depth), with caverns executed using traditional tunneling methods under strict displacement constraints due to its proximity to an existing station at the ground level.

Saint-Maur-Créteil Station is part of Line 15 South of the Grand Paris Express, located southeast of Paris. Construction began in 2017, with completion expected by the end of 2025. The project includes a central shaft (56 m long, 36.8 m wide, and 58 m deep) supported by 1.8 m thick diaphragm walls, and two caverns (13.6 m high, 21.3 m wide, 30 m long) excavated using conventional methods under 43 m of ground cover. The southern section lies beneath the operational RER-A station, necessitating strict settlement control. Settlement criteria of less than 10mm were imposed. Strict monitoring was established to follow up the construction works. Figure 8 presents the configuration of the station.

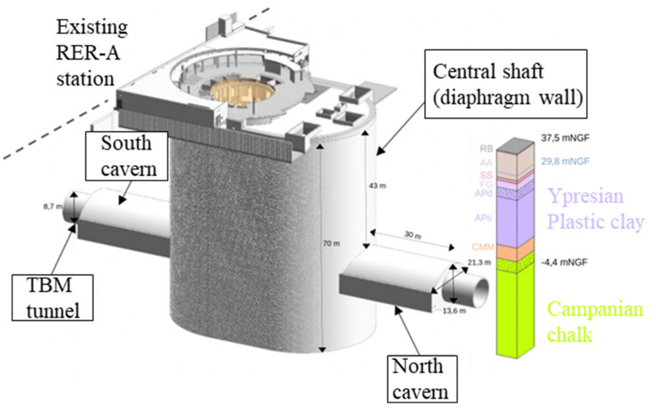

Figure 8 – Presentation of Saint-Maur-Créteil Station (Cahn et al, 2024)

A complex staged construction method was adopted to ensure safety and compliance with the displacement criteria. The summary of the execution stages is presented below and represented in Figure 9:

- Initial Work:
  - TBM passed through the unexcavated shaft (Earth Pressure Balance TBM, with a -7.2 NGF key level and an 8.7 m internal diameter. The lining consists of 40 cm segments.).
  - Ground treatment: a 5 m thick injection ring was created around the caverns from the segment lining via boreholes with Blowout Preventers.
  - Tunnel backfilled with low-dose self-compacting Regimix® grout.
- Abutment Excavation:
  - Upper half-sections excavated in parallel with heavy steel arches and a shotcrete shell (1).
  - Lower half-sections excavated similarly (2), followed by concrete filling in two stages: lower and then upper half-sections.
- Main Section Excavation:
  - Upper Half-Section: Excavated with HEB 300 beams installed every meter (3). Beams installed in three steps, with excavation in two phases: center (3a) and lateral sections (3b).
  - Vault Formation: Initially planned in 5 m plots, later optimized to 20 m using settlement monitoring (4).
  - Lower Half-Section: Excavated and invert installed in a single step along the entire length (5, 6).

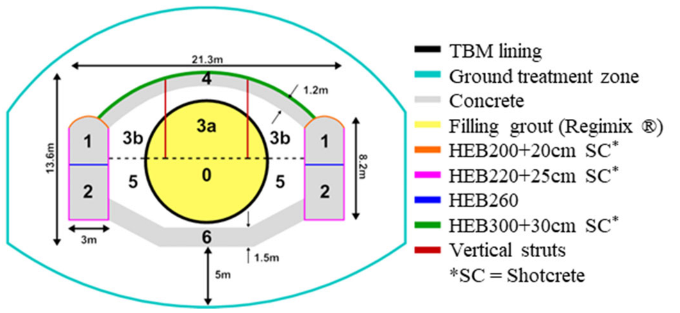

Figure 9 – Construction sequence of Saint-Maur-Créteil Station (from Cahn et al, 2024)

The geotechnical conditions are those typical of the south of Paris, including backfill overlying 10 m of rough alluvium, 3.5 m of fine sand, and 20 m of Ypresian Plastic Clay, which is overconsolidated, prone to swelling, and mechanically weak. This challenging layer governed the choice of the station's depth. Below the clay lies 5 m of marly limestone and Campanian chalk, a soft rock (σ_{ci} = 3-6 MPa, GSI = 50–65) with low permeability ($k = 1 \times 10^{-7}$ m/s). Excavations for the TBM and caverns are entirely within the chalk. Two groundwater tables are present: one in the alluvium above the clay and another in the chalk, with a pore water pressure of 485 kPa at the cavern invert, which governs the cavern design.

Table 2 – Design ground properties for St-Maur-Créteil Station (Cahn *et al*, 2024)

Gr. (*)	lvl.	γ_h	E_{50}	E_{ur}	c'	φ'	K_0	K_h=K_v
	mNGF	kN/m^3	MPa	MPa	kPa	°	-	m/s
RB	37.5	18	28	84	5	30	0.5	3.10^{-5}
AA	37.1	20	264	792	0	35	0.5	$1.5.10^{-3}$
SS	28.0	20	80	280	0	35	0.5	2.10^{-4}
FG	27.0	18	39	98	10	15	0.7	3.10^{-4}
APd	24.5	19	66	132	10[1]	20	0.8	1.10^{-9}
APs	21.2	20	80	160	30[2]	15	0.8	1.10^{-9}
CMM	4.4	21	117	305	15	30	0.5	$4.5.10^{-5}$
CBt	-0.4	21	768	1536	75	33	1	1.10^{-5}
CBc	-4.4	20	1168	4555	150	33	1	1.10^{-7}

* Ground formations: Backfills (RB); Old Alluvial Deposits (AA); Upper Sands (SS); False Clays (FG); Relaxed Plastic Clays (APd); Plastic Clays (APs); Montian Marly Limestone (CMM); Transition White Chalk (CBt); Unweather White Chalk (CBc); (1) – Cu = 90 kPa; (2) – Cu = 150 kPa

Main design and construction challenges were:

- Ensure compliance with displacement constraints, mainly at the RER-A station nearby;
- Ensure stability due to high groundwater pressures.

Regarding the settlement compliance criteria, the designer's choice was to perform multiple analyses, from 2D to 3D. While a full 3D model, taking into account all construction stages, which is time-consuming, was being set up, more simplified approaches were carried out to enable iterations and methodology definitions with stakeholders:

- 2D plane strain FEM Using the Attewell Formulas: Attewell (1982) introduced a method for evaluating the finite settlement trough, assuming that the underground volume loss is localized. This approach models an incremental volume loss, centered on the tunnel axis, for each excavation step. This enables a first evaluation of the 3D ground response due to the cavern excavation;
- 3D modelling using the "one step" technique: this technique involves summing a finite series of incremental longitudinal settlement troughs corresponding to each excavation step, effectively converting temporal integration into discrete spatial integration.
- Complete 3D model, considering all construction stages and full soil-structure interaction. Two models were built: (a) considering the presence of the existing station at the ground level, and (b) a model representative of the cavern far from the existing station.

Stability due to high groundwater pressure was managed through the installation of pressure relief drains below the cavern invert. This paper will not focus on this aspect.

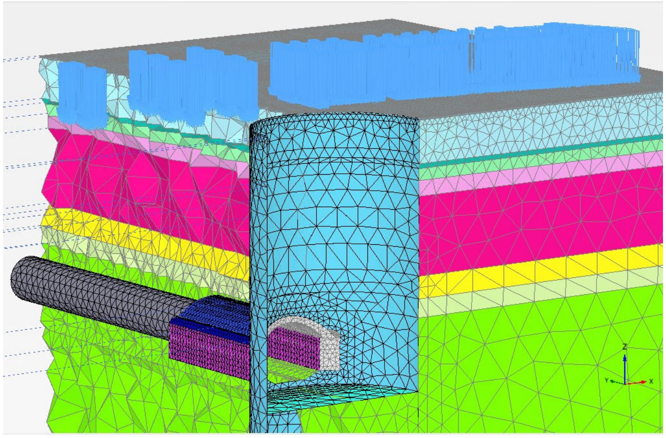

Figure 10 – Full 3D model of the St-Maur-Créteil Station (Cahn *et al*, 2024)

Figure 11 presents a comparison between settlements assessed with the three methodologies and measured on site. Comparison is presented (a) as a function of the longitudinal distance of the shaft and (b) in the transverse direction, 20m far from the shaft wall.

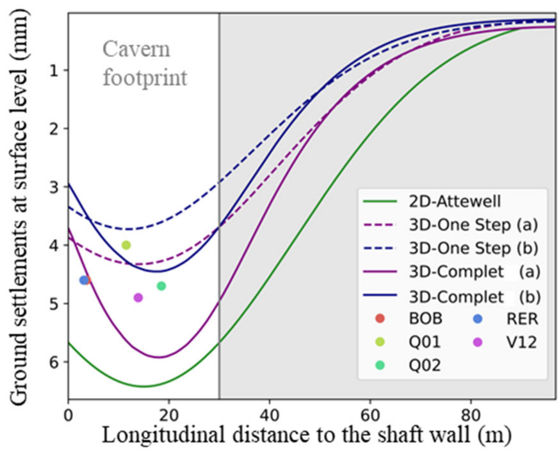

Figure 11 – Comparison between settlements assessed with the three methodologies and measured on site (Cahn *et al*, 2024)

All models capture the general magnitude of the measured settlements. However, 3D one-step models tend to slightly underestimate them, likely due to influences such as diaphragm walls, RER structures, and the excavation sequence. Conversely, the Attewell method tends to overestimate settlements, likely stemming from assumptions about deconfinement rates and constant-volume strain variations.

A key takeaway of this case study is that simple 2D finite element analyses can yield settlement predictions comparable to more sophisticated 3D models, sufficient for preliminary or even advanced design stages. The difference between the models can be explained by soil-structure interaction features, such as ground interacting with the retaining wall, or ground interacting with superstructures, which cannot be captured through the simple models.

Another important takeaway of this case regards the capability to mitigate surface settlements through ground treatment and complex construction staging. The order of magnitudes is:

- cavern dimensions: 21m x 13m x 30m,
- depth: 43 to 56m depth
- ground conditions: soft rock (chalk)
- magnitude of surface settlements: 5mm

5 CASE 3: USE OF MACHINE LEARNING FOR THE PREDICTION OF SETTLEMENTS

The present case study relates to the works of Richa (2023) related to the use of Machine Learning algorithms to predict ground induced settlements from Earth Pressure Balanced Tunnel Boring Machines (EPB TBM).

Unlike previously presented cases, this one use data gathered during construction to predict settlements, without the use of usual numerical analysis tools, that can be as complex as Finite Elements, or analytical analysis as Peck's (1969) method.

Machine Learning techniques as proposed by the author use the data gathered by the TBM sensors, its position, soil geotechnical parameters, and actual settlement measurements to predict ground settlement ahead of the tunnel face. Data gathered include: TBM position (cover depth), advance rate, cutting wheel torque, front pressure, thrust force, grout pressure, grout volume.

The algorithms cross correlate this information with the expected ground profile, and the settlement measurement at the surface, at various distances from the tunnel face. The soil profile includes an estimate of the stratigraphy, shear strength (c', ϕ'), excavated ground density, deformability (in French practice this is done through Ménard modulus E_M and Ménard coefficient α) and earth pressure coefficient K_0. As the number of variables is significant, homogenization techniques, such as presented in Figure 12 (Richa et al.,2023) are used to reduce the dimensions of the problem from the usual design parameters to simplified homogenous cross-sections.

Algorithm training involves using data collected from areas where the settlements are already stabilized to establish the implicit correlation parameters between settlement, ground conditions and TBM operation. Richa et al (2024) conclude that Random Forest and XGBoost are well suitable ML algorithms.

In the quoted work, Peck (1969) settlement trough is calibrated, as well as the cumulative Gaussian curve for longitudinal settlement (Figure 13). These curves combined enable the extrapolation of settlements measured at any distance from the tunnel face to estimate the maximum settlement after TBM crossing.

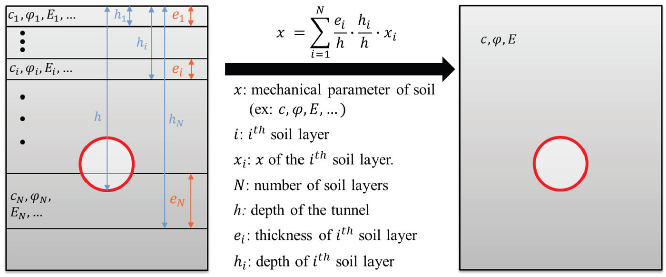

Figure 12 – Example of homogenization techniques to simplify ground model for the use of ML techniques (Richa et al, 2023)

The accuracy of the predictions can be checked within the data gathered, by splitting the dataset into two sets: training and testing. Once the training is complete, the model can be used to predict, in real time, settlements ahead of the TBM face.

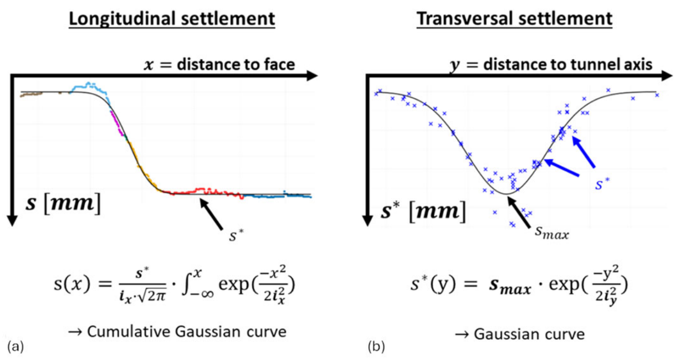

Figure 13 – Calibration of Gaussian curves based on surface measurements for application in ML (Richa et al, 2023)

In a simplified way, the procedure is the following:

- Geotechnical ground profile along the line is digitized meter by meter. Cross-sections are obtained every meter including information about stratigraphy, ground properties, tunnel cover depth.
- A relational database is established to enable storing all the required data: settlement sensors, its position, and the associated settlement measurements; TBM information such as position and sensors measurements, geotechnical information along the line.
- As the TBM operation starts, data is pre-treated and stored, and the algorithm begins to be trained.
- When sufficient data has been collected to ensure the desired level of accuracy (which can be tested within the data already gathered), it is possible to predict settlement ahead of the tunnel face.

It is important to note that data pre-treatment can be very time-consuming and be a major problem for the implementation of the method. Ideally, data should be available online, and easily accessible through programming commands. Data coming from PDF files, or Excel spreadsheets sent by email can be a source of delays and loss of interest of the method. Also, problematic sensors (in the TBM or settlement measurement) can result in an excessively difficult data treatment and make predictions poor.

Richa (2022) used data gathered in about 13km of excavation of metro lines 14 (South) and 15 (SouthWest) of Grand Paris Express metro confirming the viability of the method. Figure 14 presents the location of the settlement sensors used and Figure 15 presents an illustrative view of the digitized ground profile of line 15SW. The two lines were excavated using EPB TBM of 10m diameter at a range of depths varying between 10m and 55m to the top of the tunnel.

Figure 14 – View of the settlement sensors used in the analysis of the lines 14S and 15SW using ML (Richa et al, 2023)

Richa et al (2024) tested the capabilities of the algorithm by using a small part of the database available to train the algorithm (30%, 777 settlement observations), and the rest (70%, 1813 observations) to test its performance (Figure 16). After optimization of the obtained model, the authors conclude that, for the collected data, the accuracy of predictions was of 1mm, with the ability to predict settlements up to 150m ahead of the TBM face. In this study, and in consideration of the available data, it was concluded that 700m of excavations were required to reach this level of accuracy.

It should be noted that this performance is conditioned to the capacity of the ML algorithm to correlate parameters that have already been measured to those yet be measured. In this context, the presence of unexpected ground conditions, or sudden changes in the manner the TBM is operated, will result in loss of accuracy or error in predictions. The algorithm, as presented, needs time (data) to be trained and learn about the new excavation conditions. Thus, it cannot be used to prevent unexpected situations, which remains the main role of the engineers following the works. It can, however, be programmed to issue alerts whether there is a sudden change in expected behavior, for a given criterion (high increase in measured settlements, change in operational TBM parameters, etc).

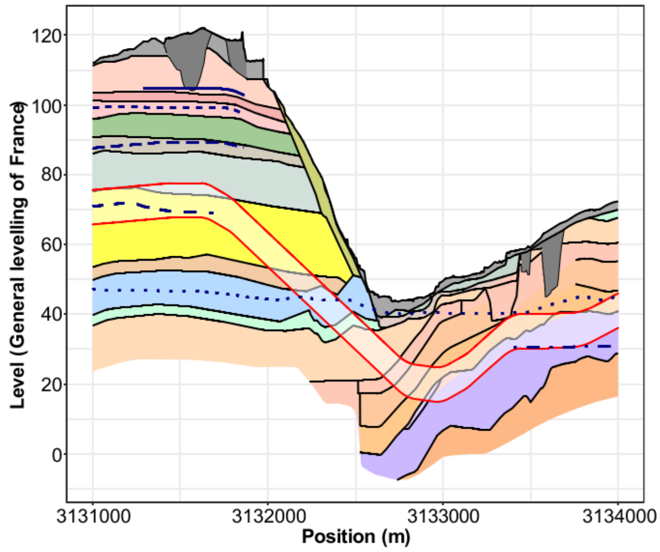

Figure 15 – Longitudinal profile of the excavation of metro line 15SW (Richa et al, 2023)

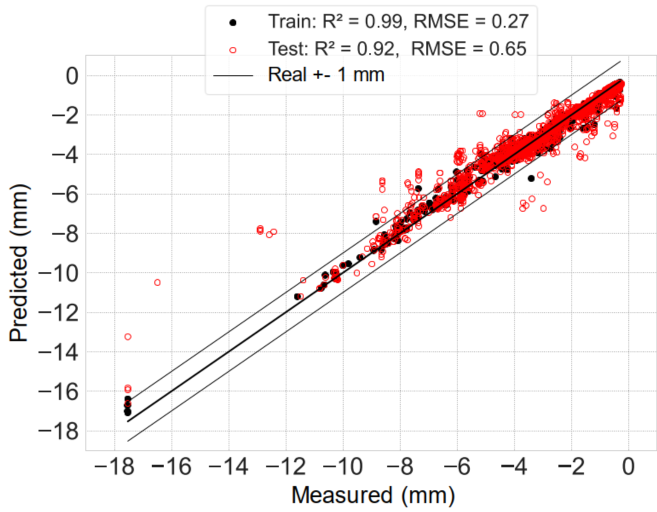

Figure 16 – Comparison between measurements and predictions of settlements using Random Forest algorithm trained with 30% of the database (Richa et al, 2023)

The main interest of the method is to provide an additional tool for the follow-up of the excavation works, in support of the engineering team in charge of following the instrumentation.

A key takeaway from this case is the promising capability to use data collected during excavation to give feedback and automatically predict the behavior of upcoming excavations. The order of magnitudes is:

- accuracy of 1mm,

- predictions up to 150m ahead of the TBM face,
- 700m of past excavations are required to train the model.

6 CONCLUSIONS

This paper presented some lessons learned from deep excavation and tunnelling projects in the Parisian region. Due to the presence of some analogous elements between the Parisian sedimentary basin, and sedimentary ground in the Sao Paulo basin, especially regarding the presence of overconsolidated clays, it is considered that the references presented in this paper can be useful for designers working in underground projects in Sao Paulo.

Some important trends are revealed by the analysis of the three recent papers quoted:

In dense urban areas, design is frequently governed by displacement criteria. This requires the use of advanced modelling techniques, which are rising in complexity, but also getting more accessible. The use of 3D FEM in current design was unimaginable 15 years ago but is now a common practice. The use of traditional modelling techniques (SRM, analytical solutions) remains pertinent and yield consistent results provided input parameters are chosen in accordance.

In the cases presented, the magnitude of settlement observed ranges between 5mm to 10mm. These values are very low. They are, at the same time, (1) a design criterion, (2) a performance indicator, for which the contractors must comply, and (3) are certainly associated with safety alert triggers. This requirement, established by owners and clients aiming at minimizing risks of disturbance of neighboring structures during construction, pushes the designers and the modelling techniques to high levels of complexity.

Where there is a requirement for settlement (or more generally, displacement) compliance, there is also a requirement for instrumentation and monitoring. Various types of instruments (inclinometers, fiber optics, strain gages, pressure cells) can be used to confirm the design assumptions, but also to optimize it, if it is used in early stages of works development.

In complement, the requirement of high-quality ground investigation comprising tests that enable to characterize the deformability moduli of ground at different strain ranges is fundamental to feed the numerical models. These tests comprise geophysics, as well as other *in situ* and laboratory mechanical tests. In French practice, pressuremeter testing has great acceptance between practitioners in the field, and recent developments are promising.

With the increasing availability of digital and connected instruments, for which data can be made available in real time through the web, we believe that the use of powerful machine learning methods to deal with the big amount of data generated will rise in popularity. They can be used simply to assess the current state of the works, but also to yield predictions on its future behavior. This requires the establishment of well-structured databases that can be easily treated by algorithms. Geotechnical engineers will need to establish standards and protocols for data sharing for each type of groundwork.

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