Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0259

Effects from extensive construction activities on pore pressure and settlements in central Oslo

Effets des travaux de construction de grande envergure sur la pression interstitielle et les tassements dans le centre d'Oslo

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ABSTRACT: For the last 10 to 15 years, the area around the central station in Oslo has been subject to extensive building and infrastructure development. Construction activities have generated major settlements in the area, primarily caused by the reduction of pore pressure which is mainly due to leakage that occurs in connection with drilling activities. Since the development of the area will continue over the next decade, the owners of projects and infrastructure within the area are interested in having a more holistic understanding of the effects of the construction activities on pore pressure and settlements. In 2014, a project has been initiated in order to gain such an integrated overview of pore pressures and settlements in the whole area, and to associate the measurements with relevant building activities. Pore pressure measurements at bedrock and settlement monitoring, both conventional and by radar interferometry (InSAR), are used to analyse the conditions. The article presents some examples of how settlements and pore pressures have developed and how they can be linked to the construction activities.

RÉSUMÉ: La zone autour de la gare centrale d'Oslo a fait l'objet d'un développement important, en particulier au cours des 10 à 15 dernières années. Les activités de construction ont généré d'importants tassements dans la région, avec une contribution considérable de la réduction de la pression interstitielle due à des fuites liées dans des forages. Étant donné que le développement de la zone se poursuivra au cours de la prochaine décennie, les propriétaires de projets et d'infrastructures de la région souhaitent mieux comprendre les effets des activités de construction sur la pression interstitielle et les zones habitées. En 2014, une étude a été lancée afin d'obtenir un suivi des pressions interstitielles et des tassements dans toute la zone et d'associer au cours du temps ces mesures aux activités de construction. Les mesures de la pression interstitielle au niveau du substratum rocheux et la surveillance des tassements, à la fois conventionnelles et par interférométrie radar (InSAR), sont utilisées pour analyser les conditions. L'article présente quelques exemples de la façon dont les tassements et les pressions interstitielles se sont développées et comment elles peuvent être reliées aux activités de construction.

Keywords: Pore pressure, settlements, deep excavations, monitoring, integrated overview

1 BACKGROUND

For the last 10 to 15 years, the area around the central station in Oslo (Oslo S) has been subject to extensive building and infrastructure development. Figure 1 and 2 show an aerial view of central Oslo in 2001 and 2018, respectively. It can be seen that huge areas, especially south of Oslo S, have changed and still change from being used for industry purposes to buildings, such as the Norwegian Opera, housing / offices in the "Barcode" area, as well as around Bispevika and Sørenga. In addition, the Follo Line project, currently the largest infrastructure project in Norway, is under construction.

Figure 1. Aerial view of central Oslo 2001

Construction activities involve extensive and partly deep excavations, as well as the use of bored tie-back anchors and foundation piles, installed from the final excavation level. As a consequence, major settlements have been observed in the area. A considerable portion of the settlements is linked to pore pressure reduction due to leakage that occurs in connection with drilling activities. The construction-induced settlements have triggered the need for considerable maintenance on existing infrastructure and surrounding constructions.

Figure 2. Aerial view of central Oslo 2018

Since the development of the area will continue over the next decade, the owners of projects and infrastructure within the area are interested in having a more holistic understanding of the effects of the construction activities on pore pressure and settlements. In 2014, a project has been initiated in order to gain such an integrated overview of pore pressures and settlements in the whole area, and to associate the measurements with relevant building activities.

2 THE PROJECT

Already in 2011, NGI took the initiative to assess the cause of settlements in the Oslo S area. Those settlements were also part of the motivation to launch the BegrensSkade / "LimitingDamage" project (BegrensSkade, 2016) which was presented by Langford et. al (2016) at the last Nordic Geotechnical Meeting.

The findings that are presented in this paper originate from an NGI-project, that was started in 2014, and that is funded by Bane NOR (responsible for the Norwegian national railway infrastructure) and Statens Vegvesen (Norwegian Public Roads Administration). The projects aims to establish an integrated overview of pore pressure and settlement developments in the area, identifying and linking relevant effect-events (pore pressure reduction and settlements) with cause-events (construction activities). The project is planned to last until 2024.

Pore pressure measurements at bedrock level and settlement monitoring, both conventional and by radar interferometry (InSAR), are used to analyse the conditions. Measurements are collected from all ongoing construction projects in the area, and the data is stored in an ArcGIS-database which makes it possible to assign geographical and other information to the data.

One example of how data then can be presented is shown in figure 3. Pore pressure levels at bedrock around turn of the year 2017/2018 are interpolated, providing a graphical presentation of the spatial variation at that time. By generating equivalent figures at different times, it is possible to track the pore pressure fluctuation with time, and easily identify which areas have been affected by pore pressure reductions.

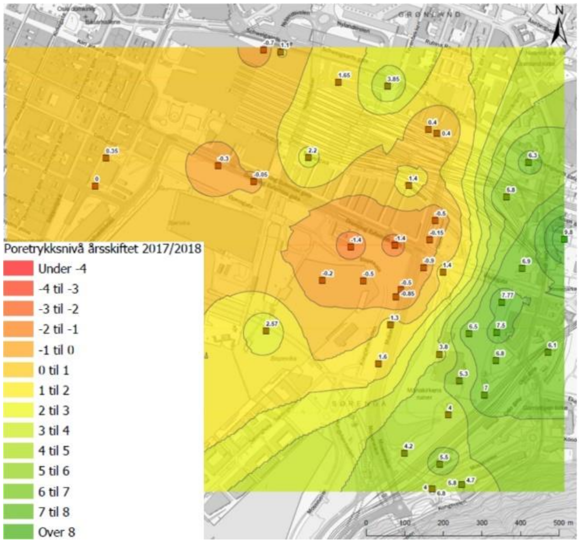


Figure 3. Pore pressure levels at bedrock around turn of the year 2017/2018 (NGI, 2018)

Since the start of the project, the database has been considerably upgraded, as per today comprising more than 100 active piezometers and a considerable number of settlement- and deformation sensors. In addition, InSAR-data is collected and processed from two different satellites, Radarsat-2 and TerraSAR-X, respectively. A majority of the project owners in the area contribute to the database, and in return they gain access to yearly status reports.

3 GROUND CONDITIONS

The general ground conditions in the area can be described as follows: the subsoil is characterized by fill mass and/or dry crust, followed by normally consolidated soft clay above bedrock. In some areas, glaciofluvial deposits (moraine) are encountered above bedrock. In the southern part of the Follo Line project, see figure 2, quick clay is present. Since the clay in the whole area is not over consolidated, it will have the potential react with significant settlements in connection with considerable pore pressure reductions at bedrock.

The depth to bedrock is quite variable: it lies mostly between 20 and 40 mbsl, but there are also some areas where the bedrock is found at considerably deeper levels, down to ca. 90 mbsl in the north-western part of the railway tracks at Oslo S.

Another characteristics of the central part of the area is that this is reclaimed land, as the shore line was located at the northern end of Oslo S around 1650. The landfill has generated settlements, and the secondary effects of those landfill activities can still be seen in form of creep settlements.

For a more detailed description of the ground conditions and the development of the shore line, please refer to NGI (2014).

4 PORE PRESSURE AND SETTLEMENT TRENDS

4.1 Introduction

In the following, three examples of how the construction activities have influenced on pore pressures and settlements in the area, are presented. The first example covers the most recent pit excavation in connection with the "Barcode"-development, field B13. The second example shows the development of pore pressures in the Bispevika-area, comprising several construction projects, and the third example covers the Follo Line project, currently being the largest ongoing infrastructure project in Norway. The approximate location of the three examples is indicated in figure 4.

Figure 4. Location of the example projects

4.2 Example 1: Barcode B13

Between 2013 and 2014, the last excavation pit in connection with the Barcode-development, B13, was executed. At that time, a comprehensive monitoring programme was available around that pit, with respect to deformation measurements of surrounding infrastructure, especially the railway tracks at Oslo S. In contrast to this, only few pore pressure measurements at bedrock had been put in place when the works started.

The excavation works started in summer 2013, including drilling for anchors and foundation piles. The foundation was done by the means of drilled steel core piles and drilled steel piles, and the foundation works were executed between October 2013 and April 2014. In connection to the drilling activities, a significant pore pressure reduction at bedrock level occurred November 2013, reducing the pore pressure level down to 3 to 4 mbsl also in piezometers that were installed in around 100 m distance from the pit. This reduction lasted for some months, and after completion of the foundation works, the pore pressure levels were rising again spring 2014.
This pore pressure reduction generated considerable settlements on the surrounding infrastructure, and the effect can clearly be seen in the settlements north of the excavation pit. Figure 5 shows rates of settlement based on conventional measurements carried out at several points on among the railway tracks, with maximum values exceeding 100 mm/year closest to the excavation. The settlements are at least partly caused by pore pressure reduction, as they also occur in considerable distance to the pit.

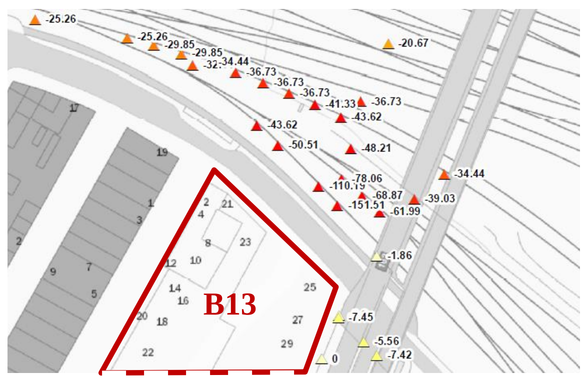


Figure 5. Measured rates of settlement [mm/year] for the first half-year in 2014 (NGI, 2015)

Figure 6 shows the average rates of settlement for a greater area, based in InSAR-data, indicating major settlements of > 14 mm/year also within a considerable distance to the excavation. In the western part of Oslo S, the settlements shown here seem more to reflect the "natural" settlements (i.e. creep settlements from former landfill activities, which are mainly dependent on the depth to bedrock).

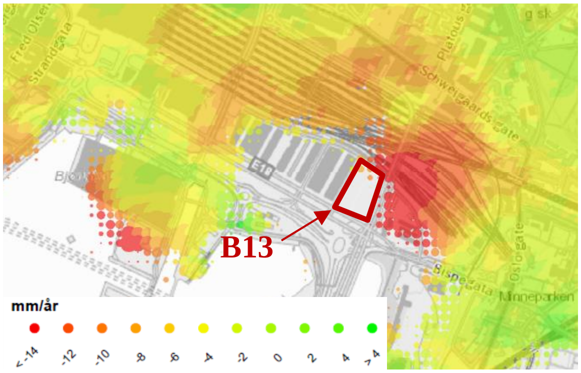


Figure 6. Average rates of settlement [mm/year] based on InSAR-data between ovember 2013 and july 2014 (NGI, 2015)

4.3 Example 2: Bispevika

Example no. 2 focuses on the Bispevika area, where the foundation works in a number of adjacent projects (B2, B3/B7 and B6a in figure 4) already have been finished. Bored steel core piles installed from the final excavation level (between level 3 to 5 mbsl) have been used as foundation method. No anchors have been used, as the retaining walls (sheet piles) have been supported by internal struts, i.e. leakage / drainage can only be caused by the foundation works. Foundation works in that area have been performed between June 2016 and June 2018.

A significant reduction in pore pressures at bedrock has been observed especially in connection with foundation works for the B7 excavation pit, where the pore pressure drops down to the installation level for piles, see figure 7. The piezometers shown in the figure have a distance to the B7 excavation of up to 300 m, where a reduction of more than 1 m in pressure level has been measured (see piezometer "Sjø PM 3B", orange line).

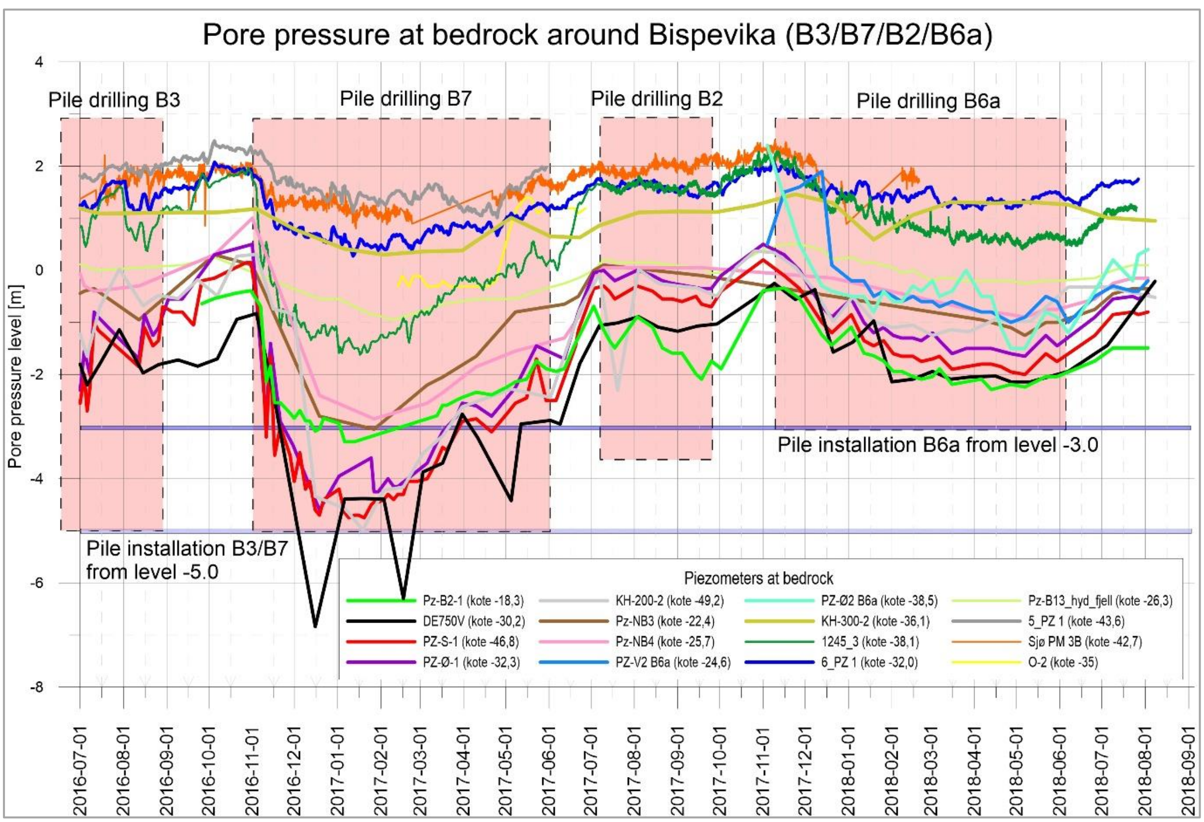


Figure 7. Pore pressure at bedrock around Bispevika between summer 2016 and summer 2018 (based on: NGI, 2018)

This is in accordance with what has been found in connection with the BegrensSkade / "Limiting-Damage" project, see figure 10, where it has been shown that leakage might cause pore pressure decrease in a distance of up to 300 to 400 m from the excavation.

As a general observation it can be stated that pore pressure at bedrock level tends to drop to the installation level of the foundation piles, and the amount of piles and the time period where drilling works are performed, have an influence on the pore pressure decrease.

4.4 Example 3: Follo Line project

In connection with the northernmost part of the Follo Line project, which comprises the approach to Oslo S, a considerable number of piezometers have been installed prior to the execution phase, both close to the planned railway tracks and also in some distance, in order to cover the potential zone of influence. The first piezometers were installed back in 2012, almost four years before the start of the main excavation works. The aim was to measure the natural pore pressure levels and their variations before the works started, as well as to follow up any impact of the works on the pore pressure.

Before the start of the works in spring 2016, a number of infiltration wells were installed around the excavation as mitigation measures against undesirable pore pressure reduction at bedrock level.

Figure 8 shows pore pressure measurements at bedrock level (for two locations: in the bedrock) for a number of piezometers that are located in the southern part of the project area, for a time period of more than two years.

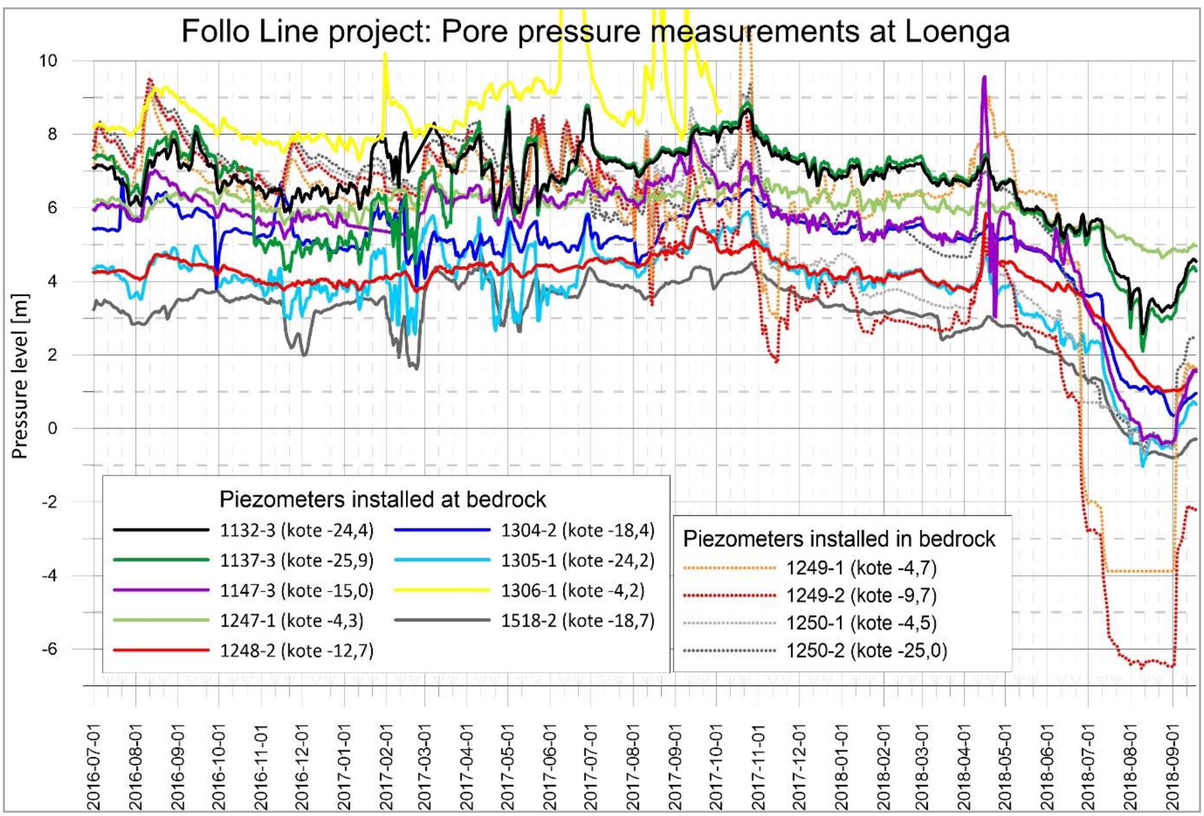


Figure 8. Pore pressure at bedrock level in the Follo Line project, southern part (Loenga), between June 2016 and June 2018

Despite the fact that the effect of different construction activities, such as ground improvement and pile drilling, is reflected in the measurements, the mitigation measures seem to have maintained a more or less unaffected pore pressure level, at least until the turn of the year 2017/2018. After that point in time, the pore pressure levels apparently show a decreasing trend in many of the piezometers.

Starting from the end of June 2018, a considerable drop in pore pressure level is measured in the majority of the piezometer locations, down to level 0 for the measurements at bedrock, and even down to 6 mbsl in one of the piezometers installed in bedrock.

The reason for this reduction could be related to the fact that the infiltration wells in that area were not operational in the time period between ca. June and beginning of September 2018. As it can be seen from figure 8, the pore pressure levels are rising in the beginning / middle of September, showing how dependent the hydrogeological system is on the infiltration wells. It is likely that the pore pressure levels between June and September indicate how the situation would have been affected by the construction works without any mitigation measures in place, possibly generating considerable settlements to the surrounding buildings and infrastructure.

The "source" of this reduction is most likely the southernmost part of the excavation, comprising a huge number of drilled anchors and foundation piles. It will take several months before the planned structure is established and all possible leakages can be sealed. The infiltration wells are therefore considered crucial in order to minimize the effect on the surroundings.

As previously stated, the effect of a pore pressure reduction due to leakage / drainage to the pit, has the potential to affect a huge area, up to several hundred meters from the source. This is illustrated in figure 9, where the area comprising all piezometers affected by the pore pressure reduction, is highlighted. The reduction can be seen in piezometers with a distance from the excavation pit in question of more than 350 m. Also for this example, this fits well with what has been found connection with the BegrensSkade / "Limiting-Damage" project, see figure 10.

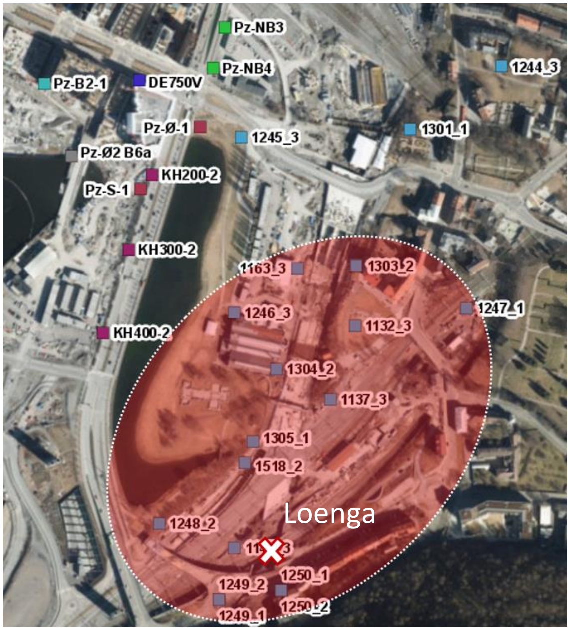


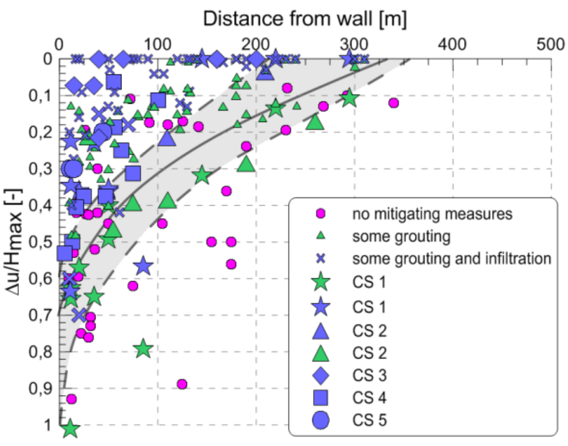
Figure 9. Aerial view of the Follo Line project area, indicating piezometers that seems to be affected by pore pressure reduction, and the location of the excavation in question (white cross)

The pore pressure reduction will generate settlements in the area, especially affecting the railway tracks at Loenga, but also the surrounding buildings and infrastructure. The magnitude will be dependent on several parameters, such as ground conditions, absolute reduction (kPa) and duration of the reduction. Closest to the excavation pit in question, the effects can already be seen in the InSAR data.

5 CONCLUSIONS

Pore pressure reductions at bedrock level, resulting from leakage / drainage to an excavation, have a potential have considerable effects on the surroundings.

The project examples presented in the article show that the effect of pore pressure reduction can reach out until 300 to 400 m from the "source", generating significant settlements to surrounding buildings and infrastructure. This is in good agreement with what has been found and documented in a recent R&D project, BegrensSkade / "LimitingDamage", see figure 10.



Figur 10. Observed normalized decrease in pore pressure at base of clay layer as function of distance from the excavation based on case records from Norway (Langford et al., 2016)

As a conclusion, it has to be stated that all construction projects that have the potential to cause leakage / drainage to the excavation, must comprise a monitoring programme, comprising measurement of pore pressure at bedrock level, which covers the entire area of influence.

In addition, choice of construction / foundation methods and execution procedures must be done having in mind the potential effects on the surroundings.

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