Halving the emissions in Malminkenttä via test structures and low-carbon geotechnical solutions

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1 Introduction

The former Malmi Airport, now Malminkenttä, is being transformed into a residential area due to City of Helsinki's growing population. Originally constructed in the 1930s, it served as Helsinki's main airport until 1952 and was decommissioned in 2021. The 2.4 km^2 area is planned to accommodate 25,000 new residents by the 2040s. Situated on a soft clay deposit (Figure 1) with undrained shear strengths ranging from 3-5 kPa in the upper layers, the area requires significant ground improvement before transitioning to housing, as no ground improvement was conducted during the original construction.

At the same time with the growth of population and need for ground improvement and construction works in Helsinki, the City of Helsinki aims to reduce emissions by 85% by 2030 and to be carbon-negative by 2040, as outlined in the Carbon Neutral Helsinki Action Plan (CNH). The climate goals concern direct emissions (scope 1 and 2) and, in the case of construction, also indirect (scope 3) emissions [1]. One of CNH scope 3 targets is to halve the emissions of ground improvement in Malminkenttä by 2030 [2]. To achieve this goal, an extensive soil investigation programme has been implemented in several stages in the area, including the design, construction, and monitoring of test structures with low-carbon ground improvement methods. A reference level for emissions, organized supervision of geotechnical design, and a process for measuring and collecting data of carbon dioxide emissions have also been established. In the following, the test structures and their monitoring are described together with the general description of the processes of collecting data on the actual emissions and the following steps in the ground improvement measures in Malminkenttä.

2 Soil conditions in Malminkenttä

Malminkenttä lies atop a clay deposit, with clay layers typically 5-15 meters thick. Under the moderate dry crust, the upper soft soil layers are very soft. The clay layers have undrained shear strengths ranging from 3-5 kPa in the upper layers (in the depth of 0-5 m) to 8-13 kPa in the lower layers (below the depth of 5 m). A very thin silt layer often separates the upper and lower clay layers. Under the clay layers there typically are 2-6 m of silt, sand and moraine layers over the bedrock. The index properties characteristic to Malminkenttä clay are detailed in Table 1.

The clay in the Malminkenttä area is predominantly acidic sulphate clay with organic content varying from 0,9 % in the lower clay layers up to 4 % in the upper clay layers, of which low pH increases the necessary binder dosage in deep mixing. The clay fraction varies typically between 75-95 %.

The goundwater conditions in Malminkenttä have been influenced by the drainage system built in 1930s. The lowered perched water table, likely due to these drainage structures, has resulted in acidic seepage through the active acid soil layers, with the dry crust exhibiting a pH as low as 3.9 [3]. This acidic seepage affects the Longinoja Creek that is a habitat for rare species of fish and therefore, the quality of the water in the creek must be protected. An automatic water quality monitoring system is in place at Longinoja to ensure continuous assessment and safeguarding of the water quality.

3 Test structures and monitoring

The extensive construction of test structures and long-term monitoring have been possible in Malminkenttä area due to the City of Helsinki being the landowner. This has allowed for the phased development of various test structures in the area.

In 2022, test deep mixing (with dry method) was conducted using 8 different low carbon binders, and in 2024, additional 2 low-carbon binders were tested in the field. The low-carbon binders used were recycled materials like fly ash- or gypsum-based materials containing low amount of Portland cement as an activator. The CO_2-emissions of low-carbon binders can be in the order of 30-50 % of the CO_2-emissions of lime-cement that is a virgin material. In 2024, a set of test embankments was built to the north of the Malminkenttä area. In 2025, further test structures were established to study perched water behaviour and the clay's corrosive properties.

Plans are in place to proceed with test deep mixing in 2026 with two to five more low-carbon binders. The locations of the test structures are depicted in Figure 2. In this paper, the column stabilised test areas and the Northern test embankments are discussed more closely.

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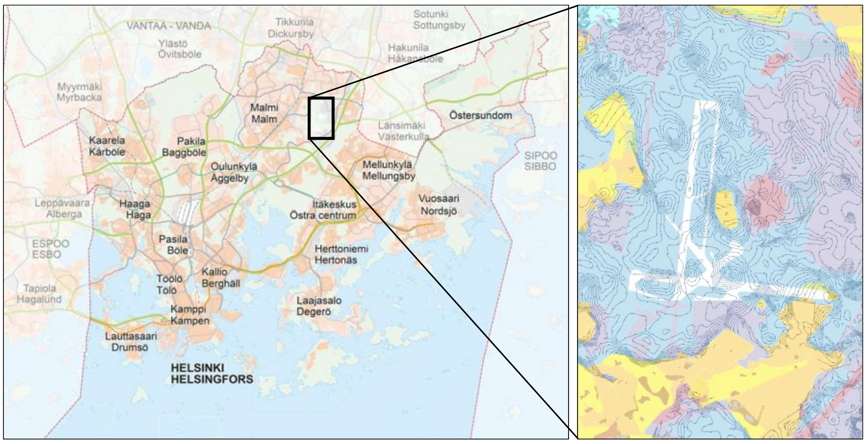

Figure 1. Map of Helsinki, where Malminkenttä is marked with a red square, and soil map of Malminkenttä (blue color indicates clay subsoil). City of Helsinki Map Service.

Table 1. Index properties of Malminkenttä clay in the Northern test embankment area.

Depth	Water content w (%)	Undrained shear strength s_u (kPa)	Fineness number (fall cone liquid limit) F	Sensitivity
0-2	101	13	75	17
2-4,5	113	4	74	24
4,5-6	71	7	56	19
6-10	44	14	47	22

3.1 Column stabilised test areas

The stabilisation tests for 2022, focusing on deep mixing in areas PS1, PS4, and PS6, were comprehensively documented in reference [4]. The binders utilized, both commercial (5) and non-commercial (2), were detailed in reference [3]. The geotechnical properties of stabilized soil using low-carbon binders are outlined in [5] and [6]. The non-commercial binders do not have the end of waste -status and their use in full-scale structures require environmental permission procedure but necessitate a lighter procedure if used in test structures. The test area PS1, located furthest north, included two sub-areas: PS1.1 was a part of a temporary road and PS1.2 was an independent test area next to the temporary road. Stabilization tests were conducted in the laboratory, with binder quantities in the field adjusted based on laboratory test outcomes. The binder dosages varied with depth of the column. An example of such variation in PS1 is 150 kg/m^3 binder in the depth of 0-1,7 m, 120 kg/m^3 in the depth of 1,7-5,7 m and 100 kg/m^3 below the depth 5,7 m. In PS1 and PS6, the columns were mixed from the top of the clay layer to the bottom of the clay layer, but in PS3 the column length varied to study the behaviour of floating columns.

In 2024, additional deep mixing was performed next to PS1.2 using two non-commercial binders. At areas PS1.2, PS4 and PS6, quality control soundings were carried out 1-, 3- and 12-months post-construction. In addition, the upper ends of five columns in PS1 were excavated, and the upper ends of two columns were raised from the ground for further studies. The studies together with the results are detailed in references [8] and [9].

Due to the necessity of conducting quality control soundings and other investigations, the monitoring of column-stabilized structures was less extensive compared to other test structures. However, settlements of the columns are extensively monitored in the test area PS3, where the lengths of the columns vary. In addition, settlements of columns have been monitored at PS1.1, PS1.2, PS4 and PS6. The monitoring equipment was installed after construction.

3.2 Northern test embankments

In addition to soil stabilization, alternative low-carbon ground improvement methods include methods such as preloading with or without vertical drains and timber piling. Timber piling, a traditional method in Finland, particularly in Helsinki's oldest city centre foundations, offers a means to sequester carbon permanently within the ground. The amount of CO_2 captured in the soil with timber piles is typically in the order of six times the CO_2-emissions of the installation of the timber piles. In the recent years some structures have been designed in Helsinki, where stabilized columns or piles have been replaced by timber piles as ground improvement rather than foundation. The feasibility of timber piling in replacing column stabilization was studied via test structure in the northern part of Malminkenttä area as well as in the crossing of Longinoja creek.

The test structure comprises two sections. In the northwest H3-H5 (in the front in Figure 2b and on the left in Figure 3) timber piles were installed with three lengths of piles and two combinations of geotextiles. In the southeast, other end of the embankment (H1) was constructed on natural clay and the other (H2) on clay with vertical drains. The vertical drains were installed so that the clay was not penetrated completely with the drains, but the bottom of the drains were approximately 1 m above the bottom of the clay layer due to artesian groundwater. The embankment's height varies, being lower at the edges for stability reasons (i.e., counter berms).

The embankment H1-H2 will be built in stages with the first phase completed. Predictions suggest that in H1 the degree of consolidation U=50 % will be achieved in 4 years and U=90 % in 15-20 years. However, in H2 with vertical drains U=95 % has been estimated to be reached in just 2 years.

Settlements and horizontal displacements are monitored in the timber piled embankment (H3-H5), and in H1-H2 also pore water pressures. The pore pressure instruments were installed prior to construction to capture the effects of installing the vertical drains and constructing the embankment.

Alarm limits for the monitoring were based on analytical calculations and numerical modelling [10]. The limits have turned out to be realistic for the measured pore pressures. The settlement difference between H1 and H2, approximately 250-280 mm, reflects the more rapid settlement due to the vertical drains. The settlements observed in the timber piled embankment (H3-H5) were very low, of the order of 0-2 mm regardless of the length of the piles.

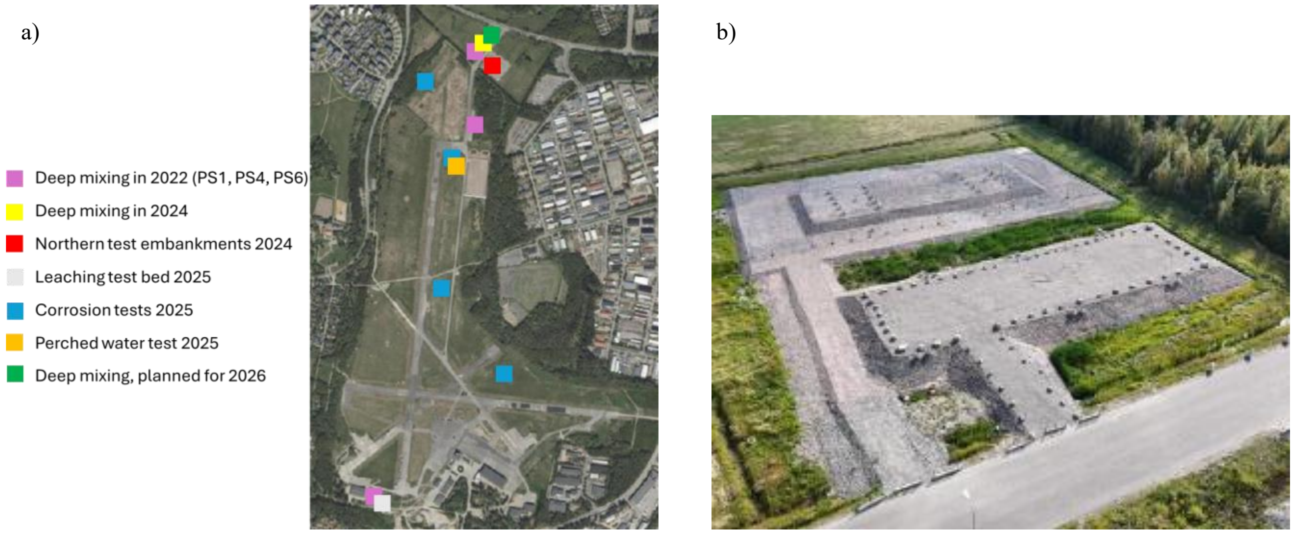

Figure 2. a) Test structures and years of construction. Aerial photo: City of Helsinki Map Service. b) The Northern test embankments. The timber piled embankment (H3-H5) in the front and the embankment partly on soil with vertical drains (H1 and H2) at the back. Photo: Harri Saarinen.

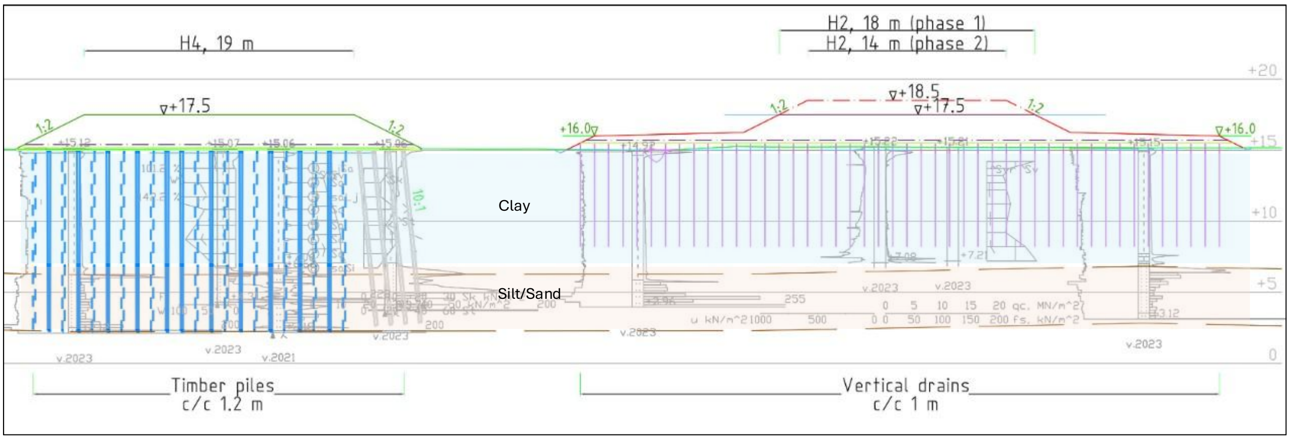

Figure 3. Cross-section of the Northern embankments.

4 Discussion and conclusions

To verify the target of halving the CO_2 emissions, there was a need for a carbon management process. The 2017 preliminary preconstruction plan served as the baseline for calculating the reference level of the emissions. This plan identified deep mixing with lime-cement (BAU) as the primary ground improvement method in the area. According to calculations, over 96 % of the total ground improvement emissions were caused by deep mixing with lime-cement, mainly resulting from the manufacturing process of the binder [7]. However, the reference calculations assuming deep mixing with low-carbon binders show that it is possible to reduce the carbon emissions by 50 %. In addition, using other low-carbon ground improvement methods (as timber piling, vertical drains and preloading) and materials alongside design optimisation, could lead to further emission reductions. A comprehensive process was developed to track emissions from design optimisation to collecting the emission data design optimization to data collection, ensuring the implementation of low-carbon methods and verifying emission levels for reporting. Using the results of the extensive test construction and monitoring data, it is possible to make even further optimisations in the ground improvement designs in Malminkenttä. The extensive test construction and monitoring in Malminkenttä have provided valuable data for refining ground improvement designs. As of now, the goal is being met. As part of the climate budget strategy of 2024, the City of Malminkenttä plans to discontinue the use of lime-cement in deep mixing and transition exclusively to low-carbon binders.

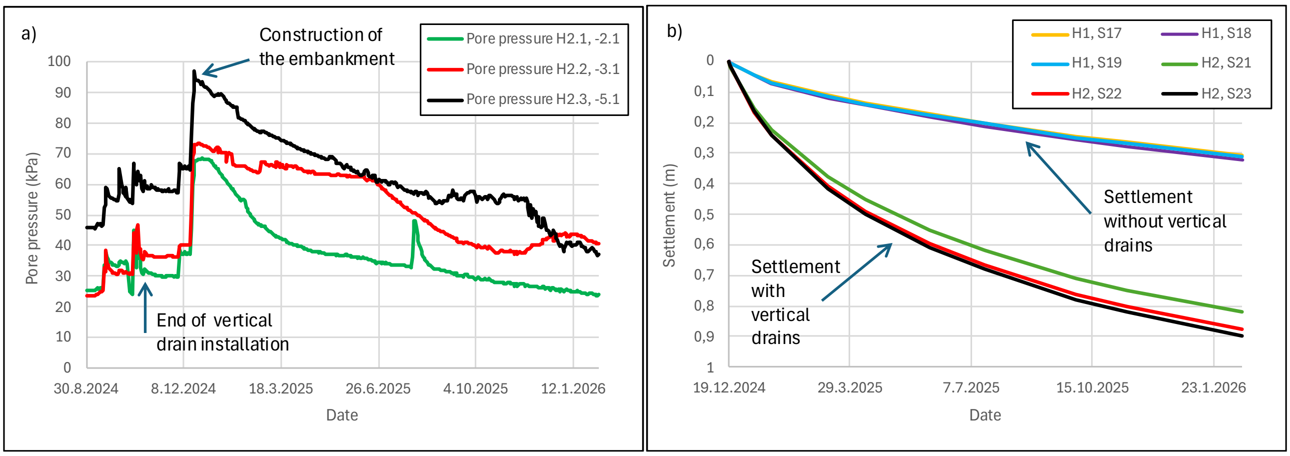

Figure 4. a) Observed pore pressures with time for the embankment on vertical drains H2. b) Observed settlements with time for the embankment with (H2) and without (H1) vertical drains.

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References

1. Hiilineutraali Helsinki – päästövähennysohjelma (in Finnish, Carbon neutral Helsinki). City of Helsinki (2022)
2. Carbon-neutral Helsinki Action plan, update 2024. City of Helsinki, publications of the Central Administration 2024:26.
3. J. Forsman, M. Löfman, J. Ikävalko and L. Korkiala-Tanttu, Low-carbon binders in six test deep mixing cases – variation of in-situ strength, Transp. Geotech. **53** (Elsevier, 2025)
4. J. Forsman, M. Löfman, F. Winqvist, O. Kaukoranta, M. Koskinen, A. Aalto, Test stabilization with low carbon binders – case Malminkenttä. Proc. of the Deep Mixing 2024, 2-5 December 2024, Yokohama, Japan, Jpn. Geotech. Soc. Spec. Publ. **11**:5 pp. 154-159 (2024). https://doi.org/10.3208/jgssp.vol11.DS-1-11
5. A. Lopez Ramírez, and L. Korkiala-Tanttu, Stabilisation of Malmi soft clay with traditional and low-CO2 binders, Transp. Geotech., **38,** 100920 (Elsevier, 2023)
6. A. Lopez Ramirez, L. Korkiala-Tanttu, and J. Forsman, Performance comparison of low-carbon binders for stabilization of soft sensitive Malminkenttä clay. Proc. of the Deep Mixing 2024 Yokohama Conference, 2-5 December 2024 in Yokohama, Japan, Jpn. Geotech. Soc. Spec. Publ. **11**:5 pp. 146-153 (2024). https://doi.org/10.3208/jgssp.vol11.DS-1-10
7. M. Löfman, S. Vicente, O. Perttu, J. Forsman, M. Koskinen, A. Aalto, and M. Suominen, Reducing the emissions from ground improvement by halve for the new part of Helsinki city - Case Malminkenttä. Proc. of the Deep Mixing 2024, 2-5 December 2024, Yokohama, Japan, Jpn. Geotech. Soc. Spec. Publ. **11**:7 pp. 278-282 (2024). https://doi.org/10.3208/jgssp.vol11.DS-3-12
8. F. Winqvist, Malmin koestabiloinnit, 28d, 90d ja 365d laadunvalvontakairausten yhteenvetoraportti (in Finnish, QC soundings report). City of Helsinki and Ramboll Finland Oy (2022-2024)
9. O. Kaukoranta, Vähähiilinen pilaristabilointi ja hankintamenettelyt (in Finnish, Low carbon column stabilization and procurement procedures). Master's thesis, Aalto University (2024)
10. T. Lehtovirta, M. Löfman and J. Forsman, Malminkenttä – Pohjoiset koepenkereet, Geotekninen mitoitus (in Finnish, geotechnical design report). City of Helsinki and Ramboll Finland Oy (2024)
11. J. Uusi-Viitala, K. Uusi-Kinnala, M. Löfman and O. Perttu, Malminkentän esirakentamisen HNH30-päästöseuranta – koontiraportti, Toteutuneet päästöt 2024 (in Finnish, report on actual emissions by 2024), Kaupunkiympäristön aineistoja 2025:24. City of Helsinki (2024)