The traffic junction Lindholmsmotet in Gothenburg: An example of creative geotechnical engineering in the construction phase

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ABSTRACT
In 2012 Skanska Sweden AB was awarded a contract for expanding the traffic junction "Lindholmsmotet" in Gothenburg. The ground conditions were challenging (very deep deposits of "Gothenburg clay", i.e. a soft, high plastic, slightly over-consolidated marine clay), but the job was mainly a construction-only contract. Therefore, only a minor engagement, handling some temporary works, was expected for the geotechnical engineers at Skanska Technology. However, the engagement successively increased since the design for the operational stage seemed unsafe – at least based on the geotechnical properties prescribed in the contract documents. After several meetings with the Client and the Client´s consultant the geotechnical engineers at Skanska decided to scrutinize the Ground Investigation Report, including e.g. triaxial tests, in detail. Based on this study the Skanska geotechnical engineers concluded that the ground conditions seemed much better - at least partly - than prescribed. Eventually, the Skanska geotechnical engineers redesigned a major part of the geotechnical solutions that were prescribed in the contract documents. The redesign was done in parallel with the ongoing construction works, which made the redesign time schedule somewhat challenging. However, thanks to a very good and close cooperation with the construction units at Skanska and the Client´s representatives, the redesign lead to a cost saving of about 10 % of the contract sum, which was 87 MSEK. A major part of the savings resulted from reducing the prescribed amount of stabilizing lime cement columns by approximately 100,000 linear meters. The redesign also contributed to the construction works being finished about 6 months earlier than originally planned. A comprehensive monitoring program was implemented in order to assure that the construction works did not jeopardize the stability conditions in the surroundings. Especially the displacements of the adjacent existing railway, of major importance for the Port of Gothenburg, was thoroughly monitored.

Keywords: Soft clay, stability, design, monitoring, case record

1 INTRODUCTION

In 2012 Skanska Sweden AB was bidding for a contract for expanding the traffic junction "Lindholmsmotet" in Gothenburg, Sweden. Due to the urban location of the junction there were several geometrical constraints to handle, such as an adjacent railway (of major importance for the Port of Gothenburg) and the existing traffic junction which both should be fully operational during the construction phase, cf. Figures 1-3.
Since the job was a construction-only contract the geotechnical engineers at Skanska were just briefly involved in the tender phase, even though the new junction included up to approximately 6-7 meter deep permanent excavations in challenging ground conditions (very deep deposits of soft clay).
As soon as Skanska was awarded the contract the geotechnical department started to examine the site conditions, with focus on the stability conditions in the construction phase. This initial study indicated that the stability stability conditions of the prescribed excavation next to the railway would be far from satisfactory even after the construction works were finished.
Due to this somewhat surprising conclusion Skanska initiated a series of meetings with

the Client (including its in-house geotechnical expert) and its geotechnical consultant. The purpose of these meetings was to get a better understanding of the background to the prescribed geotechnical properties, the prescribed required geotechnical measures and hopefully to figure out a safe and economical solution to this unexpected challenge.

This paper summarizes the outcome of these meetings, the subsequent redesign performed by the geotechnical engineers at Skanska and some experiences from the the actual construction works.

Figure 1. The original traffic junction.

F*igure 2. The new traffic junction during construction.*

Figure 3. The new traffic junction just after completion.

2 THE GEOTECHNICAL PROPERTIES AND THE REQUIRED STABILISING MEASURES ACCORDING TO THE CONTRACT DOCUMENTS

The Contract Documents included a broad description of the ground conditions. Furthermore, the characteristic values of all relevant geotechnical properties, e.g. strength and deformation properties, were prescribed in detail.

In general the ground at the site consists of about 0-4 m of fill on top of "Gothenburg clay" reaching a depth of 50-80 m. The clay is a soft, high plastic, slightly over-consolidated marine clay with a natural water content of 50-100 % and a liquid limit of 40-90 %. The unit weight is about 16 kN/m^3 and the sensitivity is 10-30.

The prescribed undrained shear strength (characteristic value) varied somewhat within the site, but it was in the order of 15-17 kPa in the upper part of the clay layer, while further down increasing by 1.3-1.5 kPa/m with depth. The prescribed preconsolidation pressure (characteristic value) was typically 4.5-5 times larger than the undrained shear strength.

The Contract Documents also included drawings showing the prescribed geotechnical measures that was required in order to fulfil the stability and/or settlement requirements after completion of the new junction. Most of the geotechnical measures consisted of lime cement columns (a total of about 150,000 linear meters), cf. Figure 4. Furthermore, two retaining walls, three sheet pile walls and two regions with embankment piling were prescribed in-depth, even though the contractor should perform the detailed design of these.

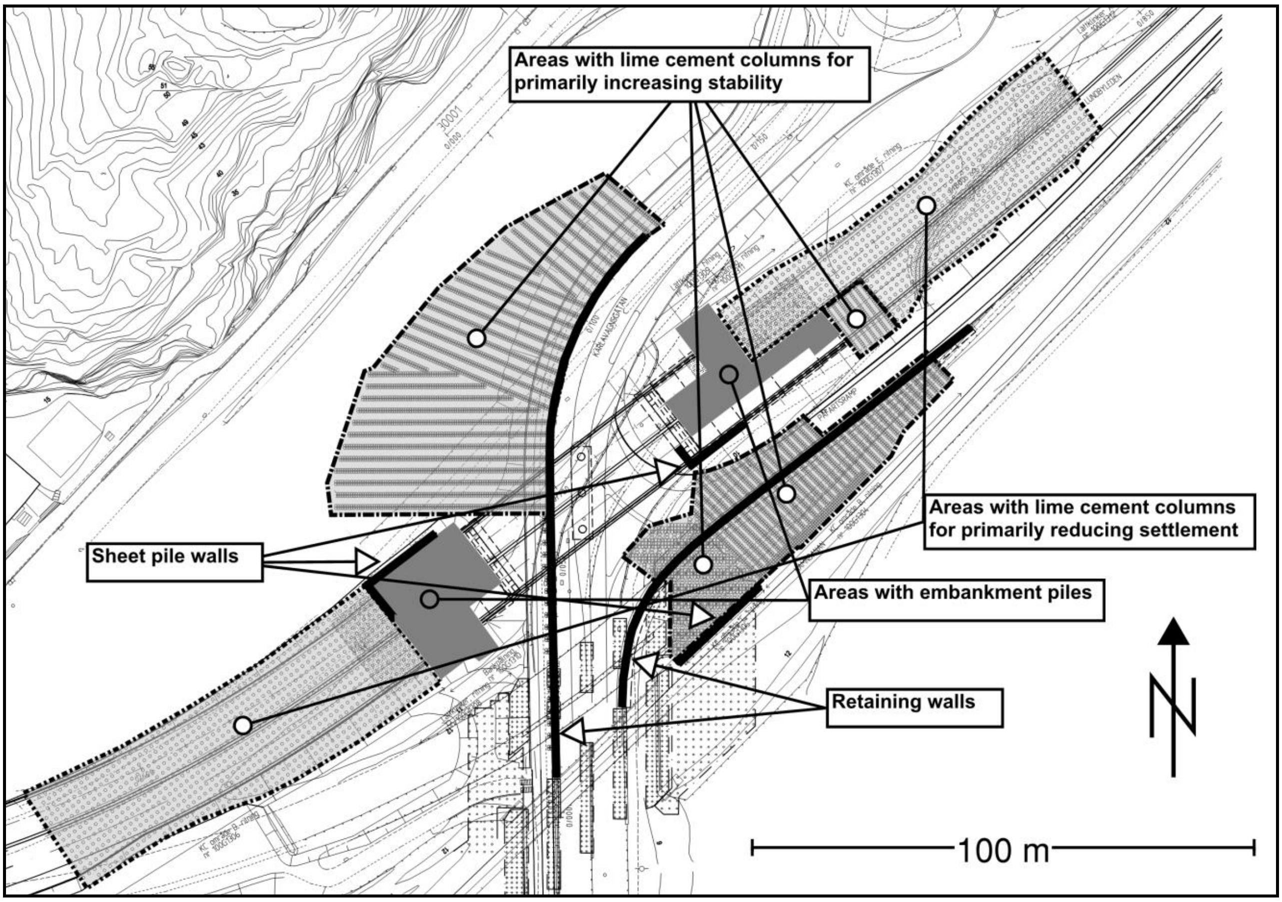


Figure 4. Plan drawing showing the major geotechnical measures (lime cement columns, embankment piles, retaining walls and sheet pile walls) that were required according to the Contract Documents.

3 THE GEOTECHNICAL PROPERTIES AND THE REQUIRED STABILISING MEASURES ACCORDING TO SKANSKA

The required geotechnical measures were prescribed in detail as the job was a construction-only contract. Therefore, in the tender phase the geotechnical engineers at Skanska only glanced through the Contract Documents, concluding that the prescribed geotechnical properties of the clay were within the typical range for “Gothenburg clay”. Therefore, at this stage it was believed that only minor modifications (if any) of the prescribed geotechnical measures were possible.

Soon after the contract was awarded some initial stability assessments were made by the geotechnical engineers at Skanska. The focus was on the area next to the railway, since it was believed that the amount of lime cement columns might be reduced compared to what was stipulated in the Contract Documents. However, the results indicated that the stability of the permanent excavation next to the railway would be far from satisfactory even after the construction works were finished. Therefore, more detailed calculations were done, but the result was essentially the same. Skanska immediately informed the Client about this somewhat unexpected conclusion and a series of “emergency meeting” was initiated, since the construction works were imminent. During the first meetings it was successively revealed that the Client´s geotechnical consultant, among other things, had assumed that the strength properties of the clay were more favorable than prescribed in the Contract Documents. Skanska´s geotechnical engineers accepted some of the assumptions, provided that they were supported by the results in the Ground Investigation Report (GIR), but they strongly questioned some other assumptions. Eventually, the geotechnical engineers at Skanska decided to scrutinize the GIR in order to make an independent evaluation of the strength properties of the clay.

The GIR included conventional geotechnical investigations, such as field vane tests, CPT:s and fall-cone tests, but also more advanced tests, such as oedometer tests (CRS), direct shear tests and triaxial tests (both active and passive). The opinion of the geotechnical engineers at Skanska was (and still is) that the results of the more advanced tests are more reliable than the other tests.

Furthermore, the geotechnical engineers at Skanska fully appreciate the close connection between the preconsolidation pressure and the undrained shear strength of clay. Therefore, by combining the site-specific results with a substantial in-house experience of the behavior of Gothenburg clay a new strength profile was suggested, cf. Figure 5.

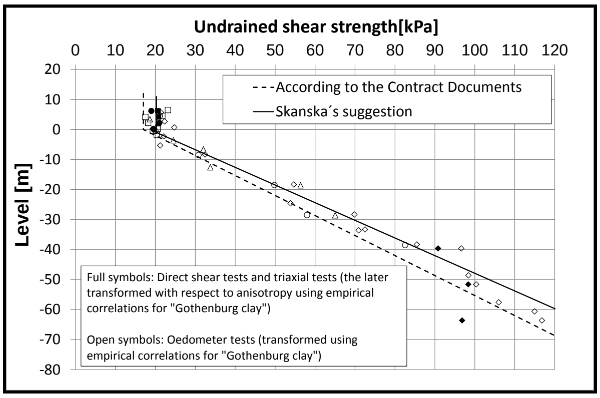


Figure 5. Strength profile of the clay according to the Contract Documents and according to Skanska.

Furthermore, Skanska´s geotechnical engineers concluded that the site specific results made it possible to account for the beneficial effect of stress induced strength anisotropy. During a couple of subsequent “emergency meetings” with the Client and its in-house geotechnical expert the Client accepted Skanska´s suggestions. Then, it was decided that Skanska should redesign all geotechnical measures within the project with focus on both the construction phase and the subsequent operational phase.

Since the construction works were already in full swing the redesign had to be performed in very close cooperation with the construction units at Skanska (especially the production manager) and the Client´s representatives (especially its in-house geotechnical expert), in order to not delay the construction works.

The geotechnical engineers at Skanska also realized that instead of removing some of the existing timber piles close to the railway (as stipulated in the Contract Documents since the piles were in geometrical conflict with the prescribed lime cement columns) their stabilizing effect could be accounted for. In order to convince the Client on how to quantify this stabilizing effect some 3D finite element analyses were performed, cf. Figure 6, in parallel with more conventional stability analyses. A combination of such analyses and a careful documentation of the actual location of the existing piles made it possible to design a tailor-made installation pattern, in which grids of lime cement columns circumscribed each individual pile.

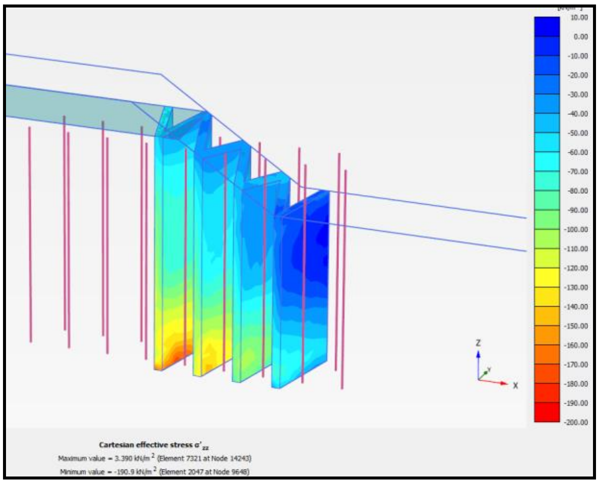


Figure 6. 3D finite element analysis for studying the stabilising effect of timber piles circumscribed by grids of lime cement columns.

Furthermore, together with Skanska´s production manager a working procedure of sequential excavation and refilling was developed.

By accounting for all these beneficial effects the following major changes were achieved due to the redesign:

- The amount of lime cement columns were reduced from about 150,000 to about 50,000 linear meters.
- One of the retaining walls (with a crest length of about 120 m) was not needed.
- No sheet pile walls were needed.
- The amount of embankment piles and pile caps were reduced from about 170 to 120.
- A cost saving of about 10 % of the contract sum, which was about 87 MSEK.
- The the amount of CO2-equivalents was reduced by several thousand tons.

The redesign also contributed to the construction works being finished about 6 months earlier than originally planned.

4 SOME EXPERIENCE FROM THE CONSTRUCTION PHASE

A comprehensive monitoring program was implemented in order to assure that the construction works did not jeopardize the stability conditions or the functionality of the surrounding railways and roads. Especially the displacements of the railway were thoroughly monitored using both automatized inclinometers, installed to a depth of about 20 m as close to the tracks as possible, and manual measurements of the railway tracks. During the installation of the lime cement columns just north of the railway the tracks were expected to displace southwards and upwards, potentially making the tracks untrafficable. The expected final displacement of the tracks and in the underlying ground were assessed in the early stage of the lime cement column installation using a method originally suggested by Sagaseta (1986) and successfully applied for pile installation in Gothenburg clay (Edstam & Kullingsjö, 2010). The assessed displacement of the tracks were larger than considered acceptable according to the Contract Documents, even though the amount of lime cement columns in the area next to the railway had been considerably reduced compared to the original requirements, cf. Figure 7. Therefore, during the installation of the columns a very close and intense communication between Skanska, the Client and the staff supervising and judging the functionality of the railway was required.

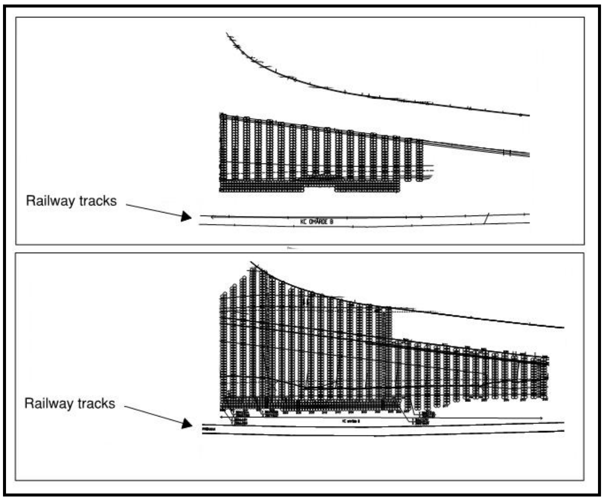


Figure 7. Lime cement columns next to the railway. Lower figure: According to the Contract Documents; Upper figure: After Skanska´s redesign.

As may be seen in Figures 8 and 9 there is a rather good agreement between the assessed and measured horizontal displacements, both at the ground surface (the tracks) and with depth. Even though the measured displacement exceeded the allowable levels the train traffic could proceed without any interruption. Only minor adjustments of the tracks were required and this could be done during time slots where no trains were passing the construction site.

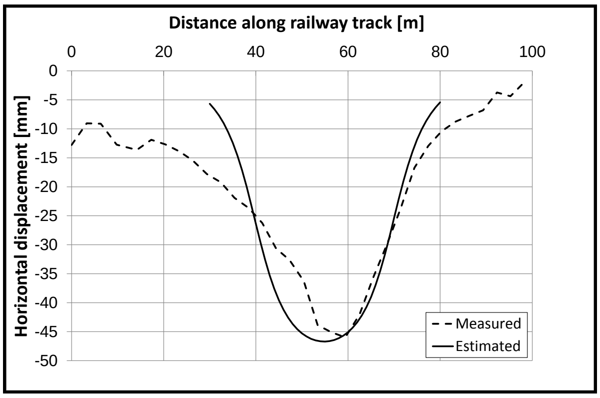


Figure 8. Assessed and measured horizontal displacement of the railway tracks.

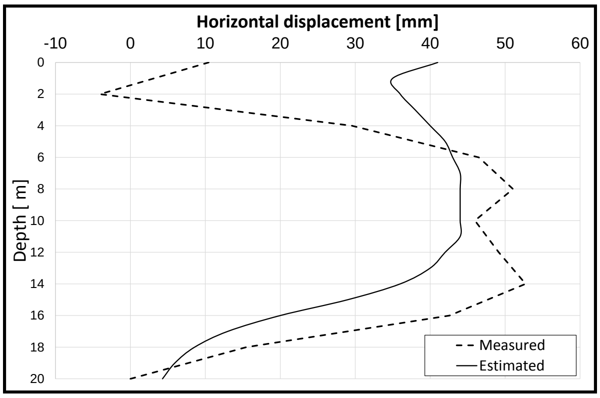
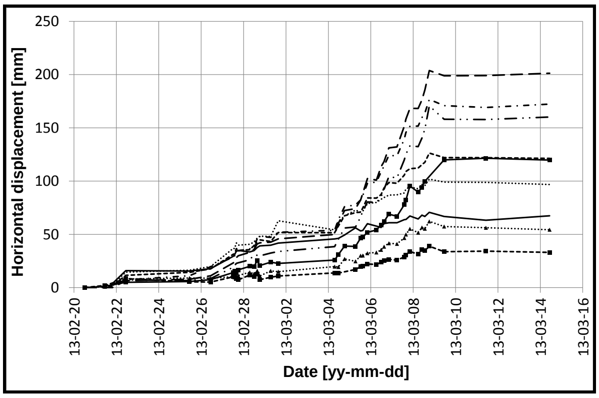


Figure 9. Assessed and measured horizontal displacement in the ground next to the railway.

The lime cement columns were partly installed just behind the crest of an existing slope with a public road next to the toe of the slope. Therefore, Skanska recommended that the stipulated monitoring program should be extended in order to keep track of the displacement of that public road. The displacements were rather modest in the early stage of the column installation. On the contrary, in the later stage the displacement increased very rapidly resulting in considerable concern about the stability conditions. Therefore, it was decided to reduce the installation rate and extend the monitoring program. During the subsequent installation works it was noted that as soon as the installation was interrupted no further ground displacements developed, indicating that the clay was very ductile. Eventually, the road was displaced up to 0,2 m horizontally and 0,45 m vertically, cf. Figure 10.
During the subsequent excavations the rail way tracks were displaced in the opposite direction to that occurring during the column installation. In the final stage, the tracks had returned to almost the same position as before the construction works commenced.



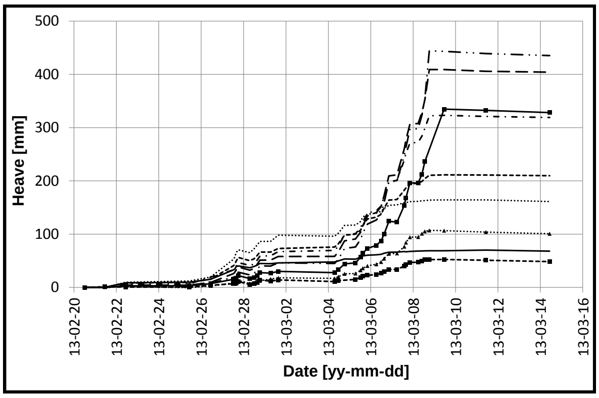


Figure 10. Measured horizontal and vertical displacement at various locations along a road located at the toe of an existing slope.

5 CONCLUSIONS

The construction works for the traffic junction “Lindholmsmotet” in Gothenburg included several geotechnical challenges. In the beginning of the construction phase it seemed as though the stabilising measures prescribed in the Contract Documents were considerably *under*estimated. However, when the geotechnical engineers at Skanska scrutinized the GIR, including fully appreciating the results of the advanced geotechnical laboratory tests, it was realised that the stabilising measures were *over*estimated.
The subsequent redesign by the geotechnical engineers at Skanska resulted in considerable savings in terms of:

- Economy (a cost saving of about 10 % of the contract sum)
- Climate impact (reducing the amount of CO2-equivalents by several thousand tons)
- Construction time (the construction works being finished about 6 months earlier than originally planned)

It is believed that the redesign could only be accomplished, especially in such a short time, due to a very close and fruitful cooperation within Skanska (its skilled and dedicated in-house geotechnical department and its equally skilled and dedicated in-house production managers) and with the Client´s in-house geotechnical expert.

During the construction works a comprehensive monitoring program was implemented, with focus on the adjacent rail way. During installation of the lime cement columns the measured and assessed displacements of the railway track were in rather good agreed agreement (in the order of 4-5 cm). In the final stage, after the construction works were finished, the rail way tracks had returned to almost the same position as before the construction works commenced.

6 REFERENCES

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