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DIRECTING CLASSICAL GEOTECHNICAL ENGINEERING TO FUTURE CHALLENGES

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Abstract. Geotechnical engineers have traditionally been focused on soil mechanics, rock mechanics and engineering geology. Thus it has been sufficient to master these topics to be recognized as a key participant in building and civil engineering projects. However, gradually concerns within both projects themselves and societies more generally are shifting towards new questions and challenges. Therefore, ensuring that geotechnical engineers remain central to all relevant projects, there is a need to master increasingly different and new ways of working together, obtaining new skills and increasing professionally pertinent knowledge and experience. This paper will give an overview of the issues geotechnical engineers have to address and master, if they are to take a lead in projects that seek to meet future challenges. This is really about working in a multi-disciplinary environment, using relevant technical methods without losing specifically engineering judgement, and then using open-minded communication skills to question previous practices that can proceed to find solutions to those future challenges identified. How is this to be done successfully within the profession? This paper offers some ideas. All professionals, and geotechnical engineers cannot be an exception, want to influence and contribute to solving current and future challenges, and thus we need to expand our knowledge awareness. The list of topics where we need to develop our knowledge is rather lengthy and include environmental considerations, contracts, law, conceptualisations of sustainability, robustness, monitoring, digitalisation, standardisation, and climate change. This paper will highlight two examples where geotechnical engineers with increased knowledge sensitivity and skills could make a significant contribution. First, there is an example from Göteborg about limiting a project impact within its zone of influence. Designing the geotechnical structure itself is only the first step, for in addition there is a need to control the building process, have sufficient monitoring, handling the expectations of society while ensuring recognition and use of a particular professional scope of operation. The other example concerns the re-use of material in our embankments to limit transportation. Which criteria should be used to determine the suitability of materials for re-use? How can we cope with societal reactions? Finally, the paper will discuss how geotechnical engineers, by combining geotechnical knowledge with new skills, can contribute with a sustainability foundation involving both relevant concepts and principles looking forward.

Keywords: Future challenges, re-use, sustainable, zone-of-influence.

1. Introduction

Geotechnical engineers tend to be recognised for knowledge of soil mechanics, rock mechanics and engineering geology. For a long time, it was sufficient to master these topics to realise their key role in building and civil engineering projects. But gradually projects and societies shifted focus towards new questions and challenges. In order to ensure that geotechnical engineers continue as key experts in such projects, we need to master new ways of working together, develop new skills and expand our knowledge.

The question raised is how geotechnical engineers with their specialised understanding of the behaviour of soil, rock and groundwater can contribute to solving readily identifiable societal challenges. What additional skills and knowledge are needed? How do we come to terms with the new working environment that is steadily developing around us?

This paper will give an overview of the issues that geotechnical engineers have to grasp, if they are to take a lead in future projects that challenge us all. It relates to working in a multi-disciplinary environment, using standard operating techniques while enhancing our engineering judgement, facilitating open-minded communication, and questioning traditional practices to discover new solutions to emerging problems. This paper does not pretend to give a solution to all the issues, but presents some ideas for the geotechnical community to discuss and develop further.

2. Facing new demands and working methods

In a historical context the main demand made from society on engineers was that they should build houses, schools and transportation systems that were functional and safe. These basic requirements are today often taken for granted and the focus in current projects is shifting to examining possible futures. This includes durability during service life (and beyond), a robust or resilient capacity if the unexpected happens and of course now there is sustainable production with sustainable materials.

It is not only the demands on the final product that are changing, but also the very framework for geotechnical design. It is one thing to design and build the foundation of a house if the construction site is in a newly developing area with no previous buildings involving conflicting activities. It is another to recognise that as a result of urbanisation, buildings are constructed in confined areas within an already built environment, causing conflicts with nearby structures and utilities, and managing issues with transportation of building material and excavation material as they arise, becoming aware of a perhaps potentially hazardous working environment due to contaminated soils and maybe the negative reaction of a neighbourhood disturbed by the working process.

Digitalisation during the last decades has rapidly changed the way we work. The pen and paper has in most cases been replaced by a computer with databases, 3D models, an endless list of documents and multiple platforms for communication. This, in combination with globalisation, make it possible to have colleagues from all over the world contributing to the project.

As a result, many geotechnical engineers find that they spend more and more time in multi-disciplinary meetings and discussing topics that first seem to have very little to do with their classical training in geotechnical engineering. However, with the right mindset, the geotechnical engineer has the potential to contribute with a sustainable foundation for the future.

3. A sustainable foundation for the future

Sustainable foundation is a rather vague expression, with perhaps as many interpretations as readers. For the agricultural industry it is about using suitable crops that give food to an increasing population without destroying the potential to use the ground for coming generations. In forestry it is about finding the best way to produce timber so it can be used as an environmentally friendly building material, with limited negative impact on the eco-system and preserving the ground conditions for new woods.

The geotechnical engineer contributes to a sustainable foundation of everything that is built, by combining geotechnical engineering judgement with new skills and knowledge. Two main aspects of a sustainable foundation are the selection of appropriate execution methods and building materials. But a sustainable foundation is also about dealing with negative impacts within a zone of influence, and thus avoiding restriction on a neighbours' possibilities to use their own site for further development. In the following sections there are given two examples of how the geotechnical engineer can contribute to a sustainable foundation.

3.1. Appropriate execution methods – limiting the impact within the zone of influence

Göteborg in Sweden is situated in an area with a soft soil condition. A piled foundation is the solution for many of the new buildings in the city. This case concerns the installation of piles on a site that is next to the ongoing construction of what will be the highest building in the Nordic countries, namely Karlatornet. For the building Riksbyggen has planned to install about 270 displacement piles (concrete, length 60 m). Normally this is a standard execution, but in this case the foundation of Karlatornet put restrictions on the execution. The requirement is given that the impact from the installation of the displacement piles at the Riksbyggen site on the foundation at Karltornet is to be less than a 2 mm deformation. This turns out to be the main challenge of the project. Figure 1 gives an illustration of the building site.

Using numerical analyses a prognosis was developed using the available information of the ground properties and site geometry. This shows that it is not enough to use pre-drilling in each pile installation point, but that additionally it is necessary to remove clay with augurs to thirty meters depth in a trench along the length of the Riksbyggen site facing Karlatornet.

An extensive monitoring program was performed to help convince the owner of Karlatornet that the installation would cause no harm to their foundation. Measuring points and inclinometers were installed in four lines. Manual measurements of the inclinometers were performed three times a week during the installation of the displacement piles. In total this meant 14 weeks of measurements. Analyses, presentation, and discussion of the results were conducted at least once weekly during the execution of the pile installation. After three weeks the results indicated large deformation and the work had to be stopped. The analyses showed that the reason for the large deformation were that the contractor had thought that they could install the larger share of the piles before they went on with pre-drilling and removal of clay. The measurements showed clearly that this was a mistake, and thus additional clay removal was performed before continuation of installation. In the following weeks removal of clay was performed in connection with the installation of the displacement piles. As a result, the measured deformation corresponded fairly well with the prognosis.

The prognosis for deformation is shown in Figure 2 in combination with measurements of actual deformations after completion of the pile installation. Based on the measured results in line 4 it was possible to predict the deformation at the interface of the large-diameters displacement piles under Karlatornet. The

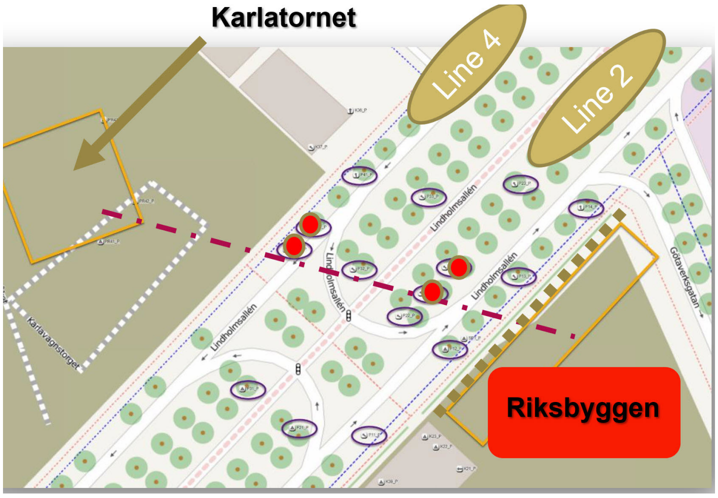

FIGURE 1. Illustration of the building site, Lindholmen, Göteborg [Red dots is the position of the inclinometers, blue circles the surface measurement points, the red line section used in Figure 2 and brown bold dashed line is the position of the trench]. The distance between Riksbyggen and Karlatornet is about 100 meters.

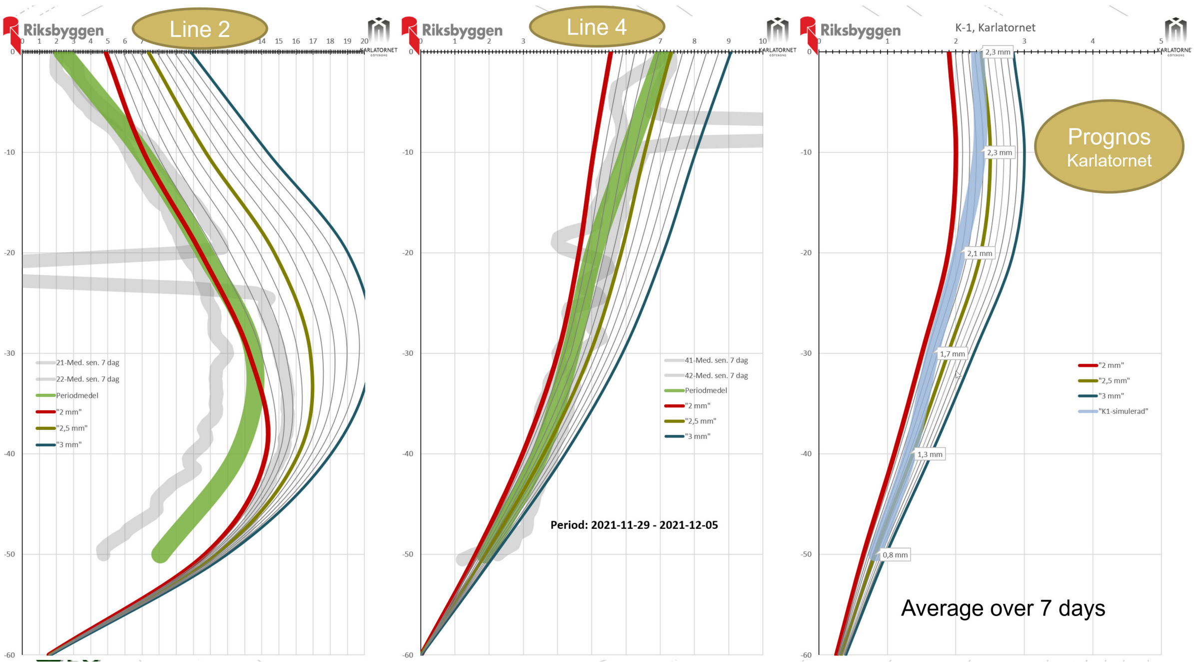

FIGURE 2. Prognosis of deformation and measured results presented along the dotted line (red) in Figure 1.

deformations were slightly larger than 2 mm, but the owner of Karltornet was persuaded that the pile installation had not caused any damage on the foundation of Karlatornet. For Riksbyggen the possibility to cause damage within the zone of influence was avoided and hence also the risk of huge claims against them.

This example shows the work situation that develops for many geotechnical engineers. They start with the geotechnical issue but find themselves then presented with endless meetings discussing measuring techniques, evaluating monitoring results, giving results, and offering their engineering judgement to convince owners and clients that there are indeed no geotechnical risks.

In addition to the skills of classical geotechnical engineering, they also need to master measurement techniques, deal in uncertainties, undertake risk management, consider legal (national) regulation and furthermore be excellent in their communication.

The question that is raised is of course if it is relevant to have this kind of requirement. It can even be questioned if it is possible to measure a 2 mm deformation with confidence. However, in this case Riksbyggen did not want to enter into a time-consuming discussion about the value of the criteria. It might have led to a more reasonable value, but in any case there would have been a need to perform monitoring in order to prove that the value in fact was not exceeded. The work at the building site would thus be postponed until there was a new agreement on this value between Karlatornet and Riksbyggen. That could take weeks or even months and cost a lot of money. Therefore, it was judged to be more efficient to perform the measuring program and try to prove that there was no influence on Karlatornet due to the installation of displacement piles at Riksbyggen. Both the removal of clay and the monitoring program were expensive, but less expensive than waiting or ending up with a claim from Karlatornet.

3.2. Appropriate building material – reuse of material

Excavated material used to be something that was removed from the building site without much discussion. Now there are numerous questions raised regarding dealing with excavated material. Is it contaminated? Can it be re-used on-site or at a close-by site? How can we limit the transportation of material? To a great extent these questions are addressed by environment experts. However, if we start discussing reuse of the material, the geotechnical engineer with knowledge of classical soil mechanics could make a huge difference. Looking at the material as a resource as indeed it is, then by adding binders, removing water, compacting it, or combining it with a geotextile, it becomes possible to make it into a suitable building material for many applications.

Similar suggestions have been presented previously for example by Vaníček et al. [1] and that the consumption of natural aggregates could be decreased by improving the properties of the natural aggregates or applying non-standard aggregates. In the same reference several possibilities for including sustainability as an aspect in design is presented. It is unfortunate that the application of the concept of sustainable design is still not common practice.

In quite a few cases it turns out not to be actual technical reasons that restrict the possibility for reuse of material, but references to common practice or public opinion. We have quite a few rules of thumb and common practice conventions from past periods and when we also had plenty of good quality building material easily accessible. It might be necessary for us to question some of these rules and grasp the opportunity to test less high-quality material. This would help to see if by compaction, using geotextiles or binders we can get as good a final product as possible. The life-cycle assessment of that product might prove to be much more sustainable.

It is not only other technical experts that might question the reuse of material. People seem to applaud reuse of material, as long as it is not close to their own backyards with maybe a risk that there is contamination in the material used. As technical experts we may know that there is no risk for the spreading of contamination, but we cannot ignore the concerns of the public. A lot of time needs to be spent on showing the benefits of re-use and that all risks are being considered.

As geotechnical engineers we have a possibility to contribute to a sustainable foundation by reusing material preferably close to the excavation site or by adding non-standard material and methods. The key is to start looking at the excavated material as a resource and have the courage to question some of our conventional truths.

3.3. The contribution from geotechnical engineers

These two examples show that the Geotechnical Engineer can play an important role in multidisciplinary projects. However, that requires that we take our knowledge about soil mechanics, rock mechanics, geology, and groundwater, and add other skills. In Figure 3 examples of the skills we need are illustrated.

Figure 3. Illustration of some of the skills that are essential to a Geotechnical Engineer in addition to their engineering skills.

Communication is one of the most important skills, and this means the ability to communicate with different audiences. Communication with society, authorities and clients requires the ability to present a huge amount of information in an easily accessible format for a non-engineering audience. This needs to be done without oversimplifying or excluding the uncertainty involved in the conclusions. If the audience instead is fellow engineers from other technical fields, the data can be presented but the challenge is then not to be misunderstood due to having a slightly different vocabulary. Chapter 4 describes how the Eurocode can be a tool for facilitating communication among engineers.

Quality control has always been a key aspect for engineers, but with multi-disciplinary and even multi-cultural projects, it becomes even more important. The key is to take the time to ask ourselves the question – is the proposed design reasonable? Does it correspond to notions of engineering judgement and their working conventions? We should also bear in mind that in all projects and especially in a multicultural project it might not be obvious for everyone to question the design or ask a principal for a second opinion. Principals do have a huge responsibility to create a working environment where the knowledge of others is used and everyone feels free to improve the design.

Uncertainty - We strive to present precise and easily accessible information. Our computer codes today allows us to present calculations in colourful graphs to several decimal precision. This might impress the client, but if we have to make sure that the design is safe and robust, we should add our interpretation of the uncertainty intrinsic to the results. No analysis is better than the quality of the input data and the precision allowed by the calculation model. Geotechnical engineers know this well, and thus as a rule we should always present openly the uncertainty discerned in the result and not just the result itself.

Risk management is not a new topic for geotechnical engineers as basically that is what we always have been working with. What is new is a need to learn to use the terminology and tools that other parts of the project are deploying, so that we can communicate the geotechnical risks in the project and contribute to control of those other risks involved.

Knowledge in related or cognate fields. Chemistry, measurement techniques, computer science, economics and law for example. The list can be extended with disciplines where either we need to develop our own understanding or find people for consultation and collaboration. The latter requires that we have an open-minded approach and are willing to listen to other disciplinary perspectives and knowledge and then be prepared to revise our own internal verities.

4. Geotechnical engineering using a multidisciplinary toolbox

4.1. The cube illustrates the societal requirements on matters of geotechnical structure

The requirements of society on geotechnical structure may be illustrated by a cube – Figure 4. On the first axis is safety, ensuring the structure shall have an appropriate probability that it will not fail during service life due to anticipated variations in the load and design situation. On the second axis we have serviceability, as the structure should be built and keep its function during the service life without causing a negative impact within the zone-of-influence on other houses, utilities and infrastructure. Deformation, groundwater, noise, and pollution are some of the impacts to consider. On the third axis robustness, durability, and sustainability, give some additional aspects to ensure that the geotechnical structure meets the societal requirements.

Eurocode, and especially EN 1997, gives the geotechnical engineer the tools to verify that the geotechnical structure is within the cube, and hence reduce the likelihood that the structure will fail, that functionality will be reduced, degraded, or bring unreasonable damage or even that sustainability is neglected. For an ultimate limit state (safety) and serviceability limit state (function) the code is mature and developed. However, for the aspects on the third axis only the basics are presented and additional guidance is needed on a national level. In many cases this guidance needs to be developed together with the other disciplines.

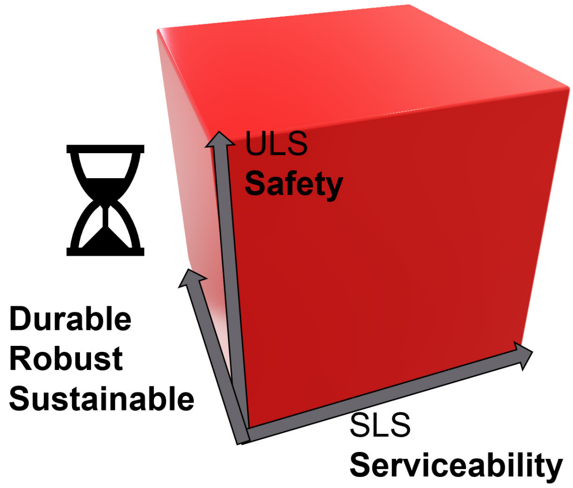

Figure 4. The cube illustrates the requirements that a society imposes on the geotechnical structure, that it be safe, functional, durable, robust and sustainable.

4.2. Eurocode as a common tool for all civil engineering

Eurocode has been developed to facilitate communication and cooperation within the building process. Therefore, all civil engineers have the same basis of design, EN 1990. In the second generation of Eurocode that is soon to be developed there is a minor change to the title of EN 1990, the specific words – and geotechnical – has been added. The question arises whether this is an editorial change or poses a major challenge. In a paper presented by Van Seters et al. 2021 [2], four main contrasts between structural engineers and geotechnical engineers are identified. The four contrasts can be summarised as follows.

Contrast 1: structural engineers know the specification for design including the material properties. Geotechnical engineers also have the specification for design in mind but must assume also ground properties based on a limited amount of data.

Contrast 2: structural engineers can select the appropriate material and dimensions to be delivered to the building site. Geotechnical engineers have to work with the available ground and minimize the uncertainty in the properties and handle any remaining uncertainty in the design.

Contrast 3: structural engineers calculate and offer calculation models that have been developed and proved for different materials and design situations. The geotechnical engineer calculates a models rele-

Contrast	Clarifications and additions in EN 1997
Know vs. assume	Ground model, nominal value
Select vs. minimize uncertainty	Geotechnical reliability, geotechnical complexity class, geotechnical category
Calculation vs. engineering judgement	Validation of calculation model, four verification methods (calculation, prescriptive rules, observational method, testing)
Build vs. adapt	Inspection, monitoring and maintenance plan, impact within the zone of influence

Table 1. Summary of additions to EN1997 due to the contrasts between structural and geotechnical engineers.

vance and its applicability has to be proven for each design. Engineering judgement is in this case key for the geotechnical engineer to select relevant calculation models or other tools for verification of the structure.

Contrast 4: the structural engineer will prepare an execution specification that will be used on site to build the structure. Supervision is performed to ensure that the specification is followed. For the geotechnical engineer the execution is the first time the hidden secret of the ground is revealed. In addition to the execution specification, there is a need for inspection and monitoring, including a plan for adapting to what is actually found at the building site.

A more extensive description of these contrasts is found in [2]. The conclusion is that it is a challenge to provide the same base for structural and geotechnical engineers. Therefore, clarifications and additions has been made in EN1997, to facilitate the applicability of Eurocode for geotechnical engineering. This is done without contradicting EN 1990 and hence keeps the common base between structural and geotechnical engineers. In Table 1 a summary of some of the clarifications and additions are presented.

4.3. Eurocode as a common basis for communication

As geotechnical engineers our focus may be soil, rock, groundwater, or engineering geology. All of us are supposed to use Eurocode 7 as a base for the design of a geotechnical structure. That is a challenge but also an opportunity. In the same way there are large differences in geology and national practice between countries in north, south, east, and west Europe. That is also a challenge but also an opportunity for development if we share our experience and identify differences during our collaboration.

In a more transnational working environment Eurocode creates a common basis for communication, enhancing shared understandings and vocabulary. However, in order to avoid potential conflicting views in projects, it is important to remember that the implementation and understanding of Eurocode might still involve some subtle differences across countries.

5. Conclusions

The conclusion of this paper can be summarized in two statements. Engineering skills must ensure that the geotechnical structure is inside the RED CUBE. Eurocode will assist with the tools to prove compliance with basic requirements on safety, serviceability, durability, robustness, and sustainability.

It is necessary to be always ready to think outside the box or beyond orthodoxies so that that there is no inhibition or limit to a professional capacity to contribute to a sustainable future and come to terms with, and master a new working environment!

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