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

doi: 10.32075/17ECSMGE-2019-0938

To perform geotechnical investigations in an (close to) inaccessible terrain

Effectuer des investigations géotechniques sur un terrain (presque) inaccessible

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ABSTRACT: What to do when a geotechnical investigation is almost impossible to perform due to inaccessible terrain? This challenge, in a project in SE Sweden, made us identify three options to consider when deciding the investigation approach in an inaccessible terrain: 1) Investigate as much as possible, wherever possible, with as many methods a possible, without carrying out any special assessments to enable accessibility; 2) Do as little geotechnical investigations as possible and 3) Accept extra costs to provide accessibility.

The three options face different challenges. For the first option low frequency of drilling, costly investigations due to struggle in rough terrain, uncertain information to contractors and surprises during construction are the most obvious risks.

In the second option the client is willing to put all risks on the contractor, which lowers costs during the design phase but hardly yields a calculable building phase.

The third option, i.e. to enable specified quantity of geotechnical drillings, at almost any cost, is initially expensive but empowers high certainty of investigation results, good correlation and interpretation between different methods, identification of risks prior to construction phase and stringent contractor tenders.

The above questions do not have a definite answer. This paper aims at pointing out that an open-minded discussion between the client and the geotechnical consultant in an early investigation stage is needed. The general requirement of keeping all costs to the lowest possible level is not always the best way to get the best solution and the over-all most economic investment.

RÉSUMÉ: Que faire lorsqu'une enquête géotechnique est presque impossible à réaliser en raison d'un terrain inaccessible? Ce défi, dans le cadre d'un projet dans le sud-est de la Suède, nous a amené à identifier trois options à prendre en compte lors du choix de l'approche d'investigation sur un terrain inaccessible: 1) Investiguer autant que possible, avec le plus grand nombre de méthodes possible, sans effectuer aucune tâche spéciale pour permettre l'accessibilité; 2) Faites le moins d' enquêtes géotechniques que possible et 3) Acceptez les coûts supplémentaires pour assurer l'accessibilité.

Les trois options sont confrontées à des défis différents, à savoir la première option: faible fréquence de forage, enquêtes coûteuses en raison de la difficulté des terrains rugueux, information incertaine des contractants et des surprises pendent la construction sont les risques les plus évidents.

Dans la deuxième option, le client est disposé à mettre tous les risques sur l'entrepreneur, ce qui réduit les coûts au cours de la phase de conception, mais ne donne pas une phase de construction calculable.

La troisième option, c'est-à-dire permettre des forages géotechniques en quantités déterminées, à presque tous les coûts, est coûteuse au départ, mais offre une grande certitude quant aux résultats d'investigation, une bonne corrélation et interprétation entre différentes méthodes, une identification des risques antérieur à la construction et des appels d'offres serrés.

Les questions ci-dessus n'ont pas de réponse définitive. Ce document vise à souligner qu'une discussion ouverte entre le client et le consultant en géotechnique est nécessaire au début d'une enquête. L'obligation générale de maintenir tous les coûts au niveau le plus bas possible n'est pas toujours le meilleur moyen d'obtenir la meilleure solution et l'investissement le plus économique.

Keywords: Geotechnical investigation; inaccessible terrain; investment costs

1 INTRODUCTION

Geotechnical investigations are usually required to be performed prior to the implementation of various types of facilities, such as roads, building, railroads etc. The question is to what cost should a geotechnical investigation be performed, and what uncertainties of the results can be accepted? How do we know that a more expensive geotechnical investigation, due to e.g. inaccessible terrain, in the end, nevertheless pays off by providing specifications for the contractor? And how important are cooperation between client and consultants when answering these questions during an ongoing project?

A geotechnical investigation constitutes ca 0,1 to 1 % of the entire construction cost. Generally, the bigger the project the smaller relative cost for the geotechnical investigation. During the construction phase, extra costs due to geotechnical surprises are overrepresented. Would more thorough and expensive geotechnical investigations provide less surprises during construction and lower total costs?

In the following text we try to provide an example of how a higher investigation cost can possibly lower the total cost.

2 BACKGROUND

In an inaccessible terrain in Blekinge, SE Sweden a 7 km long stretch of a partly new, partly rebuilt, road is planned. The new road passes through 4 km of untouched terrain (Figure 1), and the remaining 3 km is widening of the existing road .

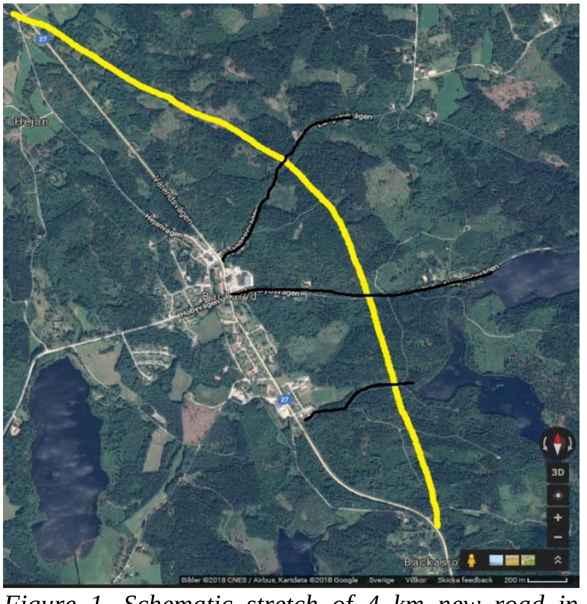

Figure 1. Schematic stretch of 4 km new road in yellow. Crossing main roads and accessible gravel roads in black.

The location of the new road is dependent on several factors, such as nature conservation protection, water protection, geology, road design requirements etc. In this context, the geological aspects are of relatively little significance, as challenges arising from geology most often can be taken care of. However, unexpected bedrock or deep peat areas often cause large extra costs during the construction.

3 GEOLOGICAL SETTING

Blekinge in SE Sweden has a hilly landscape originated in old tectonic events along with younger recurring inland ice sheets with intermediate warmer periods. Hills may be 200 m high and the depth of the soil can vary greatly, both on hills and in valleys, from a thin, ca 20 cm, soil cover to several 10's of meters. Till, sand and peat are found in the valleys whereas till typically covers the hills. The till, in turn, varies from sand till to large-scale and/or boulder-rich till with various percentage of sand, silt and clay. See Figure 2 for a schematic geological setting.

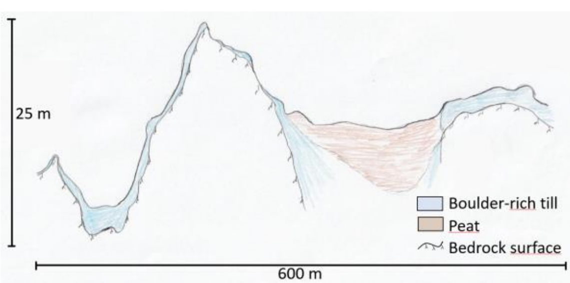

Figure 2. Schematic illustration of geological setting in the area of investigation.

The bedrock in the area consists mainly of partly fractured granitic gneiss, which in its upper part has been chemically and mechanically weathered.

For the presented project, the overall geological setting along the 4 km new road stretch in untouched terrain caused major challenges for the traditional geotechnical investigations. Access to the investigation areas consisted in most cases of machine unloading 200-300 m from the actual investigation points, which were reached at best in tracks of forestry machines but more often through completely unbroken terrain. The traditional geotechnical drilling rigs are not built to reach this type of terrain. Steep hills, boulders, dense forests and deep peat areas makes it more or less impossible to reach an investigation point with a drill rig and thus difficult to meet the requirements for maximum distance between points of investigation, which is set to 20-40 m in this type of project.

4 ACTIVE DESIGN

At the start of the project, client and consultant performed a field inventory along the entire new road stretch. The hilly terrain with several occurrences of peat areas was found to be unusually difficult to access. To get as much information about geology as possible, a holistic approach was required for the forthcoming investigations and an active design was set up to in detail describe the possibility of investigations at different localities. The active design was successively extended to include more investigation methods than the initial investigation program, which basically only included traditional geotechnical probing and sounding methods. Below the active design of the continuous investigations is presented.

4.1 Surface mapping

The initial surface mapping aimed to find access roads to unload equipment as close to the investigation points as possible; study accessibility between individual investigation point; investigate significant bedrock outcrops; investigate the extent of peat areas and their presumed bearing capacity; and get a sufficiently detailed view of the area to provide support for field personnel throughout the entire investigation process.

The surface mapping resulted in two major changes; 1) moving the planned road sideways to avoid a deep peat area and 2) defining other investigation methods with better accessibility to the investigation area.

4.2 Geophysics

Geophysical methods can be used in most terrains.

Geo-radar (GPR) is a method that includes a sledge-like antenna device (Figure 3). Here the method was initiated to be used on till-covered steep slopes, in dense forest and in peat areas. Unfortunately, the equipment failed to slide on the surface due to the presence of large boulders which occasionally led to results that were delicate to interpret.

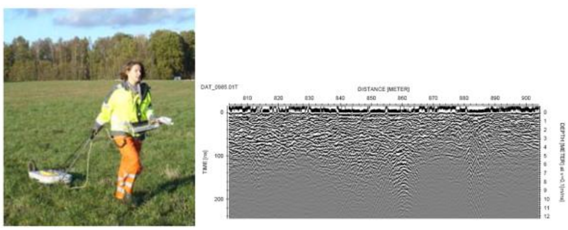

Figure 3. Left: Geo-radar (GPR) measurements. Right: Resulting radargram.

Due to the partially failed GPR surveys, the investigation in the most boulder-rich terrain was complemented with the Electrical Resistivity Tomography (ERT). However, it showed that the area was so full of boulders that there was hardly any soil between the boulders. Therefore, the electrodes used in the ERT method could not get in good enough contact and results where again difficult to interpret. Figure 4 illustrates a result from an ERT survey.

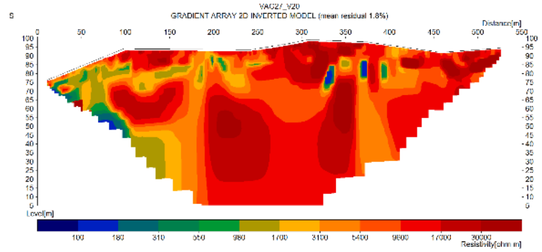

Figure 4. Illustrated resistivity survey (ERT).

4.3 Traditional geotechnical methods

Results from geophysical surveys should preferably be verified by geotechnical investigations. Hence, the GPR and ERT surveys were extended to areas that could be examined by the drill rigs.

As already pointed out, the geotechnical investigations had to be carried out wherever possible, rather than with the distance demanded in standards. The urge of getting more information about bedrock level and bedrock quality than the accessibility allowed rendered new discussions between client and consultant. A main issue for the contractor was about mass balance. To get an idea of the mass balance within the project it was critical to find the upper level of the bedrock as well as the bedrock quality.

The results from the surface mapping, the geophysical methods and the geotechnical drillings were interpreted together with bedrock maps to render a possible model of where for example fault- and/or fracture zones could be expected. A new investigation program was put together where investigation pits and core drilling were suggested to enables studies of the bedrock.

4.4 Investigation pits

The investigation pits were performed with an excavator in accessible areas, i.e. in the flatter parts of the investigation area and along existing roads. The bedrock surface was found in several of the pits and it could be determined that the upper 0,5-1 m of the bedrock often was weathered and/or fractured.

4.5 Core drillings and a Provisional road

Four core drillings were to be performed and two of them needed to be carried out in one of the most inaccessible area. After new discussions between client and consultant it was understood that a short provisional road was required. The provisional road would enable not only core drillings to be performed but also a few more geotechnical drillings, which was highly wished for. The provisional construction through the rough terrain showed to be a challenge itself but after being designed for the dumpers that provided crushed rock the provisional road was finally in place.

200 meters of provisional road enabled 2 core drillings and 5 traditional geotechnical drillings, still with challenges to get the drill rigs out to the investigation points since the provisional road was up to 20 m away from the point of investigation.

4.6 Surface mapping and light sounding

The four core drillings were displayed over ca 1500 m and there were still inaccessible areas where the bedrock level was unknown.

Another main question was to know how deep and widespread peat areas were, and what peat strength and deformation properties could be assumed.

After all attempts to carry out traditional field investigations it was finally understood that the only way to get any valuable information about the remaining areas was by foot. Mapping of bedrock outcrops, to a very detailed level, together with light sounding in the peat areas, were suggested as the only possible remaining investigation methods.

During the first surface mapping significant bedrock outcrops had been mapped, however, smaller outcrops remained to be determined, which was difficult in the boulder-rich soil. The method to determine actual bedrock outcrops was to measure strike and dip of rock surfaces. If strike and dip correlated between different small outcrops within a defined area they were assumed to be bedrock outcrops. If the strike and dip varied it was rather assumed to be a boulder.

The use of the hand-held light sounding in the peat areas was a successful method of investigating inaccessible peat areas. To avoid slumping, with risk of drowning, some of the inner peat areas were only reached after a temporary footbridge had been put out.

When the detailed bedrock outcrop mapping and light sounding were accomplished, knowledge of the examined terrains' nature was so good that it was possible to point out a few peat areas that could be investigated with GPR to get an even better understanding of the bottom surface of the peat. However, to verify the peat strength and its deformation characteristics samples needed to be taken. As the strength in many cases had shown to be low, from walking in the areas, a geotechnical drill rig was not an option for taking peat samples. Instead a Russian corer, which is a handheld utility, was used for the sampling, which allowed good peat samples.

5 RESULTS

The different surface mapping rounds, the use of handheld equipment and having one person that was involved in all investigations by foot, and hence had a detailed understanding of the area, enabled refinement of the investigation program and thus refinement of the interpretations. The outcome from the different methods are presented in Table 1.

Table 1. Results from different investigation methods.

Investigation methods	**Achieved results**	**Draw-backs**	**Upsides**
Initial surface mapping	Detection of access roads. Identification of inaccessible areas. Knowledge of the investigation area.		Knowledge of area and its accessibility.
Geo-radar (GPR)	Indication of bedrock upper level and fracture zones. Peat depth.	Positioning problems due to the terrain and dense forest. Boulder rich areas not measurable. Bedrock indistinguishable from boulder-rich till.	Quick method Some results even from areas hard to access.
Resistivity (ERT)	Indication of bedrock upper level and fracture zones.	Difficult to interpret data due to contact problems between electrodes.	Data even from areas hard to access.
Geotechnical investigations	Geotechnical investigations resulted in good data that could be interpreted in a regular way.	Inaccessibility in rough areas. Even hard albeit the provisional road. 8-wheeler would be needed.	Well known methods. Verifying geophysical methods.
Investigation pits	Identification of soil layers, water content and determining of bedrock upper level. Weathering and fracturing of rock was also indicated.	Could only be performed in accessible areas.	Detailed perception of 3D variations in soil and bedrock.
Core drillings	Core logging indicated bedrock quality and fracture zones.	Expensive. Difficult to get out to the exact investigation points albeit the provisional road.	Detailed and visible information of bedrock quality.
Bedrock outcrop mapping	Detailed interpretation of bedrock occurrence under a thin soil layer.	Outcrops could be mistaken as boulders. Deep bedrock knowledge is needed.	Detailed knowledge of the area.
Light sounding	Delimitation of peat areas and their depth.	Loose peat areas should be entered with great caution, and never alone, to avoid drowning.	Light equipment, accurate measurements and great accessibility.
Russian corer	Sampling of peat areas.	Heavy equipment if carried for long distances.	Accurate sampling and great accessibility.

The results from the different methods were co-interpreted with specialists from respective method and despite the inaccessible terrain, the results from the various methods lead to the possibility to model the bedrock surface as well as the bottom of the peat areas with unusually high resolution. Whereas a traditional triangulation model, that only draws straight lines between investigation points, a refined 3D model could be defined by the detailed knowledge of the area. A good example of engineering geology.

6 WHAT HAPPENS NOW?

The refined 3D model will be delivered along with the tender documents to the contractor. This is uncommon in a design and build contract, where usually no interpretation of results, from the design phase, are delivered. However, the uncommon methods of investigation in this project risk that contractors interpret data differently and deliver tenders with incomparable prices. To avoid speculations, the 3D model will be offered to the contractors.

7 DISCUSSION

This article describes how geotechnical-, geological-, and rock engineering investigations were carried out within a specific area for a design and build contract. The performed investigation program differs from the original investigation program, especially regarding methods and progression of the investigations. Every deviation from the original investigation program led to discussions between consultant and client. Other methods than originally calculated for and excessive costs due to the harsh terrain was thoroughly discussed and not always agreed on in terms of importance and/or economic compensation.

As in most projects the time frame was critical during the design phase. However, after the design phase, the project has been delayed, partly because it has been dropped in the client’s priority order.

8 REMAINING QUESTIONS

How much should an area be investigated prior to design and build contract? In Sweden, a public client is always required to choose the cheapest tender for which the stipulated requirements are met. Therefore, there is a risk that the consultant who has the best knowledge of a, for example difficult terrain, will offer the highest price and thus not get the contract, although this price may show to be the most correct at the end of the design phase. With a correct pricing in the beginning many frustrating discussions could be avoided during the project. Furthermore, the consultant does not get payed for the tender work but is required to have a thorough understanding of the assignment, which may be a difficult combination in a project like the one described.

There is no absolute answer to the above dilemma. In a perfect world, a client and a consultant agree on investigation progress and required arrangements. The consultant should get payed for performed work and the client should get the results and information needed to assign a contractor.

The basic line for a design and build contract is that the client should describe the conditions for the contractor so that construction costs can be estimated. In a design and build contract the contractor is responsible for technical solutions. If conditions, for example geotechnical basis, are not clearly described, the contractor needs to set the price on assumptions, which will lead to large variations of tenders between different contractors and most likely extra costs during the building phase due to unexpected conditions. This is a risk that both the client and the contractor are aware of, which explains the importance of well described conditions.

Before the start of the design phase the risks are much the same, but in this case, it is between the client and the consultant and the price tag is much lower than during the construction phase, which should facilitate a better agreement between client and consultant. As mentioned in the introduction, a geotechnical investigation constitutes ca 0,1 to 1 % of the entire construction cost. If elevated costs due to unexpected geological conditions are to be regulated during the construction, it will certainly constitute a higher percentage of the total construction cost than a more detailed initial geotechnical investigation would.

Although agreements were met in most cases between the client and consultant in the above described projects many of the challenges along the design phase were intensely discussed. And as previously mentioned the consultant was not always payed for the performed work.

8.1 Recommendations

Since this project has not yet been finalized it is not possible to say exactly how the project should have been run. For the client it must be an advantage if a project can be well calculated both by a consultant for the design phase and by a contractor for the building phase. On this basis there are some recommendations:

I. The client needs to understand the challenges a consultant may encounter and describe these challenges, so that tenders can be compared. If the consultant instead is to understand and describe the challenges it is important that the best described tender has a chance of winning the design phase contract and not only the cheapest tender. In cases with assumed difficult terrain, the client should be able to specify that some hours or days of the tender work are to be paid for to enable the consultant to get a proper idea of the challenge. However, according to Swedish regulations the client is not allowed to make such a demand.

II. If the client has good understanding of a projects inaccessibility it may be an advantage that the client specifies that they are prepared to pay for certain expenses, like a provisional road, to enable accessibility. However, it can be discussed to what extent enabling means are allowed during the design phase.

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III. In the above described project, it may have been easier for all parties if the execution of investigations was transmitted to the contractor. The consultant could have been contracted only for a desk-study. The price for a desk-study would have been minimal. However, the assignment with the contractor would risk being expensive and lead to variations in tenders from the contractors.

IV. In some projects involvement of contractor already during the design phase may be a good way of running an efficient workplan. However, in the above described project it is unclear what advantages an early contractor involvement would have yielded. Possibly could a few questions regarding for example bedrock quality be met differently.

Apart from what needs to be included/excluded from respective contract the refinement of modelling is a question that needs to be pointed out. The refinement of the model in this project would not have been possible without the detailed mapping of bedrock outcrop, the surveys with handheld equipment and people with detailed knowledge of the area involved.

A way of further refinement of a model is to include uncertainties from every method, such that every single point included in a model is accompanied with relevance. Including uncertainties in a 3D model is an ongoing study that will further improve the model relevance.

9 ACKNOWLEDGMENT

I want to thank Anders Dahlberg and Mats Svensson for valuable comments on the article. I also want to acknowledge all brave people who have been involved in the above described project, during the design phase. We did more than anybody ever could have asked for.