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Hegramo quick clay area – stability analysis and stabilisation work

Zone argileuse sensible Hegramo - analyse de la stabilité et stabilisation

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ABSTRACT: Rambøll was early 2013 requested by the municipality of Stjørdal, Norway, to perform a geotechnical soil investigation for potential sites for a new primary school in Hegra. Initially three sites were of interest, but the preferred site is situated near/into the foot of an approximately 30 meters high slope, partly with a complex terrain, and a well-established residential area, mainly single houses, on top of it. The initial field investigations indicated that the ground conditions on the site itself was suitable for the structure, however the quaternary geological mapping indicated marine sediment depositions in this area, and thereby a possible risk of quick and sensitive clay as part of these deposits. Supplementary filed investigations confirmed the presens of quick clay in the slope, possessing a potential hazard to the site of interest.

There has been some building activity near the site in the past decades. At that time, the hazard posed by potential landslides initiated outside the building site was not assessed. Today new guidelines developed by NVE and the geotechnical community are well established in Norwegian geotechnical practice. The further works therefore focused on the possible hazard these slopes represented.

Initially the slopes close to the site was investigated, and supplementary results indicated large volumes of quick clay extending to adjoining areas, resulting in further mapping and finally registration of a large quick clay area at Hegramo. The initial stability analysis for these slopes indicated a factor of safety close to 1,0, which is not unexpected for such natural slopes, created by historical erosion and landslide activity. It was obvious that mitigation measures were necessary to allow for a new school to be built at the site of interest. However, the necessary stabilization works was partly in conflict with some of the houses in the residential area on top of the slope. Some of the houses had to be demolished to allow the work to be fulfilled.

The work resulted in a new and fully studied quick clay zone/area.

RÉSUMÉ: Rambøll a été sollicité au en 2013 par la municipalité de Stjørdal, en Norvège, pour mener une étude géotechnique afin de trouver des sites pour une nouvelle école primaire à Hegra. Au départ, trois sites présentaient un intérêt, mais le site préféré est situé au pied d'une pente d'environ 30 mètres de haut, en partie avec un terrain complexe, et surplombé d'une zone résidentielle bien établie, principalement composée de maisons individuelles. Les études initiales sur le terrain ont indiqué que le sol sur le site lui-même est adapté à la structure. Cependant, la cartographie géologique quaternaire indiquait des dépôts de sédiments marins dans cette zone, et donc un

risque possible d'argile sensibles dans ces dépôts. Des études de sol supplémentaires ont confirmé la présence d'argile sensible dans la pente, présentant un aléa pour le site d'intérêt.

Des travaux de construction ont eu lieu près du site au cours des dernières décennies. L‘aléa et le risque posé par des glissements de terrain à l'extérieur du chantier de construction n'ont pas été évalués à l‘époque de ces travaux. De nos jours, les nouvelles directives élaborées par NVE et la communauté géotechnique sont bien établies dans la pratique géotechnique norvégienne. Les études géotechniques pour la nouvelle école se sont donc concentrés sur l‘étude du danger que ces pentes représentent.

Initialement, les pentes proches du site ont été étudiées et les résultats supplémentaires ont indiqué de grands volumes d'argile sensible s'étendant aux zones voisines du terrain d‘étude. Ceci a conduit à une étude plus avancée de la délimitation de la zone d‘argile sensible et finalement à l'enregistrement d'une grande zone d'argile sensible à Hegramo. L'analyse initiale de la stabilité de ces pentes a révélé un facteur de sécurité près de 1,0, ce qui n'est pas surprenant pour ces pentes naturelles, créées par l'érosion historique et les glissements de terrain. Il était donc évident que des mesures de mitigation étaient nécessaires pour permettre la construction d'une nouvelle école sur le site d'intérêt. Cependant, les travaux de stabilisation nécessaires étaient en partie en conflit avec certaines des maisons de la zone résidentielle située en haut de la pente. Certaines des maisons ont dû être démolies pour que le travail puisse être accompli.

Les travaux ont abouti à une étude complète de la zone d’argile sensible nouvellement découverte.

Keywords: Quick clay, Slope stability, Stability analysis, Stabilisation works

Figure 1. Location of Hegra, Stjørdal

1 INTRODUCTION

Rambøll was early 2013 requested by the municipality of Stjørdal, Norway, to perform a geotechnical soil investigation for potential sites for a new primary school in Hegra. Initially three sites were of interest, but the preferred site is situated near/into the foot of an approximately 30 meters high slope, partly with a complex terrain, and a well-established residential area, mainly single houses, on top of it. The initial field investigations indicated that the ground conditions on the site itself was suitable for the structure, however the quaternary geological mapping indicated marine sediment depositions in this area, and thereby a possible risk of quick and sensitive clay as part of these deposits.

Supplementary filed investigations confirmed the presens of quick clay in the slope, possessing

a potential hazard to the site of interest. There has been some building activity near the site in the past decades. At that time, the hazard posed by potential landslides initiated outside the building site was not assessed. Today new guidelines developed by NVE and the geotechnical community are well established in Norwegian geotechnical practice. The further works therefore focused on the possible hazard these slopes represented.

Initially the slopes close to the site was investigated, and supplementary results indicated large volumes of quick clay extending to adjoining areas, resulting in further mapping and finally registration of a large quick clay area at Hegramo. The initial stability analysis for these slopes indicated a factor of safety close to 1,0, which is not unexpected for such natural slopes, created by historical erosion and landslide activity. It was obvious that mitigation measures were necessary to allow for a new school to be built at the site of interest. However, the necessary stabilization works was partly in conflict with some of the houses in the residential area on top of the slope. Some of the houses had to be demolished to allow the work to be fulfilled.

2 CASE

The municipality of Stjørdal is looking for a new site for relocating the primary school in Hegra. Rambøll is asked to do the necessary geotechnical work to determine the ground condition on the site of interest and other geotechnical aspects of relevance. Location of Hegra is shown in figure 1.

3 SITE DESCRIPTION

The most suitable location for a new primary school in Hegra is situated near/into the foot of an approximately 30 meters high and steep slope. The slope is complex with a well-established residential area at the top. Hereafter this slope is referred to as slope A. In the early 1980's soil investigations for quick clay hazard zones was carried out in Stjørdal and Hegra. Boreholes in the area form these investigations are shown in figure 2 (NGI 1988).

By coincidence none of these boreholes showed traces of quick clay, only non- sensitive clay and friction masses. As Figure 1 shows, they are all placed outside what later turned out to be an extensive area where quick clay is a dominating soil deposit.

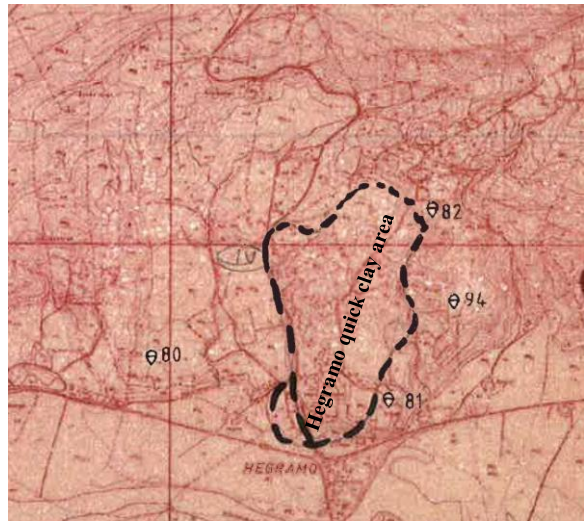

Figure 2. Boreholes carried out in Hegramo in relations with the national mapping of quick clays in Norway (NGI 1988)

When planning the preliminary soil investigations for the new primary school, the focus was to determine the soil conditions on the site of interest. Supplementary soil investigation was carried out to determine whether the more elevated surrounding areas and nearby slopes contained quick clay that could represent risk and could cause possible hazard. The area lies below the marine limit and quaternary geological maps shows marine sediment (ref. www.ngu.no).

Earlier soil investigations in relations with earlier building activity near the site, shows indications of quick clay in some nearby boreholes. The geotechnical design for these buildings was however made prior to the launch of the NVE's guidelines for building activity in quick clay areas in

2008. At that time, it was in general not widely focused on possible hazard of extensive landslide that could represent risk to a building site. However, when planning the preliminary soil investigations and the geotechnical design for the new location of the primary school in 2013, the guidelines were well established in geotechnical practice, and the focus was therefor set on the possible risk these slopes may represent. It was therefore kept in mind when planning the new soil investigations for 2 alternative sites as shown in figure 3.

Figure 3. Borehole pattern for the preliminary soil investigations (Rambøll 2013)

4 SOIL CONDITIONS

The preliminary soil investigations indicated that the ground conditions on the site itself was suitable for the structure and that there was no quick clay on the site itself (ref. fig.4). However, the results from one borehole situated on top of slope A, borehole 5, indicated possible quick clay in the ground. This was further investigated by sampling, laboratory testing and analysis that confirmed the suspicion. The suitability of the site was therefore uncertain, and a need for further soil investigations as basis for more detailed stability analysis and evaluations arose.

Supplementary soil investigations were planned and executed, and its extent was continuously adjusted according to the registrations obtained. The results showed that slope A contained large volumes of highly sensitive quick clay.

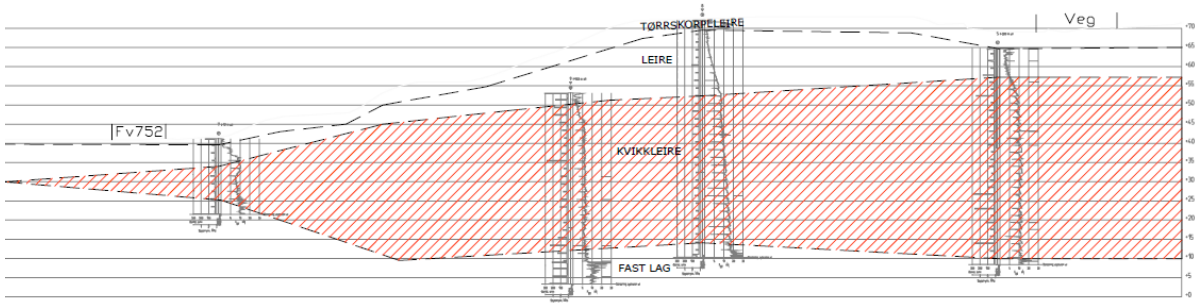

Figure 4. The most critical slope near the site (Slope A). The new primary school is planned to the left in the figure. Hatching shows the thickness of the quick clay.

5 STABILITY ANALYSIS AND RESULTS

Based on the results from the soil investigations and studies of detailed topographical maps, the most critical slope of relevance to the site (slope A) was identified, and preliminary stability calculations were carried out.

The results of undrained calculations indicated that the factor of safety for slope A was slightly above or equal to 1,0. That is, the state of the slope is close to labile. Drained calculations showed satisfying safety factor, indicating that the safety of the slope at its natural condition is acceptable. However, the low factor of safety obtained in the undrained analysis indicates that even small changes in slope geometry, caused by human actions or natural processes such as erosion, may lead to a disastrous landslide event.

Because of these findings the extent of the investigations and the stability analysis were expanded. The NVE financially supported the necessary works to map the total extent of the quick clay deposit and determine the factor of safety for several slopes of relevance.

Fig. 5. The total extent of the quick clay area and the slopes analysed concerning level of safety.

A full mapping of the area with necessary surveying was initiated. The aim of these works was to determine the risk the quick clay may represent to its surroundings, not only for the new primary school, but also the established buildings, houses and infrastructure in Hegramo.

Further works also included analysis to determine the total extent of run-out from the two most critical slopes and the possible debris flow directions based on empirical data and studies of topography in the area downstream the critical slopes.

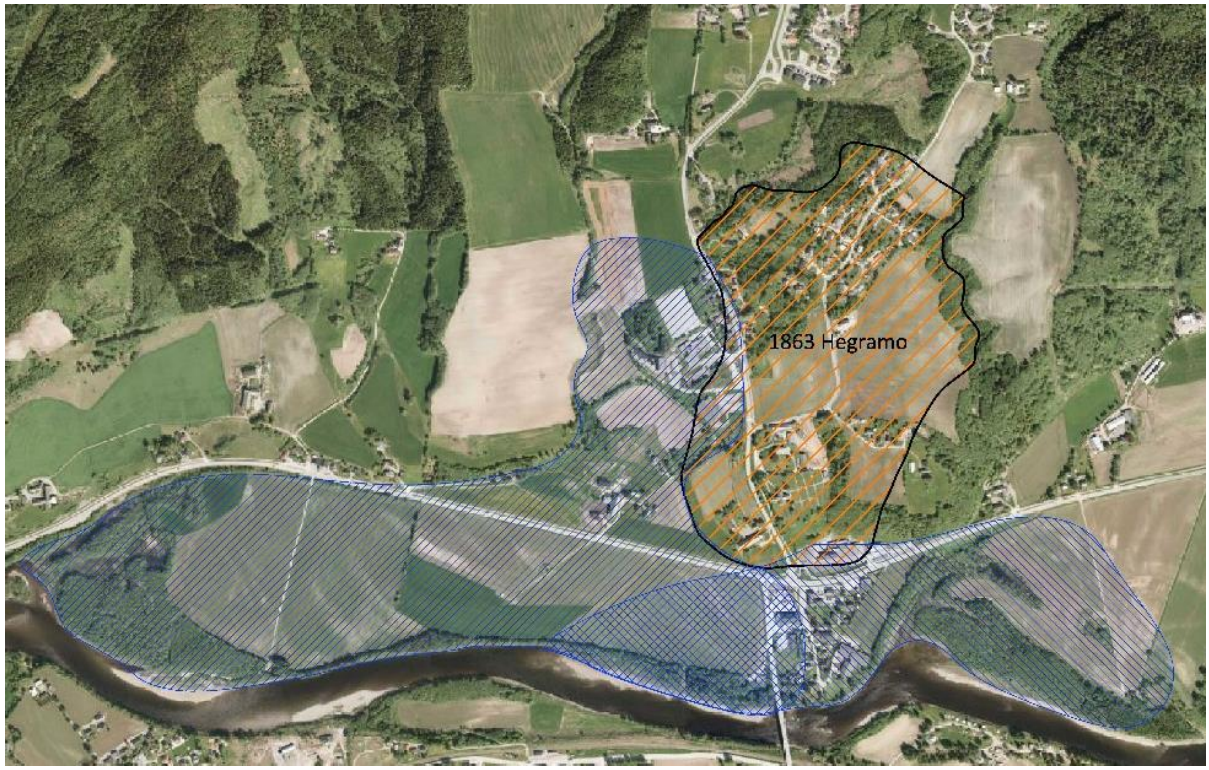

Figure. 6. The total extent of the quick clay area and areas were debris from the two most critical slopes might represent risk.

6 STABILISATION WORKS

According to the NVE guidelines (NVE 2014), the factors of safety for several slopes in the Hegra quick clay zone are insufficient and mitigation work is therefore necessary. This includes not only the new primary school, but all areas in direct contact with the quick clay deposits that may be part of a possible landslide, and areas in the run-out zone. The following design criteria was used as a design basis (NVE 2014):

a) $F \geq 1.4$, or
b) Substantial improvement if $F < 1.4$

Since the factor of safety is less than 1,4 criteria b) was relevant and an improvement of the stability up to approximately 15 % had to be achieved.

Further analysis was then concentrated on the design of necessary stabilisation works.

As a result of the widening of the area of investigations and stability analysis it was discovered that the slope north of today's primary school in Hegra, hereafter referred to as slope B, also had a factor of safety close to 1,0. As the school was in desperate need for more building area to cope with the populations growth, it was necessary to build a temporary pavilion before the autumn of 2015. However, due to the low factor of safety obtained for the critical slope, the risk of landslides was unacceptably high, and it

was necessary to do stabilization works before any permission was given from the local authorities.

As there was a cultural heritage located on top of slope B, it was only possible to stabilise the slope by introducing a counter filling. However, the calculations showed that the existing buildings was located so close to the foot of the slope that it was not enough space for the required amount of counter fill. It was therefore decided that a limited stabilization of the slope with a reduced volume of the counter fill could be enough for a temporary stabilisation of the slope. A detailed design was carried out during the spring of 2015, and the necessary descriptions of the work was prepared as basis for a tender.

A local entrepreneur was contracted, and he fulfilled the work in parallel to the construction of the supplementary school buildings during the summer of 2015. The new temporary buildings where ready for start of the fall semester of 2015. Later, a full stabilisation of the slope must be carried out to allow for new permanent residential buildings or similar buildings on the old school site, when the school is moved to its future location.

In autumn 2016, the focus is to do the necessary stabilizations works to prepare for a relocation of the primary school. The factor of safety for slope A must be increased to an acceptable level. Several possible ways of increasing the factor of safety have been discussed, however it is concluded that the most reasonable and efficient method to achieve the required factor of safety is by reducing the height of the slope. This either by levelling down the top of the slope, or by introducing a counter filling at its foot. The use of mass stabilisation is not widely investigated for this project, but traditionally it is found to be expensive, and to achieve the necessary effect, the extent of the mass stabilisation must involve a large volume of quick clay. Additionally, in established residential areas, the necessary area for such work is rarely available. Mass stabilisation was therefore excluded as an opportunity early in this process.

In this case, a counter filling will conflict with a local road located close to the foot of slope A as well as several private properties and houses. An excavation on top of the slope will conflict with private properties and houses. In an overall assessment, it was concluded that the levelling down of the slope would be the least inconvenient and most efficient solution. The extent of the top of slope A is relatively small compared to its foot and the effect of lowering it down will be more beneficial and involve less mass transportation than a counter filling. In addition, less private houses and properties are involved and, a local elevation of the road close to the foot of the slope would cause repercussions involving a need for adjusting the road several 100 metres away from the counter filling area.

Preliminary calculations showed that at least two private properties would be affected by the excavation. As a basis for more detailed calculations some supplementary soil investigation were carried out locally (reference). New, detailed calculations also involved profiles that was not calculated before to allow for more detailed specifications of the excavation. The calculations lead to a revised detailed design, and the solution now only affected one private property.

However, three houses on this property must be demolished, all of them being residential buildings. As a part of this process it was discussed and investigated whether it could be possible to save the buildings by temporary moving them while the excavation is carried out. This approach was found to be very expensive and the risk of causing severe injury to the buildings could not be excluded. It was decided to demolish the buildings and replace them when the necessary excavation is finished.

Another result from the detailed design was that a counter filling was introduced locally on a farmland near the foot of the slope, and a minor, local hill had to be levelled down.

Now the final solution was designed and Rambøll was requested by the municipality of Stjørdal to perform the detailed specification and drawings as a basis for a tender description. As

well as the geotechnical design Rambøll performed landscape architecture, design of water and wastewater systems and environmental surveys in connection with the demolition of the buildings. The stabilisation work was fulfilled during autumn/spring 2016/2017.

7 CONCLUSIONS

Often evaluations regarding mitigation works and what method to use, shows that traditional mass transportation, either by excavating the soil to lower the height of a slope, establishing a counter filling at its foot, or maybe even both in a combined solution, turns out to be the most inexpensive and least comprehensive choice. Methods involving reinforcement of the soil to improve its strength and increase the factor of safety, turns out to be more expensive and more comprehensive, and even may cause need for construction works of the same extent as traditional mass transportation. Today, there are some research being done on these topics, to find more appropriate alternatives that does not cause the need for such extensive construction works. It will be interesting to follow these works and to see its results.

8 ACKNOWLEDGEMENTS

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