An attempt towards harmonizing the Norwegian guidelines related to construction on sensitive clay

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ABSTRACT

Parts of the Norwegian road and railway network have been constructed on sensitive clays. Several new projects are facing challenges in areas with deposits of sensitive clay. The design codes and guidelines of the Norwegian Public Roads Administration (NPRA) and the Norwegian National Rail Administration (NNRA) have been developed over many years with respect to ground investigations and safety requirements. These regulations are specific for road and railway construction. In addition, there are general design codes such as Norwegian Standards and the regulations established by the Norwegian Water Resources and Energy Directorate (NVE) concerning the safety of larger areas adjacent to e.g. roads and railways. The differences in these regulations can lead to challenges during the planning of new projects, as well as in maintenance of existing roads and railways. The multi-disciplinary research project entitled "Natural Hazards" (NIFS) is a joint enterprise involving the NNRA, NPRA and NVE. This project attempts to harmonize the regulations of those three government bodies. Some specific topics were selected: definition and safety factor of local and overall stability, detection of sensitive clays using various sounding techniques, run-out distance and anisotropy. This paper addresses these topics in light of field results and numerical calculations.

Keywords: Sensitive clays, regulations, local and overall stability, landslide.

1 INTRODUCTION

In recent years, several quick clay landslides have occurred in Norway. Both natural events, like erosion, and human activity have been the causal factors, but it appears that the latter has been more frequent, at least in recent years. As discussed in the work of Oset et al. (2013), the most well known are the landslides in Verdal in 1893 (Janbu et al. 1993) and Rissa in 1979. Another well known, and more recent quick clay slide, the Skjeggestad slide, occurred on European route E18 near Mofjellbekken bridge in February 2015. Fortunately, no lives have been lost since 1996, but the socioeconomic consequences have been significant.

The three government agencies, the Norwegian Public Roads Administration (NPRA), the Norwegian National Rail Administration (NNRA) and the Norwegian Water Resources and Energy Directorate (NVE), each maintain their own regulatory framework, in which the appropriate design criteria for construction on sensitive clay deposits are addressed. These frameworks all meet the requirements set forth in national standards and Eurocode 7, but they differ in respect to i.e. the level of partial factors required for local stability and percentual improvement. Percentual improvement is allowed because the natural slope, in its current location, has a safety factor of at least 1.0. Any improvement of the safety factor is an actual improvement, and not encumbered with uncertainty in the chosen strength parameters, which would be the case when using an absolute material factor (NVE, 2014).

The NPRA, NNRA and NVE have initiated a national R&D project called "Natural Hazards", abbreviated NIFS (NIFS, 2012). Challenges associated with sensitive clays is one of the main topics for one of the NIFS subprojects (Subproject 6: Quick clay (SP6)). One of the main objectives for SP6 is to facilitate the development of regulatory frameworks (guidelines) suggested by the NIFS partners. This includes, but is not limited to, assessment of Norwegian landslide hazard mapping plans, definition and safety factors of local and overall stability, detection of sensitive clays using various sounding techniques, post-failure movements of landslides in terms of the retrogression and run-out distance, and anisotropy. By harmonizing the guidelines, regardless of who or where we build, will help achieve an equal practice in areas with sensitive clays. In the following, this paper will give a brief overview of the existing regulatory framework before presenting proposed changes in the guidelines of the NPRA, NNRA and NVE. The first part of this paper is taken directly from Oset et al. (2013) to provide the reader with an overview of the regulatory development in Norway.

2 HISTORICAL DEVELOPMENT OF REGULATIONS IN NORWAY

In the 1970s, limit state design was introduced in the Norwegian construction standards. There was a need for a corresponding set of design regulations for geotechnical aspects. A committee established by the Norwegian Geotechnical Society provided a guideline that was published by the Norwegian Standardisation authorities in 1979 (NS, 1979). In addition to earth pressure, bearing capacity, etc., this guideline also gave the first national set of regulations for the evaluation of stability of slopes and fills. The guideline established two principles regarding the partial safety related to soil strength. First, the partial safety related to effective stress analyses was differentiated with respect to damage consequence and failure mechanism, as shown in Table 1. The effective stress analyses are performed using the effective stress parameters; cohesion (c') and the frictional angle (ϕ'). Such analyses are performed to study the long-term (or drained) stability of slopes. In 1973, Janbu proposed to use the effective stress analyses along with an appropriate pore pressure profile to compute the short-term stability of natural slopes. However, during the years, total stress based undrained analyses to calculate short-term stability has been the most applied method. The undrained shear strength (c_u) is usually derived from confined triaxial tests. The principles in Table 1 have been adapted also for design based on undrained analyses.

Table 1 Partial safety factors for effective stress and total stress analyses according to Norwegian construction standards (Oset et al. (2013)).

Damage consequences	Failure mechanism		
	Dilatant	Perfectly plastic	Brittle and contractant*
Less serious	1.2	1.3	1.4
Serious	1.3	1.4	1.5
Very serious	1.4	1.5	1.6

**Sensitive clays exhibit brittle behaviour, i.e. strain softening behaviour.*

Secondly, the guideline stated that the established practice in some cases had been to take precautions that reduced the calculated mobilised shear stress along potential slip surfaces with 10–20%. This procedure for undrained total stress analyses was mainly handled as a contingency procedure for roads, railways and construction works until the introduction of the NVE regulations in 2008.

2.1 Regulatory framework by the Norwegian Public Roads Administration (NPRA)

The NPRA guidelines for geotechnical design in road construction was published in 1990, and they have been developed to the present sixth edition (NPRA, 2010). The principles in Table 2 have been maintained and adapted both for effective and total stress analyses. From the beginning, the main focus of the NPRA guidelines was safety requirements regarding local stability of construction works and slopes directly affecting the road. The stability of adjacent terrain was addressed when the stability was obviously poor, but there was no systematic requirement for the slopes not directly affected by the road construction works.

Table 2 Partial safety factors for effective stress and total stress analyses according to the NPRA guidelines (Oset et al. (2013)).

Damage consequences	Failure mechanism		
	Dilatant	Perfectly plastic	Brittle and contractant
Less serious	1.2/1.4*	1.3/1.4*	1.4
Serious	1.3/1.4*	1.4	1.5
Very serious	1.4	1.5	1.6

**The Norwegian national application of Eurocode 7 from 2008 requires γ_M > 1.4 for total stress analyses.*

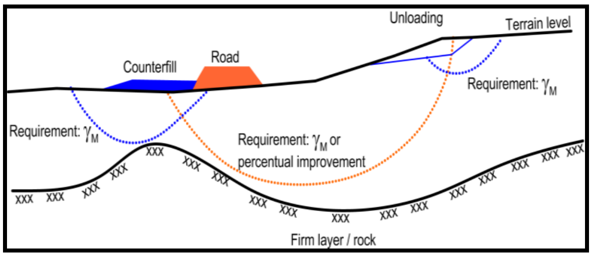

Figure 1 Principle regarding requirements with partial safety factor for local stability and partial safety factor or percentual improvement regarding larger progressive slides. Adopted from NPRA (2010).

In 2006, the possibility of percentual improvement was implemented in the NPRA regulations as a contingency procedure. The illustration in Fig. 1 was introduced in 2010 to clarify the use regarding the overall stability of larger areas. However, the local stability related to construction elements still needs to satisfy a partial safety factor as shown in Fig. 1.

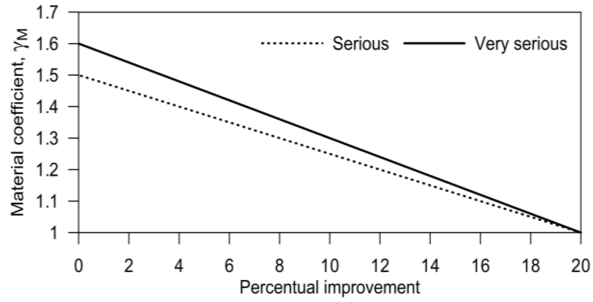

Figure 2 NPRA's recommendations concerning the percentual improvement of material coefficients regarding the overall stability of larger areas based on the consequence categories "serious" and "very serious". (Oset et al. (2013)).

2.2 Regulatory framework by the Norwegian National Rail Administration (NNRA)

The NNRA regulations (2013) for the design of railway structures are in a wiki-based framework, which is revised on a yearly basis. Safety requirements for railway construction activities are described with an absolute safety factor. For the railway embankments, the requirement in safety factor depends on the method of analysis used (drained or undrained), anisotropy, the consequence of failure and the failure mechanism. The required safety factor for railway embankments varies between 1.2 to 2.0 according to Table 3 and 4.

Table 3 Safety requirements for railway embankments analysed using drained parameters (c' and φ') and undrained (cu) parameters including anisotropic behaviour of soil (Oset et. al (2013)).

Damage consequences	Failure mechanism		
	Dilatant	Perfectly plastic	Brittle and contractant
Less serious	1.20	1.30	1.40
Serious	1.30	1.40	1.50
Very serious	1.40	1.50	1.60

Safety requirements for railway cuttings are normally met by using the framework restrictions for slope inclination for the different type of soils presented in Table 5. In the case of poor ground conditions, high cuttings or the possibility of erosion, a thorough study of slope stability has to be carried out. In that case, the safety factors according to Table 3 and 4 are required.

Table 4 Safety requirements for railway embankments analysed using undrained (cu) parameters without anisotropy factors (Oset et al. (2013)).

Damage consequences	Failure mechanism		
	Dilatant	Perfectly plastic	Brittle and contractant
Less serious	1.40	1.55	1.70
Serious	1.55	1.70	1.85
Very serious	1.70	1.85	2.00

Table 5 Maximum slope inclination for railway construction (Oset et al. (2013)).

Ground conditions	Stone rock	Gravel coarse sand	Fine sand/silt		Clay
			Dry	Layered, water dense	
Maxi inclina-tion	1:1.25	1:1.5	1:2	Special invest-igation	1:2

The presence of sensitive clay will lead to a stricter requirement for the safety factor according to Table 3. If the possibility of a progressive slide is present, safety for corresponding areas has to be investigated according to the NVE guidelines, as described in the following chapter.

2.3 Norwegian Water Resources and Energy Directorate (NVE) 2014

In 2008, the NVE published guidelines on how to assess landslide hazards in land use planning, with an emphasis on the level of zoning plans. From 2011, the guidelines were adopted as official guidelines for Norwegian regulations (NVE, 2008). The NVE revised the guidelines in 2014. The revision included a differentiation of the complexities of the planned projects and the inherent need to identify, limit and evaluate areas with quick clay. The guidelines enforce that the overall stability has to be taken into consideration in all projects in order to meet the requirements stated in section 28-1 in the Norwegian Planning and Building Act, defined in chapter 7 in the Technical Regulations (TEK10) (DiBK, 2011).

Before the guidelines were approved, geotechnical consultants and local authorities dealt with this issue at the construction stage, after the stage of zoning plans. This usually meant that overall stability was ignored in both the planning and construction stages.

The method for assessing overall stability for zoning plans can be described as a step-by-step procedure. This procedure has to be carried out by a professional geotechnical consultant, specialized in evaluating these kinds of overall stability problems.

The natural prerequisite is that the project is located under the marine limit. If this prerequisite is fulfilled, then the following steps must be carried out:

Step 1: Assessing the possibility of marine clay

This step includes a geotechnical evaluation of the terrain by using existing maps showing quaternary deposits. If these maps indicate that marine clay might be present within or adjacent to the area of the zoning plan, then the next step must be carried out.

Step 2: Evaluating the terrain

The geotechnical consultant has to evaluate if the terrain shows slopes or ravines with inclination or height differences sufficient to lead to progressive failures. If these criteria are considered to be present, then the next step must be carried out.

Step 3: Finding and evaluating existing ground investigations

This step could also be carried out together with Step 1, but it is here described as a separate exercise. The step implies that the geotechnical consultant gathers further knowledge about the presence of sensitive clay within and adjacent to the area of the actual zoning plan, gathers information about existing ground investigations, executed in accordance with other projects. Field and laboratory testing shall be performed if ground conditions are not known a-priori. Placement of boreholes must be adjusted to the actual topography. Execution of boring and laboratory testing must fulfil the requirements given in the guidelines and adjoining Norwegian standards for boring procedures (NGF, 2011). After analysing the existing ground conditions, the geotechnical consultant should evaluate if the distribution of marine clay found in Step 2 should be limited or extended, and in which levels below the ground surface marine clay could be found. The investigations might indicate whether the marine clay found can be characterized as brittle clay (defined as remoulded shear strength ≤ 2.0 kPa and Sensitivity ≥ 15 in the NVE presently valid guidelines).

Step 4: Limiting and classifying the area with potential danger

The natural boundaries for where initial slides can occur, and the area that may be affected by the development of the slide, have to be mapped. At present time, the run-out area has to be assessed by examining existing literature and/or using simple empirical values from Karlsrud et al. (1985). Together with NGI, NTNU and Multiconsult, the NIFS project is conducting a research activity on how the release area and run-out distance should be assessed. The recommendations from this activity will be incorporated in the next revision of the guidelines.

Step 5: Analysing stability and suggesting necessary preventive measures

This step includes calculations of overall and local stability, together with suggestions for preventive measures where deemed necessary to obtain a satisfactory level of safety. The NVE guidelines suggest a partial safety factor of minimum 1.4, or using percentual improvement of the initially calculated partial safety factor. The latter method implies that instead of reaching a partial safety factor of minimum 1.4, it is possible to improve the initial safety factor for every potentially critical slip surface through the zone up to a certain level. The percentual improvement required depends on the initially calculated safety factor, and the consequence category.

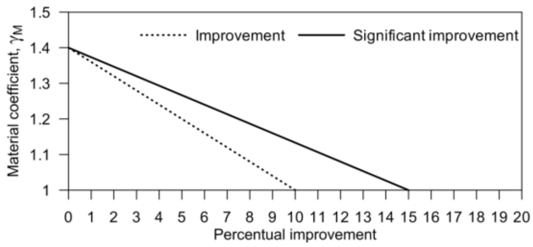

Figure 3 NVE's recommendations regarding the percentual improvement of material coefficients. "Improvement" or "significant improvement" is dependent on under which consequences category the project falls ((Oset et al. (2013)) and NVE (2014)).

It is important to state that percentual improvement can only be used by making geometrical changes (loading or unloading) in the surrounding area, or by using lightweight materials (Fig. 4). The stability calculations have to be performed as both drained and undrained analyses. The use of conventional calculation programs using limit equilibrium methods or finite element methods is allowed. The use of percentual method when calculating progressive landslides leads to the realization of more plans and projects, as it might reduce the cost of necessary preventive measures.

2.4 Eurocodes

The European Committee for Standardization (CEN) consists of members of the European countries. The committee has developed a set of design rules, which are to be used for the construction phase. These rules are to be unison for all countries participating in the committee. In 2008, the rules were officially adopted by the Norwegian authorities. Before the Eurocode came into use, Norway had its own set of national design rules for the construction phase. The Eurocode gives only a brief description of the fact that progressive failures have to be taken into account in the design. Table NA.A.4. in the Eurocode, presented in this paper as Table 6, indicates the use of an "absolute material factor" γ_M of minimum 1.25 on the friction angle and 1.4 for undrained shear strength. At the same time, the Norwegian National Annex allows for the use of percentual improvement, without any distinct requirements. Table NA.A.4. in Eurocode 7 suggests, *"material factor is increased beyond the values shown in the table at risk for progressive fracture development in brittle materials considered to be present and when it is required to bring it in line with recognized practice for the stability calculation and the present issue"*. The table further mentions "*by analysis of overall stability as conditions appear without measures one may find a lower initial material factor than mentioned in table NA.A.4 shall be assessed in relation to the landslide hazard and stability. It is usually assumed that the constructive measures are implemented in a manner that provides unchanged or increased material factor, and so that the factors which may trigger a failure or a landslide are avoided."* This corresponds with the principles of percentual improvement in the NVE regulations, but Eurocode 7 does not indicate how much increase in the material factor must be considered to account for the progressive failure mechanism.

Table 6 Partial factor for soil parameters

Soil parameters	Symbol	Values
Friction angle	$\gamma_{\varphi'}$	1.25
Effective cohesion	$\gamma_{c'}$	1.25
Undrained shear strength	γ_{cu}	1.4
Unconfined undrained strength	γ_{qu}	1.4
Unit weight	γ_{γ}	1.0

3 HARMONIZATION OF REGULATIONS

Research institutions and consultants, such as SINTEF, Multiconsult AS, the Norwegian Geotechnical Institute (NGI) and the Norwegian University of Science and Technology (NTNU), have been engaged to assist the SP6 with academic and industrial research. An important challenge for the NIFS project is to provide the basis for a harmonization of the safety regulations for the three governmental authorities. Some of the topics addressed are mentioned below:

3.1 Equality between partial safety factors and percentual improvement

This is a central issue in the harmonization of regulations, and it has been addressed in a report from SINTEF/Multiconsult (Tørum et al., 2012). Based on this report, a concept will be further investigated, in which local stability requirements are based on a partial safety factor, and the larger progressive slides may be prevented by either percentual improvement or partial safety factor requirements. The use of percentual improvement will probably be provided with a set of precautions, including requirements for the on-site control.

3.2 Definition of local and overall stability

Subproject Quick clay has proposed the following definitions and boundaries between local and overall stability. These definitions have been included in the NVE guidelines (NVE, 2014).

Local stability refers to a locally defined stability condition with the possibility of ground failure (slide). For development projects, triggering factors may be excavation/filling, base loading, piling, etc. In natural slopes, the triggering factors may be erosion or natural changes in pore pressure. The failure (slide) is limited to the area of influence of the stress changes, which are caused by the triggering factor, or that have risen in the slope due to natural changes. Typical examples are: local failure during filling or construction of a foundation (bearing capacity failure), local slide as a result of an excavation in a construction pit or in conjunction with road/railway construction (stability failure), or a local slide as a result of changes in pore pressure or erosion. Measures taken to safeguard against local stability failures must meet the requirements regarding absolute material factors, as described in the Norwegian national design rules (NS-EN 1997-1:2004+NA:2008). Any gradation of material factor beyond the specified minimum level is done in accordance with the client's guidelines.

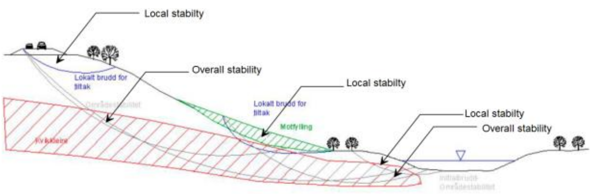

Figure 4 Local and overall stability (NIFS report 72-2012; www.naturfare.no).

Overall stability refers to a condition in which a local failure (see above) can initiate a comprehensive progressive forward or backward retrogressive slide in brittle materials, typically sensitive clay. The local failure can be initiated in both dilatant and brittle materials. In both cases, the local failure will influence and initiate a progressive failure of the brittle adjacent materials. If the brittle material has a greater extent and thickness outside the local influence area, larger areas can be affected and develop into slides. These slides can become quite extensive in areas where the remoulded brittle material has a free outlet in sloping terrain. The run-out distance of the slide will depend on downstream terrain gradient and local topography, the remoulded shear strength of the brittle material, and its thickness and volume above the release area. The level of safety for overall stability must be assessed in adjacent areas containing sensitive clays (Danger zones). The safety requirements are defined in TEK10, and specified in the NVE guidelines R2/2011.

3.3 Anisotropy

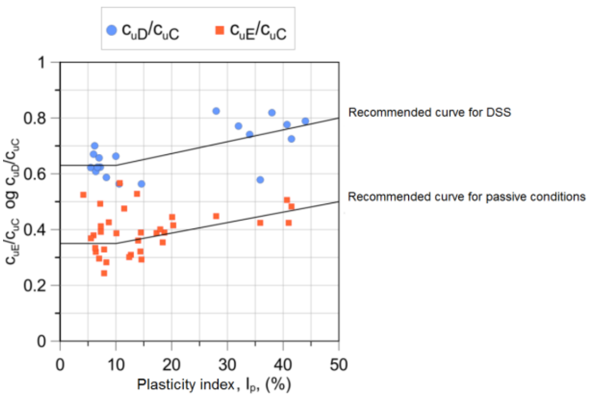

Figure 5 Recommended curves for anisotropy factors for design in Norwegian clays, correlated with plasticity index, Ip. (NIFS report 77-2014; www.naturfare.no).

The NIFS project is aiming for a standard in which the anisotropy conditions are evaluated from local conditions, and in which the use of empirical values is an exception. However, for less complex projects, empirical values can be considered adequate. As a result, during 2014, a working group comprising representatives from NGI, Multiconsult AS, SINTEF Byggforsk, NNRA, NPRA and NVE, drafted a report with a joint recommendation for the use of anisotropy factors for design in Norwegian clays (Thakur et al. 2014). The database for anisotropy related to plasticity index and other index parameters should be extended to provide a better base for the empirical relations. The report is freely available at www.naturfare.no.

3.4 Effect of strain softening

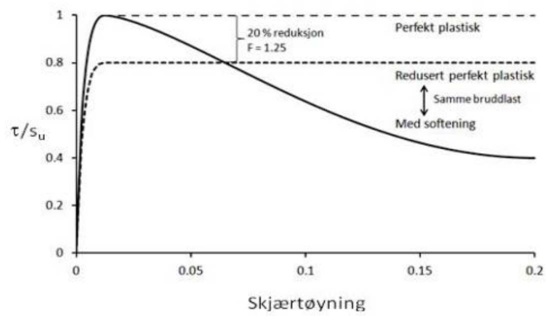

Figure 6 Effect of softening (Fornes et al. 2014).

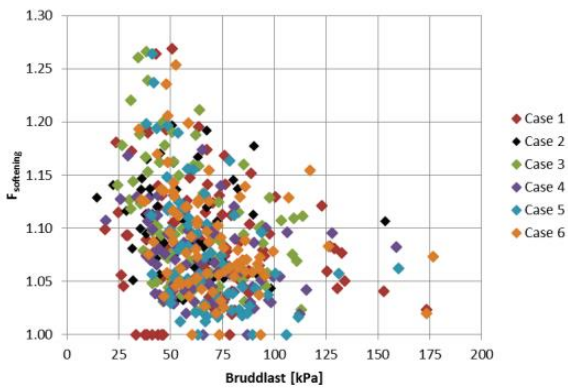

Figure 7 Correlation between softening factor and failure load for six cases with different combinations of parameters (Fornes et al. 2014).

Capacity or stability analyses performed using classical limit equilibrium theory-based calculation methods like the "method of slices" (Bishop and Morgenstern (1960) and Janbu (1973)), are based on the assumption that soil behaviour is "perfectly-plastic". However, for soft sensitive clays these classical theories have limited validity, because capacity or safety factors are overestimated if the effect of strain-softening is not accounted for in the analyses. The Norwegian code of practice suggests different material coefficients for construction activities on soft sensitive clay deposits. The guidelines by the NPRA suggest an increase in the required material coefficient from 1.4 to 1.5 or to 1.6 (about 7-14% increase) depending on the consequence category, to account for the effect of strain softening. The NVE guidelines for evaluating overall stability in areas with quick and sensitive clays suggest a material coefficient ≥1.4. The Norwegian National Annex to Eurocode 7 suggests an unspecific increase in the material coefficient from 1.4 to account for the effect of strain softening. Neither the NVE nor the Eurocode 7 guidelines are specific about an increase in the material coefficient to account for the strain softening. Using finite element calculations, Jostad et al. (2013) and Fornes et al. (2014) suggest that the capacity of Norwegian soft sensitive clays may be overestimated by an average of 6% if the effect of strain softening is neglected. From this study, it can be noted that the recommendation in the NPRA guidelines is suitable. However, further deliberations are necessary in order to find out how these results should be implemented.

3.5 Safety principles for assessing existing/natural slopes

The NIFS project initiated a workshop with participants from NTNU, NGI, Multiconsult, SINTEF and NIFS. The objective of the workshop was to establish criteria for when effective stress analyses can be used as a design basis for assessing the safety levels of natural/existing slopes. The main conclusions were that the effective stress analysis gives an accurate assessment of natural slopes, given the following circumstances: 1) The slope is in a stable and virtually stationary state, besides seasonal pore pressure variation and the impact of prolonged (extreme) precipitation. 2) The pore pressure distribution in the slope is examined thoroughly, and extreme values of pore pressure that may be critical for the slope are accounted for. Further, the effects of water-filled cracks is taken into account. 3) The effects of erosion, which could potentially lead to undrained stress changes, are attended to. 4) The robustness of the slope is satisfactory – in principle, this means that the factor of safety from an undrained analysis is above 1.2.

3.6 Post-failure movement of landslide and landslide potential in sensitive clays

According to the current practice in Norway, brittle clay is defined by a $S_t \geq 15$ and a $c_{ur} \leq$ 2.0 kPa. Thakur et al. (2012) initiated a discussion on the definition of brittle clay. This study shows that we need to understand the mechanical properties of sensitive clay better, not only numerically but also physically. Thakur et al. (2013) present a comprehensive overview of several parameters that may influence the extent of landslides, e.g. topography, stability number (Nc), remoulded shear strength (c_{ur}), liquidity index (I_L) and quickness (Q). The Norwegian landslide data as presented by Thakur and Degago (2012) and Thakur et al. (2013) support the fact that large landslides with retrogression greater than 100 metres are only possible when c_{ur} < 1,0 kPa or I_L >1,2 or Q> 15% and N_c > 4. These criteria are useful and can be used as indicators to assess the potential for occurrence of large landslides. However, determining the extent of a landslide with only an individual geotechnical parameter may not be sufficient.

A complete stress-strain behaviour of soft sensitive clays must be accounted for in the calculation of the post-failure movement of landslides. Thakur and Degago (2013) and Thakur et al. (2013 and 2015) suggest a concept of defining remoulding energy for Norwegian sensitive clays; see Figure 8.

Their work proposes determination of remoulding energy based on stress-strain relationship of sensitive clays obtained using field vane shear tests. Their work shows that a representative stress-strain behaviour of soft sensitive clays can be established using electric field vane shear method. They suggest that required remoulding energy provides a better basis for understanding the post-failure movements in terms of the retrogression and the run-out distance of landslides in sensitive clays. The finding is supported by the Canadian data.

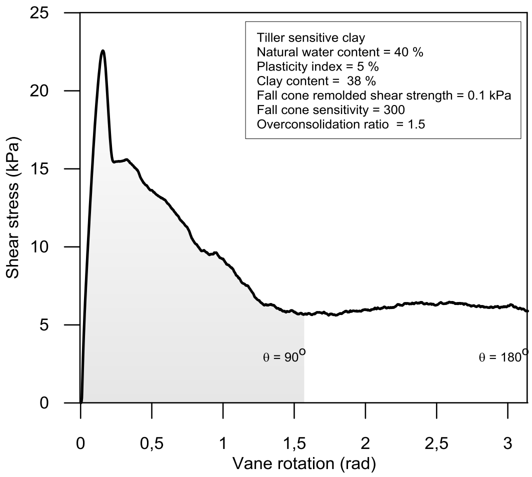

Figure 8. Shear stress vane rotation curve for the tested Tiller sensitive clay at 8.5 m depth (Thakur et al. 2015). The area covered by the stress-strain curve refers to the remoulding energy.

4 CLOSING REMARKS

By taking steps to harmonize the guidelines related to construction on sensitive clays, the NIFS project and its partners have initiated a process that will yield socioeconomic positive results. In addition, a harmonized regulatory framework will enable both private and public builders to realize both more complex and less complex projects that would previously have been rejected because of regulatory contradictions, without compromising on safety. The NIFS project represents a broad collaboration between universities and private and public sectors. This collaboration has ensured a consensual understanding and interpretation of both the safety philosophy regarding sensitive clays in Norway, as well as the physical and theoretical behaviour of brittle materials. This knowledge, and common understanding, is paramount when it comes to developing new regulatory frameworks that will ensure the safety of everyone building or living on brittle or quick clay.

5 ACKNOWLEDGEMENTS

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