State of the Art: Geotechnical Analyses

Analysis tools for Geotechnical Engineering

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Summary (This will be published at our website ‘geofuture.no’)

One aim of the GeoFuture project is to advance the state-of-the-art (SoA) of design and analysis of geotechnical foundations through new developments of analysis methods. This report gives a review of SoA analysis methods for foundation design of building, construction and transportation and recommendations for what to develop within this project.

Some of the main advantages of using the Finite Element Method (FEM) in geotechnical analyses are as follows:

- All types of 3D geometries and complex soil layering can (in principle) be modelled
- Soil structure interaction (SSI) by inclusion of structural elements as beams, walls, shells, plates, struts, springs, piles, anchors, geogrids, etc.
- Interaction or coupling between pore water and soil skeleton (fully or partly saturated soil)
- Appropriate non-linear stress-strain relationships including strength limitations (local failure), pre-consolidation pressure, strain rate effects and initial stress condition
- History or phase dependent processes as stage construction of embankments and fills, excavations and installations of earth retaining structures, and changes in ground water level
- Time dependent processes such as pore pressure dissipation and creep
- Effects of geometry changes and large deformations by including special formulations for strains, mesh (geometry) updating schemes and contacts
- Dynamic analyses by including inertia forces, damping and special boundary conditions
- Capacity and slope stability (without estimation of predefined critical slip surfaces) by strength reduction methods
- Effects of progressive failure due to strain softening and material instability by including regularization techniques with internal length scales

In order to extend conventional geotechnical analyses to more advanced 3D analyses for more economical, reliable and optimal design, it is recommended to integrate a general purpose 3D finite element code into GeoSuite.

The main advantages of implementing a 3D FEM program into GeoSuite are:

- It makes it possible to have a fully integrated data flow management
- It is possible to make a user-friendly and robust 3D calculation kernel with input data that is familiar for Scandinavian geotechnical engineers and no (or limited) need for special knowledge about the Finite Element Method (a black box)
- It will be easier to extend and develop features according to the needs of Scandinavian geotechnical engineers
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Appendix A – Development of a robust and user friendly effective stress soil model for soft clays
1. Introduction

One aim of the GeoFuture project is to advance the state-of-the-art (SoA) of design and analysis of geotechnical foundations through new developments of analysis methods. This report gives a review of SoA analysis methods for foundation design of building, construction and transportation and recommendations for what to develop within this project.

2. Review

The Finite Element Method (FEM) is during the last 3 decades increasingly used in Norway for different aspects of geotechnical design. The main reason for this is first of all the access to user-friendly and relatively inexpensive finite element programs such as Plaxis (www.plaxis.no), ZSOIL (www.zace.com) and SIGMA/W (www.geo-slope.com). Another important reason is that students become familiar with the method in courses at NTNU as for instance “Finite Elements in Geotechnical Engineering”. In addition several Scandinavian geotechnical engineers have participated in the Plaxis course organized every second year at NTNU since 2004. Over the last 10 years it is a clear trend that some of the problems that previously were limited to 2D plan-strain or axisymmetric idealizations now are analysed by full 3D models. This has become feasible due to sufficiently fast PCs but also due to optimalizations in the numerical procedures. The use of 3D analyses will in several cases give more optimum, reliable and thus economical and safe solutions compared to the traditional methods and also compared to 2D FEA.

Examples of 3D finite element models of varying complexity are shown in after Chapter 5. These are taken from the Plaxis Bulletins (www.plaxis.nl), Plaxis Workshops, varying conferences within computational geomechanics, e.g. Numerical Methods in Geomechanics I to X (1982 to 2007), Numerical Methods in Geotechnical Engineering I to VII (1986 to 2010) and ComGeo I and II (2009 and 2011), journals as International Journal for Numerical and Analytical Methods in Geotechniques and Computer & Geotechniques. More details regarding the different analyses may be found in these references.

3. Finite Element Method

1.1. Historical background

The finite element method (FEM) is a numerical technique for finding approximate solutions of partial differential equations. Pioneering work in the early fifties described for instance in Zienkiewicz (1977) gave the theoretical framework of the method used today to numerically solve continua mechanical problems. In geotechnical engineering, the method is mainly used to solve the weak form of the stress equilibrium equations. However, it is also used to find steady-state and transient pore pressure and temperature distributions in the ground.

1.2. Advantages

Some of the main advantages of using FEM in geotechnical analyses are as follows:

- All types of 3D geometries and complex soil layering can (in principle) be modelled
- Soil structure interaction (SSI) by inclusion of structural elements as beams, walls, shells, plates, struts, springs, piles, anchors, geogrids, etc.
- Interaction or coupling between pore water and soil skeleton (fully or partly saturated soil)
- Appropriate non-linear stress-strain relationships including strength limitations (local failure), pre-consolidation pressure, strain rate effects and initial stress condition
- History or phase dependent processes as stage construction of embankments and fills, excavations and installations of earth retaining structures, and changes in ground water level
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1.3. Governing formulation

i. Simple example

To demonstrate the governing behavior of the Finite Element Method we may consider a very simple problem consisting of two serial coupled springs as shown in Figure 3.1. The first spring starts at a location (nodal point 1) with coordinate \( x_1 = 0 \), and ends at a location (nodal point 2) with coordinate \( x_2 = 1.0 \) m. The second spring starts at nodal point 2 and ends at location (nodal point 3) with coordinate \( x_3 = 2.0 \) m. The nodes can move in the x-direction. The displacements of these three nodes are defined by the variables (nodal point displacements) \( r_1, r_2 \) and \( r_3 \), respectively. The property of each spring is defined by the spring stiffnesses \( k_1 \) and \( k_2 \). The force \( F_1 \) in spring 1 is defined by the relative displacement \( r_2 - r_1 \), i.e. \( F_1 = k_1 (r_2 - r_1) \), and correspondingly, the force in the second spring 2 is defined by the relative displacement \( r_3 - r_2 \), i.e. \( F_2 = k_2 (r_3 - r_2) \). This means that the springs are loaded by stretching and compression. In this example we apply a load \( R_3 \) at node 3 and keep the first node fixed, \( r_1 = 0 \) (boundary condition).

**Figure 3.1** Simple 1D problem of two serial coupled springs

In order to find the displacement \( r_3 \) of node 3, we can set up the following equation:

\[
R_3 = F_2 = k_2 (r_3 - r_2)
\]

Since the two springs both are connected to node 2, the force in spring 1 must be equal to the force in spring 2, \( F_1 = F_2 \). However, since there is no applied external force in node 2, \( R_2 \) is zero. This can be expressed as follows:

\[
R_2 = F_1 - F_2 = k_1 r_2 - k_2 (r_3 - r_2) = 0
\]
The above equation system (two equations in this example) can also be expressed in a matrix form:

$$\begin{pmatrix} (k_1 + k_2) & -k_2 \\ -k_2 & k_2 \end{pmatrix} \begin{bmatrix} r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} 0 \\ R_3 \end{bmatrix}$$

This equation system is then solved in order to find the nodal displacements $r_2$ and $r_3$:

$$r_2 = k_2 r_3 / (k_1 + k_2)$$
$$r_3 = (R_3 + k_2 r_2) / k_2 = R_3 / k_2 + r_2 = R_3 / k_2 + R_3 / (k_2 + k_3) = R_3 / (k_2 + k_3)$$

For the special condition when $k_1 = k_2 = k$, we obtain:

$$r_2 = R_3 / k$$ and $$r_3 = r_2 + R_3 / k = 2r_2 = 2R_3 / k$$

For a system consisting of several coupled springs, we need to solve the following equation system:

$$K \, r = R$$

Where $K$ is a $(n \times n)$ stiffness matrix, where $n$ is the number of free nodes (number of degrees of freedom), $r$ is a vector of $n$ nodal point displacements, and $R$ is a vector of $n$ external nodal point loads (where most of the terms generally is zero). The above equation system is then solved numerically by some direct methods (Gaussian elimination methods) or iterative methods.

For a geotechnical problem such as for instance a 1D settlement problem, each spring (element) may be represented by a vertical column with a unit cross section of (1m x 1m) and thickness $h$. The property is defined by a secant oedometer modulus $M$ (material model). The “spring” stiffness is then calculated as:

$$k = \frac{M}{h}$$

The vertical strain (in this example assumed to be constant) within the sub-layer (element) is given as:

$$\epsilon = \frac{\Delta r}{h}$$

here $\Delta r$ is the difference in vertical displacement between the top and the bottom of the sub-layer. A linear variation/interpolation of the vertical displacement is assumed within the element in this example. However, higher order interpolation functions (more element nodes) may be used. The corresponding stress and internal force within the sub-layer are:

$$\sigma = M \epsilon$$ and $$F = \sigma A$$

Other more complex material models may however be used.

1.4. 2D/3D finite element formulation

The extension of the above 1D formulation to conventional 2D and 3D displacement based continuums formulation is described in several text books, e.g. Zienkiewicz (1977).

For the general 3D condition each node with coordinates $(x, y, z)$ has three displacement components $(r_x, r_y, r_z)$. 
The element types used to model the 3D soil volume are typically a 20-noded brick, a 15-noded wedge, 12-noded prism or a 10-noded tetrahedral, where the latter is most convenient for automatic mesh generation of complex geometries.

![Typical 3D continuum elements suitable to model soil volumes](image)

Each of the three displacement components \( r_x, r_y, r_z \) is then interpolated within each element based on the corresponding displacement components in the element nodes \( r_x, r_y, r_z \) and element dependent interpolation functions \( N \):

\[
\begin{align*}
  r_x &= N_x r_x \\
  r_y &= N_y r_y \\
  r_z &= N_z r_z
\end{align*}
\]

The conventional (small) strain vector \( \varepsilon \) are then obtained from the spatial derivatives of the shape functions and the nodal point displacement vector \( r \):

\[
\varepsilon = B r
\]

where \( B \) is a \((6 \times 3 \times \text{number of element nodes})\) matrix of spatial derivatives of the shape functions. The structure of \( B \) may be found in several suitable text books, e.g. Zienkiewicz (1977). The strain vector is calculated numerically in integration points.

A material model is then required in order to calculate the stresses \( \sigma \) from the strain vector.

1.5. Material models

The most challenging part of geotechnical FE-analyses is to properly describe the constitutive behaviour of the soil. The general stress-strain relationship of soil is highly non-linear, stress-path dependent/anisotropic, history dependent (depends on previous unloading and reloading phases), strain rate dependent, time dependent (creep), scale dependent, and contains numerical challenges such as tensile failure and material instability due to non-associated plastic flow and strain softening. Due to this complex behavior of the soil it is therefore important, in the formulation of stress-strain relationships, to account for at least the most important feature of the soil for the actual problem. There is not one unified stress-strain model for soil. Instead a huge amount of different material models with different features have been developed. Different models may therefore be used for...
calculation of displacements, capacity, soil-structure-interaction, undrained/drained behavior, etc. Within the GeoFuture project an effective stress based model for typical Scandinavian clays will be developed as part of a PhD study. Some background and recommendations for this model are given in Appendix A.

1.6. Finite Element Program

A finite element code (based on an implicit solution algorithm) generally consists of the following main modules:

1. Pre-processor (input of data)
2. Mesh generator (generates nodes, elements, element topology, materials, boundary conditions, loads, etc.)
3. Solution algorithms (incrementation and iteration schemes)
4. Equation solver(s)
5. Element assembly
6. Loads and boundary conditions
7. Element library (element types)
8. Material library (material models)
9. Post-processing (output of data)

1.7. Type of analyses

Finite element analyses of geotechnical problems are often divided into the following main types of analyses:

- Drained and undrained displacement analyses
- Settlements and time dependent consolidation analyses
- Capacity and stability analyses
- Soil structure interaction (SSI) analyses
- Dynamic and earthquake analyses
- Penetration (and large deformation) analyses
- Beam-spring analyses of piles, sheet piles and plates

More details regarding the different types of analyses could be included when required. So far the following types of analyses are described in more details:

1. 1D settlements and time dependent analyses using GeoSuite Settlement (Appendix B)
2. Analyses of excavations and retaining walls, which is a type of SSI analysis (Appendix C)
3. Earthquake analyses (Appendix D)

4. Recommendations

In order to extend conventional geotechnical analyses to more advanced 3D analyses for more economical, reliable and optimal design, it is recommended to integrate a general purpose 3D finite element code into GeoSuite.
1. The program must have a modular structure which makes it easy to modify, implement new features and easy to maintain. Typical modifications are implementation of new material models, element types, equation solvers, etc.

2. The program should in the future be able to be used in all existing GeoSuite calculation modules. However, it should first be available and tested in the GeoSuite Settlement module.

3. The program should be robust and simple to use. This means that the flexibility and user control must be limited. For more complex problems commercial programs as Plaxis (www.plaxis.nl) or ABAQUS must therefore still be used.

4. The input to the program should be the same data as used in the existing calculation kernels. However, some additional material parameters will be required. In addition the user should be able to input some few additional parameters for controlling the mesh density and model size.

5. In addition to the finite element code a robust general mesh generator and a user-friendly interface for post-processing are required.

6. To implement a general effective stress based constitutive model for soft clay. The development of this model will be part of a PhD study at NTNU financed by this project.

The main advantages of implementing a 3D FEM program into GeoSuite are:

- It makes it possible to have a fully integrated data flow management
- It is possible to make a user-friendly and robust 3D calculation kernel with input data that is familiar for Scandinavian geotechnical engineers and no (or limited) need for special knowledge about the Finite Element Method (a black box)
- It will be easier to extend and develop features according to the needs of Scandinavian geotechnical engineers

5. References

3D FEM modell of pile foundation

3D FEM model of SSI problem (detailed analyses of structural elements)
3D FEM model of a piled embankment for a bridge

3D FEM model of deep excavation in Monaco. Presentation by Alain Guilloux at European Plaxis Users Meeting in 2011. Stage construction and SSI problem
motivation for investigation:

influence of silos located close to a navigable canal

3D FEM model of stability problem (silos close to a canal). Presentation by Roland Schulze at Plaxis User Meeting 2011
State of the Art

Appendix A - Development of a robust and user friendly effective stress soil model for soft clays

Project responsible: Hans Petter Jostad (NGI)
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A1 Introduction

The subtask is to be carried out as a guided PhD study supervised by professor Steinar Nordal at NTNU and førsteamanuensis Gustav Grimstad at HIOA in close cooperation with professor Hans Petter Jostad at NGI and other partners in the project. The PhD position is financed by the GeoFuture project for 3 years and a PhD candidate is to be hired by summer 2012. The position is announced.

A2 Purpose

The purpose of this subtask under the GeoFuture project is to develop an effective stress soil models that can simulate the characteristic behaviour of soft clays. A significant portion of the challenges in geotechnical engineering practice in Scandinavia relates to the behaviour of such clays and appropriate models are essential for reliable analyses of bearing capacity, settlements of and displacements around foundations and embankments, deep excavations, soil-structure interaction in general as well as slope stability. Important aspects of clay behavior include time/rate dependency, anisotropy in strength and stiffness and structuration/destructuration. Hence, appropriate design of structures on natural clays demands proper understanding of the behavior as well as sufficiently good models that may simulate the important behavior natural clays.

The models used in design today ignore many of the important features of clay. This could lead to, in worst case, underestimation of deformations or unsafe design. The design could also end up being too conservative. The task described below aim for improved, safe and reliable designs based on sound soil investigations searching for realistic soil parameters to be used in sufficiently accurate soil models for high quality finite element (FE) modeling.

A3 Background

Many robust and well working soil models are developed and implemented in commercially available computer codes. Unfortunately, the current models do not reproduce the characteristic behavior of soft clays sufficiently well. A very good model is, however, now available for clays under purely undrained conditions, the NGI-ADP model, as implemented in for instance the computer code Plaxis (www.plaxis.nl). A key feature in this model is the anistropic strength. Since the model is based on total stresses it can only be applied to short term conditions and not to cases where the load action lasts long enough for partly or full drainage to occur. In such situations the strength and stiffness change. The proposed development aims to reproduce the features of the NGI-ADP model, for short term conditions, and extend to reproduce changes in strength and stiffness with drainage. This implies that a true effective stress formulation must be applied when developing the new model.

A3.1 Soil models

The soil models, which are used in continuum calculations, can be characterized in two categories, being total and effective stress based models. The formulation principle within these two groups may
also vary. A rough categorization of the formulations is into strain based or stress based formulations, e.g. hypoplasticity, elastoplasticity etc.

A3.2 Total stress approach
In some cases it is sufficient to assume undrained behavior. However, even in undrained conditions clay is anisotropic, rate dependent and has structural effects (like softening). We have today models, based on the total stresses, that can to some extend reproduce the anisotropy in undrained shear strength (e.g. NGI-ADP model [Grimstad et al., 2012] and NGI-ANI [Andresen and Jostad, 1999]). Total stress based models including strain softening has also been developed, e.g. NGI-ADPSof [Grimstad et al., 2010a] and [Jostad and Grimstad, 2011] which is a 3D model with regularization and the earlier version of the model, the plane strain NGI-ANISof model [Jostad and Andresen, 2002]. These types of models have some advantages and disadvantages. One advantage is that a design undrained strength profile may be used directly. One major limitation of this approach is for situations where undrained behavior is not valid. It is of course recognized that it is possible to update the undrained strength due to consolidation; however the deformations during this time and the redistribution of stresses (and then also correct update of undrained strength) will not be taken into account with such a procedure. The NGI-ADP model family does not, at this time, include rate dependency, which also might play a significant role in undrained situations. Further, the NGI-ADP model has certain limitations regarding unloading-reloading even though non-linear unloading-reloading may be performed in a cyclic version of the model.

A3.3 Effective stress approach
It is generally agreed that effective stress based models are fundamentally more correct than total stress models. The main advantage with effective stress based models is that the consequence of porepressure and effective stress changes is automatically taken into account. In principle an effective stress model is able to model every phase in a project without manually adjusting model parameters controlling strength and stiffness.

Figure 1  Typical undrained effective stress paths for Scandinavian clays (illustration from user meeting 2011, GeoSuite – presentation by NGI)
However, the problem is that soil is a complex material and an effective stress model requires use of highly advanced constitutive relationships in order to accurately reproduce soil behavior under various stress and strain paths. Natural soft marine clays are, as an example, anisotropic, time/rate dependent (creep and thixotropy) and it has different degrees of unstable structure (sensitivity). Models fully covering these features are not yet taken into use in geotechnical engineering practice, even though several advanced models exist at research level around the world (references can be found in e.g. Grimstad et al. [2010b]). The models used in design today ignore many of the important features. This represents a major shortcoming for utilizing the finite element method in today’s geotechnical practice in particular when faced with soft, sensitive clays.

The effective stress models that are currently used in FE analyses in Norway for clays are the simple Mohr Coulomb models, Cam Clay models, more specifically the Hardening Soil Model or the Soft Soil Model in Plaxis (www.plaxis.nl). One particular problem with the existing models is that they do not show sufficiently low undrained strength when realistic effective stress strength parameters are used for soft Scandinavian clays. The behavior is not sufficiently contractive. Further, the significant drop in stiffness observed when loading beyond the preconsolidation level, is not reproduced. Anistropic strength is not available to the extent that is experienced in laboratory tests. Even the more advanced soil models that do better in this respect (MIT-E3 [Whittle and Kavvadas, 1994], the S-CLAY1 family [Wheeler et al., 2003] or SANICLAY [Dafalias et al., 2006]) have not solved these questions to the level needed. Some models require too many input parameters to be used in practice and most of them are not sufficiently robust. As a consequence the increased complexity of these models does not lead to significantly improved predictions. This is why it is required to develop a robust, sufficiently accurate, tailored model for soft Scandinavian clays.

A3.4 Understanding soil behavior

A3.4.1 Anisotropy
Anisotropy in strength and stiffness is considered to be an important feature of clay behavior. As a result, disregarding anisotropy of soil behavior can lead to highly inaccurate predictions of soil response under loading. A common way to introduce anisotropy in plasticity is to adopt a single yield surface with rotational hardening. The extensive amount of possible formulations for anisotropy started with the model proposed by Sekiguchi and Ohta [1977]. They proposed a fixed yield surface without kinematic hardening as a rotated version of the yield surface used in the original Cam-Clay model. Later similar models that use a rotation of the modified Cam-Clay (MCC) model, or some sort of similar surface, have been proposed. Most of these models are based on classical elastoplasticity whereas some use bounding surface plasticity as introduced by Dafalias [1987]. A more extensive list of references related to modelling of anisotropy can be found in [Grimstad et al., 2010b]. Some of these will be used in the planned new model.

A3.4.2 Creep
Creep and/or rate dependency of the irrecoverable strain are recognized as another important aspect of clay behavior. It is established that creep is best modeled by giving a unique relationship between strain rate and material state [Degago et al., 2011], i.e. assuming that the material behavior is independent of how the state is achieved. Models that are developed for use in geotechnical FE calculation are based on this principle.
It is planned to base the current work on the principles of the time resistance concept developed by Janbu [1969]. Figure 2 gives an illustration of the time resistance concept. The resistance, $R$, is defined as increment in time divided by the increment in strain (Cause/Effect). As the figure shows, $R$ will normally increase with time, and for a remolded material this increase in $R$ can be approximated to be linear, given by a dimensionless creep number, $r_s$. The advantage of basing the planned development on this or a similar creep parameter is that the parameter is available from standard laboratory tests. An important objective of the planned research is to come up with a user friendly model that is governed by relatively few, well defined parameters.

### A3.4.3 Structure

Natural sedimentary clays exhibit mechanical characteristics that are different from their reconstituted equivalents [Leonards and Altschaeffl, 1964]. In the early times, sensitivity i.e. loss of strength that accompanied the disturbance of natural clays at constant water content was used to explain differences in mechanical characteristics. Such early procedures were adopted mainly because of the lack of techniques for direct observation of soil particles as well as our inability to get natural clays in a truly undisturbed state. Nonetheless, the classical sensitivity measure of a soil is unsatisfactory simplification to quantify the amount of soil structure.

Mechanical characteristics of major importance for both natural and reconstituted clays include fabric and interparticle forces [Mitchell and Soga, 2005]. The fabric of a soil refers to the arrangement of particles, particle groups, and pore spaces in soil. Burland [1990] defined the “structure” of a natural soil to consist of fabric and bonding. Accordingly, two soils can have the same fabric but different properties if the bounding between particles and particle groups are not the same. Fabric stability is sensitive to changes in stresses and chemical environment.

During straining, these bonds can be progressively destroyed by a process called “destruction” [Leroueil et al., 1979]. Burland [1990] showed that the same soil in undisturbed and in reconstituted state gives different response during compression, as can be seen in Figure 3. He also demonstrated the advantage of using the compressibility of the reconstituted clay as a framework for interpreting
the corresponding properties of undisturbed natural clays. Within the elastoplastic framework, Gens and Nova [1993] made the first approach to model the destructuration process by relating the compressibility of the undisturbed soil to that of the reconstituted soil. In recent years, a number of constitutive models incorporating bonding and destructuration have been proposed. References to literatures on modeling of destructuration can be found for e.g. in [Karstunen et al., 2005]. The various models differ in the precise form of the destructuration rule and in the form of the underlying reference model used for the unbounded material.

![Figure 3 Oedometer results on undisturbed and reconstituted Bothkennar clay](image)

**Figure 3** Oedometer results on undisturbed and reconstituted Bothkennar clay [4 i Grimstad et al 2010b]

### A4 Scope of work

The model to be developed in this subtask of the GeoFuture project shall be based on an effective stress formulation reproducing both the anisotropic undrained strength observed during short term loading as well as the strength observed for sustained long term load. This implies that the model must involve not only effective stress strength parameters, but also stress history parameters such as preconsolidation etc.

The model shall also incorporate small strain stiffness, rate dependent behaviour (creep and thixotropy) and cover the effect of structure, building up during creep under sustained loads, but breaking down the structure when loading close to or beyond the preconsolidation level. Reproducing the effect of loss of structure is essential for modeling stiffness of soft Scandinavian clays.

It is suggested to build the development on the soil existing soil model n-SAC developed by Gustav Grimstad by extending his PhD work from NTNU 2009 [Grimstad and Degago, 2010]. The n-SAC-model is an effective stress based advanced soil model well suited for the purpose. The model must, however, be further developed and refined in order to come up with a robust model needed for practical application. This will also involve work on procedures for determination of appropriate parameters based on conventional laboratory and/or field tests, utilizing the vast experience from soft clay behavior among the partners in this project. Numerical robustness and computational effectiveness will be in focus.
The work will be coordinated with numerical development within the EU FP7 people project Creep hosted by NTNU Geotechnical Division (professor Thomas Benz) and work on soil modeling for offshore wind turbine foundations now initiated at NTNU, Geotechnical Division (professor Gudmund Eiksund).

The delivery from the project will be a subroutine that can be used in various finite element programs. The developed soil model will be tested by simulating laboratory tests, comparing the model to other models (as for example: for undrained conditions to NGI-ADP) and to experience. Real case records will also be back calculated to evaluate the model. Practitioners will be brought into the process of developing a simple user interface and a procedure for parameter determination.

**A5 Final comments**

This work aims for a user friendly soil model for practical applications in finite element analyses in geotechnical design. The model shall contribute to more efficient, safe and cost effective designs by taking full advantage of the current knowledge of the behavior of soft Scandinavian clays as observed in the laboratory and in the field.

A list of references is included to illustrate contributions that will/may be used as a platform for the work to be performed.

**A6 References**


