GEOQuébec 2015
Challenges from North to South
Des défis du Nord au Sud

GEOSUITE - A MODULAR SOFTWARE FOR GEOTECHNICAL DESIGN

S. Lacasse, H. P. Jostad, J.-S. L'Heureux, O. Torgersrud
NGI, Oslo, Norway
R. Sandven
Multiconsult AS, Trondheim, Norway

ABSTRACT
Remarkable advances in geotechnical analysis tools have happened since the 90s. Yet, experience, judgment and quality control remain the key to reliable foundation design. Software is not the asset that differentiates among consultants any more. The competence and experience of the personnel and the appropriateness of the parameters and soil models in the analyses are the factors that give competitive edge. The geotechnical profession of Norway and Sweden entered an alliance to develop GeoSuite. The first version of the software was issued in 2006, followed by a second generation in 2015. A third generation is planned for 2019. The objective is to make design as simple as possible by providing 1D, 2D and 3D calculation and visualization tools, and providing user-assistance along the way. The paper describes the GeoSuite software, and its modules for stability, settlement, bearing capacity, pile and excavation calculations, as well as the Wizard for user assistance. Plans are made for add-ons with slope runout calculations, soil profile decisions and statistical analyses of soil parameters.

RÉSUMÉ
Le code GeoSuite, présentement en évolution en Norvège et Suède, permet de faire le calcul géotechnique des fondations avec option de calculs en une, deux ou trois dimensions. Le programme de recherche et développement compte trois objectifs principaux: 1) développement et implémentation du logiciel et modèle de comportement pour analyses en 3D, 2) présentation des données en 3D, et 3) devin d'assistance pour calculs. Le code est spécialement développé pour l'ingénieur en pratique afin de l'aider avec le dimensionnement des fondations. La première version fut lancée en 2006, une seconde en 2015. Une troisième génération est planifiée pour 2019. L'article décrit le système logiciel GeoSuite et ses modules pour l'analyse de la stabilité, des tassements, de la capacité portance, pieux et fouilles, et la fonction d'assistance à l'utilisateur Wizard. Des exemples de calcul sont présentés.

1 INTRODUCTION

Remarkable changes have happened in geotechnical engineering calculations since the 70s and 90s (Duncan 2013). Many changes are due to the revolution in computers and information technology, including the ability for very detailed evaluations and three-dimensional (3D) element analyses. Although the tools in use today are much more sophisticated than earlier, it is still engineering experience, judgment and thorough quality control that are the most important components of design.

As our profession moves forward into the 21st century, Duncan (2013), Wright (2013) and Finn and Wu (2013) recommended to always use more than one computer code when doing geotechnical calculations, to check "that you have not missed anything of importance". It is not the software used that differentiates between two consultants. The knowledge and experience of the personnel and the appropriateness of the specific soil models in the calculations make the difference between two consultants.

In 2002, the geotechnical profession of Norway and Sweden (consultants, research organizations, universities and government agencies) entered an alliance to develop a suite of programs for foundation design. The development work was funded by the Research Council of Norway and the alliance partners. The first version of GeoSuite was issued in 2006. A second generation of the GeoSuite software came in 2015. A third generation is planned for 2019.

The primary objective of GeoSuite is to provide the industry with methods and tools for one-, two- and three-dimensional calculations and visualization, integrating in the software geotechnical input data and their interpretation, calculations and the result interpretation in one package. The paper presents the GeoSuite system, describes the calculations and provides examples of the assistance provided to the user.

2 NEED FOR NEW INTEGRATED SOLUTIONS

Figure 1 illustrates schematically the evolution of civil engineering practice. Compared to earlier, solutions are moving towards 3D interactive models and Building Information Modeling (BIM), where different disciplines and work flows interact. The human relationships have also evolved as the engineers and scientists work less in isolation, but increasingly in collaborative, integrated teams.

Contractors, consultants, universities and public infrastructure organizations need a common and integrated 3D engineering model in their work. In a survey, geotechnical engineers also prioritised the need for help with the selection of input parameters and the need for a seamless integration of input data, analysis modules and results.

They wished means to model and represent realistic foundation geometries, illustrate and account for spatial extent and variability of geo-data, integrate geo-calculations and enable an "interactive" modelling of foundations. And yes, they felt that there were large uncertainties in even the simpler of analyses

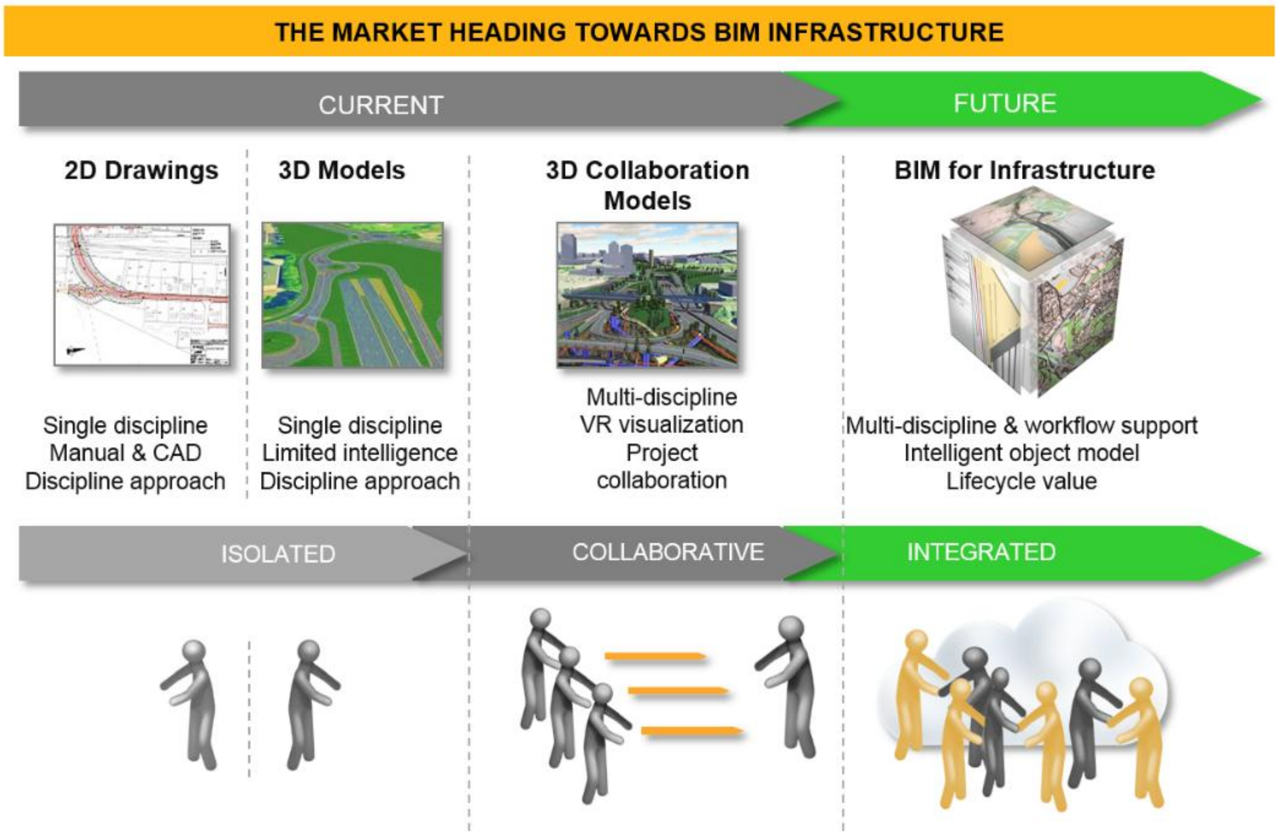

Figure 1. Evolution of civil engineering practice (*Vianova AS, P. McGloin, personal communication*)

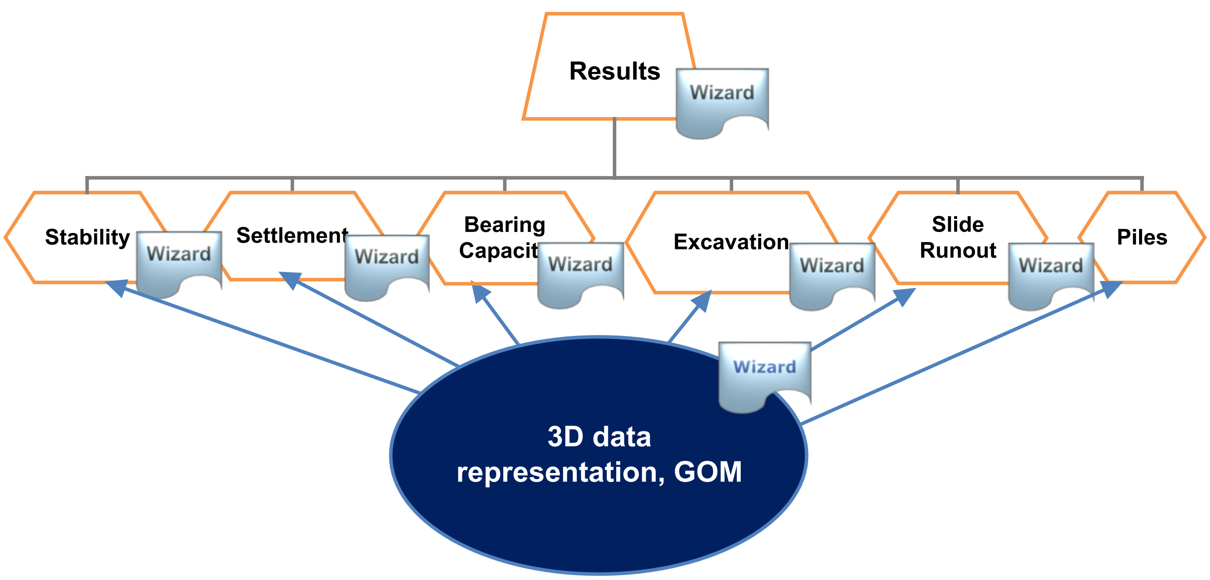

Figure 2. GeoSuite modules

3 GEOSUITE SOFTWARE

GeoSuite has a series of computer programs especially developed for a designer of geotechnical foundations, including stability, settlement, bearing capacity, pile and excavation calculations. In 2015-2016 calculations for slope run-out will be included.

The main objective of the software is to address everyday design situations, and to make the calculations simple for the user[1]. Figure 2 illustrates schematically the geotechnical components of the GeoSuite system. The key recent development features in recent years have been the integration of a 3D calculation engine, integrated input data and result presentation with possibilities of 1D, 2D and 3D visualization, series of assistance panels for the user for the selection of the soil parameters and the analysis and interpretation of the results.

The 3D data representation model (the ground observation model, GOM) is at the heart of the system and enables the user to build his model accounting for other installations already in the ground and integrating the measurements of soil properties, as available. User assistance (called 'Wizard' in Fig. 2) is provided to help establish the soil profiles for analysis. Each of the calculation modules had an input, calculation and results interpretation part, with a 'Wizard' (user assistance) available when desired by the user.

4 3D DATA REPRESENTATION MODEL

4.1 Open data model

The open data model manages the geotechnical data throughout its life cycle, for GeoSuite calculations and for use by other software/systems. The goal of an integrated open data model - geotechnical analyses, is to present in a digital terrain mode the input and results in three dimensions, including the different material layers.

Geotechnical properties and geological description in the building and construction and infrastructure sectors have gradually become a part of the Building Information Modelling (BIM[2]), and requires open standards, integrated and easy import and export of data between the BIM models and the processes governing several parties collaborating during design. The model in GeoSuite meets the requirements in ISO/TC211[3].

The open data model provides the geotechnical engineer with not only the data, the subsurface layers and the model used for the analysis, but also provide a visualization of the data and other implementations, such as roads, buildings, excavations and other structures/installations.

[1] http://www.-vianovasystems.no/Nedlasting/Novapoint-GeoSuite

[2] BIM (Building information modeling) involves the generation and management of digital representations of physical and functional characteristics as a function of location.

[3] ISO/TC 211 is a standard Technical Committee within ISO, covering the areas of digital geographic information, such as used by GIS and geomatics and preparing International Standards and Technical Specifications.

4.2 Ground Observation Model (GOM)

One of the key elements of the development was the creation of a ground observation model (GOM) directly from the open data model, and to have it act as an analysis tool for geotechnical design. A 3D cross-section of the open data model can then be selected and analysed.

The 3D data representation module (GOM) integrates seamlessly the information from geological, seismic and geotechnical *in situ* and laboratory investigations and creates a 3D graphical interface. The module creates a subsurface model for input in the geotechnical calculations. GeoSuite also aims at documenting who did what, the parameters used, and the history of the parameters and the analyses. The ground layers, represented in 3D, include all the attributes and parameters relevant for the geotechnical calculations and expertise provided by the Wizard for user assistance (Section 7).

Figures 3 and 4 give two examples of 3D representation: a 3D volume of soil to be analysed (Fig. 4), and the contours ("heat maps") of settlements in 3D (Fig. 4).

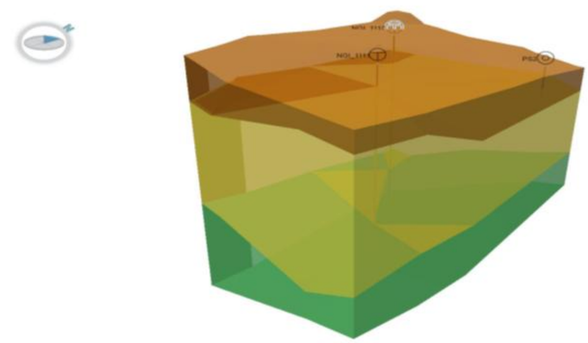

Figure 3. Example of generated 3D soil volume model

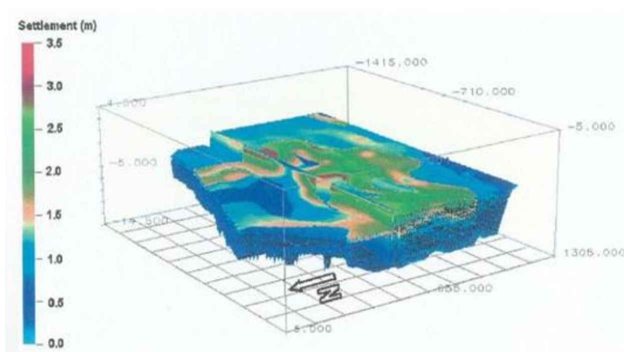

Figure 4. Example of calculated settlement in 3D model

5 SETTLEMENT MODULE

The new calculation engine developed at NGI (Jostad and Lacasse 2015) was used to check a simple case of settlement of an OC clay under a uniform load. Three software were used: Plaxis3D (www.plaxis.nl/plaxis3d) and Settle[3D] (www.rocscience.com/settle3D) and GeoSuite (denoted GS 1D and 3D). Figure 5 compares the results at the centerline and at the corner of the loading. The 3D settlement (initial and consolidation settlements) were significantly larger than the 1D settlements. The GeoSuite3D, Plaxis 3D and Settle^{3D} calculations in 3D agreed well.

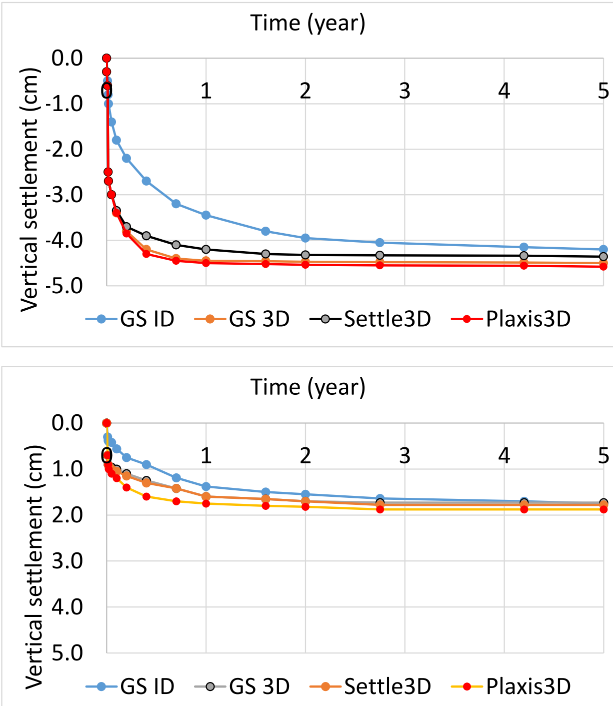

Figure 5. 1D and 3D consolidation settlements, OC clay, at centerline (upper diagram) and under corner (lower diagram) (S. Johanson NTNU, personal comm. June 2015).

6 STABILITY MODULE – 3D EFFECTS

The 3D effects were illustrated for an idealized case (Fig. 6). The effect of slope inclination was checked for inclinations 1:b with b=1, 2 and 3. The effect of the depth of the slip surface $d = D/H$ (i.e. depth to a strong soil layer or rock) was checked for d of 0 and 1, where D is the depth from the toe level to the bottom fixed boundary (or to a strong layer/bedrock). The effect of the width of the slide $w = W/H$ was checked for w of 1, 2, 4 and infinity. The mesh contained 1,392 20-noded brick elements.

The NGI-ADP constitutive model, a strain-hardening elasto-plastic total stress model with stress path dependent and anisotropic undrained shear strength (Grimstad and Jostad 2012), was used in the analyses. The input for this constitutive model are the spatial distribution of the undrained active shear strength $s_u^A(x,y,z)$ and the anisotropy strength ratios s_u^{DSS}/s_u^A and s_u^P/s_u^A [4], the corresponding shear strains at failure, γ_f^A, γ_f^{DSS} and γ_f^P, and the initial elastic shear modulus ratio, G_o/s_u^A. The factor of safety FS was calculated from:

$$FS = F_{3D} \cdot N_o \cdot s_u / \gamma H \qquad [1]$$

[4] s_u^A, s_u^{DSS}, s_u^P: s_u from triaxial compression, direct simple shear and triaxial extension tests

where F_{3D} is the 3D effect factor, N_o the stability number, s_u the isotropic average undrained shear strength, γ the total unit soil weight and H the height of the slope.

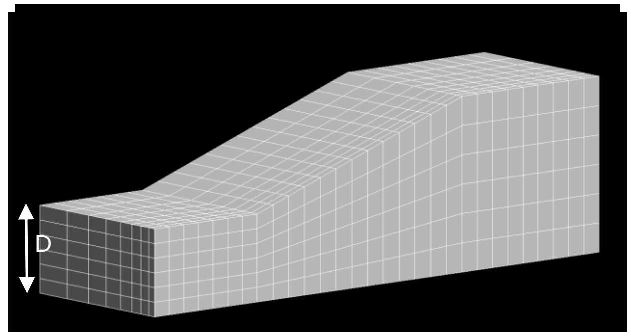

Figure 6. Finite element mesh for b=3, D=H and w=4 (inclination 1:b; slope height H; slope width W)

Failure was obtained by gradually increasing the total weight γ by a load factor p. For a total stress analyses, the FS is then equal to p. This gives the same result as an analysis with shear strength reduction, where the s_u is gradually reduced by a material factor γ_m until failure. Failure was defined when the continuing stiffness of the system became very small (see also Jostad and Lacasse 2015). At failure, the displacement increased significantly for an infinitesimal small increase in the load factor.

The 2D limit equilibrium analyses and 3D finite element analyses gave similar displacement contours at the centreline. The 2D and 3D slip surfaces for plane strain conditions differed slightly near the bottom of the slip surface. The factor of 2D safety from limit equilibrium analyses (1.26) and the 3D finite element analyses (1.24) were also very close.

However, the incremental displacements at failure differed significantly, as illustrated in Figure 7. On the left, the figure shows the Incremental displacements in the slip volume. On the right, the contours show a vertical cross-section slightly above the toe, in the plane normal to the paper. The figure illustrates that the slip surface in the direction normal to the sliding mass is elliptical.

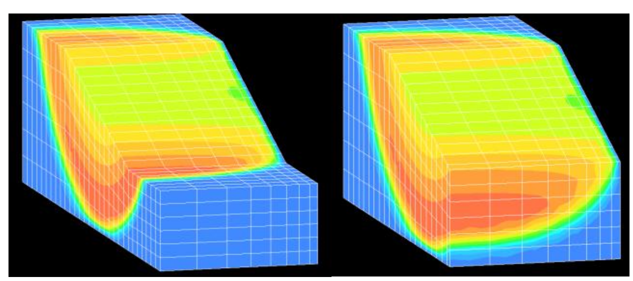

Figure 7. Incremental displacements in slip volume and cross-section slightly above the toe for b=3, D=H and $4W/2 = H/2$ (Jostad and Lacasse 2015).

Figure 8 illustrates the importance of the 3D effects as a function of the inverse of the width ratio $1/w = H/W$ (plane strain conditions for H/W = 0). The 3D effect factor F_{3D} represents the increased capacity compared to a 2D plane strain analysis. The factor F_{3D} increases approximately linearly with the *H/W* ratio. It also increases with the depth down to the strong layer (*d=D/H)*, and increases slightly with increasing slope inclination *b*.

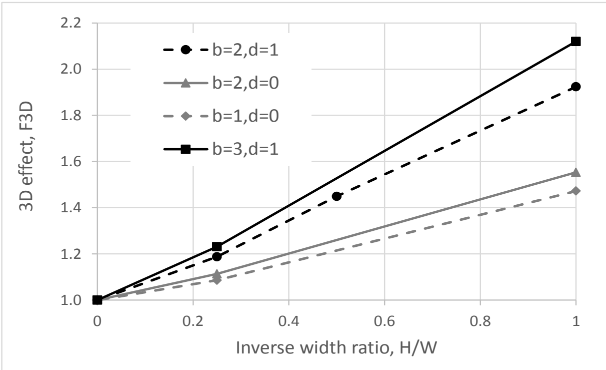

Figure 8. 3D effects vs the inverse of the width ratio *H/W* for different slope inclinations *b* and depth ratios *d =D/H*.

7 BEARING CAPACITY MODULE

The bearing capacity module introduces simpler calculations, such as Brinch-Hansen's formulas and local guidelines in Norway. In addition, the 3D calculation engine is used for finite element modelling in 2D and 3D loading situations. The FEM modelling is suitable for complex (perhaps more realistic conditions), for example, layered soils, varying strength parameters vertically or horizontally, complex geometries and loadings. The Mohr-Coulomb and NGI ADP (Grimstad and Jostad 2012) constitutive laws are implemented in the calculations. Figure 9 illustrates an embedded footing analysed in two dimensions, under moment (M), horizontal (H) and vertical (V) loading.

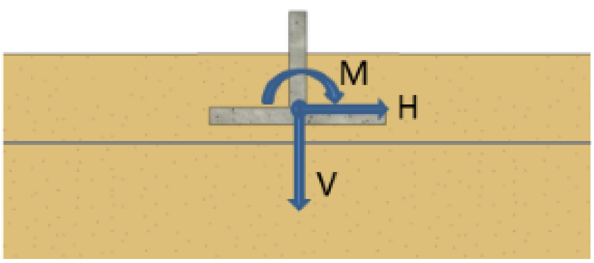

Figure 9. Bearing capacity case analysed

Figure 10 illustrates some of the results obtained in terms of strains, displacement vectors and factor of safety as a function of the calculated displacement.

8 WIZARD

Lacasse *et al* (2013) described briefly the Wizard function used in GeoSuite. Wizard is an optional, interactive assistance popping up with information on how to develop a soil profile, select a parameter, interpret *in situ* or laboratory test results, select a type of analysis, do the analysis or interpret the results of an analysis. Wizard has some but not all of the wiki-characteristics: Wizard invites the user to note down its comments within the Web site; Wizard makes topic associations with links; Wizard seeks to involve the user in an on-going process of improvement.

GeoSuite aims for day-to-day design, where a balance is held between sophisticated analyses -requiring advanced soil models and parameters and offering answers of higher accuracy-, and less sophisticated and simplified models, leading to less accuracy yet still realistic answers. For example for settlement analysis, the initial flow diagram presents to the user five steps (see Lacasse *et al* 2013 for diagram): 1) Define problem; 2) Input soil profile, models and parameters; 3) Input stress and pore pressure distributions: 4) Do settlement analysis; 5) Show the results. With the help of the Wizard, the user can initialize the data, the foundation geometry, foundation type and foundation stiffness, the construction history, ground improvement options and the load history. The use ca also initializes the stress distribution (e.g. elastic theory, *n*:1 distribution or finite element analysis of the stresses), the distribution of the initial steady state pore water (hydrostatic or non-hydrostatic conditions) and any excess pore water distribution.

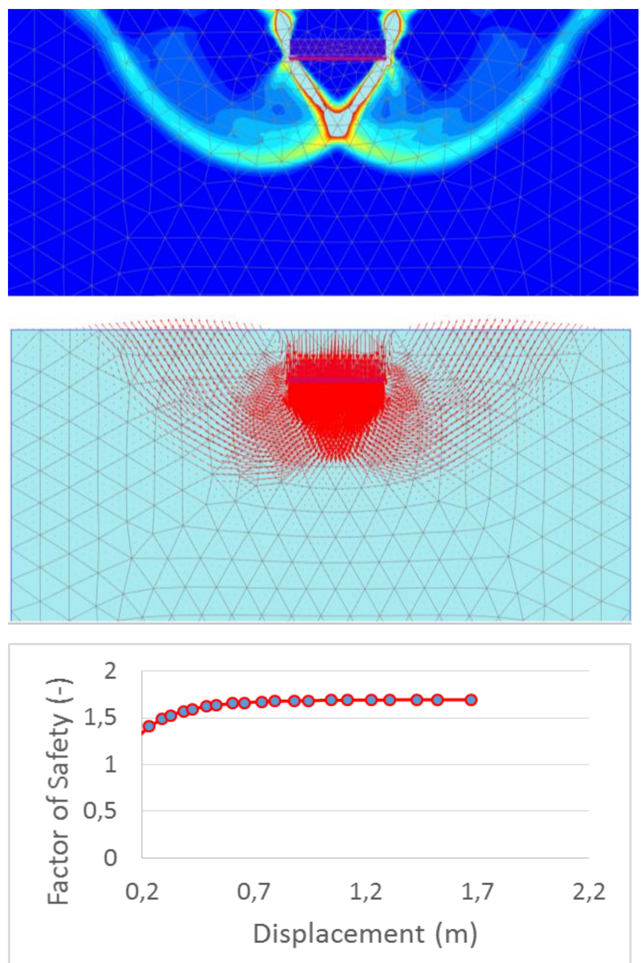

Figure 10. Bearing capacity FEM analysis of embedded footing: strains, displacement vector and factor of safety

Wizard also provides assistance on how to obtain soil parameters from the cone and piezocone penetration tests and laboratory tests. For example, the undrained shear strength, s_u, can be obtained from the measured cone resistance, the measured excess pore pressure or the net cone resistance. The preconsolidation stress, as obtained from three methods, and the end-of-primary deformation parameters, again by three methods, can be considered in light of earlier experience and in terms of the effects of sample disturbance. The undrained shear strength and overconsolidation ratio can also be obtained from or compared with from relationships in the literature. Figure 11 presents an example of a recent correlation for the permeability.

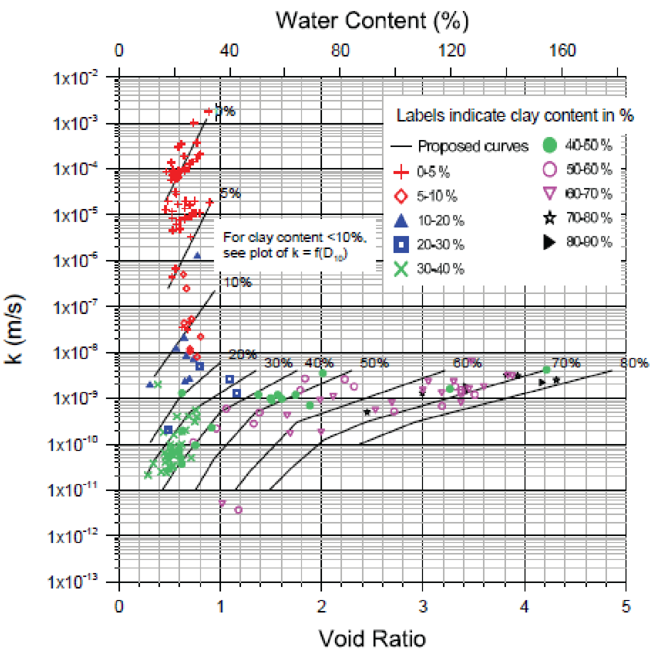

Figure 11. Permeability *k* vs void ratio, water content and clay content (Andersen and Schjetne 2013).

9 OTHER GEOTECHNICAL MODULES

The other modules (Piles, Excavation and Slide runout) have similar capabilities. In particular, the Piles module looks into both axial pile capacity and soil-pile interaction, and the Excavation module used the same 3D engine as the other geotechnical analyses (3D version to be completed by 2018). The Slide runout module is a recent addition and will present simplified calculation by 2016, with more advanced runout models by 2018. Statistical analyses associated with the selection of parameters will be included in 2016.

10 SUMMARY

The challenge in GeoSuite lies in maintaining a balance between sophisticated analyses, requiring advanced soil models and parameters –and thus offering answers of high accuracy, and less sophisticated and simplified models, leading to less accuracy, lower design costs –and yet still realistic answers.

The GeoSuite code provides the practitioner the possibility of running one-, two- and three-dimensional calculations and visualization, and helps the user with geotechnical input data, establishing soil profiles, doing the calculations and interpreting the analysis results.

The paper briefly presented the concepts behind the GeoSuite system, and some calculation examples. The system is under continuous development. The GeoSuite is a software that can be useful both in design and for checking one's calculation. The authors fully support that one should use more than one computer code when doing geotechnical calculations, to check that one has not missed any significant aspect of the problem.

ACKNOWLEDGEMENT

The authors acknowledge the financial contribution of The Research Council of Norway and the essential technical and financial contributions of the partners in the GeoSuite alliance: Geovita AS, ViaNova Systems AS, Multiconsult AS, Norconsult AS, ViaNova GeoSuite AB, AG Programutveckling Ekonomisk Förening (AGEF), SINTEF Building and Infrastructure, the Norwegian University of Science and Technology (NTNU), the Norwegian Public Roads Administration (NPRA), the Norwegian Railway Administration (JBV), Skanska AS, Cowi AS, Sweco AS, Rambøll AS and NGI. In particular, the contributions of Patrick McGloin (Vianova AS), Jan Ludvigsson and Anders Rosenquist af Akershult (Vianova GeoSuite AB) and Torbjørn Johansen (Geovita AS) are recognized.

REFERENCES

Andersen, K.H. and K. Schjetne (2013). Data base of friction angles of sand and consolidation characteristics of sand, silt and clay. ASCE J. of Geotechnical and Environmental Eng. 139 (7) 1140-1155.

Duncan, J.M. (2013). Slope stability then and now. *ASCE GeoCongress*. San Diego CA. Keynote. 2191-2210.

Finn, L. and Wu, G. (2013). Dynamic analyses of an earthfill dam on over-consolidated silt with cyclic strain softening. Keynote Lecture. *7th International Conference on Case Histories in Geotechnical engineering*. Wheeling (Chicago) IL USA.

Grimstad, G. and Jostad, H.P. 2012. Stability analyses of quick clay using FEM and an anisotropic model. NGM 2012 (*16th Nordic Geotechnical Meeting).* Copenhagen. 2. 675-680.

Jostad, H.P. and Lacasse, S (2015). 3D effects in undrained slope stability analysis of clays. Proc ECSMGE Edinburgh. Sept. 2015.

Lacasse, S. Jostad, H.P., Athanasiu C., L'Heureux, J.-S., Sandene. T. and Liu Z.Q. (2013). Assistance for the calculation of settlement. GeoMontréal 2013. Canadian Geotechnical Conference.

Wright, S.G. (2013). Slope stability. H.B. Seed Lecture. *ASCE GeoCongress*. San Diego CA USA.