GeoSuite Assistance for the Calculation of Settlement

S. Lacasse
Norwegian Geotechnical Institute (NGI), Norway, suzanne.lacasse@ngi.no

H. P. Jostad, Y. Kim, J.-S. L'Heureux, Z.Q. Liu
NGI, Oslo, Norway
R. Sandven
Multiconsult AS, Norway

ABSTRACT
As part of the development of the Norwegian-Swedish software GeoSuite, a module with geo-assistance was developed and implemented. The paper describes this user-assistance, called "Wizard", helping the user with 1D, 2D and 3D calculations of stability, settlement, piles, excavations, bearing capacity and slope run-out distance. Wizard is an optional, interactive assistance popping up with information on most of the steps of an analysis for design: developing a soil profile, selecting appropriate parameters for an analysis, interpreting *in situ* and laboratory test results, selecting a type of analysis (1D, 2D or 3D), running an analysis and interpreting the results of an analysis. For example in a settlement analysis, the user can, with the help of the Wizard, initialize the data, describe the foundation geometry, foundation type and foundation stiffness, construct the load history and select ground improvement options. The user can also initialize the stress distribution, describe the distribution of the pore water pressure and that of any excess pore water pressure. Wizard has partial wiki-characteristics: Wizard invites the user to note down its comments on a website, it makes topic associations with links and seeks to involve the user in an on-going process of improvement. The module also helps the user do simpler statistical analysis of soil parameters, examine the laboratory test results in terms of sample disturbance and compare soil parameters with published correlations among soil parameters.
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Keywords: User-assistance, settlement, software, three dimensions.

1 INTRODUCTION

Duncan (2013) described the remarkable changes in geotechnical engineering for the analysis of slopes and embankments since the 70s and 90s. Many changes are due to the revolution in computers and information technology in all aspects of our practice, including possibilities for very thorough and detailed evaluations of slope stability and performance and 3D element analyses of slopes.

As part of the development of the Norwegian-Swedish software GeoSuite, a module with geo-assistance was developed and implemented. The paper describes this user-assistance, called "Wizard", helping the user with 1D, 2D and 3D calculations of stability, settlement, piles, excavations, bearing capacity and slope runout. The paper briefly presents the GeoSuite system, and provides examples of the assistance provided to the user for the selection of the parameters and for settlement analyses.

2 GEOSUITE SYSTEM

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.

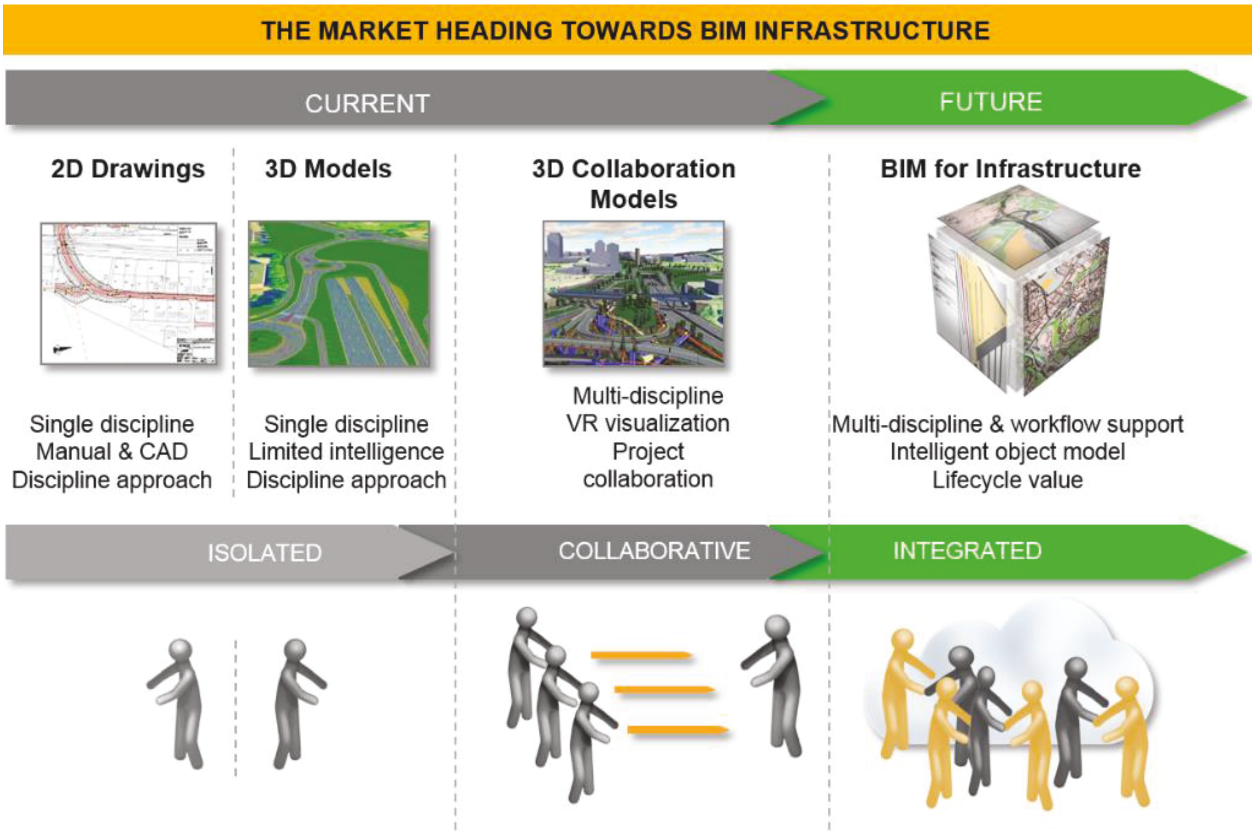

Figure 1. Evolution of civil engineering practice (Vianova AS, P. McGloin, personal communication)

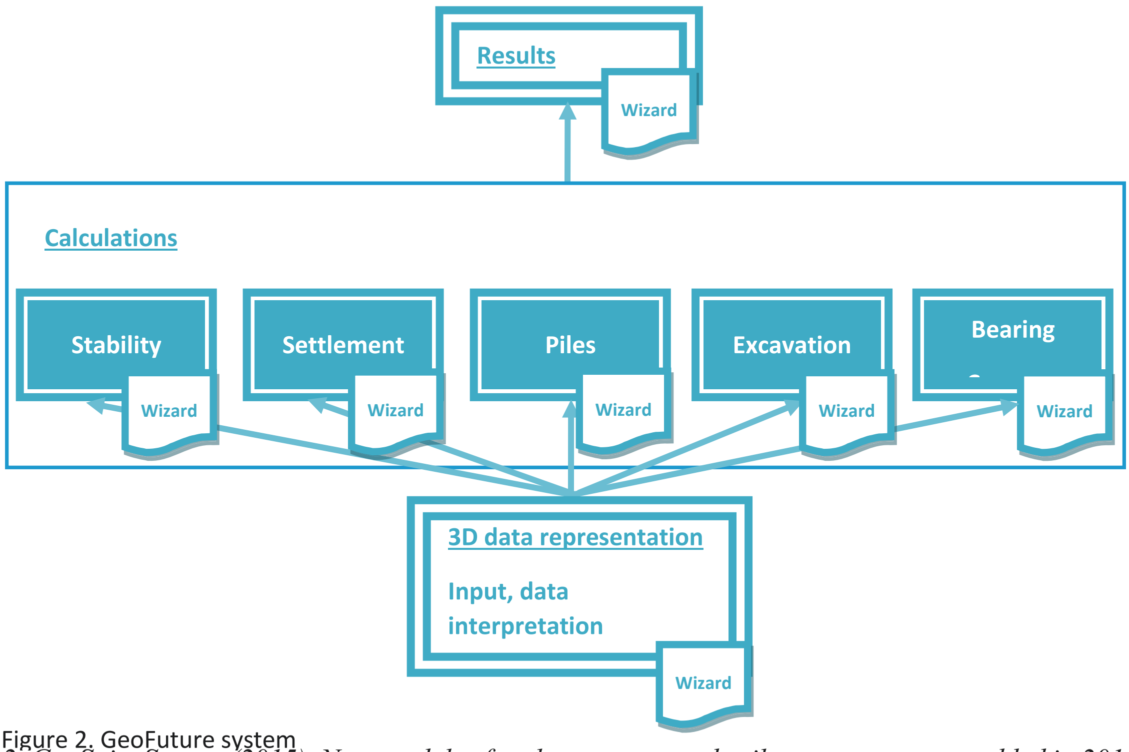

Figure 2. GeoSuite System (2015). New modules for slope runout and soil parameters were added in 2016.

Figure 2 presents schematically the GeoSuite Software. Contractors, consultants, universities and public infrastructure organizations need a common and integrated 3D engineering model in their work. In a survey, geotechnical engineers also prioritized 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, with assistance to the user.

Lacasse *et al* (2016) in a companion paper in this conference describe the GeoSuite system and its different modules for the calculation of stability, settlement, bearing capacity, piles excavation and slope runout.

3 WIZARD FOR USER ASSISTANCE

The user assistance (Fig. 2) is indicated with a symbolic Wizard. The Wizard is an interactive assistance popping up with information on how to interpret and select a parameter, select a type of analysis, do the analysis and interpret the results. The Wizard is organized such that the custodian(s) can add, modify or delete the content via a browser.

The Wiki does the knowledge management and allows note-taking. Editing the user-assistance will be limited to the custodian(s). As described by Ward Cunningham, the developer of the first wiki software, Wizard acts as a "simple online database for multi-users" ('wiki' is Hawaiian for 'fast/quick').

Wizard will act as a database for creating, browsing, and searching through information, and evolving the text. One difference with wiki pages is that the modifications will be reviewed by the custodian before being accepted. Wizard has some, but not all, of the characteristics of the wiki concept: (1) Wizard invites the user to note down its comments within the Web site; (2) Wizard associates topic with links; and (3) Wizard seeks to involve the user in an on-going process of improvement.

4 SOIL PARAMETERS AND SOIL PROFILE

Figure 3 and 4 illustrate the assistance to the user for the establishment of soil profiles. The assistance is at present placed at the before the analyses are done, and enable the user to visualize the background data and to compare with other data available.

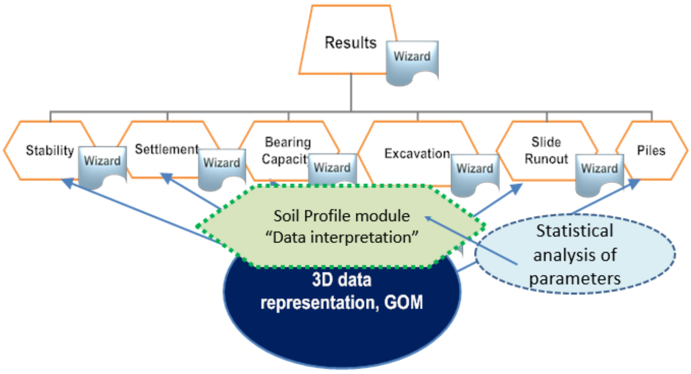

Figure 3. Wizard for soil profiles in GeoSuite

Figure 4 provides the steps in determining the soil properties and soil profiles.

Starting from the left, the user selects the parameters and boring, tests he wishes to see or use for his determination of the soil parameters. Both laboratory and *in situ* data are made available in the Ground Observation Model (GOM, Lacasse *et al* 2016). The data are tabulated and plotted, and will with time have a dynamic link with existing reliable correlations. The data are then assembled onto one or several graphs, spurious points can be eliminated or reinstated and *in situ* tests can be replaced. The data can be exported to different file formats for use in a report.

Throughout the exercise, there is a Wizard function that allows the user to retrieve supplementary or background information, documented experience or publications.

At present, GeoSuite does not have the communication with the central database with the raw laboratory test data (it does with the raw CPT/CPTU data). By the end of the project, this communication will be done.

The user needs to be aware that there is still a need for reflected intervention to select layering, the variations with depth and the parameters. Wizard, however, will:

- Get rid of 5-6 tables or Excel sheets and rather assemble all information together.
- The user select applicable correlations from a set of correlations in the Wizard.
- The user can trace the soil profile and adjust it several times.
- Different files can be saved as appropriate for different calculations.

GeoSuite plans to implement statistical tools in 2016. Figure 6 lists the tools considered.

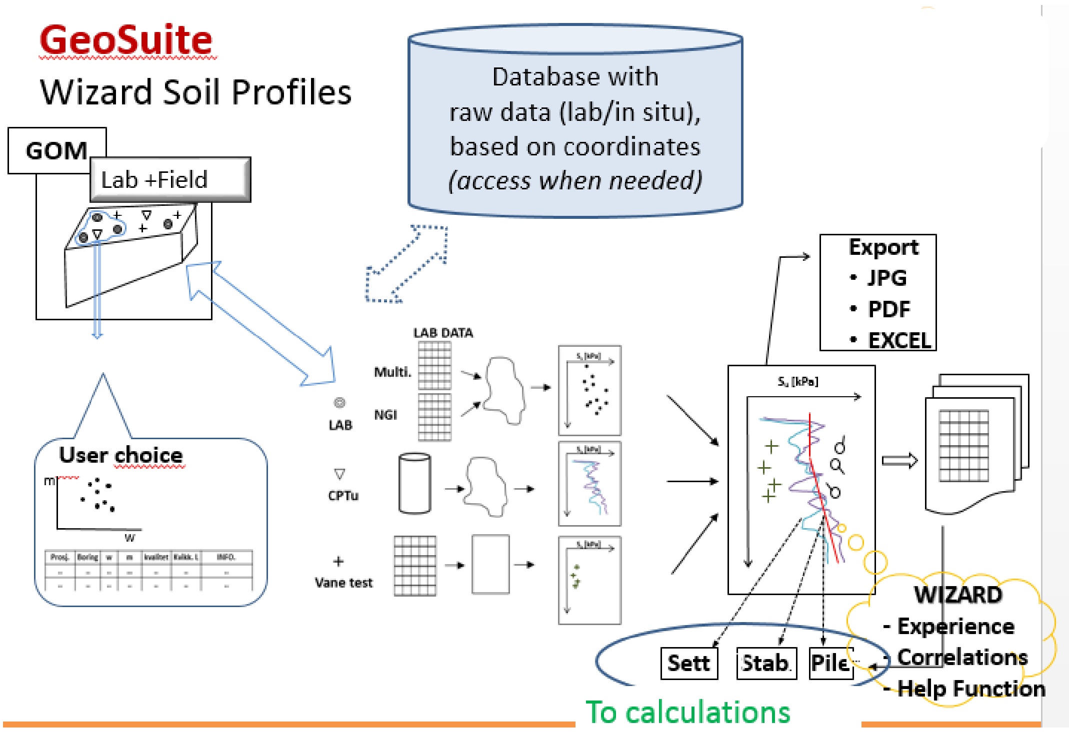

Figure 4. Schematic of Wizard Soil Profiles

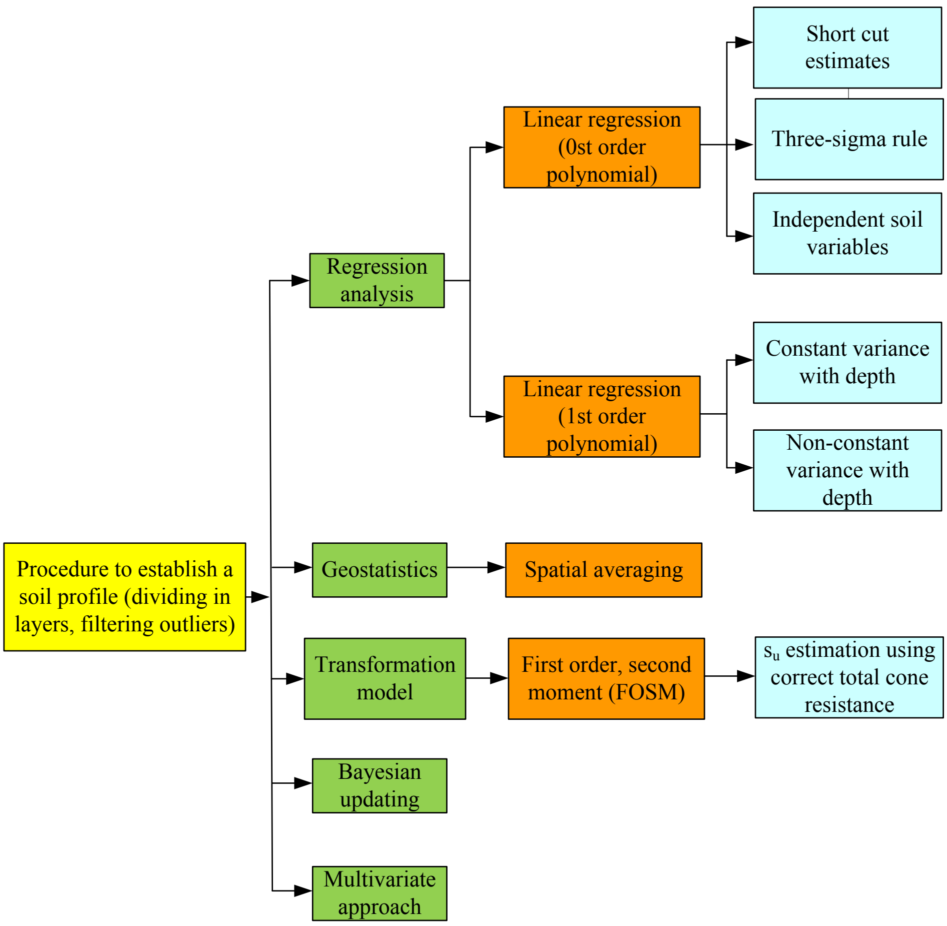

Figure 5. Statistical tools for evaluation of soil parameters

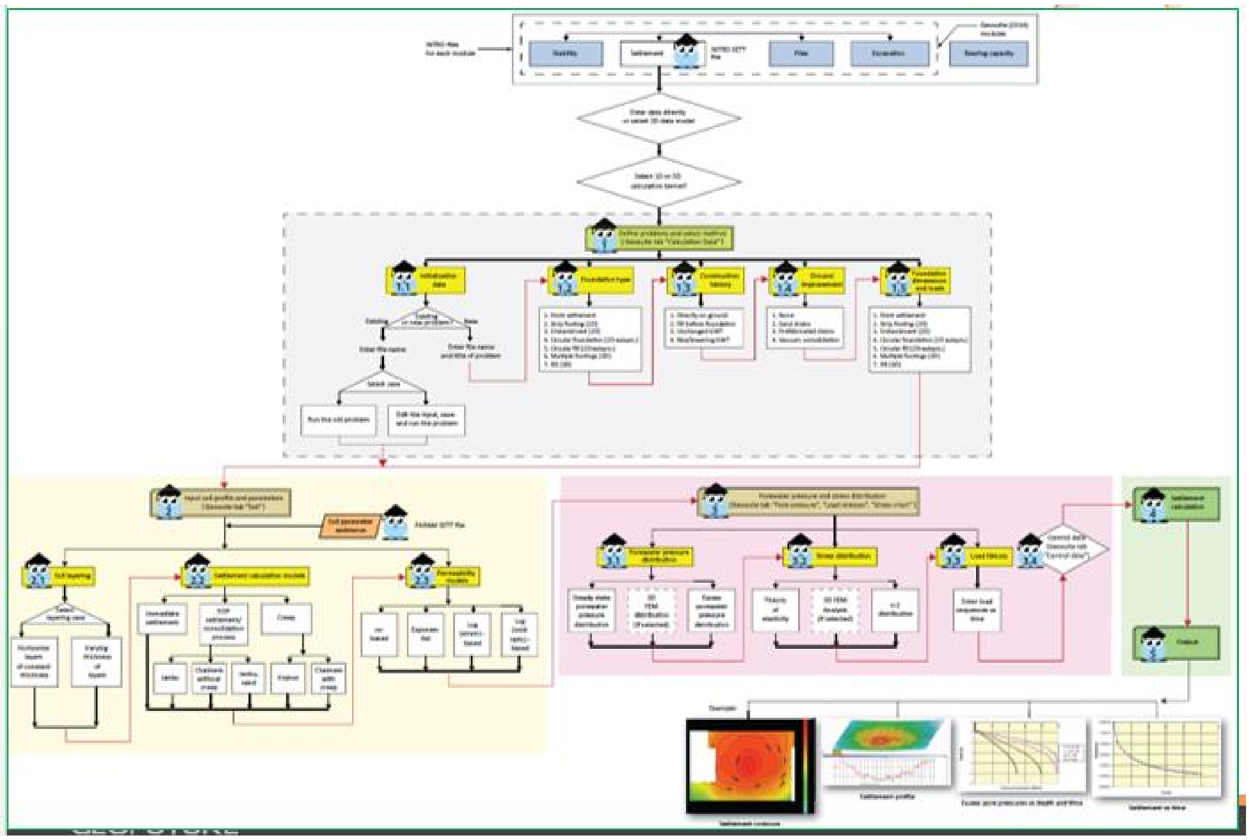

Figure 6. Flow diagram for settlement analysis

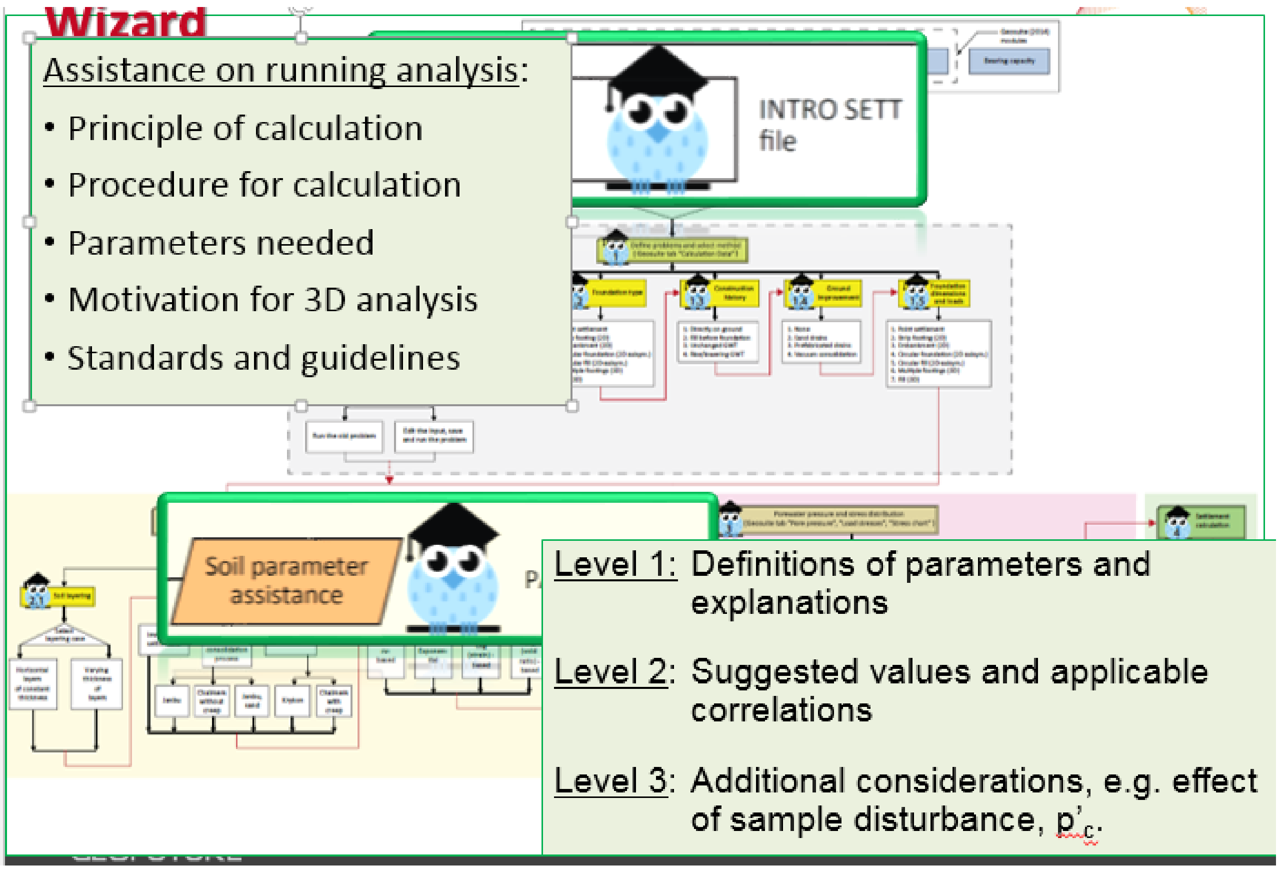

Figure 7. Wizard assistance for settlement analysis (INTROSETT and PARAMSETT file)s

5 SETTLEMENT ANALYSIS

Figure 6 presents the steps for the analysis in the Settlement module. Although nearly unreadable, the flow diagram shows five steps (Fig. 6): 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.

In step 1 (Fig. 7), the user initializes the data, the foundation geometry, foundation type and foundation stiffness, the construction history, ground improvement options and the load history. In step 3 (Fig. 8), the user initializes the stress distribution (elastic theory, n:1 stress with depth distribution or finite element analysis of the stresses), the steady state pore water distribution (hydrostatic or non-hydrostatic conditions) and the excess pore water distribution.

The Wizard assistance is developed for the ground observation model, the selection of the soil parameters, the selection of the method of analysis and the implications of the different analysis approaches, and for the interpretation of the results of the analyses. The assistance is more detailed on Figure 7. The assistance can be skipped by the user.

At the start of an analysis, the user gets assistance for running the analysis, including:

- Principle of calculation.
- Procedure for calculation.
- Parameters needed.
- Motivation for 3D analysis.
- Standards and guidelines.

For the selection of the parameters, the users get information organized in three levels:

- Level 1: Definitions of parameters and explanations.
- Level 2: Suggested values and applicable correlations (in addition to site-specific data).
- Level 3: Additional information, e.g. effect of sample disturbance, p'$_c$, effect of interpretation method, newer research etc.

6 ASSISTANCE WITH *IN SITU* TESTS

Figure 8 illustrates the Wizard for obtaining soil parameters from the cone (CPT) and piezocone (CPTU) penetration tests. The flow diagram illustrates the steps in the interpretation and the panels available to the user (orange boxes). For example, the undrained shear strength can be obtained from the cone resistance, the measured excess pore pressure or the net cone resistance. The overconsolidation ratio can be obtained from relationships in the literature.

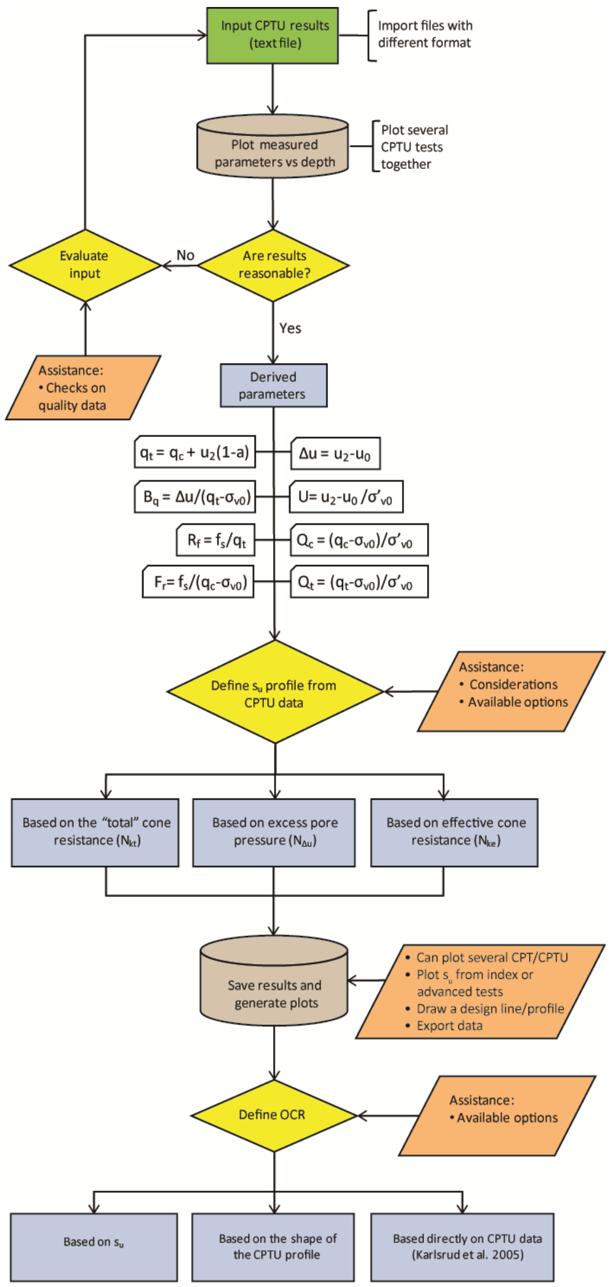

Figure 8. Wizard for CPT/CPTU tests

Figure 10 presents the interpretation of different parameters for the results of laboratory tests, e.g. the preconsolidation stress can be obtained by three methods, so the end-of-primary deformation parameters. Help panels are indicated in orange.

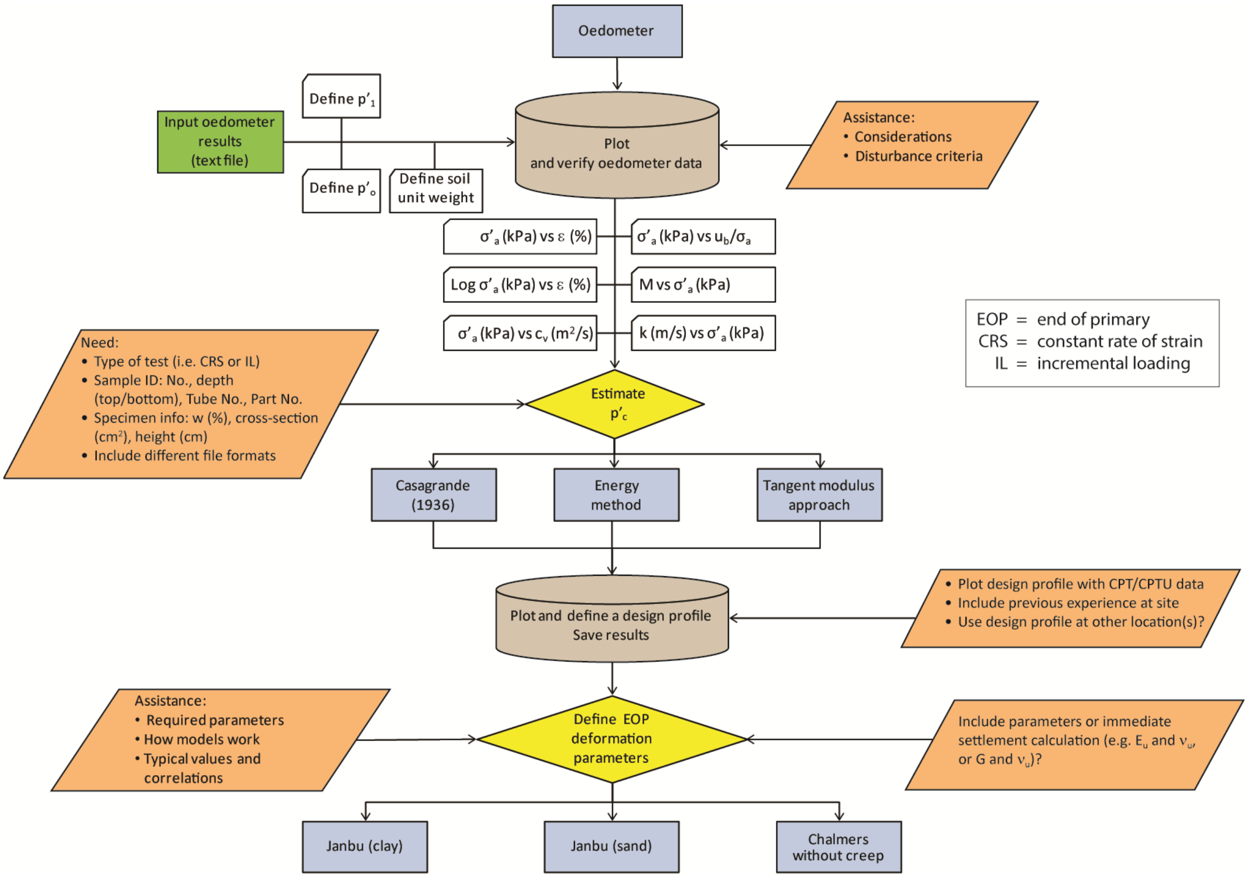

Figure 9. Wizard for oedometer test

Table 1a. Example of user assistance 's$_u$ from CPT or CPTU

Estimation of s_u from "total" q_c and N_k)

The undrained shear strength s_u from CPT using cone resistance is determined from the following equation: $s_u = \frac{(q_c - \sigma_{v0})}{N_k}$

where N_k is an empirical cone factor and σ_{v0} is the total *in situ* vertical stress. For normally consolidated marine clays with field vane as the reference test, the cone factor, N_k, varied between 11 and 19 with an average value of 15 (Lunne and Kleven, 1981).

A modification and improvement of the above approach is to use the cone resistance corrected for pore pressure effects, q_t, instead of measured cone resistance q_c. The cone factor is expressed as:

$$N_{kt} = \frac{(q_t - \sigma_{v0})}{s_u}$$

where σ_{v0} is the total overburden stress. The corrected cone resistance is expressed by $q_t = q_c + u_2(1-a)$,

where a is the area ratio of the cone (area of the central part of the cone divided by the gross area). This ratio is determined by calibration tests in the laboratory as described in Lunne et al. (1997). This area correction reduces or eliminates some of the observed differences in cone resistance obtained by using cones from different manufacturers.

Using the approach presented above, Aas *et al* (1986) and Karlsrud *et al* (2005) presented correlations between cone factor N_{kt} and plasticity index I_p, taking the average laboratory undrained shear strength $s_{u,lab} = (s_u^c + s_u^{DSS} + s_u^E)/3$

where s_u^c, s_u^{DSS} and s_u^E are the undrained shear strength from triaxial compression, direct simple shear and triaxial extension in the laboratory. The results from Karlsrud et al. (2005) are presented in Fig. 1, and suggest that N_{kt} increases with increasing plasticity. Figure 2 presents a similar relationship for the cone factor N_{kt} and the overconsolidation ratio (OCR). On the basis of a detailed study of OCR, I_p and sensitivity S_t, Karlsrud *et al* (2005) proposed the following N_{kt} relationships:

$$N_{kt} = 7.8 + 2.5 logOCR + 0.082 - I_p; \text{ for } S_t \leq 15 \text{ and } N_{kt} = 8.5 + 2.5 logOCR; \text{ for } S_t > 15$$

For the ranges of plasticity and OCR in Figs. 1 and 2, the N_{kt} factor varies between about 6-16. The variation in calculated s_u based on the correlation above typically lies around ±15% for highly sensitive clays and ±30% for the low sensitivity clays. In practice, the method of determining s_u may vary from location to location. It is emphasized that the cone factors are defined for a specific reference value of s_u. The effect of sample disturbance can be important.

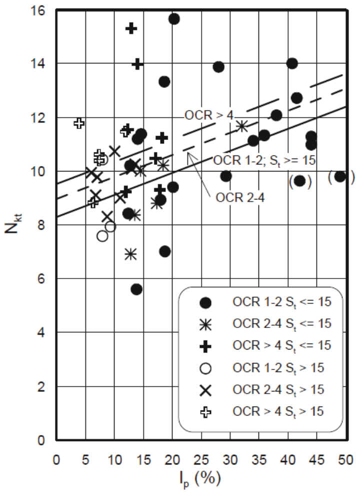

Figure 1: Influence of I_p on N_{kt} (Karlsrud *et al* 2005).

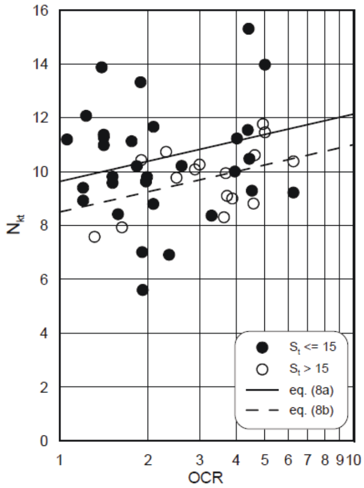

Figure 2: Nkt versus OCR (Karlsrud et al 2005).

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Lunne, T., Robertson, P.K., and Powell, J.J.M. 1997. Cone Penetration Testing In Geotechnical Practice, Spon Press, Taylor & Francis Group, London and New York, 312 p.

Table 1b. Example of user assistance 'sample quality'

Sample quality

The most common problems associated to sample disturbance when interpreting results from oedometer tests include (Fig. 1):

- Difficulties in estimating p'_c.
- Overestimating the tangent modulus (M) above p'_c.
- The reloading modulus may be underestimated.
- The permeability needs to be corrected for volume changes up to p'_0.The consolidation coefficient (c_v) needs to be corrected for the errors in modulus and permeability.

Sample quality evaluation

The volume change during re-consolidation to the *in situ* effective stresses is an indicator of sample disturbance). Lunne *et al* (1997) proposed a scale for sample quality in terms of the change in void ratio normalized by the initial void ratio (Table 1).

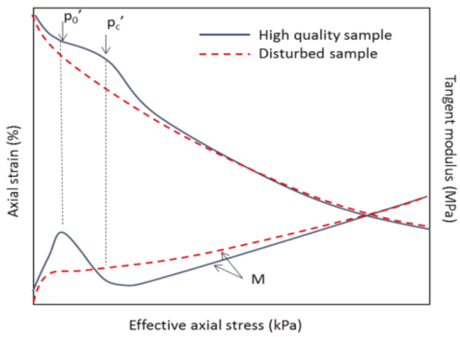

Figure 1: Typical oedometer response

Table 1: Quality index from $\Delta e/e_0$ (Lunne *et al* 1997)

OCR	$\Delta e/e_0$			
	Very good to excellent	Good to fair	Poor	Very poor
1-2	<0.04	0.04-0.07	0.07-0.14	>0.14
2-4	<0.03	0.03-0.05	0.05-0.10	>0.10
4-6	<0.02	0.02-0.035	0.035-0.07	>0.07
Quality	1	2	3	4

In this method, the sample quality is associated to changes in void ratio during the consolidation phase ($\Delta e/e_0$); where Δe denotes the change in void ratio from the start of the consolidation process until the *in situ* stresses are reached (i.e. p'_0), while e_0 is the initial void ratio at the start of the consolidation process.

Volumetric strains are equal to axial strains in the oedometer (i.e. $\varepsilon_{vol} = \varepsilon_a$) and $\Delta e/e_0$ can be found by the following equations for saturated soils: $\Delta \epsilon = \epsilon_{vol}(1 + \epsilon_0) = \epsilon_a(1 + \epsilon_0)$ and $\epsilon_0 = \gamma_s \cdot w_i$

where γ_s is the particle density, usually 2.65-2.75, and w_i is the water content at the start of the test.

Reference

Lunne, T., Berre, T., and Strandvik, S. 1997. Sample disturbance effects in soft low plastic Norwegian clay. Proc. Conf. Recent Developments in Soil and Pavement Mechanics, Rio de Janeiro, Brazil, Ed M. Almeida. A.A. Balkema, Rotterdam, NL. 81–102.

Table 1 (parts a, b and c on previous 2 pages) provides examples of the help texts in Wizard, with guidance on the interpretation and methods of calculations.

7 SUMMARY

GeoFuture is based on the concept that it will be used for day-to-day design analyses, where a balance needs to be 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.

Each calculation module in GeoFuture is developed similarly to the settlement module. The Wizard for data representation and selection of parameters are generalized for the Stability, Piles, Excavation, Bearing Capacity and Slope Runout modules. Two features are under development for the Wizard: Interactive correlations for a comparison of the results of *in situ* and laboratory tests and to select the design parameters in each of the analyses, and implementation of statistical approaches.

The introduction of a module for the statistical analysis of the parameters. Soil is a complex material because of the way the deposits are formed and the continuous alteration processes. The uncertainty in soil properties is due to e.g. the natural variability within a volume, insufficient data, imperfect interpretation models, measurement errors and limited knowledge. Statistical estimates should be used as a complement to actual data and engineering judgment when one is selecting parameters for design. The different statistical approaches can be applied to laboratory and in situ testing data, especially when a lot of data are available such as the cone and piezocone penetration tests.

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