Analysis of one-dimensional consolidation processes
in single- and multi-layered systems

GGU-CONSOLIDATE

VERSION 5

Last revision: April 2012

Technical implementation and sales: Civilserve GmbH, Steinfeld

Contents:

List of figures:

1 Preface

If cohesive layers are loaded faster than they can expel their pore water, excess pore water pressures result, which are only gradually dissipated. This process is known as consolidation.

Settlement analyses to DIN 4019 do not take the fact into consideration that a large part of the settlement is often already complete during the construction phase. Most buildings are already being subjected to 80% of final loads by the time the shell is complete. Settlements, and therefore differential settlements, are generally non-critical at this stage, as they are manifested in masonry and other joints, which are then covered by pointing and paintwork in the "***post-shell***" phase. For cohesive soils in particular, therefore, a forecast of the temporal development of settlements, even for "***simple***" buildings, is an vital prerequisite for the safe judgement of possibly damaging differential settlements. The **GGU-CONSOLIDATE** program can assist you in these tasks.

The **GGU-CONSOLIDATE** program system allows the analysis of one-dimensional consolidation processes in single and multi-layered systems. Any pore water distribution configuration may be defined. Using this program, you can also generate a pore water pressure distribution resulting from a foundation load. The de-watering conditions at the upper and lower layer boundaries can be defined separately. A load can also be applied to the system as a function of the time. It is also possible to take secondary settlements into consideration.

Beside the calculation of analytically derived solutions (*Terzaghi*), the **GGU-CONSOLIDATE** program is also capable of numerically modelling multi-layered systems. As well as classical consolidation theory, systems with installed vertical drainage can also be investigated. A combination of both systems (with and without vertical drainage) is also possible.

Thus, five different ***consolidation types*** are offered:

- **Consolidation (analytical)**
  One-dimensional consolidation theory after *Terzaghi* for a system with one layer and constant pore water pressure distribution across the whole layer depth at time t = 0. Modelling is performed using the analytical relationships given in the literature.
- **Consolidation (numerical)**
  One-dimensional consolidation theory after *Terzaghi* for a system with several layers and arbitrary pore water pressure distribution at time t = 0. Furthermore, loading can be defined as a function of time. Modelling is numerical, using difference equations. The modelling of one-layer systems with constant pore water distribution using available analytical solutions as described above can of course also be performed with the numerical model. Analytical consolidation has nevertheless been incorporated into the program, as this solution will always require shorter calculation times. Furthermore, you can check the very good quality of the numerical solution on simple examples.
- **Consolidation (analytical) with vertical drainage**
  Consolidation theory in a system with vertical drains. Pore water pressure dissipation is always directed horizontally towards the vertical drains. The pore water pressure is therefore temporally constant across the whole layer depth. Input of layer thickness in such systems is superfluous and has no influence on the temporal course of settlement.
- **Consolidation (numerical) with vertical drainage**
  In complete analogy to analytical modelling, a multi-layer system with vertical drainage can be processed. Here too, pore water pressure dissipation is exclusively horizontal towards the vertical drains. The pore water pressure is therefore temporally constant in each layer. As the pore water pressure is integrated across the layer for the whole time range, layer thickness input for multiple layer systems is important for the temporal settlement course, in contrast to one-layer systems.

- **Consolidation (numerical) with both types**
  It is possible to investigate systems in which vertical drains are only installed at a later, user-defined time.

All principal data and modelling results will be displayed on the screen. A total of five, or eight, graphical elements (see menu "**Output preferences**") can be presented:

- Legend with general information
- Table with the consolidation values at specified times
- Pore water pressure profile/consolidation ratio across the layer depth
- System visualisation
- Time-dependent development of degree of consolidation, settlement or pore water pressure
- Legend with soil properties (numerical modelling only)
- Type of load increase (numerical modelling only)
- Pore ratio diagram (only for calculation with the compression index C_C)

The size and position of these five, or eight, elements can be edited as wished. Graphic output supports the true-type fonts supplied with WINDOWS, so that excellent layout is guaranteed. Colour output and any graphics (e.g. files in formats BMP, JPG, PSP, TIF, etc.) are supported. DXF files can also be imported by means of the integrated Mini-CAD module (see the **Mini-CAD** manual). Stamp fields (e.g. company logo) can be added in that manner. The default presentation is an A3 page. You can also define your own page format if desired (e.g. A0).

The program has been thoroughly tested. No faults have been found. Nevertheless, liability for completeness and correctness of the program and the manual, and for any damage resulting from incompleteness or incorrectness, cannot be accepted.

2 Licence protection and installation

In order to guarantee a high degree of quality, a hardware-based copy protection system is used for the **GGU-CONSOLIDATE** program.

The GGU software protected by the ***CodeMeter*** copy protection system is only available in conjunction with the ***CodeMeter stick*** copy protection component (hardware for connection to the PC, "***CM stick***"). Because of the way the system is configured, the protected software can only be operated with the corresponding CM stick. This creates a fixed link between the software licence and the CM stick copy protection hardware; the licence as such is thus represented by the CM stick. The correct Runtime Kit for the CodeMeter stick must be installed on your PC.

Upon start-up and during running, the **GGU-CONSOLIDATE** program checks that a CM stick is connected. If it has been removed, the program can no longer be executed.

For installation of GGU software and the CodeMeter software please refer to the information in the ***Installation notes for GGU Software International***, which are supplied with the program.

3 Language selection

GGU-CONSOLIDATE is a bilingual program. The program always starts with the language setting applicable when it was last ended.

The language preferences can be changed at any time in the "**?**" menu, using the menu item "**Spracheinstellung**" (for German) or "**Language preferences**" (for English).

4 Starting the program

After starting the program, you will see two menus at the top of the window**:**

- File
- ?

By going to the "**File**" menu, a previously analysed system can be loaded by means of the "**Load**" menu item, or a new one created using "**New**". The program allows simple input procedures by moving directly to a dialogue box after "**New**" is clicked; this can also be reached by pointing to the "**File/new**" menu item (see Section 7.1.1) or "**Edit/Type of consolidation**" menu item. You can now directly select the analysis method and the units of time and constrained modulus to be adopted. After confirming your inputs, you then see six menus at the top of the window:

- File
- Edit
- System
- Output preferences
- Graphics preferences
- ?

After clicking one of these menus, the so-called menu items roll down, allowing you access to all program functions.

The program works on the principle of ***What you see is what you get***. This means that the screen presentation represents, overall, what you will see on your printer. In the last consequence, this would mean that the screen presentation would have to be refreshed after every alteration you make. For reasons of efficiency and as this can take several seconds for complex screen contents, the **GGU-CONSOLIDATE** screen is not refreshed after every alteration.

If you would like to refresh the screen contents, press either [**F2**] or [**Esc**]. The [**Esc**] key additionally sets the screen presentation back to your current zoom, which has the default value 1.0, corresponding to an A3 format sheet.

5 Theoretical principles

5.1 Consolidation theory after Terzaghi and analytical solution

If cohesive layers are loaded faster than they can release their pore water, excess pore water pressures result, which are only gradually dissipated. This process is known as consolidation. Assuming the validity of Darcy's Law ($v = k \cdot i$) and Hooke's Law ($\varepsilon = \sigma'/E_S$), the following differential equation must be solved:

$$\frac{\vartheta(\Delta u(z,t))}{\vartheta t} = \frac{k \cdot E_S}{\gamma_W} \cdot \frac{\vartheta(\Delta u(z,t))}{\vartheta z^2}$$

For the one-dimensional case with constant pore water pressure, a closed solution exists (see e.g. *Grundbautaschenbuch* 1990, Teil 3 - "*Foundation Engineering Pocketbook* 1990, Part 3" -, or *Braya M. Das* (1983); Advanced Soil Mechanics; McGraw Hill). The following input values are required:

- Δu = excess pore water pressure (constant for the whole layer depth) = surcharge p
- E_s = constrained modulus of layer
- k = permeability of layer
- d = thickness of layer
- t = time at which the excess pore water pressure is to be determined.

The program computes the consolidation coefficient C_V from the constrained modulusand permeability.

$$\mathbf{C_V = E_S \cdot k / \gamma_W}$$

Where

$$\gamma_W = 10 \text{ kN/m}^3 = \text{unit weight of water}$$

In some cases, this value is known from load-settlement tests, making input of constrained modulus and permeability superfluous. Using the switch provided, you can define whether input is to be via constrained modulus + permeability or via consolidation coefficient C_V.

Furthermore, the drainage conditions of the layer must be considered:

- Draining to the top and bottom;
- Draining to the top only;
- Draining to the bottom only.

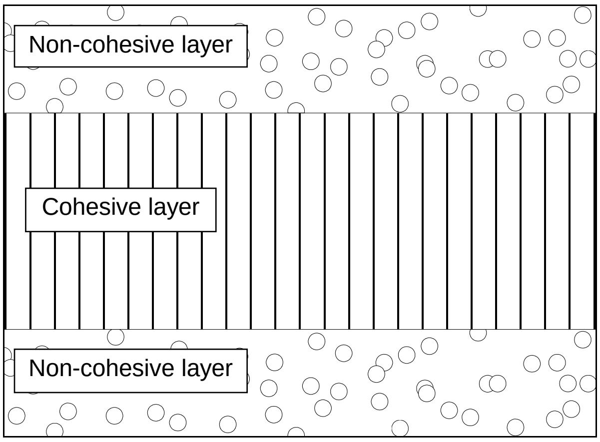


Figure 1 Consolidation layer

In Figure 1, a consolidation layer is shown, which can drain to the top and bottom. The pore water pressure distribution is constant across the whole layer depth and corresponds to the surcharge load p, which can be defined within the program. The program models the pore water pressure distribution u across the layer depth in definable, constant, vertical steps, at user-defined times. The area of the pore water pressure distributions is numerically integrated. By comparing this with the constant pressure distribution in the unconsolidated state (t = 0), the degree of consolidation U can be determined. The following is valid:

$$U = \frac{s(t)}{s(t=\infty)} = 1.0 - \frac{\int u(t) \cdot dx}{\int u(t=0) \cdot dx}$$

A further term is the consolidation ratio U_z, which is defined as:

$$U_z = 1.0 - u / u_m$$

where

u = pore water pressure
u_m = u / surcharge load

5.2 Numerical solution with difference equations

5.2.1 Fundamentals

In complete analogy to the above relationships, a numerical solution can also be modelled with difference equations. The numerical solution offers no advantages for the system described in the above figure, as generally more time will be needed to model the results. The uncontested advantages of the numerical solution for a consolidation problem can only be brought into play if a system with more than one layer is being processed and/or if the pore water pressure distribution at time t = 0 is not constant across the whole layer depth. The relationships used to solve the problem can be found in

- *Braya M. Das (1983)*
  ADVANCED SOIL MECHANICS
  McGraw-Hill

and are comprehensively described there. There is no need to ***ruminate*** on the derivations at this point.

Difference equations are applied to the depth distribution of the pore water pressures as well as to the time dimension. It is important to remember that the quality of the numerical solution is dependent upon the iteration size (small iterations = high precision but longer computing times). The depth distribution steps for pore water pressures (Δz) can be user-defined. The time dimension step Δt will be automatically selected by the program such that convergence is guaranteed. The following is valid after *Das* with regard to the relationship of the normalised values $\Delta \underline{z}$ and $\Delta \underline{t}$:

$$\mathbf{\Delta \underline{t} / (\Delta \underline{z})^2 < 0.5}$$

In the program, the stricter demand of **0.2** is implemented as opposed to **0.5**.

5.2.2 Multi-layered system

When you investigate a multi-layered system with differing permeabilities or - strictly theoretically - differing consolidation coefficients C_V, the program must always orient itself around the larger permeability value with regard to defining the necessary time steps. As rapid changes in pore water pressure can take place in layers with high permeability, a very small time step must be selected in order to achieve sufficiently accurate results. If both low-permeability and high-permeability soils are present, long consolidation times are required. In extreme situations this can lead to modelling times which, depending on the power of the computer used, can easily require several days (!).

High-permeability soils require only small time steps. Low-permeability soils require longer consolidation times.

For example, extreme modelling times may occur if you arrange a permeable sand layer (e.g. $k = 10^{-4}$ m/s) between two cohesive layers of low permeability (e.g. $k = 10^{-9}$ m/s). In such systems the sand layer can generally be neglected, unless it can drain externally to the system. In this case it is simpler not to model this soil as sand, but instead to define boundary conditions for the sand region with, e.g., a pore water pressure u = 0.

Before each computation commences, the program will estimate the expected modelling time; this helps to visualise the problem of long modelling times. You can then attempt to reduce the modelling time by making sensible increases in the iteration steps (depth). But also remember that this decreases the quality of the solution. You should also investigate the system with a view to possible simplifications. A permeable layer at the upper or lower system boundary can generally be ignored. A permeable sand layer between two layers of low permeability also plays an important role only if it can drain externally to the system under consideration (see above).

5.2.3 Continuous load application

The previous explanations assume that the load is applied immediately. Generally, however, load application is continuous during the construction phase of the structure. This effect can be considered by the program. To do this, define the load increase as a function of time using a polygon course. A linear increase, for example, would then be converted to a step function. The type of step function is dependent upon the times given by you for consolidation modelling.

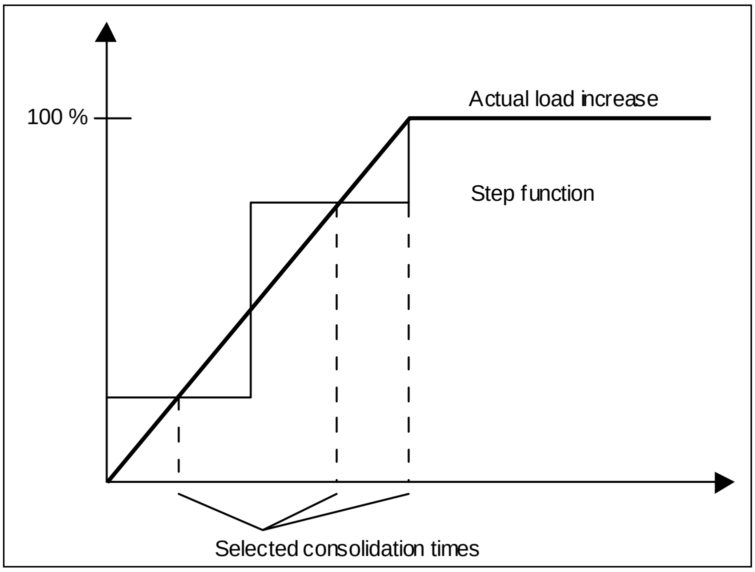


Figure 2 Step function

If you would like a more precise approximation of the linear course, you need only ***donate*** a few additional times in the load increase region when carrying out system input. The load increase need not necessarily be defined as linear but can be entered as any polygon course. In previous program versions only monotonic load increase was allowed. In the current version, modelling with load decrease is also possible.

You will attain theoretically correct results if the consolidation coefficient C_v is the same for load increase and decrease.

5.3 Consolidation settlements for non-linear compression

This approach is based on a suggestion by Prof. Dr.-Ing. Hartmut Schulz. The explanatory text originates principally from Prof. Schulz.

In Figure 3, this approach is demonstrated. Such representations are attained from the evaluation of load-settlement tests. The **GGU-OEDOM** program allows such representations and test evaluations.

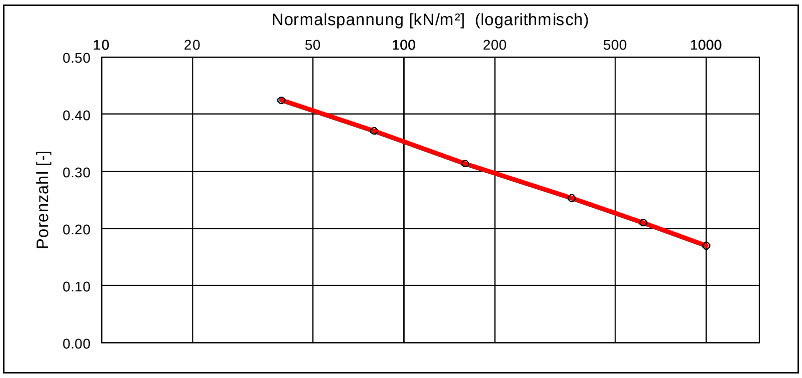


Figure 3 Stress - pore ratio relationship (GGU-OEDOM program)

The initial assumption is of a linear reduction of the pore ratio e with the logarithm of the effective vertical stress σ'. From this, the compression ε is found by relating it to the total volume.

$$\varepsilon(z,t) = \frac{C_C}{1+e_0(z)} \cdot \ln(\frac{\sigma'(z,t)+\Delta\sigma'(z,t)}{\sigma_0'(z)}$$

- $\varepsilon(z,t)$ = compression as a function of the location z and the time t
- C_C = compression index
- $e_0(z)$ = pore ratio at z before loading
- σ_0' (z) = stress at z before load increase
- $\Delta\sigma_0'$ (z,t) = compression change as a function of z and t

The effective vertical stresses as a function of the location z within the layer and the time t during the consolidation process are already integrated into this equation. Furthermore, the fact that the pore ratio changes linearly with the logarithm of the stress change is also considered. It follows from this that the compression index C_C is a constant. The evaluation in Figure 3 corresponds to the example in Figure 4, which shows that in this case the compression index C_C is almost constant across the complete stress region ($C_C \approx 0.08$). Only then can calculations be carried out using this approach.

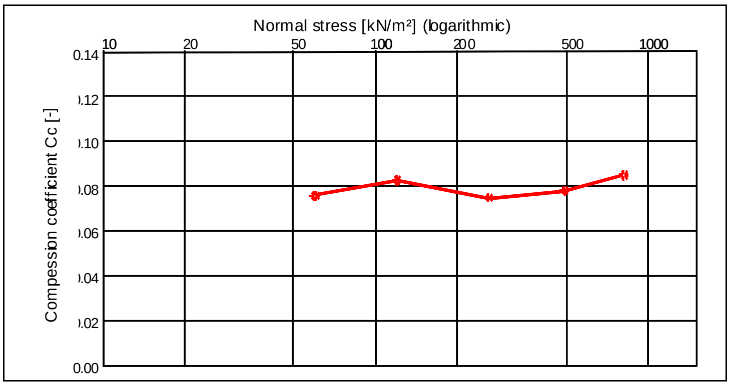


Figure 4 Stress - compression index relationship (GGU-OEDOM program)

The following input values are required for each layer:

- Compression index C_C
- Pore ratio $e_{0(top)}$ = pore ratio e_0 at top of layer
- Stress $\sigma'_{0(top)}$ = effective stress σ'_0 at the top of the layer before loading
- Stress $\sigma'_{0(bottom)}$ = effective stress σ'_0 at the bottom of the layer before loading

The program first determines the pore water pressure distribution Δu(t,z) at time t across the layer depth z. The procedures described in Sections 5.1 and 5.2 are applied for this purpose. The stress change is then calculated:

$$\Delta\sigma'(z,t) = \sigma_0'(z) + \Delta u(z,t)$$

$\sigma_0'(z)$ can be calculated from $\sigma'_{0(top)}$ and $\sigma'_{0(bottom)}$.

Further, the pore ratio $e_0(z)$ is computed from:

$$e_0(z) = e_{0(top)} + \ln(\sigma'_{0(top)} / \sigma_0'(z)) \cdot C_C$$

We now have all variables to facilitate evaluation of the above equation.

$$\varepsilon(z,t) = \frac{C_C}{1 + e_0(z)} \cdot \ln(\frac{\sigma'(z,t) + \Delta\sigma'(z,t)}{\sigma_0^{'}(z)}$$

A dimensionless compression for the depth z is acquired for each time step. The integration of these values across the depth provides the settlements(t).

$$s(t) = \int_0^D \varepsilon(z,t) \cdot dz$$

D = layer thickness

The equations described here are implemented in the program.

If you use the consolidation coefficient C_V and the compression index C_C in your calculations, the program also provides a permeability determined using:

$$k = \frac{C_V \cdot C_C \cdot \gamma_W}{(1+e_0) \cdot \sigma'}$$

5.4 Analytical solution with vertical drainage

Besides classical consolidation theory, the program also commands cases in which consolidation is accelerated by vertical drains (e.g. sand drains). These principles are also explained in *Braya M. Das (1983)*; Advanced Soil Mechanics; McGraw Hill.

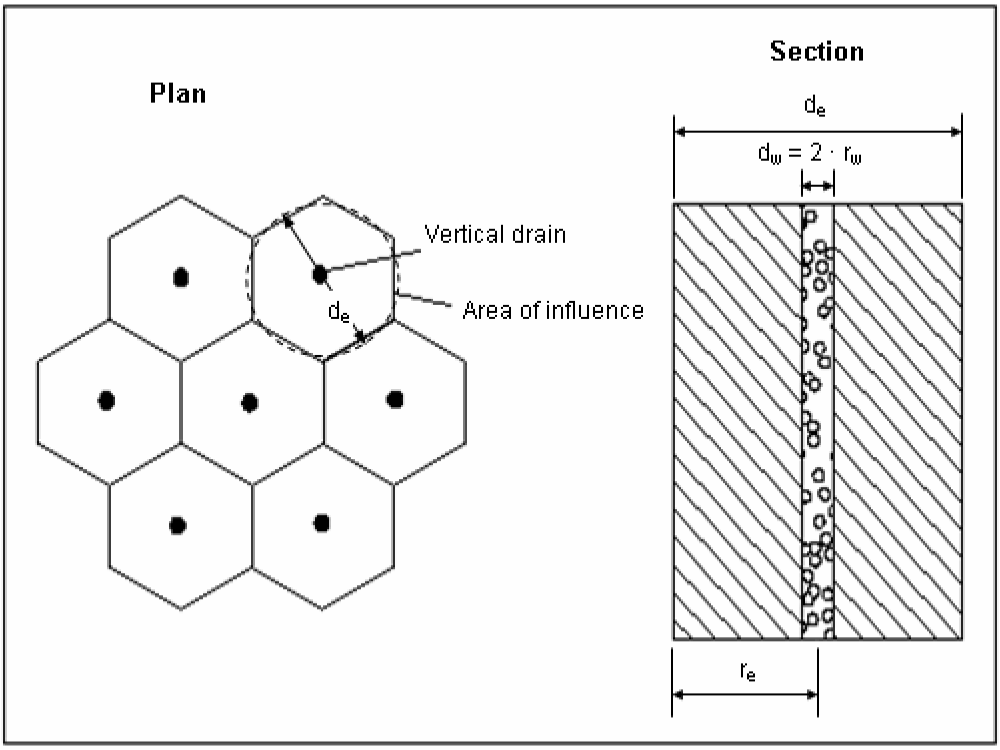


Figure 5 Vertical drains

The honeycomb structure surrounding a drain can be converted to an equivalent circle, so that axis-symmetrical consolidation modelling can be performed for each drain. In this case, according to theory, dissipation of excess pore water pressure only occurs horizontal to the drains (axis-symmetrical), so the drainage conditions at the top and base of the layer need not be given. However, the centres d_e of the drains and the radius r_w of the drains must be given. In consolidation layers with vertical drains the excess pore water pressure at any time is constant across the whole layer depth. The excess pore water pressure is, however, variable as a function of the distance r_e from the axis of the vertical drain. **GGU-CONSOLIDATE** determines the average pore water pressure distribution.

5.5 Numerical solution with vertical drainage

In contrast to the analytical solution with vertical drainage, the numerical solution also allows multi-layer systems, arbitrary pore water pressure distribution and load increase. Analytical methods with horizontal subdivisions, the spacing of which can be defined using the menu item "**Edit/System parameters**", are used for modelling the numerical solution in accordance with the previous sections. The consolidation degree U is then determined using numerical integration for the given times.

5.6 Secondary settlements

Secondary settlements are the result of volume changes occurring under constant effective stresses. Current scientific knowledge indicates that the increase in settlement with time is independent of the size of the effective stresses. The volume changes can be mathematically described as follows (Garlanger, 1972):

$$e = e_{98} + C_\alpha \cdot \ln(t/t_{98}) \qquad (1)$$

Where:

e	void ratio,
e_{98}	void ratio for a degree of consolidation of 98% (practical end of consolidation),
C_α	creep coefficient, relative to void ratio,
t	time from commencement of consolidation, $t \geq t_{98}$,
t_{98}	time for a degree of consolidation of 98%, from commencement of consolidation.

Secondary settlements are caused by viscous effects in the ground or porewater. The governing laws were first reported by Buisman, 1936, based on settlement observations:

$$\varepsilon = \varepsilon_{98} + C_B \cdot \ln(\frac{t}{t_{98}}) \qquad (2)$$

where:

ε	compression,
ε_{98}	compression for a degree of consolidation of 98%, (practical end of consolidation),
C_B	creep coefficient, relative to compression ε,
t	time from commencement of consolidation, $t \geq t_{98}$,
t_{98}	time for a degree of consolidation of 98%, from commencement of consolidation.

It should be noted at this point that Equations (1) and (2) are used in the literature with both the natural and the decadal logarithm. In practice the decadal logarithm appears to be in more widespread use than the natural logarithm.

The secondary settlements relevant for practical purposes are given by Equation (2) by integration over the stratum thickness:

$$s_{sek}(t) = \int_0^D \varepsilon_{98} dz + C_{B\log} \cdot \log(\frac{t}{t_{98}}) \cdot \int_0^D dz \tag{3}$$

where:

$s_{sek}(t)$	secondary settlements as a function of time t,
z	depth coordinate [m],
D	original stratum depth [m],
$C_{B\log}$	creep coefficient, relative to compression ε and the decadal logarithm.

If integration is performed and the entire settlement process is adopted as a function of time, the following expressions result:

$$\begin{aligned} \bar{s}(t) &= s(t) && t \le t_{98} \\ \bar{s}(t) &= s(t_{98}) + D \cdot C_{B\log} \cdot \log(\frac{t}{t_{98}}) && t > t_{98} \end{aligned} \tag{4}$$

with the additional variables:

$\bar{s}(t)$	secondary settlements as a function of time t [m],
$s(t)$	consolidation settlements as a function of time t [m],
$s(t_{98})$	settlement as a result of consolidation and a degree of consolidation of 98% [m].

Strictly, secondary settlements commence together with consolidation settlements. They are allowed to begin later for analyses.

According to Kulhawy and Mayne, 1990, the ratio c_α/c_c may lie between 0.04 and 0.06 for organic soils: c_α can be interpreted as a compression index for secondary settlements and is a function of the compression index for primary settlements. If the mean value of this ratio is adopted it may be written as follows:

$$c_\alpha(I_p) = 0.05 \cdot c_c(I_p) \text{ bzw. } c_\alpha(w_L) = 0.05 \cdot c_c(w_L) \tag{11}$$

This relationship also applies if the compression index is represented as a function of the water content at the liquid limit. It gives the time-dependent secondary settlements by integrating the change in void ratio ∂e over the strata thickness d:

$$s_{sek}(t_d, I_p) = 0.05 \cdot c_c(I_p) \cdot D \cdot \int_0^1 \frac{\log(t_d)}{1 + e_s(\varsigma, t_{Kons})} d\varsigma \tag{12}$$

Rough numerical values (abstract from TUM handouts by Prof. Vogt):

The following empirical values may be adopted in terms of secondary settlements: $C_\alpha < 0.005$ for overconsolidated clays, $0.005 < C_\alpha < 0.05$ for normally consolidated clays and $0.05 < C_\alpha < 0.5$ for organic and humous soils. Rheologically, soil creep is regarded as viscous behaviour.

If changes in relative settlements or vertical strains ε are described instead of the change in void ratios, the Buisman factor C_B (BUISMAN, 1936) is adopted instead of the creep factor C_α. Where:

$$C_B = \left|\frac{\Delta\varepsilon}{\Delta ln\, t}\right| = \frac{\varepsilon 1 - \varepsilon 2}{ln(t_2) - ln(t_1)} \qquad \textit{and} \qquad C_\alpha = C_B \cdot (1 + e_0)$$

A relationship exists between the Buisman constant C_B and the compression index C_C for primary settlement via the toughness index l_v where $C_B = C_C \cdot I_v /(1 + e)$.

The toughness index I_v correlates well with the water content at the liquid limit w_L.

$$I_v\ [\%] = -7.02 + 2.55 \cdot ln\ (w_L\ [\%]).$$

A relationship also exists between creep velocities (compression rates) ε, reference times t (theoretical time since load application), toughness index I_v and effective stresses σ' (KRIEG 2000):

$$\frac{\sigma_0'}{\sigma_1'} = \left(\frac{\dot{\varepsilon}_0}{\dot{\varepsilon}_1}\right)^{Iv} = \left(\frac{t_1}{t_0}\right)^{Iv} = \left(\frac{t + t_0}{t_0}\right)^{Iv}$$

In this context it is obvious that the creep velocities can be reduced by reducing the effective loads and that compression rates are a function of both the stress levels and the time elapsed since the load was applied.

KRIEG, S. (2000): Viskoses Verhalten von Mudden, Seeton und Klei. Heft 150, Veröff. Inst. Bodenm. u. Felsm. Univ. Karlsruhe

Further reading:

Bjerrum, L.	1967	Engineering geology of Norwegian normally consolidated marine clays as related to settlements of buildings. Seventh Rankine lecture. Geotechnique, 17: 81-118
Buisman, A.S.K.	1936	Results of long duration settlement tests. Proc. 1st ICSMFE, Cam-bridge, Mass., Vol.l:103-107
Crawford, C.B.	1964	Interpretation of the consolidation test,Journal of the Soil Mechanics and Foundations Division, ASCE, 90: 87-102
Garlanger, J. E.	1972	The consoidation of soils exhibiting creep under constant effective stress, Geotechnique 22, 71-78
Gudehus, G.,	1981	Bodenmechanik, Ferdinand Enke Verlag Stuttgart
Hvorslev, M.J.,	1960	Physical Components of the Shear Strength of Saturated Clays, Proceedings ASCE Research Conference on Shear Strength of Cohesive Soils – Boulder, Colorado
Kulhawy, F.H., Mayne, P.W.	1990	Manual on Estimating Soil Properties for Foundation Design, EL-6800 Research Project 1493-6, prepared for Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, California, 94304
Schulz, H.	2002	Setzungsprognosen für weiche Böden, Bauingenieur, Band 77, September 2002, S. 407
Schulz, H.	2003	Prediction of Settlements of Soft Soils, Int. Workshop on Geotechnics of Soft Soils-Theory and Practice. Vermeer, Schweiger, Karstunen & Cudny (eds.) © 2003 VGE
Stolle, D.F.E., Vermeer, P.A., Bonnier, P.G.	1999	A consolidation model for creeping clay, Can. Geotech. Journal, 36: 754-759

6 Short introduction using worked examples

6.1 Example system

The following system is given:

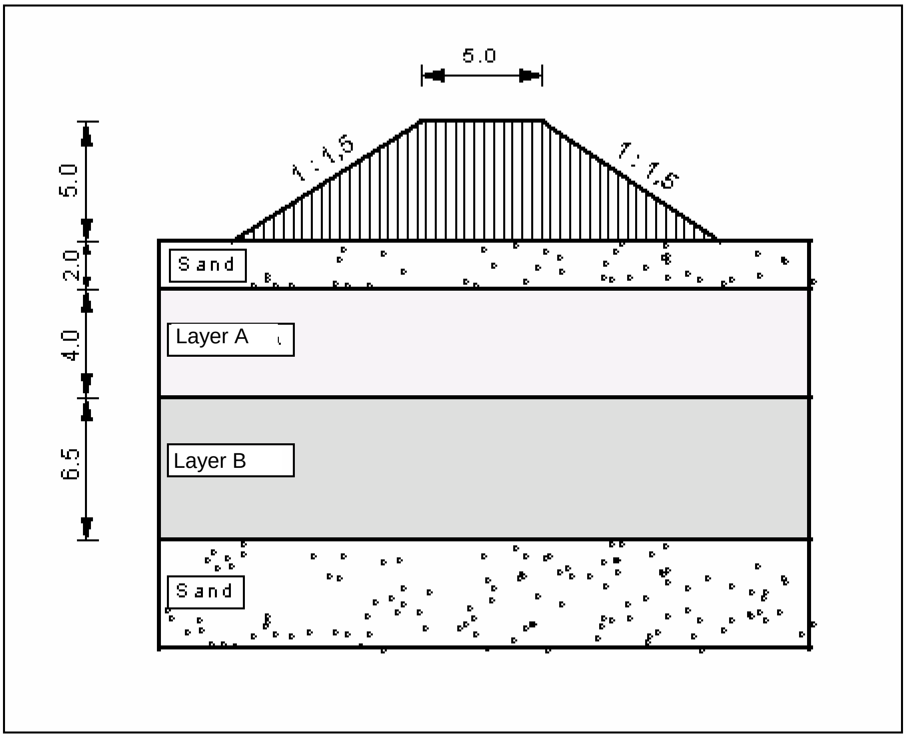


Figure 6 Example system

The unit weight of the embankment material is 19 kN/m³. The crown width is 5.0 m. The slopes are inclined at 1 : 1.5. The following laboratory test values were determined for both consolidation layers:

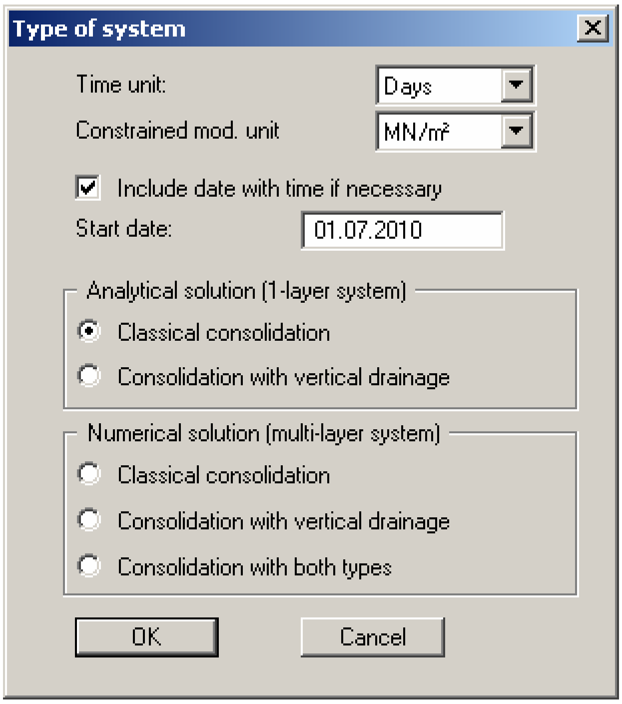
- **Layer A**
  E_S = 4 MN/m²
  k = 1 · 10^{-8} m/s
- **Layer B**
  E_S = 2 MN/m²
  k = 1 · 10^{-9} m/s

The maximum surcharge on the embankment is 5 · 19 = 95 kN/m². The system can drain to the top and bottom. The settlement at time t = ∞ is approx. 40 cm. The embankment is tipped in approx. 100 days. The question to be clarified is: at what point in time is 80 % of settlement achieved.

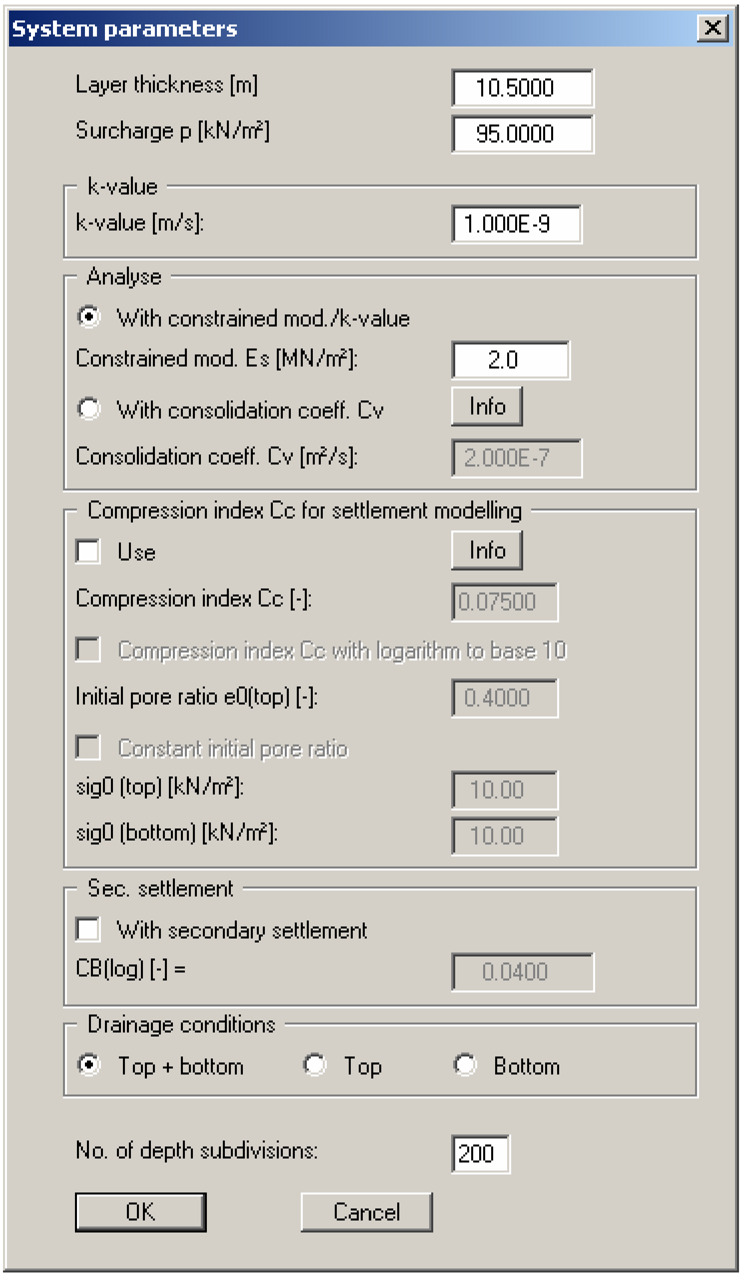
6.2 Test 1: Consolidation (analytical)

First, the system will be investigated using classical consolidation theory. As this is actually a two-layer system, we must simplify. The most ***brutal*** type of simplification is to model with a layer thickness of 10.5 m, the smallest constrained modulus of E_S = 2 MN/m² and the smallest permeability of k = 10^{-9} m/s.

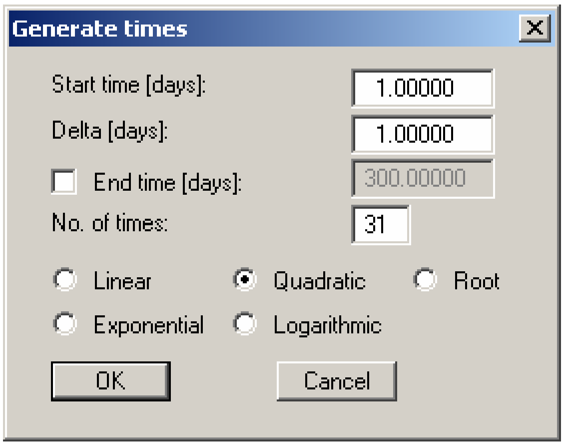
Start the program. Select the menu item "**File/New**" or, if you already have a file loaded, "**Edit/Type of consolidation**" and enter the preferences from the following dialogue box:



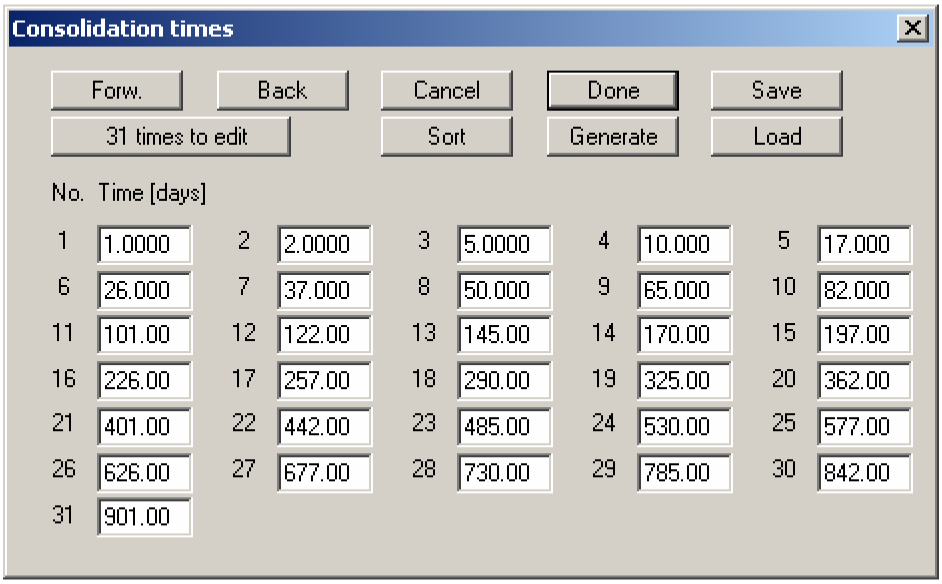
Select the menu item "**Edit/System parameters**" and enter the values from the following dialogue box:



Select the menu item "**Edit/Define times**". The times given here are unsuitable for this problem, as the consolidation time will certainly be more than 12 days for the current system. You can easily convince yourself of this by leaving the box with "**Cancel**" and selecting the menu item "**System/Analyse**" and then examining the temporal development of the degree of consolidation in the diagram at the lower right. If necessary, use the zoom function to enlarge the diagram (menu item "**Graphics preferences/Zoom info**"). Now return to this menu item. You can now individually edit the times given in the input fields; this is simpler, however, with the "**Generate**" button.



Enter the values as shown in the dialogue box and confirm with "**OK**". Don't forget to activate the "**Quadratic**" check box. Voila!



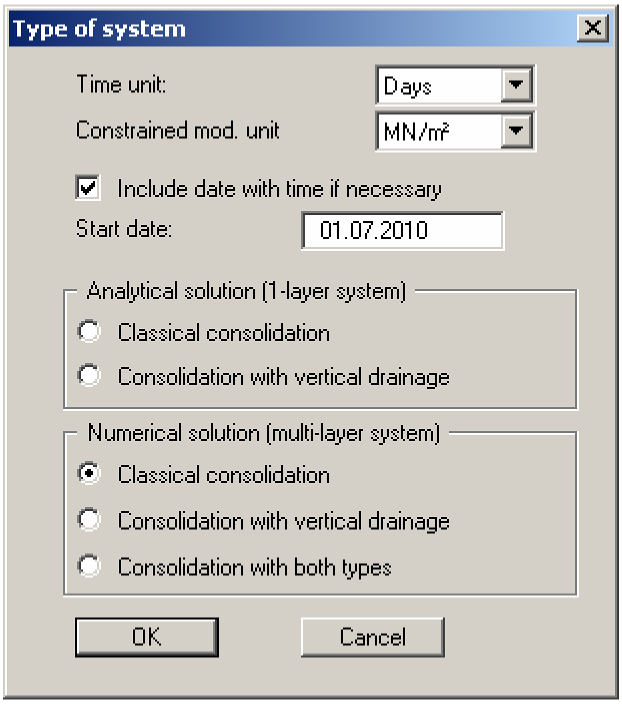
You have now generated a time series with a quadratic increase up to 901 days. Leave the dialogue box using "**Done**".

Now select the "**System/Analyse**" menu item. After a short time you will see the results. If everything has been entered correctly you can see from the time-settlement graphic at the lower right that around 900 days are needed until 80% settlement has occurred. Alternatively, you can read off the respective values from the table at the left page margin.

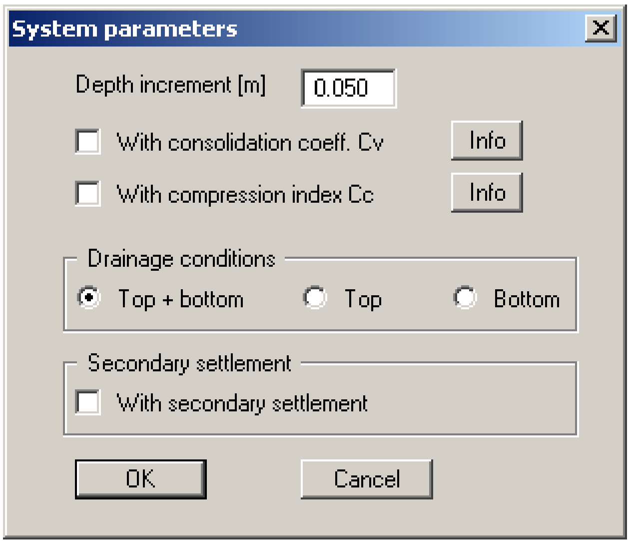
A 3-year embankment lying time would be unacceptable to the client. The system will therefore be examined below in more detail.

6.3 *Test 2: Consolidation (numerical)*

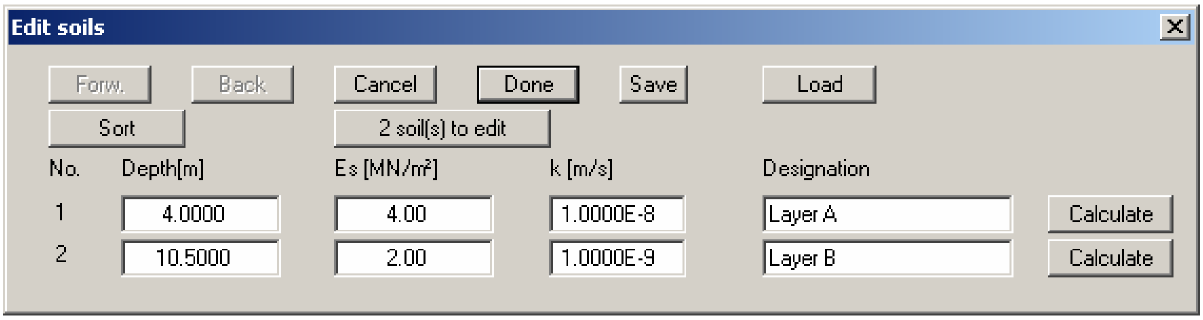
With numerical consolidation, the two-layer system can be considered. Select the following preferences from the menu item "**Edit/Type of consolidation**":



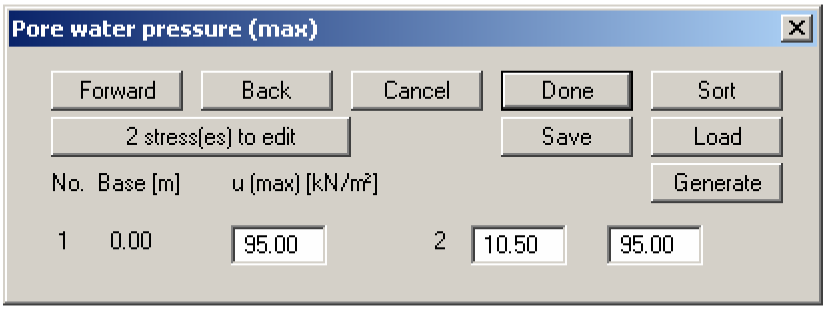
The number of menu items in the "**Edit**" menu has increased. Select the menu item "**Edit/System parameters**" and enter the data from the following dialogue box:



You can skip the menu item "**Edit/Define times**", as the same times as for ***Test 1*** will be used. Select the menu item "**Edit/Soils**". Enter the following values into the dialogue box and confirm with "**Done**".



Select the menu item "**Edit/Pore water pressure (max)**", in order to enter the pore water pressure distribution at the start of consolidation. Edit the number of stresses to **2** with the "**x stress(es) to edit**" button. Then enter the values into the dialogue box.

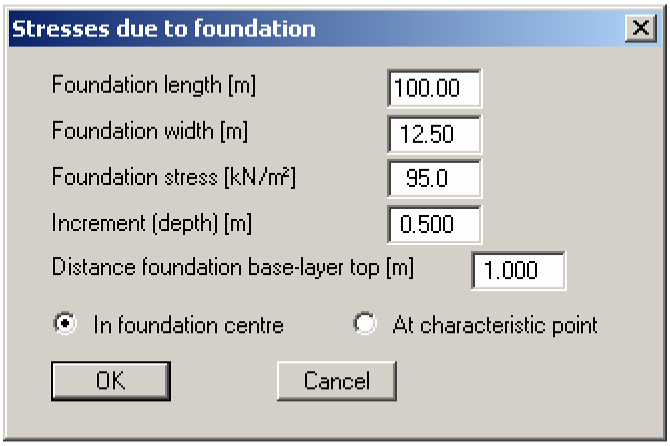


You thus define a constant pore water pressure of 95.0 kN/m² across both layers. Now select the menu item "**System/Analyse**". The program first performs an estimate of the modelling time required. If the forecast modelling time is greater than 5 seconds, a message box opens, allowing you to start or abort the analysis. Information on reducing the modelling time is available by pressing the "**Info**" button. If you click "**Yes**", modelling follows. If everything has been entered correctly you can see from the time-settlement graphic at the lower right that around 350 days are needed until 80% settlement has occurred. Alternatively, you can also read the respective values from the table at the left page margin.

In contrast to the ***brutal*** forecast of 900 days in ***Test 1***, this more sensitive investigation has brought about a reduction in the lying time by a factor of approximately 3. The client, however, is impatient and will still not accept an embankment lying time of around 1 year. The system will therefore be examined below in even more detail.

6.4 Test 3: Consolidation (numerical) with real pore water pressure distribution

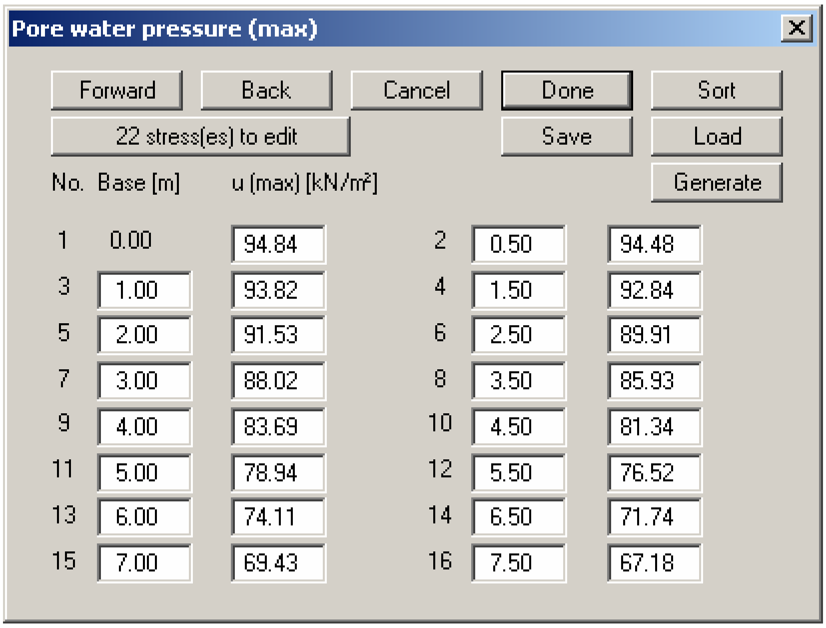
The assumption that the pore water pressure at time t = 0 is constant across the whole layer depth is not exactly true. Because of the infinite extent of the embankment in section, lower pressures result. In order to consider the real pore water pressure distribution, select the menu item "**Edit/Pore water pressure (max)**" and then the "**Generate**" button. Enter the values into the dialogue box.



The foundation width of 12.50 m is approximately the crown width of the embankment and half of each slope width.

> For "**Distance foundation base - layer top [m]**", the top of the uppermost consolidation layer should always be taken as reference.
> This is not necessarily ground level, but must be taken from the system to be investigated.

In this example, the top of the uppermost consolidation layer is 2.0 m below the embankment; you must therefore enter a value of **2.0** for "**Distance foundation base - layer top [m]**". After confirming with "**OK**" the program models the stress distribution across the consolidation layers in accordance with elastic-isotropic half-space theory.



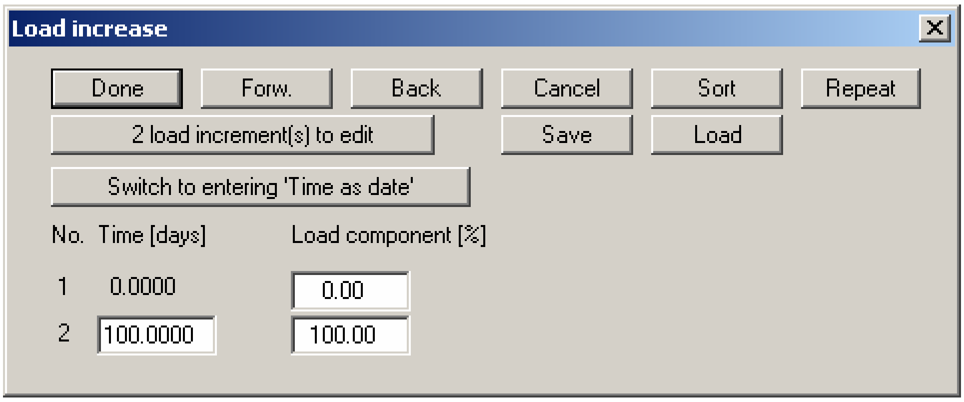
Using the "**Forward**" button, navigate through the list to view the stresses at a depth of 10.5 m. As an alternative to the automatic generation of pore water pressures you can, of course, also enter the values ***manually***.

Select the "**System/Analyse**" menu item. Evaluation of the analysis shows that the consolidation time for 80% settlement has now been reduced to approx. 330 days, which is, of course, still not satisfactory for the impatient client.

In the initial task formulation it was noted that the embankment tipping time was around 100 days. The influence of this will now be investigated.

6.5 Test 4: Consolidation (numerical) with real pore water pressure distribution and time-dependent loading function

It will be assumed that the 95 kN/m² surcharge is applied approximately linearly over a period of 100 days. In principal, the program can cope with any kind of stress increase. Select the menu item "**Edit/Load increase**". Change the number of load increments to **2** and enter the values from the following dialogue box.



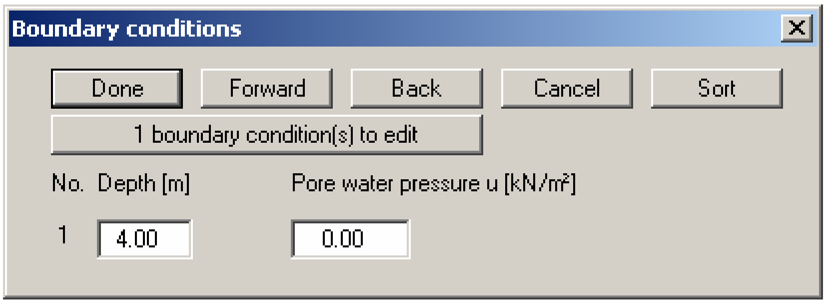
For times which exceed the final time given here, a load component of 100% will always be assumed, so that no further input is necessary.

Select the "**System/Analyse**" menu item. An evaluation of the analysis shows that the consolidation time until 80% settlement is achieved is now around 380 days. However, as this analysis also includes the tipping time of 100 days, the lying time after completion of tipping is reduced to 280 days, which represents a gain of 50 days compared to the ***Test 3*** model.

The client is still not satisfied with this. Luckily, however, drilling carried out in the meantime has shown that there is a thin layer of sand between the two cohesive layers, which can drain laterally. The influence this is investigated in ***Test 5*** below.

6.6 Test 5: Consolidation (numerical) with real pore water pressure distribution and time-dependent loading function and boundary condition

Under the assumption that the intercalated sand layer can take on a pore water pressure u = 0, the system can be adjusted accordingly. Select the menu item "**Edit/Boundary conditions**" and set the number of boundary conditions to **1**. Then enter the following values:

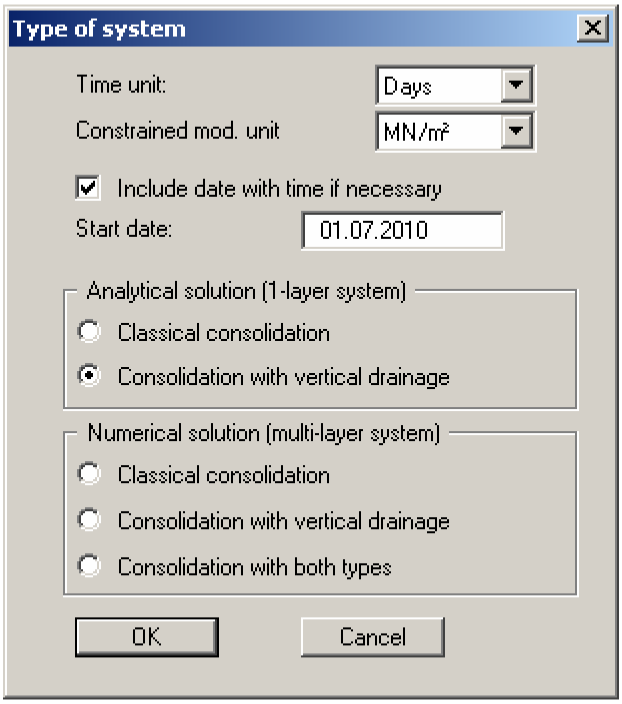


This simulates a pore water pressure of "**0**" in the transition zone between the layers during consolidation.

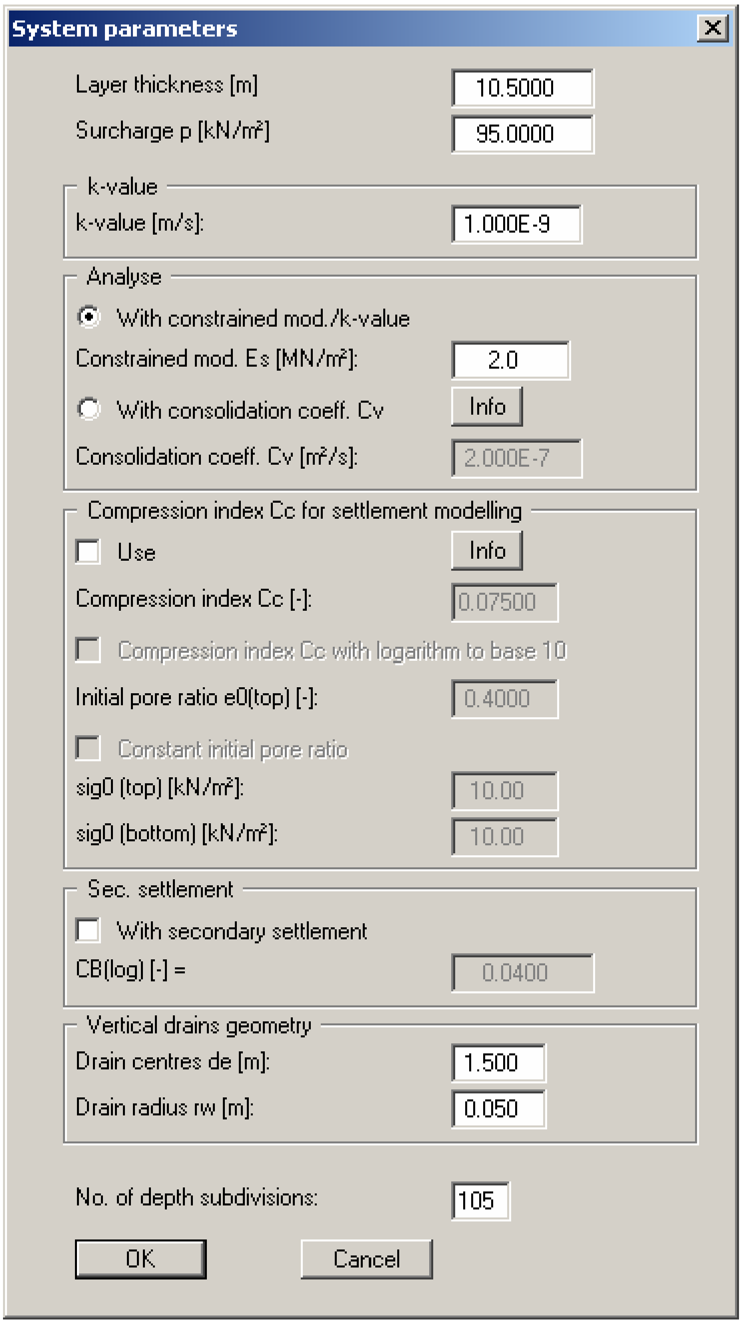
Select the "**System/Analyse**" menu item. An evaluation of the analysis shows that the consolidation time until 80% settlement is achieved is now around 310 days. However, as this analysis also includes the tipping time of 100 days, the lying time after completion of tipping is reduced to 210 days. The clients asks if it cannot be done quicker. Of course it can, but only using vertical drains (see ***Test 6***).

6.7 Test 6: Consolidation (analytical) with vertical drains

Select the menu item "**Edit/Type of consolidation**" and apply the following settings:



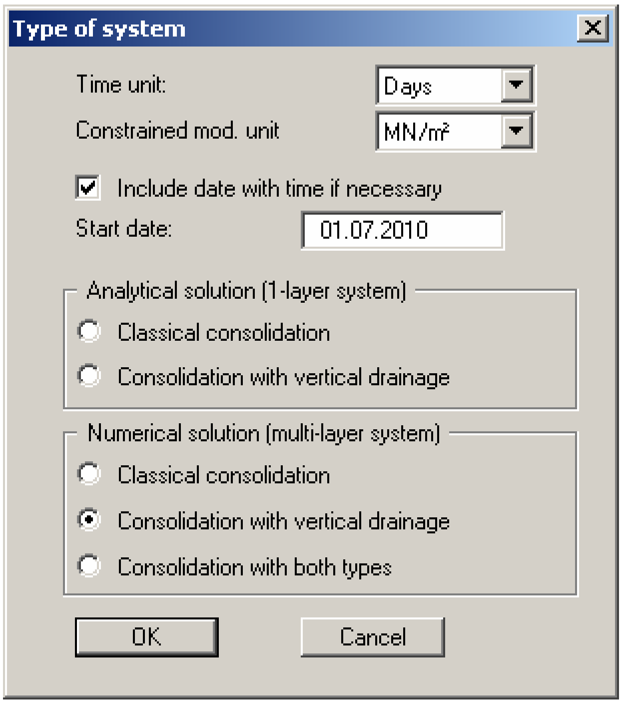
Consolidation modelling with vertical drains will first be performed on a one-layer system. It is therefore necessary, as in ***Test 1***, to simplify the current two-layer system to a system with one layer. Select the menu item "**Edit/System parameters**" and enter the values from the following dialogue box, similar to ***Test 1***. Afterwards, analyse the system.



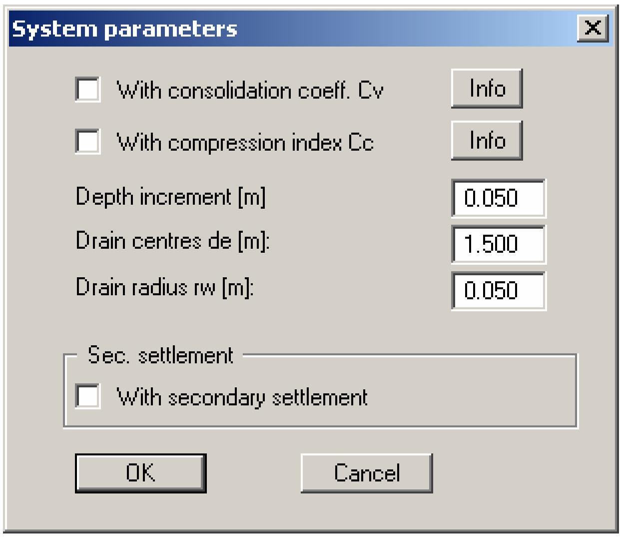
For drain centres of 1.5 m and a drain radius of 0.05 m the lying time is now only 50 days until 80% of settlements have occurred. The client is ***still*** not satisfied with this. So, last try!

6.8 Test 7: Consolidation (numerical) with vertical drains and actual pore water pressure distribution and time-dependent loading function

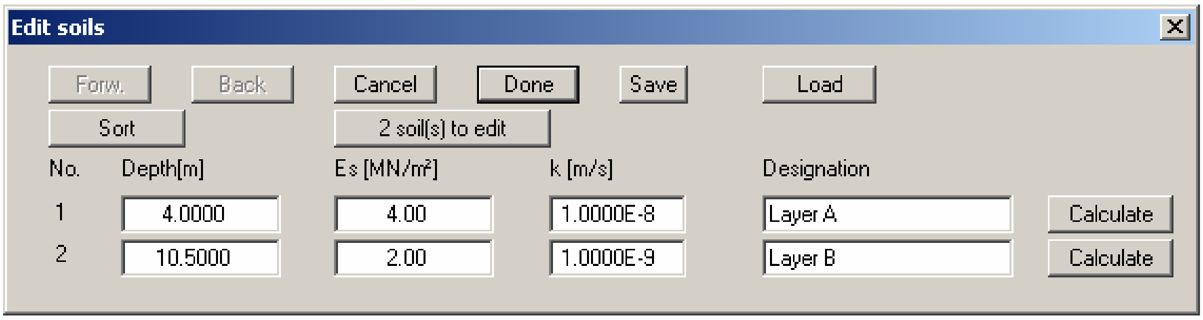
In analogy to ***Test 6***, a two-layer system will now be investigated. Select the following preferences from the menu item "**Edit/Type of consolidation**":

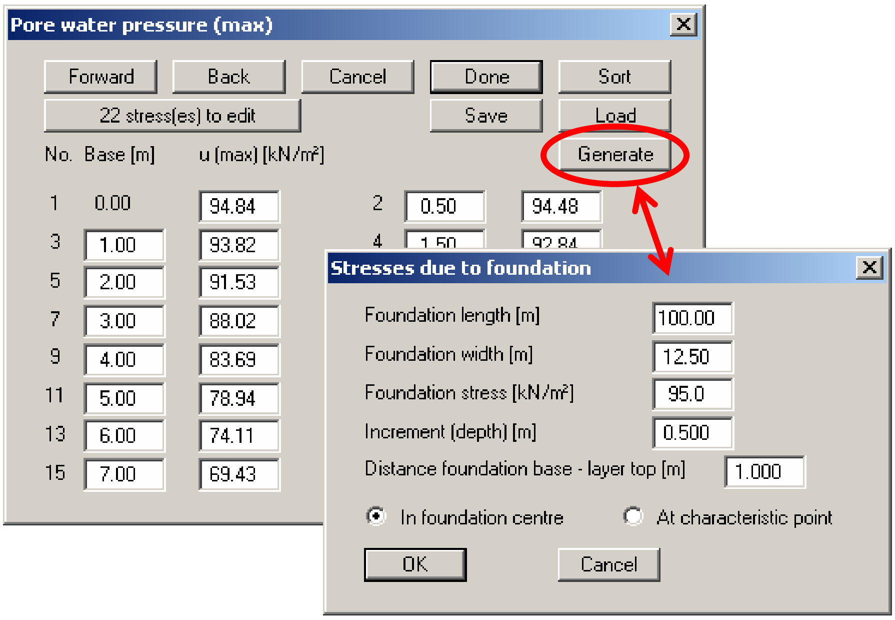


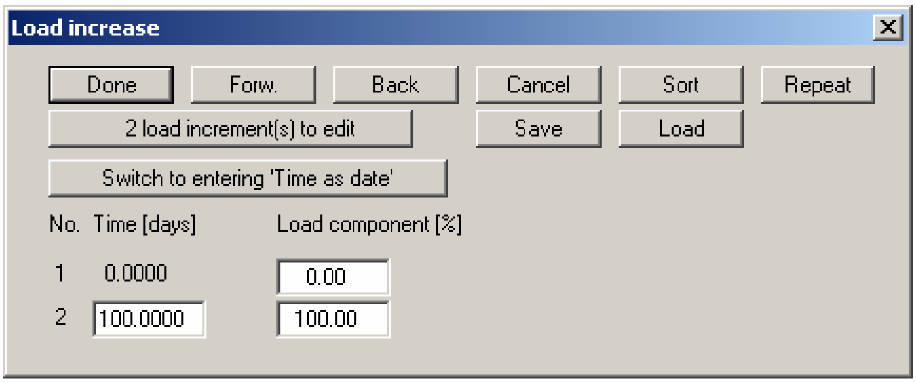
In "**Edit/System parameters**", enter the following values:



Input for soil properties, pore water pressure distribution and load increases are analogous to ***Tests 2 to 4***. The easiest way is to load the file for ***Test 4***.







Boundary conditions can not be applied for numerical modelling of vertical drains.

The analysis shows that - after the tipping time of 100 days is complete - 80% of settlements have occurred after a further lying time of only 10 days. This is still too long for the client.

Complete soil replacement is currently planned within the protection of a complex sheet pile wall structure. The replacement material has a permeability of > $1 \cdot 10^{-5}$ m/s. Apart from the substantial reduction in absolute settlements, a projection of the time-settlement profile shows that 99% of settlement has already occurred after approx. 2 hours. Can we live with this?

6.9 Test 8: Worked example with compression index C_C

On the basis of ***Test 5*** (see Section 6.6), time-settlement analysis with compression indices (see Section 5.3) shall now be demonstrated. In addition to the values from ***Test 5***, we need the following input data:

- Compression index C_C
- Pore ratio $e_{0(top)}$ = pore ratio e_0 at top of layer
- Stress $\sigma'_{0(top)}$ = effective stress σ'_0 at the top of the layer before loading
- Stress $\sigma'_{0(bottom)}$ = effective stress σ'_0 at the bottom of the layer before loading

The compression indices C_C and the pore ratio $e_{0(top)}$ are known from load-settlement tests.

- **Layer A**
  $C_C = 0.08$
  $e_{0(top)} = 0.42$
- **Layer B**
  $C_C = 0.11$
  $e_{0(top)} = 0.45$

The stresses $\sigma'_{0(top)}$ and $\sigma'_{0(bottom)}$ prior to loading can be determined from the unit weights of the individual layers and their thicknesses. We have the following unit weights:

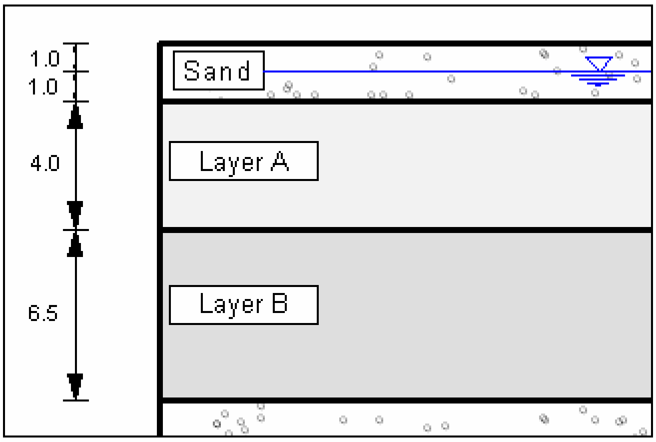


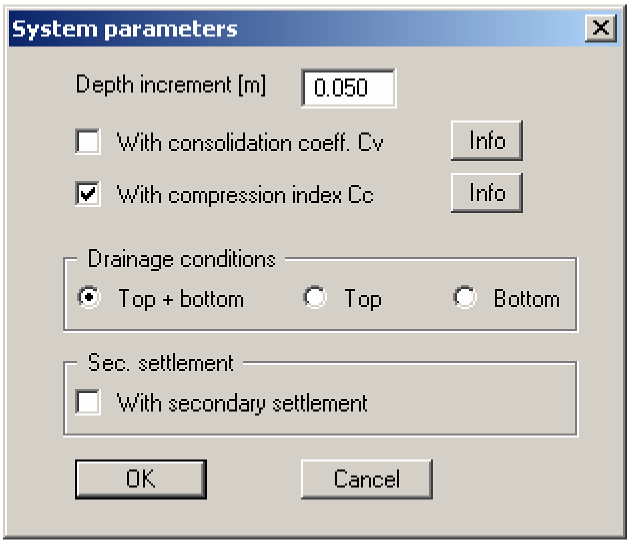
Figure 7 Section of example system

- **Sand**
  $\gamma/\gamma' = 20/10$ kN /m³
- **Layer A**
  $\gamma' = 8$ kN /m³
- **Layer B**
  $\gamma' = 5$ kN /m³

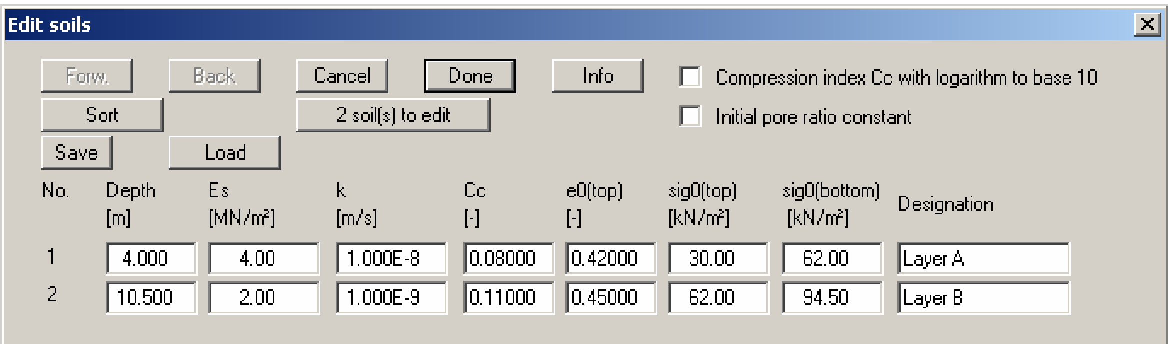
The groundwater level is at 1.0 m below the embankment formation level. This gives us the following stress values:

- **Layer A**
  $\sigma'_{0(top)} = 1.0 \cdot 20.0 + 1.0 \cdot 10.0 = 30$ kN/m²
  $\sigma'_{0(bottom)} = 30.0 + 4.0 \cdot 8.0 = 62$ kN/m²
- **Layer B**
  $\sigma'_{0(top)} = 62$ kN/m²
  $\sigma'_{0(bottom)} = 62.0 + 6.5 \cdot 5.0 = 94.5$ kN/m²

Now enter the values from ***Test 5*** or open the corresponding data record. Then select the menu item "**Edit/System parameters**". Activate the button "**With compression index Cc**" and confirm with "**OK**".



Select the menu item "**Edit/Soils**" and enter the following values:



Go to the "**System/Analyse**" menu item. The various result graphics are then displayed on the screen, including the pore water pressure diagram.

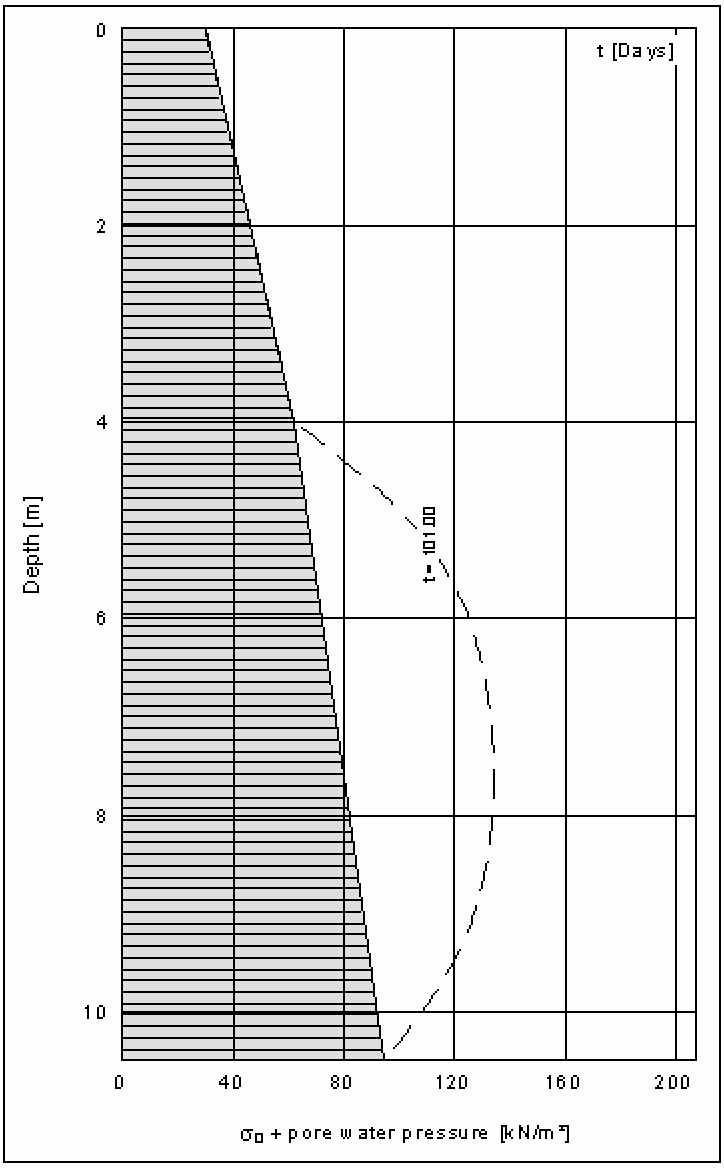


Figure 8 Pore water pressure diagram test 8

Double-clicking in the diagram opens the editor box; here, you can select a visualisation using ***101 days*** by pressing the "**Select times**" button. The effective stresses σ'_0 are also displayed in the pore water pressure diagram.

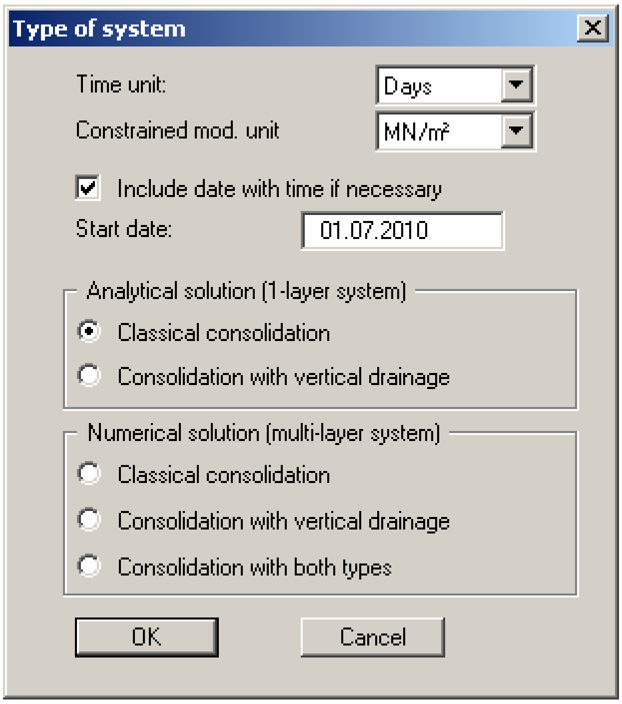
An evaluation of the analysis shows that the consolidation time until 80% settlement is achieved is around 210 days. However, as this analysis also includes the tipping time of 100 days, the lying time after completion of tipping is reduced to 110 days.

7 Description of menu items

7.1 File menu

7.1.1 "New" menu item

The desired solution method can be defined in a dialogue box. You will see the same dialogue box by going to the "**Edit/Type of consolidation**" menu item.



In the dialogue box you define the unit of time to work with and whether the constrained modulus is given as "**kN/m²**" or "**MN/m²**". If the "**Include date with time if necessary**" check box is activated the date can be displayed in the time axis in the subsequent evaluation diagram. The settlement period can thus be better visualised than when only a number of days are given.

Explanations of the consolidation types can be found in the "**Preface**" (see Section 1) and in the "**Theoretical principles**" (see Section 5).

7.1.2 "Load" menu item

You can load a file with system data, which was created and saved at a previous sitting, and then edit the system.

7.1.3 "Save" menu item

You can save data entered or edited during program use to a file, in order to have them available at a later date, or to archive them. The data is saved without prompting with the name of the current file. Loading again later creates exactly the same presentation as was present at the time of saving.

7.1.4 "Save as" menu item

You can save data entered during program use to an existing file or to a new file, i.e. using a new file name. For reasons of clarity, it makes sense to use "**.kon**" as file suffix, as this is the suffix used in the file requester box for the menu item "**File/Load**". If you choose not to enter an extension when saving, "**.kon**" will be used automatically.

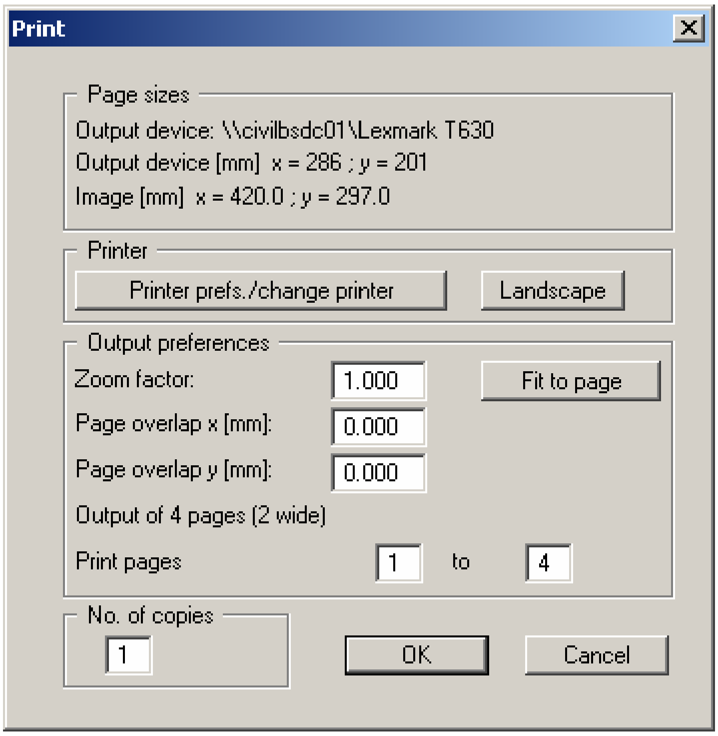
7.1.5 "Printer preferences" menu item

You can edit printer preferences (e.g. swap between portrait and landscape) or change the printer in accordance with WINDOWS conventions.

7.1.6 "Print and export" menu item

You can select your output format in a dialogue box. You have the following options:

- "**Printer**"
  allows graphic output of the current screen contents. to the WINDOWS standard printer or to any other printer selected using the menu item "**File/Printer preferences**". But you may also select a different printer in the following dialogue box by pressing the "'**Printer prefs./change printer**" button.



In the upper part of the dialogue box, the maximum dimensions which the printer can accept are given. Below this, the dimensions of the image to be printed are given. If the image is larger than the output format of the printer, the image will be printed to several pages (in the above example, 4). In order to facilitate better re-connection of the images, the possibility of entering an overlap for each page, in x and y direction, is given. Alternatively, you also have the possibility of selecting a smaller zoom factor, ensuring output to one page ("**Fit to page**" button). Following this, you can enlarge to the original format on a copying machine, to ensure true scaling. Furthermore, you may enter the number of copies to be printed.

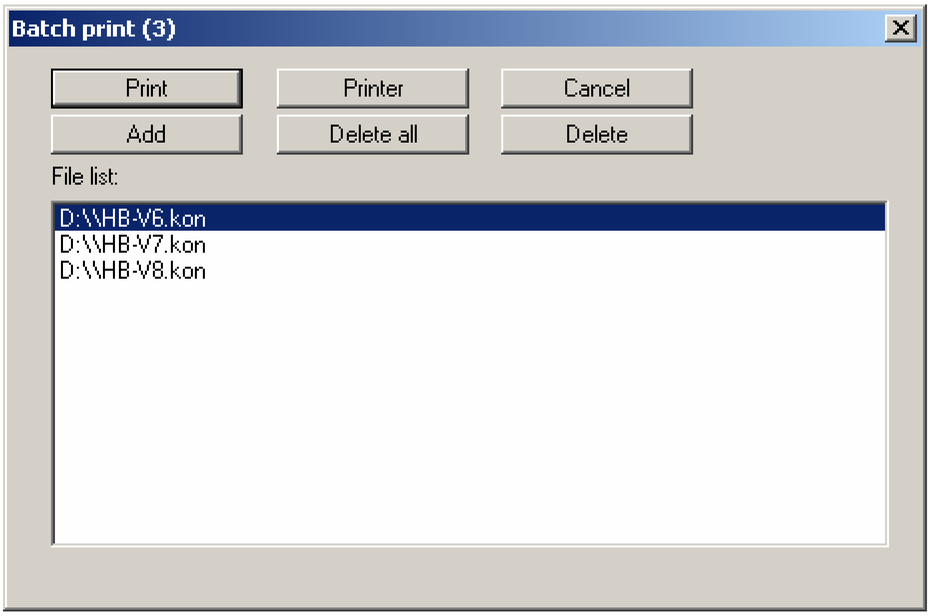
- "**DXF file**"
  allows output of the graphics to a DXF file. DXF is a common file format for transferring graphics between a variety of applications.
- "**GGUCAD file**"
  allows output of the graphics to a file, in order to enable further processing with the **GGUCAD** program. Compared to output as a DXF file this has the advantage that no loss of colour quality occurs during export.
- "**Clipboard**"
  The graphics are copied to the WINDOWS clipboard. From there, they can be imported into other WINDOWS programs for further processing, e.g. into a word processor. In order to import into any other WINDOWS program you must generally use the "*Edit/Paste*" function of the respective application.
- "**Metafile**"
  allows output of the graphics to a file in order to be further processed with third party software. Output is in the standardised EMF format (Enhanced Metafile format). Use of the Metafile format guarantees the best possible quality when transferring graphics.

> If you select the "**Copy/print area**" tool from the toolbar, you can copy parts of the graphics to the clipboard or save them to an EMF file. Alternatively you can send the marked area directly to your printer (see "**Tips and tricks**", Section 8.3).
>
> Using the "**Mini-CAD**" program module you can also import EMF files generated using other GGU applications into your graphics.

- "**MiniCAD**"
  allows export of the graphics to a file in order to enable importing to different GGU applications with the **Mini-CAD** module.
- "**GGUMiniCAD**"
  allows export of the graphics to a file in order to enable processing in the **GGUMiniCAD** program.
- "**Cancel**"
  Printing is cancelled.

7.1.7 "Batch print" menu item

If you would like to print several appendices at once, select this menu item. You will see the following dialogue box:



Create a list of files for printing using "**Add**" and selecting the desired files. The number of files is displayed in the dialogue box header. Using "**Delete**" you can mark and delete selected individual files from the list. After selecting the "**Delete all**" button, you can compile a new list. Selection of the desired printer and printer preferences is achieved by pressing the "**Printer**" button.

You then start printing by using the "**Print**" button. In the dialogue box which then appears you can select further preferences for printer output such as, e.g., the number of copies. These preferences will be applied to all files in the list.

7.1.8 "Exit" menu item

After a confirmation prompt, you can quit the program.

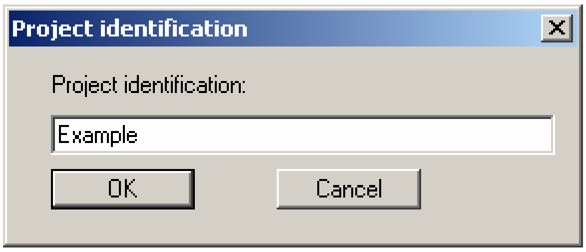
7.1.9 "1, 2, 3, 4" menu items

The "**1, 2, 3, 4**" menu items show the last four files worked on. By selecting one of these menu items the listed file will be loaded. If you have saved files in any other folder than the program folder, you can save yourself the occasionally onerous ***rummaging*** through various sub-folders.

7.2 Edit menu

7.2.1 "Project identification" menu item

You may enter a more detailed description of the system, which will be automatically entered into the ***General legend*** (see Section 7.4.1).



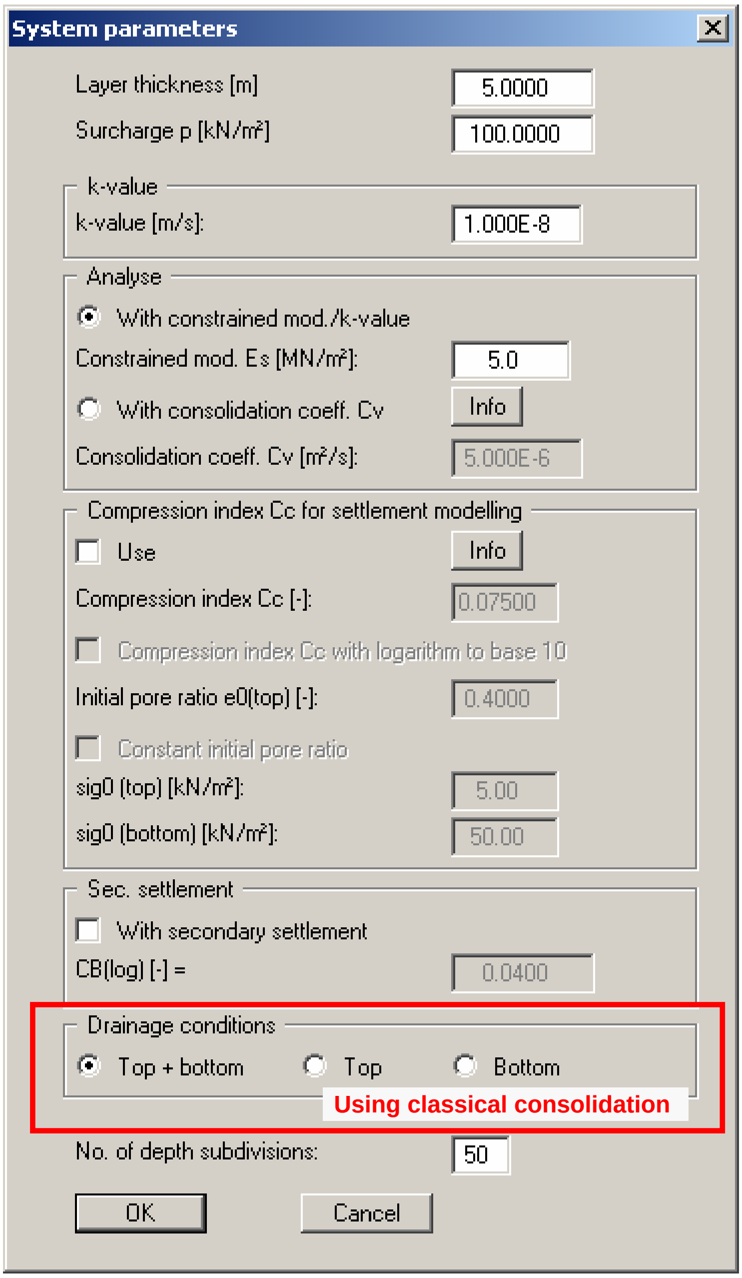
7.2.2 "Type of consolidation" menu item

Using this menu item you can edit the default preferences of the current system. The dialogue box corresponds to the box in the menu item "**File/New**" (see descriptions in Section 7.1.1).

7.2.3 "System parameters" menu item

7.2.3.1 Analytical methods

The governing system boundary conditions are entered using the menu item "**Edit/System parameters**". If you have chosen to use an ***analytical*** method to solve the problem, you will see the following dialogue box (example):



You must first enter the layer thickness and the load that initiates the consolidation process.

In order to properly model the temporal development of settlement, the consolidation coefficient C_V is required. This can be calculated from the constrained modulus E_S and the permeability coefficient k or be entered directly, if the value is known from oedometer tests. Enter your data according to the activated check boxes.

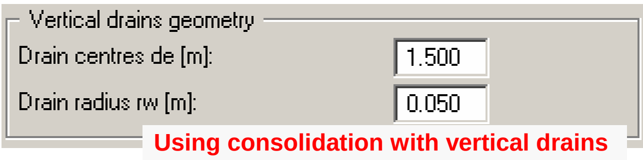
Alternatively, the settlements can also be calculated using the compression index C_C. Further information on this can be read by pressing the "**Info**" button after activating the "**Use**" compression index C_C check box. In the English-speaking world, in contrast to Germany, the compression index C_C is not defined to base $\boldsymbol{log_e}$, but to base $\boldsymbol{log_{10}}$. This can be specified here.

If a secondary settlement is adopted activate the "**With secondary settlement**" check box and enter the soil parameter $C_{B(\log)}$ (see "**Theoretical principles/Secondary settlements**" in Section 5.6).

For the "**Classical consolidation (analytical)**" you then define the drainage conditions (see lower section of the above dialogue box). The number given after "**No. of depth subdivisions**" defines the number of points at which the program determines the pore water pressure. Because the program performs an integration of the pore water pressures at these points to determine the degree of consolidation, you should ensure that the number of subdivisions is not too small.

For a system utilising "**Consolidation (analytical) with vertical drains**", drainage is exclusively horizontal, resulting in constant pore water pressures across the layer thickness for all time steps. The "**No. of depth subdivisions**" in a system with vertical drains can therefore be defined using the minimum value of "**3**", thereby reducing modelling time. For the same reason, layer thickness does not influence the modelling results. It is only useful for the graphical representation of the pore water pressure distribution.

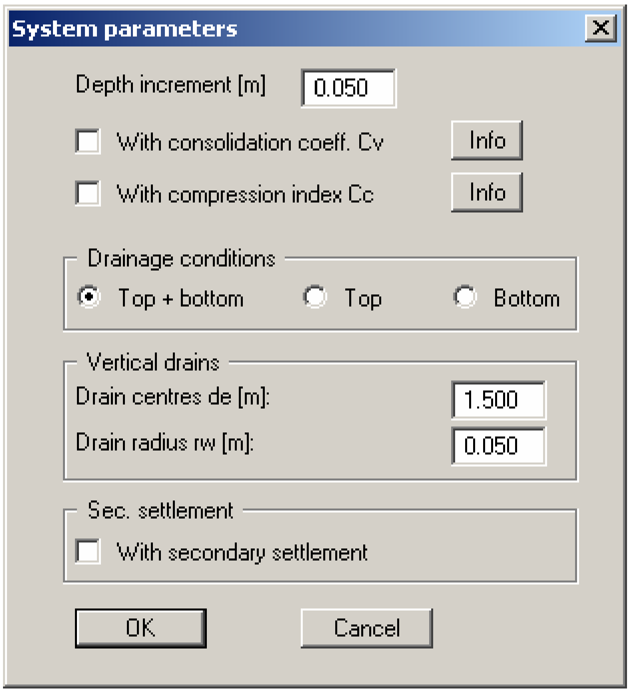
It is not necessary to define drainage conditions in a system employing vertical drains. Instead of the drainage conditions the "**Vertical drainage geometry**" group box is shown. Here, you define the drain centres and the drain radius (also see Figure 5 in "**Theoretical principles**", Section 5.4).



Using consolidation with vertical drains

7.2.3.2 Numerical methods

If you chose to employ a ***numerical*** solution method, you need only select general boundary conditions in "**Edit/System parameters**". Input of soil properties can be carried out by going to the "**Edit/Soils**" menu item (see Section 7.2.5). When you go to "**Consolidation with both types (numerical)**", the following dialogue box opens



You must first enter the depth increment (difference equations). The proposed default value of **0.05** is generally sufficient for all but very thin layers. If you are unsure about the selected time increment, repeat a previous calculation using either half or double the increment and then compare the two results. If the deviation is only ***minor***, the selected time increment was sufficiently small.

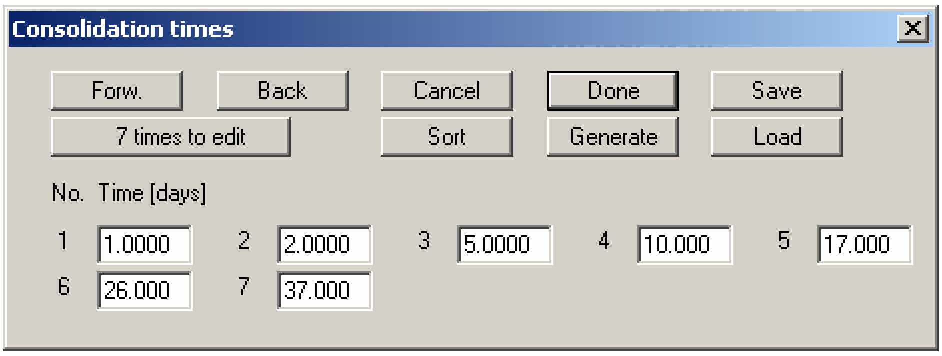
Here, you also specify whether modelling is carried out using the consolidation coefficient C_V and/or the compression index C_C.

Define the drainage conditions and the dimensions of the vertical drains in the lower group box. If you select one of the other ***numerical*** methods in the "**Edit/Type of consolidation**" menu item, only the respective relevant group box ("**Drainage conditions**" or "**Vertical drains**") is displayed in the above dialogue box.

If a secondary settlement is adopted activate the "**With secondary settlement**" check box. The soil parameter $C_{B(\log)}$ for the individual soil strata is entered using the menu item "**Edit/Secondary settlements**" (see Section 7.2.10).

7.2.4 "Define times" menu item

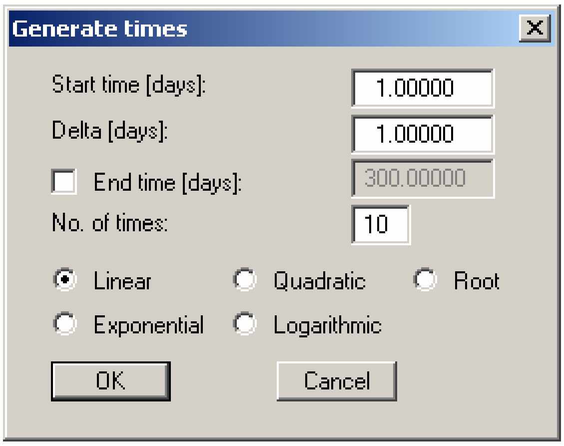
This menu item allows you to define times for the consolidation analysis.



If you would like to edit the number of times used, press the "**x times to edit**" button and then enter the new number of times. Use the "**Sort**" button to achieve ascending sorting of times. This sorting is carried out automatically upon leaving the dialogue box, without the function being explicitly called-up.

> You can also use this function to eliminate a time from the table.
>
> Simply assign the time to be eliminated a large value (e.g. 9999.0) and then click the "**Sort**" button. The corresponding time is now the last time in the table and can be ***deleted*** by reducing the number of times accordingly.

Using the "**Generate**" button you can easily generate a large number of new times applying a predefined ***increase mechanism*** (also see the example in ***Test 1***, Section 6.2).

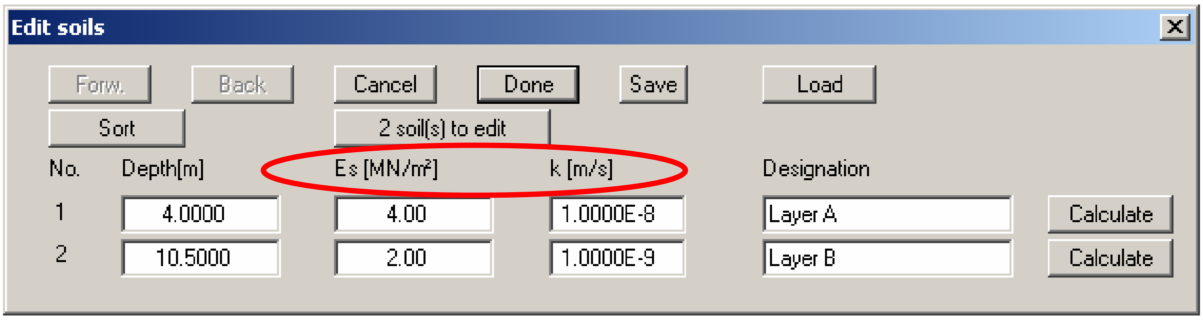


7.2.5 "Soils" menu item

> This menu item is only available for the ***numerical*** methods. The soil properties are entered in "**Edit/System parameters**" when employing ***analytical*** methods.

First, define the number of soils in your system using the "**x soil(s) to edit**" button. Using the "**Sort**" button, you can sort the soils according to depth; otherwise, sorting is carried out automatically upon leaving the dialogue box. To delete soil layers simply assign the soil a ***large*** depth value (e.g. 99.0) and then press the "**Sort**" button. The corresponding soil is now at the end of the table and can be ***deleted*** by reducing the number of soils accordingly.

If you activated neither "**With consolidation coefficient Cv**" nor "**With compression index Cc**" in the "**Edit/System parameters**" menu item, you will see the following dialogue box.



The layer depths (base) are with reference to the top of the uppermost consolidation layer, as are all other inputs. Furthermore:

- E_S = constrained modulus of soil [kN/m²]
- k = permeability of soil [m/s].

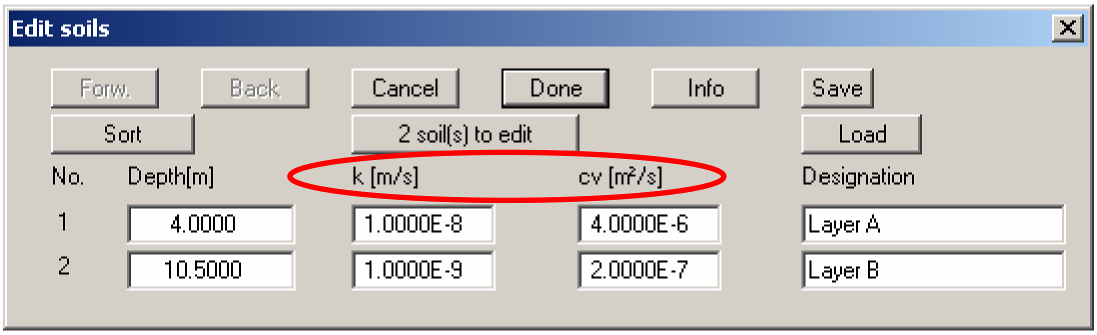
You can alter the units for the constrained modulus to "**kN/m²**" in "**Edit/Type of consolidation**".

In order to allow modelling of the temporal development of settlement, the consolidation coefficient C_V is required. This can be calculated from the constrained modulus E_S and the permeability coefficient k:

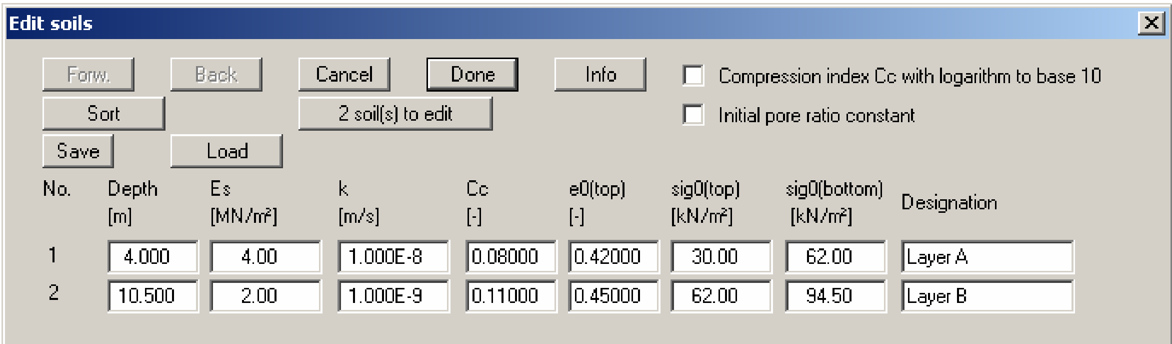
$$\mathbf{C_V = E_S \cdot k / gamma(water)}$$

Using the "**Calculate**" buttons it is possible to determine the constrained modulus or the value of k for a given value of C_V and to adopt this as the new parameter.

If you activated "**With consolidation coefficient Cv**" in the "**Edit/System parameters**" menu item, enter the value of k and the consolidation coefficient into the slightly different dialogue box.



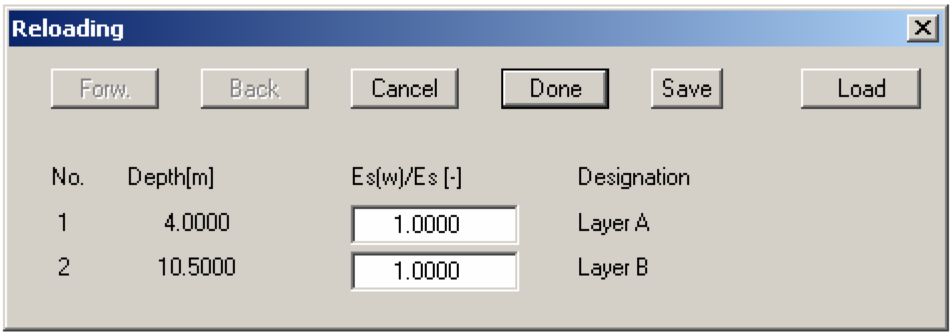
If you activated "**With compression index Cc**" in the "**Edit/System parameters**" menu item, the soils dialogue box is expanded by the corresponding parameters. Depending on whether you are also working with the consolidation coefficient C_V, you will see the corresponding input boxes for C_V or constrained modulus and k (see the following example).



7.2.6 "Soils (reloading)" menu item

This menu item is only available if you have selected ***numerical*** methods and you are working with a non-monotonous load increase.

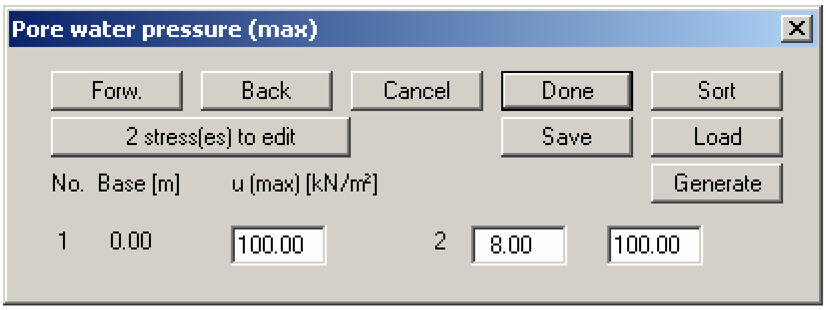
In the dialogue box you define the ratio of the constrained modulus for reloading to the constrained modulus for initial loading for each type of soil. If you are working with the compression index, define C_C/C_S accordingly.



7.2.7 "Pore water pressure (max)" menu item

This menu item is only active if you have selected one of the ***numerical*** methods.

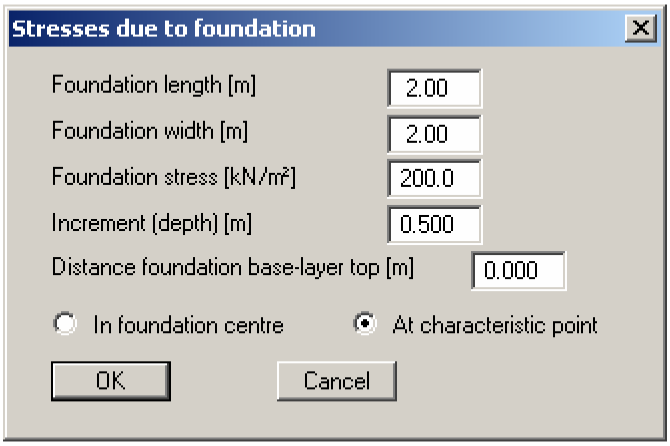
If you would like to edit the number of stresses, select the "**x stresses to edit**" button and then enter the new number of stresses. Using the "**Sort**" button, you can sort the stresses according to depth. This sorting is carried out automatically upon leaving the dialogue box, without the function being explicitly called-up.



The layer depths (base) are with reference to the top of the uppermost consolidation layer, as are all other inputs. You must also define the governing pore water pressures *u* corresponding to the given depths.

The pore water pressure distribution can be saved to a "**.kon_spg**" file using the "**Save**" button; it can be reloaded later using the "**Load**" button and thus be adopted for a different system.

A special ***delicacy*** here is the "**Generate**" button:

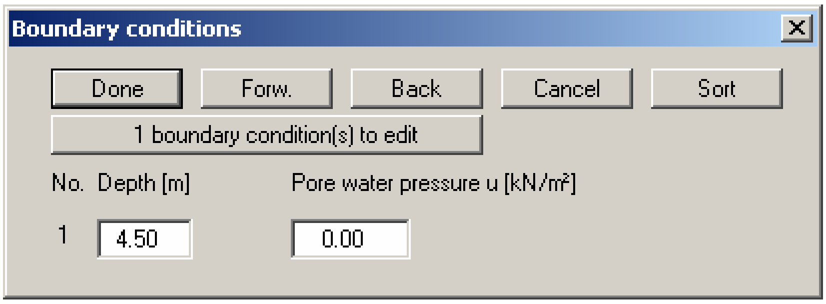


It allows you to generate the stress distribution of any footing foundation at either the characteristic point or at the foundation centre. The "**Increment (depth)**" input specifies the ***dept subdivisions*** at which the stresses are calculated. If the footing is located above the consolidating layer, specify the distance in "**Distance foundation base-layer top [m]**".

7.2.8 "Boundary conditions" menu item

> This menu item is only active if you have selected "**Classical consolidation (numerical)**" as the consolidation type.

If there are permeable layers within the system which can drain externally, it is possible to use this menu item to take this influence into consideration by means of boundary conditions (also see "**Theoretical principles**", Section 5.2.2).

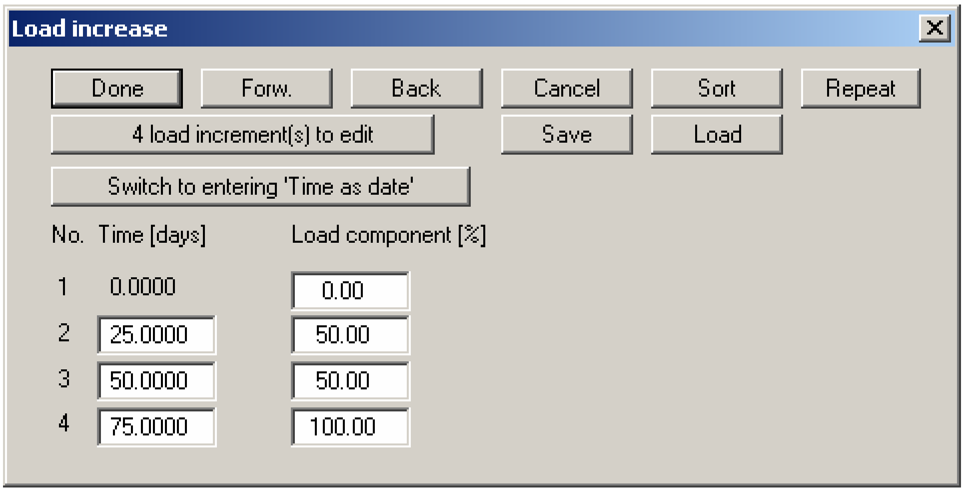


Enter the depth and the respective pore water pressure, which will then be kept constant for a subsequent analysis for the entire duration of consolidation.

7.2.9 "Load increase" menu item

This menu item is only active if you have selected one of the ***numerical*** methods.

Consideration of a continuous load application during a structure's entire manufacturing phase can be achieved using this menu item. Using the "**x load increments to edit**" button in the following dialogue box you first define the number of load increases.

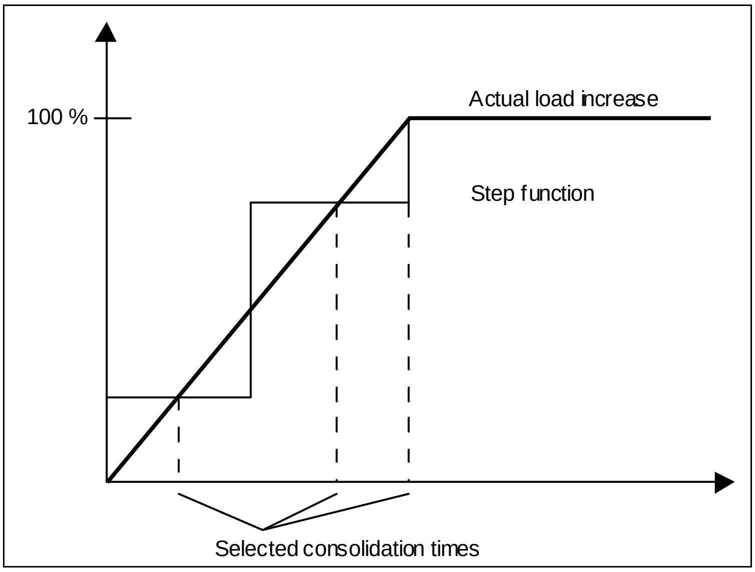


The load increase need not necessarily be defined as linear but can be entered as any kind of polygon course. Define the time and corresponding percentage load increase. It is also possible to model a load decrease.

A given, repetitive load pattern can be automatically created using the "**Repeat**" button. This makes it unnecessary to enter the entire sequence using individual values.

For long consolidation periods it may be useful to define the load increase by specifying dates (see the "**Example with date.kon**" file). Click the "**Switch to entering "Time as date"**" button. The previously entered times are automatically converted to the start date (see dialogue box "**File/New**", Section 7.1.1). After changing the button reads "**Switch to entering "Time as number"**". It is possible to change back to entering the loads in the selected time units, e.g. in days, by clicking the button.

The defined load increase is converted to a step function. The exact form of the step function depends on the time steps selected for use in the consolidation analysis (see menu item "**Edit/Define times**", Section 7.2.4).

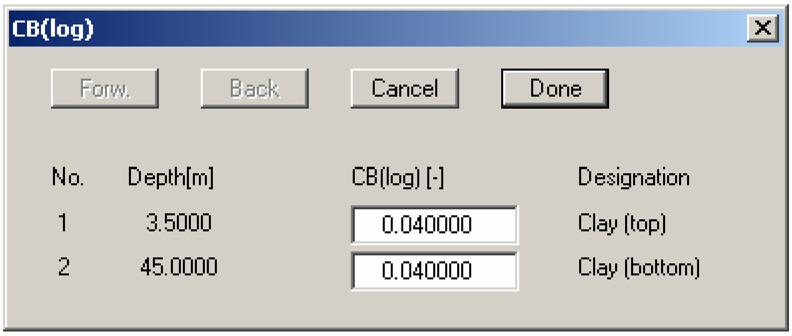


The more consolidation times are defined in the region of the load increase, the more precise will be the approximation of the real function to the step function.

7.2.10 "Secondary settlements"

> This menu item is only active if you have selected one of the ***numerical*** methods.

If secondary settlements are activated in the system data the following dialogue box opens via this menu item:



The respective soil parameter $C_{B(\log)}$ for the soil strata can be defined here (see "**Theoretical principles/Secondary settlements**" in Section 5.6).

7.2.11 "Installation time (vertical drains)" menu item

> This menu item is only active if you have selected "**Consolidation with both types (numerical)**" as the consolidation type.

You must define the installation time of the vertical drains. The time from which the vertical drains are incorporated in the analysis is marked in the evaluation diagrams.

7.2.12 "cv(axial)/cv" menu item

> This menu item is only active if you have selected "**Consolidation with both types (numerical)**" as the consolidation type.

You define the ratio of the consolidation coefficients C_V (axial)/C_V .

7.3 System menu

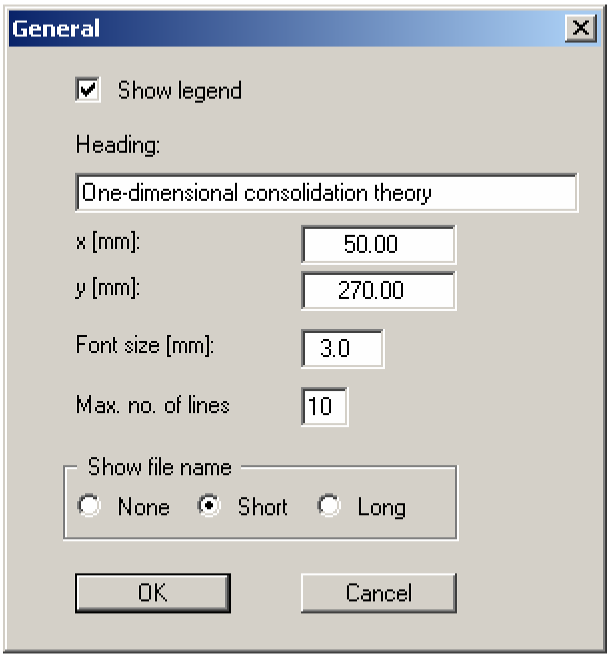
7.3.1 "Analyse" menu item

This starts the analysis. Alternatively, press the [**F5**] function key or click on the ***Calculator*** in the tool bar. If you have specified particular settings for the system the program notified you of these settings before analysis begins. The program first performs an estimate of the modelling time required. If the forecast modelling time is greater than 5 seconds, a message box opens, allowing you to start or abort the analysis. Information on reducing the modelling time is available by pressing the "**Info**" button. If you click "**Yes**", modelling follows. Once complete, the modelled system is displayed.

7.4 *Output preferences menu*

7.4.1 "General legend" menu item

A legend with general properties will be displayed on your output sheet if you have activated the "**Show legend**" check box. Using this menu item you can alter the type of presentation.



You can edit the legend "**Heading**" at will. The position of the legend can be defined and edited using the values "**x value**" and "**y value**". You control the size of the legend using "**Font size**" and "**Max. no. of lines**"; where necessary, several columns are used.

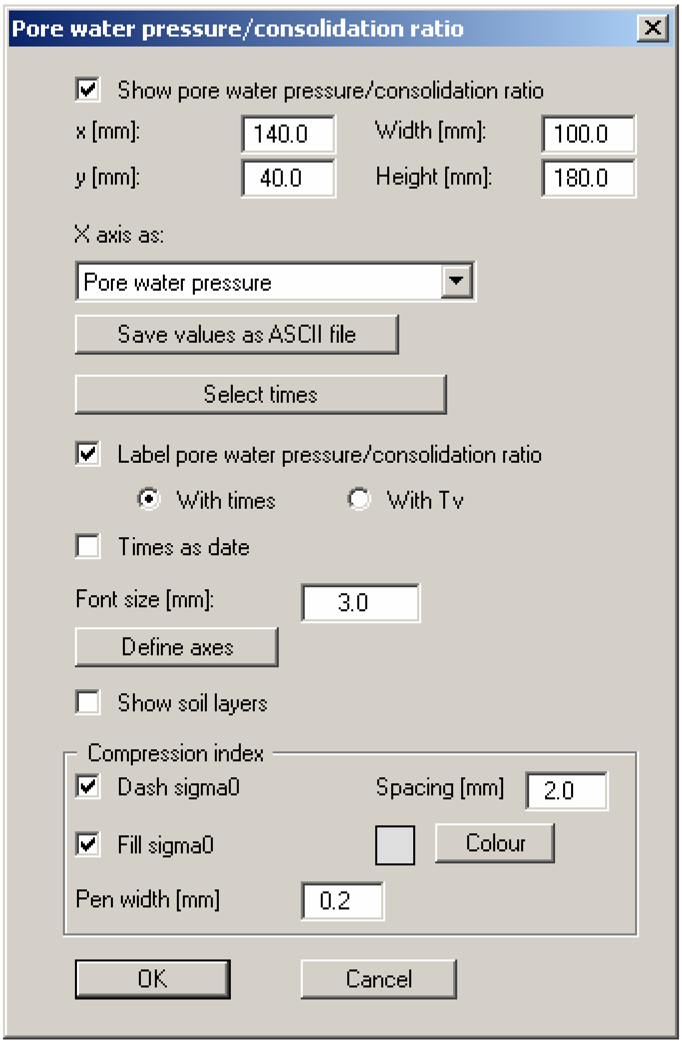
> The fastest way to modify the position of the legend is to press the [**F11**] function key and then to pull the legend to the new position with the left mouse button pressed.

The file name can be switched off ("**None**" option button) or be displayed automatically with or without the path by selecting the appropriate "**Short**" or "**Long**" option button.

Any project identification entered (see Section 7.2.1) will also be shown in the general legend.

7.4.2 "Pore water pressure/consolidation ratio" menu item

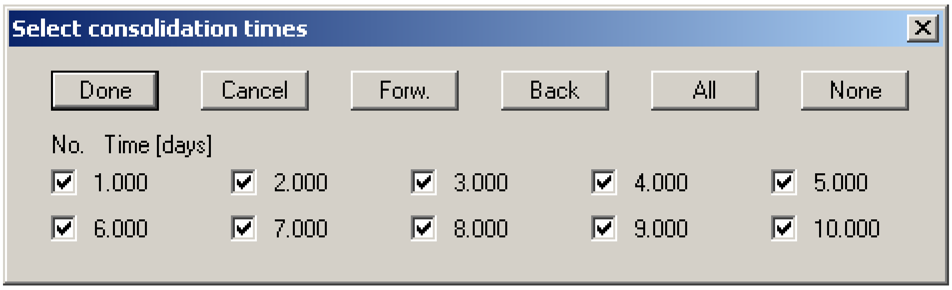
If you activate the "**Show pore water pressure/consolidation ratio**" check box in the dialogue box for this menu item, your output sheet will display a graphical representation of the pore water pressure profile across the depth, or the consolidation ratio (see "**Theoretical principles**"). A variety of settings are available in the dialogue box, depending on the type of consolidation selected and the system defaults.



You can define and edit position and size of the graphics by editing the values "**x**" and "**y**", and "**Width**" and "**Height**". You can also edit these values from within the screen presentation by pressing the [**F11**] function key (see Section 7.4.10).

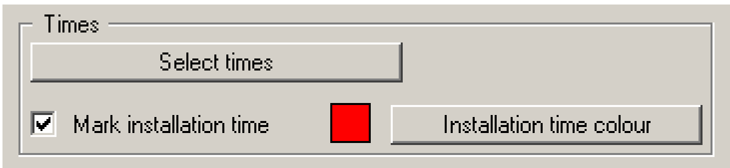
With the help of the combi-box below "**X axis as:**", the representation of the x-axis can be switched from pore water pressure in [kN/m²] or [MN/m²] to a representation as the dimensionless consolidation ratio U_Z. The calculated pore water pressures can also be saved as an ASCII file. Here, you can define the time up to which the values are saved in the dialogue box.

The "**Select times**" button activates the following dialogue box where you can select those of the defined times to be displayed in the pore water pressure distribution or consolidation ratio graphics.



All times are activated by pressing the "**All**" button. All times are deactivated by pressing the "**None**" button. This selection is particularly useful because as many points (times) as possible should be used in order to achieve a continuous smooth course in the graphical representation of the temporal development of the consolidation degree. However, too many distribution lines disturb the graphical representation of pore water pressure profiles, as they often merge into one another. If the "**Times as date**" check box in the above dialogue box is activated, the date for the respective consolidation period is shown instead of the time in the selected units.

If vertical drains are subsequently installed (consolidation type "**Numerical consolidation with both drain types**") the installation time can also be marked in the specified colour in the active "**Times**" group box.



If you activate the "**Show pore water pressure/consolidation ratio**" check box the distribution lines are labelled with either the "**Times**" or the auxiliary value "$\mathbf{T_V}$". T_V is defined as

$$\mathbf{T_V = C_V / H^2 \cdot t}$$

C_V = consolidation coefficient = $k \cdot E_S/\gamma_W$
H = layer thickness
t = time

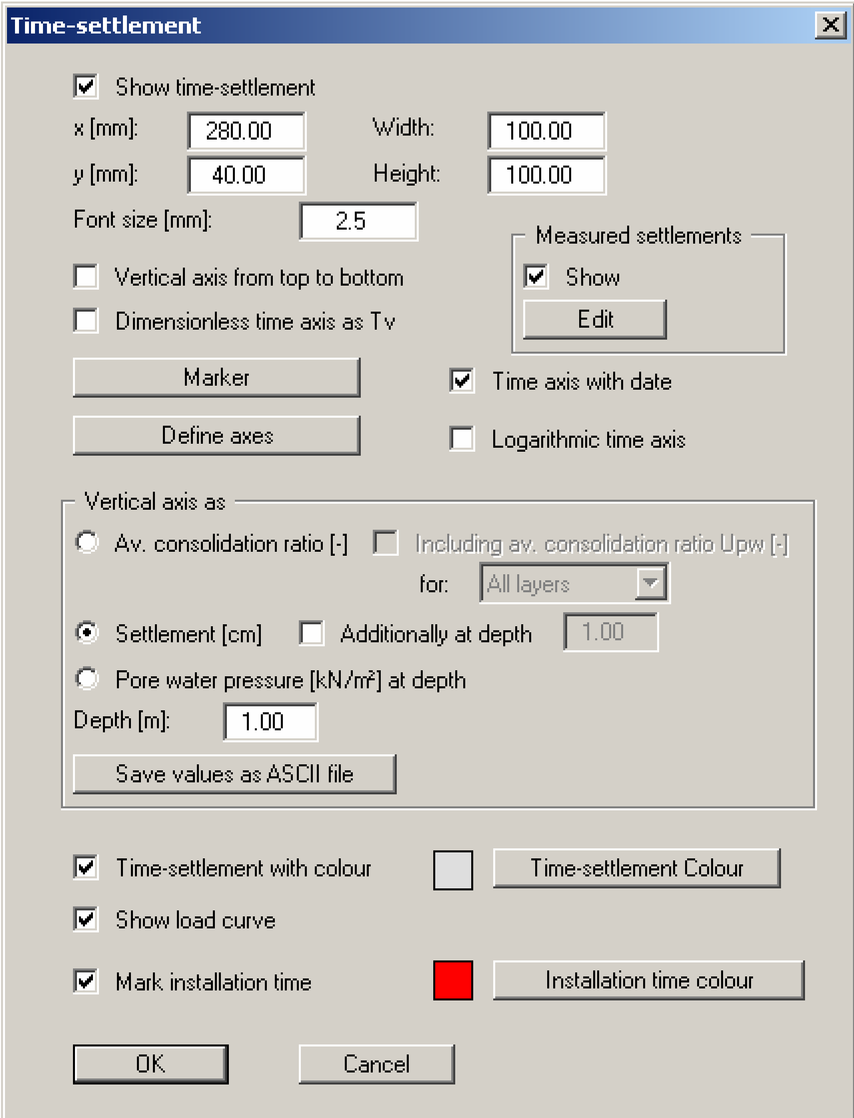
> Representation of the curve by means of "$\mathbf{T_V}$" is generally only useful when re-modelling standardised curves from the literature.

For long consolidation periods it may be useful to label the time axis with the date instead of days or another defined time unit (see the "**Example with date.kon**" file). Activate the "**Times as date**" check box to enable this option. The date function must be activated in the "**File/New**" or "**Edit/Type of consolidation**" menu item dialogue boxes to use this function (see Section 7.1.1). It is also possible to define the diagram "**Font size**" and user-defined axes values. The "**Max. ratio**" of the x- and y-axes are defined after clicking "**Define axes**".

If you activate the "**Show soil layers**" check box, the current soil sequence is displayed in the graphics. This check box is only available when using a ***numerical*** method. When modelling with the ***compression index*** C_C a number of selections affecting the representation can be made in the lower group box.

7.4.3 "Time-settlement" menu item

If you activate the "**Show time-settlement**" check box in the dialogue box for this menu item, the temporal profile of the degree of consolidation is displayed on the screen.



You can define and edit position and size of the graphics by editing the values "**x**" and "**y**", and "**Width**" and "**Height**". You can also edit these values from within the screen presentation by pressing the [**F11**] function key (see Section 7.4.10).

If the "**Vertical axis from top to bottom**" check box is activated, representation is ***reversed*** with regard to the normal representation of settlements. Using the "**Dimensionless time axis as T_V**" check box it is possible to switch representation of the time axis to dimensionless T_V values. This is generally only useful when re-modelling standardised curves from the literature.

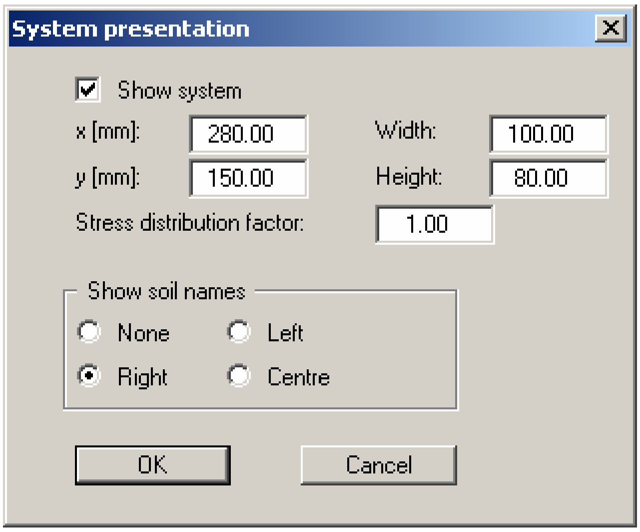
You can indicate your selected times with a marker; the size, colour and shape of the marker can be specified in a dialogue box by pressing the "**Marker**" button. Alternatively, you can choose user-defined axes or a logarithmic time axis. If the labelling of the time axis is too tight, you can edit the units of time in the "**Edit/Type of consolidation**" menu item (see Section 7.1.1). If the date function is also activated, additional labelling with the date can be achieved in the time-settlement diagram by activating the "**Time axis with date**" check box.

In the "**Vertical axis as**" group box you define the variable to be drawn versus the time axis. This also activates further fields for specifying preferences with regard to the selected variable, depending on the chosen representation. In the above dialogue box the "**Settlement [cm]**" option button is activated. So the "**Measured settlements**" group box is also active and you can display individual measured values, for example measured at on-site settlement gauges, in addition to the calculated settlement curve. The additional measured values are entered into a separate dialogue box which opens after you click the "**Edit**" button. If pore water pressure visualisation is active the pore water pressure values calculated for a given depth can be saved in an ASCII file.

Further graphic elements can be activated at the bottom of the dialogue box; the time-settlement area can be colour-backed, for example. If you have defined a load increase, the step function on which modelling is based can be displayed in the graphics by activating the "**Show load curve**" check box. This makes a separate representation of the load curve unnecessary (see Section 7.4.7). Preferences can be defined for the pen colour and width in the menu item "**Graphics preferences/Pen colour and width**" (see Section 7.5.5). If vertical drains are subsequently installed (consolidation type "**Numerical consolidation with both drain types**") the installation time can also be marked in the specified colour.

7.4.4 "System presentation" menu item

The current system is displayed in the graphics when you activate the "**Show system**" check box. The format and appearance of the graphics can be altered using this menu item.

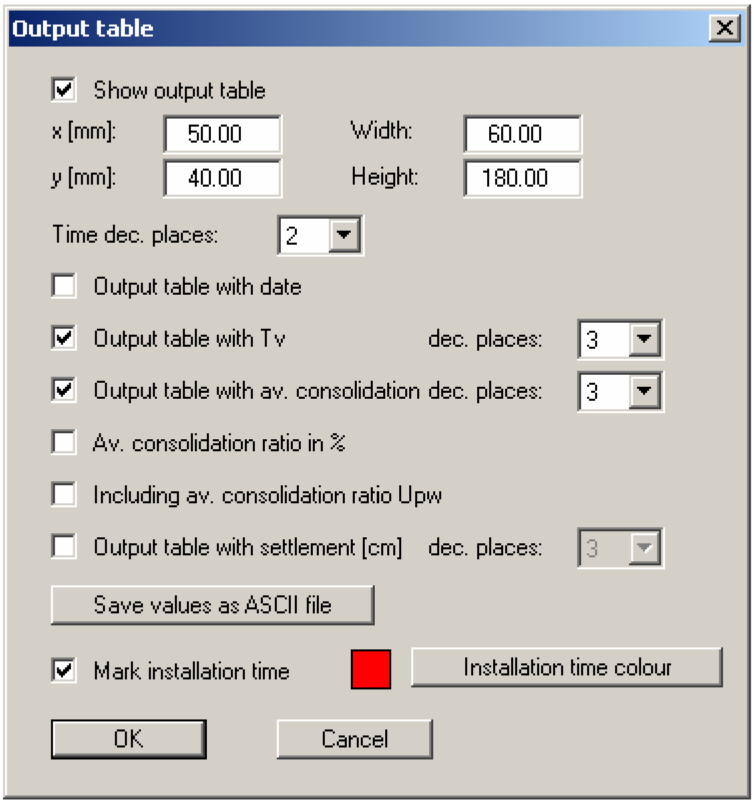


You can define and edit position and size of the graphics by editing the values "**x**" and "**y**", and "**Width**" and "**Height**". You can also edit these values from within the screen presentation by pressing the [**F11**] function key (see Section 7.4.10).

If you have selected a ***numerical*** method for the type of consolidation, you can label the system diagram with the soil names at the desired position (see dialogue box above).

7.4.5 "Output table" menu item

In addition to graphically representing the temporal profile of the degree of consolidation, a table (output table) containing the degree of consolidation is also displayed if the "**Show output table**" check box is activated in the dialogue box. The settlements can also be shown in the output table.



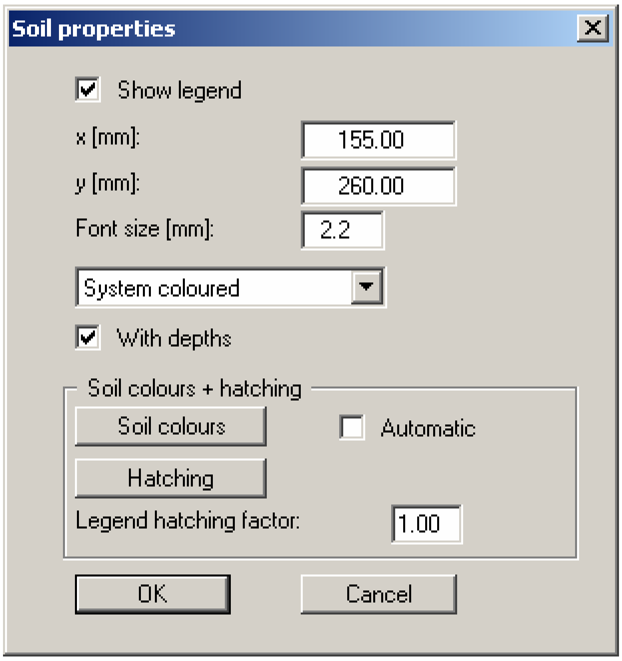
You can define and edit position and size of the table by editing the values "**x**" and "**y**", and "**Width**" and "**Height**". You can also edit these values from within the screen presentation by pressing the [**F11**] function key (see Section 7.4.10). The font size used for the output table entries is automatically adapted by the program to suit the size of the table.

By default, the output table also uses the dimensionless time value T_V. The T_V entry can be suppressed by deactivating the "**Output table with T_V**" check box. Further entries can also be adopted for the output table. In addition, it is possible to save the output table by clicking the "**Save values as ASCII file**" button.

7.4.6 "Soil properties legend" menu item

This menu item is only active if you have selected one of the ***numerical*** methods.

A legend containing the soil properties is displayed with the graphics. If the "**Show legend**" check box is activated you can edit the legendrepresentation in the dialogue box for this menu item.



You can define and edit the position of the legend using the values "**x**" and "**y**". The size of the legend is controlled by the values for "**Font size**". The fastest way to modify the position of the legend is to press the [**F11**] function key and then to pull the legend to the new position while holding the left mouse button.

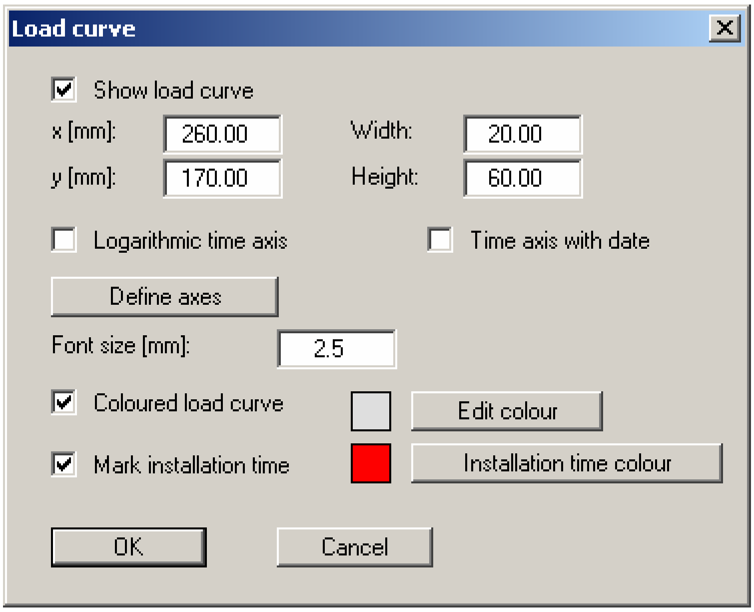
If "**System coloured**" is activated in the combi-box, the soils will be displayed coloured both in the soil properties legend and in the system graphics (see Section 7.4.4). You can also define either hatching or colour fill and hatching for the different soil types in the combi-box. If you select "**System without all**", the soils are merely numbered. The depths of the individual soil layers are shown in the legend if the "**With depths**" check box is activated. The required settings can be made in the "**Soil colours + hatching**" group box:

- "**Automatic**"
  The soils are assigned soils colours automatically by the program. If the check box is not selected, the soil colours individually defined using the "**Soil colours**" button will be adopted.
- "**Soil colours**"
  You will see a dialogue box, in which you can define your preferences. After clicking the button with the desired number you can assign each soil layer a new number or reorganise using the "**Soil colours/Reorganise**" command button. You can save your colour preferences to a file with "**Soil colours/Save**" and use them for different systems by means of the "**Soil colours/Load**" command button. In the lower group box you can also transfer the colour preferences to the Windows colour management dialogue box, or vice versa, as user-defined colour preferences for example. You can read a further description by pressing the "**Info**" button.

- "**Hatching**"
  Opens a dialogue box in which you can define different hatching for each soil.
- "**Legend hatching factor**"
  Input here allows tighter hatching in the soil legend. Input < **1.00** can be useful if the hatching spacing is so large that the differences in the hatching of individual soils can no longer be properly discerned in the relatively small boxes used in the legend.

7.4.7 "Load curve" menu item

If you have defined a load increase, the load curve can be displayed in the graphics. In addition to the actual load curve, the step function used as the basis for modelling, resulting from the user-defined consolidation times, is also represented. If the "**Show load curve**" check box is activated you can edit the representation in the dialogue box for this menu item.



You can define and edit position and size of the graphics by editing the values "**x**" and "**y**", and "**Width**" and "**Height**". You can also edit these values from within the screen presentation by pressing the [**F11**] function key (see Section 7.4.10).

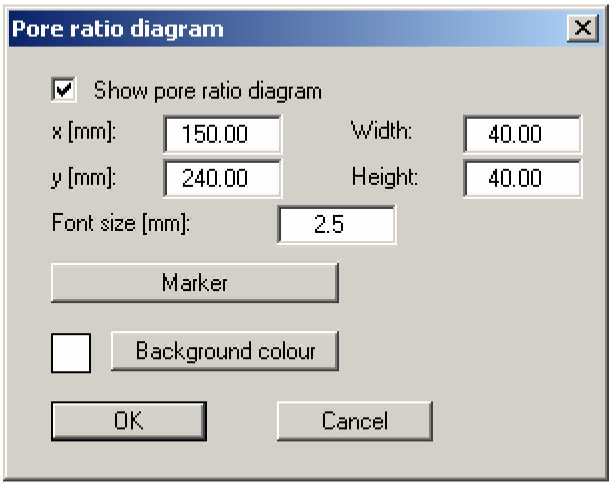
A logarithmic time axis or an additional date display on the time axis can be activated. The date function must be activated in the "**File/New**" or "**Edit/Type of consolidation**" menu item dialogue boxes for this (see Section 7.1.1). Alter the axes selected by the program using the "**Define axes**" button. In the subsequent dialogue box you specify the times and load values as minimum and maximum values to be used for the x- and y-axes.

The "**Load curve with colour**" check box activates a colour-backing in the specified colour for the load area. Preferences can be defined for the pen colour and width in the menu item "**Graphics preferences/Pen colour and width**" (see Section 7.5.5). If vertical drains are subsequently installed (consolidation type "**Numerical consolidation with both drain types**") the installation time can also be marked in the specified colour.

7.4.8 "Pore ratio diagram" menu item

This menu item is only active if you have selected ***Compression index C_C*** for the settlement analysis (see menu item "**Edit/System parameters**", Section 7.2.3).

If the "**Show pore ratio diagram**" check box is activated you can edit the graphical representation in the dialogue box for this menu item.

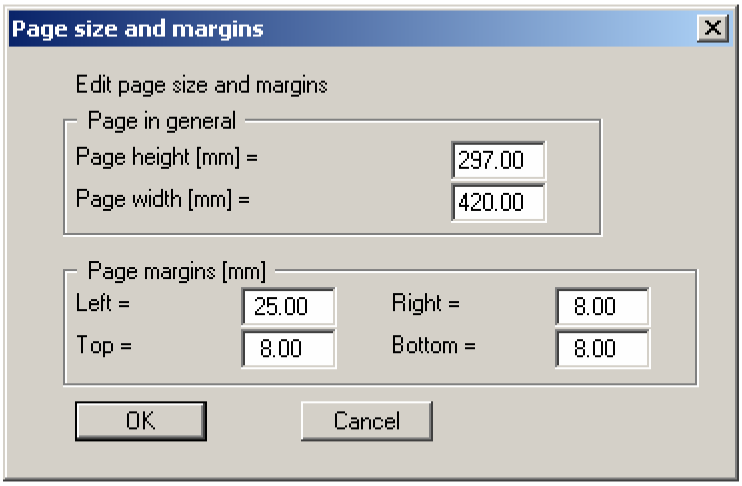


You can define and edit the position of the graphics by editing the values "**x**" and "**y**", and "**Width**" and "**Height**". You can also edit these values from within the screen presentation by pressing the [**F11**] function key (see Section 7.4.10). The background colour of the legend can be altered.

By pressing the "**Marker**" button a further dialogue box opens allowing you to define the size, colour and shape of the marker (e.g. triangle, rectangle, circle) according to your wishes. In order to suppress a representation with markers, deactivate the "**Pore ratio diagram with markers**" check box in this dialogue box.

7.4.9 "Page size and margins" menu item

The default page set-up is A3 when the program is started. You can edit the page format in the following dialogue box.



- "**Page in general**" defines the size of the output sheet. The A3 format is set as default. The program automatically draws thin cutting borders around the page, which are required when using a plotter on paper rolls. The borders can be switched off using the menu item "**Graphics preferences/With borders**" (see Section 7.5.4).
- "**Page margins**" defines the position of a frame as a distance to the margins. This frame encloses the subsequent diagram.

7.4.10 "Move objects" menu item

When you go to this item you can move the various objects and legends with the aid of the mouse. Move the mouse over the object to be moved. When you are located above a moveable object the mouse pointer appears in the shape of a cross. You can now press and hold the left mouse button and drag the object to the required position.

After going to this menu item only one object at a time can be moved using the mouse or its size be altered.

In order to move or edit several objects, this function can be more quickly activated by pressing [**F11**] or the  icon.

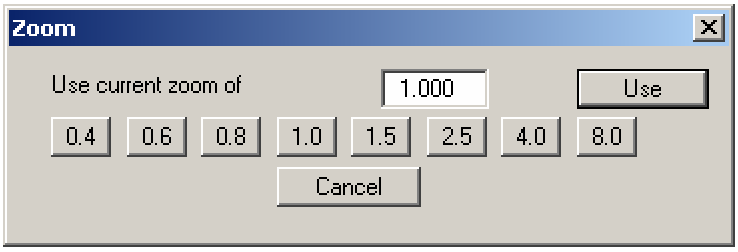
The size of an object can also be altered using this menu item or the [**F11**] key. If you move over the frame of a changeable object after activating this function the mouse assumed the shape of a double-headed arrow. Hold the left mouse button and move the frame until the element has reached the required size. To retain the ratio of the sides, pull at one corner only. If on one side only is pulled the object will become higher or wider.

7.5 Graphics preferences menu

7.5.1 "Refresh and zoom" menu item

The program works on the principle of ***What you see is what you get***. This means that the screen presentation represents, overall, what you will see on your printer. In the last consequence, this would mean that the screen presentation would have to be refreshed after every alteration you make. For reasons of efficiency and as this can take several seconds for complex screen contents, the screen is not refreshed after every alteration.

If, e.g., after using the zoom function (see below), only part of the image is visible, you can achieve a complete view using this menu item.



A zoom factor between 0.4 and 8.0 can be entered in the input box. By then clicking on "**Use**" to exit the box the current factor is accepted. By clicking on the "**0.4**", "**0.6**", etc. buttons, the selected factor is used directly and the dialogue box closed.

It is much simpler, however, to get a complete overview using [**Esc**]. Pressing [**Esc**] allows a complete screen presentation using the zoom factor specified in this menu item. The [**F2**] key allows screen refreshing without altering the coordinates and zoom factor.

7.5.2 "Zoom info" menu item

By clicking two diametrically opposed points you can enlarge a section of the screen in order to view details better. An information box provides information on activating the zoom function and on available options.

7.5.3 "Legend font selection" menu item

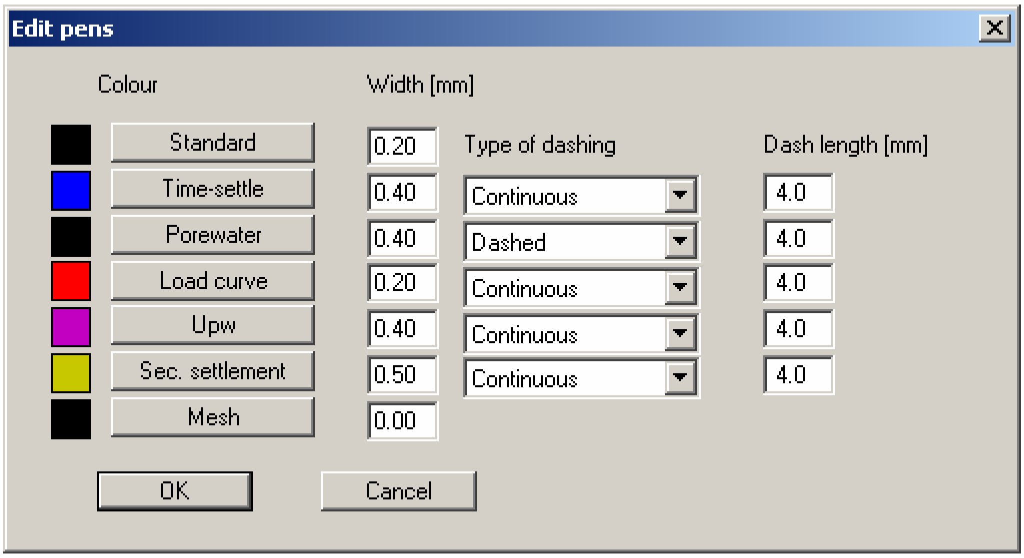
With this menu item you can switch to a different true-type font. All available true-type fonts are displayed in the dialogue box.

7.5.4 "With borders" menu item

The program automatically draws thin cutting borders around the page, which are required when using a plotter on paper rolls. The borders can be switched on or off using this menu item(see also menu item "**Output preferences/Page size and margins**", Section 7.4.9).

7.5.5 "Pen colour and width" menu item

In order to enhance the clarity of the graphics you can edit the pen settings for various graphical elements.



You can edit the pen widths and types for the elements shown in the dialogue box; by clicking on the button with the element designation you can also edit the pen colours. The vertical and horizontal auxiliary lines form the ***mesh*** in the graphical representation of the pore water pressure profile and the degree of consolidation.

On ***monochrome printers*** (e.g. laser printers), colours are shown in a corresponding grey scale. Graphic elements employing very light colours may be difficult to see. In such cases it makes sense to edit the colour preferences.

7.5.6 "Mini-CAD toolbar" menu item

Using this menu item you can add free text to the graphics and add lines, circles, polygons and images (e.g. files in formats BMP, JPG, PSP, TIF, etc.). A pop-up menu opens, the icons and functions used are described in more detail in the **Mini-CAD** manual provided.

Objects created with the "**Mini-CAD**" tool are based on the page format (in mm). This makes you independent of the coordinate system and keeps you in the same position on the page. You should select the "**Mini-CAD toolbar**" if you wish to place general information on the drawing (company logo, report numbers, plan numbers, stamp etc.). Once you have saved the header information to disk (see **Mini-CAD** user manual), you can load it into completely different systems (with different system coordinates). The saved header information will appear in exactly the same position on the page, which greatly simplifies the creation of general page information

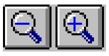
7.5.7 "Toolbar preferences" menu item

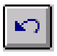
After starting the program a horizontal toolbar appears below the program menu bar. If you would rather work with a popup window with several columns, you can specify your preferences using this menu item. The smarticons can also be switched off.

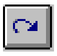
At the bottom of the program window you find a status bar with further information. You can also activate or switch off the status bar here. The preferences will be saved in the "**GGU-CONSOLIDATE.alg**" file (see menu item "**Graphics preferences/Save graphics preferences**") and will be active at the next time the program is started.

By clicking on the tools (Smarticons) you can directly reach most of the program functions. The meaning of the Smarticons appears as a text box if you hover with the mouse pointer over the tools. Some of the tool functions can be activated from the normal menu items.

 "**Zoom out**"
If you have previously ***zoomed in***, this tool returns to a full screen display.

 "**Zoom (-)**"/"**Zoom (+)**"
With the zoom functions you can zoom in or out of parts of the image, by clicking the left mouse button.

 "**Undo move object**"
By clicking this icon the last performed movement of graphical elements made using the [**F11**] function key or the menu item "**Output preferences/Move objects**" can be undone.

 "**Restore move object**"
By clicking this symbol, the last object movement undo carried out using "**Undo move object**" can be restored.

 "**Copy/print area**"
Use this tool to copy only parts of the graphics in order to paste them, e.g. to a report. You will see information on this function and can then mark an area, which is copied to the clipboard or can be saved in a file. Alternatively you can send the marked area directly to your printer (see "**Tips and tricks**", Section 8.3).

 "**Colour on/off**"
If you need to remove the colour from the system presentation, to create a black and white print-out, for example, use this on/off switch.

7.5.8 "Load graphics preferences" menu item

You can reload a graphics preferences file into the program, which was saved using the "**Graphics preferences/Save graphics preferences**" menu item. Only the corresponding data will be refreshed.

7.5.9 "Save graphics preferences" menu item

Some of the preferences you made with the menu items of the "**Graphics preferences**" menu can be saved to a file. If you select "**GGU-CONSOLIDATE.alg**" as file name, and save the file on the same level as the program, the data will be automatically loaded the next time the program is started and need not be entered again.

> If you do not go to "**File/New**" upon starting the program, but open a previously saved file instead, the preferences used at the time of saving are shown. If subsequent changes in the general preferences are to be used for existing files, these preferences must be imported using the menu item "**Graphics preferences/Load graphics preferences**".

7.6 ? menu

7.6.1 "Copyright" menu item

You will see a copyright message and information on the program version number.

The "**System**" button shows information on your computer configuration and the folders used by **GGU-CONSOLIDATE**.

7.6.2 "Help" menu item

The **GGU-CONSOLIDATE** manual is opened as a PDF document. The help function can also be accessed using the [**F1**] function key.

7.6.3 "GGU on the web" menu item

Using this menu item you can access the GGU Software website: www.ggu-software.com.
Keep in touch with new program versions and the regular ***download*** offers.

If you would like to be automatically notified about program innovations, please register for the Newsletter in our Knowledge Base. Go to the following website: http://kbase.civilserve.com.

7.6.4 "GGU support" menu item

This menu item takes to the GGU-Software Support area at www.ggu-software.com.

7.6.5 "What's new?" menu item

You will see information on program improvements in comparison to older versions.

7.6.6 "Language preferences" menu item

This menu item allows you to switch the menus and the graphics from German to English and vice versa. To work in German, deactivate the two check boxes "**Dialoge + Menüs übersetzen (translate dialogues, menus)**" und "**Graphiktexte übersetzen (translate graphics)**".

Alternatively, you can work bilingually, e.g. with German dialogue boxes but with graphic output in English. The program always starts with the language setting applicable when it was last ended.

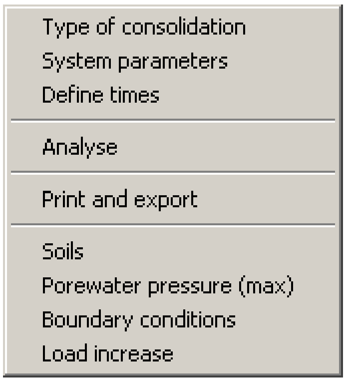
8 Tips and tricks

8.1 Keyboard and mouse

You can scroll the screen with the keyboard using the cursor keys and the [**Page up**] and [**Page down**] keys. By clicking and pulling with the mouse, with [**Ctrl**] pressed, you activate the zoom function, i.e. the selected section will fill the screen. Furthermore you can use the mouse wheel to zoom in/out or scrolling the screen presentation. The following mouse wheel functions are available:

- Mouse wheel up = move screen image up
- Mouse wheel down = move screen image down
- [**Ctrl**] + mouse wheel up = enlarge screen image (zoom in)
- [**Ctrl**] + mouse wheel down = shrink screen image (zoom out)
- [**Shift**] + mouse wheel up = move screen image right
- [**Shift**] + mouse wheel down = move screen image left

If you click the right mouse button anywhere on the screen a context menu containing the principal menu items opens.



By double-clicking the left mouse button on legends or **Mini-CAD** objects, you will immediately move to the editor for the selected object and can then edit it.

8.2 Function keys

Some of the function keys are assigned program functions. The allocations are noted after the corresponding menu items. The individual function key allocations are:

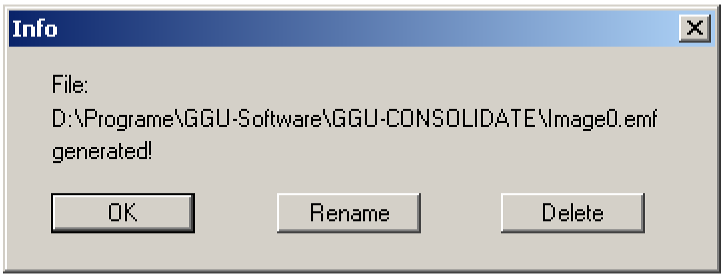
- [**Esc**] refreshes the screen contents and sets the screen back to the given format. This is useful if, for example, you have used the zoom function to display parts of the screen and would like to quickly return to a complete overview.
- [**F1**] opens the manual file.
- [**F2**] refreshes the screen without altering the current magnification.
- [**F3**] opens the menu item "**Edit/System parameters**".
- [**F5**] opens the menu item "**System/Analyse**".
- [**F11**] activates the menu item "**Output preferences/Move objects**".

8.3 "Copy/print area" icon

A dialogue box opens when the "**Copy/print area**" icon  in the menu toolbar is clicked, describing the options available for this function. For example, using this icon it is possible to either copy areas of the screen graphics and paste them into the report, or send them directly to a printer.

In the dialogue box, first select where the copied area should be transferred to: "**Clipboard**", "**File**" or "**Printer**". The cursor is displayed as a cross after leaving the dialogue box and, keeping the left mouse button pressed, the required area may be enclosed. If the marked area does not suit your requirements, abort the subsequent boxes and restart the function by clicking the icon again.

If "**Clipboard**" was selected, move to the MS Word document (for example) after marking the area and paste the copied graphics using "*Edit/Paste*". If "**File**" was selected, the following dialogue box opens once the area has been defined:



The default location of the file is the folder from which the program is started and, if several files are created, the file is given the file name "**Image0.emf**" with sequential numbering. If the "**Rename**" button in the dialogue box is clicked, a file selector box opens and the copied area can be saved under a different name in a user-defined folder. Saving can be aborted by pressing the "**Delete**" button.

If the "**Printer**" button was pressed in the first dialogue box, a dialogue box for defining the printer settings opens after marking the area. Following this, a dialogue box for defining the image output settings opens. After confirming the settings the defined area is output to the selected printer.

9 Index

M

O

P

R

S

T

U

V

W

Z