GeoteknikPro

STUDIO — SEEPAGE / GROUNDWATER

Version 3.0.1

USER GUIDE

and Calculation Methods Document

Materials and permeability · Section and boundary conditions · Steady-state and transient seepage · Wells · Heave and piping · Drawdown settlement · Adjacent building damage · Report and drawing · Transfer to Slope and Excavation Support

Methods are given together with their source references

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Contents

Contents 2
List of Figures 4
List of Tables 5
Symbols and Units 6
1. Introduction 7
1.1 What the program does 7
1.2 Scope 7
1.3 Who it is for 7
1.4 Place of the module in the main program 7
2. Screen and Workflow 9
2.1 Window layout 9
2.2 Menus 9
2.3 Four-step workflow 10
2.4 Results when the input changes 10
2.5 Progress indicator and cancel 10
3. Ways of Building the Model 11
3.1 Building the model by hand 11
3.2 TRANSFER DATA: building the model from other modules 11
3.3 Example and benchmark projects 12
3.4 Project saving 12
4. Materials and Permeability 12
4.1 Material table 12
4.2 Permeability source and SUGGEST k 13
4.3 Parameter library 14
4.4 Storage and compressibility parameters 14
5. Section, Groundwater and Boundary Conditions 15
5.1 Section types 15
5.2 Groundwater inputs 15
5.3 Excavation, wall and sheet pile 15
5.4 Slope and dam section 16
5.5 Boundary condition types 17
5.6 Target triangle edge length 17
6. Solution Method 17
6.1 Steady state, saturated 18
6.2 Steady state, free surface 18
6.3 Transient 19
6.4 Water level program 19
6.5 Flow lines 20
6.6 Representation of wells in the section 20

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6.7 Unsaturated flow 21
7. Dewatering, Wells and Adjacent Buildings 22
7.1 Wells 22
7.2 Drawdown-induced settlement 22
7.3 Adjacent building damage 22
7.4 Monitoring points 23
8. Excavation Support Tab and Well Group in Plan 24
8.1 Excavation support: staged excavation 24
8.2 Well group in plan (6 · Well Group in Plan) 25
9. Analysis and Results 26
9.1 SOLVE and notes 26
9.2 Boundary discharges 26
9.3 Hydraulic gradient, heave and piping 26
9.4 Results tab 27
10. Settings 30
11. Report, Drawing and Transfers 31
11.1 Word report 31
11.2 DXF drawing sheet 31
11.3 Transfer package and CSV 31
11.4 Transfer to Slope 32
11.5 Transfer to Excavation Support 32
11.6 Transfer back to source 32
11.7 Use together with the Data Report 32
12. Verification and Benchmarks 33
12.1 Verification approach 33
12.2 Comparison with closed-form and analytical solutions 33
12.3 Comparison with other programs 33
12.4 Known differences 34
13. Points to Watch 35
14. Code and Source References 36
14.1 Source check against Powers et al. (2007) 36
15. Known Limitations 37
16. References 38

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List of Figures

Figure 1. 1 · Materials · Permeability tab: material table (k, source, γ_{sat}, classification data); storage and compressibility table below 13

Figure 2. 2 · Section · Boundary Conditions tab: choice of section type (excavation or slope/dam), layers, layout and excavation inputs; section preview on the right 15

Figure 3. Walled excavation section: layers, dewatering line inside the excavation, equipotentials and flow lines 16

Figure 4. Slope/dam section inputs: ground line points, left and right edge water levels and the seepage face option 17

Figure 5. Free-surface slope example: layers, left and right edge water levels and monitoring points (before solution) 18

Figure 6. Steady-state free-surface solution of the same slope: pore water pressure u map, phreatic line and boundary discharges 19

Figure 7. Rapid drawdown with the water level program (upstream water level from 9 m to 2 m): variation of the total head h map with time 20

Figure 8. End of rapid drawdown (t = 20 days): pore water pressure u map and values at the monitoring points 20

Figure 9. 5 · Excavation Support · Wall Water Pressure tab: excavation stages, stage results and back, front and net water pressure along the wall 24

Figure 10. Hydraulic gradient i map: gradient concentrated at the excavation base, and the monitoring points table 26

Figure 11. 4 · Results · Transfer tab: total head h map, flow lines and boundary discharge labels; summary boxes at the top 27

Figure 12. Pore water pressure u map (Rainbow palette) 28

Figure 13. Pore water pressure u map (colour-blind friendly palette) 28

Figure 14. Vertical velocity v_z map (+ upwards): upward flow at the excavation base 29

Figure 15. View selection: excavation support stages (Stage 1–3) and the pore water pressure u map for Stage 1 29

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List of Tables

Table 1. Symbols used in the guide 6
Table 2. Tabs of the Seepage module 9
Table 3. Menu items 9
Table 4. Comparison of the ways of building the model 11
Table 5. TRANSFER DATA sources 11
Table 6. Material table columns 13
Table 7. Lower table parameters 14
Table 8. Boundary conditions 17
Table 9. Well table columns 22
Table 10. Excavation support result table 24
Table 11. Well group in plan methods 25
Table 12. Results tab controls 27
Table 13. Option settings 30
Table 14. Numerical settings 30
Table 15. Report chapters 31
Table 16. Comparison with closed-form solutions 33
Table 17. Comparison with GEO5 (discharge, m^3/day/m) 34
Table 18. Comparison with SEEP/W and classical solutions (discharge, m^3/s/m) 34
Table 19. Code and source references 36

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Symbols and Units

Throughout the guide the unit of force is kN, the unit of length is m, the unit of stress and pressure is kPa and the unit of permeability is m/s. The calculation is made for a unit width (1 m) perpendicular to the section; discharge is therefore given in $m^3/s/m$ (on screen $m^3/day/m$).

Table 1. Symbols used in the guide

Symbol	Description	Unit
h	Total hydraulic (piezometric) head	m
u	Pore water pressure	kPa
k, k_x, k_y	Coefficient of permeability (horizontal, vertical)	m/s
v	Darcy flow velocity	m/s
i	Hydraulic gradient, $i = -\nabla h$	—
i_{exit}, i_{cr}	Exit hydraulic gradient; critical gradient, $i_{cr} = \gamma'/\gamma_w$	—
FS	Factor of safety against heave and piping, i_{cr}/i_{exit}	—
γ_{sat}, γ_{moist}, γ'	Saturated and moist unit weight; submerged unit weight	kN/m^3
γ_w	Unit weight of water (9.807)	kN/m^3
q, Q	Discharge per unit section width; total or well discharge	$m^3/s/m$; L/s
S_s, S_y	Specific storage; specific yield	1/m; —
E_s	Soil modulus of elasticity for elastic settlement	kPa
C_c, C_r, e_0, σ'_p	Compression and swelling index; initial void ratio; preconsolidation pressure	—; kPa
ψ_a	Capillary fringe (air entry pressure) parameter	kPa
a, r_w	Well spacing; well radius	m
R, s	Radius of influence; drawdown	m
Δ/L, β, ε_h	Deflection ratio; angular distortion; horizontal strain	—; —; %
ε_{lim}	Limiting tensile strain (for the Burland category)	%
$\gamma_{G,dst}$, $\gamma_{G,stb}$	EN 1997-1 HYD partial factors (destabilising, stabilising)	—

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1. Introduction

1.1 What the program does

The GeoteknikPro Studio Seepage (Groundwater) module solves groundwater flow in a two-dimensional section with the finite element method and links its results to a series of geotechnical checks. The user defines the section (layers, groundwater, excavation, wall or slope), the permeability of each material and the boundary conditions; the program calculates the hydraulic head h and pore water pressure u fields, the boundary discharges, the flow lines and the hydraulic gradients.

The following calculations are linked to the same solution chain: heave and piping checks at the excavation base (comparison of the exit gradient with the critical gradient and with the EN 1997-1 HYD criterion), net water pressure along the wall and hydraulic base failure in staged excavation, dewatering with wells, transient head drawdown, dewatering-induced settlement and damage assessment for adjacent buildings. The results can be obtained as a Word report, a DXF drawing sheet and a CSV file; the pore water pressure can be transferred to the Slope and Excavation Support Structures modules (Section 11).

The module also contains a well group in plan calculation that works independently of the section (Thiem, Dupuit–Thiem, Theis and image well methods) (Section 8.2).

1.2 Scope

The working principles and scope of the module are as follows.

- The permeability k is the largest uncertainty in the module. The user enters its value from tests or from a literature range with a known source; the choice is written to the report together with its source (Section 4).
- The flow is two-dimensional: like plane strain, the section is assumed to be infinitely long in the direction perpendicular to it. Wells are represented in the section as a well row, i.e. an equivalent trench; for the effect of individual wells in plan there is the well group in plan calculation.
- Unsaturated flow is optional and off by default. When it is off, the zone above the water table is assumed dry in the free-surface regime (Section 6.2); when it is turned on in the Settings, flow in the unsaturated zone is solved with the Richards equation, using the water-retention curve and permeability function defined for the material (Section 6.7).
- The module produces pore water pressures and water levels; bearing capacity, slope stability and the structural design of walls are done in the Slope, Excavation Support Structures and other modules that use these outputs.
- The settlement calculation is limited to settlement caused by dewatering; settlements due to structural loads, seismic action and time-dependent creep are out of scope.
- If a required input is missing, the calculation stops and states the reason (well parameter, storage coefficient, compressibility parameter); no assumption is put in place of the missing value.

1.3 Who it is for

The module has been prepared for users with engineering training who are familiar with the concepts of seepage, filters and groundwater control (Darcy’s law, hydraulic head, flow net, critical gradient, well hydraulics). Model set-up, the choice of the k value and the interpretation of the results belong to the user; the program calculates and records the results together with their sources.

1.4 Place of the module in the main program

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The module runs inside GeoteknikPro Studio as the Seepage tab; its data are stored in the main project file (*.geos). When the module is not used, the results of the Slope, Excavation Support Structures and other modules do not change: these modules continue to work with their own classical water assumptions (straight phreatic line, hydrostatic diagram, single groundwater level). Using the Seepage result in another module is always optional and requires the user's confirmation (Sections 11.4, 11.5). This guide corresponds to version 3.0.1.

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2. Screen and Workflow

2.1 Window layout

Above the Seepage tab is the common band of the main program: the module's commands are in the Seepage menu, the report and drawing commands are in the Seepage submenu of the Report / Drawing menu, and the settings are on the "Groundwater / Seepage" tab of the Settings window. Below the band there is a flow strip showing the four steps and an instruction line; below that are the tabs, and at the very bottom the status line. The step strip shows, in order, the steps "1 · Materials (k)", "2 · Section and boundaries", "3 · Analysis" and "4 · Results and transfer"; the instruction line tells you what the current step expects (for example in the first step: enter the materials and the permeability source first; the program does not assume a value for k).

Table 2. Tabs of the Seepage module

Tab	Content	Section
1 · Materials · Permeability	Material table: k, source, γ_{sat}, soil class; storage and compressibility sub-table; SUGGEST k and LIBRARY	4
2 · Section · Boundary Conditions	Section type (excavation or slope/dam), layers, groundwater level, excavation, sheet pile, layout, BUILD SECTION	5
2b · Dewatering · Wells · Adjacent Buildings	Well row, adjacent buildings, monitoring points, pre-drawdown water level	7
3 · Analysis	SOLVE, progress and CANCEL, notes and assumptions, boundary discharges, transfer package, Word report	9
4 · Results · Transfer	Colour map, iso-pressure lines, flow lines, mesh, settlement, monitoring points, DXF, transfer back to source	9, 11
5 · Excavation Support · Wall Water Pressure	Staged excavation: wall water pressure, hydraulic base failure, inflow to the excavation	8.1
6 · Well Group in Plan	Analytical dewatering: Thiem, Dupuit–Thiem, Theis, image well	8.2

While the "Show all tabs (regardless of job type)" option in the Seepage › Edit menu is off, the program brings forward the tabs relevant to the project job type (excavation support, slope/embankment, well dewatering, free section). The job type is not asked separately; it is set automatically from the section type (slope/dam), from use of the Excavation Support tab, from the TRANSFER DATA source or from the loaded example. The job type affects only the view; the calculation is the same.

2.2 Menus

Table 3. Menu items

Menu	Item	Function
Seepage	New Project (this module only)	Deletes only the Seepage data and starts the module empty; the other modules of the main project are not affected (Section 3.4)
Seepage	File › Site examples; Benchmark problems; load example excavation/slope	Ready-made example and benchmark projects (Section 3.3)
Seepage	Edit › Show all tabs (regardless of job type)	Tab visibility
Seepage	Edit › Water level program (rapid drawdown · flood)…	Time-dependent edge water level program (Section 6.4)
Seepage	Edit › Undo	Undoes the last edit
Report / Drawing	Seepage › Report › REPORT (docx)…	Word report (Section 11.1)
Report / Drawing	Seepage › Drawing › FLOW NET SHEET (DXF)…	DXF drawing sheet with the view in the Results tab (Section 11.2)

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Menu	Item	Function
Main band	Settings › Groundwater / Seepage tab	Seepage page of the single Settings window (Section 10)

2.3 Four-step workflow

- Materials: a material row is opened for each layer; the k value and its source are entered (1 · Materials · Permeability).
- Section: ground elevation, groundwater level, layer thicknesses and materials, and excavation or slope geometry are entered; regions and boundary conditions are created with BUILD SECTION (2 · Section · Boundary Conditions). Wells, adjacent buildings and monitoring points, if any, are defined on tab 2b.
- Analysis: the regime and criteria are selected in the Settings window; the target triangle edge length is set and the SOLVE button is pressed (3 · Analysis).
- Results: the map, flow lines and monitoring points are reviewed; the report, DXF, transfer package or Slope/Excavation Support transfer is produced (4 · Results · Transfer).

2.4 Results when the input changes

When the input changes, the old result is not left on screen, so that old equipotentials and new labels do not get mixed. SOLVE takes the latest input; however, if the section has been changed, the regions and boundary conditions must first be rebuilt with BUILD SECTION. If the input is changed while the solution is running, the result of the running calculation is discarded.

2.5 Progress indicator and cancel

SOLVE runs the calculation in the background on a copy of the project; the window does not freeze. The 3 · Analysis tab shows the percentage and the elapsed and remaining time; the calculation stages are: mesh, steady final state, time step, free surface iteration and settlement. The CANCEL button stops the running calculation. When the estimated number of nodes exceeds 40 000, the program asks for confirmation before solving. The combination of a very fine mesh (0.25 m) with the transient regime can take minutes; the progress is shown on screen and the calculation can be cancelled.

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3. Ways of Building the Model

A model can be built in three ways: manual input, TRANSFER DATA from other modules, and ready-made example/benchmark projects. DXF is produced only as an output (Section 11.2).

Table 4. Comparison of the ways of building the model

Way	When	What is built
Manual (tabs 1 and 2)	Any situation; the most flexible way	Materials, layers, groundwater level, excavation/sheet pile or slope line
TRANSFER DATA	If Geotechnical Report boreholes, an Excavation Support face, a Slope section or a Retaining Structures wall exist	Depending on the source: borehole/layers, wall and stages, material regions, water
Example and benchmark projects	Learning, benchmarking, quick trials	Ready-made projects

3.1 Building the model by hand

First the materials are entered on the 1 · Materials · Permeability tab (Section 4), then the section on the 2 · Section · Boundary Conditions tab (Section 5). The section width is the sum of the left soil length, the excavation width and the right soil length. For the left and right soil lengths, 2–3 times the excavation width is a good starting value; to see that the boundary effect does not spoil the result, this length should be increased and it should be checked that the result does not change. If the fixed-head side boundary lies within the radius of influence of the dewatering, the program issues a “BOUNDARY EFFECT” warning (Section 13).

3.2 TRANSFER DATA: building the model from other modules

The TRANSFER DATA… button on the flow strip opens a small window. The window contains, in order, the source module, the source item, the data groups to be transferred and a one-line summary; it ends with the TRANSFER and Close buttons. If a model already exists, you are asked to confirm overwriting it. At the end of the transfer a summary is shown, consisting of what arrived, what was accepted, what did not arrive or cannot be represented in Seepage, and information notes.

Table 5. TRANSFER DATA sources

Source module	Item	Transferred	Not transferred (written in the summary)
Geotechnical Report	Boreholes	Boreholes and layers, groundwater level, foundation (data groups can be ticked; for an unticked group the existing value is kept)	No section is built; material and groundwater level behaviour
Excavation Support	Face	Wall type, top and tip elevation, permeability, all distinct stage depths, the face’s own layers, back and front water, excavation width, face length	Jet grout block; opposite face (the section is built symmetrically); anchors and struts (no effect on flow)
Slope	Section	Material regions (polygon and material), ground line, edge water levels from the water line	Excavation stage concept; structures, rigid blocks and voids are removed as no-flow regions; loads and supports do not enter the flow
Retaining Structures	Wall	Front and back soil, the step of the wall body, a vertical impermeable line for an impermeable wall, selected backfill wedge, face with weep holes (seepage face), heel pipe (point drain), water	Horizontal impermeability of the foundation base; inclined back face (only the vertical impermeable line is carried over)

- If the source module has no analysis or its analysis is out of date (the result record is no longer current), the “First run the analysis of the source module” option in the window comes ticked; the analysis is run through that module’s own route with a progress window. “Geometry only (no analysis)” can be

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selected. For Retaining Structures no analysis is run, because the wall geometry is independent of the analysis.

- The units of the Geotechnical Report are converted: values in t/m^3 for γ and t/m^2 for c are multiplied by 9.807 and converted to kN/m^3 and kPa; c_u is already in kPa.
- If there is no k in the source, k is assigned from the soil class (USCS or name; for example “silty SAND” goes to the sand class): the logarithmic middle of the literature range of the class is taken, the source is flagged “k assigned from class”, and it goes into the report as a literature/user assumption. If no class can be found, k is not assigned; this is stated in the summary. The assigned value should be replaced by the user with a site-specific k.
- The source of the transferred model is remembered; the “Transfer back to source” button on the Results tab uses this information (Section 11.6).

Relation to the Data Report

The borehole and soil data of the Data Report module are not transferred directly to Seepage but first to the Geotechnical Report (“Transfer from Data Report to Geotechnical Report…” in the Data menu of the main program); Seepage takes these boreholes from the “Geotechnical Report” source. See the Data Report guide for details.

3.3 Example and benchmark projects

The Seepage › File menu offers ready-made projects that can be solved immediately. The Site examples submenu has five examples: a road cut slope (perched water, seepage on the slope face); a deep excavation, a diaphragm wall socketed into clay and an adjacent building; pre-drainage with wells (transient, soft clay settlement); staged excavation support (wall water pressure, hydraulic base failure, inflow); and an embankment with rapid drawdown. “Load example excavation” (walled excavation and dewatering), “Load example pit (water BELOW the base — drain line)” and “Load example slope / embankment (free surface)” are also in this menu. The projects in the Benchmark problems submenu are for comparison with a closed-form solution or with another program (Section 12). When a benchmark project is opened and SOLVE is pressed, a “COMPARISON” line appears in the Notes: the percentage difference from the closed-form solution and the verdict “CONSISTENT” or “INCONSISTENT”.

Unsaturated flow and suction transfer to Slope have also been checked with four further benchmark examples: A (Srivastava–Yeh steady 1D infiltration column), B (rainfall on a slope, ponding, no-flow left edge), C (B with suction transfer to Slope, antecedent steady start) and C2 (C with a water-table and 75 kPa suction cap start). Their results are in Sections 12.2 and 12.3.

3.4 Project saving

The Seepage data (inputs, settings, outputs and transfer package, benchmark information, the source the transfer came from) are stored in the main project file (*.geos); you save and open the project from the main program. To reset the module’s data, the Seepage › New Project (this module only) command is used: after confirmation only the Seepage data are deleted and the module starts empty; the other modules of the main project are not affected.

4. Materials and Permeability

4.1 Material table

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On the 1 · Materials · Permeability tab a row is opened for each layer (ADD MATERIAL, DELETE SELECTED ROW). The only compulsory input is the permeability k; the source type and source text are optional, and if left empty “USER ASSUMPTION (manual)” is written to the report.

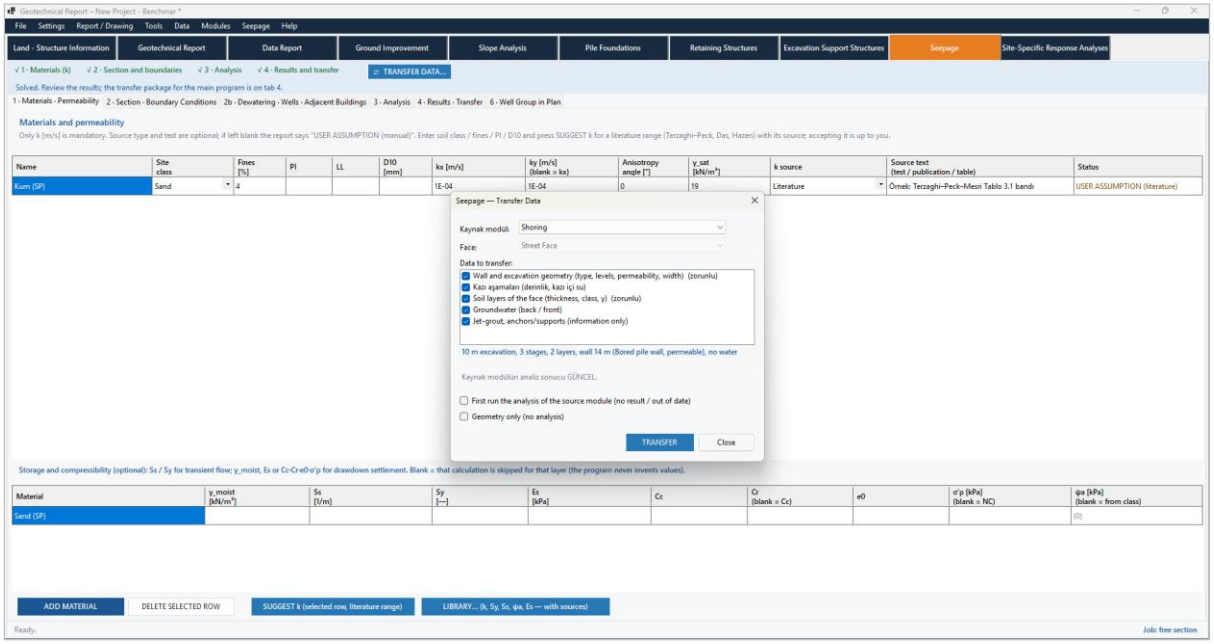


Figure 1. 1 · Materials · Permeability tab: material table (k, source, γ_{sat}, classification data); storage and compressibility table below

Table 6. Material table columns

Column	Meaning
Name	Material name
k_x [m/s], k_y [m/s]	Horizontal and vertical permeability; if k_y is empty, k_x is taken
Anisotropy angle [°]	Angle of the principal permeability axis with the horizontal
k source, Source text	Source type (test, literature, etc.) and test/publication/table reference
γ_{sat} [kN/m³]	Required for heave safety ($\gamma' = \gamma_{sat} - \gamma_w$) and for settlement
Status	Missing/complete status of the row
Soil class, Fines [%], PI, LL, D_{10} [mm]	Classification data for SUGGEST k and class estimation

4.2 Permeability source and SUGGEST k

The k value is entered by the user; if no field permeability test is available, entering the soil class, fines content, PI and LL, D_{10} and pressing the SUGGEST k (selected row, literature range) button makes the program propose a literature range with its source (Terzaghi–Peck–Mesri and Das tables; the Hazen relation for D_{10}). Accepting the proposal is up to the user: if accepted, the logarithmic middle of the range is written as k_x=k_y and the source text is filled in automatically. The accepted value is written to the report with its literature source and as a user assumption.

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The uncertainty in k affects the result proportionally

The discharge is directly proportional to k. In dewatering with wells, the well discharge and the radius of influence, and in free-surface flow the position of the free surface, depend on k and on the ratios between the k values. It should not be forgotten that a literature range spans one or two orders of magnitude; wherever possible, a field test (pumping, Lefranc, Lugeon) or a laboratory test should be preferred. For sensitivity, repeating the solution with the lower and upper values of the range for k is recommended.

4.3 Parameter library

The LIBRARY… button (k, S_y, S_s, ψ_a, E_s — with sources) opens the "Parameter library" window. Each row is given together with its source; the selected value is written to the target material with "Write to material" and enters the report with its source. The window has filters for parameter, soil class and source/country, and a search box; the reference and note of the row appear in the lower area. Some of the values in the library have not been compared with their source, and this is indicated in the "Status" column; with the "I checked it against the source…" button the user marks that he or she has verified the record against the source. You can add your own records, such as a company archive, a field test average or a source from another country, to the user library with "Save to my library" and delete them with "Delete my record".

4.4 Storage and compressibility parameters

The lower table of the Materials tab contains optional parameters. For a parameter left empty, the related calculation is not done in that layer.

Table 7. Lower table parameters

Parameter	What for	If missing
S_s [1/m]	Specific storage in the saturated zone; transient regime	The transient calculation stops
S_y [—]	Specific yield in elements cutting the free surface; transient regime	The transient calculation stops
γ_{moist} [kN/m³]	Unit weight in the part above the water table	γ_{sat} is used (makes a difference in settlement)
E_s [kPa]	Elastic settlement	Elastic settlement is not calculated; a note is added
C_c, C_r, e_0, σ'_p [kPa]	Consolidation settlement (if σ'_p is empty, normally consolidated)	Consolidation settlement is not calculated; if C_r is empty, C_c is taken
ψ_a [kPa]	Capillary fringe (suction above the water table)	If empty, program assumption from the soil class; if 0 is entered, no fringe
SWCC, k(ψ)	Unsaturated flow: water-retention curve (Saturated (none) / van Genuchten / Fredlund–Xing) and permeability function (van Genuchten–Mualem / Gardner (exponential) / Fredlund–Xing–Huang)	If SWCC is blank the material is taken as saturated; effective only when unsaturated flow is on
α [1/m], n_vG, θs, θr; a_FX [kPa], n_FX, m_FX	Water-retention curve parameters (van Genuchten or Fredlund–Xing); θs is required for the transient solution	If θr is blank, 0 is taken
χ Slope	Suction-transfer coefficient for Slope (0…1, ≈ tanϕb/tanϕ')	If blank, the global χ in the Settings is used

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5. Section, Groundwater and Boundary Conditions

5.1 Section types

The 2 · Section · Boundary Conditions tab offers two section types: excavation and slope/dam. In both types the section consists of horizontal layers; the layers are entered from top to bottom by thickness (the bottom elevation appears as an information column). Once the inputs have been entered, the “BUILD SECTION (regions + boundary conditions)” button divides the geometry into regions and creates the boundary conditions. While there is no solution, the canvas shows only the edge water levels entered and a thin “input” line between them; the water table is found only with SOLVE. After the solution, the light blue fill shows the saturated zone (u > 0), the dark dashed line the computed u = 0 line, and thin blue lines the equipotentials. The “Show triangular mesh”, “Show flow lines” and “Show adjacent buildings” boxes change the view.

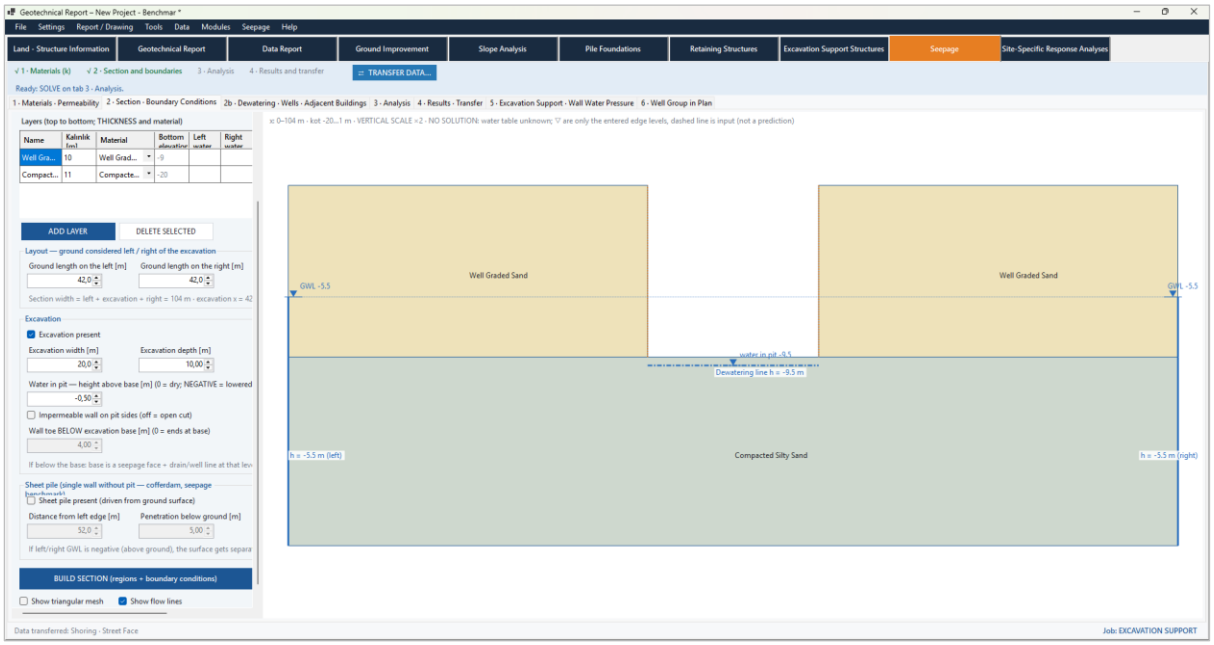


Figure 2. 2 · Section · Boundary Conditions tab: choice of section type (excavation or slope/dam), layers, layout and excavation inputs; section preview on the right

5.2 Groundwater inputs

- Ground elevation and groundwater level depth: entered separately for the left and right edges. At the edges the water is assumed fixed at this level (far field). A negative depth denotes water above the ground: in this case the ground surface also becomes a fixed-head boundary (reservoir); an excavation or sheet pile divides the surface.
- Edge water level per layer: if the “Left water level” and “Right water level” columns in the layer table are empty, the general groundwater level is used. Layers with separate piezometric levels (for example a confined gravel) are defined with these columns. At the shared corner on the interface between layers, the elevation of the lower layer applies, and this is recorded as a note.
- Water inside the excavation: entered as a height above the base (0 = dry excavation). If the value is entered as negative, the water has been lowered below the excavation base: the base becomes a seepage face, a horizontal fixed-head line (drain or well line) across the excavation width is added at that elevation, and the regime automatically becomes free-surface. The line “DEWATERING: discharge to hold the level at ‘…’” is written in the Notes.

5.3 Excavation, wall and sheet pile

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In the excavation group, “Excavation present” is ticked and the excavation width and depth are entered. If “Impermeable wall on pit sides” is ticked, the side faces are taken as impermeable; if it is not ticked, it is an open cut. The “Wall toe BELOW excavation base” field gives the embedment length of the wall (0 = ends at the base). The two faces of the wall are represented in the mesh by separate nodes, with a shared tip; the number of triangles crossing the wall is reported and must be zero.

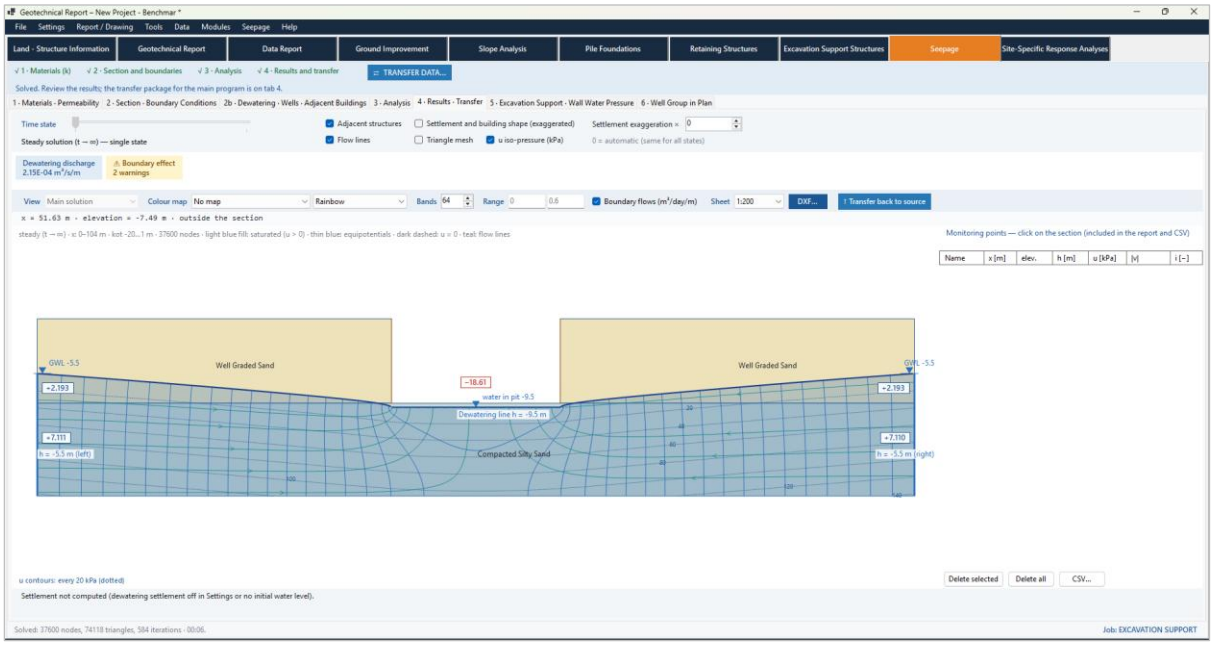


Figure 3. Walled excavation section: layers, dewatering line inside the excavation, equipotentials and flow lines

The sheet pile group is for a single wall without excavation (cofferdam, the classical seepage problem): the distance from the left edge and the penetration from the ground are entered. The ground surface is divided at the wall and becomes two separate fixed heads with the left/right water levels.

5.4 Slope and dam section

In the slope/dam type the ground line (x, elevation) is entered as points from left to right (ADD POINT); the layer bottoms are horizontal. The left and right edge water levels are entered. If the option “Ground surface and the edges above water are seepage faces (free-surface regime)” is ticked, the program sets the regime to free-surface. The submerged part of the ground surface is a fixed head at the reservoir level, and the parts above water are seepage face candidates; edges to the left of the crest take the left water level and those to the right the right water level. The edge type (“Fixed water level (h)” or “No-flow (q = 0)”) is also chosen for the left and the right edge; rainfall on the ground surface is given in the “Rainfall (ground-surface flux boundary)” group (Section 6.7).

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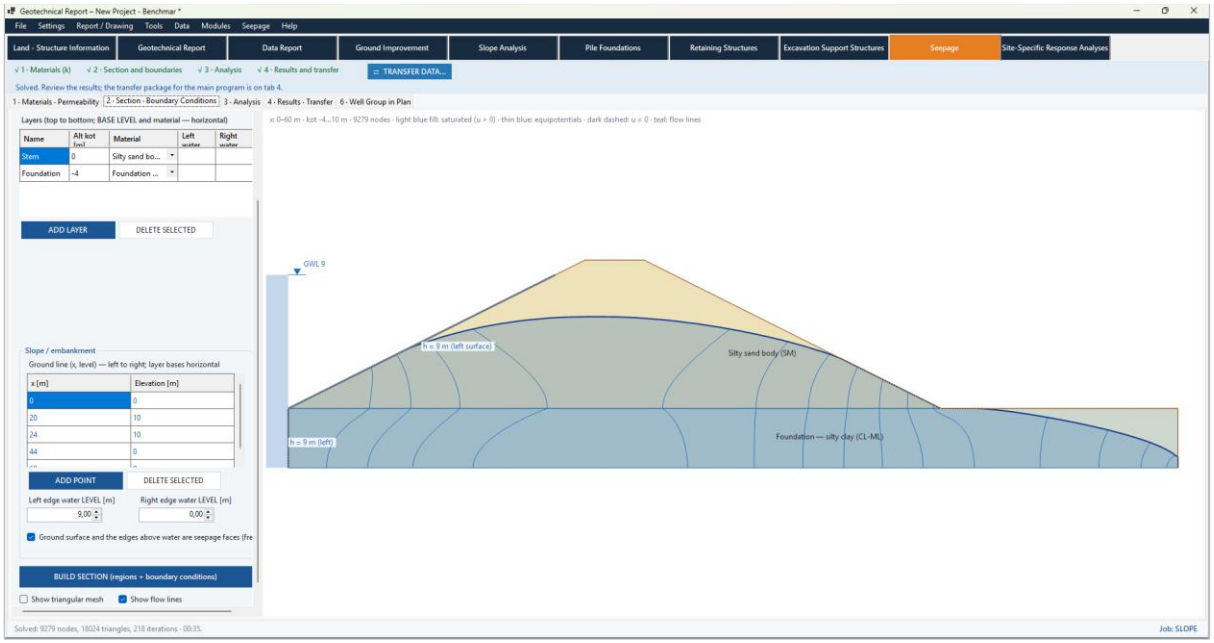


Figure 4. Slope/dam section inputs: ground line points, left and right edge water levels and the seepage face option

5.5 Boundary condition types

Table 8. Boundary conditions

Type	Meaning	Where it is used
No flow	q = 0 (default; not defined separately)	Impermeable wall, impermeable base, bottom and side boundaries of the section
Fixed head h	The hydraulic head is prescribed	Reservoir, edge groundwater level, water inside the excavation, water level in a well, drain line
Seepage face	Above water, h = y (atmospheric pressure); outflow only	Slope face, downstream face of a dam, excavation base (if the water is below the base)
Internal fixed-head line	Horizontal fixed head inside the section	Idealisation of a drain or well line
Rainfall (flux)	Flux applied to the ground surface: the rainfall intensity (mm/h) is converted into nodal flux per horizontal projection; if a potential evaporation E is entered, the net flux q − E is used. With ponding on, the surface becomes h = y at a node where ψ > 0 and the excess runs off. Rainfall is ignored at submerged (fixed-head) nodes	Ground surface not under water; the “Rainfall (ground-surface flux boundary)” group on the Section tab (Section 6.7)

The fixed head is applied only to submerged nodes; the boundary above water is assumed dry and no-flow.

5.6 Target triangle edge length

The mesh is generated with the Delaunay method. The target edge length is given on the 3 · Analysis tab and in the Settings; the default is 0.5 m. To see that the result is mesh-independent, a comparison with 0.25 m is recommended (an example for a sheet pile is given in Section 12).

6. Solution Method

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In a saturated medium, flow is expressed by Darcy's law and the continuity equation. The domain is discretised with three-node linear triangular elements (constant gradient, CST). Because the velocity is constant within an element, the area-weighted average of the neighbouring elements is carried to the nodes; this is for display only, and the calculation uses the element value. The resulting sparse system of equations is solved with the conjugate gradient method (Jacobi preconditioned). The flow regime in the Settings window is one of three options.

6.1 Steady state, saturated

The Laplace equation is solved. The position of the water table is given by the boundary conditions (fixed groundwater level); no free surface is searched for. This is the default regime for walled excavation, sheet pile and confined layer problems.

6.2 Steady state, free surface

The position of the water table is part of the solution. Dry elements are given a very small permeability factor ($k \cdot 10^{-4}$), seepage face nodes are tied to the condition h = y, nodes with inflow are released, and this process is repeated in outer iterations (Bathe and Khoshgoftaar, 1979). For the slope/dam type and in cases where the water inside the excavation is lowered below the base, the regime switches to this option automatically. If the iteration does not converge, a warning appears in the Notes. In a dry element the Darcy velocity is calculated with the permeability multiplied by the saturation factor; equipotential lines are drawn only in the saturated zone.

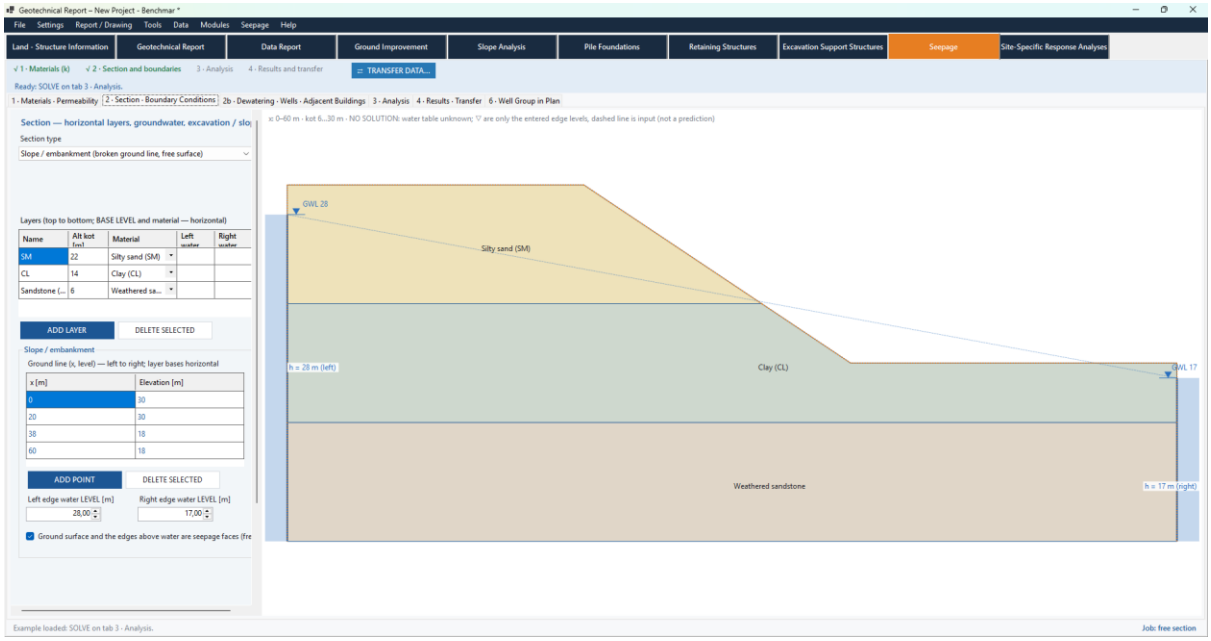


Figure 5. Free-surface slope example: layers, left and right edge water levels and monitoring points (before solution)

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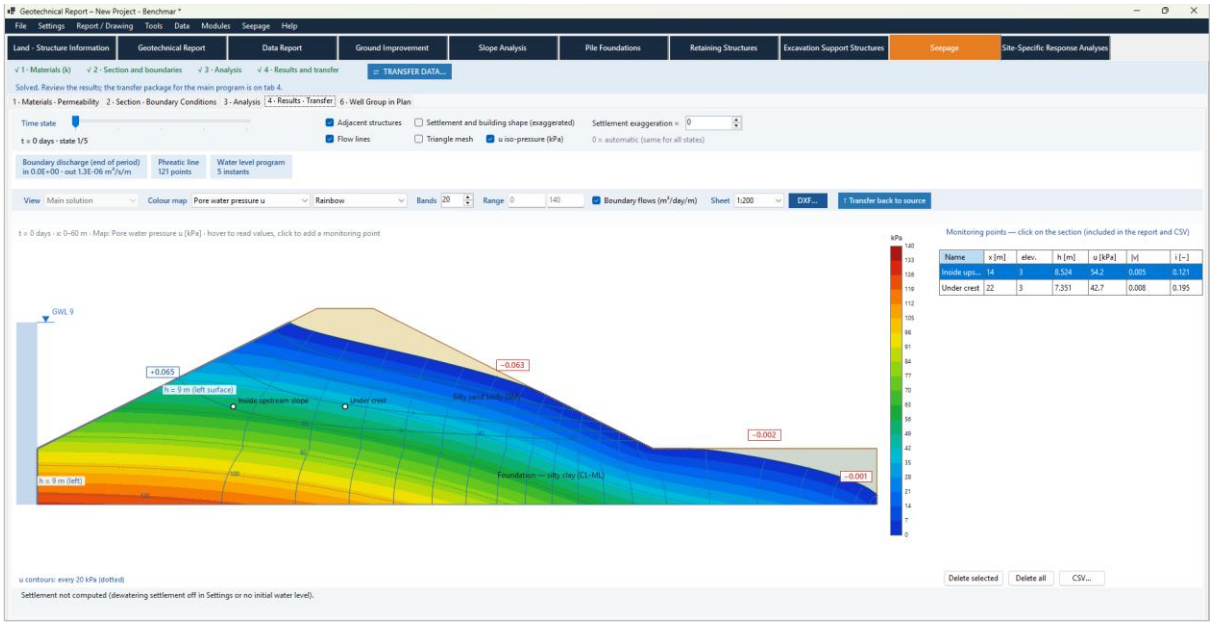


Figure 6. Steady-state free-surface solution of the same slope: pore water pressure u map, phreatic line and boundary discharges

6.3 Transient

By default, initially h over the whole domain equals the initial water level (hydrostatic) (initial condition options: Section 6.7); at time t = 0^+ the boundary conditions come into action. The time step advances with the backward Euler method; the steps grow geometrically (the first step is small). Storage is taken into account with S_s in a saturated element and with S_y spread over the element height in an element cutting the free surface. If S_s and S_y are empty in the material, the calculation stops. The total duration and the number of steps in the settings determine the solution; the instants stored for the report are at five equal intervals by default.

Outputs: the field solution at the selected instants, the time series of the boundary discharge, h(t) at the monitoring points and the time to reach 95% of the steady drawdown. If ticked on the Excavation Support tab, the excavation stages are solved as a chained transient (Section 8.1).

6.4 Water level program

The Seepage › Edit › Water level program (rapid drawdown · flood)… window defines the variation with time of the water level of the fixed-head boundaries on the selected side (the edge and the submerged ground surface). Linear variation is assumed between the points (t [days], water level [m]). The start is the steady solution at the t = 0 level (reservoir full for a long time). In the “Rapid drawdown — fill the table” section, the initial level, the final level and the duration are entered and “Write to table” is clicked; APPLY writes the program, and “Delete the program on this side” removes it. The program is effective only in the transient regime and requires S_s and S_y in the materials. It is used for rapid drawdown, river level and flood scenarios.

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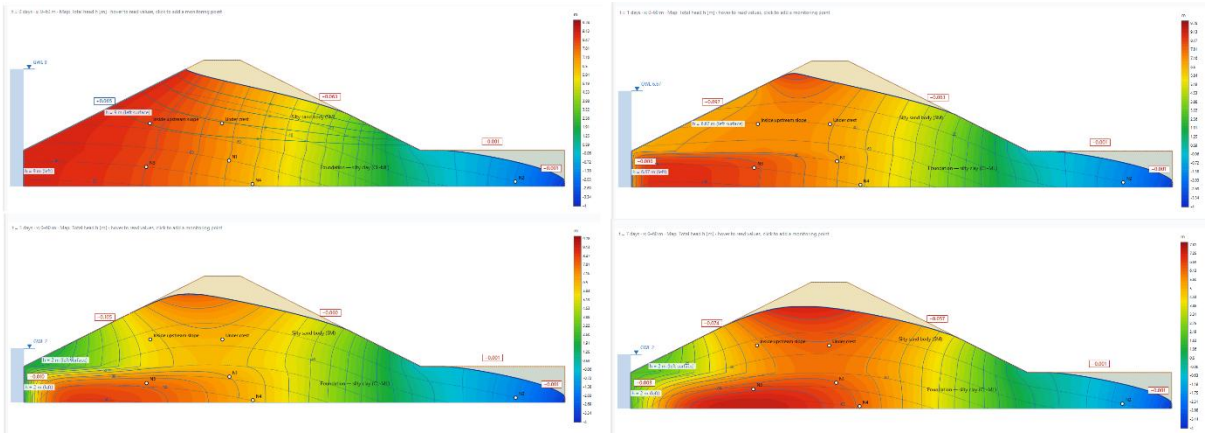


Figure 7. Rapid drawdown with the water level program (upstream water level from 9 m to 2 m): variation of the total head h map with time

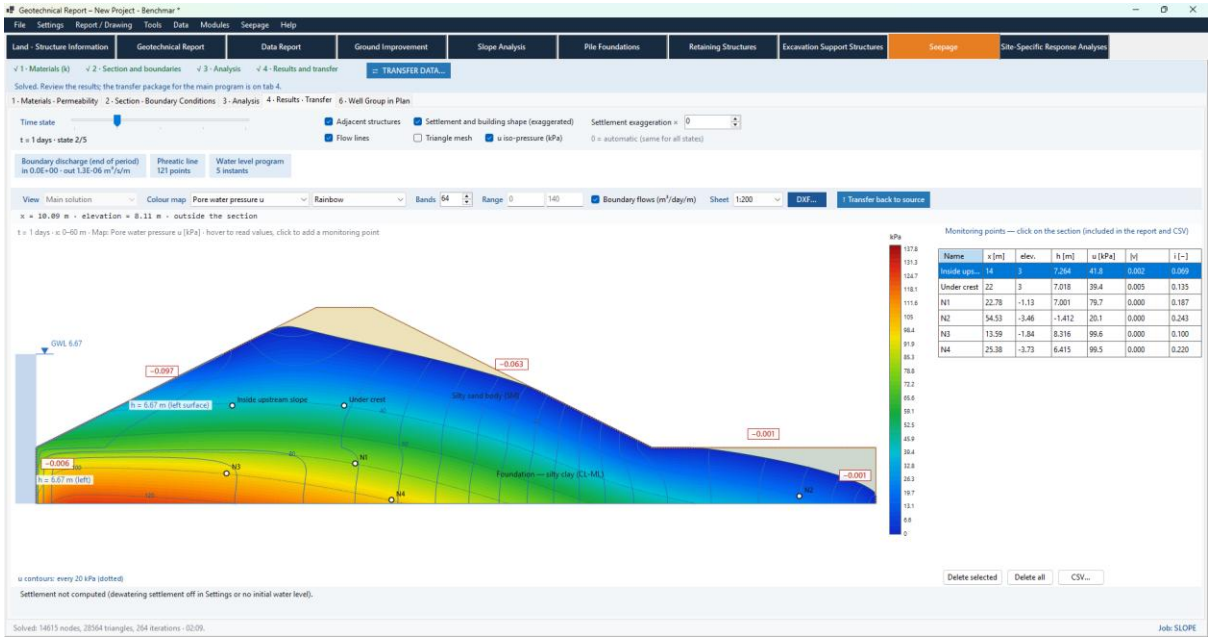


Figure 8. End of rapid drawdown (t = 20 days): pore water pressure u map and values at the monitoring points

6.5 Flow lines

Flow lines are drawn from the velocity field obtained after the solution: the element velocities are averaged to the nodes, made tangential on no-flow boundaries and wall faces, and particle tracking (second-order Runge–Kutta) is applied. The lines are started from the inflow boundaries with equal shares of discharge; they end at a fixed-head edge (exit, drain line, well screen) and go around the wall tip. The tube between two neighbouring lines carries the same discharge (Q/N). This is controlled with the number of flow tubes N in the Settings (0 = do not draw). Flow lines are visual only and do not affect the calculation. A line hitting a wall face slides along the face; two lines very close to the wall may merge at the tip.

6.6 Representation of wells in the section

Wells are defined on tab 2b (Section 7.1) as a well row perpendicular to the section plane; the row is modelled as a vertical line along the screen. If the water level in the well is given, the submerged part of the line becomes a fixed head and the part above it a seepage face. If the discharge per well Q is given, the value q = Q/a is distributed along the screen over the wet part only (a dry screen cannot draw water).

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6.7 Unsaturated flow

Unsaturated flow is optional and is turned on in the Settings. When it is on, flow is also solved in the zone above the water table and suction (negative pore water pressure) is calculated. The inputs and options are as follows.

- Settings strip: the “Unsaturated flow (Richards; material SWCC + k(ψ) required)” box is OFF by default. When it is on, the Richards equation is solved; Picard is the default method, and the “Newton iteration (steep SWCC; Picard fallback)” option is available for steep water-retention curves. If the solution does not converge a warning is given, the last iterate is kept and the program does not stop.
- Materials tab (lower table): the water-retention curve is chosen in the “SWCC (blank = saturated)” column: Saturated (none), van Genuchten (α, n_vG, θs, θr) or Fredlund–Xing (a_FX, n_FX, m_FX, θs). The permeability function is chosen in the “k(ψ)” column: van Genuchten–Mualem, Gardner (exponential) or Fredlund–Xing–Huang (Section 4.4).
- Section tab, “Rainfall (ground-surface flux boundary)” group: the “Apply rainfall to the ground surface not under water” box and the rainfall intensity (mm/h, per horizontal projection); the “Ponding: when ψ > 0 the surface becomes h = y (excess runs off)” box; the “Time series…” window (rainfall varying with time; effective only in the transient regime); “Potential evaporation E” (mm/day) and the minimum suction “ψ_min [m]”.
- The initial condition (transient solution) is chosen from the “Transient initial state:” list in the Settings. “Default (steady solve if a level programme exists, else hydrostatic)”: if a level programme exists, a steady solution at the t = 0 levels, otherwise the initial water level everywhere. “Water table + suction cap (hydrostatic, capped)”: hydrostatic u is built from the given water table (“Water-table level y_st [m]”; if empty, the initial water level of the project); in the unsaturated zone the suction is capped at “Suction cap ψ_max [kPa]” (75 when the box is ticked; unlimited if empty). Only a horizontal water table is supported.
- Side boundaries: in the slope/dam section, “Fixed water level (h)” or “No-flow (q = 0)” is chosen separately for the left and the right edge. On a no-flow edge the water level box is not used (its value is kept) and no seepage face is set on that edge. An edge without a water level is no-flow.
- Output: suction (negative u) is shown in the colour map and with contours (Section 9.4).
- Transfer to Slope: the “Suction transfer to Slope (u < 0)” box in the Settings is optional and off by default, i.e. on the safe side (u < 0 is taken as zero in Slope). If it is turned on, u_eff = χ·u is used in Slope: the global χ (χ ≈ tanϕb/tanϕ′) starts at 0.50 when the box is ticked; a material with “χ Slope (blank = global)” entered in the material table uses its own value. With χ = 0 no suction is transferred (u < 0 is taken as zero in Slope). The choice is a USER ASSUMPTION (Section 11.4).

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7. Dewatering, Wells and Adjacent Buildings

This section describes the 2b · Dewatering · Wells · Adjacent Buildings tab. At the top of the tab is the “Initial (pre-drawdown) water level” field; this level gives the start of the settlement calculation and of the transient solution. If “= left water level of the section (automatic)” is ticked, the initial water level is taken from the left water level of the section.

7.1 Wells

Table 9. Well table columns

Column	Meaning
Name	Well name
x [m]	Horizontal position of the well in the section
Screen top elevation, Screen bottom elevation [m]	Screen length; the fixed head or discharge is applied over this interval
Water level in well [m]	Fixed-head condition if given
Q [L/s] (per well)	Fixed-discharge condition if given
Spacing a [m] (empty = trench)	Distance between wells; if empty, a continuous trench is assumed
r_w [m]	Well radius

For a well, either the water level or Q is entered (if both are given, the water level applies). If the spacing a is given, Q per well and the additional drawdown inside the well are reported. The additional drawdown inside the well, the difference between the equivalent trench level of the well row and the water level inside the well, is given by the relation $\Delta s = Q/(2\pi kb)\cdot\ln(a/2\pi r_w)$. The source of this relation could not be verified in the source check (Section 14); the result should be read for information only, and a pumping test or manufacturer data should be used as the basis for well losses.

7.2 Drawdown-induced settlement

Settlement is switched on with the “Drawdown-induced settlement” option in the Settings (Not computed, 1D elastic, 1D consolidation, Both). The calculation is made on one vertical column per station. The effective stress increase is the difference between the change in total stress and the change in pore water pressure ($\Delta\sigma' = \Delta\sigma_{total} - \Delta u$); in the part that rises above the water table, the unit weight changes from γ_{sat} to γ_{moist}. The elastic method uses E_s; the consolidation method uses C_c, C_r, e_0 and σ'_p and distinguishes between the overconsolidated and normally consolidated branches. With the “Both” option, whichever is defined is calculated for each layer; if both are defined, both are reported. A layer with missing parameters is skipped and a note is added. The capillary fringe (ψ_a) defines a suction zone above the water table.

The settlement is only the settlement caused by dewatering; it is not the total settlement, and this is stated in the Notes. The station spacing and sublayer thickness can be changed in the Settings. On the Results tab the settlement and building shape can be drawn exaggerated; if 0 is entered for the exaggeration, it is chosen automatically.

7.3 Adjacent building damage

Adjacent buildings are entered in the table with x_1, x_2, height H, foundation level and horizontal strain ε_h [%] (ADD BUILDING). The building is assessed as a deep beam on the settlement profile (E/G = 2.6). The deflection ratio Δ/L is found separately for sagging and hogging; through the Burland–Wroth deep beam bending and shear strains, their combination with the horizontal strain according to Boscardin–Cording and the limiting tensile

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strain, the Burland (1995) damage category is given as 0–5. In addition the tilt, the angular distortion β and the Bjerrum (1963) verdict are written. The Bjerrum criterion alone can also be selected in the settings.

If ε_h is not entered, the category is a lower bound

In dewatering the horizontal strain is generally taken as zero. When $\varepsilon_h = 0$ is entered, the result is the lower bound of the damage category; the note says so. Entering it is recommended where the horizontal strain is known or measured. For the adjacent building assessment, drawdown settlement must have been selected in the Settings.

7.4 Monitoring points

Monitoring points (name, x, y/elevation) give h(t) and the 95% time in the transient solution. These points can also be added by clicking on the section in the Results tab (Section 9.4).

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8. Excavation Support Tab and Well Group in Plan

8.1 Excavation support: staged excavation

The 5 · Excavation Support · Wall Water Pressure tab calculates the wall water pressure in staged excavation (input for a beam-on-springs model), hydraulic base failure and the inflow to the excavation. The excavation stages are entered in the table from top to bottom (ADD STAGE, DELETE SELECTED STAGE): stage name, excavation base elevation, water level inside the excavation and duration [days]. The wall tip elevation is fixed according to the last stage. Each stage is solved separately with steady seepage. “Excavation length (normal to section)” is used to find the total discharge. If “Chained transient stages” is ticked, the duration column is used (S_s and S_y are required); in this case the stages are solved as a continuation of one another.

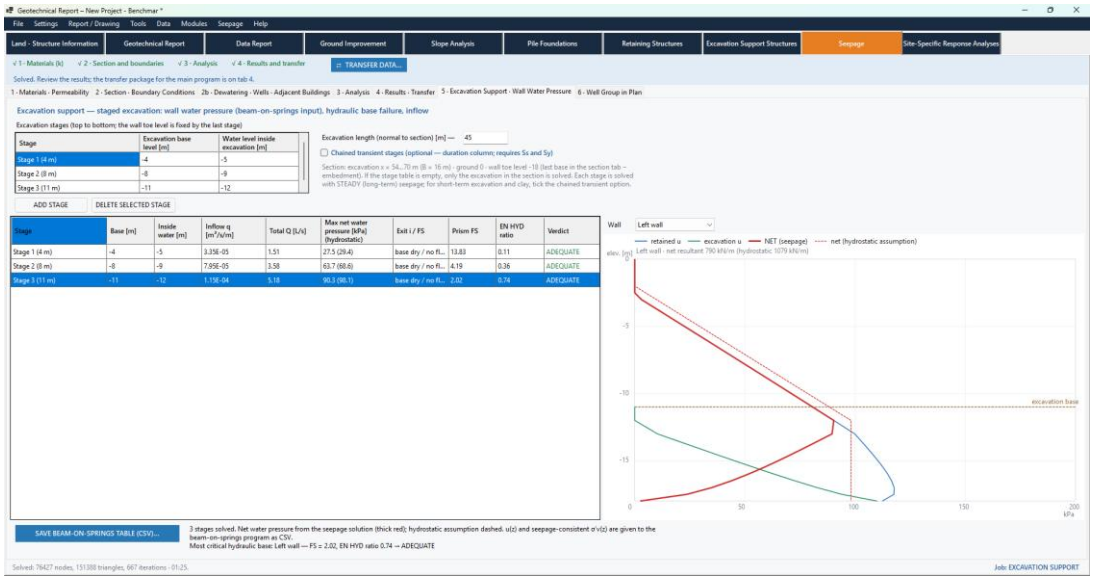


Figure 9. 5 · Excavation Support · Wall Water Pressure tab: excavation stages, stage results and back, front and net water pressure along the wall

Table 10. Excavation support result table

Column	Meaning
Inflow q [m³/s/m], Total Q [L/s]	Discharge entering the excavation
Max net water pressure [kPa] (hydrostatic)	Wall back face u − front face u (0 if u < 0); in brackets the classical hydrostatic counterpart
Exit i / FS	Exit gradient and heave safety at the excavation base
Prism FS	Safety against hydraulic base failure with the Terzaghi prism
EN HYD ratio	EN 1997-1 HYD utilisation ratio E_d/R_d; satisfied if ≤ 1
Verdict	ADEQUATE or INADEQUATE

Hydraulic base failure is checked with two criteria: the Terzaghi prism (width D/2, depth D = wall embedment length) and the EN 1997-1 HYD criterion. The average excess pore water pressure u is read along the base of the prism; FS = G′/S is found with the submerged weight G′ of the prism and the water thrust S, and the HYD ratio is given as $\gamma_{G,dst}\cdot S / (\gamma_{G,stb}\cdot G')$. If the wall does not go below the excavation base (D = 0), this check is not calculated. If γ_{sat} has not been entered, G′ and FS are not calculated and only the excess u is reported.

In the “Wall” section, the elevation, back u, front u, net u and the vertical effective stresses consistent with the seepage are listed for the selected wall. The “SAVE BEAM-ON-SPRINGS TABLE (CSV)…” button writes this water pressure table to a CSV file as input for a beam-on-springs model. Because the net water pressure is given side by side with the hydrostatic assumption, the difference is seen at once; on the front side the upward flow reduces σ'_v below $\gamma'\cdot z$.

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8.2 Well group in plan (6 · Well Group in Plan)

This tab calculates wells in plan with closed-form solutions and superposition; it does not affect the 2D section solution and is recalculated with every change. Aquifer parameters: aquifer type (unconfined or confined), permeability k (can be taken from the section with the Suggest from section button), static water level, aquifer base elevation, top elevation if confined, radius of influence R (Sichardt if empty), pumping duration (steady if empty) and, for a time-dependent calculation, storage S or S_y.

Table 11. Well group in plan methods

Case	Method
Confined, steady	Thiem
Unconfined, steady	Dupuit–Thiem (h^2 superposed)
Time-dependent (duration entered)	Theis; Jacob correction for unconfined; consistent with Cooper–Jacob for long durations
Boundary	Image well method: recharge boundary or impermeable boundary (line through points A and B)
Radius of influence	If not entered, found according to Sichardt by iteration with the drawdown at the well
Well capacity	Comparison with the Sichardt well capacity; a warning if exceeded, and a warning for a well that remains dry in an unconfined aquifer

The excavation polygon is entered in plan in sequence, and the highest target water level inside the excavation is given (for example excavation base − 0.5 m). The target drawdown is the difference between the static water level and this level; this drawdown must be achieved everywhere in the excavation (corners, mid-sides, inner grid). There are two modes: “Check: I enter the wells and discharges” and “Design: place around the excavation, find the discharge meeting the target”; in design mode the number of wells, the distance from the edge and the well radius are given, and the program places the wells at equal spacing and finds the equal discharge that meets the target. “Copy design wells to table” transfers the design result to the check table. “Save plan DXF” writes the drawdown contours and the wells with real coordinates (1 unit = 1 m).

Assumptions of the analytical solution

The solution assumes a homogeneous, isotropic aquifer with a horizontal base and fully penetrating wells; the change of the flow caused by the excavation (seepage face, wall) is not taken into account. If the radius of influence was found with the Sichardt relation, it is empirical. If a required value has not been entered (k, S for a time-dependent calculation), no calculation is made and the reason is stated.

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9. Analysis and Results

9.1 SOLVE and notes

On the 3 · Analysis tab the flow regime is shown (selected in the Settings), the target triangle edge length is entered and the “SOLVE (seepage · heave · wells · settlement · damage)” button is pressed. The calculation follows this order: seepage (steady or transient), heave, wells, settlement, damage and the transfer package. The “Notes and assumptions” tab gives the mesh summary, convergence information, assumptions, warnings, the excavation base heave line and, if present, the COMPARISON line. If there is a wall, the back and front u values at the wall tip are also written to the Notes.

9.2 Boundary discharges

The “Boundary discharges” tab gives, for each boundary (region, edge), the fixed head h [m] and the discharge [m^3/s/m] (+ inflow). The mass balance is checked: what enters from the edges must equal what leaves through the base, the wells or the seepage face. On the Results tab the discharge labels are in m^3/day/m.

9.3 Hydraulic gradient, heave and piping

The hydraulic gradient is i = −∇h. The exit gradient is taken, in the triangles touching a boundary (excavation base, downstream face), as the component in the direction of the outward normal of the edge; on a horizontal edge this equals −∂h/∂y (upward flow). The critical gradient is $i_{cr} = \gamma'/\gamma_w$. The largest upward hydraulic gradient i_{exit} at the excavation base is found, and the factor of safety is given as $FS = i_{cr}/i_{exit}$. In the settings, “Required heave safety factor (report verdict)” is a value set by the user (default 1.5), and the verdict is written as ADEQUATE or INADEQUATE accordingly. If γ_{sat} has not been entered, FS cannot be calculated.

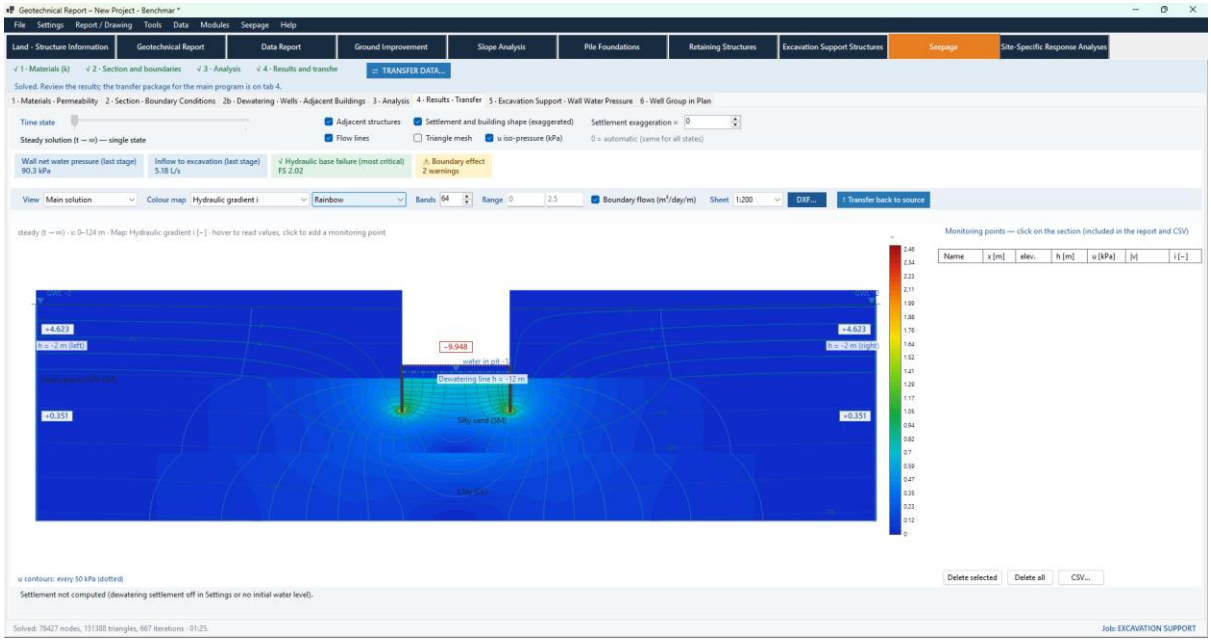


Figure 10. Hydraulic gradient i map: gradient concentrated at the excavation base, and the monitoring points table

The heave criterion has two options in the Settings: “i_{exit} / i_{cr} (Terzaghi)” and “EN 1997-1 HYD — Terzaghi prism”. If HYD is selected, the partial factors $\gamma_{G,dst}$ and $\gamma_{G,stb}$ appear in the Settings (Section 10).

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9.4 Results tab

On the 4 · Results · Transfer tab, the desired instant of the transient solution is shown with the “Time state” selection. The tab contains the following.

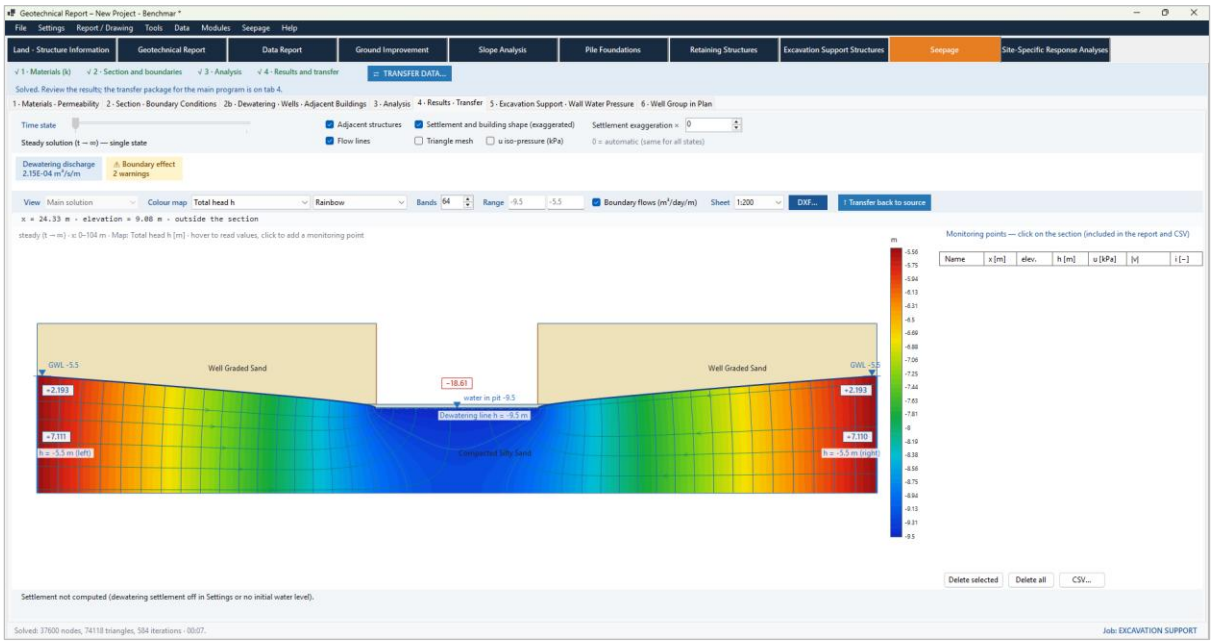


Figure 11. 4 · Results · Transfer tab: total head h map, flow lines and boundary discharge labels; summary boxes at the top

Table 12. Results tab controls

Control	Function
View	Main solution or excavation support stage (“Stage: …”)
Adjacent buildings; Settlement and building shape (exaggerated); Flow lines; Triangular mesh; u iso-pressure (kPa)	Drawing layers
Settlement exaggeration ×	0 = automatic (the same for all instants)
Colour map	No map; Total head h; Pore water pressure u; Flow velocity |v|; Vertical velocity v_z (+ upward); Hydraulic gradient i
Palette	Rainbow or Colour-blind friendly
Bands and Range	Number of colour bands and range
Boundary discharges (m^3/day/m)	Shows the discharge labels
Sheet and DXF…	Sheet scale (1:n) and DXF output
Monitoring points	A point is added by clicking on the section; the table gives the h, u, |v|, i values; Delete selected, Delete all, CSV…

When unsaturated flow is off, the h and u maps are coloured only in the saturated zone ($u \geq 0$); h in the dry zone is a by-product of the solution. When unsaturated flow is on, suction (negative u) is also coloured, enters the colour scale and its contours are drawn. Velocity and gradient are constant within an element, and the nodal values are area-weighted averages of the neighbouring elements. The monitoring points go into the report and the CSV.

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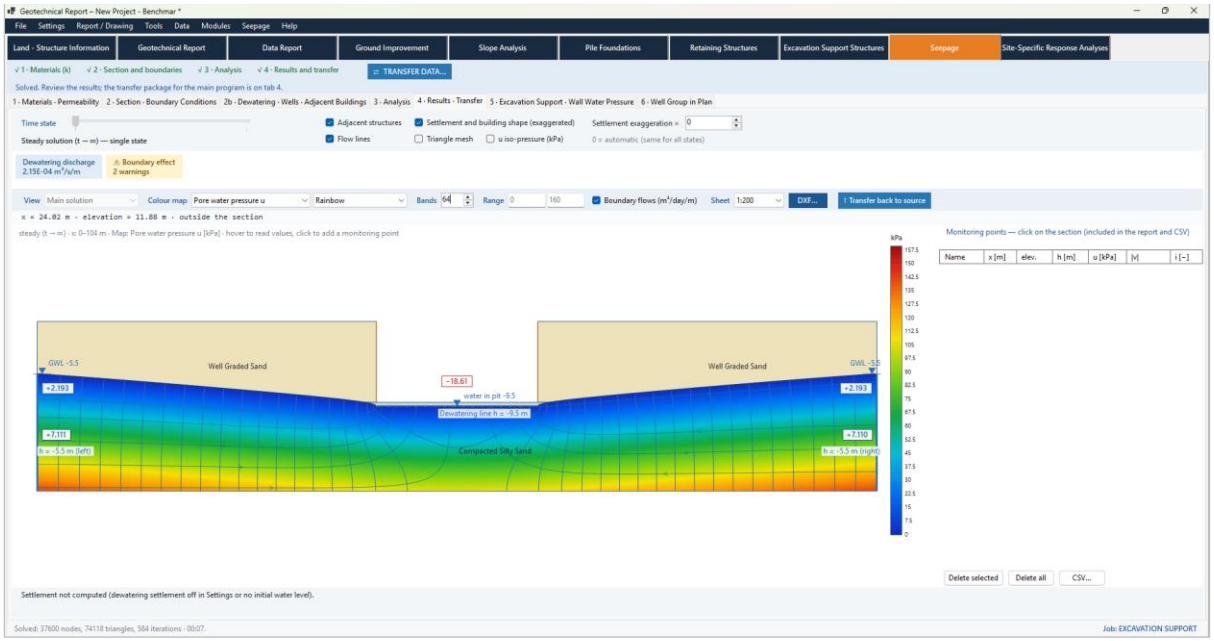


Figure 12. Pore water pressure u map (Rainbow palette)

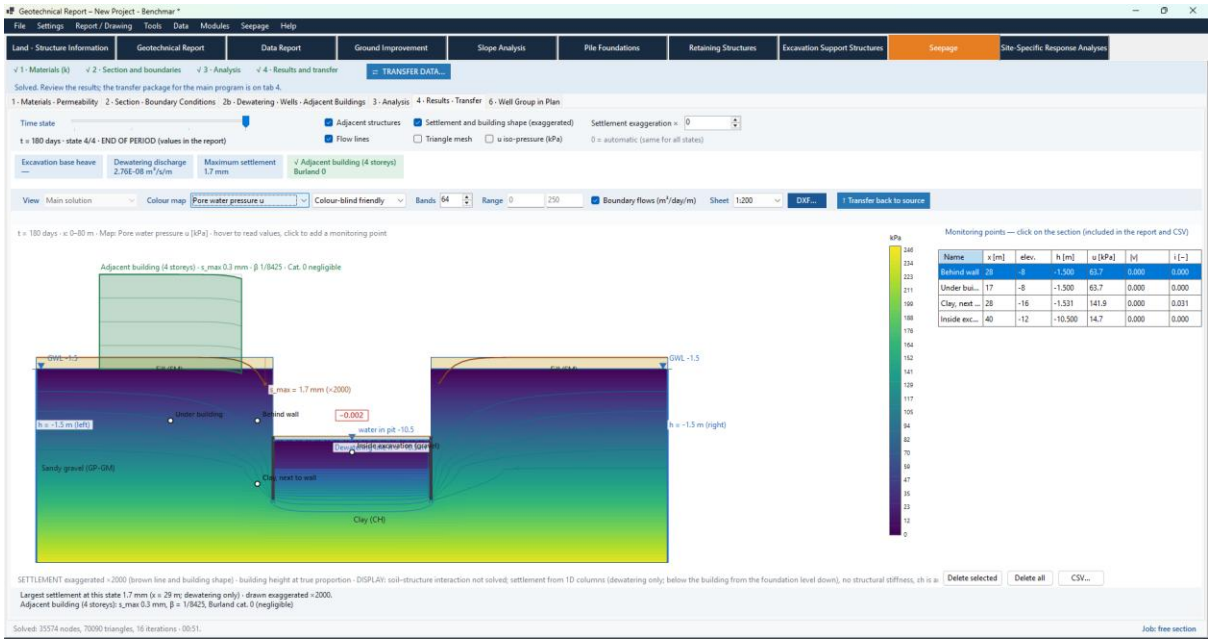


Figure 13. Pore water pressure u map (colour-blind friendly palette)

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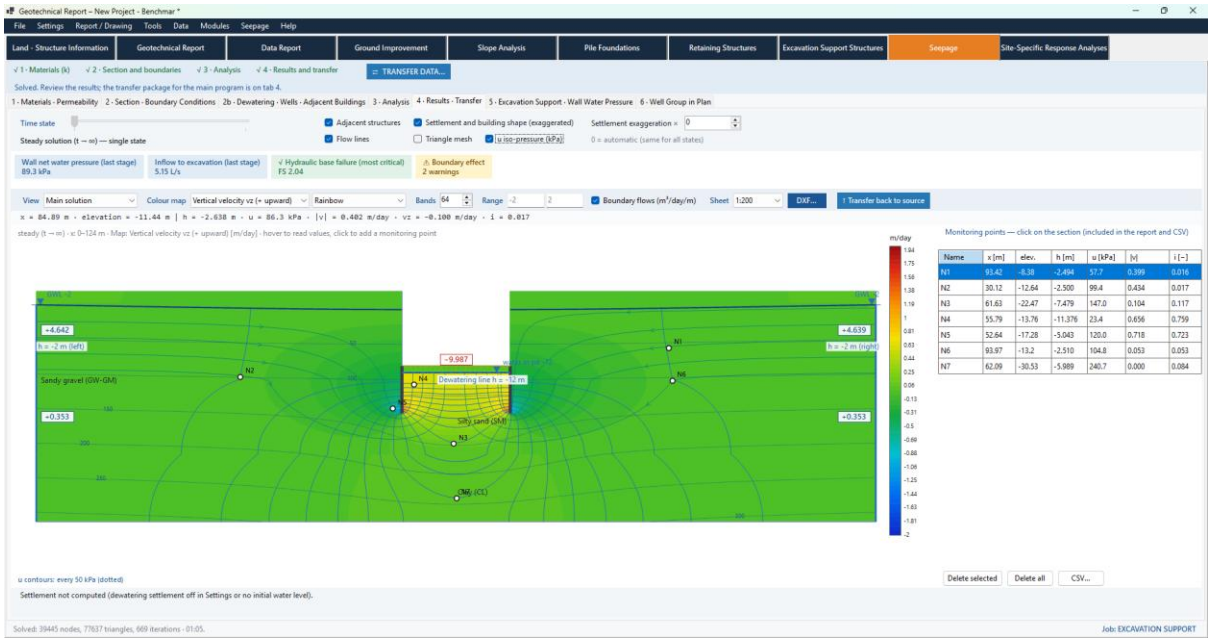


Figure 14. Vertical velocity v_z map (+ upwards): upward flow at the excavation base

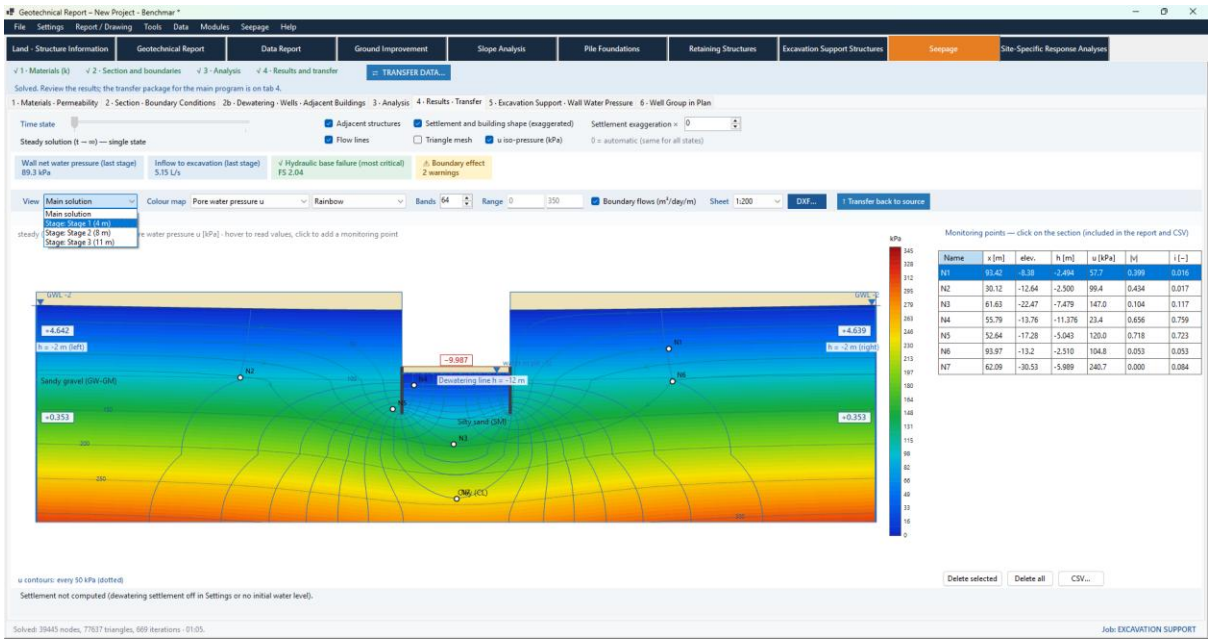


Figure 15. View selection: excavation support stages (Stage 1–3) and the pore water pressure u map for Stage 1

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10. Settings

The settings are on the “Groundwater / Seepage” tab of the Settings window in the main band; the window’s common Apply, Save as default and Cancel buttons apply to all modules. The options are each in a separate selection box; options shown in grey cannot be used in this version yet. The source of the selected method is written on the page and enters the report as the “Settings and sources” table; a row deviating from the default carries the USER ASSUMPTION label. The page also has a choice of interface language (Türkçe, English, Español, Русский). The “Show advanced settings” box makes the solver, mesh generator, well method, number of flow tubes and HYD factors visible. Apply writes the settings to the project; Save as default makes these settings the starting values for new projects.

The page has two more strips: the unsaturated flow, Newton option and suction transfer to Slope (χ) strip, and the transient initial state strip (Section 6.7). Unsaturated flow is not in the flow regime list but a separate box.

Table 13. Option settings

Setting	Options	Default
Flow regime	Steady state, saturated (Laplace); Steady state, free surface; Transient (S_s, S_y; backward Euler)	Steady state, saturated
Linear solver	Conjugate gradient (Jacobi preconditioned, sparse); Banded LDL^T (not available in this version)	Conjugate gradient
Mesh generator	Delaunay (unconstrained, with boundary sampling); Constrained Delaunay (not available in this version)	Delaunay
Dewatering with wells	Finite element (in the section plane); Dupuit–Thiem and Theis (not available in this version)	Finite element
Heave / piping criterion	i_{exit} / i_{cr} (Terzaghi); EN 1997-1 HYD — Terzaghi prism	i_{exit} / i_{cr}
Drawdown-induced settlement	Not computed; 1D elastic; 1D consolidation; Both	Not computed
Adjacent building damage criterion	Burland + Boscardin–Cording + Bjerrum; Bjerrum β only	Burland, Boscardin–Cording, Bjerrum

Table 14. Numerical settings

Setting	Default	Note
Target triangle edge length [m]	0.5	Reducing it slows the calculation
Required heave safety factor	1.5	User value for the report verdict; the source is the user
EN 1997-1 HYD: $\gamma_{G,dst}$ / $\gamma_{G,stb}$	1.35 / 0.90	Recommended values of Annex A Table A.17; the national annex may differ
Number of flow tubes N	10	0 = do not draw flow lines; visual only
Transient: total duration [days]	30	In the transient regime
Transient: number of steps	40	Geometric, first step small
Settlement station spacing [m]	1.0	Along the section
Settlement sublayer thickness [m]	0.25	Δσ’ integration

If setting values are out of range, the program resets them to the defaults and reports this. The unit weight of water is taken as 9.807 kN/m^3 in all calculations and is written to the report.

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11. Report, Drawing and Transfers

11.1 Word report

The Report / Drawing › Seepage › Report › REPORT (docx)… command or the “CREATE WORD REPORT (.docx)…” button on the 3 · Analysis tab generates the report. A chapter without data is not included in the report. The chapters are as follows.

Table 15. Report chapters

Chapter	Content	Inclusion condition
Cover, approvals, contents, symbols	The lists of figures and tables are Word fields	Always
1 Introduction and scope	Scope, summary	Always
2 Soil profile and parameters	Layers and k sources	Always
3 Calculation model and boundary conditions	Model, boundary conditions, wells	Always
4 Seepage analysis results	Discharges, wall u(z)	Always (wall section if there is a wall)
5 Excavation base heave / piping check	i_{exit}, i_{cr}, FS, verdict	If there is a heave calculation
5A Excavation support	Stages, wall water pressure, hydraulic base failure	If there are excavation support stages
5B Well group in plan	Inputs, wells, check points	If the well group has been calculated
6 Transient solution	Initial condition, development of the drawdown	In the transient regime
7 Drawdown-induced settlement	Settlement profile	If settlement is on
8 Adjacent building damage assessment	Burland category, Bjerrum verdict	If there are adjacent buildings
9 Benchmark comparison	Difference from the closed-form solution	If it is a benchmark project
10 Settings and sources	Settings table; USER ASSUMPTION rows	Always
11 Conclusion and assessment	Decision and qualification rows	Always
12 References; Appendices	Reference list; figures	Always

The report figures are generated as PNG images: section and flow net, wall u(z), drawdown–time, discharge–time and settlement profile; the chapter of a calculation that has not been performed is not included in the report.

In the transient solution chapter the initial condition is written as a separate sentence and follows the choice in the Settings (Sections 6.3, 6.7): with “Water table + suction cap (hydrostatic, capped)” selected, the water-table level and the suction cap; with a water level programme, “steady seepage solution at the t = 0 levels (water level programme)”; otherwise “water level … m over the whole domain (hydrostatic)”. If the section was not built with the section generator (BUILD SECTION), “geometry entered manually” is written in the calculation model chapter.

11.2 DXF drawing sheet

The Report / Drawing › Seepage › Drawing › FLOW NET SHEET (DXF)… command and the DXF… button on the Results tab write a DXF file with the view on screen (map, stage, scale). The file is in R12 format and ASCII only; the drawing unit is the metre (1 unit = 1 m). The sheet scale is chosen from the standard series (1:50, 1:100, 1:200, 1:250, 1:500, 1:1000, 1:2000); the drawing stays at the selected scale, and the paper grows to fit the drawing if necessary. The well group tab also produces a plan DXF (Section 8.2).

11.3 Transfer package and CSV

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The “SAVE TRANSFER PACKAGE (JSON)…” button collects the outputs to be passed to the main program in a single JSON file: the pore water pressure field u(x,y), the u(z) diagram along the wall, the exit hydraulic gradient and heave safety, the lowered water level and its time function, the settlement trough and the adjacent building damage. The monitoring points are exported as CSV; the Excavation Support beam-on-springs table is saved as a separate CSV.

11.4 Transfer to Slope

The “Seepage → Slope: Transfer Water Line…” command in the Data menu of the main program deletes the existing water line in the Slope section and writes the phreatic line of the Seepage solution (you can go back with Undo in Slope). If the Seepage and Slope sections overlap by less than 10% in the x direction, the transfer is rejected. After the command, the program asks whether the pore water pressure field u(x,y) should also be transferred. YES: the u value at the slice base is read from the Seepage field (the classical calculation continues outside the mesh). NO: the classical calculation, i.e. only the water line and hydrostatic u, is used; the field is stored and can be switched on later from the Slope settings panel. In the transferred field suction ($u < 0$) is clipped to zero by default; if “Suction transfer to Slope ($u < 0$)” is turned on in the Settings, $u_eff = \chi \cdot u$ is used in Slope (Section 6.7).

11.5 Transfer to Excavation Support

The “Seepage → Shoring: Transfer Water Levels…” command writes the back and front phreatic depths of the deepest stage (from the top of the wall, m) to the active face in Excavation Support; they replace the existing values and confirmation is asked. If there is no water on the front side, this is reported. You are then asked whether the u(z) profile along the wall should also be transferred. YES: the nodal water pressure is taken from the Seepage profile. NO: Excavation Support builds its own water diagram from the two levels above; the profile is stored and can be switched on later.

11.6 Transfer back to source

For a model built with TRANSFER DATA, the “Transfer back to source” button appears on the Results tab. With an Excavation Support source, the face of the source is selected and the water levels (optionally u(z)) are written to Excavation Support; with a Slope source, the water line and optionally u(x,y) are written to Slope. Transfer back is for Excavation Support and Slope sources: the water input of Retaining Structures is entered by hand per wall, and the groundwater level in the Geotechnical Report is a measurement and is therefore not replaced by the Seepage result. If there is no Seepage solution or it is out of date, SOLVE is first run on 3 · Analysis.

11.7 Use together with the Data Report

The borehole and layer information in the Data Report is carried over to the Geotechnical Report with the “Transfer from Data Report to Geotechnical Report…” command in the main program (boreholes are matched by name; only those existing only in the Data Report are added, and the design parameters are taken from the old layer with the greatest overlap). Seepage takes these boreholes and layers from the “Geotechnical Report” source in the TRANSFER DATA window. The Data Report does not pull data directly from Seepage.

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12. Verification and Benchmarks

12.1 Verification approach

The calculations in this module have been checked against independent verification examples and hand calculations. The comparisons with closed-form solutions and with other programs are given in the following sections.

12.2 Comparison with closed-form and analytical solutions

Table 16. Comparison with closed-form solutions

Example	Reference	Program	Difference	Status
Single sheet pile, finite thickness (T = 10 m, s = 5 m, H = 1 m, k = $1\cdot10^{-4}$ m/s); 0.5 m mesh	q = $5.000\cdot10^{-5}$ m³/s/m (Harr 1962; Polubarinova-Kochina 1962)	$5.102\cdot10^{-5}$	+2.0%	Consistent (band 6%)
Same sheet pile; 0.25 m mesh	$5.000\cdot10^{-5}$	$5.055\cdot10^{-5}$	+1.1%	Consistent (band 3%)
Rectangular dam (h_1 = 10 m, h_2 = 2 m, L = 20 m, k = $1\cdot10^{-4}$ m/s)	q = $2.400\cdot10^{-4}$ m³/s/m (Charny; Dupuit)	$2.390\cdot10^{-4}$	−0.4%	Consistent
Same dam: upstream discharge	Dupuit q = $k(h_1^2-h_2^2)/2L$	$2.39\cdot10^{-4}$	−0.48% (band 8%)	Consistent
Same dam: free surface at mid-section	Dupuit parabola (7.211 m)	7.45 m	+3.3% (band 12%)	Consistent
Terzaghi 1D consolidation, T = 0.2 and 0.5	U = 0.504 and 0.764; ũ/Δ profile (closed-form solution)	0.4998 and 0.7529	−0.85% and −1.4%	Consistent
Sudden head drop in a confined strip, two times, three points	Carslaw–Jaeger erfc solution	largest difference 0.008 m	±0.03 m (within band)	Consistent
Homogeneous sand, water 0 → −3 m, elastic settlement	12.50 mm (hand calculation)	12.50 mm	exact match	Consistent
Same column, γ_{moist} = 17 kN/m³	9.95 mm (12.50 − 2.55; hand calculation)	9.95 mm	exact match	Consistent
Theis well function W(u): u = 0.01; 0.1; 1; 5	4.0379; 1.8229; 0.21938; $1.148\cdot10^{-3}$	—	relative $2\cdot10^{-4}$ (10^{-3} for u = 5)	Consistent
Well group in plan: Thiem, Dupuit–Thiem, superposition, image well	Closed-form solutions (hand calculation)	—	relative 10^{-9}	Consistent
Steady 1D unsaturated infiltration column (L = 5 m, q/ks = 0.1, Gardner α = 1 1/m); example A	Srivastava and Yeh (1991) closed form, ψ(z = 1 / 2.5 / 4 / 5 m) = −0.8414 / −1.7494 / −2.1500 / −2.2437 m	−0.8413 / −1.7495 / −2.1502 / −2.2438 m	at most 0.02%; discharge q·B within ±1%	Consistent (criterion 1%)

In the rows marked "—" in the table (Theis and well group in plan), the program's relations have been compared one-to-one with the closed-form values; for Theis W(0.01) the program gives 4.03793 (reference 4.0379), and the Thiem and Dupuit–Thiem relations are identical to the reference at r = 10 m. The sheet pile problem has also been checked with an independent finite difference model. It has also been checked that the flow lines pass beneath the sheet pile, do not enter the dry zone, and that mass is conserved.

12.3 Comparison with other programs

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The comparisons have been made against GEO5 and SEEP/W results; these program results are not a reference (closed-form solution) but another numerical solution. The difference is therefore not a "deviation from the correct value" but the difference between two methods.

Table 17. Comparison with GEO5 (discharge, m^3/day/m)

Example	GEO5	Program	Difference	Band	Status
EM32 earth dam, stage 1, upstream 2 m (total discharge)	0.288	0.297	+3.1%	5%	Consistent
EM32, stage 2, upstream 9 m (total discharge)	2.284	2.266	−0.8%	5%	Consistent
EM32, stage 3, upstream 10.8 m (total discharge)	3.304	3.315	+0.3%	5%	Consistent
EM32, stage 3: exit through the downstream face	0.503	0.470	−6.6%	15%	Consistent
2026 FEM Model 1: sheet pile	4.255 (Harr closed-form solution 4.32)	4.368	+2.6% (+1.1% relative to Harr)	5%	Consistent
2026 FEM Model 2: excavation support, sand	30.641	30.999	+1.2%	5%	Consistent
2026 FEM Model 3: excavation support, clay over sand	0.610	0.630	+3.2%	5%	Consistent

In stages 1 and 2 of the EM32 dam no exit through the downstream face is expected (as in GEO5), and the exit is zero in the program as well. In Model 2 the total head at five points read from the GEO5 colour band was found within ±0.15 m.

Table 18. Comparison with SEEP/W and classical solutions (discharge, m^3/s/m)

Example	SEEP/W	Classical solution	Program	Difference (SEEP/W)	Difference (classical)
Dam on an impermeable foundation, without drain	$2.140 \cdot 10^{-6}$	$1.793 \cdot 10^{-6}$ (Casagrande)	$2.020 \cdot 10^{-6}$	−5.6%	+12.7%
Same dam, with toe drain	$2.499 \cdot 10^{-6}$	$2.042 \cdot 10^{-6}$ (Kozeny)	$2.272 \cdot 10^{-6}$	−9.1%	+11.3%

In these two problems the expectation is that the program discharge lies between SEEP/W and the classical closed-form solution (from 95% of the classical value to 105% of the SEEP/W value); the program lies between the two references. The closed-form values (Casagrande, Kozeny) have also been checked by hand calculation ($1.794 \cdot 10^{-6}$ and $2.043 \cdot 10^{-6}$).

The rainfall slope examples (B, C, C2) are ILLUSTRATIVE: geometry, soil and rainfall are inspired by Rahardjo et al. (2007) and the GeoStudio example that rebuilds it; closeness is an indicator of consistency, not proof of a literature match. Example B is checked with an independent 1D ordinary differential equation solution, the Dupuit solution (left-edge head 15.85 m; Dupuit 16.54 m, −4.2%) and the mass balance. Slope factor of safety (with the field transferred from Seepage, $\chi = 0.746$): in example C 1.821 with suction (GeoStudio Case 5: 1.845; −1.3%), 0.773 without suction (GeoStudio 0.799; −3.3%); in example C2 (water table 10 m, suction cap 75 kPa) 1.924 (GeoStudio Case 1b: 1.933; −0.5%).

12.4 Known differences

- Because of the singularity at the sheet pile tip, unless the mesh is fine the discharge comes out a few per cent higher than the closed-form solution (2.0% with a 0.5 m mesh, 1.1% with a 0.25 m mesh). In critical problems users should check mesh convergence themselves.
- The well row and the transient solution have not yet been compared with another software package; these solutions have been verified against closed-form solutions (Theis, Carslaw–Jaeger, Terzaghi). Use their results with caution.

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Benchmark files

The benchmark problems can be opened from the Seepage › File › Benchmark problems menu (Harr sheet pile, Charny dam, GEO5 EM32 three stages, SEEP/W two dams, GEO5 2026 FEM three models). After SOLVE, the COMPARISON line in the Notes gives the difference from the closed-form solution as a percentage, with the verdict CONSISTENT or INCONSISTENT.

13. Points to Watch

- The permeability k is the largest uncertainty in the model. If a k assigned from the class or a literature range has been used, the sensitivity of the result should be checked with the lower and upper values of k (Section 4.2).
- The section boundaries must be far enough away. If the fixed-head side boundary lies within the radius of influence of the dewatering, the boundary feeds water and artificially brings the drawdown and settlement to zero towards the boundary. In this case the program issues a “BOUNDARY EFFECT” warning (the radius of influence is estimated with the empirical Sichardt relation; warning only). For a walled excavation this warning is not issued, because the wall cuts off the flow.
- Mesh convergence should be checked. The target edge length should be compared between 0.5 m and 0.25 m; around the wall tip, the well screen and the seepage face the results are sensitive to the mesh.
- In the free-surface regime the iteration information in the Notes should be read; a solution that has not converged should not be reported.
- The drain line and the well row are idealisations as horizontal or vertical fixed-head lines in the section plane. A three-dimensional well layout should be examined separately with the well group in plan calculation.
- The settlement is due to dewatering only. In adjacent building damage, if $\varepsilon_h = 0$ the category is a lower bound (Section 7.3).
- Transferring pore water pressure to another module (Section 11) changes the result of that module. The choice asked in the two-way transfer should be made consciously; if NO is selected, the classical calculation is preserved exactly.
- Suction transfer to Slope (χ) increases the shear strength in Slope; for this reason it is off by default. Turning it on and the χ value are a USER ASSUMPTION (Section 6.7).
- The velocity field and flow lines are visual only; in dry elements the velocity is found with the permeability multiplied by the saturation factor.
- Options in the settings that are not available in this version (grey) cannot be used in the calculation.

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14. Code and Source References

Table 19. Code and source references

Topic	Basis	Note
Site and foundation investigation, groundwater information	Communiqué on the Principles of Soil and Foundation Investigation and the Report Format (Zemin ve Temel Etüdü Uygulama Esasları ve Rapor Formatına Dair Tebliğ, 2019); TBDY 2018 Chapter 16	Included in the report's reference list
Hydraulic base failure (HYD)	EN 1997-1 §2.4.7.5, §10.3, Annex A Table A.17	$\gamma_{G,dst}$, $\gamma_{G,stb}$ in the Settings; the national annex may differ
Piping / heave, critical gradient	Terzaghi (1943); Terzaghi, Peck and Mesri (1996)	$i_{cr} = \gamma'/\gamma_w$
Free-surface seepage	Bathe and Khoshgoftaar (1979)	Dry element factor and seepage face iteration
Transient free-surface flow	Neuman (1972); Bear (1979)	With S_s and S_y
Seepage under a sheet pile, closed-form solution	Harr (1962); Polubarinova-Kochina (1962)	Benchmark problem
Rectangular dam discharge	Charny (1951)	Benchmark problem
Well hydraulics	Thiem (1906); Dupuit (1863); Theis (1935); Cooper and Jacob (1946); Jacob (1944); Sichardt (1928); Kruseman and de Ridder (1994)	Well group in plan
Equivalent trench and well row	Powers et al. (2007) Chapter 6; CIRIA C515	See the source check note below
Drawdown settlement	Terzaghi, Peck and Mesri (1996); Das (2010)	Elastic and log-linear consolidation
Adjacent building damage	Burland and Wroth (1974); Boscardin and Cording (1989); Burland (1995); Bjerrum (1963)	Deep beam model, category 0–5

14.1 Source check against Powers et al. (2007)

The well hydraulics relations of the module have been compared with Powers et al. (2007) Chapter 6. The relations in the program that match the book one-to-one are: the Thiem relation for a confined aquifer (Eq. 6.1), the Dupuit–Thiem form for an unconfined aquifer (6.3) and the mixed aquifer form (6.5), the line source trench relations (6.6, 6.7; twice that for flow from both sides), the equivalent radius (6.8, 6.9), the Sichardt–Kyrieleis relation for the radius of influence (6.12; the book gives mixed units, the module uses metres and m/s) and the Sichardt relation for well capacity (6.17–6.18). The partial penetration correction (Butler; 6.14) is not in the module.

The source of the additional in-well drawdown relation could not be verified

The additional in-well drawdown relation for a well row, $\Delta s = Q/(2\pi kb)\cdot\ln(a/2\pi r_w)$, was not found in Powers et al. (2007) Chapter 6; nor is it in CIRIA C515 Chapter 6 (both books treat well losses separately and recommend a pumping test). Possible sources are Mansur and Kaufman (1962) and USACE EM 1110-2-1914; these citations have not yet been verified against the sources. The relation should therefore be used for information only, and a pumping test or manufacturer data should be consulted for well losses. The Burland–Wroth deep beam relations and the category limits have not yet been compared with Burland (1995), nor the class values of the capillary fringe ψa with Das's capillary rise table; use these values with caution.

The equivalent radius form of CIRIA C515 differs from that of Powers: Powers $r_s = \sqrt{(ab/\pi)}$, CIRIA $r_e = (a+b)/\pi$; both are accepted and give different results for long, narrow systems. In the relation for the radius of influence $R_0 = C\cdot(H-h_w)\cdot\sqrt{k}$, h_w is the target drawdown at the equivalent well, not at the individual wells.

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15. Known Limitations

- The section is two-dimensional; a well is represented not individually but as a well row.
- When unsaturated flow is off (default), flow in the unsaturated zone is not solved; the free-surface regime uses a small permeability factor for dry elements. When unsaturated flow is on and the solution does not converge, a warning is given and the last iterate is kept (Section 6.7).
- In the transient solution, free-surface storage (S_y) is taken into account with an approximation distributed over the element height.
- At the shared corner on a layer interface, the edge water level of the lower layer applies; the head is discontinuous at this point.
- On a flat surface without a wall or excavation, if the two sides are under water at different levels, the surface is left as no-flow and a note is added.
- Flow lines hitting a wall face slide along the face; lines very close to the wall may merge at the tip (visual only).
- Adjacent building damage is a deep beam idealisation; building stiffness and soil–structure interaction are not modelled separately.
- With TRANSFER DATA, the jet grout block, opposite face, anchors and struts of Excavation Support, the excavation stage of Slope, and the horizontal impermeability of the foundation base and the inclined back face of Retaining Structures cannot be represented; this is stated in the summary.
- The banded LDL^T solver, constrained Delaunay, and the Dupuit–Thiem and Theis well methods (in the section solution) in the settings are not available in this version.

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