



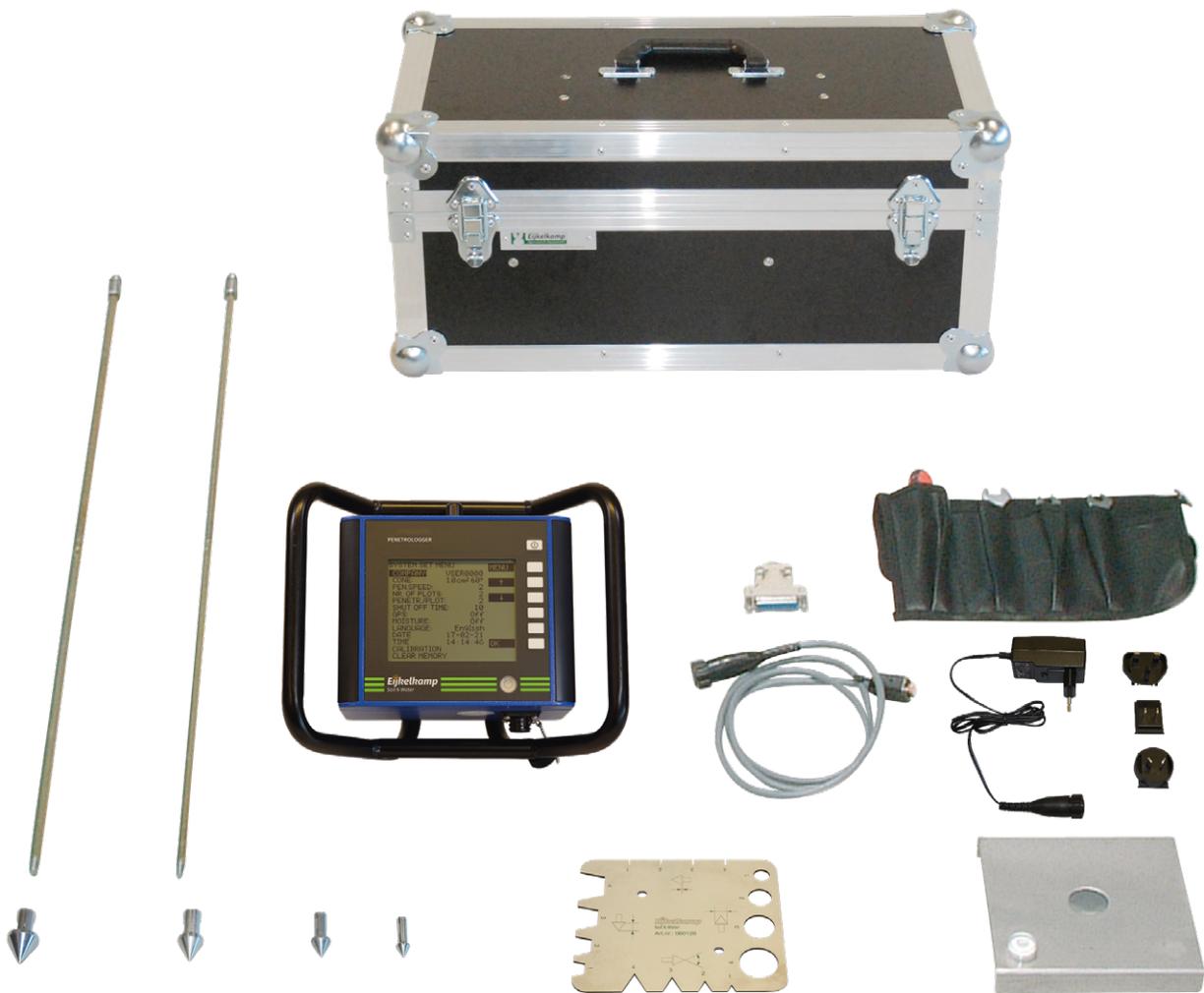
Penetrologger

User manual

Brand data

Hardware version : 6.00
Software version : 6.03
Penetroviewer version : 6.08

Serial number :



Meet the difference

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On these operating instructions



If the text follows a mark (as shown on the left), this means that an important instruction follows.



If the text follows a mark (as shown on the left), this means that an important warning follows relating to danger to the user or damage to the apparatus. The user is always responsible for its own personal protection.

Text

Italic indicated text indicates that the text concerned appears in writing on the display (or must be typed).

Introduction

The penetrometer has been especially developed to measure the resistance to penetration of the soil and to save the measuring results to digitally process them on a computer. The penetrometer is ergonomically designed, lightweight and easy to use. It can be used to measure to a depth of 80 cm.

The penetrometer gives the Cone Index (CI) per measurement.

The penetrometer comprises an accurate internal GPS-system (50 channels) to determine the exact measuring point. The coordinates saved in the penetrometer can be linked to a place or map using software (or less accurately via Internet).

Optionally, a soil moisture sensor (art. no. 061550) can be connected to make a one point measurement and record the soil moisture percentage at the measuring point.

The resistance to penetration of the soil is the resistance of the soil to the force of penetration per unit area, expressed in $[N/m^2]$ or in $[MPa]$. The resistance to penetration depends on soil properties such as bulk density, moisture content, soil structure and –texture and organic matter content.

The penetrometer is suitable to save and process 1500 sets of measuring data (penetration resistance value incl. GPS and soil moisture data), which is ideal for carrying out large numbers of measurements. It has a built-in penetration speed control facility (rapid and jerky penetration produces unreliable data). The penetrometer method is accurate and has a measuring range of 1000 N.

The penetrometer is used in civil engineering, soil sciences, agriculture, determination of carrying capacity of building sites, and the maintenance of sports fields, parks and public gardens.

1. Measuring the resistance to penetration

The resistance to penetration of the soil or shallow subsoil, measured by the penetrometer is a measure of compaction or the bearing capacity of the ground. In civil engineering, a high level of resistance to penetration can prove to be essential for the foundation of buildings or infrastructural projects.

The penetration resistance of the soil is used for assessing the accessibility of (construction) sites with the aid of the Cone Index and Vehicle Cone Index (see section 12).

In agriculture, however, too high a level of resistance may be problematic. Too much compaction may hinder the rootage of crops or the supply of oxygen. Too low a level of resistance renders insufficient bearing capacity to carry the weight of cattle or agricultural implements

1.1 Bearing capacity

In agriculture the bearing capacity is crucial in view of the soil resistivity to the weight of cattle or agricultural implements. In farming sufficient bearing capacity is essential for cultivation and harvesting activities. In grassland management the bearing capacity is important to allow the mechanical spread of manure or fertilisers, extending the grazing period or to avoid the loss of grazing surface by trampling.

To assess the bearing capacity, a critical limit can be set for several applications. In the case the resistance to penetration is above this critical limit, the bearing capacity is sufficient, below that limit it the capacity is insufficient.

Appendix 1 lists the critical limits for the bearing capacity of pastures and sports fields, as well as the recommendations for the size of the cones to be used when measuring with the penetrometer.

1.2 Rootability

The maximum of 1 MPa can be considered as a guideline of rootability, which is the force roots exert on soil particles. However, roots in their development cause crevices and macro-pores, and tend to grow around the stones in the soil. The penetrometer cannot achieve this; therefore, the critical limit of rootability exceeds 1 MPa (as measured by the penetrometer).

According to Locher & De Bakker (1990) uninterrupted root growth can take place at penetration resistance values below 1.5 MPa. A value of approx. 3 MPa can be regarded as the upper limit for uninterrupted root growth. Interrupted root growth leads to reduced water and nutrient absorption, and ultimately to reduced crop production.

1.3 The effect of soil moisture and the organic matter content

The resistance to penetration of the soil is related, among other things, to soil moisture properties. The higher the moisture content of the soil, the lower the resistance to penetration and hence the bearing capacity. Therefore, in order to compare the resistance to penetration measured in several periods (for example before and after tillage) it is essential that the moisture contents of the soil conditions in those periods are comparable. To ensure comparable soil moisture content conditions in practice it is best to determine the resistance to penetration at field capacity (pF 2).

The soil moisture level at the measuring point can be measured and saved using the optional soil moisture sensor (art. no.: 061550). See Appendix 5 for a short manual.

The organic matter content positively affects the bearing capacity. A peaty topsoil with low bulk density compares to a sandy topsoil with little organic matter (see Appendix 1).



1.4 Spatial variability

When determining the resistance to penetration it is essential to take the spatial variability of soils into account. Differences in texture, structure and organic matter content may vary considerably from plot to plot. As all these factors affect the resistance to penetration, it is necessary to carry out replicate measuring to obtain representative values.

The number of replicate measurements depends on the accuracy required and on the natural variability of the soil. Campbell & O'Sullivan (1991) recommend 10 measurements per plot. The distance between the plots is minimally 50 – 60 cm in view of possible deformation of the soil resulting from insertion of the cone. The Dutch norm for electrical sounding (NEN 5140,1996) recommends an in-between distance of at least 100 cm.

The choice of representative measuring locations will vary per application. It will not suffice to measure in a tractor track to determine the general resistance to penetration, whereas this would be appropriate to obtain a measure of compaction resulting from traffic.

2. Description

The penetrometer is available as a complete set suitable for measurements up to a depth of 80 cm. The set consists of the penetrometer, cones, conecheck, probing rod, a depth reference plate, a set of tools, a battery charger, a cable, downloadable software and a test report. Optionally various accessories are available such as a soil moisture sensor (art. no. 061550) and various cones. The set is contained in an transport case.

The penetrometer itself (see picture) consists of:

1. Water-resistant housing
2. Impact absorber
3. Bipartite probing rod
4. Cone
5. Depth reference plate
6. Communication port
7. GPS antenna
8. LCD screen
9. Control panel
10. Level
11. Electrically insulated grips
12. Conecheck

As internal power source, the penetrometer requires 5 rechargeable AA NiMH batteries.

A cone (4) is screwed onto the bottom end of a bipartite probing rod (3). Depending on the application and the expected resistance to penetration different cones can be attached. The cones supplied have 60° top angle (according NEN 5140) and various base areas (see table).

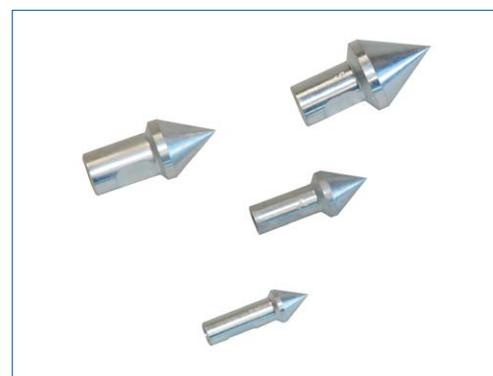
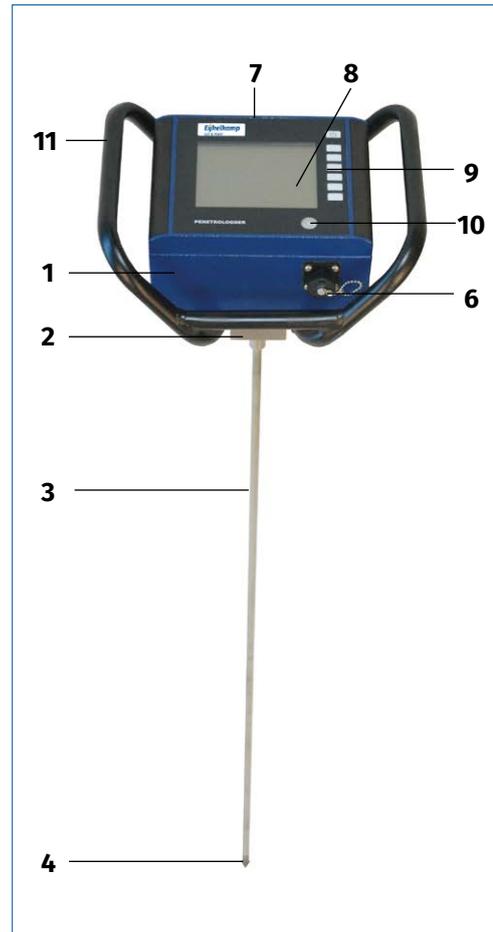
| No. | Base area (cm ²) | Nominal diameter (mm) | Reject diameter (mm) |
|-----|------------------------------|-----------------------|----------------------|
| 1 | 1 | 11.28 | 11.00 |
| 2 | 2 | 15.96 | 15.55 |
| 3 | 3.33 | 20.60 | 20.08 |
| 4 | 5 | 25.23 | 24.59 |

The probing rod consists of two parts and is attached to the impact absorber (2) under the penetrometer, using a quick coupling. The smaller cones match the 8 mm probing rod, the broader cones match the 10 mm rod.

During insertion of the cone the internal ultrasonic sensor of the penetrometer accurately registers the depth up to 80 cm, thereby using the depth reference plate (5).

The measured penetration resistance, the GPS data and, if the optional soil moisture sensor is connected to the communication port (6), the soil moisture percentage, are saved in the internal logger of the penetrometer.

From these measuring data the average and standard deviation can be determined.



A cable between the communication port (6) and the computer allows the exchange of data between the logger and the computer. The software enables the graphical and numerical display of the data on the computer and printing as well.

The conecheck is used to check the cones for wear according to NEN 3860, NEN 5140 (cone length, -angle, -diameter and shaft length).

3. Technical specifications

| Item | Specifications |
|----------------------------|--|
| Operational temperature | 0 – 50 °C |
| Operational humidity | IP 54 (water-resistant) |
| Penetrologger weight | 3.4 kg (not including probing rod, including batteries) |
| Set weight | 15.5 kg |
| Transport case dimensions | 58 x 29 x 25 cm |
| Memory | 1500 measurements |
| Max. penetration force | 1000 N |
| Force resolution | 1 N |
| Total length measuring rod | 97 cm (excl. cone) |
| Depth registration | 80 cm |
| Depth resolution | 1 cm |
| GPS accuracy | 2 m CEP Circular Error Probable SEP Spherical Error Probable (Egnos compensated) CEP, 50% 24 Hours static, - 130 dBm (type µBlox LEA-6H) < 2.5 m CEP (Circular Error Probable) 3.5 m |
| Soil moisture resolution | 1% |
| Batteries | 5 x AA NiMH 2600 |

4. Method

Before any measuring using the penetrometer can take place, a fieldwork plan must be drawn up (see 5. Fieldwork plan). A plan includes defining the fieldwork plots, the number of measurements per plot, and the settings of the penetrometer (for example cone type and penetration speed).

It is possible to 'create' or program the plan on the penetrometer (see 7. Using the penetrometer to program the plan), but it is more convenient to use a computer (see 6. Computer-based programming of the plan).

To this purpose the Penetroviewer software, that can be downloaded from eijkelkamp.com (search for Penetroviewer), needs to be installed on the computer. Linkage of the computer to the penetrometer, using a cable, permits sending the programmed plan from the computer to the penetrometer.

Upon programming of the plan, the penetrometer is ready for reading the resistance to penetration. In the field the required number of measurements is carried out for each programmed plot (see 8. Measuring). The data, to a maximum of 500 measurements, are automatically stored in the logger memory. If necessary, adjustments to the plan can be made in situ (Paragraph 7.4).

The measurement data can be viewed in graphical or numerical display on the penetrometer in situ (see 9. Processing the data). The software allows reading and processing the data on the computer and printing them on a printer or plotter.

5. Fieldwork plan

5.1 Drawing up a plan

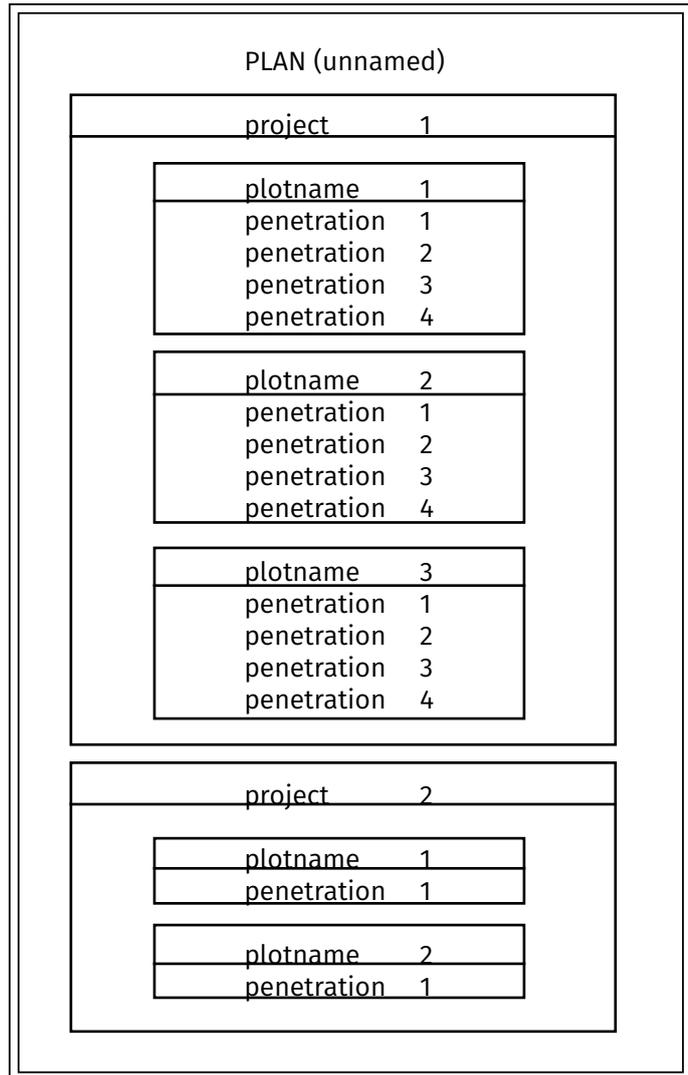
A plan consists of a hierarchical structure of projects, plots and penetrations (see figure).

A project is a complex of various locations for measuring ('plots'). The resistance of penetration is determined for each plot.

One or several measurements or 'penetrations' are carried out per plot to obtain a representative average result per plot.

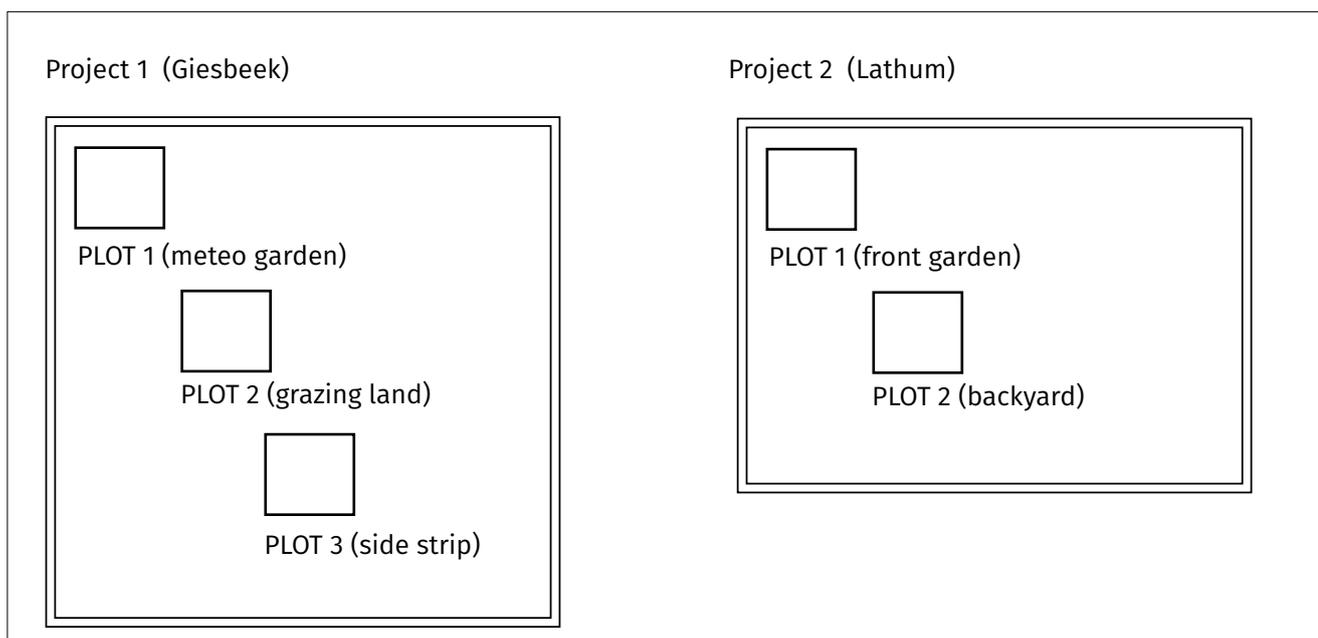
Per project the following general data is programmed:

- Project name
- User name (company name)
- Plot names
- Type of cone
- Penetration speed
- Number of plots
- Number of penetrations per plot (max. 20)



5.2 Example

An example of such a plan is given:



6. Programming with PC software

The input of data on a computer using the keyboard and then sending them to the penetrologger is far more convenient than programming directly on the penetrologger. Keying-in the special names of plots on the penetrologger is very time-consuming. Therefore, the use of a computer is to be preferred. Per plan one or several projects with a maximum of 500 penetrations can be defined.



The memory of a computer can hold several projects and they can be retrieved at any desired time, whereas the memory of the penetrologger can hold only one single plan. If the field situation requires working with several plans, a laptop may be the solution.



To be able to work with the PC software (Penetroviewer) for the penetrologger you need full read and write rights.

6.1 Software installation

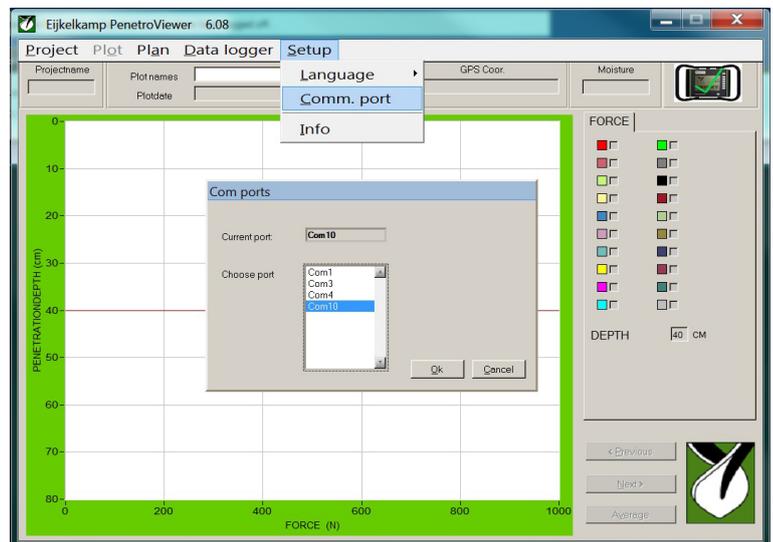
System requirements:

- Windows 7, 8 en 10.

1. Download and install the Penetroviewer software (search on eijkelkamp.com for Penetroviewer). Click on the *Setup.exe* file and the installation starts, follow the instructions on the display.
2. To select another directory for Penetroviewer click *Change* and type the directory of your choice. Default is: "C:\Eijkelkamp Penetroviewer 6.08\".
3. Click *Next* to start the installation, or *Cancel* to discontinue the installation. Click *Finish* to finish the installation.
4. You must restart your computer for the configuration changes made to Eijkelkamp Penetroviewer to take effect. Click *Yes* to restart now or *No* if you plan to manually restart later.

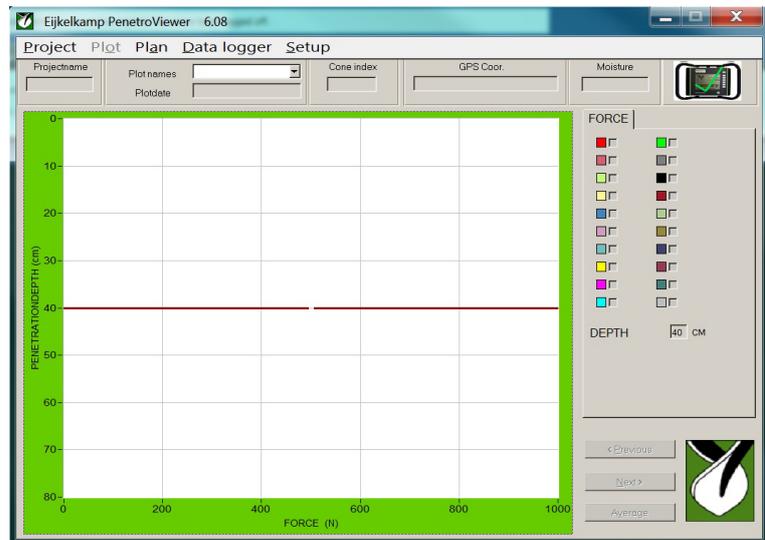
The Penetroviewer software automatically detects which communication ports are available on the computer you are using. The first time you connect the Penetrologger to the computer you need to select the communication port.

Connect the Penetrologger to your computer and switch it on. Go to *Setup* → *Comm. Port* and select one of the available communication ports. If you choose the correct port, the small Penetrologger picture on the right side of the screen will get a green '✓' if not you will see a red 'X' and need to choose a different port.



6.2 Initialising and closing down the Penetroviewer

1. Start Penetroviewer by clicking the *Eijkelkamp Penetroviewer* shortcut in *Programmes* in the *Windows Start Menu*, *Eijkelkamp Penetroviewer*.
A window displays the Eijkelkamp logo and after 4 seconds the Penetroviewer main window pops up (see figure).
2. The first time running the programme gives an English-language menu bar. It's possible to change the language by clicking *Setup*, *Language*, and checking *English*, *German*, *French*, *Spanish* or *Dutch*.
3. To close the Penetroviewer: *Quit* in the menu bar under *Project*, or click the top right corner cross.



6.3 Setting the preferences for the parameters

Prior to programming a plan, a number of preferences for parameters have to be set. The corresponding values are automatically used during programming, which is time-saving.

Fill in the following parameters under *Plan*, *Setup* in the menu bar:

- | | |
|------------------------|--|
| <i>Company</i> | Type a name to a maximum of 8 characters, no spaces included, lower cast or upper cast. The standard setting has the name in clamps. At first use: [EAE]. |
| <i>Number of plots</i> | Fill in the required number of plots to a maximum of 1500 for a project. The standard value is set in clamps. On first use: [25]. |
| <i>Pen. per plot</i> | Check the required number of measurements per plot (max. 20). The standard value per plot: [1]. |
| <i>Pen. Speed</i> | Check the desired penetration speed [cm/sec] to be used in measurements. Recommended speed: 2 cm/sec (see paragraph 7.2) Standard value: [2] |
| <i>Cone Type</i> | Select the required type of cone. Selection allows 9 standard type of cones and two types to be defined. The first four types of cones are standard to the penetrometer set. Other types are defined according to ASAE standard (ASAES313.1) A 30°-top angle and a 1.0 cm ² , 2.0 cm ² , 3.3 cm ² , and 5.0 cm ² base area. The two self-defined types can be modified using <i>Modify</i> . See Appendix 1 for the recommended type of cone. Standard the first cone selected is: 10 cm ² , 60°. |

6.4 Programming the plan

6.4.1 Creating a plan

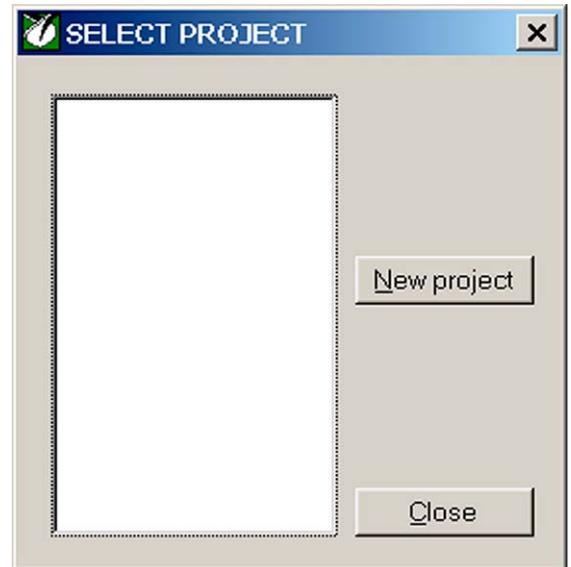
1. Create a plan clicking *New/Edit* under *Plan* in the menu bar.

The 'Select Project' window opens.

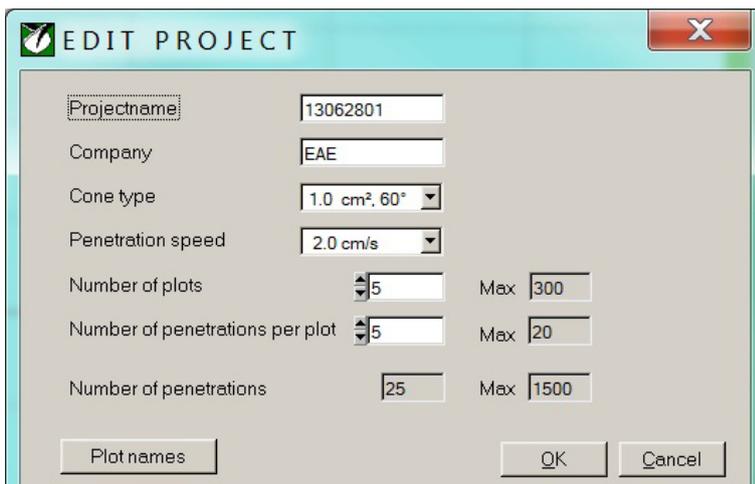


A new plan can only be created provided the Penetroviewer holds no other plan. If so, close the plan in the Penetroviewer (see paragraph 6.4.2).

2. Click *New Project* to create a new project in the plan.
The 'EDIT PROJECT' window opens (see figure)



3. The following items can be modified:



Project name

Standard: a unique name according to year-month-day and serial number. Max. 8 characters.

Company

Set as under *Preferences/Plan* in menu bar. Max.: 8 characters

Cone type

Set as under *Preferences/Plan* in menu bar

Penetration speed

Set as under *Preferences/Plan* in menu bar. Select 1, 2, 3, 4 or 5 cm/s.

Number of plots

Set as under *Preferences/Plan* in menu bar (max. 20).

Number of penetrations per plot

Set as under *Preferences/Plan* in menu bar.

Plot names

All plots in a project have standard a unique name according to a serial number. Max.: 8 characters.



To obtain reproducible data, use identical penetration speeds in multiple measurements.

4. Click *OK* to define the project when all Preferences have been set (or click *Cancel* to cancel the project).
5. Repeat steps 2 – 4 until the required number of projects has been defined.

Up to a maximum of 1500 penetrations are storable in the penetrolgger. Once this number has been reached during programming, (the Penetroviewer calculates this figure automatically) the button *New project* in the '*SELECT PROJECT*' window will not be highlighted. Furthermore, no additional plots and penetrations can be defined.

6. Save the completed plan (see paragraph 6.4.2).

6.4.2 Saving the plan and closing down



Prior to closing down it is advisable to save the plan on the hard disk of the computer (as this does not take place upon closing down). The plan will be saved for later use or modifications (see paragraph 6.4.3).

1. Select the option *Save* under *Plan* in the menu bar. Name the file and indicate in which directory to save the file. The extension will be 'pla'.
In case the name already exists, a dialogue box opens asking if you want to replace the existing file. Click *Yes* to replace or *No* to rename it.
2. To close the plan (after having saved), select *Close* under *Plan* in the menu bar.
A dialogue box will open asking whether you want to clear the plan. Click *Yes* to close or *No* to cancel closing (the plan will NOT be removed from the hard disk!).

Upon closing the plan, Penetroviewer can be used to create a new plan or to load an existing one.

6.4.3 Opening and modifying the plan

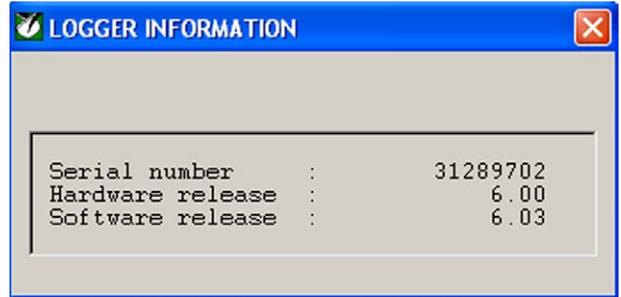
1. Open an existing plan by selecting *Open* under *Plan* in the menu bar.
The Penetroviewer can hold only one plan at a time in memory. If a plan has been activated and modifications have been made, a dialogue box will ask you to save the current plan.
2. Select the directory containing the file with extension 'pla' and select the file. Check *Select* to load the file or *Cancel* not to load it.
3. To modify the file on screen, select *New/Edit* under *Plan* in the menu bar. When a project has been selected, *Modify* can be used to alter the settings.

6.5 Sending the plan to the penetrolgger

The plan that has been prepared is ready for sending to the penetrolgger. To this purpose, the penetrolgger needs to be linked to the computer.

1. Remove the protecting cap from the communication port on the penetrolgger. Connect the cable to the port. It will fit only one way. Press the connector well into the socket and lock it by tightening the ring closure.
2. Connect the other end of the cable to the serial port of the computer.
3. Check the right communication port for the Penetroviewer at *Comm. Port*, under *Setup* in the menu bar.
4. Switch on the penetrolgger by pressing the upper white knob. Make sure the batteries have been placed into the penetrolgger (see 14. Power supply and Maintenance). The computer will automatically register the connection to the penetrolgger and activate the *Datalogger* menu bar.

5. Select *Identify* under *Datalogger* in the menu bar. Now the computer will identify the Penetrologger. On the penetrologger a message saying 'COMMUNICATION WITH PC !' is displayed. In the Penetroviewer a 'LOGGER INFORMATION' window opens showing the serial number, the hardware release and the software release. Close the window to proceed.



6. Send the plan to penetrologger using *Send plan* under *Datalogger* in the menu bar. In the dialogue box you will be asked to if you want to program the logger. Click Yes to send the plan or No to cancel.



Upon sending the plan to the penetrologger, all existing data (the plan including existing measurement data) in the penetrologger will be erased. The penetrologger can only hold one plan!

Now, the penetrologger is ready for measurement. If necessary, the plan can be modified in the penetrologger (See 7 Using the penetrologger to program the plan).

7. Remove the cable and re-attach the protecting cap.

7. Using the penetrologger to program the plan

Programming the plan in the penetrologger has the advantage of being able to create or modify the plan in situ. This is particularly convenient when the number of plots and their location, or the type of cone are not known in advance. As during programming parameter preferences can be set, programming in the field is not too time-consuming.

7.1 Operation of the penetrologger

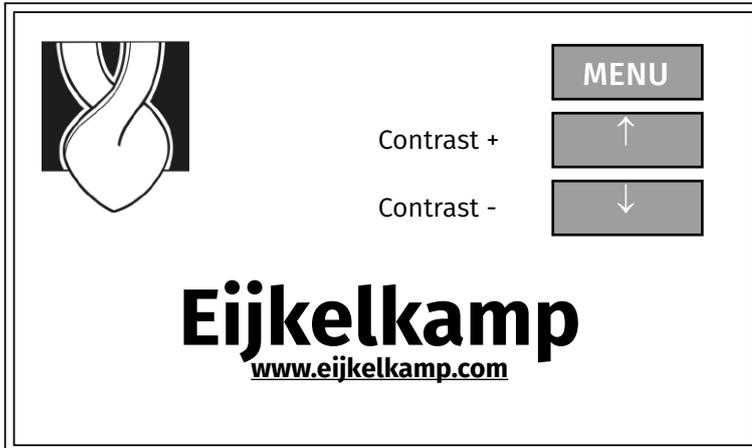
The penetrologger has 7 keys with the following functions:

The key functions are indicated on the display in a dark text block next to the key. All menu functions are listed in Appendix 2.

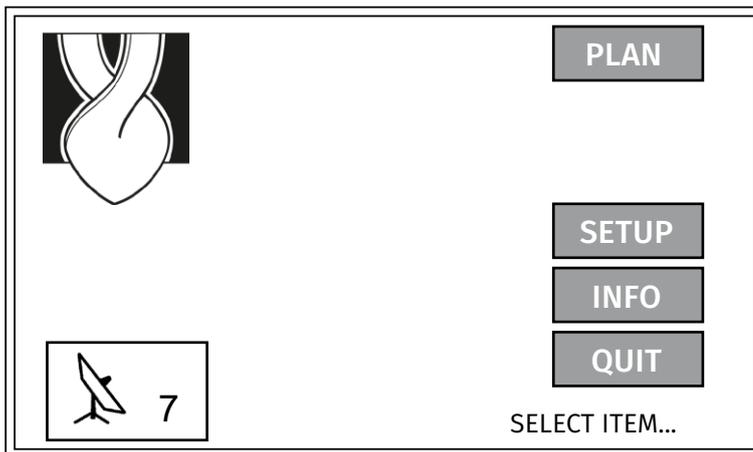
| Key | Function |
|-----|--------------------------------|
| 1 | Switch on |
| 2 | Menu |
| 3-7 | Depending on the selected menu |



1. Press key 1 to activate the penetrolgger. The start menu window opens.



2. Adjust the contrast of the LCD screen using the cursor keys
3. Select *MENU* to display the main menu.

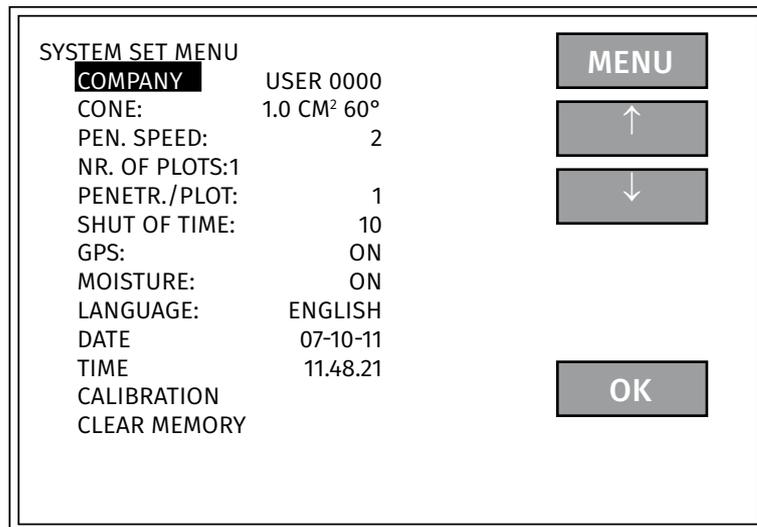


4. If necessary, the language can be set to English first:
 1. Press *SETUP* or *SET* (depending on the selected language) in the menu bar.
 2. Use the pointer keys to select the language: *LANGUAGE English*, *IDIOMA Espanol*, *LANGUE Francais*, *SPRACHE Deutsch* or *TAAL Nederlands* and press *OK*.
 3. Select *ENGLISH*. It takes a few seconds to set the language.

7.2 Preferences and settings of the parameters

Prior to programming of the plan a number of parameter preferences are set. These values are automatically used during programming, which is time-saving. In the process a number of penetrolgger settings can be defined as well.

1. Key *SET UP* in the main menu. The system set menu pops up.



2. Adjust the parameter preferences and penetrologger settings in the system set menu. Notice that the preferences are set independently of the Penetroviewer. This demonstrates that in the computer and the penetrologger different preferences can be set.

To modify these items use the cursor key to select them, and confirm with OK. Use the horizontal cursor key to select the required position and use the vertical cursor key to modify the symbol. Press OK to confirm, or MENU to cancel the changes and to return to the previous menu.

The options of the SYSTEM SET MENU are listed below:

Parameter preferences.

| | | |
|-----------------|---------------------------|--|
| Company | [USER 0000] | User name. |
| CONE | [1.0 cm ² 60°] | Cone type (see Appendix for a recommended type) |
| PENETR. SPEED | [2] | Penetration speed in cm/s. The recommended speed is 2 cm/s with a maximum deviation of 0.5 cm/s (according to NEN 5140, 1996). |
| NR. OF PLOTS | [1] | Number of plots in the project (1 – 1500). |
| PENETR./PLOT | [1] | Number of penetrations per plot (1 – 20). |
| SWITCH-OFF TIME | [10] | Time in minutes until the penetrologger automatically closes down. Choice between 1 - 60 min. Five beeps signal the closing down. |
| GPS | [On] | GPS on/off |
| MOISTURE | [On] | Optional soil moisture sensor on/off |
| LANGUAGE | [ENGLISH] | Language selection:English, German, French, Spanish or Dutch |
| DATE | [07-10-11] | Current date. Year date as of 2000 will displayed as 00, 01. |
| TIME | [11:48.21] | Current time |
| CALIBRATION | | Access to the calibration menu. A menu is opened in which the question is asked: <i>CALIBRATION ARE YOU SURE?</i> You can choose <i>YES</i> to start calibration (to prevent unintended calibration the button must be pressed for 5 seconds). Choose <i>NO</i> to quit and return to the SYSTEM SET MENU. |



Do not calibrate the penetrologger yourself. Calibration has been done at the manufacturer and needs no adjustment (the default values will be lost). Royal Eijkelpamp recommends to have the penetrologger calibrated annually.

CLEAR MEMORY

Clear the penetrologger memory. After selection of this option a frame displays: *Clear memory OK ?* Press *YES* for 5 seconds (five beeps are audible) to clear the penetrologger memory, or *NO* to cancel, and to return to SYSTEM SET MENU.



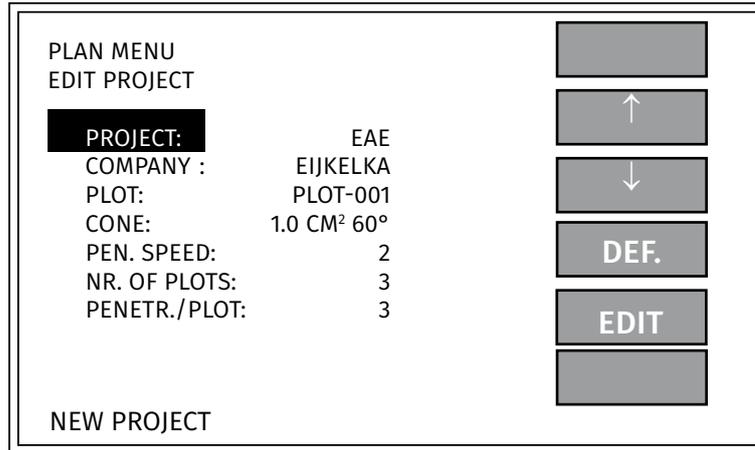
Clear the memory once it is certain that the current data (plan and measurements) in the penetrologger are not needed for further use. Clearing the memory will erase the current data.

7.3 Programming the plan

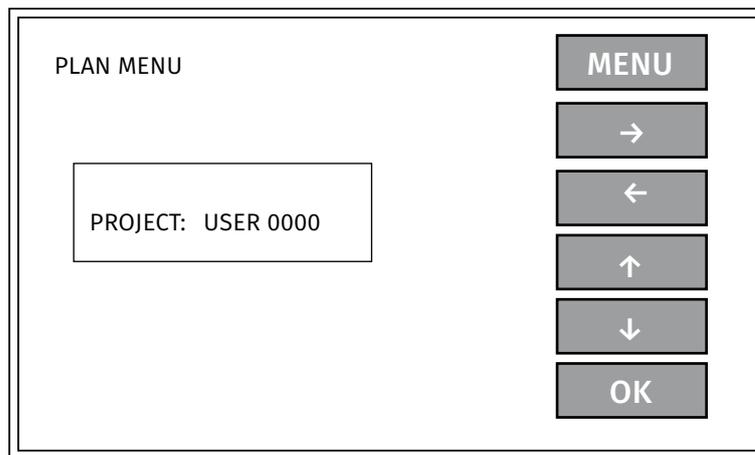
1. The penetrologger's memory allows programming of only one single plan. If necessary save the current plan on your PC. Prior to programming, erase the current plan by:
 - Clearing the penetrologger memory (see paragraph 7.2) or
 - Programming the plan on your PC, and sending it to the penetrologger which automatically clears the penetrologger memory.
2. Select *PLAN* in the MAIN MENU. PLAN MENU pops up.

| | | |
|--------------------|--|--------|
| PLAN MENU | | MENU |
| SELECT PROJECT | | ↑ PROJ |
| PROJECT: EAE | | ↓ PROJ |
| COMPANY : EIJKELKA | | ↑ PLOT |
| PLOT: PLOT-001 | | ↓ PLOT |
| CONE: 1.0 CM2 60° | | OK |
| PEN. SPEED: 2 | | |
| NR. OF PLOTS: 3 | | |
| PENETR./PLOT: 3 | | |
| NEW PROJECT | | |

3. Select a project and a plot with ↑PROJ, ↓PROJ, ↑PLOT or ↓PLOT.
In addition to a previously defined project, a new, undefined project is standard available, which can be identified by 'NEW PROJECT' on the bottom line of the display. The project name consists of a unique number, made up from year – month- day – serial number. Use this new project to set up a new project. Select *OK* to set up the project. The EDIT PROJECT submenu pops up (see next page).



4. To modify the project, change the items using *EDIT*. The PLAN MENU submenu pops up. (See figure below)



Use the cursor keys to alter the items in the PLAN MENU submenu. Press *OK* to save the changes or *MENU* to cancel and to return to the SELECT. ITEM menu.
Notice that only the plot name in the selected plot in step 3 can be changed.

5. Define the prepared project with *DEF.*
In the display bottom line '*PROJECT DEFINED*' pops up.



In the definition process a final copy of the project is stored. The number of plots and penetrations cannot be changed now!

6. Select *OK* or *MENU* to return to the SELECT PROJECT menu. If necessary, change the other plot names in the defined project following steps 3 and 4.
7. If necessary, set up other projects following steps 3–5.
8. Select *MENU* to return to the MAIN MENU and to conclude programming.

7.4 Modifying the plan



The number of plots and the number of penetrations can not be changed in the penetrometer. It also isn't possible to remove a single project out of the plan.

1. Switch on the penetrometer and select the (main) *MENU*.
2. Follow steps 3 and 4 in paragraph 7.3.

If measurements in a previously defined project have been stored, the project cannot be modified. In 'PLAN MENU' the project in question can be selected, but the OK-key is not active. On the bottom line of the display 'PLOT STARTED' and 'PROJECT STARTED' pops up.

3. Select *MENU* to return to the MAIN MENU.

Note:

A defined project may not be satisfactory for reasons of faulty programming or the situation may have changed. Two options are available:

- Create a new project and leave the other project as it is. Make sure to utilise the appropriate projects in the field.
- Erase the plan by clearing the penetrometer memory. Then a new plan can be created. Notice this will clear all data (plan and measuring data) in the penetrometer! See paragraph 7.2 on how to clear the logger memory.

8. Measuring

1. Select a type of cone (see 11. Application). As a rule a 1 cm² - and a 60° - top angle cone is used in soil research. Too large a cone may lead to exceeding the maximum penetration force of the penetrometer. Too small a cone may yield inaccurate measurement data as only a minor impact is measured.
2. Attach the probing rod and screw the cone onto it. Use the tools to tighten and loosen the parts. Click the probing rod with quick coupling onto the penetrometer and tighten the screw.

As the cones wear out it is recommended to check the dimensions before use with the conecheck. Should the dimensions have fallen below the reject diameter (see 2. Description) the cones cannot be used for reliable measurements. Cone ends that have become asymmetrical are unacceptable.

3. Connect the optional soil moisture sensor (art. no.: 061550) to the communication port of the penetrometer.

Upon programming and assembling the penetrometer, measuring can start.

4. Switch on the penetrometer.

If the penetrometer is used for the first time in a certain area, the GPS determination will require more time than usual. This will be quicker with subsequent measurements (< 8 sec.).

5. Select *Measr* in the MAIN MENU.

Select a required project from the MEASR MENU. The project settings will be displayed. (See figure below)

| | | |
|------------------------------------|-------------------------|-------|
| MEASUREMENT MENU SELECT PROJECT | | MENU |
| PROJECT: | EAE | ↑PROJ |
| COMPANY: | EIJKELKA | ↓PROJ |
| PLOT: | PLOT-001 | |
| CONE: | 1.0 CM ² 60° | |
| PEN. SPEED: | 2 | |
| NR. OF PLOTS: 3 | | |
| PENETR./PLOT: | 3 | |
| PROJECT DEFINED | | OK |

Select a project and choose *OK*.

The measuring window pops up. Measuring of the first plot of the selected project can take place.

| | | |
|--|-----------------|-------------|
| MEASUREMENT MENU | | MENU |
| L D E P T H C M S 0 | PROJECT: EAE | CI: |
| | PLOT: PLOT--001 | |
| | PENETR.: 1 | |
| | ----- | |
| | | START |
| | | |
| | | Press |
| | | 0.0 |
| | | Depth |
| | | 0 |
| | | PRESS (MPa) |



The plots can only be measured in the order of definition of the project.

6. Place the depth reference plate on the ground surface. The raised edges should point downwards. Place the penetrometer cone through the hole in the plate. Make sure to hold it as vertical as possible with an aim to:

- Prevent friction between the rod and the soil affecting the resistance to penetration.
- Obtain a correct depth registration. The ultrasonic sensor measures the depth. The ultrasonic signals transmitted by the sensor are reflected via the depth reference plate to the sensor.



Therefore, the penetrometer gradient should not deviate over 3.5° from the vertical position.

For correct measurements with the ultrasonic sensor, we recommend standing with your back against the wind on windy days (the noise of the wind can otherwise upset the ultrasonic measurement).

7. Select **START** to begin measuring.
 If Moisture is Yes (see Par. 7.2), then the penetrometer will indicate: *Place Thetaprobe and press Start*. First a soil moisture percentage appears: *ThetaProbe ...% VOL. SAVE DATA?*
 If this is ok, press **YES** (percentage is saved).
 Pressing again on **START** will start the measurement.

Select **YES** in response to the question whether the measurement must be saved (measurement, GPS coordinates and any soil moisture percentage are saved), or **NO** if you do not want to use the measurement and you want to perform it again.

8. Insert the penetrometer evenly and as vertically as possible, at a constant speed set in the plan. At a recommended speed of 2cm/s the time needed to reach 80 cm will be 40 seconds.

 **Use the level on the penetrometer to check the vertical position of the penetrometer.**

A speed indicator shows the deviation from the set speed (± 40 percent) on the display.

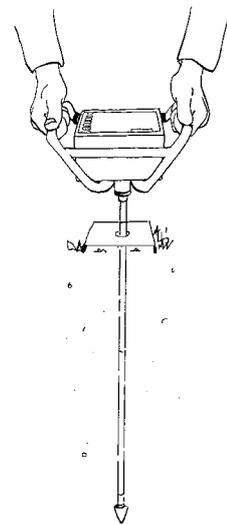
 **A downward deflection (to “S”) on the speed indicator means the insertion speed is too high. Reduce pushing speed.**
An upward deflection (to “L”) on the speed indicator means the insertion speed is too low. Increase pushing speed.

A penetration speed exceeding the measuring limit (the logger starts beeping) will yield unreliable values; therefore measuring should be terminated. Do not save these data. In the bottom right-hand corner of the display the actual measuring values of the pressure (i.e. the resistance to penetration) and depth are given. Should the sensor not receive the ultrasonic signals and consequently no accurate depth measuring take place, the display will indicate ‘- - -’. Measuring should be terminated.

9. At a depth of 80 cm, measuring should be terminated. Select **STOP** to prematurely break off measuring if the maximum depth is not possible or required. Select **YES** to confirm saving the measurement (measurement, GPS coordinates and eventually percent soil moisture volume), or **NO** not to save the measurement and to restart.
10. If necessary, carry out replicate measuring on the same plot (depending on the set number of penetrations per plot). Select a spot at least 1 m away from other measuring plots to avoid mutually affecting measurements. Proceed measuring the other plots.

A number of items can be checked in the **SYSTEM INFO MENU** (Select **INFO** in the **MAIN MENU**) before measuring:

- Actual date and time
- GPS status
- Battery. The remaining battery power in % (battery voltage). A 100% value indicates a full battery.
- The penetrometer serial number
- Software version
- Hardware version
- Number of measurements (penetrations) held in memory
- Remaining measurements to carry out (“Reserved”)
- Remaining memory.



9. Processing the data

9.1 Using the computer to read the results

1. To read the results, connect the penetrometer to the computer. See steps 1-4 in paragraph 6.5.

2. Select *Read Data* under *Datalogger* in the menu bar.

All measuring data (only of the measurements that have been carried out) will be read by the computer. A transient window displays the following information:

- Logger language
- Number of projects def.
- Max. number of penetrations
- Number of penetrations carried out
- Reserved penetrations

3. After the computer has read the data for each defined project, a file will be created with the extension 'pen'. For each project a window opens and a file name and directory should be selected.

4. Finally, switch off the penetrometer, remove the communication cable, and re-attach the protecting cap to the port.



9.2 Computer display

The measuring data can be viewed in the Penetroviewer. They are graphically or numerically displayed per project. The project files can be edited in a spreadsheet.

9.2.1 Opening and closing a project file

1. Select *Open* under *Project* in the menu bar. Select the required 'pen'-file (project) from the directory. Click *Select* to open the file.

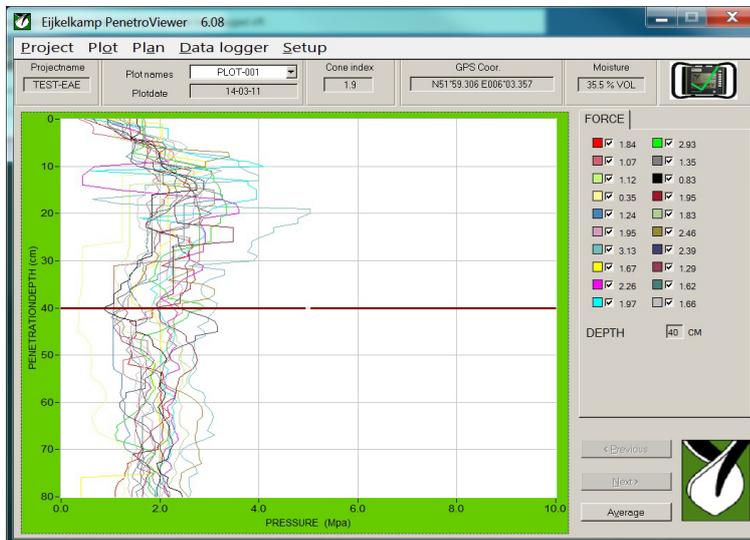
An example file 'Example.pen' is standard available in the Penetroviewer programme directory.

When a file is opened, a graphical display of the plot results is presented and the Plot-menu is available in the menu bar.

2. Select *Quit* under *Project* in the menu bar to close a project file.

9.2.2 Graphical display

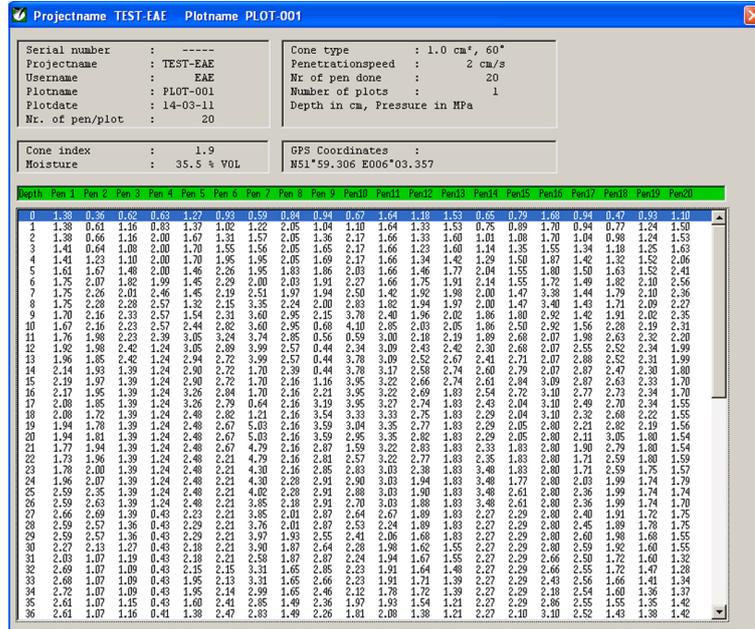
For a graphical display of the results the following options are available (see figure):



- Standard all measurements (penetrations) of the plot are displayed. Clicking a coloured square next to the graph will hide or re-select a measurement.
- Clicking the key *Previous* or *Next* in the bottom right-hand corner, or under *Plot* in the menu bar will display the results of the previous or next plot in the project.
- The *Average* key displays the average measuring value of selected measurements. Hence, if only three out of ten measurements have been selected (the remainder has been de-selected by clicking the coloured squares) the average of those three measurements will be determined. This is very useful in excluding unwanted measurements. A standard deviation is displayed at every 10 cm of depth if the average is determined of at least two measurements.
- Clicking again on *Average* causes all the individual lines to be displayed again
- The line style is selected at *Line style* under *Plot* in the menu bar. Select *Line*, *Points* or *Fat line*.
- Checking *Grid* under *Plot* in the menu bar activates the raster.
- The horizontal measuring line in the graph area is moved by dragging it up or down or by clicking in empty space with the mouse (use the cursor keys if necessary). Next to the graph area, under '*DEPTH*' the depth (cm) which refers to the depth indicated by the measuring line, is displayed. Under '*PRESSURE*', which refers to the depth indicated by the measuring line, the colour and numerical value (MPa) is displayed for all the measurements of the plot.
- Above the graph area, the CI value of the measurement concerned is given under *Cone index*. The GPS coordinates are displayed under *GPS Coord.* And the soil moisture percentage is displayed under *Soil moisture*.

9.2.3 Numerical value

Select *Numerical* under *Plot* in the menu bar to display the numerical list of currently selected measurements (penetrations) (See figure).



The measuring value is listed per centimetre in depth. The presentation of an average line in graphical display will also produce the numerical data of the average and standard deviation. The plot information is presented as well.

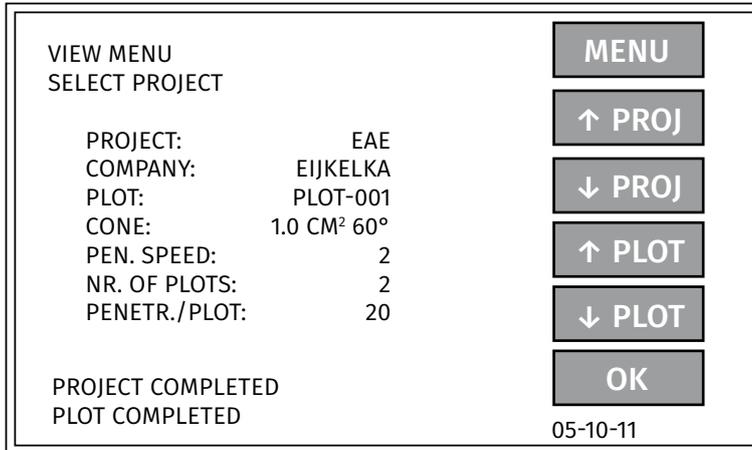
9.2.4 External processing of measurements

- Save the lists as a text file (ASCII) with extension 'txt'. Select *Save as text* under *Project* in the menu bar. The current, active measuring data (selected measurements or averages with standard deviation) will be saved. Here measuring data is saved as resistance to penetration in Megapascal. (To open a textfile in, for example, Excel: chose *file*, *open*, chose *delimited*, chose *Tab* and *Space* as separation mark and finish. Note: Only the data of the active plot are stored.
- The 'txt' files can be read in a spreadsheet. The data are horizontally arranged. In up to a maximum of 20 rows (max. 20 measurements per plot are possible) 81 columns with data (0 – 80 cm depth) are presented.
- Measuring data saved as 'pen' file, is stored as force (Newton). To convert the data to resistance to penetration, for example with use of a spreadsheet, the following formula can be used.

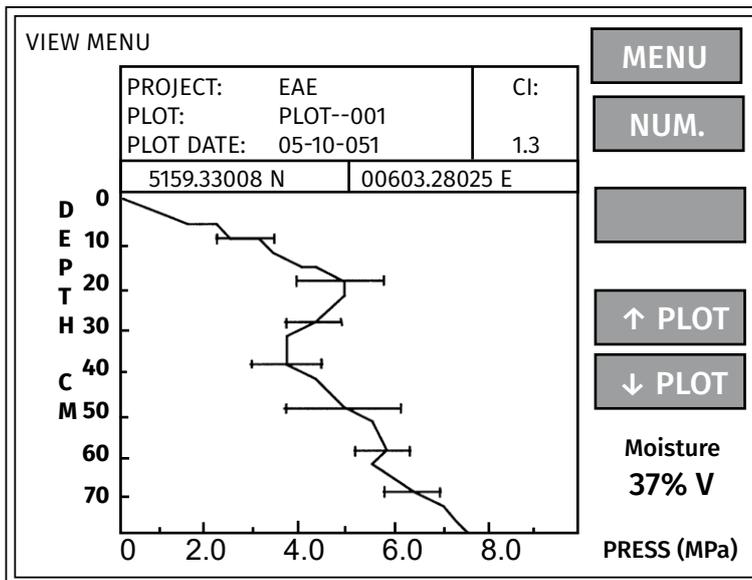
$$\text{resistance to penetration in megapascal} = \frac{\text{Force (N)}}{S (\text{cone surface in mm}^2)}$$

9.3 Penetrologger display

1. Select *VIEW* in the MAIN MENU to view the measuring results of penetrations in the penetrometer. The VIEW MENU opens.



2. Select a project and plot and press *OK* to view the graphic results. The RESULT GRAPHICAL menu opens. It lists the average value of the penetrations of the current plot. The standard deviation (if possible) is displayed every 10 cm with a horizontal line. The line will not be displayed when the standard deviation is insignificant.



3. Press *NUM.* to obtain a numerical display of the results. The average resistance to penetration of the current plot is displayed for every centimetre of depth.
4. Select *GRAPH* to return to graphical display, or *MENU* to return to the VIEW MENU.
5. Select *MENU* to return to the MAIN MENU.

9.4 Printing via a PC

Using the Penetroviewer the measuring results can be graphically or numerically printed on either a printer or a plotter. Depending on the type of display the separate penetrations of a plot or the average with standard deviation will be printed:

- Select '*Graphical*' at *Print* under *Project* in the menu bar to print the graph.
- Select '*Numerical*' at *Print* under *Project* in the menu bar to print the numerical results.
Default all the results of a plot are printed. It is not possible to select a number of measurements. In a spreadsheet it is possible.

10. Interpreting the measuring data

When interpreting the measuring results bear the following issues in mind:

- The reliability of the measuring results depend on the number of measurements per plot and on the natural variability of the resistance to penetration in situ.
- The penetrometer appears to measure a high level of resistance to penetration as compared to the resistance roots encounter. This is caused by the fact that whereas roots may follow crevices and macro-pores the penetrometer's cone can not.
- The presence of stones in a soil profile tends to distort the measurement, and correction of the results will be necessary. As roots tend to grow around the stones the penetrometer will produce a higher value than the one roots encounter.
- To fully interpret the resistance to penetration in root research, it is necessary to describe the soil structure as well.
- Although the penetrometer is very suitable to compare different cultivation techniques, the complicating effects of types of soils on the resistance to penetration hamper their comparison.
- The high correlation between resistance to penetration and other soil properties (Campbell & O' Sullivan, 1991) renders the penetrometer useful for research into the spatial variability of the soil and for assessing other soil properties.
- The standard unit of resistance to penetration (MPa) can be converted to other unities. See Appendix 3.
- Taking into account the type of cone, the measured penetration resistance can be converted from pressure (in MPa or Y) to exercised force (N). See appendix 4.

11. Application

The penetrometer comes with various cones which, depending on the application and the research purpose, can be selected. The smallest cone is suitable for high-penetration resistance soils; the largest cone is appropriate for weaker soils. In soil research usually the 1 cm², 60° cone is used.

The penetrometer is suitable for measuring the resistance to penetration of the soil to a depth of 80 cm. It is applied in:

- General soil research.
- Assessing the accessibility of (construction) sites (see section 12).
- Location of compacted soil layers, for example a beak.
- Soil assessment for agricultural purposes.
- Soil assessment for pedestrian- and vehicle traffic purposes.
- Civil engineering, in particular road and waterways construction.
- Research into the vegetation growing conditions in for instance parks, public gardens, tree nurseries and horticultural centres.
- Management of sports fields.

12. Determination of the accessibility of (construction) sites

For the determination of the accessibility of the (construction) sites for persons and vehicles, we look at the pressure that is exercised on the ground by the person or vehicle (Vehicle Cone Index). This is related to the penetration resistance that the soil can offer (in Mpa). This value is indicated on the penetrometer as CI-value (Cone index). (For more info: www.nvaf.nl [in Dutch])

To determine negotiability, a visual and manual assessment must also be made. Visual: presence of pools, wet spots, evidence of slipping, etc.

Manual assessment: determine the percentage of clay, loam, peat, etc.

12.1 Determination of the Vehicle Cone Index (VCI)

For personnel, certain fixed values are assumed:

| VCI | Description |
|------|---------------------------------|
| 0.08 | weight 85 kg |
| 0.12 | weight 85 with 25 kg yield load |
| 0.14 | weight 85 with 50 kg yield load |

There are 2 values for vehicles, namely:

VCI(1): for a single movement

VCI(50): working at 1 location and repeated driving over 1 track



The categories below give a rough VCI-value; an exact VCI for the vehicles must be calculated.

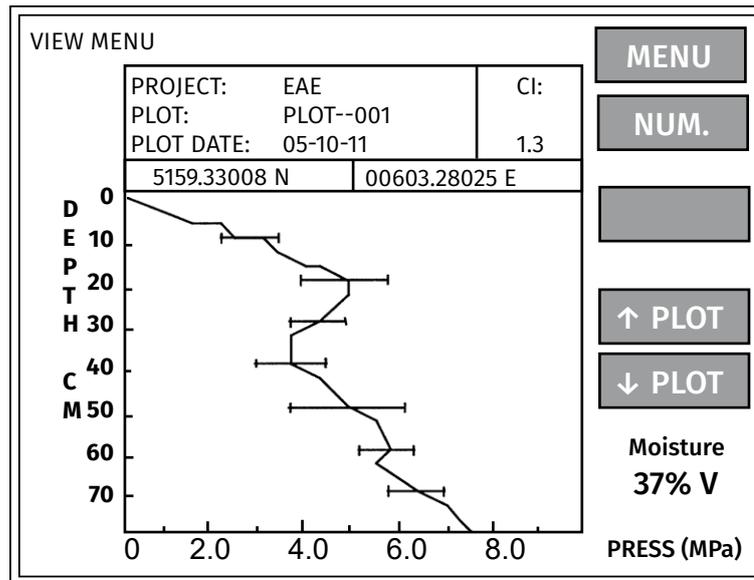
| Cat. | Range | | Vehicle description |
|------|-----------|-----------|--|
| | VCI(1) | VCI(50) | |
| 1 | <0.08 | <0.2 | Lightweight (low contact pressure) |
| 2 | 0.08-0.15 | 0.2-0.34 | Speed tractors (wide tracks and low contact pressure) |
| 3 | 0.15-0.18 | 0.34-0.41 | Tractors (average contact pressure) Caterpillar-tracked vehicles (low contact pressure) Wheeled vehicles (very low contact pressure) |
| 4 | 0.18-0.21 | 0.41-0.48 | Caterpillar-tracked vehicles up to 60 tons (average contact pressure) Tractors (high contact pressure) AWD lorries with trailer (low contact pressure) |
| 5 | 0.21-0.24 | 0.48-0.55 | Single AWD trucks (low contact pressure) Heavy caterpillar-tracked vehicles (>60 ton) |
| 6 | 0.24-0.30 | 0.55-0.88 | Most AWD trucks |
| 7 | >0.30 | >0.68 | Trucks (rear-wheel drive) |

12.2 Performing resistance to penetration measurements

Perform one single CI-MPa penetration at approx 10 m intervals along the vehicle trace and walkways. If this CI-MPa value is lower than the VCI-MPa for people and/or the planned machine, a complete CI-MPa measurement must be performed at this point.

Single CI-MPa penetration:

Press the cone (2cm² and 60°) evenly in the ground (2 cm/sec). If the measurement is done correctly, the CI value appears in the upper right of the display (this is the average of the measured resistance at 1, 15, 30 and 45 cm).



Complete CI-MPa measurement

- Perform 5 single penetrations within a circle of 1 m diameter.
- The average of the CI values is the complete CI value.

12.3 Comparison of CI with VCI value

■ CI is smaller than VCI

The site is not accessible. Vehicles and/or personnel will sink to a depth at which the CI is equal or greater than the VCI-value of the people/machine.

■ CI is smaller or equal to VCI

The site is difficult to access. Vehicles and/or personnel will have the tendency to make tracks. These tracks will rapidly become deeper if it rains.

■ CI is larger than the VCI

The site is accessible. The surplus value of the CI will determine what the possibilities will be for people and machines.

13. Troubleshooting

13.1 Computer and penetrologger communication

- The “*Datalogger* menu” of the Penetroviewer PC-software is not active (red cross) whereas the penetrologger is connected to the computer by the cable.
 - Check the setting of the communication port at *Comm. Port, Setup* in the menu bar.
 - Make sure the penetrologger is switched on (a menu is active on the display).
 - Check the battery power.
- The “*Datalogger* menu” of the Penetroviewer PC-software is active, whereas the penetrologger is not connected to the computer by the cable.
 - Another instrument is connected to the communication port set in the Penetroviewer. This does not affect the Penetroviewer.
 - Select another com port.

13.2 Operation of the penetrologger

- Legibility of the display is inadequate. Adjust the display contrast settings using the vertical cursor keys in the start menu, or with *CONTRAST* in the *SYSTEM SET MENU*.
- The *MEASURE* option is not available in the *MAIN MENU*. Program a plan on the computer or in the penetrologger with *PLAN*.
- The *DISPLAY* option is not available in the *MAIN MENU*. First carry out measurements in the field.
- The penetrologger closes down between measurements. Increase the value of the *SWITCH-OFF TIME* in the *SYSTEM SET MENU*.
- The batteries are empty. Charge the rechargeable batteries using the special battery charger.

13.3 Programming a plan

- Creating a new plan in the penetrologger or in the Penetroviewer is not possible. Erase the current plan from memory (paragraph 6.4.2) after storing it.
- Defining a new project is not possible. The maximum number of 1500 measurements has been reserved, thereby reaching the plan’s limit. Define a new plan with the Penetroviewer or re-arrange the plan.
- Projects have been incorrectly defined, or have been modified.
 - Penetrologger. A defined project cannot be removed separately from the plan. This can be solved by either defining a new project or by ignoring the incorrectly defined ones during measuring. If faulty programming has led to a maximum reservation of 1500 measurements, the plan cannot be further used. Erase the plan and re-program the plan.
 - Penetroviewer. Erase or modify the projects.
- While measuring, the number of plots and number of penetrations per plot need to be modified. If additional plots need to be measured, make a new project for those plots.
- It is not possible to handle several plans at the same time. Program all measurements for one working day in the field within one plan. Should it prove necessary to have several plans, use a laptop to read the results, and to send a new plan to the penetrologger.

13.4 Measuring

- 'DEEP' in the 'MEASURE MENU' of the penetrometer displays ' – ' (even though the speed indicator emits signals). This indicates that the ultrasonic signals are not being received well enough. Stop measuring without saving the data. Measure again and:
 - Make sure the penetrometer is held in a vertical position (max. deviation 3.5°).
 - Stand with your back to the wind during the measurement and ensure that no clothing or similar items get between the ultrasonic sensor and the depth reference plate during the measurement.
 - Make sure the depth reference plate is placed horizontally placed on the ground surface.
 - Make sure the sensor is dry. Any moisture may affect measuring. Condensation may form on the ultrasonic sensor when moving the penetrometer from a cool to a warm (or the reverse) environment. Have the penetrometer acclimatise to make sure the moist evaporates.
- Measuring will be prematurely interrupted when the insertion speed of the cone is too high or too low. Push faster when the speed indicator (at left in the display) swings upward. Push gently when it swings downward.
- During measuring the cone cannot be further inserted. The cone has stricken a hard, impermeable layer, such as a gravelly, stony layer or one containing debris.
Do not proceed measuring. Use a smaller type of cone if the soil appears to be stiff.
- During measuring a low, inaccurate resistance to penetration is registered; the soil is weak and penetration is effortless. Select a larger type of cone.
- The internal GPS receives no signals: interfering objects are in the vicinity of the measurement, meaning no satellite signals can be received: select another measuring point.



13.5 Penetroviewer

- Printing in graphical display is not successful. Make sure the printer resolution has been set to max. 300 dpi (dots per inch).
- The graphical print is cut off at the paper's edge. Use a spreadsheet programme to print the results.

13.6 Depth calibration of the penetrometer in the field

In order to 'Depth calibrate' your penetrometer you need to follow the next steps:

1. Place the 8 mm probing rod (061510) with the 1 cm² cone in the rod mounting block.
2. Switch the penetrometer ON
3. Press [MENU] to enter the *Main menu*
4. Press [SETUP] to enter the *System setup menu*
5. Select CALIBRATION with the up ↑ and down ↓ arrows and press [OK]
6. The question appears: CALIBRATION – ARE YOU SURE ? Press the [YES] button for 5 seconds.
7. Select CAL. DEPTH NULL with the up ↑ and down ↓ arrows and press [OK]
8. Set the reference depth on -4 (minus 4) with the up ↑ and down ↓ arrows

9. Place the probing rod on the ground (mind the spirit level for horizontal positioning). See photo below.
10. Press [CAL] to calibrate. The DEPTH NULL is now calibrated
11. Press [MENU]
12. Select CAL. DEPTH SCALE with the up ↑ and down ↓ arrows and press [OK]
13. Place the calibration tool (standard in your set, labelled calibration tool) in the rod mounting block
14. Place your penetrometer, on the ground (or table). See photo below
15. Press [CAL] to calibrate. The DEPTH SCALE is now calibrated
16. Press 3 times [MENU] to enter the *Main menu*



13.7 Force calibration



Normally accurate force calibration of the penetrometer is done at the Eijkelkamp factory using a specialized accurate calibration tool. Calibration cannot and should not be performed in the field. Normally there is no need to recalibrate the penetrometer by the user.



In order to 'Force calibrate' your penetrometer in case of urgent operational conditions where the factory calibration is not possible you need to follow the next steps.

1. Remove the penetration rods and screw
2. Switch the penetrometer ON
3. Press [MENU] to enter the *Main menu*
4. Press [SETUP] to enter the *System setup menu*
5. Select CALIBRATION
6. The question appears: CALIBRATION – ARE YOU SURE ? Press the [YES] button for 5 seconds.
7. Select CAL. FORCE NULL with the up ↑ and down ↓ arrows and press [OK]
8. Hold your penetrometer above the ground. See photo below.
9. Press [CAL] to calibrate. The FORCE NULL is now calibrated
10. Press [MENU]
11. Select CAL. FORCE SCALE with the up ↑ and down ↓ arrows and press [OK]
12. Place your penetrometer, on the rod mounting block, on the ground (or table see photo below).
Do not put any extra force on the instrument. The instrument should measure its own weight a value *CURR. FORCE* between 34 and 36 N. If this indicates correct, end the procedure by pressing *MENU*

13. In case of incorrect reading: Select *REF.FORCE* '35' with the up ↑ and down ↓ arrows
14. Press [CAL] to calibrate. The *FORCE SCALE* is now calibrated and both *REF.FORCE* as *CURR.FORCE* should read 35 N
15. Press [MENU] to enter the Main menu.



13.8 Resetting the penetrometer

In order to make a general resetting of the penetrometer (when the program crashes):

1. Switch off the logger.
2. Switch on the penetrometer with the on/off button, after this press the same button for 3 seconds.
3. The penetrometer has now been reset, all display functions are reset, the memory with the measurements has not been changed.

14. Power supply and maintenance

14.1 Power supply

- Rechargeable batteries power the penetrometer. The penetrometer comes with 5 NiMH 2600 (minimal) format AA batteries. Always use 5 batteries with the same MH value. 1.5 Volt alkaline batteries can also be used (Note: Do not charge!).

Changing the batteries (not recommended).



Work antistatic!

Remove the two black strips from the top side. Unscrew the four screws on top of the penetrometer and open the penetrometer. To prevent damage to the penetrometer we advise to send it to Royal Eijkelkamp.



Make sure to place them properly to avoid damage.

Charging the batteries

Use the charger in the set to charge the batteries. The charger has been designed to match the penetrometer and cannot be replaced by another type of charger. Attach the charger cable to the penetrometer communication port and plug the other end into a wall socket (100-240 V, 50/60 Hz).

The battery charger stops charging when the battery is full (normally after 10 hours) and then automatically changes over to so-called trickle charge. The penetrometer is then ready for use.



Non-rechargeable batteries can never be used in combination with a battery charger. Remove empty batteries to avoid leaking. It is advisable to remove the batteries when storing the penetrometer.

Checking remaining power

The SYSTEM INFO MENU of the penetrometer (see also 8. Measuring) displays the battery condition in 10 percents. When empty the penetrometer makes a rattling sound. This indicates five minutes of measuring left before shut down.

At a residual capacitance of 2% the penetrometer starts beeping (three short beeps every five seconds). At a residual capacitance of 0% a message "Battery empty" is displayed and after five seconds shut down follows.

Battery life

The service life of the penetrometer with rechargeable batteries lasts approx. 1500 measurements or a period of 8 hours continuous measuring, which equals a working day in the field. The instrument will perform an automatic shut down to prevent unnecessary discharge of the batteries. The period of time for automatic switch off is set in the penetrometer SYSTEM SET MENU (see paragraph 7.2).

Internal battery

The penetrometer has an internal battery for the internal clock (RTC = Real Time Clock). When the batteries are empty the penetrometer will lose the (correctly) set time and date and will switch to a undefined time and date. When using the penetrometer this undefined time will be written with the measurement data. The measurement data that were saved in the memory before will be saved with the correct time. The lifetime of this internal battery is ca. 5 years (depending of use). When the penetrometer is sent to Eijkelkamp for service / calibration Royal Eijkelkamp will replace the battery if necessary.

14.2 Maintenance

- Make sure to clean all parts during and after use. Dried up soil sticking to the cone increases the measured resistance to penetration.
- Make sure to keep the ultrasonic sensor dry to avoid failures in depth measurements.
- It is recommended to send the penetrometer every year to Royal Eijkelkamp for service and calibration.

Literature

Campbell, D.J. & M.F. O'Sullivan, 1991. The Cone Penetrometer in Relation to Trafficability, Compaction, and Tillage. In: *Smith, K.A. and C.E. Mullins. Soil Analysis. Physical Methods. Books in Soils, Plants and the Environment.*

Locher, W.P. & H. de Bakker (eds), 1990. Bodemkunde van Nederland. *Malmberg*. Den Bosch.

NEN 5140, 1996. Geotechniek. Bepaling van de conusweerstand en de plaatselijke wrijvingsweerstand van de grond. Elektrische sondeermethode. *Nederlands Normalisatie-instituut*

Schothorst, C.J., 1968. De relatieve dichtheid van humeuze gronden. *De Ingenieur 80(2); pp. B1-B8. Also: Verspr. Overdr. 53, Instituut voor Cultuurtechniek en Waterhuishouding, Wageningen.*

Vereniging voor Landinrichting, 1992. Cultuurtechnisch Vademecum. *Brouwer Offset*, Utrecht.

Appendix 1 Reference resistance values

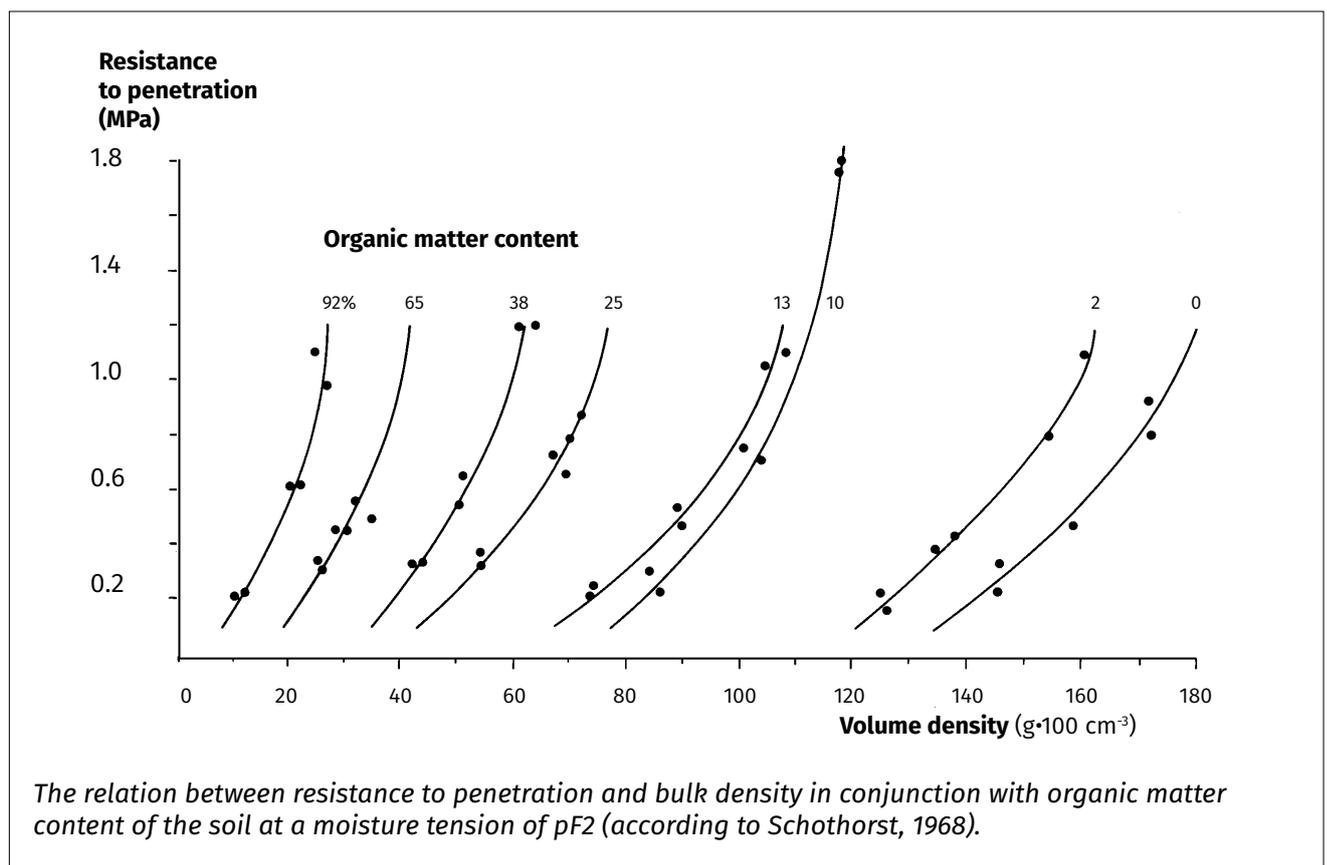
Bearing capacity of pastures, related to the resistance to penetration (MPa) of the sod layer.

| Application | Recommended cone | Bearing capacity |
|---|-----------------------------------|--|
| Pasturing: mechanical spread of liquid manure; cultivation, harvesting in arable farming. | 5 cm ² , 60° top angle | Major > 0.6 Moderate 0.3 – 0.6 Minor < 0.3 |
| Sports fields | 1 cm ² , 60° top angle | Major > 1.4 Moderate 1.0 – 1.4 Minor < 1.0 |

As a rule a cone with a 1 cm² base area and a 60° top angle is applied in soil research fieldwork.

Source: Vereniging voor Landinrichting, 1992

The effect of organic matter content on the resistance to penetration.



Appendix 2 Penetrologger menus

START MENU

| | |
|------|----------------------|
| MENU | Go to MAIN MENU |
| ↑ | Set contrast display |
| ↓ | Set contrast display |

MAIN MENU

| | |
|---------|--|
| PLAN | Go to PLAN MENU to program plan |
| MEASURE | Go to MEASURE MENU to carry out measurements (active when plan has been defined) |
| DISPLAY | Go to DISPLAY MENU to display measuring results (active when measurements have been made and stored) |
| SET | Go to SYSTEM SET MENU to set parameter preferences |
| INFO | Go to SYSTEM INFO MENU for system information |
| END | Switch off penetrolgger |

PLAN MENU

SELECT. PROJECT

| | |
|--------|---|
| MENU | Return to MAIN MENU |
| ↑ PROJ | Select previous project |
| ↓ PROJ | Select next project |
| ↑ PLOT | Select previous plot |
| ↓ PLOT | Select next plot |
| OK | Select this project and this plot and go to SELECT. ITEM menu |

PLAN MENU

SELECT. ITEM

| | |
|------|---|
| MENU | Return to SELECT. PROJECT menu |
| ↑ | Select previous item |
| ↓ | Select next item |
| DEF. | Define Project (active when programming a new plan) |
| EDIT | Go to EDIT ITEM menu to modify settings of the selected item |
| OK | Return to SELECT. PROJECT menu (only active in a defined project) |

PLAN MENU

EDIT ITEM

| | |
|------|---|
| MENU | Cancel changes and return to SELECT. ITEM menu |
| ← | Go to previous position |
| → | Go to next position |
| ↑ | Change into next character (choose from 26 characters, 10 figures, “-”, or space) |
| ↓ | Change into previous character (choose from 26 characters, 10 figures, “-”, or space) |
| OK | Confirm changes and Return to SELECT. ITEM menu |

MEASURE MENU

SELECT. PROJECT

| | |
|--------|---------------------------------------|
| MENU | Return to MAIN MENU |
| ↑ PROJ | Select previous project |
| ↓ PROJ | Select next project |
| OK | Select project and go to MEASURE MENU |

MEASURE MENU

| | |
|-------|--------------------------------|
| MENU | Return to SELECT. PROJECT menu |
| START | Start measuring |
| STOP | Stop measuring |

DISPLAY MENU

SELECT. PROJECT

| | |
|--------|---|
| MENU | Return to MAIN MENU |
| ↑ PROJ | Select previous project |
| ↓ PROJ | Select next project |
| ↑ PLOT | Select previous plot |
| ↓ PLOT | Select next plot |
| OK | Select this project and this plot and go to RESULT. GRAFIC menu |

RESULT. GRAFIC

| | |
|--------|--|
| MENU | Return to DISPLAY MENU |
| NUM. | Numerical display of measuring data (mean values of a selected plot) |
| GRAF. | Graphical display of measuring data (mean values of a selected plot) |
| ↑ PLOT | View the measuring data of the previous plot |
| ↓ PLOT | View the measuring data of the next plot |

SYSTEM SET MENU (1)

| | |
|------|---|
| MENU | Return to the MAIN MENU |
| ↑ | Select next item |
| ↓ | Select previous item |
| OK | Select the item and proceed automatically to the SYSTEM SET MENU (2) of SYSTEM SET MENU (3) |

SYSTEM SET MENU (2)

| | |
|------|--|
| MENU | Cancel changes and Return to SYSTEM SET MENU (1) |
| ← | Go to previous position (only available if needed) |
| → | Go to next position (only available if needed) |
| ↑ | Change into next character (choose from 26 characters, 10 figures, "-", space) |
| ↓ | Change into previous character (choose from 26 characters, 10 figures, "-", space) |
| OK | Save changes and return to SYSTEM SET MENU (1) |

SYSTEM SET MENU (3)

| | |
|-----|---|
| YES | Executes command when during 5 beeps key is pressed (Pressing the key less than 5 beeps yields no result) |
| NO | Cancel and return to SYSTEM SET MENU (1) |

SYSTEM INFO MENU

| | |
|------|---------------------|
| MENU | Return to MAIN MENU |
|------|---------------------|

Appendix 3 Conversion factors

Conversion factors units of force:

| | | | | |
|--------|---|-------|---|--------|
| Newton | * | 0,102 | = | kgf |
| kgf | * | 9,807 | = | Newton |

Conversion factor units of pressure:

| | | | | |
|-----|---|----------|---|------------------------------|
| MPa | * | 145,0 | = | PSI (Pounds per square inch) |
| MPa | * | 10,0 | = | bar |
| PSI | * | 0,006897 | = | MPa |
| PSI | * | 0,06897 | = | bar |
| bar | * | 0,1 | = | MPa |
| bar | * | 14,5 | = | PSI |

Appendix 4 Conversion tables

Conversion between pressure and force at various cone base areas.

| Force Newton | Pressure MPascal | Pressure MPascal | Pressure MPascal | Pressure MPascal | Pressure MPascal | Pressure MPascal | Pressure MPascal | Pressure MPascal |
|-----------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) |
| | 100 | 130 | 200 | 323 | 333 | 500 | 750 | 1000 |
| 50 | 0,50 | 0,38 | 0,25 | 0,15 | 0,15 | 0,10 | 0,07 | 0,05 |
| 100 | 1,00 | 0,77 | 0,50 | 0,31 | 0,30 | 0,20 | 0,13 | 0,10 |
| 150 | 1,50 | 1,15 | 0,75 | 0,46 | 0,45 | 0,30 | 0,20 | 0,15 |
| 200 | 2,00 | 1,54 | 1,00 | 0,62 | 0,60 | 0,40 | 0,27 | 0,20 |
| 250 | 2,50 | 1,92 | 1,25 | 0,77 | 0,75 | 0,50 | 0,33 | 0,25 |
| 300 | 3,00 | 2,31 | 1,50 | 0,93 | 0,90 | 0,60 | 0,40 | 0,30 |
| 350 | 3,50 | 2,69 | 1,75 | 1,08 | 1,05 | 0,70 | 0,47 | 0,35 |
| 400 | 4,00 | 3,08 | 2,00 | 1,24 | 1,20 | 0,80 | 0,53 | 0,40 |
| 450 | 4,50 | 3,46 | 2,25 | 1,39 | 1,35 | 0,90 | 0,60 | 0,45 |
| 500 | 5,00 | 3,85 | 2,50 | 1,55 | 1,50 | 1,00 | 0,67 | 0,50 |
| 550 | 5,50 | 4,23 | 2,75 | 1,70 | 1,65 | 1,10 | 0,73 | 0,55 |
| 600 | 6,00 | 4,62 | 3,00 | 1,86 | 1,80 | 1,20 | 0,80 | 0,60 |
| 650 | 6,50 | 5,00 | 3,25 | 2,01 | 1,95 | 1,30 | 0,87 | 0,65 |
| 700 | 7,00 | 5,38 | 3,50 | 2,17 | 2,10 | 1,40 | 0,93 | 0,70 |
| 750 | 7,50 | 5,77 | 3,75 | 2,32 | 2,25 | 1,50 | 1,00 | 0,75 |
| 800 | 8,00 | 6,15 | 4,00 | 2,48 | 2,40 | 1,60 | 1,07 | 0,80 |
| 850 | 8,50 | 6,54 | 4,25 | 2,63 | 2,55 | 1,70 | 1,13 | 0,85 |
| 900 | 9,00 | 6,92 | 4,50 | 2,79 | 2,70 | 1,80 | 1,20 | 0,90 |
| 950 | 9,50 | 7,31 | 4,75 | 2,94 | 2,85 | 1,90 | 1,27 | 0,95 |
| 1000 | 10,00 | 7,69 | 5,00 | 3,10 | 3,00 | 2,00 | 1,33 | 1,00 |
| | | | | | | | | |
| | | | | | | | | |
| Force Newton | Pressure PSI | Pressure PSI | Pressure PSI | Pressure PSI | Pressure PSI | Pressure PSI | Pressure PSI | Pressure PSI |
| | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) | surf. (mm2) |
| | 100 | 130 | 200 | 323 | 333 | 500 | 750 | 1000 |
| 50 | 72,50 | 55,77 | 36,25 | 22,45 | 21,77 | 14,50 | 9,67 | 7,25 |
| 100 | 145,00 | 111,54 | 72,50 | 44,89 | 43,54 | 29,00 | 19,33 | 14,50 |
| 150 | 217,50 | 167,31 | 108,75 | 67,34 | 65,32 | 43,50 | 29,00 | 21,75 |
| 200 | 290,00 | 223,08 | 145,00 | 89,78 | 87,09 | 58,00 | 38,67 | 29,00 |
| 250 | 362,50 | 278,85 | 181,25 | 112,23 | 108,86 | 72,50 | 48,33 | 36,25 |
| 300 | 435,00 | 334,62 | 217,50 | 134,67 | 130,63 | 87,00 | 58,00 | 43,50 |
| 350 | 507,50 | 390,38 | 253,75 | 157,12 | 152,40 | 101,50 | 67,67 | 50,75 |
| 400 | 580,00 | 446,15 | 290,00 | 179,57 | 174,17 | 116,00 | 77,33 | 58,00 |
| 450 | 652,50 | 501,92 | 326,25 | 202,01 | 195,95 | 130,50 | 87,00 | 65,25 |
| 500 | 725,00 | 557,69 | 362,50 | 224,46 | 217,72 | 145,00 | 96,67 | 72,50 |
| 550 | 797,50 | 613,46 | 398,75 | 246,90 | 239,49 | 159,50 | 106,33 | 79,75 |
| 600 | 870,00 | 669,23 | 435,00 | 269,35 | 261,26 | 174,00 | 116,00 | 87,00 |
| 650 | 942,50 | 725,00 | 471,25 | 291,80 | 283,03 | 188,50 | 125,67 | 94,25 |
| 700 | 1015,00 | 780,77 | 507,50 | 314,24 | 304,80 | 203,00 | 135,33 | 101,50 |
| 750 | 1087,50 | 836,54 | 543,75 | 336,69 | 326,58 | 217,50 | 145,00 | 108,75 |
| 800 | 1160,00 | 892,31 | 580,00 | 359,13 | 348,35 | 232,00 | 154,67 | 116,00 |
| 850 | 1232,50 | 948,08 | 616,25 | 381,58 | 370,12 | 246,50 | 164,33 | 123,25 |
| 900 | 1305,00 | 1003,85 | 652,50 | 404,02 | 391,89 | 261,00 | 174,00 | 130,50 |
| 950 | 1377,50 | 1059,62 | 688,75 | 426,47 | 413,66 | 275,50 | 183,67 | 137,75 |
| 1000 | 1450,00 | 1115,38 | 725,00 | 448,92 | 435,44 | 290,00 | 193,33 | 145,00 |

Appendix 5 Operating instructions Soil moisture probe 061550

1. Introduction & description

The ThetaProbe measures volumetric soil moisture content, θ_v , by the well established method of responding to changes in the apparent dielectric constant. These changes are converted into a DC voltage, virtually proportional to soil moisture content over a wide working range.

Volumetric soil moisture content is the ratio between the volume of water present and the total volume of the sample. This is a dimensionless parameter, expressed either as a percentage (%vol), or a ratio ($\text{m}^3.\text{m}^{-3}$).

Thus $0.0 \text{ m}^3.\text{m}^{-3}$ corresponds to a completely dry soil, and pure water gives a reading of $1.0 \text{ m}^3.\text{m}^{-3}$. There are important differences between volumetric and gravimetric soil moisture contents.

2. Operating principles

The ThetaProbe consists of a waterproof housing which contains the electronics, and, attached to it at one end, four sharpened stainless steel rods that are inserted into the soil.

The probe generates a 100 MHz sinusoidal signal which is applied to a specially designed internal transmission line that extends into the soil by means of the array of four rods. The impedance of this array varies with the impedance of the soil, which has two components - the apparent dielectric constant and the ionic conductivity. The 100 MHz signal frequency has been chosen to minimise the effect of ionic conductivity, so that changes in the transmission line impedance are dependent almost solely on the soil's apparent dielectric constant. Because the dielectric of water (~81) is very much higher than soil (typically 3 to 5) and air (1), the dielectric constant of soil is determined primarily by its water content.

The impedance of the rod array affects the reflection of the 100 MHz signal, and these reflections combine with the applied signal to form a voltage standing wave along the transmission line. The output of the ThetaProbe is an analogue voltage proportional to the difference in amplitude of this standing wave at two points, and this forms a sensitive and precise measure of soil water content.

Work published over many years by Whalley, White, Knight Zegelin and Topp and others, shows almost linear correlation between the square root of the dielectric constant, ($\sqrt{\epsilon}$), and volumetric moisture content, (θ_v), and this has been documented for many soil types.

Each ThetaProbe is adjusted during manufacture to provide a consistent output when measuring media of known dielectric constant, making them readily interchangeable without system re-calibration.

The output signal is 0 to 1V DC for a range of soil dielectric constant, ϵ , between 1 and 32, which corresponds to approximately $0.5 \text{ m}^3.\text{m}^{-3}$ volumetric soil moisture content for mineral soils.

3. Installation

Essentially installation is very simple - you just push the probe into the soil until the rods are fully covered, connect up the power supply and take readings from the analogue output. Optional extension tubes are available for monitoring a soil layer below the surface. However, it is quite possible to get sampling errors greater than $0.1 \text{ m}^3.\text{m}^{-3}$, and in extreme cases damage the probe if you don't pay due care and attention to the details of the installation of ThetaProbes when making measurements of soil water content.

You will need to consider each of the following factors when setting up a measurement:

Air pockets

The ThetaProbe is sensitive to the water content of the soil sample held within its array of 4 stainless steel rods, but this sensitivity is biased towards the central rod and falls off towards the outside of this cylindrical sampling volume. The presence of air pockets around the rods, particularly around the central rod, will reduce the value of soil

moisture content measured. In particular, you need to be very careful when removing and re-inserting the probe into a previous location.

Insertion angle

If the probe is going to be left in situ, and measurements taken during and after rainfall, it is a good idea to insert it at an angle (say 20°), so that any water running down the side of the probe housing tends to be carried away from the rods.

Soil sampling points

The soil water content measured by a ThetaProbe within one small locality can be affected by :

- Variations in soil density and composition
- Stones close to the rods
- Roots (either nearby or pierced by the rods)
- Earth worm holes (or even mole holes!)
- Subsoil drainage
- Small scale variability in transpiration and evaporation losses

It is important to take the degree of variability of these various parameters into account when deciding on the number of probes to use at any particular location. If the soil is known to be very heterogeneous, it will be necessary to take measurements from at least three closely-spaced locations.

4. Care and maintenance

ThetaProbes are sealed after calibration, require no routine maintenance and are constructed of materials selected for robust field operation. However, please pay careful attention to the following 3 points:

1. **Do not remove the cross-head sealing screws.** This may damage the seal and will invalidate your guarantee. No internal maintenance or repair can be performed by the user.
2. **Do not remove the ThetaProbe from soil by pulling on the cable.** If the measurement rods become bent in use, they can be carefully unscrewed from the body and straightened. They have a right-handed thread.
3. **Do not attempt to straighten the measurement rods while they are still attached to the probe body.** This may break the rods or damage the case seal.

Even a small degree of bending in the rods (>1 mm out of parallel), although not enough to affect the inherent ThetaProbe accuracy, will increase the likelihood of air pockets around the rods during insertion, and so should be avoided. Replacement rods are available if required (type ML-RODS). Ensure that they are fully tightened on reassembly, but do not apply excessive force, as this will cause damage to the probe body seal.

Pre-preparation of holes to accept ThetaProbe measuring rods is recommended in stony soils or other hard materials.

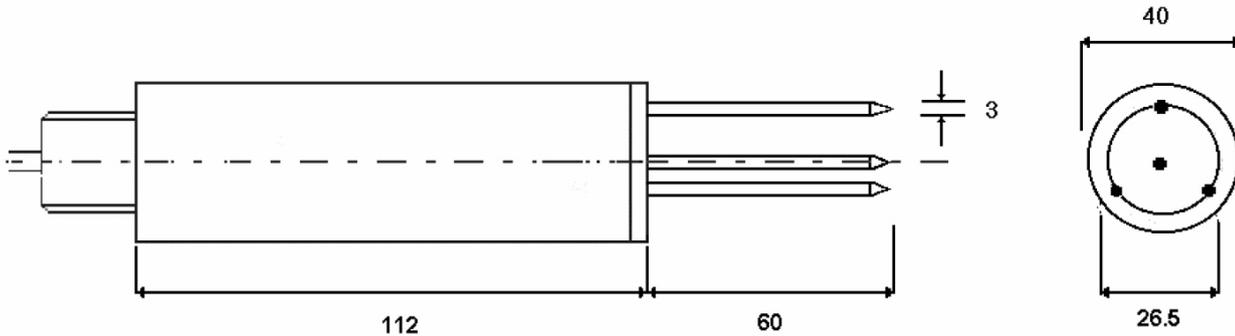
5. Electromagnetic Compatibility (EMC)

ThetaProbe has been assessed for compatibility under the European Union EMC Directive 89/336/EEC and conforms to the appropriate standards, provided the moisture measuring rods and probe body are completely immersed in the soil or other material being measured. The cable connecting the ThetaProbe to its associated instrumentation should also be routed along the surface of the soil. If the probe is not installed in this way, some interference may be experienced on nearby radio equipment. Under most conditions, moving the equipment further from

ThetaProbe (typically 1-2 metres) will stop the interference. ThetaProbes installed near to each other will not malfunction due to interference.

6. Mechanical and electrical specifications

Dimensions in mm



| Technical specifications | | |
|--|---|--|
| Type No. | ML3 | |
| Measurement parameter | Volumetric soil moisture content, θ_V ($\text{m}^3.\text{m}^{-3}$ or %vol.) | |
| Range | Accuracy figures apply from 0.05 to 0.6 $\text{m}^3.\text{m}^{-3}$ Full range is from 0.0 to 1.0 $\text{m}^3.\text{m}^{-3}$ | |
| Accuracy | $\pm 0.01 \text{ m}^3.\text{m}^{-3}$, 0 to 40°C $\pm 0.02 \text{ m}^3.\text{m}^{-3}$, 40 to 70°C | after calibration to a specific soil type |
| subject to soil salinity errors, see below | $\pm 0.05 \text{ m}^3.\text{m}^{-3}$, 0 to 70°C | using the supplied soil calibration, in all 'normal' soils |
| Soil salinity errors | 0.0 to 250 $\text{mS}.\text{m}^{-1}$, < -0.0001 $\text{m}^3.\text{m}^{-3}$ change per $\text{mS}.\text{m}^{-1}$ 250 to 2000 $\text{mS}.\text{m}^{-1}$, no significant change | |
| Soil sampling volume | >95% influence within cylinder of 4.0 cm diam., 6 cm long, (approx 75 cm^3), surrounding central rod | |
| Environment | Will withstand burial in wide ranging soil types or water for long periods without malfunction or corrosion (IP68 to 5 m) | |
| Stabilization time | 1 to 5 sec. from power-up, depending on accuracy required | |
| Response time | Less than 0.5 sec. to 99% of change | |
| Duty cycle | 100 % (continuous operation possible) | |
| Interface | Input requirements: 5-15 V DC unregulated Current consumption: 19 mA typical, 23 mA max. Output signal: approx. 0-1 V DC for 0-0.5 $\text{m}^3.\text{m}^{-3}$ | |
| Case material | PVC | |
| Rod material | Stainless steel | |
| Cable length | Standard: 5 m. Maximum length: 100 m | |
| Weight | 350 gr. approx. with 5 m cable | |

For more information on the soil moisture probe see: M-14260702E



Declaration of Conformity Déclaration de Conformité Konformitätserklärung

This corresponds to EN ISO/IEC 17050-1

We / Nous / Wir
Royal Eijkelkamp, 6987 EN Giesbeek

declare under our sole responsibility that the product
déclarons sous notre seule responsabilité que le produit
erklären in alleiniger Verantwortung, dass das Produkt

061531 Penetrologger

to which this declaration relates is in conformity with the following standards
auquel se réfère cette déclaration est conforme aux normes
auf das sich diese Erklärung bezieht, mit den folgenden Normen übereinstimmt

EMC directive 89/336/EEG:
Generic standard EN50081-1: emission tests, light industrial.
Generic standard EN50082-1: immunity tests, light industrial.

Royal Eijkelkamp,
October 2017



H. Eijkelkamp
CEO