

The DynaRoot dynamic root evaluation system

Fakopp Enterprise Bt.

October 12, 2016

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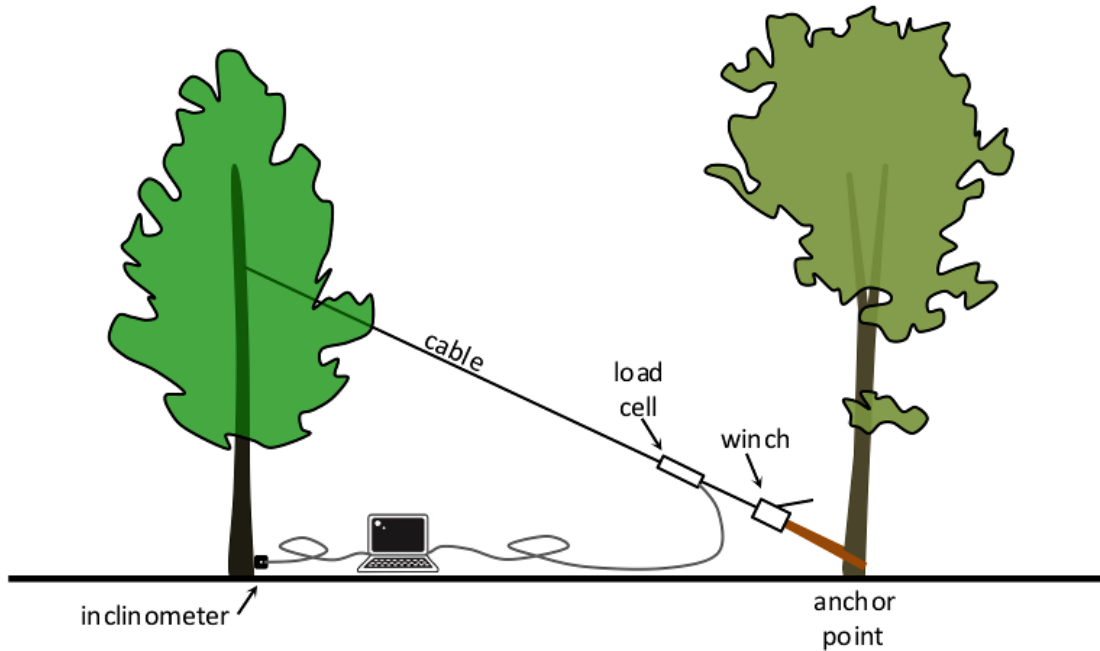
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1 Introduction

The stability of urban trees is a key question that affects everyone. Diseased and unstable urban trees pose much risk for everyone, and are a serious liability for municipalities in case of an accident. Tree stability assessment is therefore of the utmost importance. In the meantime it tends to be much neglected in many areas.

At present, there is only one accepted method for tree stability assessment. The pulling test, while well established and accepted, has several drawbacks, both in terms of reliability and ease of use. Dynamic root stability determination is based on real life wind loads, and is therefore more appropriate for assessing real life risks. It is also much simpler to carry out than the traditional pulling test, with the only drawback being that it requires windy weather to carry out.

Figure 1: Schematic of the pulling test.



2 The pulling test

The pulling test is based on affixing a cable at approximately mid-height on the tree to be evaluated, and applying a moderate load, while measuring the inclination at the base of the trunk. The induced inclination is very moderate (less than .25 degrees), to make sure that the test itself does not damage or start uprooting the tree. Based on the measured load, it is possible to extrapolate to the approximate torque required to uproot the tree. The maximum torque that may arise due to adverse weather conditions can also be calculated based on the crown surface, aerodynamic drag factor and the maximum wind velocity likely to occur in the area. The ratio of the two values is the safety factor (SF) of the given tree. If this value is above 1.5, the tree is declared safe, while a SF below 1 signals high risk. In-between these two values, the safety of the tree is considered uncertain.

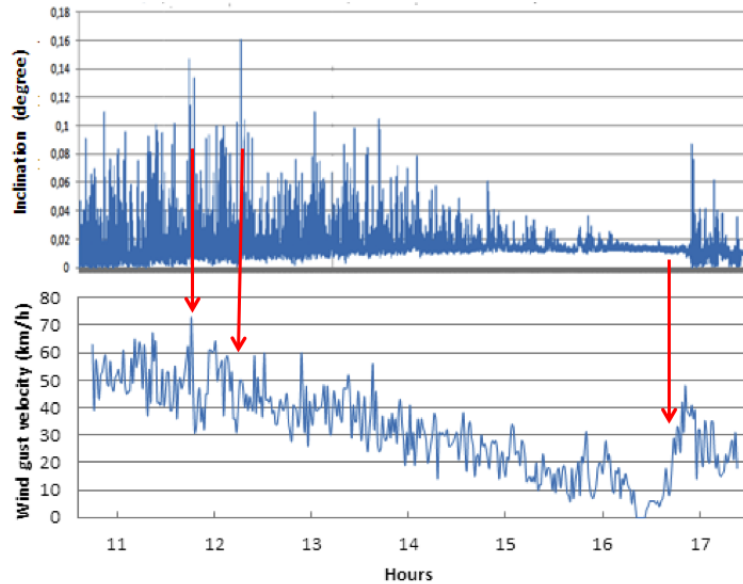
The advantage of the pulling test is that it is a fairly straightforward, well-researched and established method. On the other hand, the applied static load approximates the real life situation, where trees are subjected to dynamic loading, rather poorly. It is also quite cumbersome; requires heavy equipment (high capacity cable and ratchet) and a ladder to be carried to the test site, lengthy preparation and physical exertion during testing. The pulling cable has to be fastened to some well-secured object on the ground (like another tree trunk or stump) that may or may not be readily available.

3 The DynaRoot dynamic root evaluation system

It would be much simpler to use the loads that arise from the actual wind rather than a loaded cable, to assess the tree's safety in a high wind situation. There are, however, two interrelated problems that makes this very complicated:

1. Trees consist of a complicated network of trunk, major, minor branches, twigs and (in the summer) leaves. This situation is not unlike a multiple pendulum that reacts to loading in a very unpredictable,

Figure 2: Two-dimensional time series plot of inclination and wind velocity.



erratic manner, when the load is not applied directly to the trunk (as is the case in the pulling test).

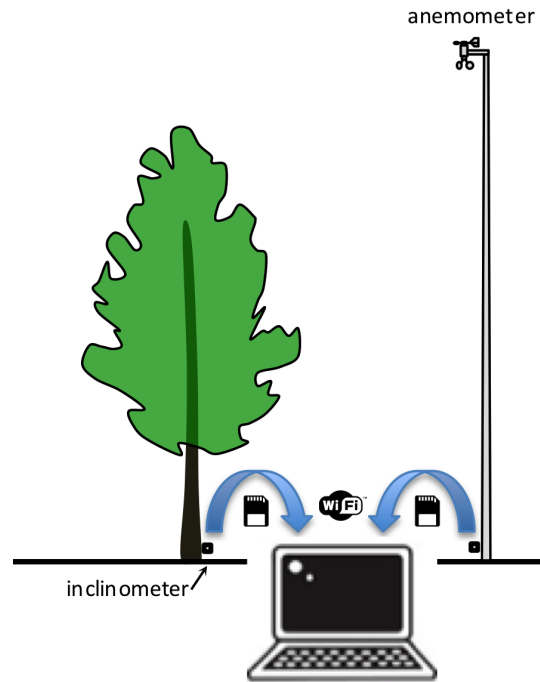


2. As a result, there is no direct relationship between the wind load (wind velocity) and the immediate response of the tree, i.e. no correlation between the load and the inclination of the trunk (see Figure 2).

The behavior of a tree in the wind is highly sensitive to the initial conditions. Small differences in initial conditions yield widely diverging outcomes for such dynamic systems (a situation popularly referred to as “the butterfly effect”). It is impossible to predict the behavior of such systems on the long run. A definite relationship exists between the wind velocity and the inclination of the tree, but it is a complex relationship, not one of immediate cause and effect.

One way to evaluate such systems is using statistical parameters of the data taken over longer intervals. There is no immediate relationship between the wind velocity and the inclination at any given moment, but there is a relationship between their averages and other statistical parameters observed over a longer interval. The DynaRoot system takes advantage of this statistical relationship.

Figure 3: Components of the DynaRoot system



4 How does DynaRoot work?

The DynaRoot system consists of three components (see Figure 3):

1. **Anemometer:** an instrument for measuring wind velocity at or near the tree to be evaluated. The closer to the better, but, depending on wind velocity DynaRoot may provide reliable data even with measurements taken several kilometres / miles away. The anemometer provides wind velocity data of sufficient frequency. Ideally the anemometer should be clear of buildings or other objects that may obstruct the wind, at a height of at least 10 m.
2. **Inclinometer:** an instrument affixed to the root collar that measures the inclination of the trunk in two different directions. The instrument provides very accurate inclination data with sufficient frequency.
3. **Evaluation software:** a PC software for evaluating wind velocity, x and y inclination. The data, recorded over a period of several hours, are transferred from the anemometer and inclinometer on memory cards or wirelessly via Wi-Fi. The software breaks the data down into shorter intervals, and calculates statistic parameters for each interval that are used for the tree stability evaluation.

The Safety Factor calculation is not unlike the one used for the pulling test, except, in this case, wind pressure is used instead of force, and statistical parameters used instead of the momentary wind pressure and inclination values. There is a tangential relationship between the wind pressure and the inclination of the tree, and the critical wind pressure can be calculated from the curves (see Figure 4). This critical value is used for calculating the SF, which is interpreted much the same way as the one calculated from the static pull test.

Figure 4: Relationship between the wind pressure and the inclination

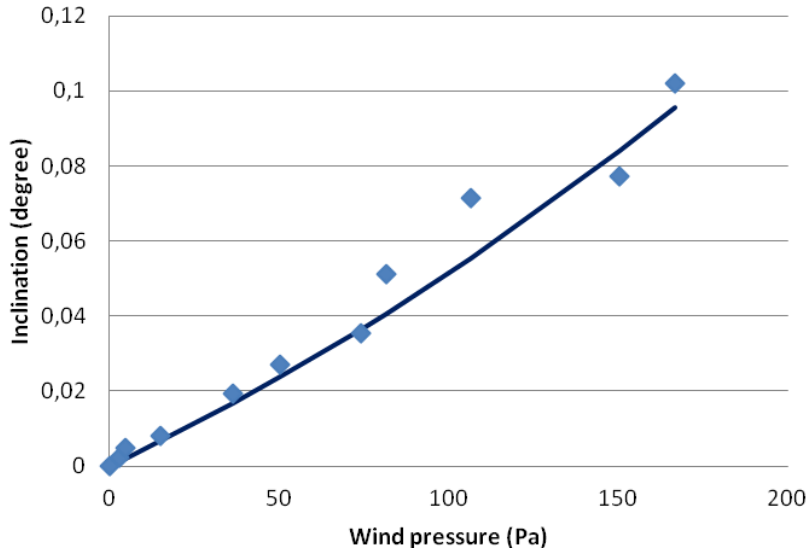
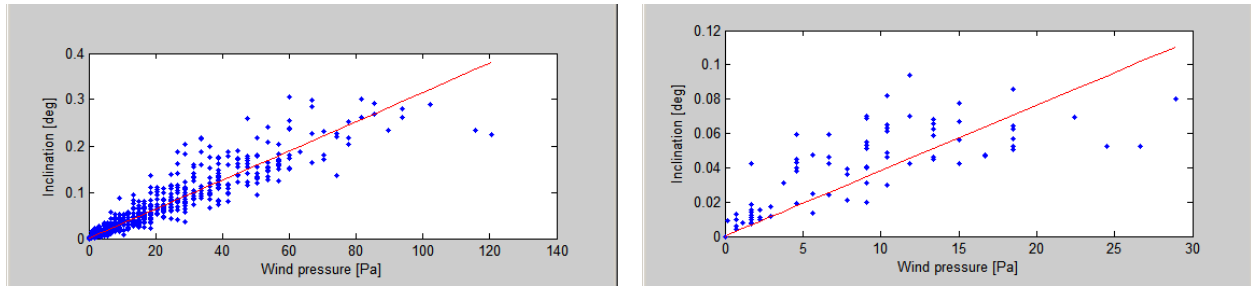


Figure 5: An important condition for DynaRoot to be applicable is a sufficiently large wind speed.



5 Some considerations concerning the measurement

5.1 The distance between the measured tree and the anemometer

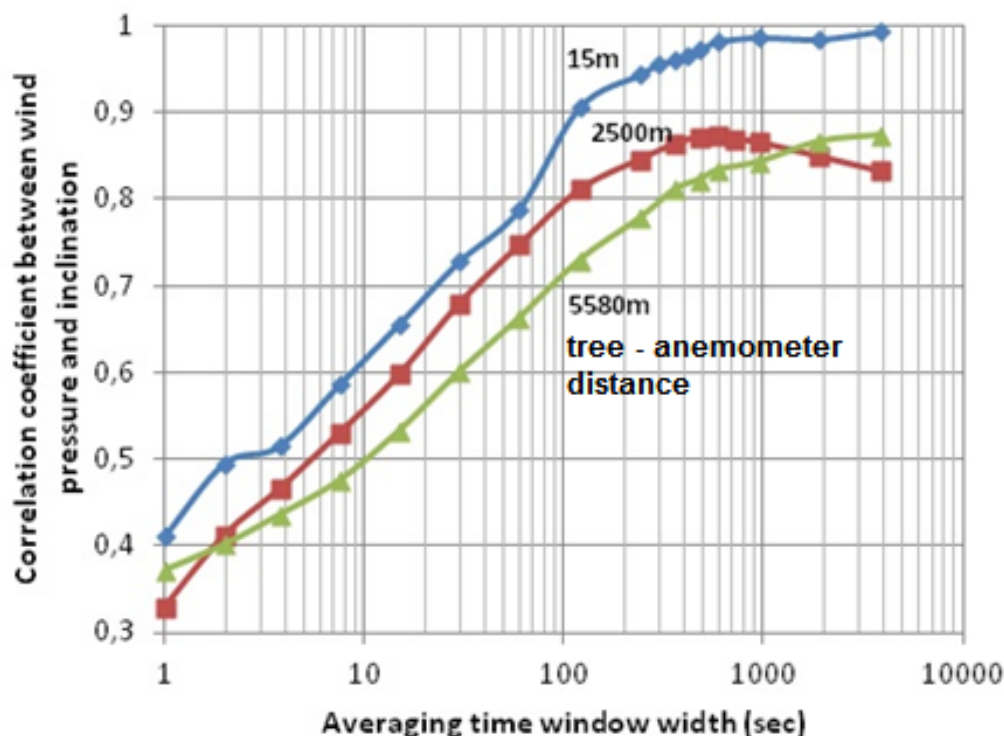
The intensity of the wind gusts may be different from location to location, even within a relatively small area. The relationship between wind intensity and inclination is obviously closer if wind velocity is measured close to the tree. Nevertheless, fairly accurate correlations can be achieved if the anemometer is located within 1.5 km (1 mile) of the tree, and meaningful data has been collected when the distance was as high as 5 km (3 miles), unless wind gusts originate from localized weather events (like a tornado).

It is, of course, best to set up the anemometer close to the measured tree, but this may not always be possible due to the terrain constraints. It is also possible that we want to assess multiple trees, or we want to use data from a nearby weather station (possible if they can provide at least one wind velocity reading per second). As long as wind data is collected reasonably close, the evaluation is possible.

5.2 Wind velocity

The most important condition for the application of this technique is windy weather. The higher the wind, the better the accuracy of the measurement. The minimum requirement is a wind speed of at least 25 km/h \sim 15 mph (see Figure 5).

Figure 6: Relationship between averaging time and the resulting correlation coefficient



5.3 Statistical approach

As mentioned before, instead of using momentary wind velocity and inclination data, values are collected over a longer period, and several minutes' worth of information is evaluated statistically. The accuracy of the data (the tightness of the correlation) depends on the time interval (see Figure ??). The time interval may be specified in the software when evaluating. 10 minutes provides the best results; however, this also means that long measurement periods are required to collect enough data points. 5 min (default setting) or even 2 min measurement intervals offer more data points without seriously compromising the accuracy of the measurements, if wind velocity is measured nearby. (If wind velocity is measured more than 1.5 km or 1 mile away, we recommend long collection periods and using 20-minute intervals for the statistics.)

5.4 Multiple measurements

The efficiency of the DynaRoot system multiples when measuring several trees simultaneously. This is possible, because – unlike in the case of the pulling test – the operator doesn't have to supply the pulling load for each tree. The only thing required is a relatively inexpensive inclinometer mounted on each tree to be evaluated, while the same anemometer can provide the wind velocity data for each tree (within a radius of several kms or miles). There is no theoretical limit to the number of trees to be assessed simultaneously.

5.5 Advantages and disadvantages

The DynaRoot system offers inclination measurements under real life wind load conditions, which is a better approximation of the actual situation that eventually leads to the uprooting of a tree, and therefore may be a more reliable measurement than the pulling test. It is also easier to set up and carry out; no need for

Table 1: Comparison of DynaRoot and the traditional pulling test

Issue	Pulling test	DynaRoot
Required equipment	Cable, ratchet, load cell, ladder, inclinometer (approx. 50 kg)	Anemometer, inclinometer (approx. 10 kg)
Load	Static	Realistic
Time required	1-3 hrs / tree	3 hrs / several trees
SF calculation	Crown area, drag factor and critical wind speed required	Only critical wind speed required
Weather conditions	Wind speed < 25 km/h	Wind speed > 25 km/h

heavy equipment, ladders and physical exertion during the test. There are only two disadvantages to this measurement. One is that sufficiently high wind velocities (at least 25 km/h or 15 mph) are required, which may be a problem when urgent results are expected. The other issue is that the measurement is more time consuming than the traditional pulling test. However, it does not require constant monitoring – after setup, the system can be left alone for the several hours required to collect the data. It can also be more efficient than the traditional test when measuring multiple trees simultaneously. Table 1 compares DynaRoot to the traditional pulling test.

6 System components

6.1 Anemometer

- Dual axis ultrasonic wind velocity meter
- Sampling rate: 1 Hz
- Measurement range: 0-150 km/h
- Accuracy: 0.2 km/h
- Integrated GPS
- Data storage capacity: 8 GB (SD card)
- Best location: open field, 10 m height, undisturbed by buildings or other large objects
- Completely weather proof



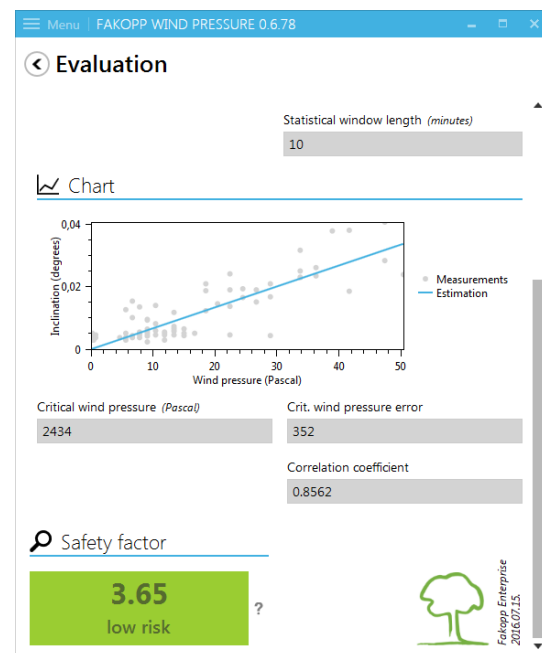
6.2 Dual axis inclinometer

- Measurement range ± 2 degrees
- Resolution: 0.001 degree
- Temperature compensated
- Sampling rate: 10 Hz
- Integrated GPS
- Data storage capacity: 8 GB (SD card)
- Mounted by a single screw
- Operating voltage and current: 12V, 20 mA
- Completely weather proof, IP65



6.3 DynaRoot software

- Simple yet efficient software for determining the safety factor
- Automatic merging of wind velocity and inclination data
- Diagram, critical wind pressure, correlation coefficient and safety factor calculation
- Runs under MS Windows.



7 Operation guide

DynaRoot system should be used on days with at least 25 km/h (15 mph) wind gust velocities. Setting up the measurement involves mounting the inclinometer(s) on the tree(s) root collar to be assessed, and erecting the anemometer in the vicinity of the trees.

Figure 7: Indicator lights on the LED display panel

in the case of an inclinometer.

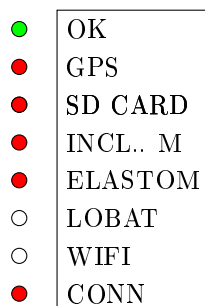
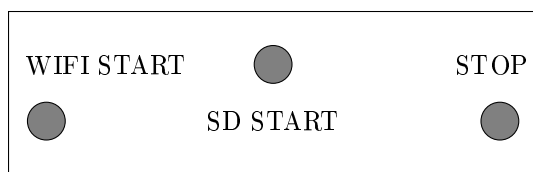


Figure 8: Buttons of the control panel



7.1 Inclinator setup

- attach the mounting plate using a screw to the tree collar (as close to ground level as possible.)
- use the ball head to level the mounting plate (using the two leveling tubes) and set it in the horizontal position.
- slide the inclinometer onto the mounting plate, and secure it with the bolt.
- connect the LED display panel (henceforth LDP) shown on figure 7.
- connect the wires to the external battery (12 VDC). Make sure not to reverse the polarity!
- wait for the OK LED to light up. This may take a few minutes depending on the quality of GPS signal reception.
- when the OK LED is lit, you may press SD START on the control panel located on the side of the instrument box (see figure 8). Use the provided magnetic stick to operate the buttons. Once pressed, the OK led starts blinking. You may now optionally disconnect the LDP.
- record data for a suitably long period of time (the longer the better. The minimum is 1 hr, but 3 hrs are recommended.)
- hit STOP on the control panel and wait for the recording to finish. (approx 1-2 s, until the SD led (3) goes off).
- transfer the data from the SD card to a different device for further processing (see subsection 7.3 for more instructions).
- remove the power cable.

The instructions above should be sufficient to get you started with data acquisition. However, under some circumstances the above mentioned procedure might partially or completely fail. Fortunately, the 8 led indicators on the LDP (see figure 7) provide us information concerning the operating conditions. Below we give a more detailed description about how to interpret the combination of signals on the LDP.

At the moment of powering up the device, all leds are on for the duration of a second. The boot process is the following

- if the LOBAT led turns on, you won't be able to use the instrument for data recording. Replace the battery with a sufficiently charged one.
- If power supply was found to be appropriate, the process continues with checking the GPS signal. This process takes at most 3 minutes, but may finish as early as 30 seconds if the reception is good. There are 3 possible outcomes:
 - if the GPS led turns off, it means that both time and position was received successfully.
 - if after 3 minutes the GPS led is blinking, it means that time was received but position was not.
 - if after 3 minutes the GPS led becomes continuous, it means that neither time nor position was received. In such cases make sure that nothing blocks the reception of the satellite signals, disconnect the wires of the battery and restart the boot process by connecting it again. If after rebooting you don't end up in any of the previous 2 cases (and there won't be other failures during the boot process), you will still be able to use your device but you have to use an external clock to note down the time when the SD START and STOP buttons were pressed and contact us for further assistance.
- if the INCL..M led stays on, then there is a problem with reading out data from the inclinometer therefore registration won't be possible. Try to reboot by disconnecting then reconnecting to the battery. If it doesn't help, contact us for further assistance.
- if the SD CARD led stays on, it indicates that the SD card has an error and registration won't be possible. Replace your SD card with an intact one.

To summarize it, if either the LOBAT, the SD CARD or the INCL..M leds stay on, then you won't be able to use your device for registration. If the GPS led stays on (either continuously or blinking), you can use your device but have to note down the time when the measurement was started and stopped manually. If all the lights goes off except the OK light then it indicates that everything went well and registration can be started.

7.2 Anemometer setup

Assemble the anemometer tower, attach the anemometer on the top, and erect the tower. Wind velocity readings are sent to, and data is collected at the instrument box located at the bottom of the tower.

Starting and stopping the data collection, recording and transferring data happens much the same way as described above at the inclinometer. The instrument box contains the same control panel (including start and stop buttons) as that of the inclinometer.

Do not forget to press "Tara" button inside the instrument box before raising the anemometer. Cover the sensor by a plastic bag to stop wind in the sensor area while performing "tara" function. After pressing "tara" please remove plastic bag.

Warning! Make sure that you setup and start the anemometer before the inclinometer(s), otherwise you won't be able to evaluate the part of the inclination data recorded before starting the anemometer!

7.3 Transferring data from the SD card to a different device

During the data acquisition phase, several files with the extensions `txt` or `csv` are created on the SD card of your inclino- or anemometer. The number of `csv` files created are roughly equal to the hours of operation in the case of the inclinometer and three times the hours of operation in the case of the anemometer. The DynaRoot evaluation software will automatically know how to interpret the format of these files so there is no need to do any preliminary conversions.

After the data acquisition phase you need to transfer the data stored on the SD card in the instrument box to your mobile device or your PC for further analysis. At the moment there are two possible ways to accomplish this:

1. Opening the instrument box and removing the SD card manually.
2. Putting the instrument into Wi-Fi mode and downloading/deleting data from the SD card via FTP without opening the case.

The first method should be straightforward and won't be detailed here.

Warning! Always make sure that the OK LED on the LDP is continuous. If it's blinking instead, then it indicates that registration is still on and it needs to be stopped first by pressing the STOP button on the instrument. If you remove the SD card while the green OK light is blinking it may result in data loss or damage to your card.

Since this method has the slight disadvantage of having to open the case of the instrument, Fakopp Enterprise offers a second solution that utilizes wireless communication technology. Transferring data wirelessly to an external device with a wireless network interface consists of

1. Putting the instrument into WiFi mode,
2. connecting to the wireless network of the instrument from the external device and
3. downloading data to the external device via FTP protocol.

In order to establish wireless connection to your device, it should be set into Wi-Fi mode by pressing the WIFI START button.

Warning! If the green indicator light labeled OK on the LED display panel is still blinking then it indicates that registration is still on and it needs to be stopped first by pressing the STOP button prior to activating Wi-Fi mode.

If Wi-Fi mode is successfully activated, then the white indicator light labeled WIFI on the LDP is continuous and the device is ready to accept connection requests from any sort of devices which has a wireless network interface (such as a laptop, a mobile device or even a desktop PC). The SSID of the network to connect to always has the form of DDAR-XX:XX:XX:XX:XX:XX, where the part of SSID following the hyphen is a valid MAC address unique to the purchased instrument instance. The connection uses the WPA security protocol for authentication, for which the passphrase is `Ddar-123`. In the following we are going to illustrate this process under Android OS. The steps need to be taken are very similar on other platforms.

Figure 9: Go to Settings / Wi-Fi to see the available Wi-Fi networks. Select the network with SSID DDAR-XX:XX:XX:XX:XX:XX, where the part after the hyphen is a unique MAC address. In the concrete example shown on the picture below, it is the sequence 5E:CF:7F:1B:43:52. Evidently, if you purchased two different HPI recorders, then both will have different SSIDs associated to them.

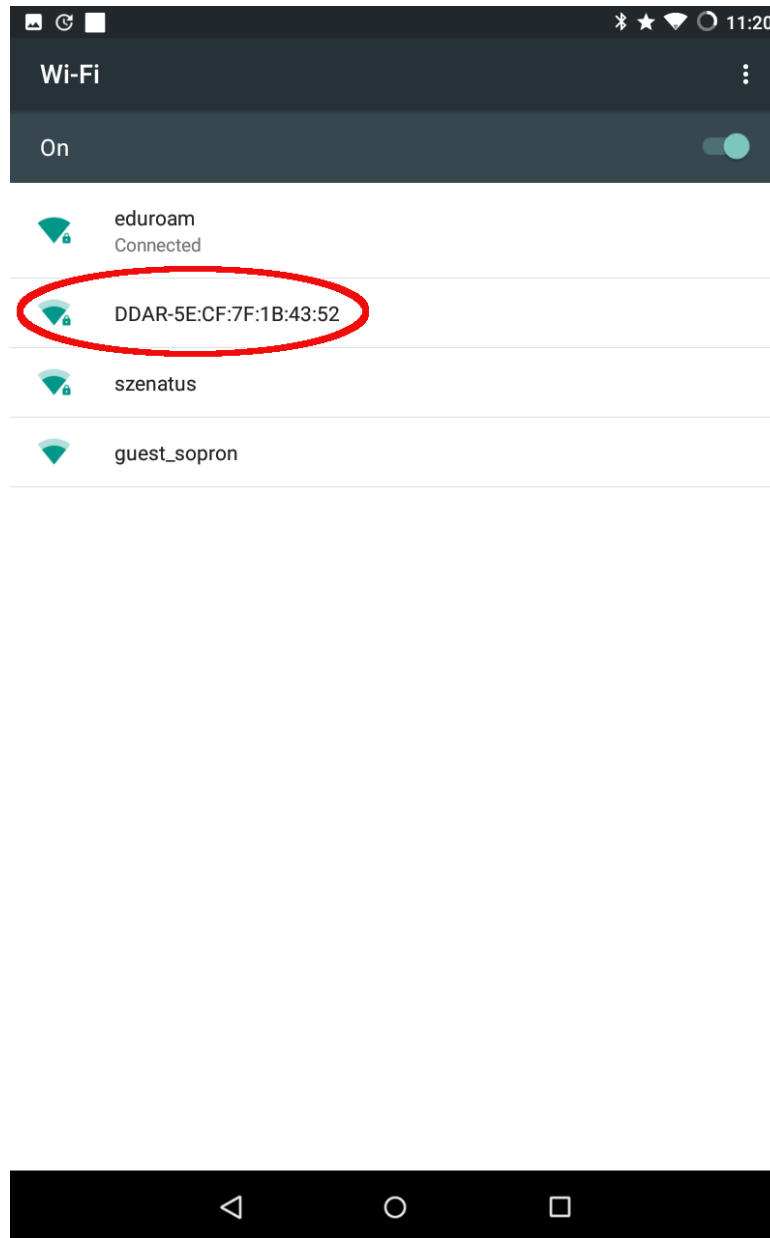


Figure 10: Enter the passphrase Ddar-123.

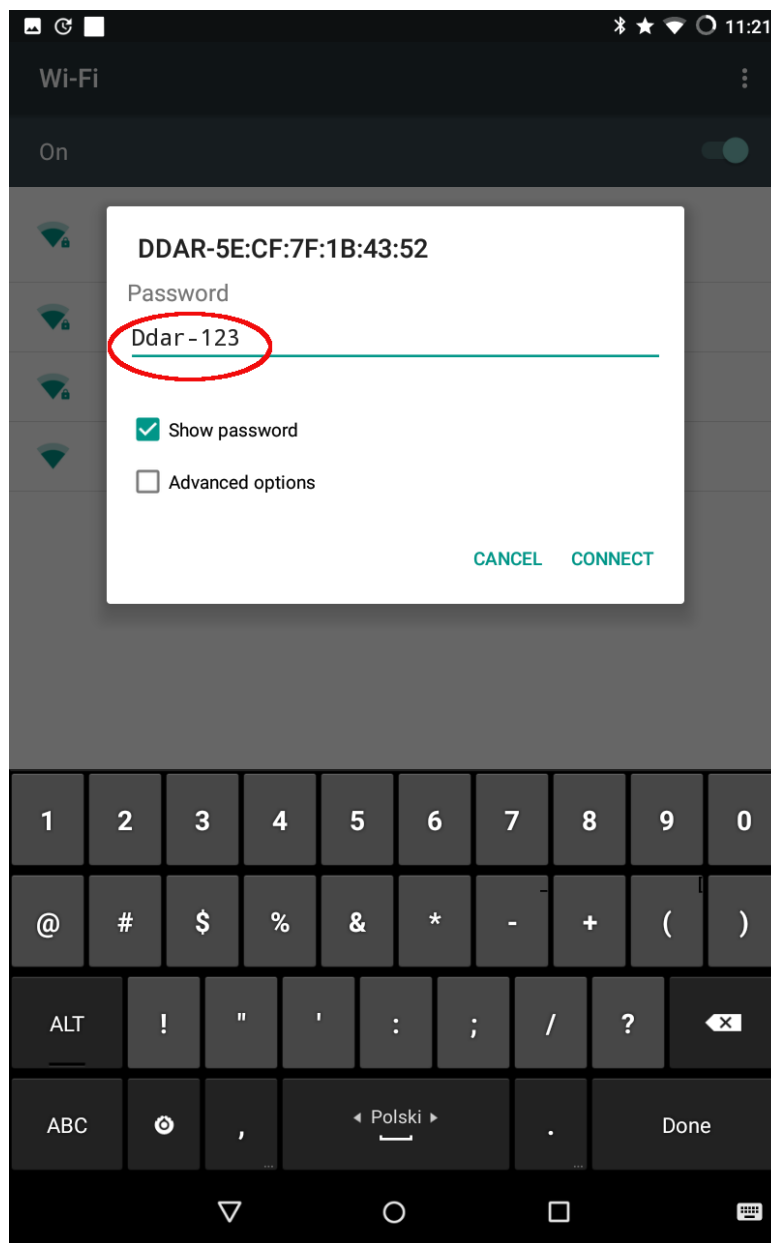


Figure 11: The status message 'Obtaining IP address...' should appear below the network name.

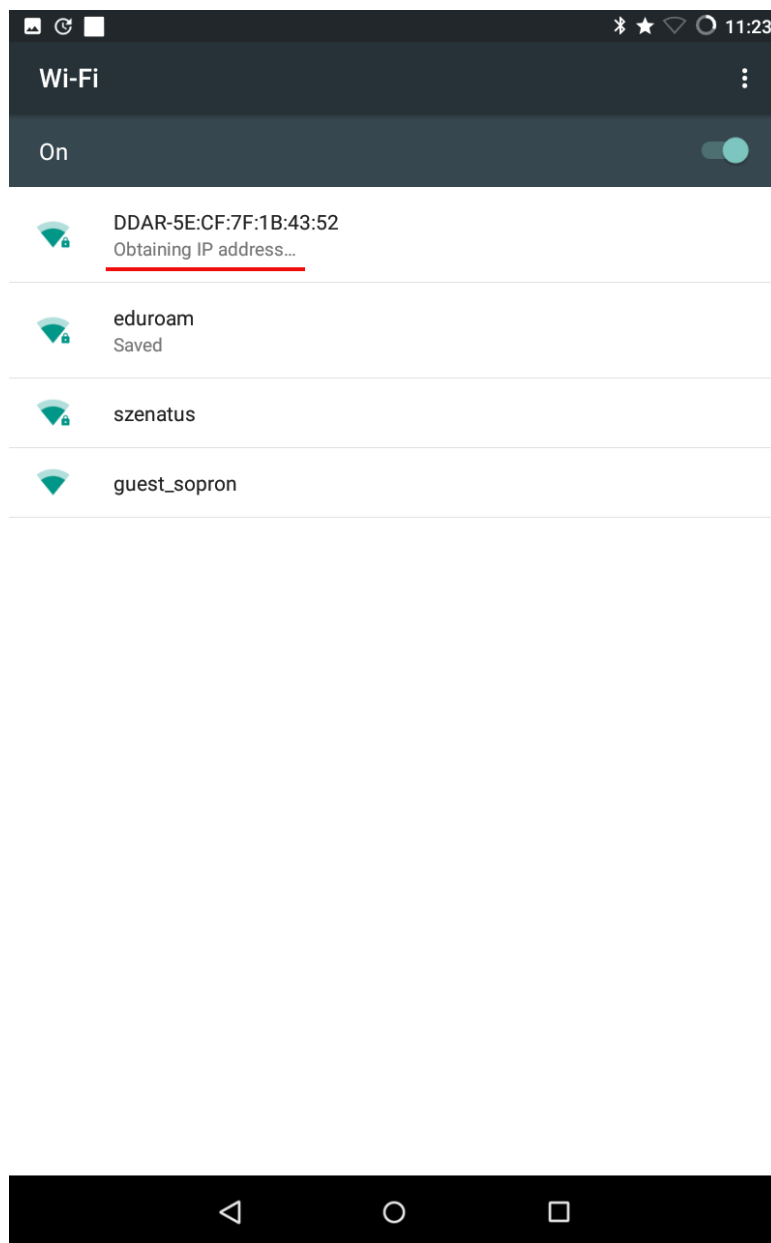
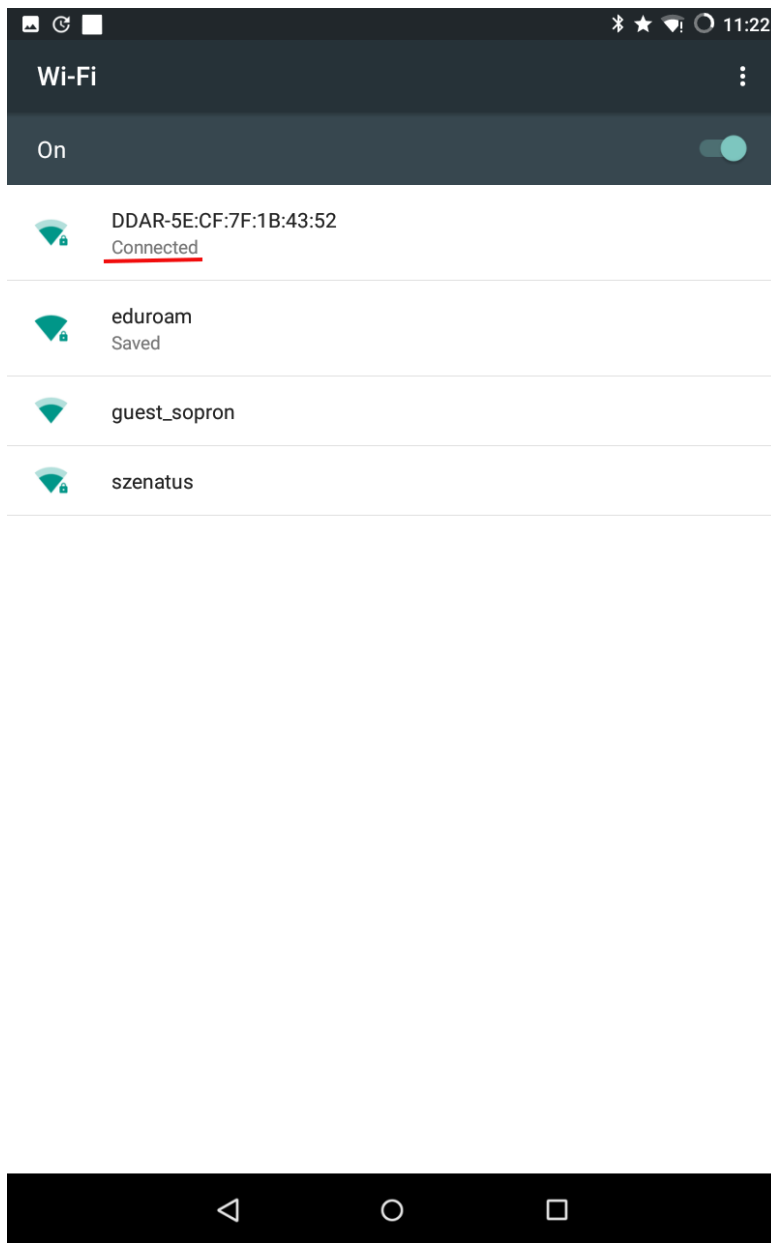


Figure 12: When the connection is successful, then the previous message changes to 'Connected'.



Once the connection to the WiFi network of the instrument is established, we are ready to transfer/delete files using a suitable FTP client. We are going to demonstrate this process on Android platform using the FTP client program named Turbo FTP ¹. The required steps are as follows.

¹<https://play.google.com/store/apps/details?id=turbo.client>

Figure 13: Press the menu icon on the top left. It might be possible that the menu panel is already active in which case this step can be omitted.

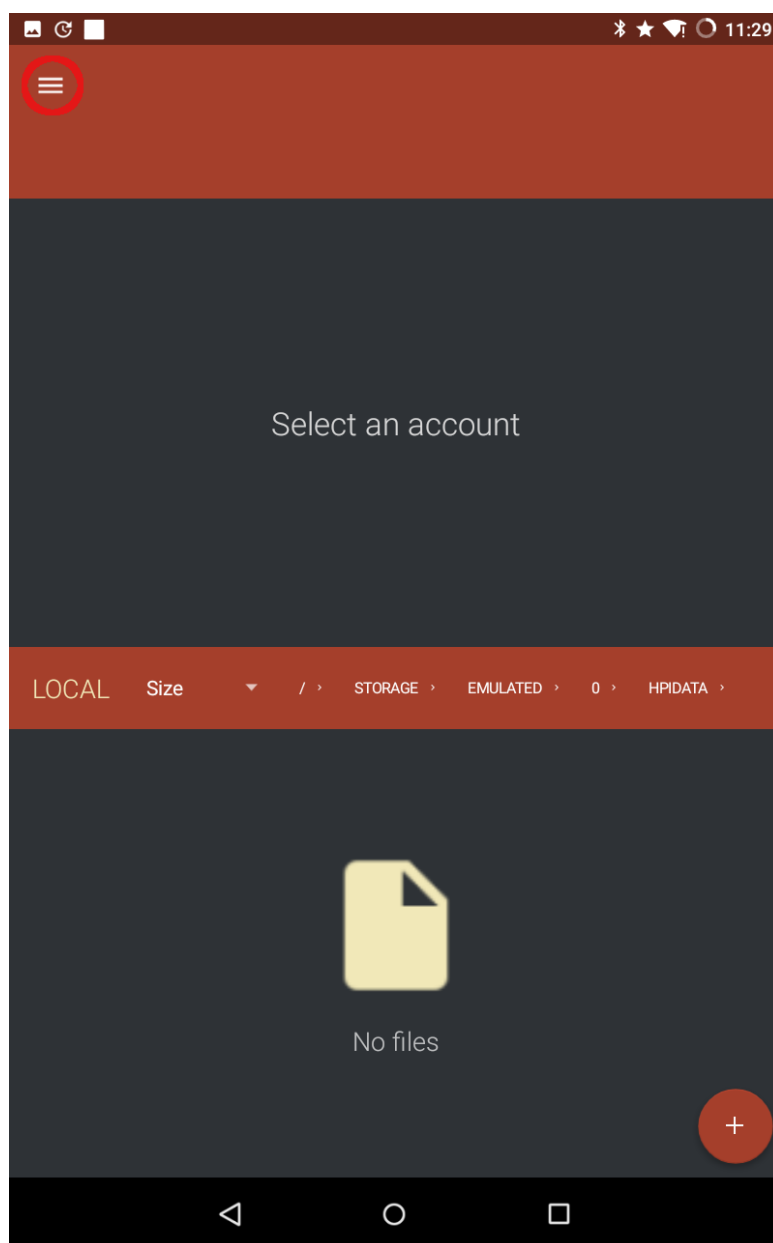


Figure 14: Select 'Create a new account' from the menu.

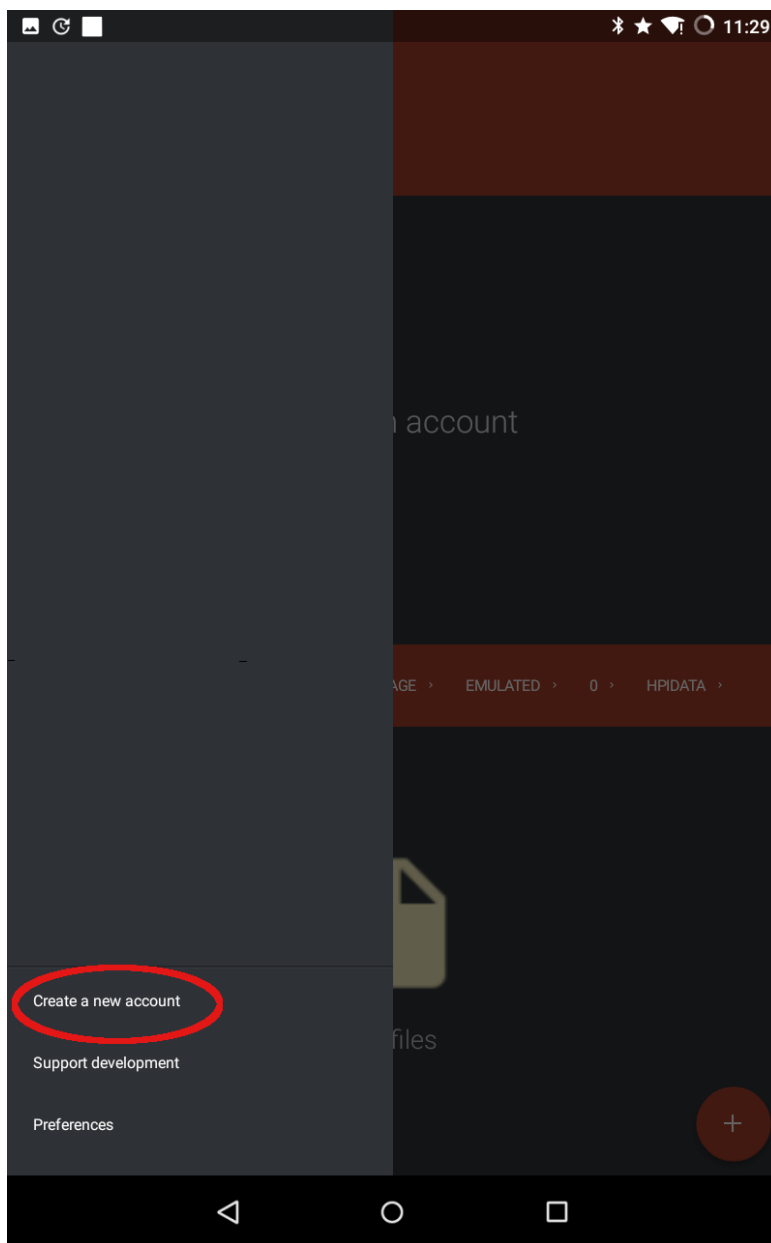


Figure 15: Select 'FTP'.

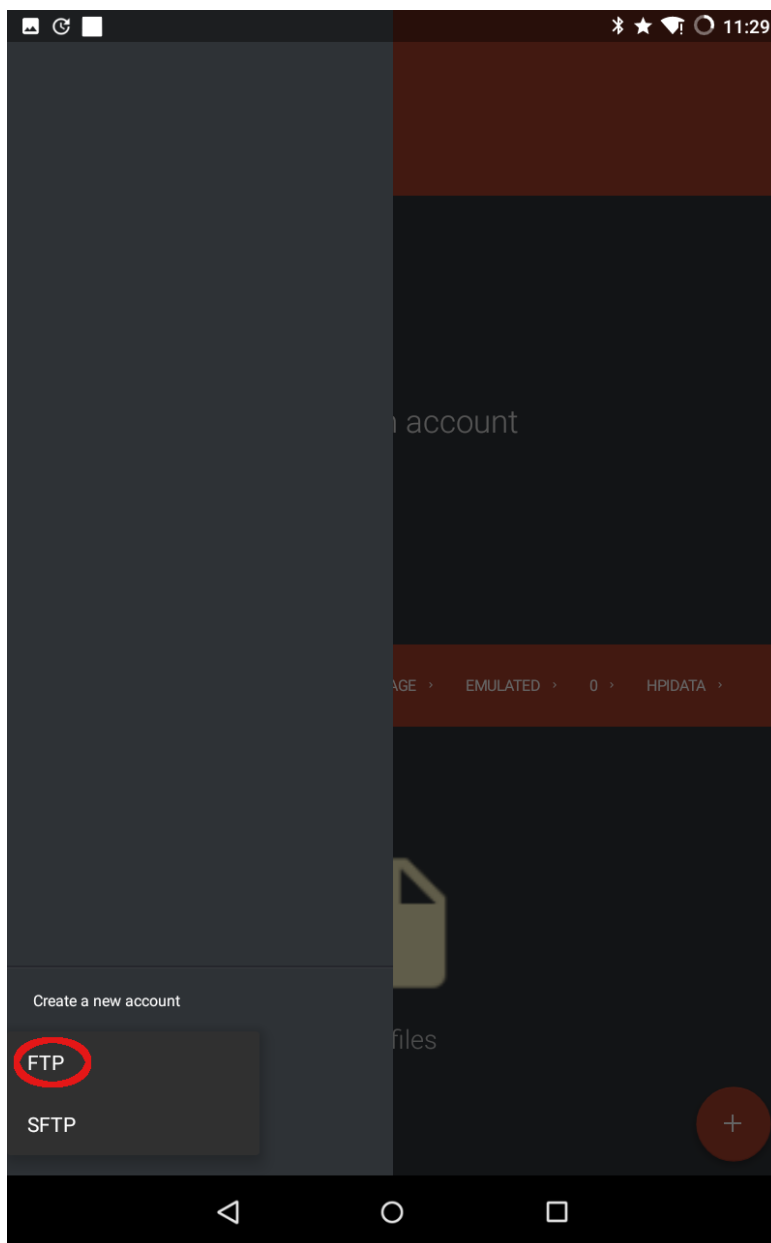


Figure 16: Enter an arbitrary name in the 'Connection Name' field. In this example we named our connection 'hpi recorder', which is an abbreviation of High Precision Inclination Recorder.

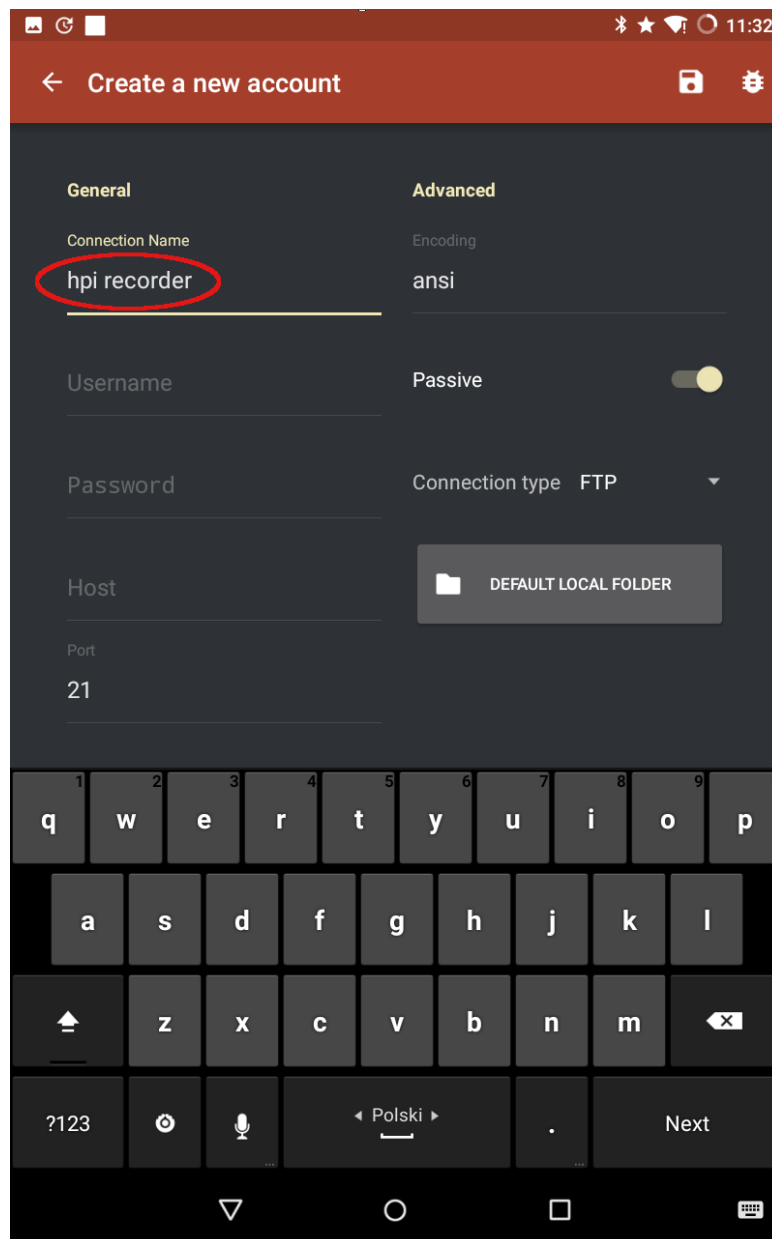


Figure 17: Enter 'ddar' in the 'Username' field.

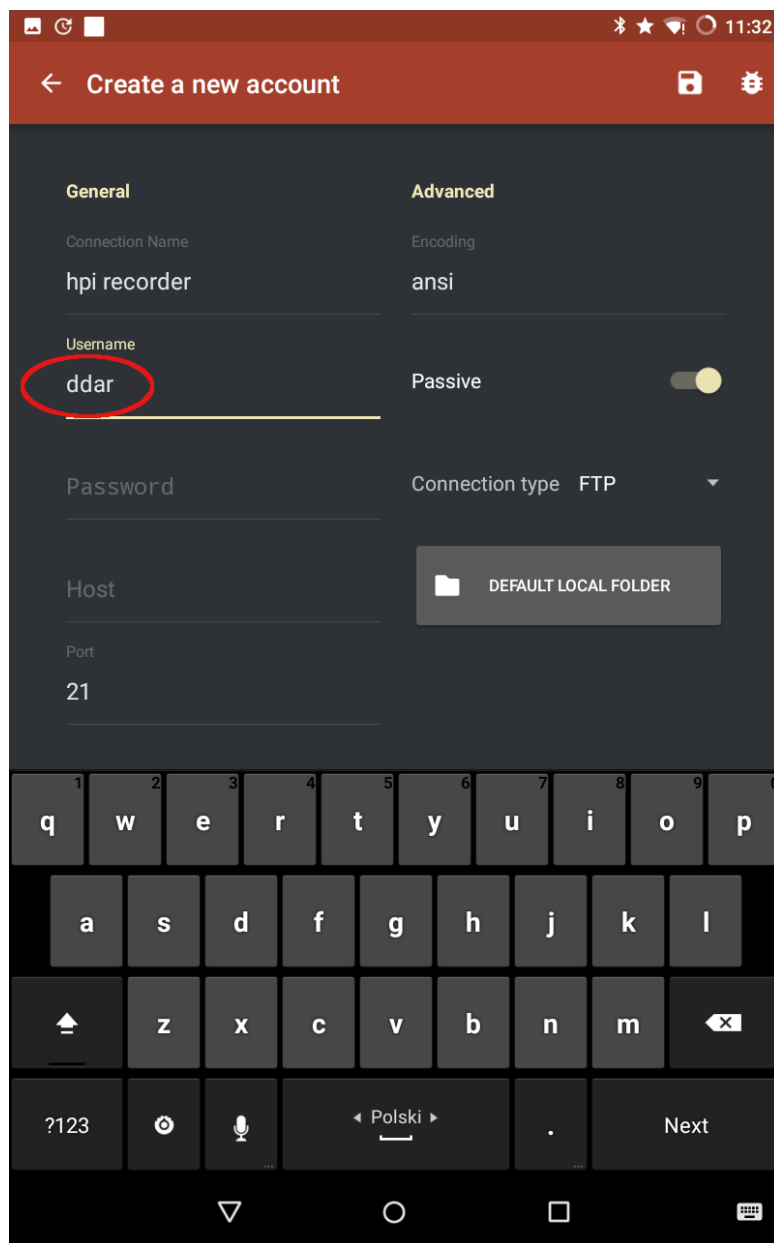


Figure 18: Enter 'ddar9876' in the 'Password' field.

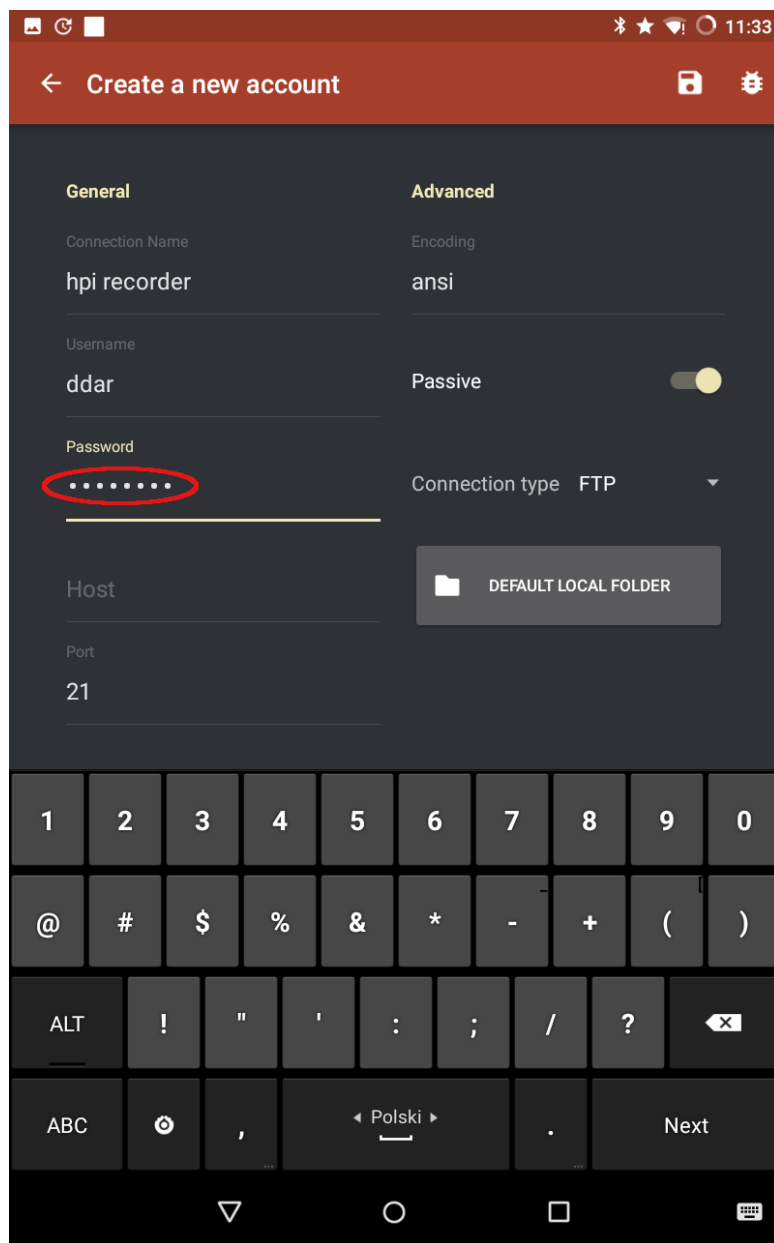


Figure 19: Enter the IP address '192.168.4.1' in the Host field.

Create a new account

General

Connection Name
hpi recorder

Username
ddar

Password
.....

Host
192.168.4.1

Port
21

Advanced

Encoding
ansi

Passive ☒

Connection type FTP

DEFAULT LOCAL FOLDER

1 2 3 4 5 6 7 8 9 0

@ # \$ % & * - + ()

ALT ! " ' : ; / ?

ABC , < Polski > . Next

Figure 20: Turn passive mode off.

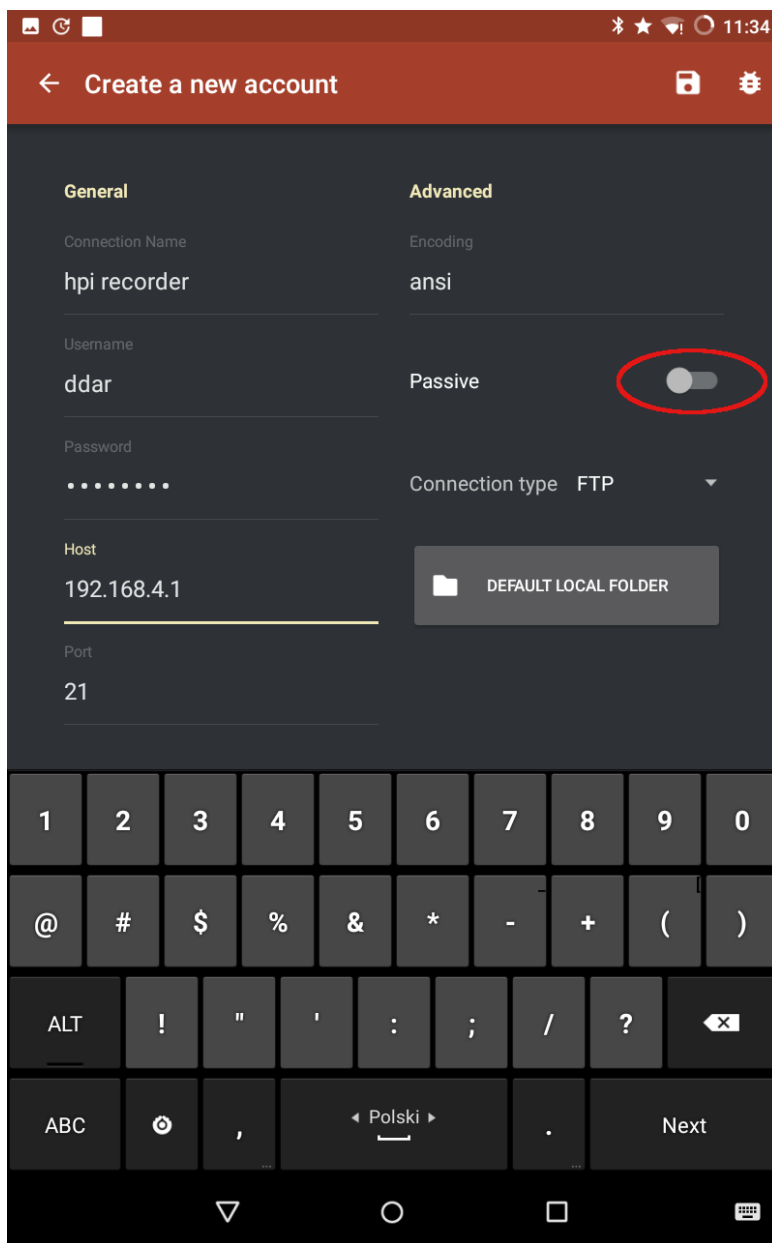


Figure 21: Press the 'DEFAULT LOCAL FOLDER' button to set the location where the files on the SD card will be saved.

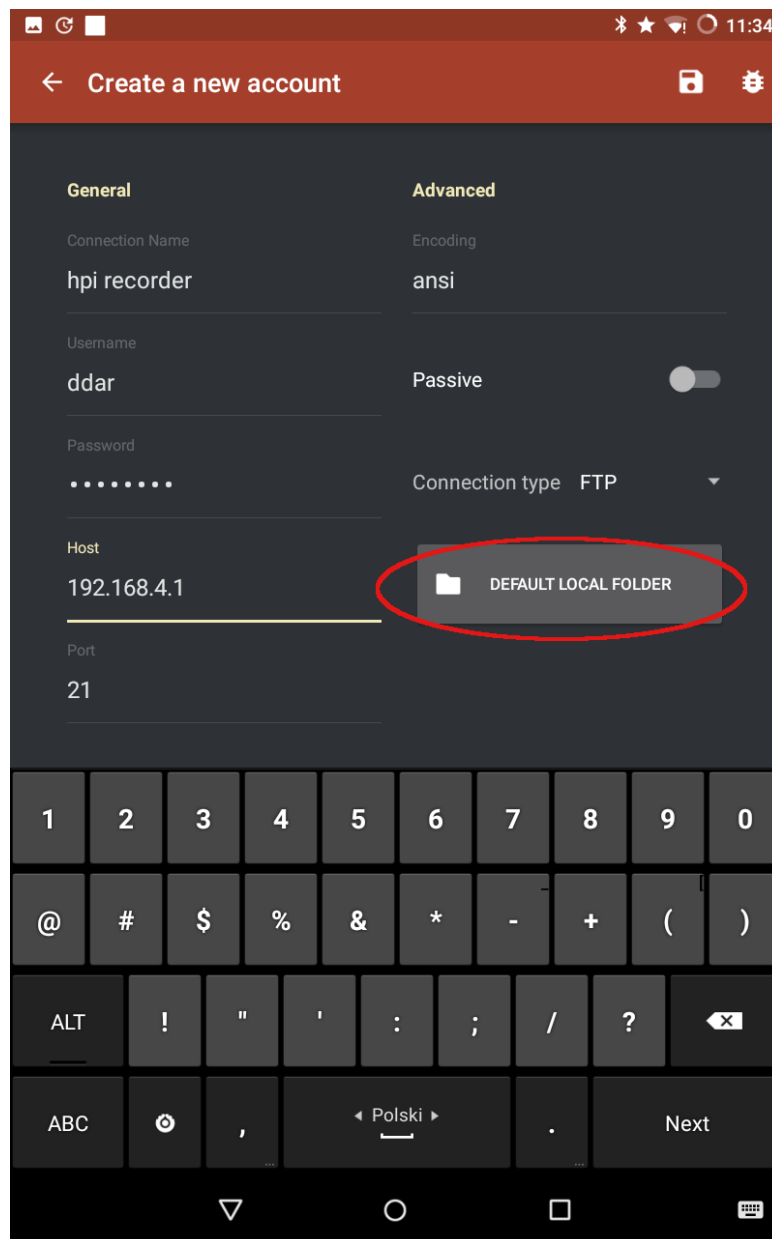


Figure 22: Browse to the desired folder on your device and press '✓SELECT'. In the example below, we've selected the folder called 'hpidata'.

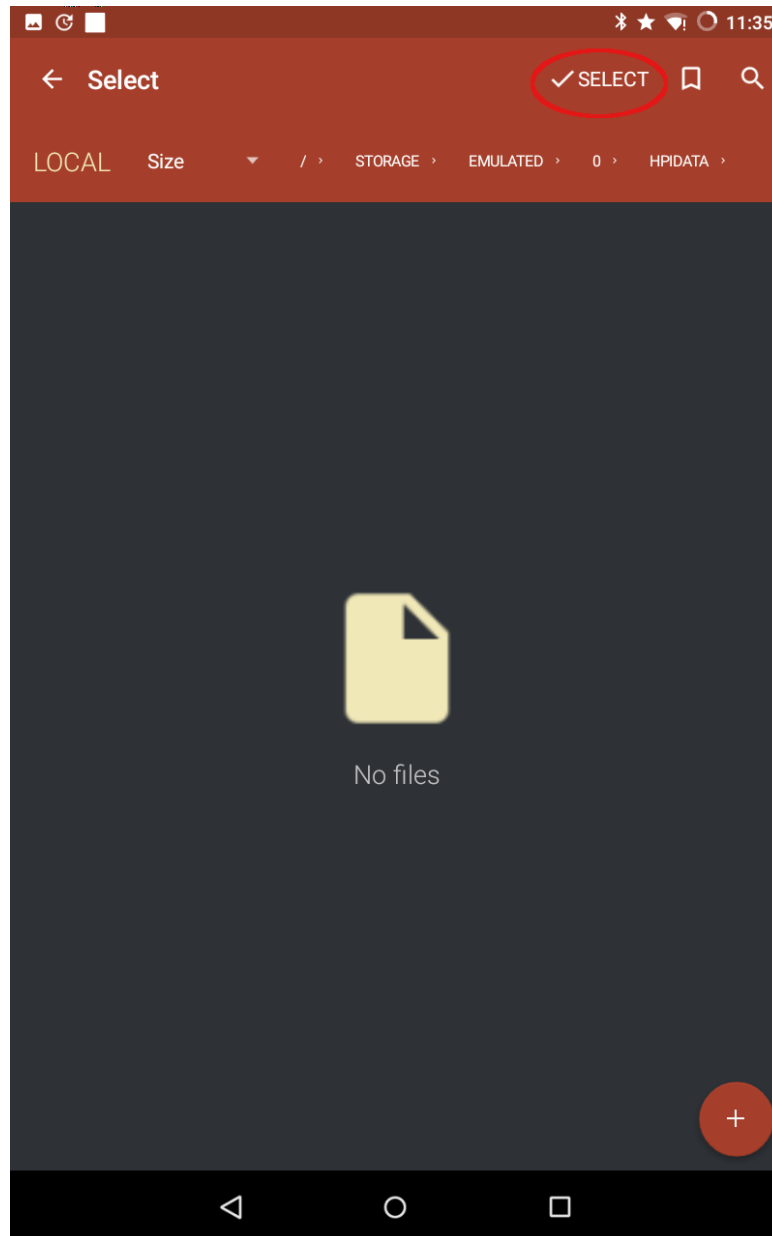


Figure 23: Press the save icon on the top right.

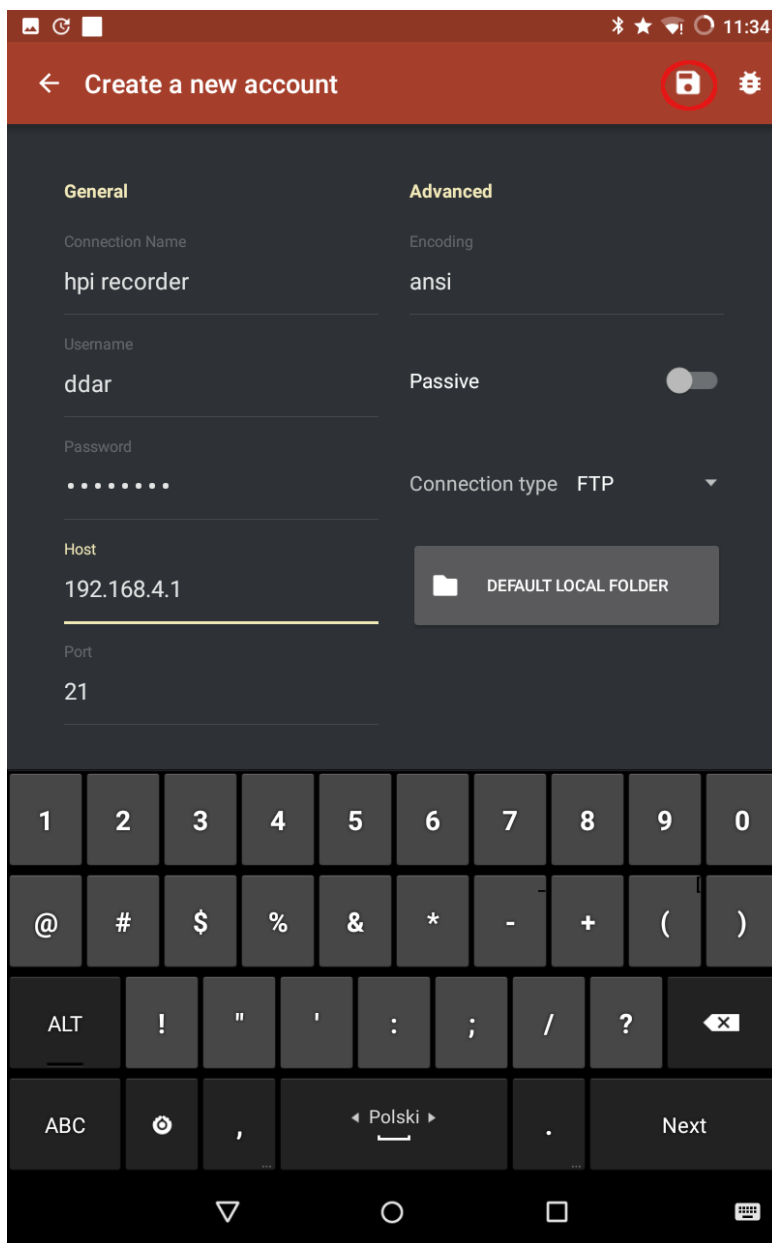


Figure 24: Press the menu icon again. A new connection named 'hpi recorder' should appear in the list. Press it to activate the FTP connection to your instrument..

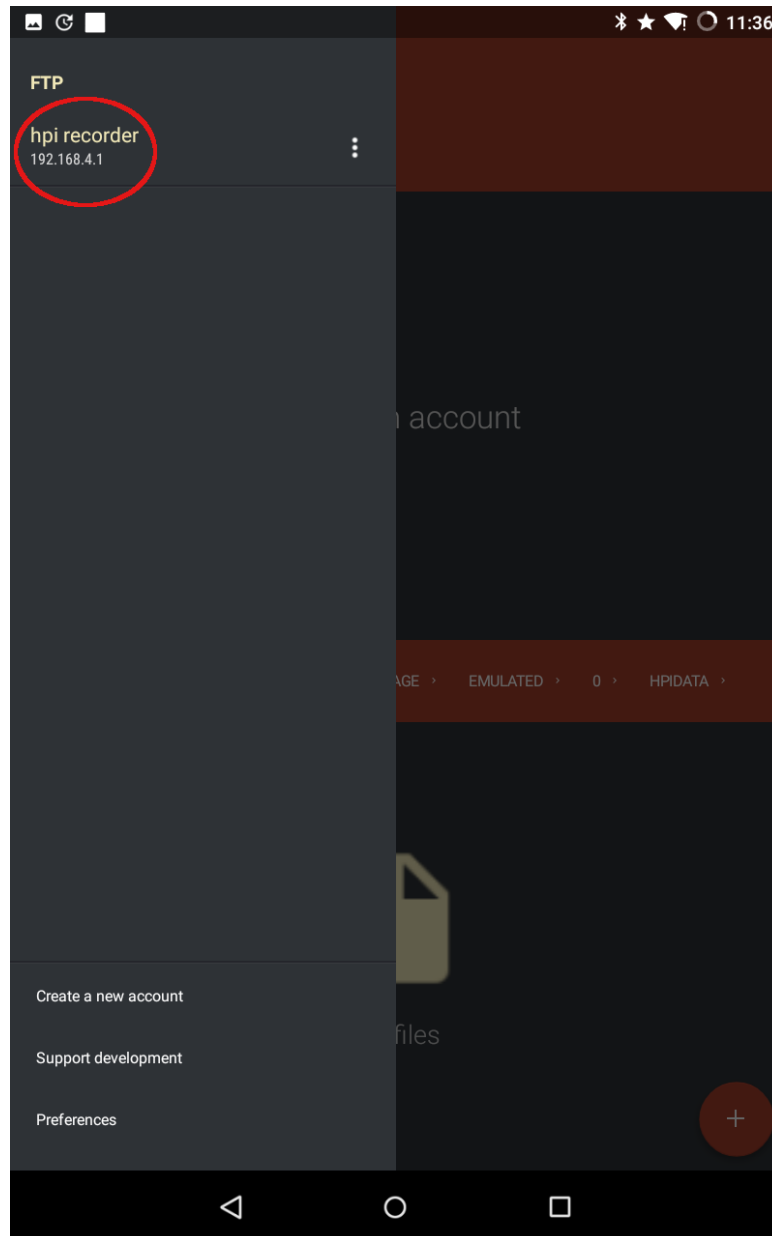


Figure 25: The list of files on the SD card of the instrument should appear in the 'REMOTE' pane of the application.

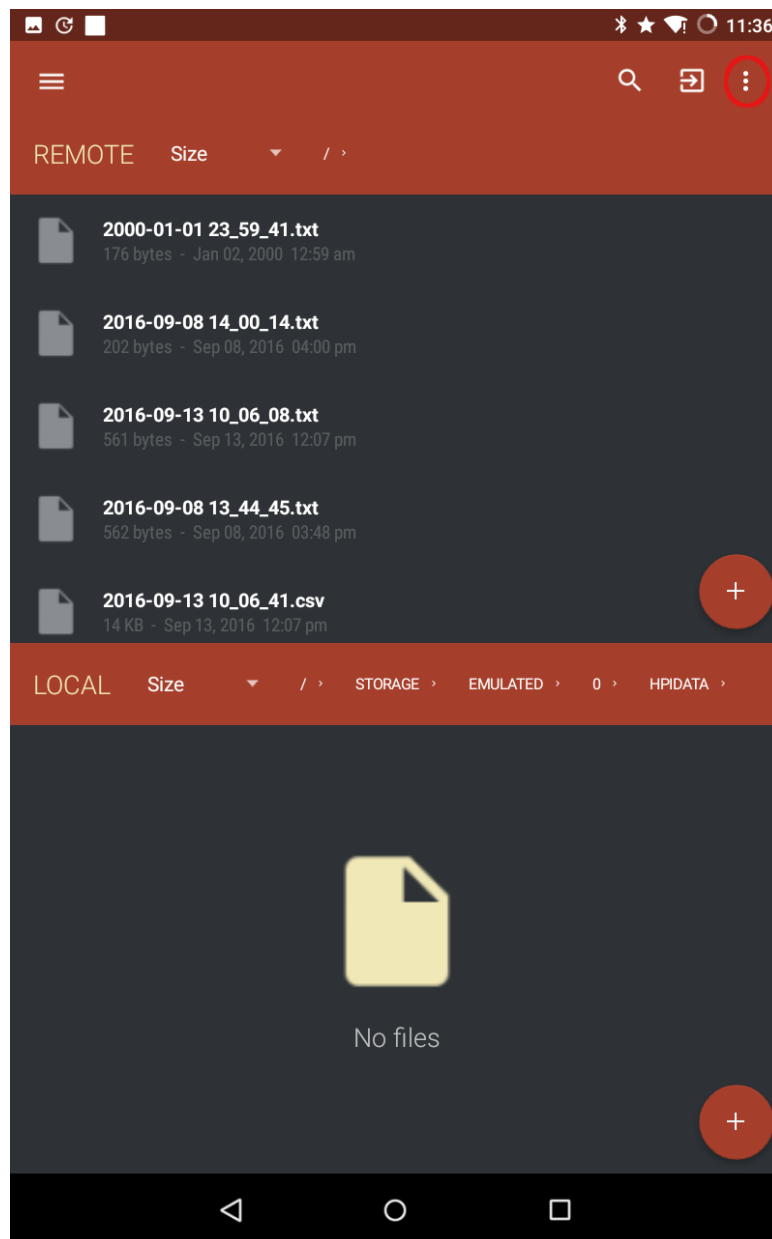


Figure 26: The list of files on the SD card of the instrument should appear in the 'REMOTE' pane of the application. In order to download the files they must be selected first. Press the menu icon at the top right...

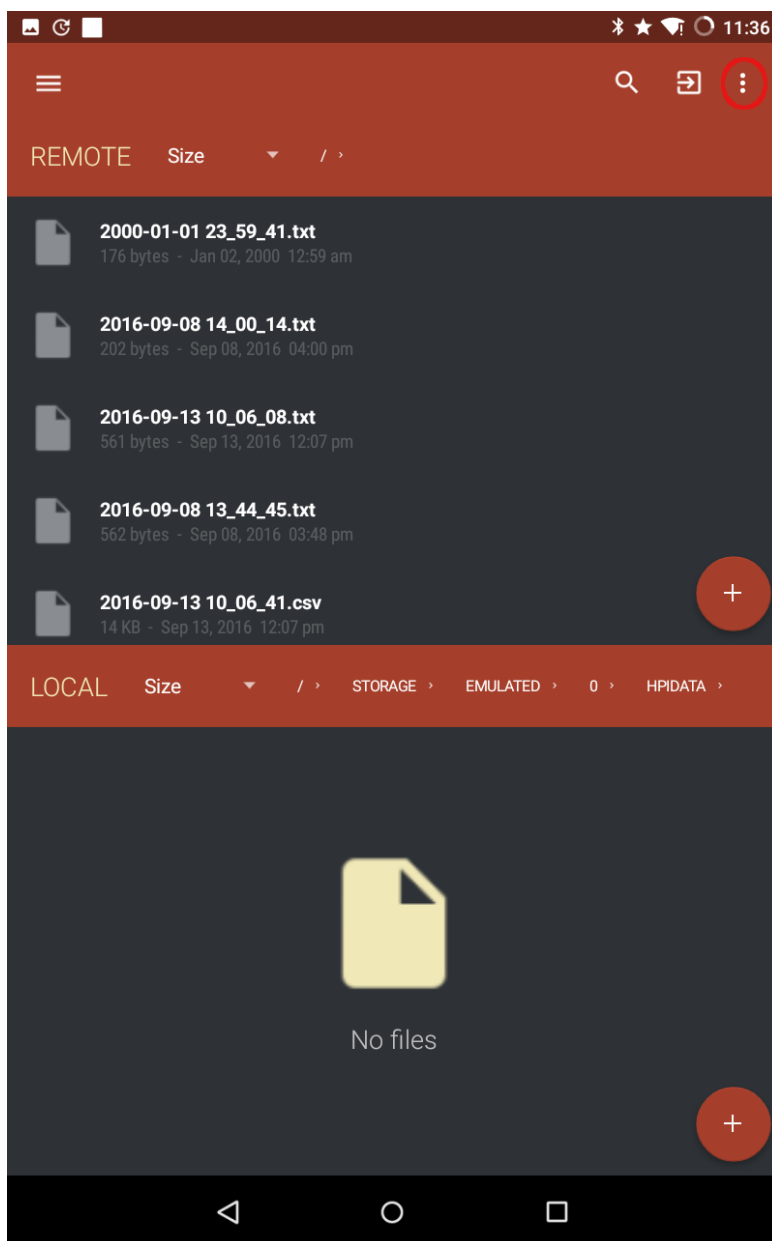


Figure 27: ...and choose 'Select all' from the dropdown menu.

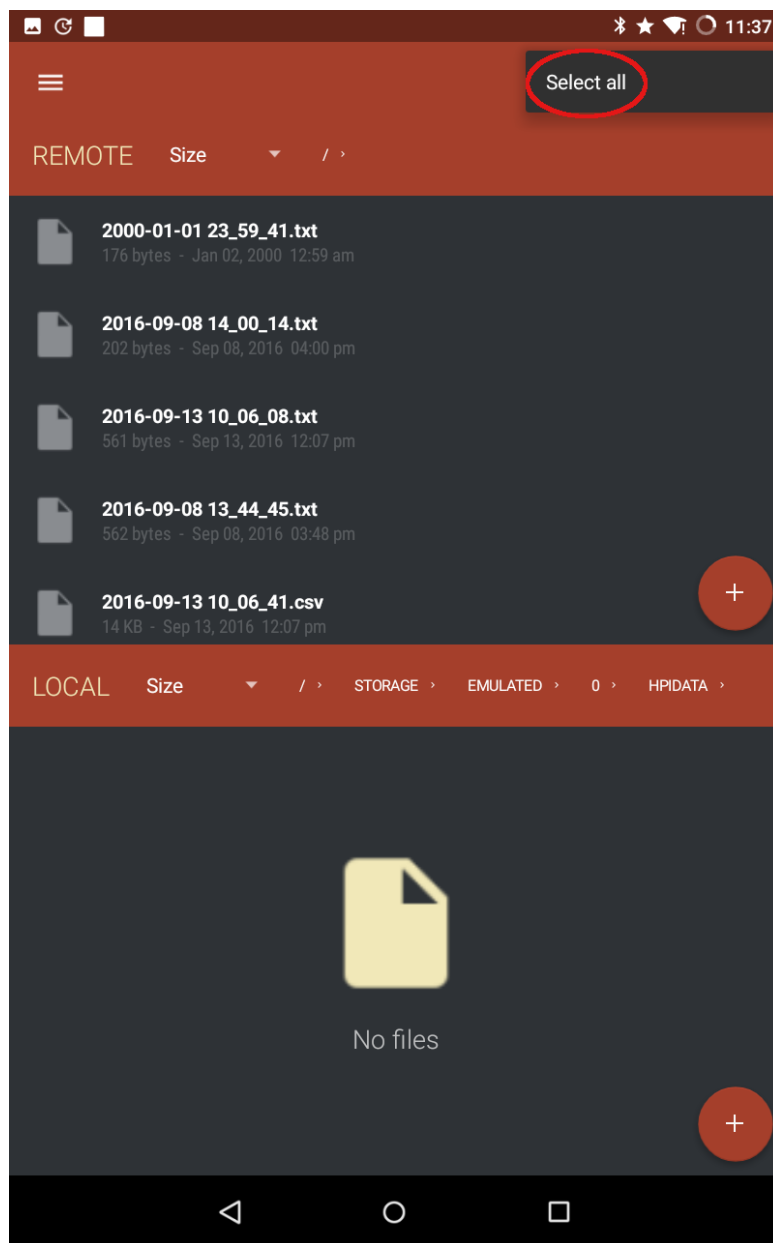


Figure 28: Press the download icon to initiate the download process.

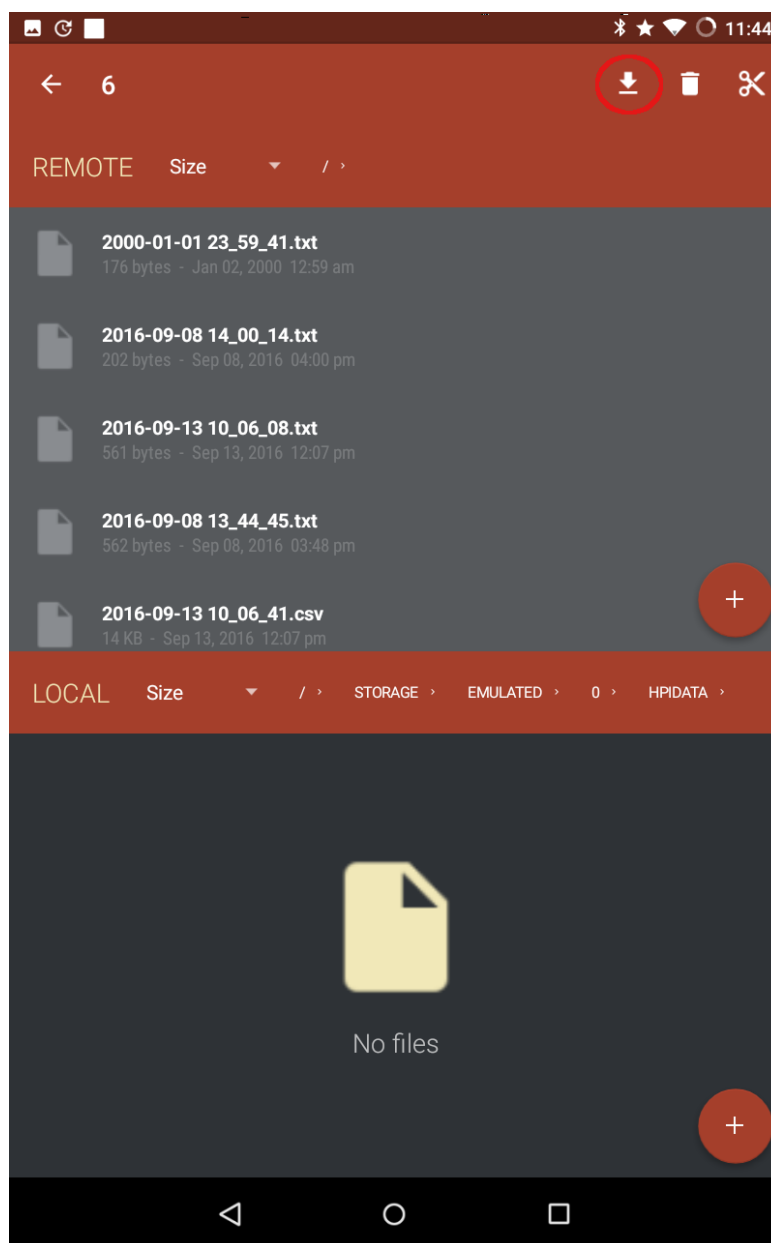


Figure 29: After the process is complete the downloaded files immediately appear in the 'LOCAL' pane of the application. Optionally, press the waste bin icon for deleting the selected files from the SD card in the instrument. We highly recommend to empty your SD card before using your instrument again to avoid confusions.

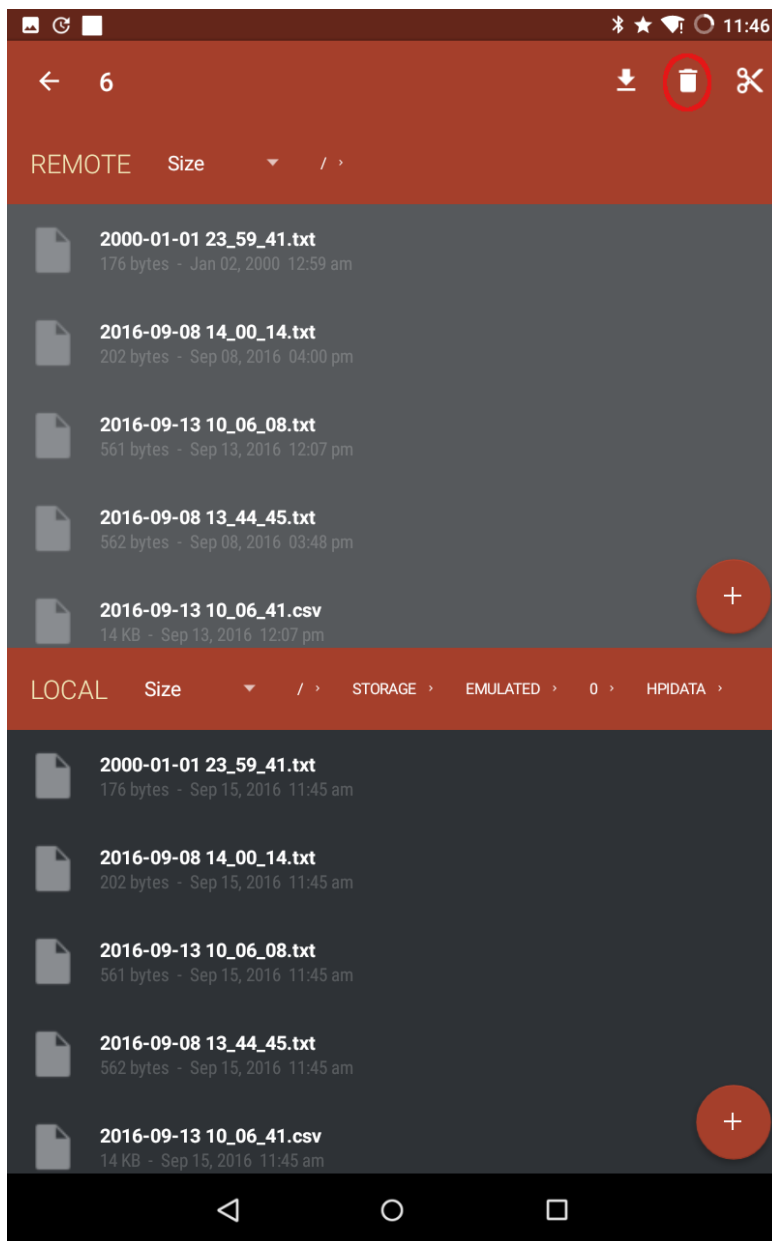
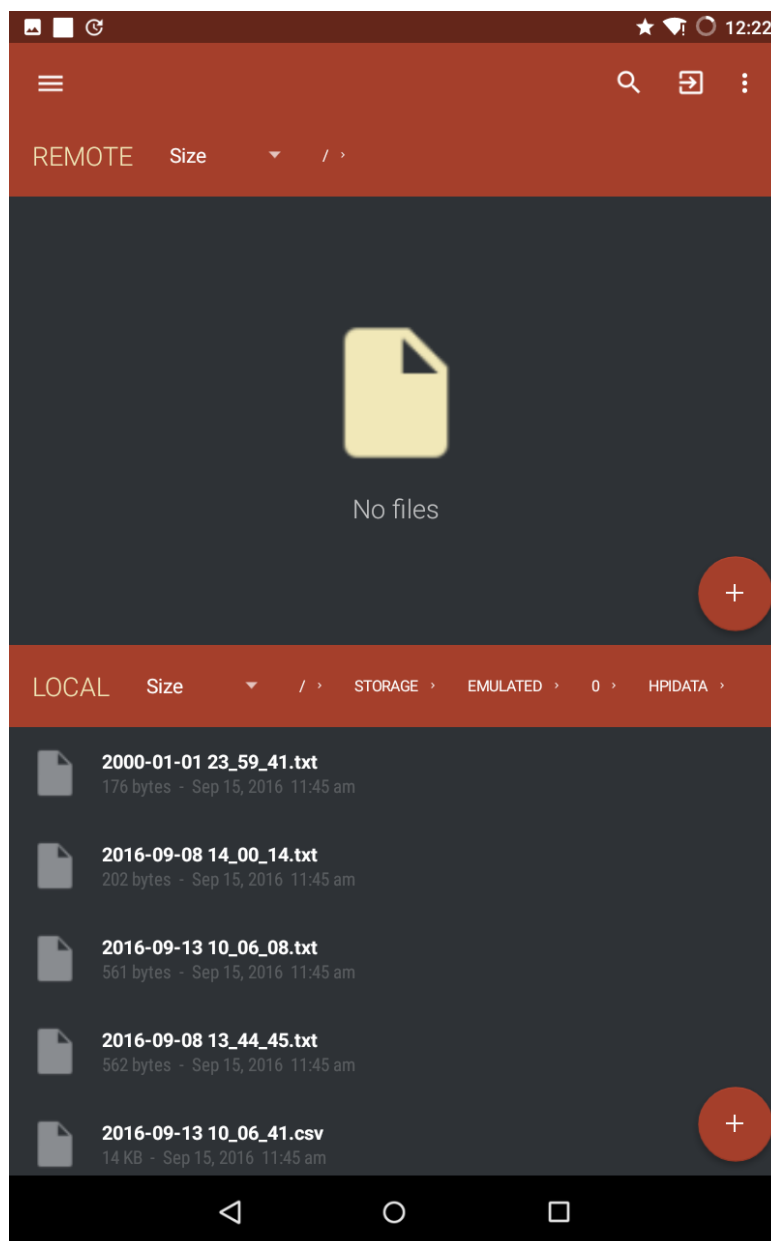


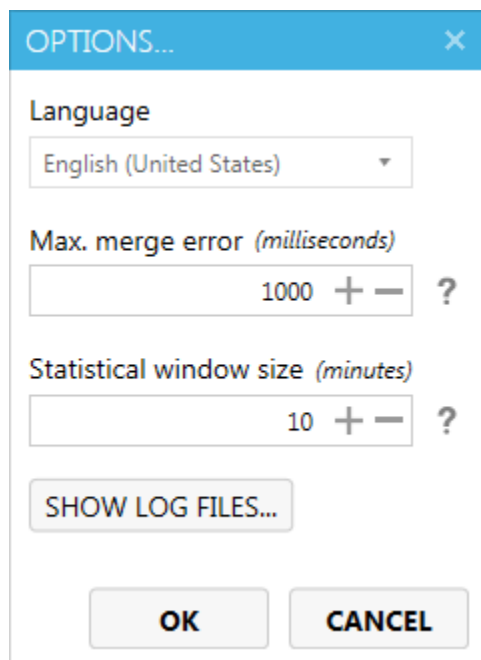
Figure 30: If the waste bin icon was pressed in the previous step then all files from the 'REMOTE' pane of the application disappears, i.e. the SD card in your instrument is empty.



7.4 Analysis using the DynaRoot software

In the rest of this subsection we will assume that data is successfully transferred from the inclinometer(s) and the anemometer to a PC that runs MS Windows and has the DynaRoot software installed. After starting the program, first enter the options menu on the top left corner. See Figure 31 for a screenshot of the menu. This is where you can choose your language (default is English). The maximum merge error specifies how much wind and inclination data may be shifted from one another. Statistical window size specifies the length of the interval, over which statistical parameters of wind velocity and inclination is generated. You only need to specify this information once.

Figure 31: The options menu



After returning to the data window (see Figure 32), you can specify the location of the tree (optional), and the location of the source data. First you need to choose the type of anemometer (this is required because of the different data formats). Currently, there are two types of anemometers included in the software: a cup type mechanical anemometer, or the FAKOPP ultrasonic anemometer. You can enter the name and location of the wind velocity source file and the inclination data folder, or use the browse button next to the data field. Finally, you need to supply the maximum wind velocity, for which you wish to calculate the Safety Factor. After entering all of the information, hit the calculate button.

The evaluation window (see Figure 33) displays the location of the tree, which you can also verify in google map by clicking the *Show in browser* link. The software displays the average wind direction, the starting time and duration of the measurement, and the statistical window length.

The measured wind velocity (converted to wind pressure) and inclination data points are displayed in a diagram, along with the tangential curve fitted on the values. (You will typically see only a small section of the curve that looks linear.) The software calculates the critical wind pressure and its error and the correlation coefficient. The higher the coefficient, the better the data fit the curve (1 means perfect correlation.) **Reject the results if the correlation coefficient is below 0.75!** (In this case you may want to go back to the data window, change the statistical window length, and recalculate the results. Longer statistical windows typically result in better correlation.)

Finally, the Safety Factor (SF) is also calculated. A safety factor above 1.5 represents low risk, and one below 1.0 indicates a serious risk of uprooting. If SF is between 1.0 and 1.5, the risk is moderate.

Warning! the Safety Factor depends on the maximum wind velocity specified! Even low risk trees may be uprooted if winds higher than the specified maximum occur!

Figure 32: The data window

The screenshot shows the 'Data' configuration window of the FAKOPP WIND PRESSURE 0.6.78 software. The window has a blue title bar with a menu icon, the text 'Menu | FAKOPP WIND PRESSURE 0.6.78', and standard window controls. The main content area is titled 'Data' and contains several configuration sections:

- Tree**: Includes a 'Location' text field with the value 'Kosice, Kassa, Slovakia' and a help icon (?).
- Inclinometer**: Includes a 'Folder' dropdown menu showing 'D:\Kassa\doles1' and a folder icon.
- Anemometer**: Includes a 'Device' dropdown menu showing 'Mechanical anemometer' and a help icon (?).
- Evaluation**: Includes a 'Max. wind speed (kilometers per hour)' input field with the value '120' and increment/decrement buttons (+, -) and a help icon (?).
- File**: Includes a file selection field showing 'D:\Kassa\wind_d2016_05_24_17_41_10.csv' and a folder icon.
- UTC offset (hours:minutes)**: Includes a text field with the value '00:00'.

A blue 'calculate' button is located at the bottom center of the window.

Figure 33: The evaluation window

