FAKOPP
Pulling Test Manual

Fakopp Enterprise Bt
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WARNING! Special care needs to be taken at all times. Although the software tries to over-estimate the risks, the computation of the safety factor contains simplifications and even the input data might be disrupted. You are solely responsible for ensuring that the System is appropriate for the use you put it to, and you understand that it is only one part of what is needed to assess the health of trees. Please understand that the System is just one tool to be used, along with your experience and training in assessing these living organisms, that the System cannot be relied upon as the sole source of evaluations, and that all hardware and software is subject to failure or misuse.

Introduction

Urban tree stability is a critical concern for safety. Diseased and unstable trees pose significant risks and liabilities for municipalities, making assessments essential.

The pulling test is the most accepted method for evaluating the safety and stability of a root system. This involves applying a bending load to the trunk via a cable attached to the tree. The method can be used to estimate the uprooting force by measuring the inclination at the bottom of the trunk. In addition, trunk breakage may be estimated by measuring the bending stress using elastometers attached to the trunk. Both methods are described in the manual.

Parts of the system

Force meter

Kaliber 5t force meter

- S-Beam load cell
- Working load limit: 50kN
- Resolution: 1 kgf
- Display Unit
- 2 omega shackles
- Can be connected to the Central Unit or directly to the computer with a USB-Serial cable or Bluetooth

LineScale 3t force meter

- 30 kN working load limit
- Integrated backlit OLED graphic display
- Bluetooth (BLE) or USB cable connection directly to the PC

Central Unit

- Provides power to the components connected
- Transmits data to the PC

Connects to:

- 2 inclinometers
- Kaliber force meter
- Elastometer box
- PC

High precision Inclinometer

- Measuring inclination at the root collar
- Range: +/-30°
- Resolution: 0.001°
- Connects to the Central Unit

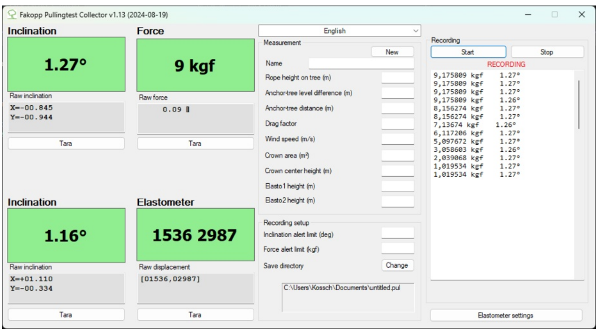
Elastometer

Elastometer data can be used to estimate the elastic limit of the trunk.

- Elastometer sensors measure trunk deformation during the pull
    - Range: 4 mm
    - Resolution: 0.001 mm
- Elastometer box: connects to two elastometer sensors and the Central Unit

Evaluation software

- Collects and saves data
- Evaluation for uprooting and trunk breaking force
- Wind load estimation based on EN1991 standard



Pulling test setup and the necessary devices

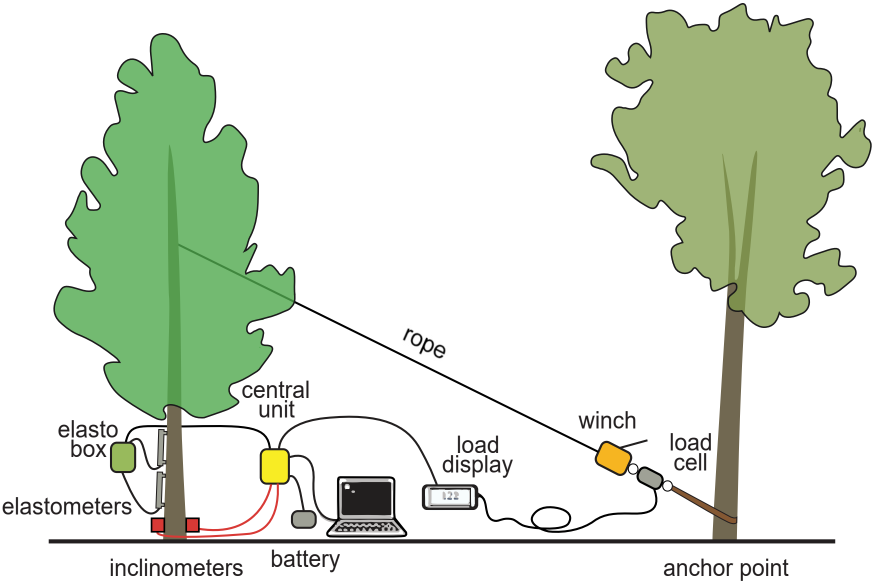


Figure 1: Pulling Test setup for root and trunk evaluation

Devices

- Inclinometers: 2 sensors
- Elastometer box + 2 sensors
- Force meter, Display Unit
- Central Unit

Tools

The following tools are not included in the Pulling Test product. These should be provided by the user.

- Winch
- Cable
- 2 endless round lifting slings (to go around the trees)
- Ladder
- Foldable table (optional)
- Laptop PC with at least Windows 10 operation system and Pulling Test software

Figure 2: Endless round lifting sling

Figure 3: Equipment for measurement. Note: the winch is not part of the product, other types are applicable as well.

Measurement procedure

The pulling test involves affixing a cable to the crown center of the measured tree. A moderate load is then applied while measuring the inclination at the base of the trunk (at the root collar). The induced inclination is kept below 0.25 degrees to ensure that the test does not damage the roots.

Ideally the cable should be attached to the crown center. Make sure to attach the cable on the trunk where the branches are strong enough to withstand the pull. If the crown center cannot support the load, it is common to affix the cable around the mid-height of the tree. This typically requires a ladder or climbing the tree to the appropriate height. A cable of appropriate loading capacity is then attached to the main branch. An endless round lifting sling (see Figure 2) is typically used for this to avoid damaging the tree. The other end of the cable enters a winch, which is affixed to an anchor point. The anchor point can be any object that is safely secured to the ground, most often the bottom of another tree. If another tree is used, care should be taken that the bark is not damaged (typically by using a soft belt such as an endless round lifting sling).

The winch applies tension to the cable. The force meter is connected between the winch and the soft belt at the anchor point or at the other end in the crown. It measures the tensile load. Since the cable is at an angle, the horizontal component of the load is calculated and used for the evaluation. The load is continually measured and sent to a computer for recording and evaluation.

Uprooting safety evaluation

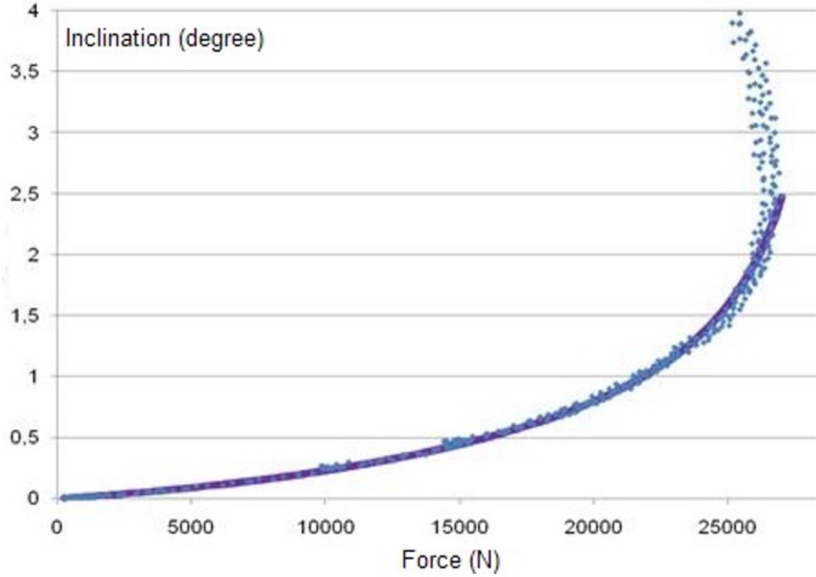


Figure 4: A typical tipping or uprooting curve

Uprooting safety evaluation requires inclination and force data. Inclination is measured at the root collar, while force is measured on the cable. Both sets of data are sent to a PC for recording and evaluation.

General uprooting curve

$$\varphi = \frac{1}{3}\tan\left(\frac{100}{73.85}\frac{F}{F_{max}}\right) + \frac{1}{3}\left(\frac{F}{F_{max}}\right)^2 - \frac{1}{10}\left(\frac{F}{F_{max}}\right)$$

Formula 1: The general uprooting function

Where:

φ [deg]	inclination at the root collar
F [N]	horizontal load
F_{max} *[N]*	maximum horizontal load

By fitting the general uprooting function to the measured load and inclination data, it is possible to estimate F_{max}, the horizontal load required to uproot the tree. From F_{max}, we can calculate the maximum torque (M_{max}) that the tree can withstand without uprooting.

$$M_{max} = F_{max} h$$

Where:

M_{max} *[Nm]*	maximum torque
h [m]	height of the rope on the tree

Uprooting wind velocity

Based on M_{max}, it is possible to calculate the risk of uprooting at a given wind velocity. The torque acting on the tree at a certain wind velocity is calculated using the following equation.

$$M_{wind} = A \frac{\rho}{2} v^2 c_w h_{cr}$$

Where:

M_{wind} [Nm]	torque acting on the tree
A [m^2]	crown surface area
ρ [kg/m^3]	air density
v [m/s]	wind velocity
C_W	aerodynamic drag factor
h_{cr} [m]	the height of the crown center point

The drag factor is a constant that depends on the species. Drag factor values are provided in Appendix B (based on Wessoly and Erb 1998).

By calculating the ratio of M_{wind} (maximum torque from wind) and M_{max} (maximum torque the tree can withstand), we can calculate the Safety Factor (SF). This ratio estimates the safety of the tree.

$$SF = \frac{M_{max}}{M_{wind}}$$

If the safety factor (SF) is above 1.5, the tree is considered safe. An SF below 1 indicates a high risk, while values between 1 and 1.5 suggest a moderate risk of uprooting. When multiple safety factors are assessed for the same tree, use the smallest value.

A pulling test provides useful information on root safety only when the root collar (where the inclinometer is positioned) moves together with the roots themselves. If there is substantial decay at the root collar, the connection between the roots and the collar may be compromised, resulting in potentially misleading safety factor assessments.

Trunk safety evaluation

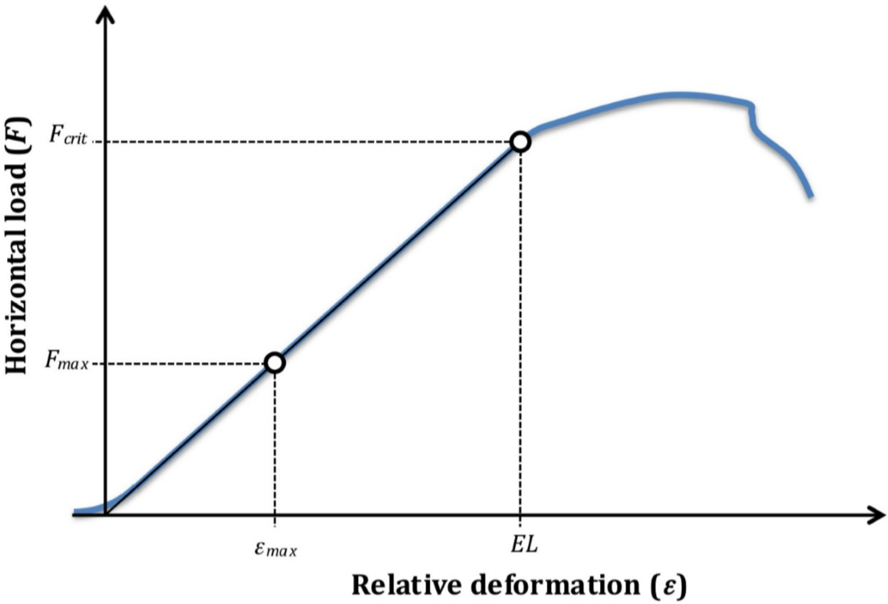
The trunk safety evaluation is similar to the uprooting safety evaluation, but we measure the deformation of the tree trunk instead of its inclination. During the pulling test, the trunk bends, causing compression on the side closest to the cable and elongation on the opposite side. By measuring this deformation on one or both sides, we can estimate the risk of trunk damage.

The testing procedure is similar to uprooting safety determination, but an elastometer is used on the compression or tension side (or both sides) of the trunk instead of an inclinometer. Load and deformation data are collected and analyzed using a computer software.

Trunk safety is determined by the linear elastic limit. When trees bend, their deformation remains linear up to a certain point. Importantly, this deformation is not permanent, and within this range, there is no damage to the trunk. This safe limit of relative deformation is referred to as the linear elastic limit (EL).

The linear elastic limit is a constant that depends on tree species (see the table at Appendix B). Normally, the deformation induced by the pulling test (ε_{max}) stays well below the EL.

After the measurement we have load-deformation data up to the point of F_{max} and ε_{max}. The software fits a linear function to the measured data points. This function is then extrapolated to the



point of EL, which gives us the critical load (F_{crit}).

Once we have the critical load, the Safety Factor calculation is very similar to the one used for uprooting safety.

$$M_{crit} = F_{crit} h$$

M_{crit} *[Nm]*	critical torque
Fcrit [N]	critical horizontal force
h [m]	height of the rope on the tree

The safety factor is the ratio of the critical torque (M_{crit}) and the torque from the wind (M_{wind}).

$$SF = \frac{M_{crit}}{M_{wind}}$$

Here M_{wind} is calculated the same way as described at the uprooting safety calculations, and the meaning of SF is similar as well. If SF is above 1.5, then the tree is safe, a value below 1 signals high risk, and in between there is a moderate risk of trunk failure. If there are several safety factors evaluated for the same tree, accept and use the smallest one.

Setup guide

Cable

Attach the cable to the trunk in the crown of the tree, as close to the crown center as possible. Attach it to the trunk or a strong, centrally located branch. Use a soft belt (Figure 2), in order to avoid damaging the bark.

Choose an anchor point in the appropriate direction from the tree. The distance should be at minimum two times the height of the rope on the tree, however more is better, because we want to maximize the horizontal force component.

Finally set up the winch and cables. Always follow safety instructions!

Force meter

Kaliber 5t force meter

- Connect the load cell between the winch and the soft belt at the anchor point or at the other end in the crown
- Connect the force meter to the external Display Unit
- Connect the Display Unit to the Central Unit

LineScale 3t force meter

- Connect the load cell between the winch and the soft belt at the anchor point or at the other end in the crown

Inclinometers

- Install the mounting plate on the tree trunk, as close to the ground as possible, using the screws
- Avoid placing the inclinometers on decayed areas
- Attach the inclinometer sensor and level it with the bi-axial leveling device
- Connect the inclinometer to the Central Unit
- Optionally, repeat the process for the second inclinometer

Elastometers

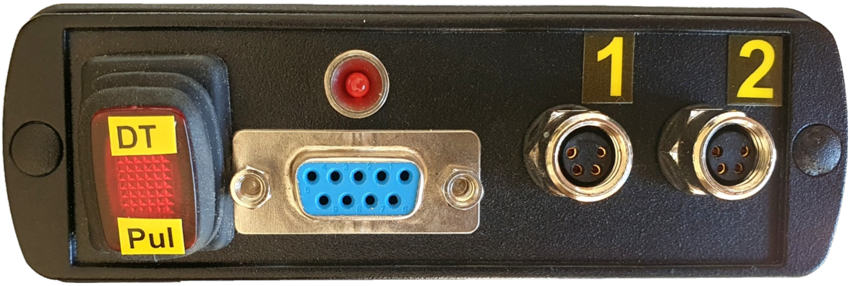
Elastometer mounting

- Screw in the top (2) and bottom (6) screws without releasing the securing jaws
- Loosen the thumb screw (4) and slide up the collar (3) to release the jaws (5)
- At this point the elastometer rod (7) should be able to move freely

Elastometer positioning

- Always place the elastometers facing towards or away from the pulling direction, always in the same line as defined by the cable
- Possible placements:
  - both on compression side
  - both on tension side
  - one on tension and one on the compression side
- Sensor height
  - based on visual indicators try to find a height that is most likely a weak point of the trunk
  - the maximum height is half of the cable height on the tree

Elastometer connections



- Connect the elastometer cables to the dual elastometer unit (the “elasto box”)
- Connect the elasto box the Central Unit
- Make sure that the switch on the elastometer unit is in **Pul** position

Central Unit and starting up

- Connect the battery to the Central Unit
- Turn on the Central Unit
- Kaliber force meter: switch on the unit and press “Tara”. The force should show zero. The cable should not be strained.
- LineScale force meter: Press and hold the red button to turn on the device
- On the Central Unit each device has a corresponding LED near the communication ports which indicates communication by blinking

LM048 Bluetooth unit

You can use LM048 to provide connection between the Central Unit and the PC or between the Kaliber force meter and the PC.

- Make sure that LM048 is switched to the DTE position
- To use LM048 between the computer and Central Unit, connect LM048 to the Central Unit's Bluetooth connector
- To use LM048 between Kaliber force meter and Central Unit, connect LM048 to the force meter's Bluetooth connector

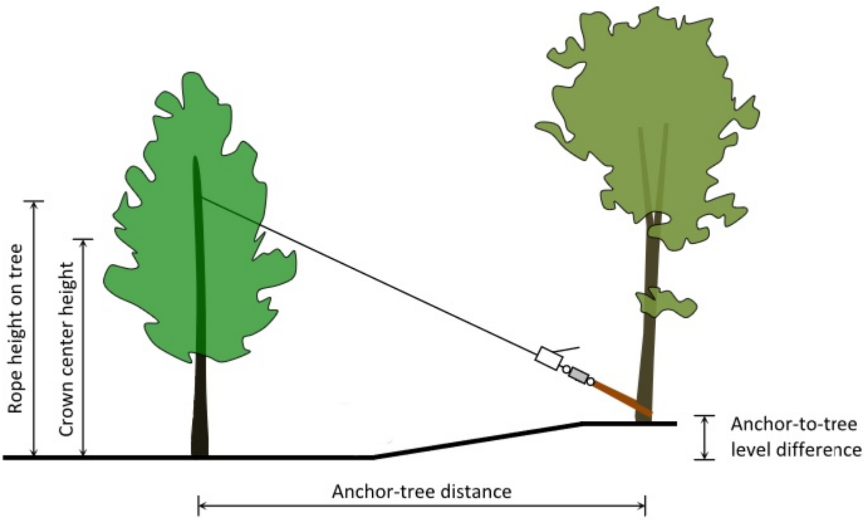
When connected to the LM048 unit, the Kaliber force meter does not get any charge from the Central Unit. Please place four fully charged AA size batteries into the Kaliber force meter Display Unit. Do not forget to remove the batteries after the test. Never use batteries with Kaliber force meter when powering it from the Central Unit.

Measurement & software

- Ensure that the Central Unit is connected to the PC
- Start the PullingCollect application which can be used to collect and record sensor data
- Readout areas in the Collector application show up with red background when there is no data
- These areas turn green once the data is available

- Elastometers produced before 2021: Enter the calibration constant for both elastometers by pressing the "Elastometer settings" button

Measurement parameters



Anchor-to-tree level difference should be positive when the anchor point is above the level of the measured tree as in the picture above.

The drag factor is a species dependent value, these values can be found in Appendix B.

Elastic limit is given in Appendix B in percentage (%). However the software expects the value in *per mille* (‰). You need to multiply the elastic limit value in the table by 10 when entering it into the software.

The wind speed for which the SF is to be calculated, and the crown area (m^2) should also be entered here. Finally, you can choose the name of your file, and change the folder where files are saved. Test parameters may also be entered or changed in the viewer window later.

Don't forget to set inclination and force alerts and "*Tara*" before starting the measurement. The software will give an alarm sound when the measured values pass the limits. The Kaliber force meter has a maximum capacity of 5 tonnes, but the winch is commonly capable of only 1.6 tonnes or 3.2 tonnes. Set the alert limits below the capabilities of your weakest component. For example for the 1.6 tonnes winch, use 1500 kg. Make sure to use the "*Tara*" buttons to set the zero position of the devices.

Preparation in the Collector

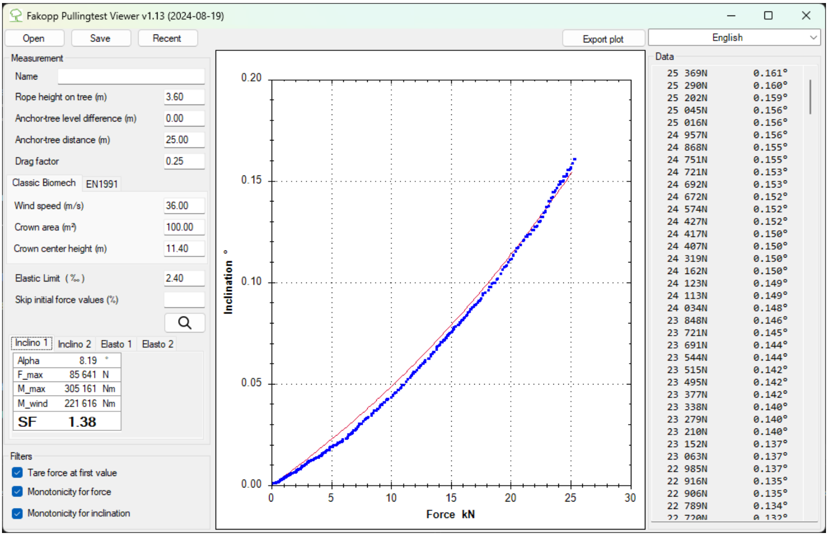
- Fill the parameters.
- Make sure that all connected devices have good readings and their readout areas are green.
- Set Inclination alert limit to 0.2 degrees.
- Set Force alert limit according to your equipment: winch capacity or the capacity of force meter, whichever is the lowest. Once you reach either of these values, the program will warn you by beeping.
- Observing these limits ensure that there is no danger of permanent damage to the tree in most cases. Special care should be taken if the tree is already severely damaged.

Measurement in the Pulling Collector

Make sure that you observe the safety guidelines throughout the test!

- **Tara all devices**
- Click “*Start*”
- Load the cable slowly and evenly using the winch
- Load continuously until reaching 0.2 degrees of inclination or winch capacity or the capacity of force meter, whichever is the lowest
- When reaching one of the limits, start unloading the cable
- Click “*Stop*” to end the measurement after unloading the cable
- Click “*Open in viewer*” to open the measurement in the Viewer

Pulling Viewer



You can toggle between the inclinometer and the two elastometer curves using the tabs underneath the test parameters.

The software automatically fits the generalized uprooting curve (Formula 1) to the inclination data and a linear function to the elastometer data when filters are turned on. Data filtering is required for a proper function fitting.

The software also calculates the statistical parameters and the Safety Factor based on each measurement.

Evaluation

After the test is complete, you can immediately establish whether the tree is safe, based on the calculated Safety Factor if you have provided all the necessary parameters. If SF is above 1.5, the tree is considered to be safe (please note that pulling test takes no notice of the environment. Trees standing in wind tunnels can be dangerous even with higher safety factors).

SF below 1 signals high risk. In between these two values, there is a moderate risk. Separate SF values are calculated for uprooting (inclination) and for each of the elastometers. (Elongation-based SF-values signal the safety of the section of the trunk where each elastometer was mounted.) Remember that the SF is specific to the wind velocity entered. A tree declared safe at a certain wind velocity may be unsafe at higher winds.

Note: pulling test data points typically fit the curve / trend-line very well. In case of a poor fit, the results and the calculated SF should not be trusted. This may typically occur if there are high winds at the time of testing. Reject your results and repeat the test when winds are lower. Do not use the pulling test when there are wind gusts above 25 km/h.

A saved measurement may be opened in the viewer window for later reference or further evaluation. Use the "*Open*" or "*Recent*" buttons to open and view earlier test results.

You can convert a pulling test measurement to be opened in Excel:

- Right click on a measurement file
- "*Show more options*" (only for Windows 11)
- "*Open with Excel*"

Safety guidelines

Significant loads of up to 3.2t may be applied during the pulling test. Pulling test may be dangerous if proper protocol is not observed. Cable failure can cause serious injury. Follow the safety instructions.

Always check the winch for metal burrs! Deburr the winch if necessary. Burrs may even damage the cable.

Check the endless round lifting slings (Figure 2) for damage.

1. The leader of the pulling test team is responsible for the safe execution of the test
2. Only trained personnel is allowed to perform the pulling test
3. The pulling device, including belts, cable and winch must be intact. Inspect the equipment before the test for any damages or burrs
4. All components must be protected from high moisture, frost and extended periods of sunlight exposure
5. The work area should be closed off from the public. Unauthorized personnel must not be allowed to pass under or climb over the cable
6. Pulling test team members need to stay at least 2 m from the cable, except for the winch operator
7. Above 1 kN of load, the winch operator should use the long arm, and stand as far as possible from the cable
8. Be always prepared for equipment failure or tree breakage
9. Stop the pulling test after reaching 0.2 degrees of inclination
10. Follow safety instructions of all of your equipment
11. Pulling test must not be performed in rain or in freezing temperatures

IMPORTANT NOTICE: the pulling apparatus, including the ropes, cable and winch are not part of the Fakopp PullingTest product. These should be sourced by the users. **Fakopp Enterprise Bt. is not responsible for any damage or injury related to the pulling test procedure!**

Important notes

Visual examination is the first step of tree evaluation. The arborist, the examiner should be able to decide if a pulling test can be carried out without any risks. There are cases when pulling is not advised at all while in other cases extra care may be needed.

Avoid performing a Pulling Test:

- If the trunk is split
- If there is a risk of breakage
- If there is a fork in the trunk and the pulling could open it
- If there is windy or rainy weather

If the root collar is in bad condition, please use 2 inclinometers for the test. Both of them should be on the root collar, as close to the ground as it is possible. Do not put them onto damaged areas. If the evaluated safety factors differ more than 50% from each other, it means that the measurement should not be trusted.

Inclinometers should be positioned at 90 degrees to each other on the root collar. If the root collar is elliptical, place one inclinometer along the major axis and the other along the minor axis.

Pull the tree from the direction which seems to be the weakest for the tree.

If pulling is necessary on a tree with fork, always avoid opening the fork. Pull perpendicular to the fork and use a Prusik Minding Pulley.

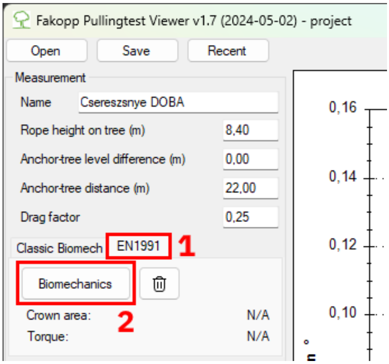
The elastometers have high power consumption. If you use elastometers in cold weather, the battery can run out of power in an hour.

Guide to EN1991 Biomechanics

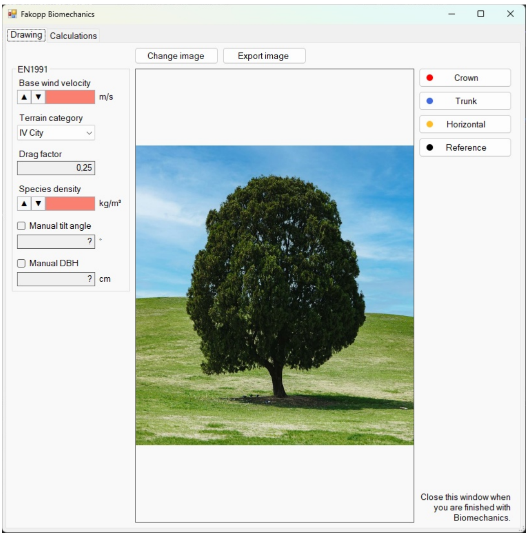
Start biomechanics

To start EN1991 based biomechanics:

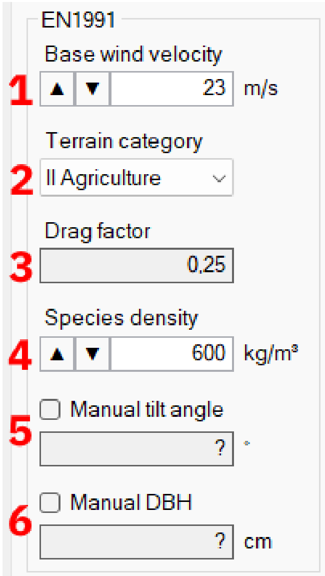
1. Click on the “EN1991” tab
2. Click on the “Biomech” button



- Select an image of the tree being measured. (Make sure that the tree takes up most of the image.)
- The Biomechanics window will show the image:



Set EN1991 parameters



Start by entering the parameters of the model:

1. The base wind velocity: declared in section 4.2 of the EN1991-1-4 standard, and should be given in the National Annex.
2. Terrain category: defined in table 4.1 of section 4.3.2 of the EN1991-1-4 standard, and may be given in the National Annex.
3. The drag factor of the tree (can be specified in the main window, above the EN1991 tab).
4. The density of the tree species.
5. The tilt angle is calculated from the image once all lines are drawn. Alternatively it can be entered by checking the “Manual tilt angle” box. (This is necessary when the tree tilt amount is not clearly visible on the image.)
6. The “Diameter at breast height” (DBH), measured at 1.3 m height (Forest mensuration by Kershaw et al., 2016). It is used to estimate the volume and self-weight torque (see the Calculations page). By default this parameter is calculated from the image once all lines are drawn. Manual entry when DBH is measured on site.

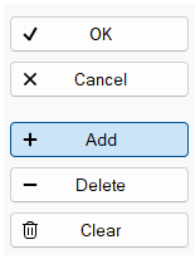
Define tree dimensions

Start drawing on the image by clicking on one of the buttons to the right.

- Crown: draw the outline of the tree crown
- Trunk: draw the outline of the tree trunk
- Horizontal: draw a horizontal line representing the horizontal level of the image at the base of the tree
- Reference: draw a line representing a known length on the image (most commonly the height of the tree)

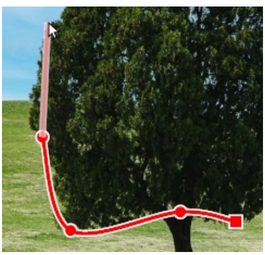
Add points

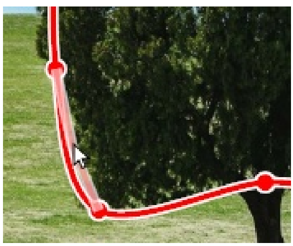
To add points to any line:



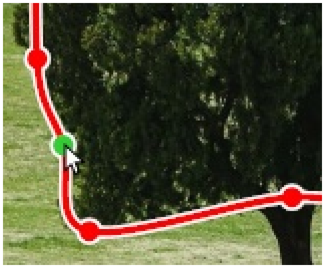
- Ensure the “Add” button is selected
- Click to add a new point to the end of the line
- You can also insert a point when the mouse cursor is close to the line

Points already placed may also be moved by dragging them while the left mouse button is pressed.





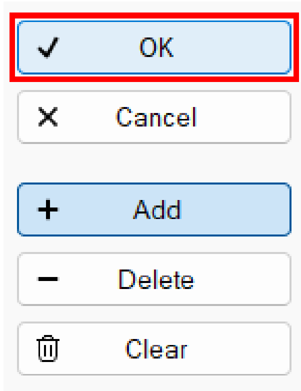
Remove points



To remove a point:

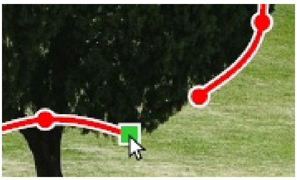
- In “Add” mode: Right click a point
- In “Delete” mode: simply click on a point
- “Clear” button: removes all points

Finish Drawing



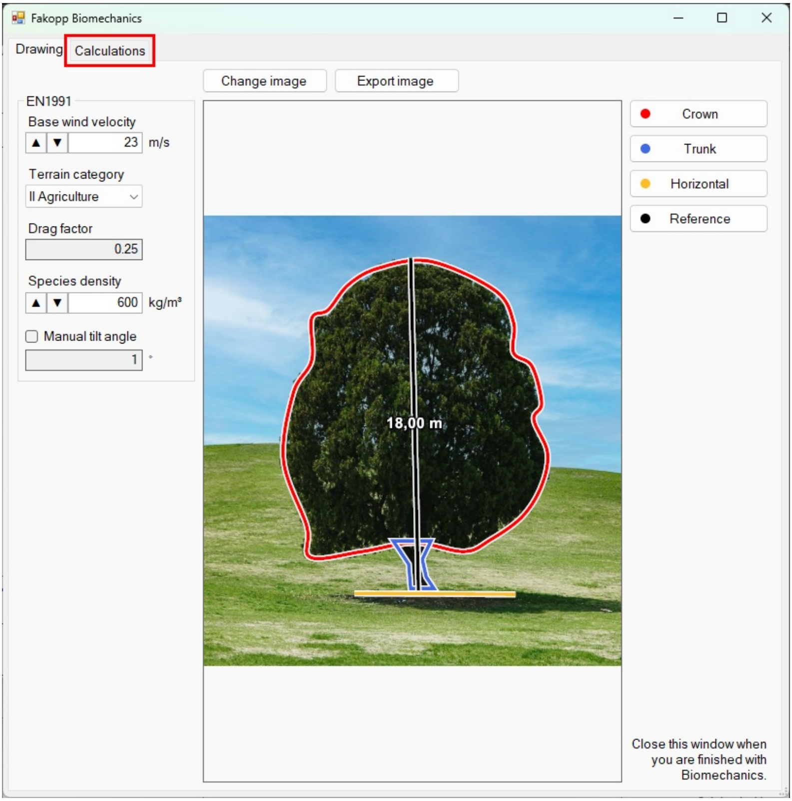
To finish drawing, you can either:

- Click on the OK button
- For the crown and trunk you can left click on the first point placed



Calculate results

- Once you finish drawing, ensure that all parameters and lines are correct.
- If everything looks correct, click the "Calculations" tab to calculate the model. You can always return later to make corrections.

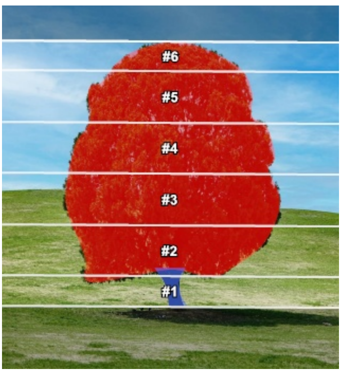


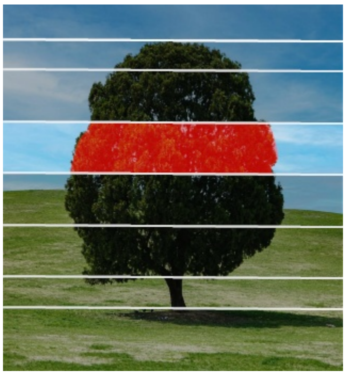
“Parts” table

The model divides the surface facing the wind into a number of “parts” based on the terrain category and tree height:

part	bottom	top	torque
All parts	0.00 m	17.74 m	350 kNm
#6	15.74 m	17.74 m	46 kNm
#5	12.30 m	15.74 m	113 kNm
#4	8.87 m	12.30 m	98 kNm
#3	5.43 m	8.87 m	66 kNm
#2	2.00 m	5.43 m	26 kNm
#1	0.00 m	2.00 m	1 kNm

- Parts are numbered from the ground up, with #1 being the bottom-most part.
- The “All parts” row at the top of the table represents the whole tree.
- The “bottom” and “top” columns show the height of the bottom and top of each part relative to the ground.
- The “torque” column shows the total torque of each part.





“Results” table

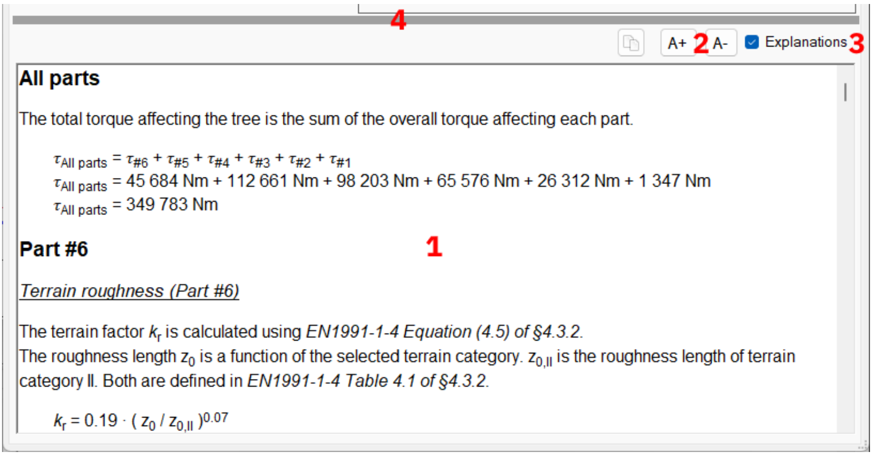
The results table summarizes the model result by displaying the trunk and crown areas as well as the total torque of the whole tree.

Crown area	179.75 m^2
Trunk area	2.94 m^2
Total torque	349 783 Nm

Model calculations

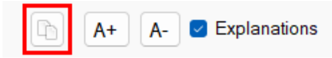
The bottom half of the "Calculations" tab details how the model results were calculated.

1. Formulas and brief explanations.
2. The font sizes may be adjusted using the "A+" and "A-" buttons.
3. The "Explanations" check-box determines whether the formulas may be accompanied by brief explanations.
4. The gray horizontal line is a draggable divider that allows resizing the contents of the window.



Exporting data

1. You can copy the calculations using the copy button above them.

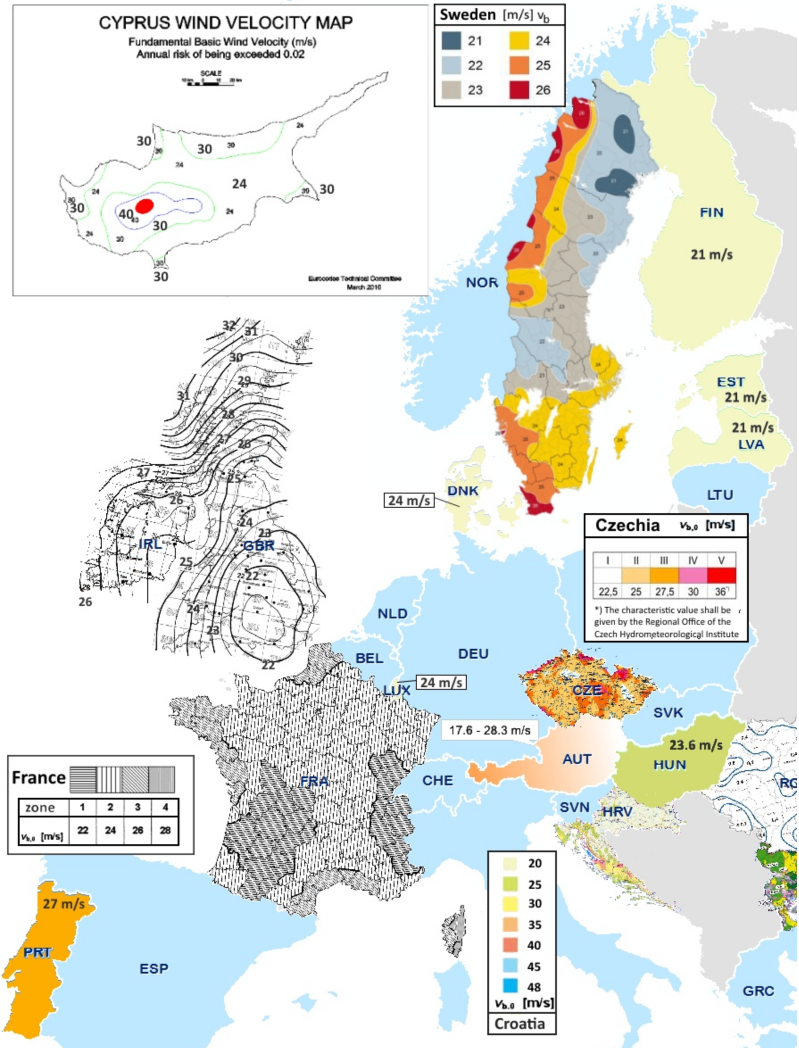


2. The drawn image may be exported using the “Export image” button.

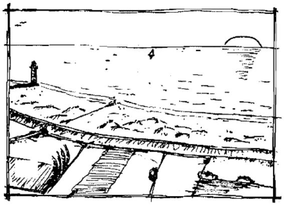
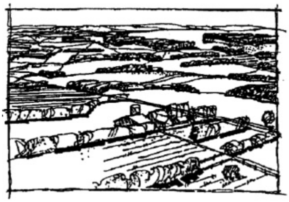
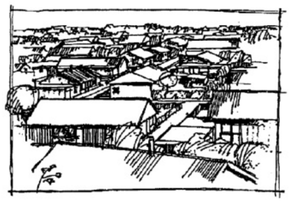
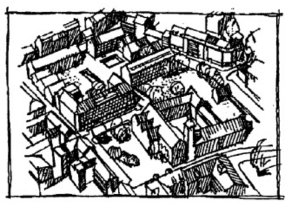
Leaving the Biomechanics editor

1. Simply close the window once done.
2. To store your work, save the project as usual (using the “Save” button in the top-left corner of the main window).

EN1991 Annex A: wind maps



EN1991 Annex B: Terrain categories

0	Sea or coastal area exposed to the open sea	
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	

Appendix A

Load cell – force meter

Kaliber 5t force meter

- Calibrated load cell, 5t capacity
- External Display Unit by Rinstrum
- Serial connection to Central Unit
- Sampling rate: 1 Hz
- Omega shackle
- 4 AA size rechargeable batteries + charger

Inclinometer

- Inclinometer sensor
- Sensor mounting plate
- External battery unit with Bluetooth signal source (Central Unit)
- Bi-axial leveling device
- 9V rechargeable battery + charger
- Measurement range ± 2 degrees (for research purposes ± 5 degrees is available)
- Resolution: 0.001 degree
- Temperature compensated
- Sampling rate: 10 Hz
- Mounted by screws

- Operating voltage and current: 12V, 20 mA
- Weather proof, IP65

Elastometers

The system includes two LVDT elastometers that are mountable on the tree trunk. Signal is sent to the Central Unit via the elastometer box.

- LVDT elastometers
- Dimensions: 30x30x270 mm (closed)
- Span: 250 mm
- Sampling rate: 1 Hz
- Power source: 12V

Note for units manufactured before February 1, 2021 : calibration constants are specified on the calibration sheet and they should be entered in the software upon the first time when the device is used.

Pulling test software

- PC software, runs under Windows 10 or higher
- Simultaneous measurement of force, inclination and deformation
- Evaluates load-inclination and load-deformation curves
- Automatic Safety Factor calculation for uprooting and trunk safety
- Supports two inclinometers and two elastometers simultaneously

Appendix B

Table 1. Stuttgart table of wood strength (Wessolly and Erb 1998).

Species	Modulus of elasticity (N/mm²)	Comparable strength in longitude (N/mm²)	Elastic limit (%)	Proposed Aerodynamic drag factor (c_w)
Abies alba	9500	15	0.16	0.20
Acer pseudoplatanus	8500	25	0.29	0.25
Acer negundo	5600	20	0.36	0.25
Acer campestre	6000	25.5	0.43	0.25
Acer saccharinum	6000	20	0.33	0.25
Acer saccharum	5450	20	0.37	0.25
Aesculus hippocastanum	5250	14	0.26	0.35
Ailanthus altissima	6400	16	0.25	0.15
Betula pendula	7050	22	0.31	0.12
Chamaecyparis lawsonia	7350	20	0.27	0.20
Cedrus deodora	7650	15	0.20	0.20
Fagus sylvatica	8500	22.5	0.26	0.25–0.30
Alnus glutinosa	8000	20	0.25	0.25
Fraxinus excelsior	6250	26	0.42	0.20
Picea abies	9000	21	0.23	0.20
Picea omorika	9000	16	0.18	0.20
Carpinus betulus	8800	16	0.18	0.25
Castanea sativa	6000	25	0.42	0.25
Cercis siliquastrum	0	15	—	0.20
Larix decidua	5035	17	0.32	0.15
Liriodendron tulipifera	5000	17	0.34	0.25
Pinus pinaster	8500	18	0.21	0.20
Pinus sylvestris	5800	17	0.29	0.15
Platanus × hybrid	6250	27	0.43	0.25
Populus × canescens	6050	20	0.33	0.2–0.25
Populus nigra 'Italica'	6800	16	0.24	0.30
Populus nigra	6520	20	0.31	0.2
Populus alba	6400	20	0.31	0.2
Pseudotsuga menziesii	1000	20	0.20	0.20
Pyrus communis	5800	17	0.29	0.30
Quercus robur	6900	28	0.41	0.25
Quercus rubra	7200	20	0.28	0.25
Robinia pseudoacacia	7050	20	0.28	0.15
Robinia monophyla	5200	20	0.38	0.15–0.20
Salix alba	7750	16	0.21	0.20
Salix alba 'Tristis'	7000	16	0.23	0.20
Sequoiadendron gigantum	4550	18	0.40	0.20
Sophora japonica	6450	20	0.31	0.15
Sorbus aria	6000	16	0.27	0.25
Tilia x *hollandica*	4500	17	0.38	0.25
Tilia euchlora	7000	17.5	0.25	0.25
Tilia tomentosa	8350	20	0.24	0.25–0.30
Tilia platyphyllos	8000	20	0.25	0.25
Tilia cordata	8300	20	0.24	0.25
Ulmus glabra	5700	20	0.35	0.25

(Source: Wessolly, L., and M. Erb 1998. Handbuch der Baumstatik und Baumkontrolle. Patzer Verlag, Berlin, Germany.)