Manual for the
PULLING TEST

2021. 03. 09.

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Welcome

Welcome as a new Pulling Test owner. Pulling Test is designed to get information about root and/or trunk conditions of a tree non-destructively.

Manufacturer information

Pulling Test is manufactured by:

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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. Therefore, tree stability and safety assessment are of the utmost importance. In the meantime, it tends to be much neglected in many areas.

At present, the most accepted method for evaluating the safety and stability of tree root system is the pulling test. It involves applying a bending load on the trunk via a cable attached to the tree. The method can be used either to assess the uprooting stability of the tree (by measuring the inclination at the bottom of the trunk, on the root collar), or to establish the risk of trunk breakage (through measuring the bending stresses using elastometers attached to the trunk). Both methods are introduced briefly in the manual.

Parts of the system

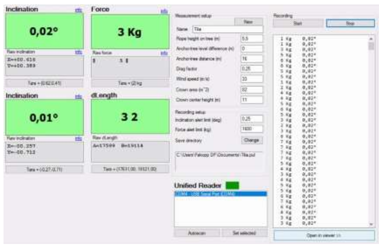
- Force meter and display with 2 shackles – measuring the force and sending the data to the Central Unit or to the computer. Range is 50 kN, resolution is 1 kgf.

- Central Unit – for battery and for data transmission

- High Precision Inclinometer – for measuring inclination of the root collar. It can be used to get information about root safety. Range: +/-2°, resolution: 0,001°, battery operated

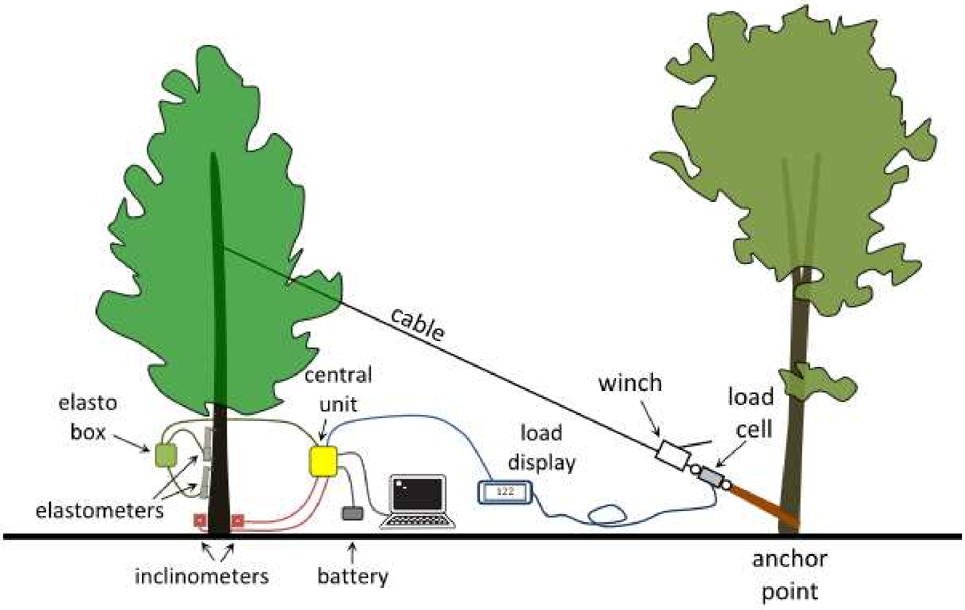
- Elastometer – to measure tiny elongations of the trunk. It can be used to get information about the status of the trunk. Range: 10mm, resolution: 0,001mm
- Elasto Box – 2 elastometers can be connected here. It is responsible for collecting and transmitting data.

- Evaluation software – collects and saves data. Uprooting and/or trunk breaking force is evaluated, while safety can also be assessed if the proper data are entered (crown surface, height,…)



Technical data is in the appendix A.

Pulling test setup and the necessary devices



The setup for Pulling Test for both root and trunk evaluation.

Recommended devices for this setup:

- Force meter, central unit, battery
- 2 inclinometers (use 2 inclinometers if the status of the tree is questionable, more information is in Important remarks about pulling test chapter)
- One elastometer kit with 2 elastometers
- Winch, steel cable, 2 endless round lifting slings (to go around the trees)
- Laptop with Windows operation system and Pulling Test software
- Ladder, foldable table

Remarks:

- Usually winch, cable, endless round lifting slings, laptop, ladder, and table are not included in the Pulling Test kit
- Some parts are heavy, raise and move them carefully
- The pull itself require physical effort

The recommended devices are force meter, central unit, inclinometers and elastometer (in the grey cases), winch (yellow), cables (both steel cable and softer, endless round lifting slings to go around the tree), ladder or (climbing tools), table and laptop (in the black bag)

Technical data of the parts can be found in the appendix A.

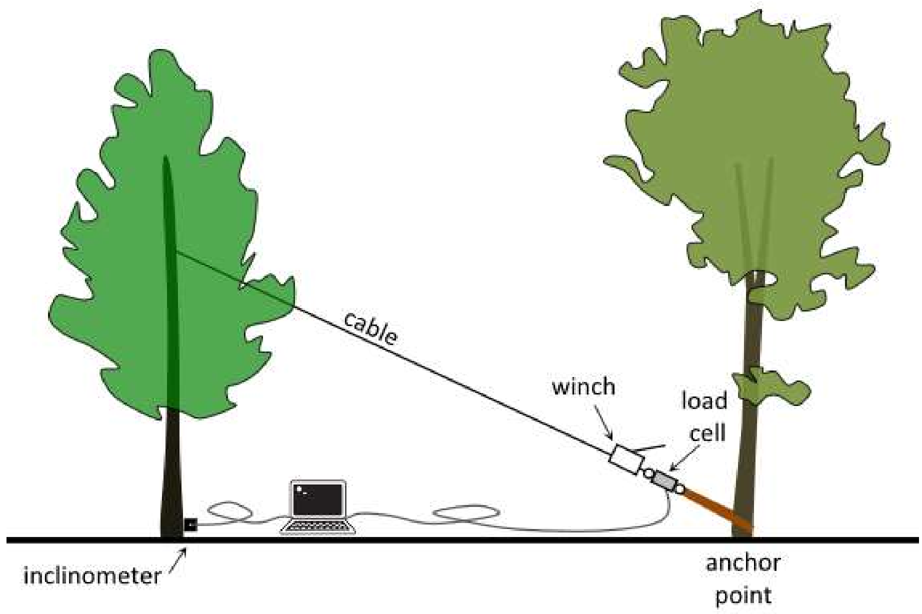
The pulling

The pulling test is based on affixing a cable as close to the crown center, as it is possible, and applying a moderate load, while measuring the inclination at the base of the trunk, at the root collar. The induced inclination is slight (less than 0.25 degrees), to make sure that the test itself does not damage or start uprooting the tree.

The cable is attached to the tree at approximately mid-height in the crown in ideal case. (Do not pull if the branches are too small. It is usual that the pull is under the mid-height.) This typically requires a ladder or climbing the tree to the appropriate height. A steel cable of appropriate loading capacity is attached to the main branch. A soft belt (an endless round lifting sling) 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 a stump or the bottom of another tree. If another tree is used, care should be taken that the bark is not damaged (typically using a soft rope or belt).

The winch applies tension to the cable. A force meter is connected between the winch and the soft belt on the anchor point and 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. A relatively moderate load is applied in order to avoid causing damage to the trunk or uprooting the tree. Load is continually measured and sent to a computer for recording and evaluation.

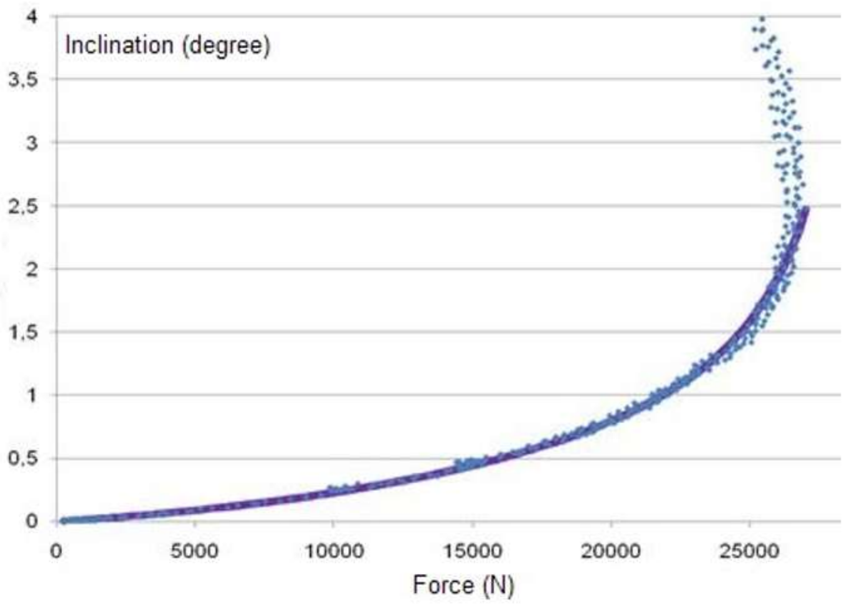
Pulling test for uprooting safety evaluation



Pulling Test setup for trunk evaluation

Uprooting safety evaluation requires inclination, as well as load data. Inclination is measured at the root collar. The inclinometer(s) provides data of sufficient precision and frequency. This data is also sent to the same computer where it is recorded and evaluated simultaneously with the load measurements.

A typical tipping or uprooting curve which was recorded during an uprooting:



The general uprooting function below approximates the curve:

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

Where:	φ	- inclination at the root collar
	F	- the horizontal load
	F_{max}	- the maximum horizontal load.

Fitting the equation to the measured load and inclination data, it is possible to estimate F_{max}, the horizontal load required to uproot the tree, and from F_{max}, we can calculate M_{max}, the maximum torque that the tree can withstand without uprooting:

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

where h is the height at which the rope is attached to the tree.

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:	A	- crown surface area,
	ρ	- air density
	v	- wind velocity
	c_w	- aerodynamic drag factor
	h_{cr}	- the height of the crown center point

The drag factor is a constant that is different for each wood species. The drag factor values are provided in the table in Appendix B (based on Wessoly and Erb 1998).

Comparing M_{wind} to M_{max}, we can calculate the so-called Safety Factor (SF) that indicates a safety parameter, which is based on the maximum torque that a tree can withstand without uprooting and indicates the risk the root system contains:

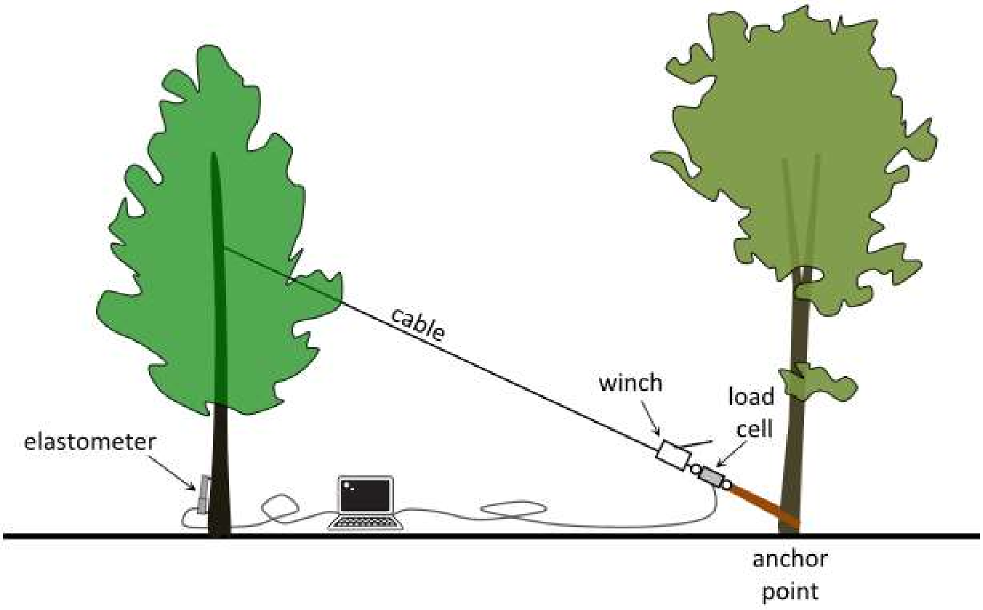
$$SF = \frac{M_{max}}{M_{wind}}$$

If this value is above 1.5, the tree is considered to be safe, while a SF below 1 signals high risk. In-between these two values, there is a moderate risk of uprooting. If there are several safety factors evaluated for the same tree, accept and use the smallest one.

Pulling test gives information about root safety only if the root collar (where the inclinometer is placed) moves together with the root. In case of serious decay in the area of the root collar, the connection between roots and root collar can be reduced and the evaluated safety factor can be misleading.

Pulling test for trunk safety evaluation

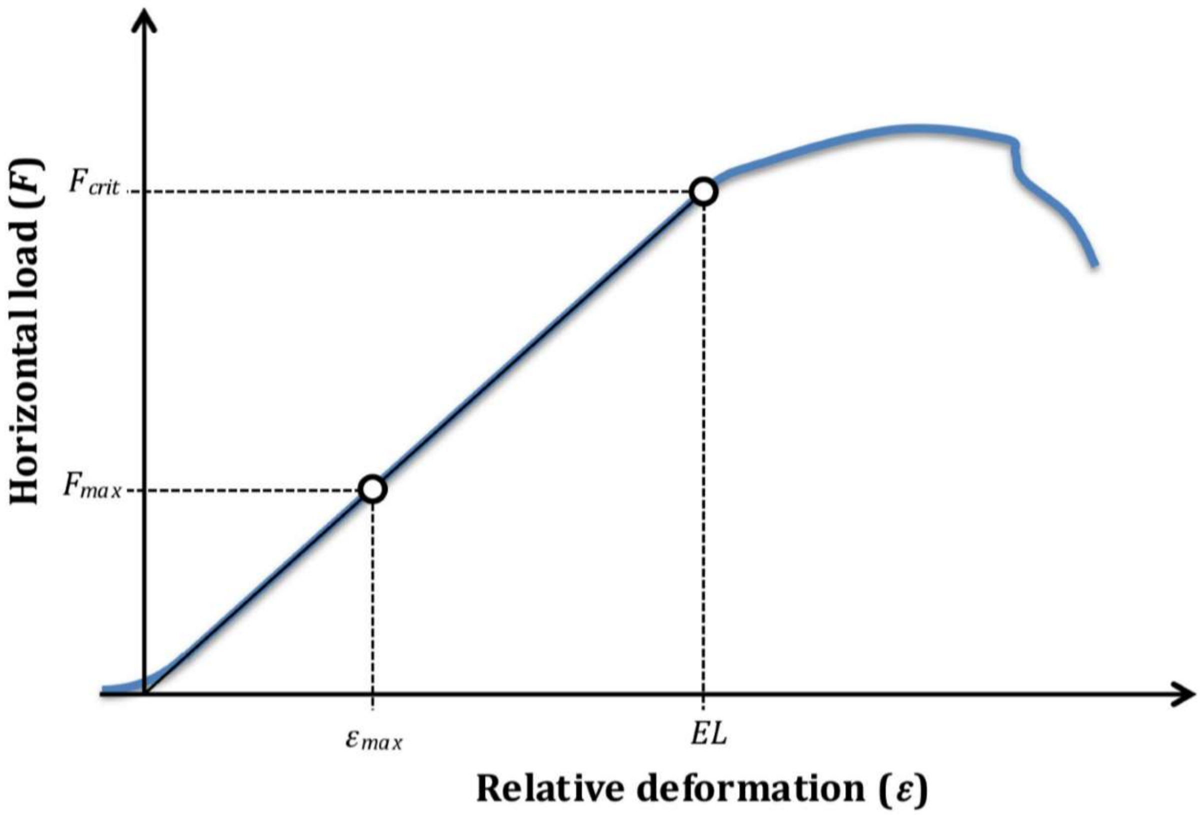
When trees sway in the wind, the trunk of the tree bends. If the wind load is severe, excessive bending may lead to permanent damage, or even the breakage of the tree trunk, even if the roots are strong enough to hold. This is especially true if the trunk is diseased, hollow, or otherwise damaged. The trunk safety test is designed to assess the safety of the tree in this aspect.



Trunk safety evaluation is a technique very similar to uprooting safety evaluation, except, in this case, instead of inclination, we measure the deformation of the tree trunk. During the pulling test, the trunk bends. Bending causes both compaction and elongation in the trunk, on the side nearest to and farthest from the cable, respectively. By measuring the extent of this deformation on either or both sides, it is possible to predict the safety of the tree against trunk damage.

The testing procedure is much the same as in the case of uprooting safety determination, but in this case an elastometer is used on the compression or the tension side (or possibly both sides) of the trunk, instead of an inclinometer. The load and deformation data are collected and analyzed by a computer software.

Trunk safety is determined based on the so-called linear elastic limit. When trees bend, up to a point, their deformation is linear. More importantly, this deformation is not permanent, and, up to this point, there is no damage to the trunk. This safe limit of relative deformation is called the linear elastic limit (EL).



The linear elastic limit is a constant that depends on tree species (see the table at Appendix B). In the usual trunk situation (e.g. the trunk shape is not like a splitted tube), like in the case of the uprooting test, the deformation induced by the pulling test (ε_{max}) stays well below the *EL*. Based on the measured horizontal load and deformation data, it is possible to extrapolate to the critical load (F_{crit}) that would be required to reach the *EL*.

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

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

and

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

where M_{wind} is calculated the same way as described at the uprooting safety calculations, and the meaning of SF is similar as well, i.e. if it is above 1.5, 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.

The FAKOPP pulling test operation guide

Setting up the test

- Attach the cable to the trunk in the crown of the tree, as close to the crown center as possible. In case you are above the top end of the trunk, attach it to a strong, centrally located branch. Use a soft belt, in order to avoid damaging the bark.
- Chose an anchor point in the appropriate direction, about 10 to 15 m from the tree.
- Set up the winch and ropes according to the guide. **<u>Follow the safety instructions!</u>**
- Install the load cell using the hex key. <u>Avoid over-tightening the bolts!</u> Select the optimal position, relatively low to the ground, but not too close to the winch. Connect the force meter to the external display unit and the display unit to the central unit.
- Install the first inclinometer sensor mounting plate on the tree trunk, as close to the ground as possible, by screwing the mounting plate. In case of decay in the tree trunk, the position of the inclinometer may greatly affect the test result. We recommend that you avoid decayed areas when mounting the device. (For more information you can also check Important remarks about pulling test chapter.)
- Attach the inclinometer sensor and level it with the biaxial leveling device.
- Connect the inclinometer to the Central unit.
- Optionally, repeat the process for the other inclinometer.
- Mount the first elastometer on the tree trunk. Try to select the weakest height (based on visual inspection.) Screw in the top (2) and bottom (6) screws without releasing the securing jaws. Then loosen the thumb screw (4) and slide up the collar (3) to release the jaws (5) and thus allow the elastometer to move freely.

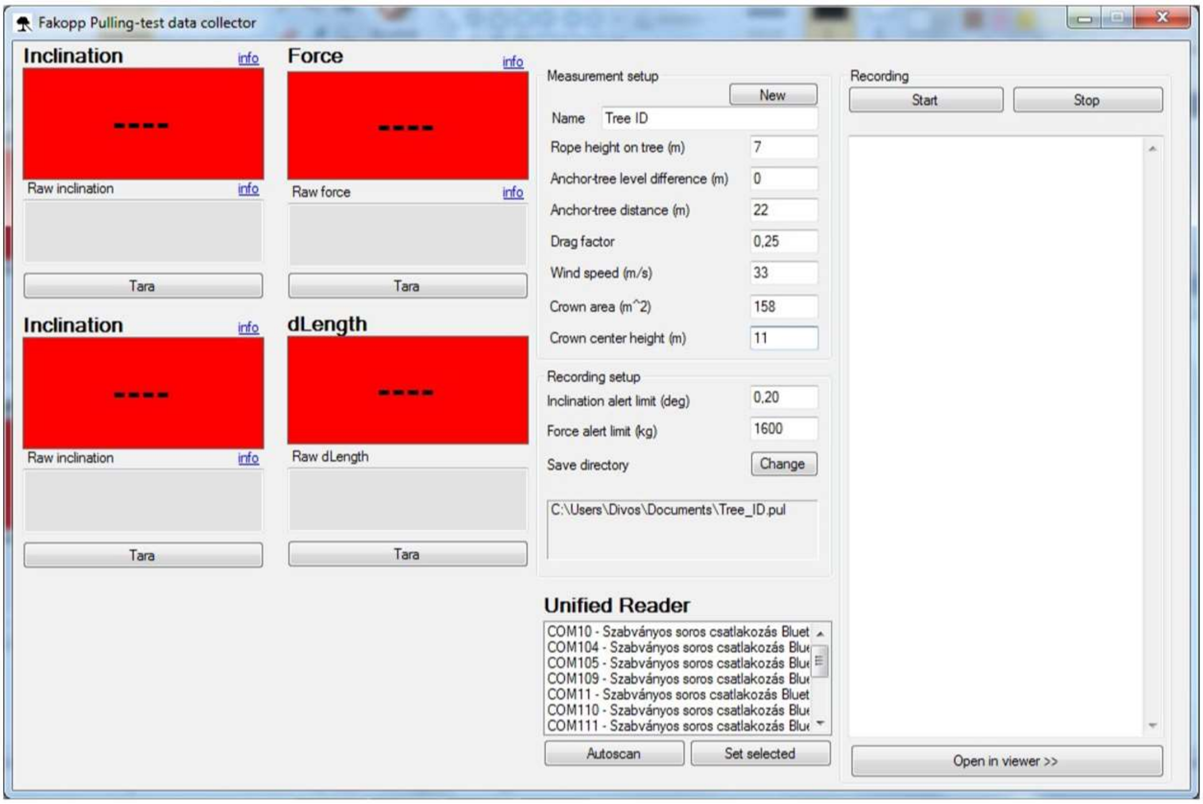
- Optionally, repeat the process for the other elastometer (in another questionable height).
- <u>Note</u>: you may mount the elastometers either on the tension or on the compression side of the trunk (i.e. the side closest to or farthest from the anchor point, respectively), or even on alternate sides, but **do not mount them in any other position** around the trunk!
- Connect the elastometer cables to the dual elastometer unit (the "elasto box") and connect the unit to the central unit. (If you have an elastometer unit which can be

used for dynamic and pulling test too, be sure that the switch on the elastometer unit is in “Pul” position. See below)

- Connect the battery to the Central unit. It can provide electricity for the other electric parts.
- Switch on the units and press “Tara” on the force meter’s display unit. The measured force should turn to zero. The cable should be loose.
- If the computer is too far from the Central Unit or the Central Unit is too far from the force meter, you can use a Bluetooth module instead of cables.
  - If you would like to use the Bluetooth unit between the computer and Central Unit, connect the Bluetooth Unit to the Central Unit’s Bluetooth connector. Switch the Bluetooth Unit to DTE position. (DTE is for transmitting data, DCE is for programing the unit.)
  - If you would like to use the Bluetooth unit between the force meter and Central Unit, connect the Bluetooth Unit to the force meter’s Bluetooth connector. Switch the Bluetooth Unit to DTE position. (DTE is for transmitting data, DCE is for programing the unit.)
    - In this case the force meter does not get any charge from the Central Unit. Please place four well-charged AA size batteries into the force meter. Please do not forget to remove the batteries after the test or if you connect the force meter to the Central Unit via cable.
- Start the Fakopp Pulling Test software.

Test procedure

- **Setting the COM port**: the LEDs are blinking, the power supply via the USB port is enough. Once connected, your computer assigns a communication (COM) port to the Pulling test central unit. The software can automatically find the proper port, or it can be done manually.
- **Setting up the software**: start the program PullingCollect.exe. This will open the setup window:

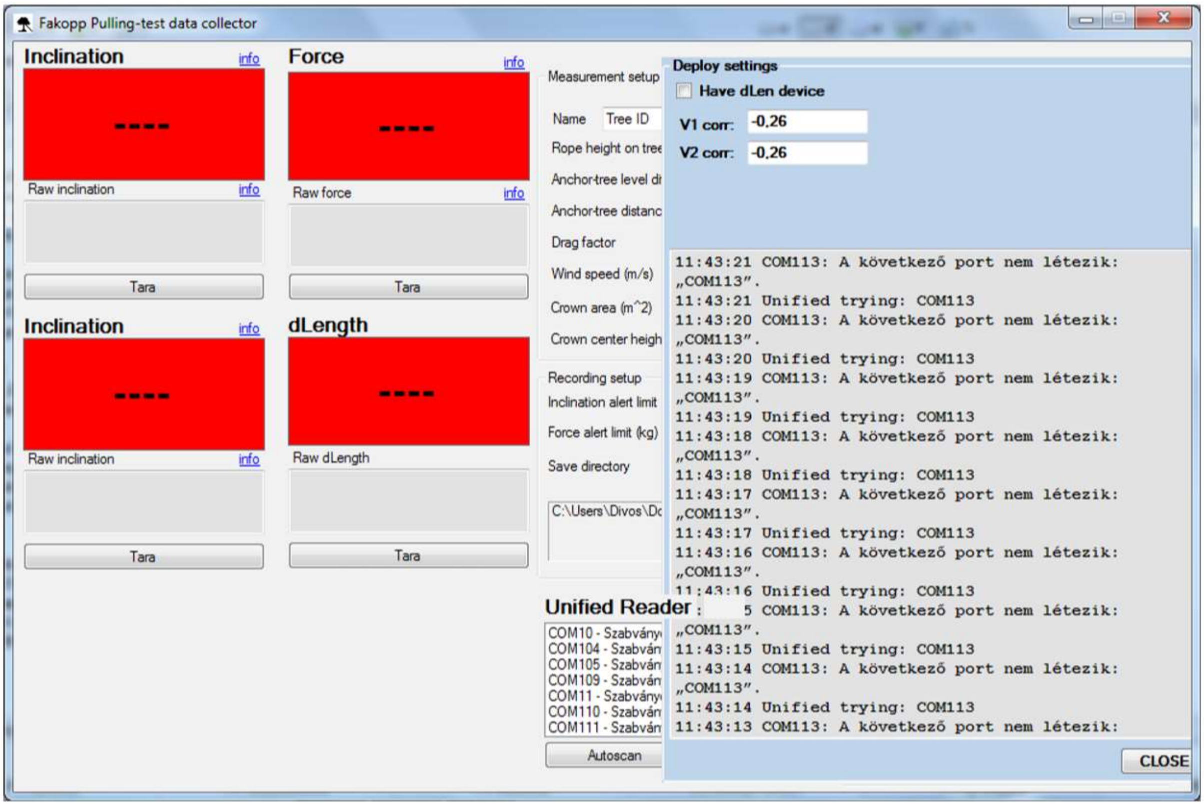


First, you need to find the communication port for the central unit. This can be done automatically by clicking the Autoscan button. The central unit needs to be connected to the computer for this to work. The Autoscan process may take a long time if it has to scan through many ports, i.e. if there had been many devices connected to it in the past. In this case, it may be a good idea to locate the ports manually from Device Manager then choose the appropriate port from the list and click 'Set selected'.

Once the central unit has been found and readings are being received, the red LEDs near the communication ports starts blinking (rapidly), the red readout areas in the software turn green, and you can see the values.

You can tare each value by hitting the Tara button.

If you are connecting the elastometer for the first time, or after repairs or recalibration, you need to enter the calibration constant for both elastometers. There is a hidden button in your setup window, right below the 'Open in viewer »' button. Click this area to access the settings:



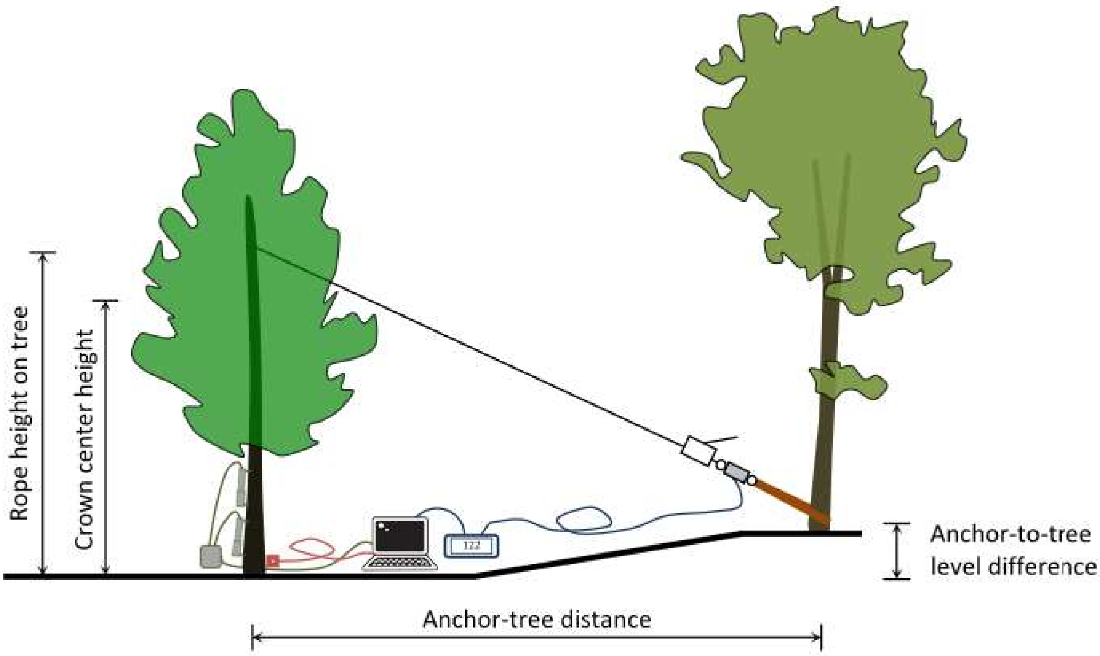
Enter the calibration constant for elastometer #1 and #2 (V1 corr and V2 corr, respectively.) The constants are indicated in the calibration sheet. Make sure that you do not mix up the two elastometers. Direction dependance (prolongation and compression) is included in the latest software, so there is no need to set the sign (negative or positive) of the calibration constant.

The program remembers the calibration constant, so you don't need to re-enter it for each measurement, except when using a new elastometer or after repairs and recalibration.

Elastometers purchased after 2021 February 1st and onwards already has their calibration constant set in the hardware, no further setting is required. Latest Pulling Test software is required for this, which is found on fakopp.com.

Finally, you need to enter the test parameters. This includes the following parameters:

- Rope height on tree
- Crown center height
- Anchor-tree distance
- Anchor-to-tree level difference
- Drag factor
- Wind speed
- Crown area



(The geometric parameters are needed for the program to calculate the angle of the pulling cable, in order to calculate the horizontal component of the pulling force and the torque. The crown center height is needed for the wind load calculation.)

Test parameters also include the aerodynamic drag factor and the elastic limit. These are characteristic to the given tree species. Drag factor and Elastic limit values are listed in the table in Appendix B for many species. (NOTE: the elastic limit is given in %, but is to be entered as ‰, i.e. you need to multiply the elastic limit value in the table by 10.)

The wind speed for which the SF is to be calculated, and the estimated crown area (m2) should also be entered here. (Note that you can evaluate the crown area in ArborSonic software from a photo.) 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.

Please note: when entering values, use decimal point. The decimal comma does not work in the program.

Don't forget to set inclination and force alerts (the force meter is capable till 5 t, but the wincher is capable for only 1.6 t or 3.2 t it is recommended to set the limit to 1600 kg.)

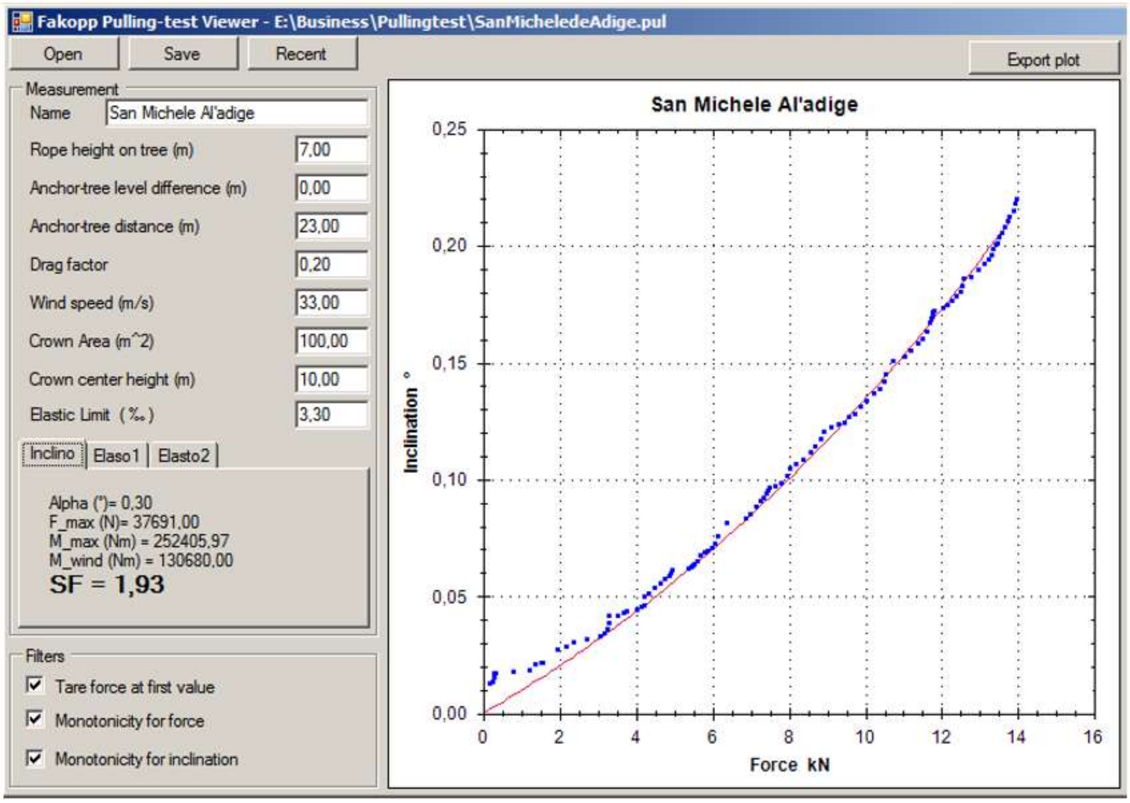
Testing

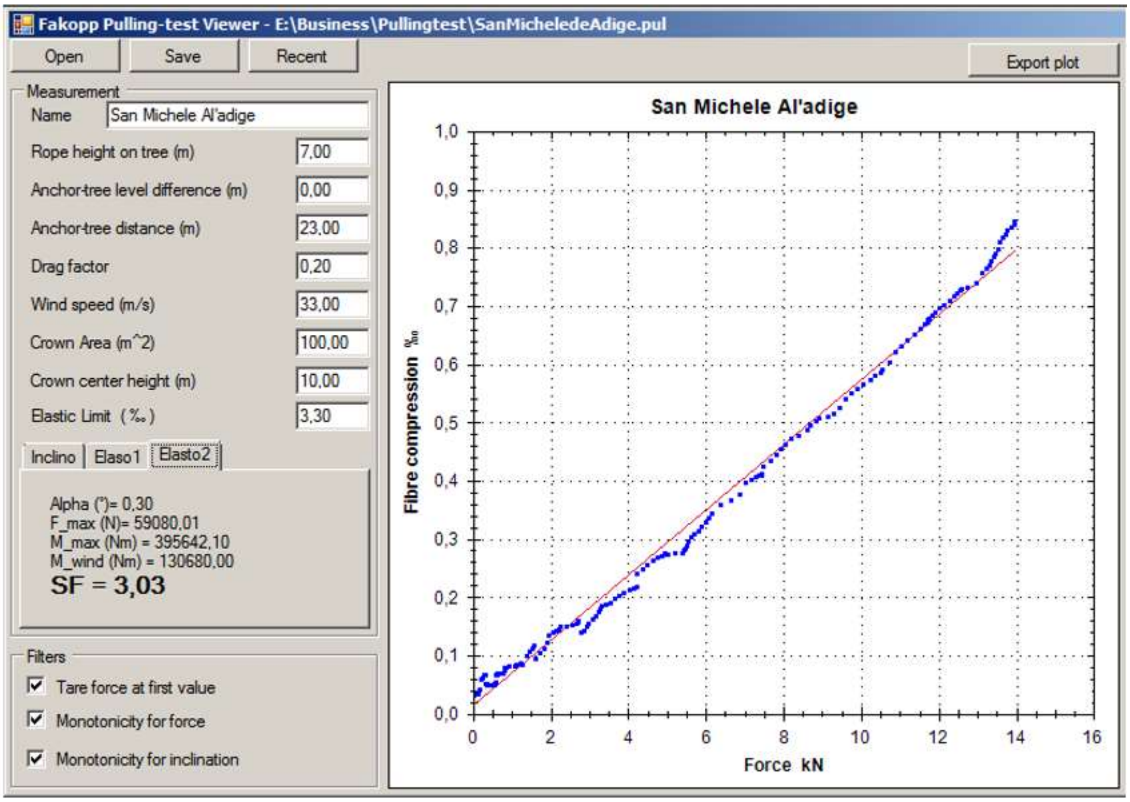
Once everything is set up, you may start your test. Load the cable slowly and evenly using the winch. Load continuously until reaching 0.2 degrees of inclination or winch capacity or the capacity of force meter, whichever comes first. You can set up the maximum inclination and load capacity in the setup window.

Once you reach either of these values, the program will warn you by beeping. Observing these limits will *almost* certainly ensure that there is no danger of trunk damage either. In case of a severely decayed trunk, you should also monitor the fibre compression so that it does not approach the elastic limit. (Note: the software does not warn you for excessive deformation, you should monitor this yourself!)

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

After the test you can switch to the viewer.





You can toggle between the inclinometer and the two elastometer curves using the tabs underneath the test parameters. The program automatically fits the appropriate tangential function and straight trendlines on the inclination and deformation data, if tare at first value, monotonicity for force and monotonicity for inclination are checked in. These filters are need for the fitting. (Raw data includes the loops as the wincher pulled and pulled again.)

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

Upon completion of the test, click save to terminate data collection. Your data will be saved in a format that allows viewing in the viewer window later.

After the test is complete, turn off the sensors, release the winch, and remove the sensors and ropes. Make sure that you observe the safety guidelines!

Data evaluation

After the test is complete, you can immediately establish whether the tree is safe, based on the calculated Safety Factor. 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 / trendline 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 implement pulling test when there are wind gusts faster than 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. After opening a measurement file (or after the conclusion of the test), you can also export the results in comma-delimited (CVS) format, for opening it in a spreadsheet program (e.g. MS 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. Rope failure can cause serious injury, so follow the safety instructions:

Check the wincher for metal burrs. Deburr the wincher if it is needed. Burrs may even cut the tight steel cable, causing an extremely dangerous situation.
Check the endless round lifting slings (the softer cables to go around the trees).

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 devices 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 persons 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. Check your escape route from the test site to a safe place. In case of any unexpected event like tree breakage or cable failure, immediately run for cover.
9. Stop the pulling test after reaching 0.2 degree of inclination.
10. Follow all of the safety instructions listed in the winch's operation manual.
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 furnished by a third party vendor. **Fakopp Enterprise Bt. is not responsible for any damage or injury related to the pulling test procedure!**

Important remarks about pulling test

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.

Please consider pulling

- if the trunk has a tube-like shape and the trunk is split
- if the root collar is decayed
- if there is a fork in the trunk and the pulling could open it
- if the weather is windy or rainy.

If the root collar is in questionable 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 bark areas. If the evaluated safety factors differ more than 50% from each other it refers to questionable conditions. It might be a problem happened during setup, measurement or with the tree.

Inclinometers are recommended to put onto the root collar 90 degree to each other. If the root collar is elliptic, place one inclinometer to the major axis and the other to the minor axis.

Pull the tree from the riskiest direction. It is recommended to pull from 2 perpendicular directions.

If pulling is necessary on a tree with fork, pull perpendicular to the forks and use prusik minding pulley to avoid opening it.

The elastometer unit is relatively high powered. If you use elastometer in cold weather the battery can run out power in one hour.

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 is only one part of what is needed to assess the health of trees and similar green assets. 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.

Comparison of pulling and dynamic tests

	Pulling test	**Dynamic evaluation**
Anchor point	Necessary	No
Tools	Ropes and pulling device, force meter	Anemometer
Load	Static	Realistic
Time of the test	1-3 hours / tree	3 hours / 10 trees
Crown area, drag factor	Necessary	No
Weather condition	Wind speed < 25 km/h	Wind speed > 25 km/h
Result	Safety factor	Safety factor

APPENDIX A -
Technical specifications

Cable and winch

The system contains a 20-meter (65 feet) length of high capacity metal cable with a 1.6 metric ton (optionally 3.2 ton) manually operated winch. The winch has a ratchet mechanism that multiplies the force of the operator to generate sufficient tension on the cable. The cable and the winch are equipped with safety hooks and two soft belts for fitting it around the tree trunk and the anchor point.

Load cell – 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)
- Biaxial 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 a common interface box. Elastometer parameters:

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

Note: calibration constants are indicated in the calibration sheet and they should to be entered to the software upon the first time when the device is used. Units manufactured after February1, 2021 calibration coefficient is hardware set, NO user action is necessary.

The FAKOPP Pulling test software
- PC software, runs under Windows7 or higher,
- Simultaneous load, inclination and extension measurements,
- Load-inclination and load-deformation curves generated
- Automatic Safety Factor calculation for uprooting and trunk safety
- Can handle two inclinometers and two elastometers simultaneously
- Drag Factor and Elastic Limit entered manually
- Other data like crown area, heights,… are also should be entered manually
- Continuous software development
- Latest version is available to download from fakopp.com

APPENDIX B -
Stuttgart table of wood strength (Wessolly and Erb 1998)

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

Species	Modulus of elasticity (N/mm^2)	Comparable strength in longitude (N/mm^2)	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.)