Appendix A: SIM (Statics Integrated Method) Tree Pulling Test Methodology

Overview of the pulling test methodology

The advanced tree stability assessments were carried out using the Statics Integrated Methodology (SIM), which is also known as the elasto-inclino method or a "tree pulling test". The purpose of the assessments and subsequent data analysis was to determine the tree's resistance to uprooting and/or stem breakage (as specified in the report) in the event of a significant wind event, defined as a wind speed of 22.5 m/s (81 km/h) and wind gust speeds of 28.5 m/s, or approximately 102.5 km/h.

The SIM methodology is described in detail, below.

In order to assess the uprooting stability and resistance to stem breakage of the subject tree, a "Statics Integrated Methodology" pulling test was employed. This type of test is carried out by attaching a steel or high-strength polyethylene cable to a sling that has been installed in the crown of the subject tree. The other end of the cable is attached to a winch that is anchored to a nearby tree or ground anchor in the appropriate pulling direction. The winch is attached to a dynamometer that measures the force in the cable with a resolution of 0.01 kN. The winch is used to simulate wind forces acting on the crown of the tree. The root plate reactions are measured with a device called an inclinometer. This device measures deflections in the angle of the root plate with a precision of 1/1000th of a degree.

The Statics Integrated Methodology, developed in Germany, closely adheres to the structural engineering principles that apply to measuring wind forces on buildings. The specifications of German DIN Norm 1055-4 and the Eurocode EN 1 (EN 1991-1-4) were modified for this special application to facilitate a more precise load analysis of different crown forms in trees. This means that the methods of determining wind loads, as proposed by Davenport et al. (1965), were modified to reflect the results of research into ground winds and the responses of trees to natural winds (Forschungsprojekt of the Sonderforschungsbereich 230 at the University of Stuttgart 1985-1990).

During a pulling test, the tree's reactions are measured with the precision instruments while the winch is used to simulate forces equivalent to wind acting on the crown at relatively low wind speeds. These data, combined with digital photographs of the tree, are then entered into a computer program that extrapolates how the tree would react if it were subjected to greater wind velocities. The analysis is always undertaken on the side of caution in order to accommodate for the well documented variability in the material properties of different tree species and in site conditions. The 'generalized tipping curve' according to Wessolly (1996) and the findings from more recent research (Detter and Rust 2013) provide a basis to extrapolate from miniscule root plate rotation to the minimum expected strength of the root-soil-matrix.

The method integrates loading, material properties and the geometry of the subject tree, thus providing both specific information about the weak area being examined and also an overview of the entire tree stability situation. When measuring for the root stability or uprooting safety of a tree, the inclinometer can measure the relevant reactions of the anchoring system of the subject tree. The data obtained during these tests, combined with tree specific data such as height, diameter, crown size, etc., are evaluated by the Arbostat evaluation software. The software produces graphic output to display the calculated safety margins against uprooting and a numerical expression of the safety factors.

Simulated wind force application

A cable is attached to the stem of the subject tree using a wide protective eye sling. A 'Tirfor T532' winch is used to tension the cable. In situations where there is no appropriate anchor available, a self-contained 'earth anchor' or heavily-loaded dump truck can be used. The simulated wind load applied by the pulling system is measured by an electronic dynamometer that is attached to the winch.

When determining the loading direction for a pulling test, one must consider the predominant wind direction, the orientation of the largest effective wind surface and the position of compromised areas of the tree with respect to the maximum wind loading (e.g. root damage, cavities, leans). A substitute wind load can be applied in either a positive or negative direction, resulting in comparable inverse measurements.

Geometry of the cross section (for stem breakage resistance assessment)

Trees optimize themselves to resist prevailing wind loads and leans by building reaction wood. The growth of this reaction wood can create a more oval shape in the affected cross section that is often pronounced enough to be measured with a calliper. Conifers build reaction wood in areas where the fibres are compressed while deciduous trees build reaction wood in areas where the fibres are under tension. The cross - sectional modulus (or resistive bending moment) describes the geometry of the load bearing capacity. The bending moment is proportional to the cube of the diameter of the tree. This means that a tree with twice the stem diameter of its neighbour will have 8 times more resistance to bending as compared to its thinner neighbour. Because of this fact, a tree can afford to lose wood near the neutral bending axis (near the centre of the tree) and still maintain a high margin of safety. The most important fibres that resist bending are located at the margins of the cross-section. When decay removes wood from the centre of the tree, the bending moment is not greatly affected until the residual wall becomes very thin.

Rooting stability

Root plate stability is assessed from extrapolations based on the typical tipping behaviour of trees (Coutts, 1983; Wessolly, 1996). In a first step, the values measured during the pulling test are extrapolated along an exponential function. Thus, the load that would be required to reach an inclination of 0.25 ° at the root crown is determined. Up to this point, the tipping behaviour is relatively congruent for all trees studied to date.

For higher degrees of inclination, the studies show a strong scatter in the data. Therefore, in a second step the tipping load is assessed from the moment required to arrive at 0.25° inclination. Conservatively, this value is multiplied by a factor of 2.5 to estimate the peak load during the tipping process. This approach is supported by other studies that indicate a close correlation between loads at low inclination and the tipping load (e.g. Smiley, 2008). Although most trees actually have even greater root strength, the heterogeneity of trees and their roots systems requires using the lowest tolerable loads in order to err on the side of caution.

Safety factors

Following general structural engineering standards, the safety margins are determined using a threshold value of 150%. A tree with safety values of more than 150% is expected to be able to withstand subject test wind velocities (gust force up to 102.5 km/h) (green area in Figure 2). Trees with values between 100 and 150% have reduced safety margins (grey area in Figure 2). If these trees are subjected to the modelled wind gust, they may or may not remain standing or resist breaking. These trees may require reduction pruning or other mitigation works to reduce the size of the crown (thereby reducing the forces exerted by wind). Stability can be increased by this reduction of crown area. Trees with safety values of less than 100 % are considered at a high likelihood of failure under the design wind load or potentially at lower wind speeds and loading (red area in Figure 2). It should be noted that the likelihood of failure (uprooting or stem fracture) is only one component of the tree risk rating matrix, and trees with low safety factors do not necessarily pose high risk. The actual results sheets from the analyses can be found in Appendix B.

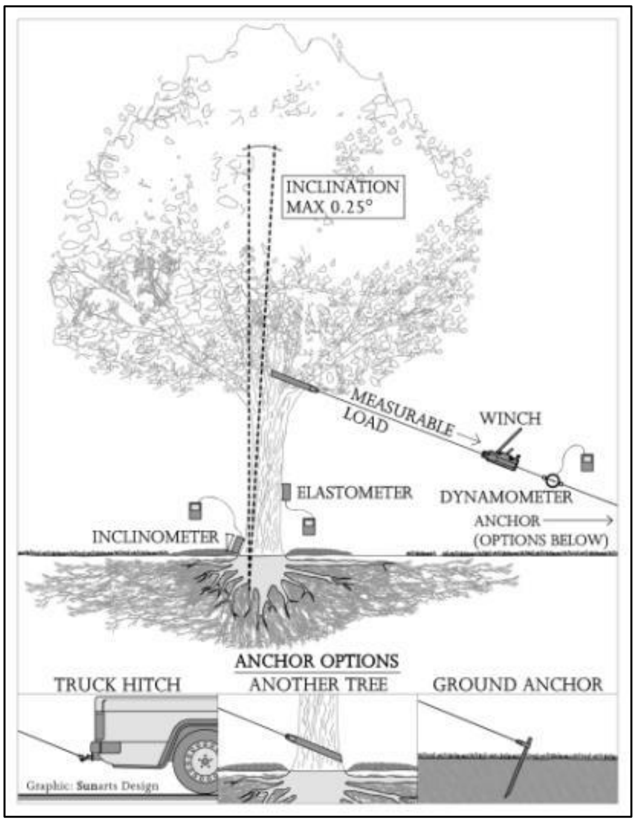
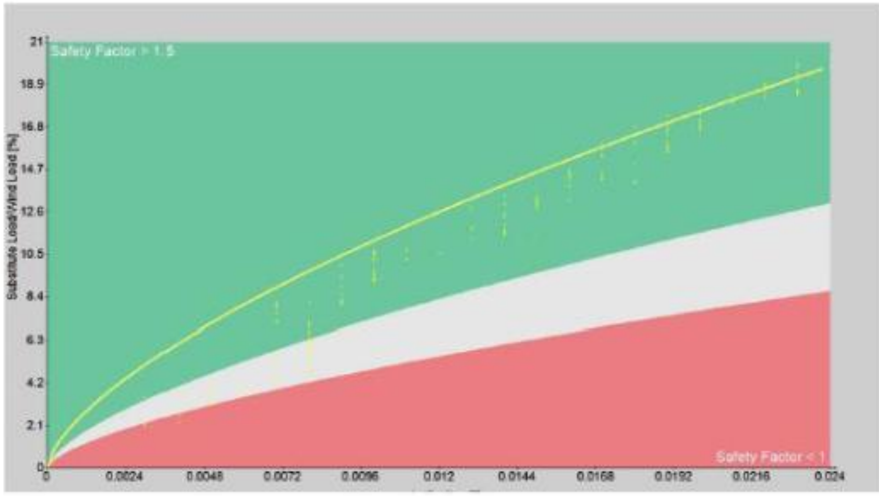


Figure A-A1: Schematic showing set-up of a tree pulling test.



Tipping Stability (based on Generalized Tipping Curve)

Safety Factor	2.28

Figure A-A2: Example graphic from wind load analysis results. Green area shows range of acceptable safety margins. Gray area shows range of compromised safety margins. Red area shows range where tree is prone to failure at area measured. The safety factor shown in the red circle. N.B. – *This graphic does not represent results from subject tree, and is used as a 'general example only.'*

Figure A-A3: Typical tree pulling test instrument set-up. Inset details show the winch and anchor assembly (top) and elastometer/inclinometer installation (below). For illustrative purposes only; not on subject tree.