Stability of Trees

Explanation of the Tipping Process

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A tree or parts of it may break, or the whole tree may be thrown over, with part of its roots being pulled out. This type of failure is caused by over-load as a consequence of release, root damage of all kinds, digging operations, and undermining. If the tree is particularly capable of oscillation, the Paradontos effect also applies, viz. shaking loose during prolonged storms. Forest trees are particularly affected by this, but forked trees also tend to exhibit this kind of failure. The common feature in all stability problems is that the deficit or the damage is hidden in the soil. Partial excavations can provide no information, for the urban tree will root where it can, and rarely in an ideal circle. Accordingly the question was clear: with roots developed in any way and differing soil conditions, can a mathematical relationship be found which will allow us to predict a tree's tip-over load? Like the Elastometer method, the method should be non-destructive, and naturally the safety determination procedure should satisfy German Standard DIN 1055 Part 4. In other words, it should be statically integrated.

After seven years' practical experience with stability measurements via tension tests measuring inclination, over 400 tip tests were evaluated and considered together. They produced a relationship valid for all trees, which allows non-destructive measurement and thus prediction of the tip-over load. The safety status is known by incorporating the results into the tree's statics situation.

1. The mechanical principle of tip-over

The mechanical relationships are best understood if they are reduced to the essentials. It comes down to the lever relationships (Figs. 1, 2 and 3). The tree crown offers the wind a surface to work on with infinitely many small forces and distances from the ground. All these forces and distances can be replaced by a single load and a single lever, namely wind-force and load-lever. The higher the crown, and the longer and more effective the lever, the more the anchorage has to withstand. For the tree not to tip over the same principle must work in reverse: the vertical anchoring roots apply the opposing force, and the horizontal parts of the roots form the counter-lever.
Normally nature has arranged everything so that the tree stands safely, but serious impairments are caused by age and especially by human interventions, which always have a negative influence on the safe lever relationships.

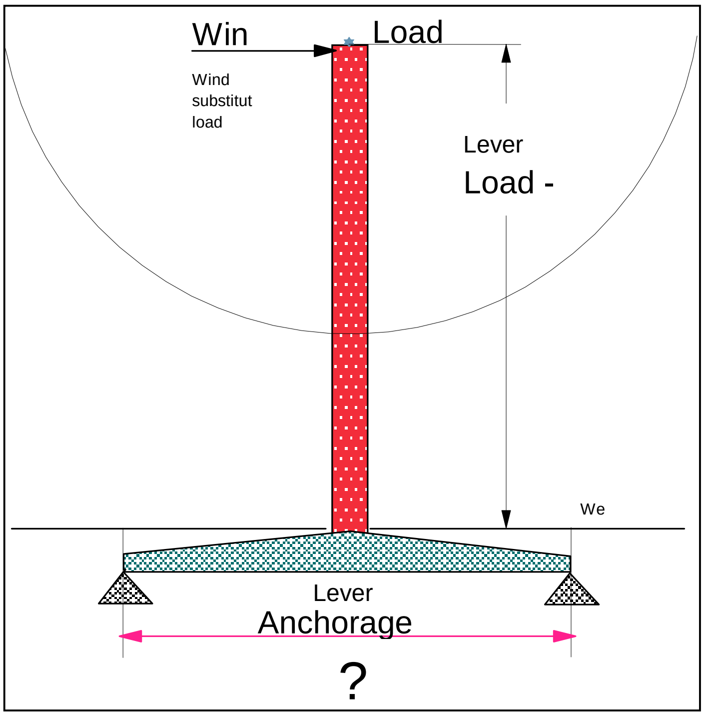

Fig. 1.

The tipping process can be explained by reducing the tree to lever relationships.

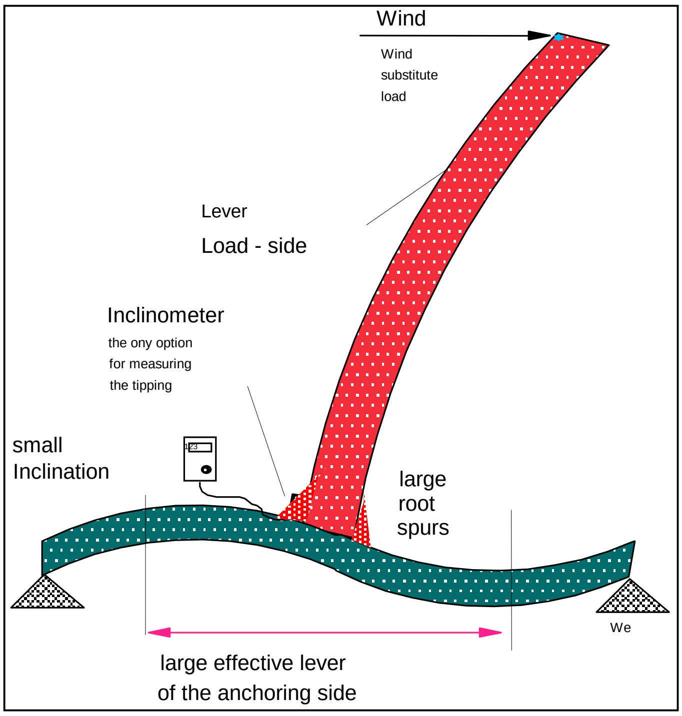

Fig. 2.

The anchorage of the tree is not rigid. The greater the root spur development, the greater the effective counter-lever on the anchoring side.

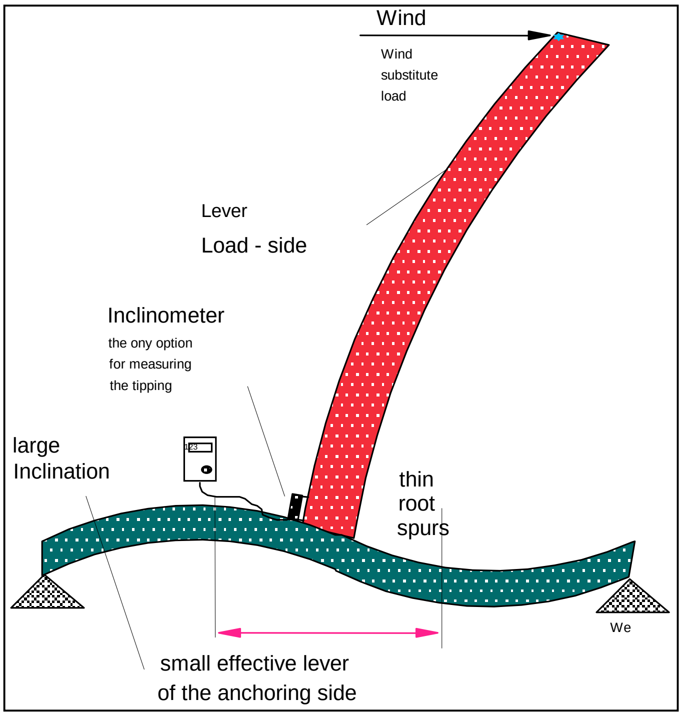

Fig. 3.

Soft thin root-spurs reduce the effective counterlever on the anchoring side. Still, the relaxed root-plate pulled out may be just as large as in Fig. 2
Example: a man's shoe size says nothing about his stability.

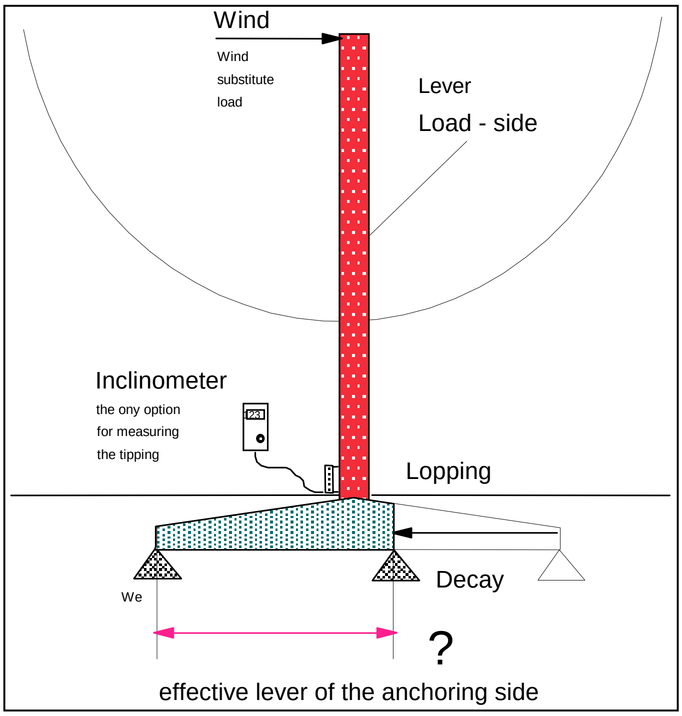

Fig. 4.

Lopping or undermining the roots shortens the counter-lever on the anchoring side. Decay has the same significance

2. Release
If a tree previously standing in association with its neighbours, admittedly competing for light but still jointly contending with the wind, is suddenly exposed to the storm alone, it is not prepared for it. Its point of load concentration is too high. It is not certain whether the basic safety of the anchorage is sufficient to prevent tipping over in strong wind.

3. Raising the wind velocity by building measures
Buildings hinder the free development of full wind velocity increasingly so the higher and more projecting they are. The storm is the air's form of energy, expressed as mass x velocity squared. And energy does not just disappear, it must be converted into another form, i.e. friction heat. But that can hardly happen with a tall building. This means that if the velocity is braked at one place, it must be increased at another, and that can only be near the roof and the side of the building. If there is a tree standing there, it is not accustomed to a wind pressure that may be more than doubled. Despite the load-arm being the same, safety may be doubtful under certain circumstances.

4. Damage to the anchoring lever
Damage may still be visible in the part of the tree above ground, but below ground it escapes notice. Recognition is made more difficult as there is little agreement between statics and crown appearance. In such cases often only the memory of an older colleague can provide information as to previous interference in the rooting zone. Construction trenches and the fruit bodies of polypores form exceptions.

5. Lopping of the roots - acute danger
Lopping or damage to the root system (Fig. 4) is mainly responsible for stability problems. Here acute danger of tipping over must be distinguished from that to be expected in the longer term. When estimating the danger, the basic safety must first be determined. As shown in the first section, considerable differences exist, depending on crown size, crown form and crown transparency. However, from the mechanical picture of the lever relationships and after many tip-over experiments, it can be deduced that root lopping only

becomes an acute problem when it comes close to the tree. Root lopping frequently occurs with trenching operations -not selectively lopping one root but severing along a line. Evaluation 0 crack patterns in the soil has confirmed that with a tree 20 m high acute danger will occur only if the lopping comes closer than 1 m to the stem.

6. Undercutting
Excavation work loosens the subsoil. With loose sandy soils and deep trenches, even with manual digging there is the danger of lever-shortening by eliminating support for the roots (Fig. 4).

7. Distance from a wall
If the tree has grown up near a wall, it will have tried to incorporate it into its statics system. If the wall is removed or is broken, the counter-lever is shortened. Here again the rule-of-thumb for acute danger applies: less than 1 m distance for a tree 20 m high. Cracks in walls which are further away are attributable to growth pressure of one root, as they lie outside the effective anchoring lever.

8. Decay of roots
The causes of root decay are mechanical or chemical damage which harmful fungi then take advantage of.

8.1 Mechanical damage
Mechanical damage either causes openings in the protective bark, or the root is completely severed, and again excavation works are primarily responsible here. The nearer and the thicker the root is, the guicker the fungus advances (Balder). Even a clean lopping, a smooth cut and the application of wound sealants will not alter things basically. The clean cut only promotes the formation of adventitious roots. Because of better nutrition these may favour compartmentalization but only retard the progress of the decay. A clean cut is possible with manual digging. Mechanical excavators do not cut the roots but rip them, either causing longitudinal cracks or pulling the root so much at its bifurcation with the next larger root that it tears here. Entry ports for fungi are created much nearer the stem. If the roots are severed along a whole line, the stability problem will occur 10-20 years later. If just one single large root is affected, the tree will fail later with insidious root-collar fracture. This form of failure is much more of a problem than tipping over with part of the root-plate, because the roots break the fall of the tree as it tips over.

Here again the energy conservation law applies: the potential energy of the tree's centre of gravity, which is released on failure, is consumed during tip-over by frictional energy in the soil, depending on the number of roots. This may go so far that little energy is left over for destruction. Matters are different with root-collar fracture: here the energy is almost completely converted into motion energy and thus into destructive potential. The only thing still braking it is the crown sail. Accordingly, with broadleaves the destruction is greater in winter than in summer. Rootcollar fracture is dangerous in another respect: the direction of fall need not coincide with the wind direction. It depends on the fracture pattern, and so this tree reels like a smitten boxer before falling.
Grass-mower damage, skidding damage and collision damage at the root spur are also forms of mechanical damage which may later cause stability problems.

8.2. Chemical damage
This encompasses the whole range involving direct poisoning or hindering of the gas exchange. Usually whole areas of the roots have died off. Direct chemical damage includes de-icing salts, dog urine, weedkillers, mineral oils, acids, alkalis, and gasses. Roots are indirectly damaged by soil compaction, sealing, compost heaps, waterlogging or drought, following changes in the site.

9. Age damage

in very old beech trees a harmful fungus does occur which cannot necessarily be attributed to actual damage. This is the giant polypore. It prefers to attack the roots. This fungus impairs tree statics and biology equally. As shown in Table 1 in Part 1 of the paper on Fracture Diagnosis (Wessolly, 1995), despite ring-shaped occurrence of fruit-bodies, only 2 of the 18 trees investigated were no longer sufficiently stable.

10. The generalized tipping curve

Evaluation of over 400 tipped-over trees has revealed the principle of the effective lever and also a further relationship generally valid for the trees: the generalized tipping curve (Fig. 5). All trees can be tipped over with increasing load only up to about 2.5° inclination (of the root system). This is the threshold inclination. Beyond this, no further increase in load is needed to pull the tree over. The generalized tipping curve exhibits a natural scatter like a comet (Fig. 5), caused by the soil conditions. Nevertheless, the general validity of this curve makes it possible to predict the tipping load accurately even with small inclinations. If the load needed at 0.3° inclination is known, then the ultimate tipping load is also known from the generalized curve. Up to 0.5° inclination, no damage occurs to the root system.
Naturally this relationship even applies with very shallow soil situations of 40 cm cover and 24 m tree height (Norway maple) (Wessolly, 1993). Even root-collar fractures reveal themselves by increased tilting inclination and fit into the generalized curve.

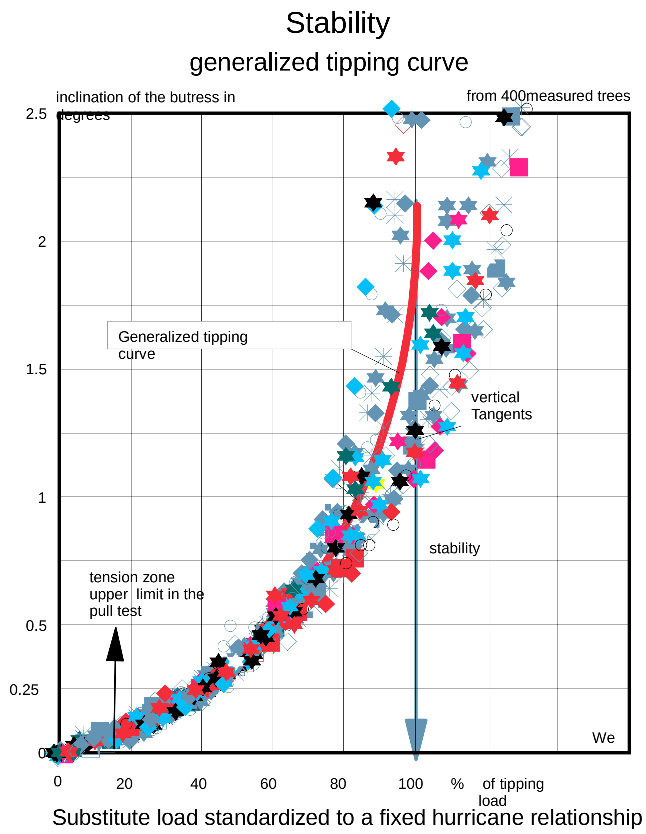

Fig. 5

The evaluation of over 400 extremely tipped trees shows that the pattern is always the same: no further load increase is possible between 2° and 3° inclination. The Inclinometer method is based on this. If the force is known for 0.30, it is also known for the threshold inclination of 2.5° and hence the tipping load is known. It only needs to be related to the hurricane load and then one knows the stability

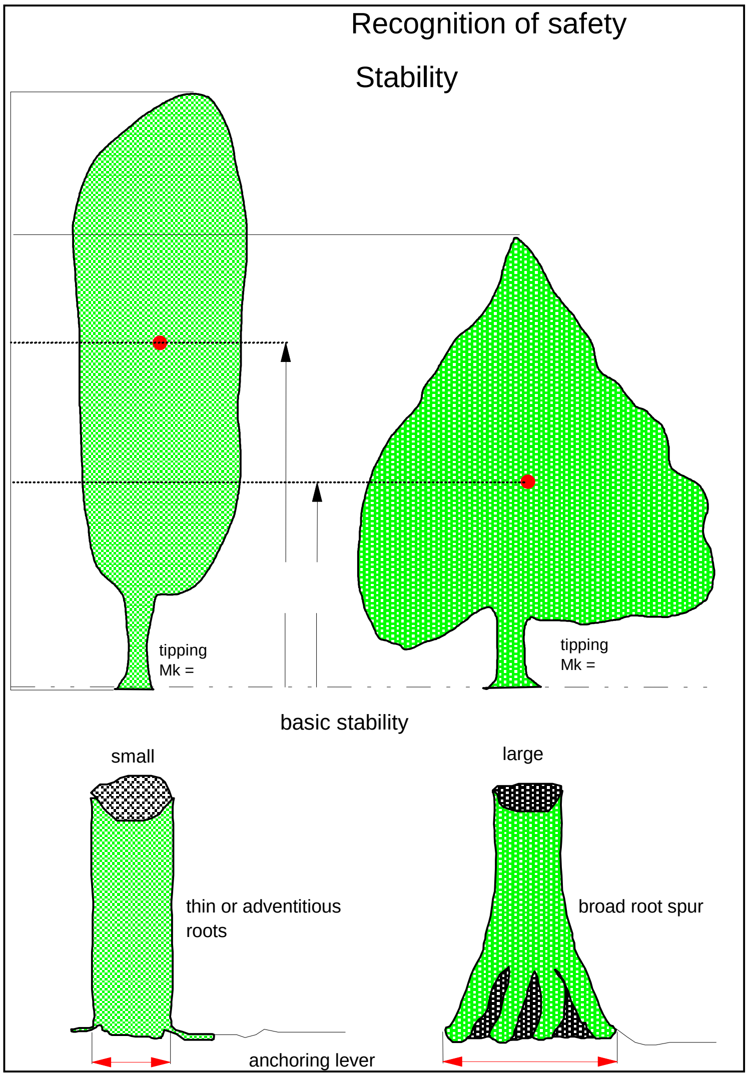

Fig. 6.

The lever relationships influence stability on the load-side and the anchorage-side. The tipping moment of the slender tree is therefore disproportionately greater because the wind speed increases with distance from the ground. The measure for the anchoring lever is shown only as a trend. Unlike the load lever, it cannot be calculated easily.

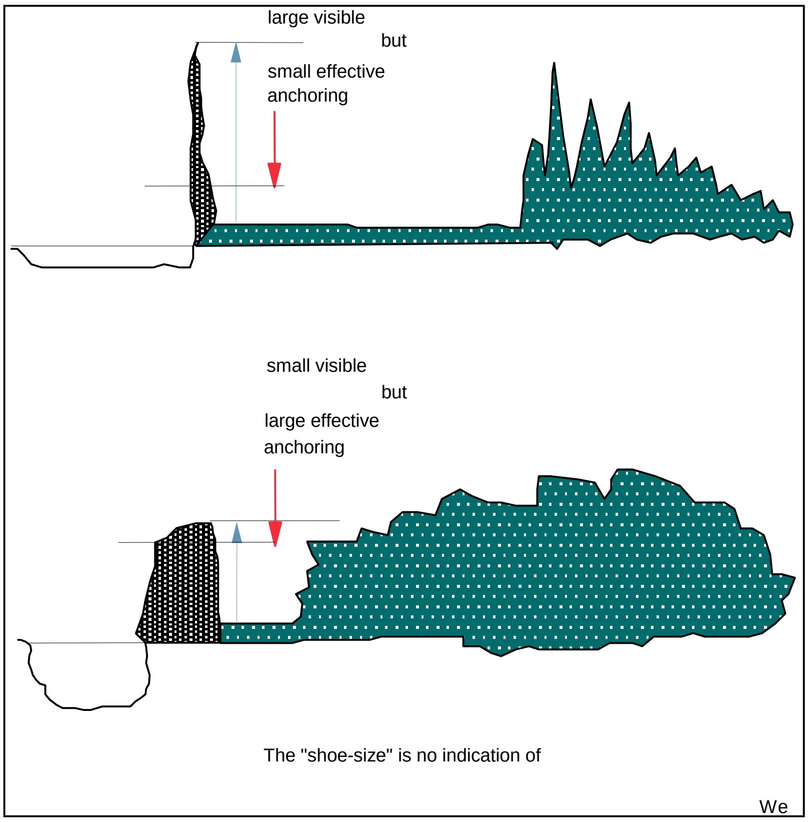

Fig. 7.

The effective counter-lever is not identical with the extent of the root-plate.

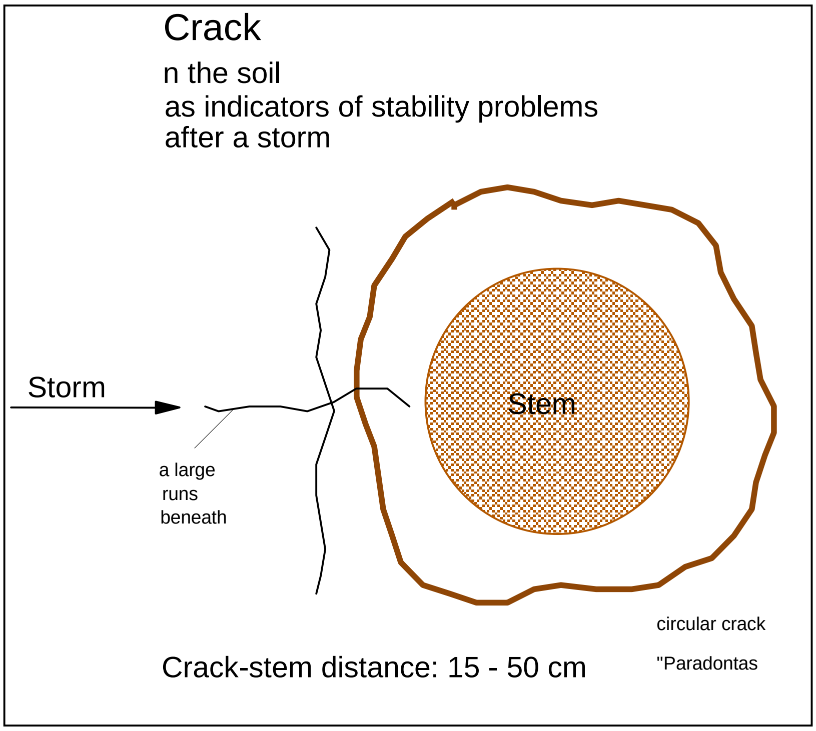

Fig. 8.

Severe wind events provide the practitioner with a stability diagnosis. Cracks in the soil near the stem indicate stability problems after a storm.

Conclusions

The conclusion from this evaluation is that the projecting root-plate of a tree can never provide information on the statically effective rooting space (Fig. 6), because the projecting plate shows the released unbent lever. Accordingly, neither washing nor subsequent excavation can reveal the statics situation. Measuring the root-plate (for statistical purposes) has the same importance for a tree's stability as shoe size has for a man's, namely none at all. As the effective anchoring lever is decisively determined by the give, the area extent is unimportant. The softer the anchorage, the smaller is the effective lever and the sooner the tree tips over. Accordingly, the relaxed root-plate when the tree is horizontal may have the same extent with a large effective anchoring lever as with a small one (Fig. 7.).

Remember the very thin but large root-plates of windthrown spruce trees during the hurricane. The effective counter-lever cannot be determined with a tape-measure. It is composed of the width, thickness and diameter of the root spurs and the give of the subsoil. It can only be measured integrally, i.e. in its effect. Like the stretching of the peripheral fibres in bending the inclination of the root spur is representative for the whole event underground.

The existence of the generalized tipping curve has scientifically confirmed that injury-free Inclinometer measurement with a tension test is the correct way of monitoring stability.

Accordingly, the Inclinometer is the correct instrument for the expert to be able to determine the tipping load in any anchorage situation, non-destructively and in accordance with German Standard DIN 1055 Part 4 and ZTV Tree Care 1993.

The information first distilled from nearly 1000 investigations (Wessolly, 1995) shows that the wind load is the decisive criterion for assessing safety. The same naturally applies for stability. Only when incorporated into the statics does knowledge of the tipping load become important for assessing the traffic safety. That is the Inclinometer method.

On site the practitioner has to decide whether this highly developed method needs to be used. The visual possibilities of recognizing stability problems are as follows:

1. Tall slender trees are more dangerous than squat specimens because of the danger of shaking.

2. The same applies for forked trees.

3. Because of their softness for bending, the formation of adventitious roots represents a shortening of the effective anchoring lever. If they are formed all around the stem, an acute anchoring weakness exists.

4. Soil crackinq near the stem after severe wind events draws attention to problem trees (Fig. 8). Cracks in the soil within 1 m around the stem show that stability is no longer certain. However, drought cracks may look similar.

5. Fruit bodies of giant polypore or honey fungus in the rooting area may indicate problems. However, they need not necessarily be present (see Table 2 in Part 3 of Fracture Diagnosis, Wessolly, 1995)

6. The most important criterion for excluding cases of failure is a comparison of the age between the tree and any building work near the roots. If it is more than 20 years ago, look out for fungus fruiting bodies between the root-spurs. If they occur on one specimen in a row of trees, there is a great probability of problems in the other trees. But the problem may exist even without fungus fruit bodies.

7. Then the advice is to solve the problem with a tension test. The Inclinometer method with the generalized tipping curve is the correct answer to the stability question.

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