Andreas Detter— Applied Tree Statics: Lessons Learned from Static Load Tests for Visual Tree Inspection

Paige Taylor: [00:00:12] Hello and welcome to the ISA Conference Rewind video series. I'm Paige Taylor, Marketing Assistant with the International Society of Arboriculture. Today, ISA is excited to bring you a presentation by Andreas Detter on applied tree statics and visual tree inspections. This presentation was originally given at the 2022 ISA Virtual Conference, so the views seen here are those of the presenters. So, if you are interested in learning about pull tests and methods of assessing a tree's likelihood of failure, I expect you will like this presentation. Now, sit back and enjoy.

Andreas Detter: Hello, my name is Andreas Detter from Germany. I'm speaking today on work with tree statics, lessons we learned from performing pulling tests, especially with the focus on [00:01:00] applications in visual tree inspection for people who do not necessarily apply the static load test method. This presentation goes back to my work with Professor Dr. Steffen Rust of the university in Gottingen where we did research in tree biomechanics in the last years, and also to the experience of other members of the tree consultants experts group tree statics, SAG Tree Statics. I'm the chairman of this organization, and people gather in this association to share, their experiences, with engineering approaches to visual assessment basically.

So, I'm trying to form a bridge between the visual assessment of trees and the pulling test method which is one of the [00:02:00] methods that we have for advanced tree assessment to assess the stability, and fracture strength, and the likelihood of failure of trees. So, in visual assessment, I want to focus here on assessing the likelihood of failure. You're all aware of the fact that tree risk assessment is more than just assessing the likelihood of failure, but all the other parts that consider the target and the severity of the results of an accident are left aside. So, we focus on the aspects that give us an idea about the likelihood that a tree or parts of the tree may fail. And the pulling test method focuses on the tree biomechanics basically.

So, when we perform a pulling test, the method itself aims at assessing the load that the tree is exposed to in a storm and strength [00:03:00] that the tree has to withstand such loads. For a full picture of the likelihood of failure of a tree, that's not enough. We also have to take into account tree biology and the biology of the pathogen, especially when we talk about the long-term perspective that the tree has to retain its stability or a degradation or decline of the tree and its increasing likelihood of failure over time.

So, we get also when we carry out pulling tests, we also get information that helps us better understand how trees are able to compartmentalize and compensate damages by growth, by adding new layers of wood, and we also get some information on the biology of pathogens and how they, as they decay the wood and spread within the wooden body, [00:04:00] may affect the stability of a tree and the likelihood of failure. So, I will try to give you some ideas, some lessons that we learned from looking back on a long time of performing pulling tests and many, many trees that we tested.

Basically, this idea came up when a colleague of mine said, "Can you not give me some more information on how a specific fungus - for example, *Kretzschmaria ustilina*, as it's often called as well - how it really affects the stability of trees?" Everybody talks about *Kretzschmaria* being a big threat to tree stability, but you may have data. So, I thought well, actually, yes, we do have data, we just never used it, and that is the basis for this presentation here.

Just to give you a quick idea of what the pulling test method is, in case you haven't had contact with it, had never seen it, [00:05:00] the basic idea is very simple. When you have a tree that has a problem, it may be decayed in the stem, it may be decay in the root, it may be severed roots. Basically, you try and find another tree or use a lorry as a ground anchor, and you basically exert a force on the tree that you want to test. So, we are artificially loading the tree. We are exposing it to a bending moment, and we record the force that is applied to the tree. The very early forms of the pulling test use just the force meter and a microphone attached to the tree. So, when the first cracking sounds were heard, that was the strength that the tree had before the test. Afterwards, it may not have had the same test.

So today, the method is a bit more sophisticated. We have high resolution instruments [00:06:00] that allow us to test the tree in the non-destructive range. So, without causing any damage and it allows us while we are applying the force to constantly monitor how the tree responds. And, of course, we are monitoring the weakest spots in this test. For example, with the elastometers, we're able to record the change in length of the fibers. As we bend the tree to one side, the fibers are compressed on one side, the fibers are stretched on the other side, and this change in length, we can record with the resolution of one ten thousandth of a millimeter and with an accuracy of a thousandth of a millimeter. And at the same time as the stem bends, force is also transferred into the root system and the entire root system starts to rotate.

And we can record this miniscule rotation [00:07:00] to a level of a thousandths of a degree change intonation. So, we can very precisely measure the response and make sure we're not overloading the tree. And the data that we gather from this test allows us to estimate how strong the tree is, strength of the stem and the anchoring strength of the root system. And we are stopping the test at very small degrees of response. So, the inclination, the maximum that we do is a quarter of a degree, and usually we stop the test at 100 or 200 micrometers of change in length of the fiber. So, 0.1 or 0.2. mm change in length over a base length of 20 cm. So, it's very, very small changes that you would not be able to see with the naked eye and that don't do any damage to the trees [00:08:00] structure.

This is an example of where the instruments are located at the base of the trunk, 6 mm, and along the stem at the areas of interest. Where we suspect weak spots, we place the elastometers. The result is the data of the actual test. This is the data of inclinometers. See the little dots there. We are using curves to illustrate the trend of this. Intonation versus the force, the force is in the vertical so to say, and then the green, the gray, and the red areas, they are the overlay of our tests with the assessment of the wind load. Because what we need on one hand is an assessment of how strong the trees, and on the other side, we need an approximation of the load that is exposed.

And for this wind load assessment, [00:09:00] we use methods that are based on engineering standards. For example, the software ArboStat that we use works based on a procedure that's fixed in a wind code. It's this Euro code that is designed for point-like oscillating structures. And we also use statistical wind data on the structure of the wind and the wind speeds that occur in a certain region from these national wind codes. In the US is the Association of Civil Engineers, and this is code 7-1 for wind effects on structures. And there obviously are the natural national regulations that are all very similar in their structure and you can use that data to assess the wind loads on trees as well. But we need to have adaptions for tree exposure in an urban environment, [00:10:00] because these guidelines they are not designed for trees; they're designed for the built environment, for build structures, and there are obviously differences for trees.

But we can also use the dynamic modeling that is established in these building codes with the adaptions that we have to mimic a trees behavior in natural wind. And this is basically based on the idea that the tree is taken along with the gust of wind, and then starts to come back a little bit, and then the next gust comes and takes it along again. And when it's force is greater than the wind force, it will slide back a little bit again, and this mechanism leads to a picture that you see here in this cloud of strings – as Ken James called that - this is a pattern of tree behavior and wind. And you see it's chaotic, but there's also the [00:11:00] typical structure of these oscillations twisting, turning, and then reaching the maximum deflection, which is what we use as a reference for the static load test.

What I did here in this graph is just adding up wind load estimations for a great number of trees. This is 850 trees roughly. We have many more. This is just a selection of some years of our work, and you can see when you know the tree height - that's on the base line - you get an idea how great the wind loads are. Of course, this is a big variation, because the actual wind effects on a tree depend on many parameters and properties of the tree, characteristics of the built environment. This is all parts of the estimation that we make to get the wind load, but we can see here that the estimations [00:12:00] are very sensitive to tree height. The tree height works roughly in the third power. So, if you have a 15-meter-high tree, you are roughly at something like 125 kilonewton meter. And if you double the tree height, you get eight times the wind load with 30-meter height. This is more than 1,000 kilonewton meters. This sensitivity makes it so important to really measure the tree height and get accurate measurements of tree height, because that's an important basis for the assessment. Even if you just increase the height of the tree a little bit, let's say from 20 meters to 21 meters, that's a 5% increase in height. 1 meter in 20-meter height, and with 5% increase in height, this power of three correlation would lead to lead to fifteen percent increase in the wind load.

So, you can see that increase in height generates quickly, [00:13:00] a rather high wind load the size of the circles, here, is the stem diameters that we measured to the same scale. We can also look at the site where the tree is growing and compare win loads that we determine with our weight load estimations between trees that grow in the landscape - in the open landscape - and compare that to the built environment. And from this graph, you can see that on average, of course, there's lots of variability, because tree heights are different, crown sizes are different the actual conditions at the location are different.

But you can see on average in the city, the wind load is only half of the wind loads that may occur in the open landscape on average. And that is again interesting for your assessment of the stability of trees and the visual assessment. [00:14:00] You can keep in mind that trees in the city environment will experience much lower wind load than the trees in the open landscape. If they have the same size, similar crown shape, you can make that comparison. In general, the wind load side is only one part of the picture, but we know that trees stop to grow at a certain age in height. So, the tree height will not really be increased a lot as the tree has reached a certain age, and by their biology, trees never stop to grow in diameter. Every year they put on a new layer of wood. So, they generate a surplus of strength, and I've done a presentation last year on the online ISA congress with similar content on this idea of assessing this reserves of strength, this initial strength of trees, [00:15:00] when we assess the stability of trees with simple strength loss approaches.

So, also trees are able to increase their strength even when they have damages and when the wind load doesn't change anymore or not change significantly anymore. This regeneration is very effective and also very old trees are even able to reduce their height, which we call retrenchment. So, that the stem can actually experience a great degree of damage like you often experience in very old trees, because at the same time, the wind load will be reduced as the tree loses height, loses parts of the crown and forms a new less high, a lower tree crown that is vigorous and can still be supported by the stem.

[00:16:00] The assessment methods that we have for this is our simple methods like the SIA method, TreeCalc - you may have come across that. You can try these methods out if you like with this promotion code to get you free calculations for TreeCalc. The SIA method is for free. You can do that on the internet. TreeCalc has a different approach in the wing load assessment. So, there's more variability for you to change the data. It's also in imperial units available, so that maybe helpful for some people. But you have to pay for that; it's roughly like two euros per calculation that you would have to pay to do that. It allows you to assess the basic safety of stem - so, how much safety reserves the tree has gathered in its life - and also allows you to analyze strength loss due to decay in the central part of in the stem.

The basis of the shapes that we use here, [00:17:00] the crown shapes that we use in TreeCalc, can also be compared to the analysis that we've done. When we carry out pulling tests, we analyze the wind load on the basis of a picture of the tree. We draw an outline of the crown, and this is an overlay of 60 crown outlines of just one genus *Tilia*. And you can see it starts to level to some certain shape, which is a typical shape that we also have available then in TreeCalc. Don't misunderstand it, this picture. It doesn't mean that I'm implying that you should prune *Tilia* trees to this shape that we use. It's an idealized, it's a generalized picture that allows us to base our calculations on this typical shape. But of course, tree crowns have great variability of shapes. [00:18:00] And that's good. We don't want you to observe something in nature and then shape the nature after your generalized idea.

This is another analysis of these wind load assessments. It looks at the center of gravity for this wind load action on the tree. And you can see that there is a variability of the height where the center of wind pressure is located. In the crown, it's the theoretical value. But looking at this, it's obvious that we have an average height of 60 percent of tree height roughly. So, there is a general understanding that you would like to place cabling systems at roughly 2/3 of the tree height.

So, looking at this graph, it allows you also to vary the actual height of the cabling system, because the center of wind pressure [00:19:00] can be as low as 45 percent of tree height but can also be as high as 75% of tree height. And when the crown shapes allow for that, it is of course a big advantage if you can put the cabling system higher up in the tree, because the higher the lever arm length, the lower the forces that will be acting on the cabling system. With the pulling test method, we also get a different approach a little bit to how trees deform when they are exposed to forces. If you do a lot of pulling tests and you are actually pulling on the tree with a certain force, you can feel when you're working on the winch, as the tree is bending, the more it is bending, the more force you have to apply, because [00:20:00] as the force is applied, the tree generates what we call a restoring force as a response to the force acting on the stem. As it bends, the more it bends, the higher the restoring force and the higher the force you have to apply. So, there is, in a way, a correlation between the applied force and the deflection of the tree, how much it bends. And this correlation helps us or is maybe helpful for understanding how cabling systems work. Because when there is not a lot of wind, the wind force acting on a stem will cause it to bend. And this is equivalent to a certain restoring force where actually the tree is able to stop the movement, the wind acts on it and it stops the movement by generating a sufficient restoring force to balance the wind effect.

[00:21:00] When there is a lot of wind, then the stem has to deflect a lot to allow its fibers to build up a restoring force that is able to balance the wind force. And in the end, if the wind force is too high, the deflection will be too high, the compression in the fibers will become too high, and that will initiate tree failure. Now, when we apply a cabling system, and we are using a rigid cabling system, we are restricting the stem's ability to bend. So, when we have high wind forces, only very little bending will be allowed, because the rigid cable will stop the tree from bending, which means that the amount of restoring force is limited, [00:22:00] because that's directly correlated to the amount of bending that we have. And we will have to use a high rope force to replace the force that we don't allow the stem to do when we restrict the pending.

If we use a dynamic cabling system, the same wind effect, the same force acting exerted by the wind, causes a larger deflection, because we have a dynamic, a flexible cabling system. So, we allow a large restoring force to be built up by the tree and only the surplus will be covered, will be taken over by the rope force. Now, of course, the secret is to stop the movement of the stem before failure will be initiated. And this is how we have to design, the cabling system to allow enough flexibility in the stem to build as high as possible [00:23:00] restoring force which is limited by the residual strength of this stem that we are cabling of course, and stop the movement before the failure will occur. And there is experience necessary to do that. There are guidelines - there is guidance necessary to do that, but this is how dynamic cabling systems work. Even when their strength is much lower than static steel cabling systems, because we are able to use the tree's own strength to replace some part of the strengths that we would, otherwise need in the steel cable.

Of course, if for example, a branch union or a stem union is broken already, then there is very little residual strength. So, we have to use static cabling systems, steel cabling systems because we don't want the tree to, but if it's just a fork that we're worried about, [00:24:00] that we are not sure whether it's strong enough, or whether this leader has some decay where we want to limit. So, to say the response, the deflection that it will experience in wind then the dynamic cabling systems are a good choice. This is a graph that's generated from pulling a tree to failure, and this is from the tree biomechanics research week in 2010. And at that occasion, I would like to thank again all the people who have made this possible, this great event. I hope it will be continued in the future.

We had a chance to pull this London plane to failure, and you can see we measure trunk deflection, and the force. And this is a picture of how trees are actually breaking, because they don't break at once. And that's what we also can use in the cabling systems. We can restrict the movement [00:25:00] to this part of the graph where we have a linear correlation where everything is elastic and reversible, we have to avoid exceeding, the proportional limit when the first fibers on the compression side will be crushed, and the ultimate failure is still far away.

From the loads that we have, as a reference for this prompt proportional limit, we call that primary failure versus the ultimate failure. And what happens at this proportional limit is what we looked at in the lab by bending green stems beyond this proportional limit and then really cutting up the surface on the compression side, and we could show that as the proportional limit is exceeded the first fibers on the compression side crush. We've got these buckled fibers on the microscopic level. This is visible. You don't see that with the naked eye, but if you look [00:26:00] at it under an electron microscope, you can see that the originally straight fibers are now sideways deviated and looking at the surface of the trunk. So, this is a tangential cut. We are scratching off bit by bit the wood from outside of the stem, and there, you can see the deviations of the fibers. And when you look at it in greater magnification, you can see that there is really cracks in the wood rays. There is buckling in the cell walls and you can also see horizontal cracks in the cell structure.

But this is the compression side. Remember, on the compression side, we get horizontal cracks in the microstructure. Now you can imagine when you load that same section in tension again, these cracks will propagate through the material. We also have longitudinal cracks between the vessels and the fibrous [00:27:00], very often in the cell walls. So, on the compression side, we get these micro cracks. They are permanent, unreversible changes in the structure. So, this tree is actually - has exceeded its strength limits, even though it's not broken. When we evaluate the tests that we've done on many trees, that we broke basically on purpose and we recorded the loads that were necessary to exceed the primary failure point, then we can also reference this to the standard tables that we use in the in the pulling test method, and we can see that the range of data in the so-called Stuttgard tables which are often used for the pulling test method for the evaluation of strength.

They are actually very well within [00:28:00] the values that we find for those species. This is just six species out of many others. You can see, there is a big difference for the first one, which is a substitute of *Platanus*, where the data in the Stuttgard tables is very, very conservative. Actually, the trees that we tested were much stronger than we supposed from the tables. And the reason behind that is we only tested very young, a substitute of *Platanus*, and young trees have much greater possibilities to undergo high bending, high deflection before they fail. So, if you apply the standard values from Stuttgart tables to young trees, you will very much air on the side of caution. Whereas, with the other ones, you're still on [00:29:00] the side of caution, but not to such a large degree. So, young trees must be treated differently.

And this is one of the experiences also that you can take home for the visual assessment that young trees can withstand much greater loads than we would expect and much better deal with the large deflections and old trees. This is actually also true for the anchor, for the anchoring, for the root systems, where we also have data that show that young trees have much more flexibility in their root system than mature trees, and all that allows them to really be stable with less material so they can focus on growing in height and don't have to develop their root system and their stem to the same volume that all the trees are able to do. Also, you can see not in this graph, but I'd like to state that the data from the [00:30:00] Stuttgart tables are very well within the range of other tables for green wood. They're very well comparable.

So, this is data that is used for the pulling test frequently. If you exceed the proportional limit, if fibers on the compression side buckle, the tree is not broken. It is still standing and biologically will survive, and it responds to these microcracks by the formation of what we call Wulstholz which can be translated to "bulge" wood. This is a German term. I've never come across an English term for this formation of a certain form of reaction wood. Actually, you can see the horizontal bulges in the left picture, and in the right picture, they're more at an angle which is also typical for these microcracks on the compression side, that they run sideways. And then, the tree forms greater volume of wood above the [00:31:00] microcracks in the structure. And it's also, at the same time, more flexible wood, so it doesn't bear the danger for the crack to propagate in the new wood. If it was very rigid and underneath the crack, then the likelihood of cracks propagating through the new layers of wood would be very big. We know that from other material that things like that can happen.

So, this Wulstholz accommodates for the greater flexibility of the cracks in the structure and is able to restore the original strength. I find it quite relaxing that whenever you see bands of new wood along the stem, be it on the left side here at a node on an oak tree. You see a wide band of strong increment growth or here on the right side, wound wood next to a cavity, you see these bands of strong growth. All the literature actually [00:32:00] agrees that this is a sign of successful compensation. It doesn't indicate failure processes that are still ongoing and wood failing. It is the successful compensation in many cases of these buckled fibers, but like in the oak on the left side, there is not a failure underneath that all. This is just an anatomical feature that you find very often in oaks. Also, you may find locally increased growth along what we call cambial bridges that connect the root and stem. And of course you see wound wood, which is also a form of compensation.

And we carried out tests on trees that look like that. That have wound wood that form these, strong growing cambial bridges. And when you test them, you find that actually in the pulling test method, [00:33:00] we can show that this wound wood or the strong growing part of the stem are actually able to restore the strength to compensate for the loss in strength in many, many cases. Especially when the trees are really vigorous, this is a typical thing that we experience. And this is one case study again from the tree biomechanics research week. We tested the tree that had a basal decay - you see that in the picture - and radial "shear" cracks from the base of the trunk, running up the trunk, and when we bent this tree, we tested again with the elastometer how much strain we get in the fibers, how much the fiber is deformed at different heights. So, at the base with the large cavity, then the second highest one with the radial crack, and the third as well, and then on the top, the one is in the undamaged area. And we can see that from our test results, all these sensors give us a very, very [00:34:00] similar strain reading.

So, the idea that's now published also in scientific literature that trees don't necessarily level out stresses, but level out the strains. So, the tendency in the tree is to get to a state where the fibers are stretched or compressed to a similar degree all over the length of the trunk. This is something that we can confirm from the pulling tests. And the tree broke well above the damage in an undamaged section. The end.

This view on tree stability that we get from pulling tests is something that can help you also in your visual assessment. The formation of buttress roots can fully compensate for central cavities. We call this the Eiffel Tower strategy. The Eiffel Tower in Paris that is on wide spreading legs, is situated on wide spreading legs, and the central part is empty on the Eiffel Tower. [00:35:00] And in this picture that you see here, you have a tree that somehow looks like the Eiffel Tower. And actually, when we measure in the pulling class, when we measure the strains in the fibers, here is where we get the high deformations. Here is where the stresses are really concentrating, where under the stress, the fibers deform, where you measure the maximum response of the fibers. If you put an instrument here or here, you will not measure any deformation when the tree is loaded in this direction. So, these parts that are actually missing in this tree are not the ones where we really would have the load dissipated into the ground but rather in the periphery. And that allows the tree to remain stable, despite a large degree of cavity on the inside. This is now about the uprooting process.

[00:36:00] This image shows you the current state of the knowledge I would say how trees fail when they uproot. We have this knowledge already since the 80s but our studies, where we uprooted trees, confirm that. But also when we just pull the trees in the non-destructive range, we see a similar behavior of a hinge point, or a hinge on the leeward side where the root system does not sink into the ground, because the ground is very resistant to compression. But if the tree wants to start and increase its lean, if the tensile roots want to come up here at that hinge point, you have to overcome the strength of the roots that are located here. And that's a section very close to the stem.

And I've got this little film here to illustrate that this is an accidental recording. [00:37:00] We pulled the tree. We wanted to pull the tree to failure for a study project, and when the rope broke you can see how the root system actually is shaking very close to the trunk. This is what we call the static effective area. It's positioned roughly one to one and a half times the stem diameter to both sides of the stem base, and here's where we get the maximum deformations of the ground as the tree is suddenly released and shakes back and forth. This was for me a quite good illustration of where actually the strength of the root system is generated.

And after a storm you may look for the cracks in this static effective zone. So that's a picture taken after a strong storm where that tree was not fully tipped over. It's not on the ground. It's still standing, but we see [00:38:00] the large cracks in the ground at the periphery of this static effective area. We also at the tree biomechanics week, I had the chance that some colleagues - I think it was colleagues from Bartlett - were using an air spade to excavate the root zone of one tree, two trees actually, that we pulled to uprooting failure, where they were strongly leaning and they couldn't resist anymore, but we didn't pull into the ground, but let them stand back up. You have another presentation at this ISA Web Conference by Philip van Wassenaar who worked on this project with me, where we also looked at the development of some of those trees that were not pulled to the ground all over the years. And here is one of the trees that was overloaded, with the root system was really overloaded, and the resistance of the root system was overcome, [00:39:00] and you can see, we pulled the tree to this side and in this hinge zone is where the root is damaged. The surface. The upper surface is damaged by compression so that the bark was actually detached by the strong compression of the fibrous, and it is cracked from the underside and cracked along the axis because of the overloading.

And if now, you want to apply that to visual assessment, this hinge area is where you may look for where damages to the stem have a large impact on the stability of the tree. If the tree wants to restore its strength, it will grow strongly exactly in that zone where the greatest stresses can be expected, and that growth happens on a concave structure. So, it's curved [00:40:00] inwards. The bark is on the very outside. The cambium is on the outside and the cambium forces new layers of wood every year. And if there is a strong increment growth, the outer parts of the bark are always pushed aside, and the distance from one of the upper red dot to the lower red dot gets shorter every year. The shortest distance would be the direct connection.

So as the tree grows in this region, unavoidably, there is a lack of space and this effect may cause bark folds, and they're often suspected to be a sign for failure. Actually, it's the sign for strengthening for response of the tree to increase its stability in the ground. You may find the same thing on the underside of branches. If there is a strong growth on the underside of the branch, we call that supporting wood. Then in this concave structure [00:41:00] under a branch you have the same effect of bark folds to occur.

And this is the last example that I wanted to show you on *Kretzschmaria* and its effect on the strength of trees. We did an analysis of all the trees in our data set and compared the initial safety. That's just derived from how much, how great the diameter of the tree is compared to its size and sail area, and compared that to the actual measured fracture safety and tipping safety from the result of the pulling test. And if you look at all trees, you can see, we always or nearly always test trees that have a problem. We don't perform pulling tests on trees that don't have any signs of decay or damage or cut roots and over a large number of trees. You can see that the fracture safety, the safety of the stem against fracture and the tipping safety, [00:42:00] safety of the root system against uprooting is on a similar level and it's lower than the original strength due to the decay.

Now, if you look at trees with *Kretzschmaria*, you can see that the fracture safety typically is much lower than the tipping safety, which I found surprising because *Kretzschmaria* is described as a fungus that acts on the roots. So, I would have expected the tipping safety to be lower, but you have to keep in mind that we position the elastometers to measure the fracture safety at all heights of the stem. So, also, at the very base, and *Kretzschmaria* generates a decay in the base of the trunk originating from the roots. If it's only in the root system, its effect is different from when it enters the stem base, the wooden parts that are actually part of the stem. And you can see this effect also in [00:43:00] this last graph that may confuse you completely. I'm sorry for that, but what it wants to show you is basically only that the fracture safety.

When you have *Kretzschmaria* in the tree, the fracture safety may change depending on how large the diameter of the stem is. The basic safety is not a good indicator for the fracture safety of the tree when you have *Kretzschmaria*, but the tipping safety, where it's very much with the basic safety. So the lesson from that is if you have a fungus, from the root system, that originates from the root system into the base of the trunk and can spread rapidly into the sap wood, which is what *Kretzschmaria* is known to do, the tipping safety is basically correlated somehow with the [00:44:00] initial safety that the tree has. So, if there is one root that's damaged or two roots that's damaged, it depends on how strong the overall anchorage was, how much resistance you still have against uprooting? But the fracture safety may change completely independent of the basic safety, if the fungus is able to grow through the ring of sapwood that would support the tree.

So, the changes are more unexpectedly on the fracture safety than on the tipping safety. As a consequence in the pulling test, we will always measure the strain of the fibers with the elastometers and the inclination of the root plate within inclinometers in order to really get a full picture of how safe this tree is against uprooting or fracture, how great the likelihood is of failure, [00:45:00] and then both of these methods link together and give us a good picture. This is what I wanted to show you about the pulling test method.

Thank you for listening. I hope you can get some advantage from these lessons for visual assessment. Thanks for your attention and hope to see you again soon.