Causes, Tests and Prevention

Why do tree roots penetrate pipes - and not only where the pipe is damaged? Root damage to the pipe connections of duly laid, intact pipes causes millions of damages per year. Engineers and biologists prospected the reasons together. Their results are already turning past theories topsy-turvy and have consequences for laying pipes.

Sewers are a rather inconspicuous property of cities and municipalities. But there are few things so important for the community. This becomes particularly obvious, when sewers do not work properly. A frequent cause are roots growing into pipes. While one can resort to bottled mineral water instead of drinking water, help out with aggregates in the case of electrical current and simply do without television occasionally, a defective sewage system is always an acute problem, that has to be solved quickly.

We have investigated why roots represent a problem for piping systems at all in a co-operation project of the Chair for Systematic Botany and the Botanical Garden of the Ruhr-University with the IKT - Institute for Underground Infrastructure. Concepts to avoid this damage are to be developed, based on the accurate knowledge of what happens when roots penetrate. Sound precautions are particularly important, since it usually takes more than 10 years from pipe laying to the occurrence of damage and pipes should last for a long time (service life: 50 to 100 years).

Figure 1: Excavating a pipe penetrated by roots calls an archaeological approach to mind

Biologists and underground engineers seem to be „natural enemies“ in this respect, because one group argues, that nothing can happen, if the pipes are „decently“ laid, while the other considers wood as an aggressive destroyer of the marvel of their engineering art. A biology student, who jobbed in underground engineering and returned to his academic roots with this problem, made the contact between both worlds.

Biologists and engineers both initially assumed, that the roots find the pipe, because small amounts of water escape through leaks: The roots grow along moisture gradients (soil area with increasing water saturation) towards the pipe, since the primary function of the roots is water absorption; they then penetrate into the pipe through the leaking locations - because there is even more water there. Robot cameras, driven through the pipes, show us nowadays from close up, what really is happening in the pipe. How the root grows towards the pipe connection before penetrating can however only be recognised, if a defective pipe area is carefully excavated (s. Figure 1).

Root penetration in sewers

The driving videos already show amazing things: The roots usually hang into the pipe from above and end just over the water level. (s. Figure 2A and B)

Fresh, well growing roots also died within days to weeks in different waste water samples in control experiments with rooted cuttings.

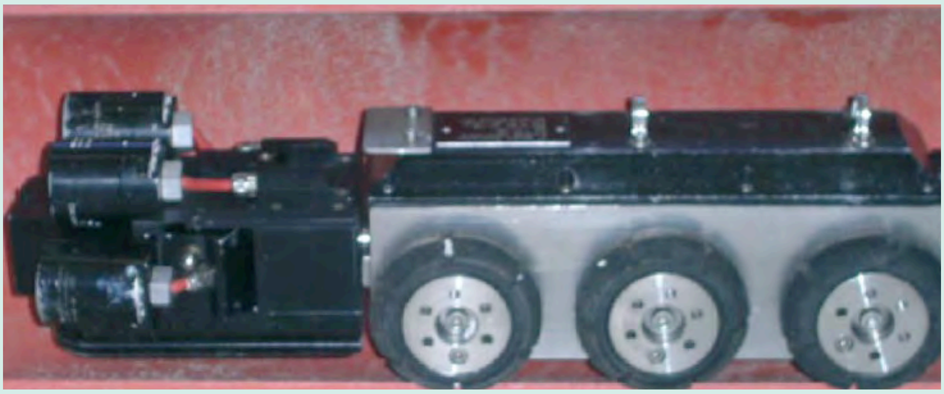


Figure 2: The robot camera (A) drives through the pipe system and „views" root damage (B) from close up.

They do not reach their assumed goal - the water. We therefore examined, what happens during root penetration into the pipe in a project promoted by the Department of the Environment of the province North-Rhine/Westphalia. We then experimentally examined the hypotheses gained from the excavations as a next step. The excavations also resulted in surprising results: Waste water and rain water conduits differ from each other in root growth (s. Figure 3 and Figure 4). The roots always penetrate the pipe above the medium water level in waste water conduits, where they immediately branch out strongly. The roots parts immersed in the waste water were strongly damaged or had died. They erode in the water and form a plug, which then does not dip or only slightly dips into the water.

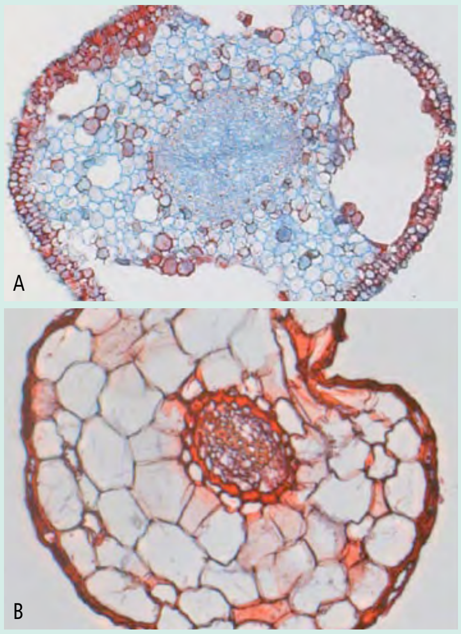
The colour of the immersed roots already indicates that they had died, which was then confirmed by the histological analysis. (s. Figure 5 A and B)

The water from sewers will probably not be the goal of root growth, if it kills the roots so quickly. The penetration of the roots into the pipe above the water level also contrasts the idea that leaking water is the primary cause of damage. The moisture of the few water drops leaving leaking pipes is not sufficient for building up an adequate moisture gradient, since birches or populars need up to 300 litres water per day. Likewise because the root hardly branches out outside the pipe, which is normally the case in moisture gradients. The root also penetrates the side of the pipe connection in rain water conduits but meter-long root system develop every now and then on the conduit base (s. Figure 4). The roots are in a much better condition than in waste water conduit, although there are many dead roots there as well. However these show no decomposition characteristics, but have probably just simply dried. Pure rain water conduits dry out faster than soil in summer during long fair weather periods. Sufficient water is also present outside the pipe during rain. The first excavations suggested that the roots do not grow towards leaking pipes and then into them due to loss of water. But then what is the reason for the root growth? We chose two approaches in our project: IKT researchers measured, which forces roots can actively muster. Pavements and tar coatings lifted by roots are not very informative in this respect, since thermal movements probably create the space, with in-grown roots only maintain.

Figure 3: The roots penetrate the pipe above the medium water level in waste water conduits and immediately branch out strongly.

Figure 4: The roots develop meter-long root trails on the base of rain water conduits.

Figure 5: A section of a root immersed in waste water makes the damage visible under the microscope (A). Comparison: Cross-section of a healthy root (B)



Measuring the root force

The physiological characteristics suggest, that some roots can apply pressures of approximately 6 bar. This was approved by a special test assembly at IKT. Root forces of 5.9 bar were be measured by a pressure sensitive film (s. Figure 6). Thereby the engineers measured in a first step the pressure of roots growing in a continuously decreasing growth space made of plaster (s. Figure 7). In a second step they looked at the pipes. Using similar pressure sensitive films they mesured the surface pressure of different joints while increasing the shear load up to a limit required by standards (s. Figure 8 as an example). The comparision of both results leads to the statement whether the pressure applied by roots can push the seal aside.

Figure 6: Test assembly for the determination of the root force: How far and with which force can the roots penetrate into an ever closer pressure sensitive film?

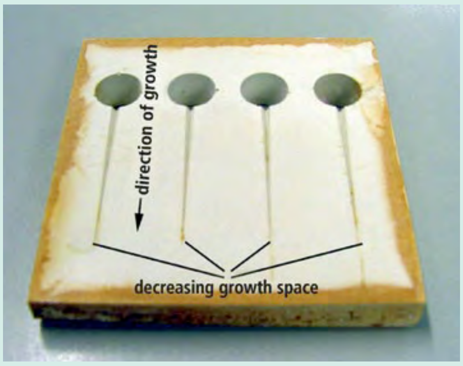


Figure 7: Pressure plate made of plaster

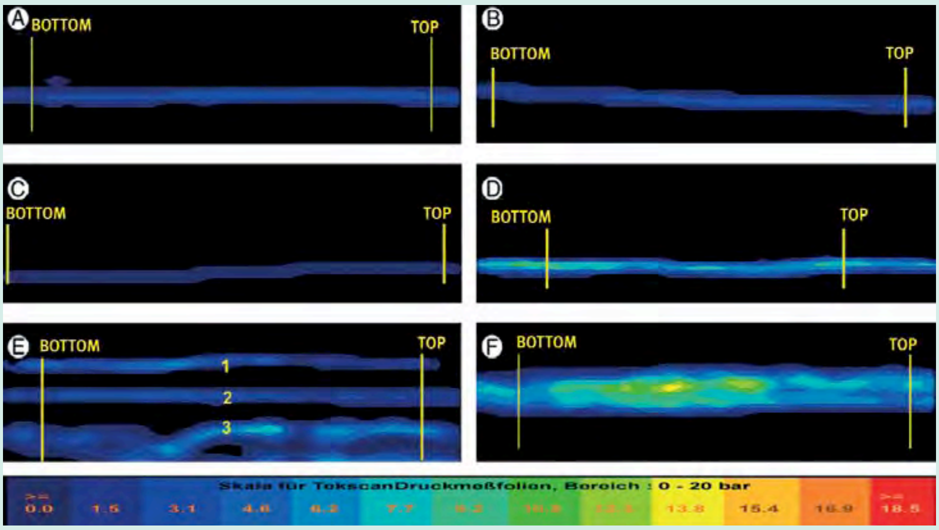


Figure 8: Measuring the changing of pressure and pressure area under shear-load using pressure sensitive films [1] (Tyton connection with a diameter of 150 mm). A Without load: Relevant surface pressure of 6.6 bar. B 1. Step: shear-load of 971 N: Relevant surface pressure of 5.5 bar. C 2. Step: shear-load of 1942 N. Relevant surface pressure of 3.1 bar. D 3. Step: Shear-load of 2914 N. Relevant surface pressure of 3.1 bar. E 4. Step: Shear-load of 4500 N. Relevant surface pressure of 2.6 bar. F After1,5 hours, under a shear-load of 4500 N: No significant change in comparison to E.

At the Ruhr University it was examined how a root in the soil „decides", where to grow. It is well-known that root tips perceive gravity by starch grains, because they sink downwards in the cell. Moisture, temperature and nutrient gradients are probably also important for directional growth. But how does a root find its way around an obstacle, e.g. a stone? There must still be other reasons for this growth, since roots grow into cellars through foundations or through green roofs into rooms, where it is neither damper nor richer in nutrients. Little is known about the behaviour of the roots in soil, since physiological investigations are usually carried out on radicles and in nutritive liquids for practical reasons.

Understanding these processes requires the knowledge of the root tip structure (s. Figure 9 and Figure 10): The root tip is a short multifunction organ. Its root cap (Calyptra) protects the growth zone and consists of desintegrating cells. The initial zone is located below the cap.

The longitudinal growth starts from here and new calyptra cells are also formed. The root hair zone follows the growth and elongation zone. Root hairs are usually short lived, their function is seen as surface enlargement for waterabsorbtion. The so called endodermis is an important root layer. Water is pumped into the conducting tissue of the root in the endodermis cells using energy. Energy is required, because the water absorption must take place against the concentration gradient of ions such as sodium or chloride; otherwise salt crusts would rapidly develop on the leaves, where large amounts of water evaporate. Oxygen must be present or transported to the root, where no photosynthesis takes place, since energy expenditure always means oxygen consumption.

The gradient is actively built up by the endodermis in the root. Surface enlargements take place above all, where the gradient is built up, where ever physiological processes play a role. The root hair surface enlargement is relatively insignificant in this respect. Surface enlargement seems to be

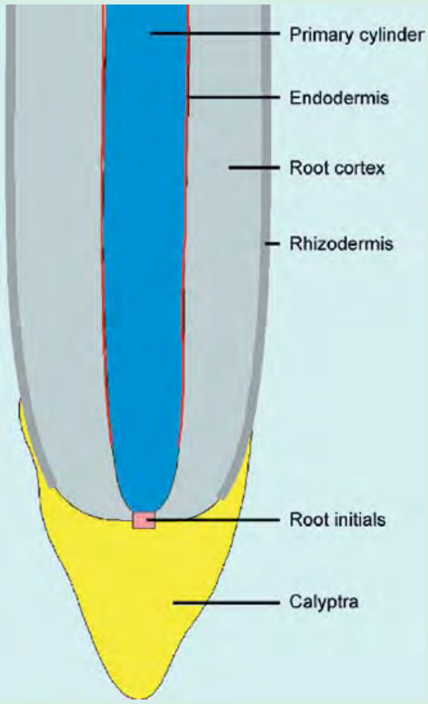


Figure 9: Build-up of the root tip

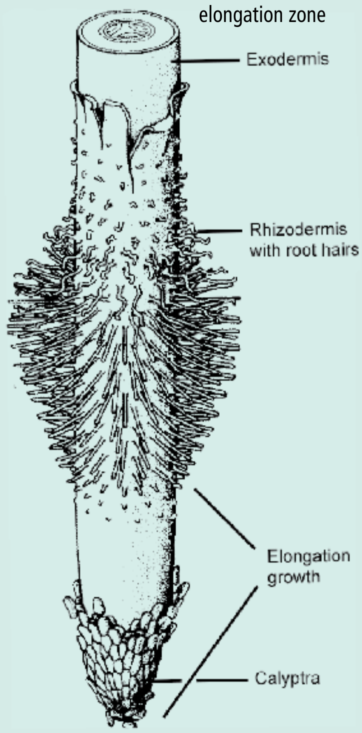


Figure 10: The root hair zone follows the growth and elongation zone

irrelevant in respect to roothairs as the gradient is not performed there. An leek plant forms e.g. over 50 cm long roots, which however do not branch and only exhibit root hairs at the tip. If root hairs would primarily serve for water absorption, then the overall root length increase of the leek plant would be in vain, since the absorbing surface - the root hair zone - only shifts, but does not increase. It seems obvious, that roothairs are predominantly formed for anchoring purposes. They function quasi as counter bearings, when the root tip is pressed into the substrate.

Soil density determines direction of root growth

The root cap has not only a passive protective function during this process. The cells are pressed forwards away from the initials and form a channel, into which the root grows. The root cap is therefore the drilling head of the root. But the root cap consists of dying, isolated cells, particularly within the foremost area. How does this drill find its direction? The calyptra cells are passively pressed forward by cells located farther back. The soil density (substrate) determines the direction of root growth, just as further groups move to where there is room in a football stadium crowd: The roots always grow into the less dense substrate at a density border.

The drilling head can work against this growth trend, although extremely limited, by unilateral growth behind the initial zone. The growth direction is thereby the result of at least two factors - the force of gravity and the substrate density. A dominating factor can sometimes define the growth direction. This happens e.g. if the root reaches a pipe connection. A cavity, which cannot be filled out and compressed, always results prior to the seal due to its construction (s. Figure 11). The root grows into this cavity once it has found it and can only get out again, when this pipe connection area is filled with root mass as densely as or more dense than the surroundings. Whether it then grows into the surrounding substrate or into the pipe, is probably just by chance. But if the root grows around the pipe within the joint and enlarges afterwards due to secondary thickening growth, it blocks its way back to the substrate. It then pushes the rubber seal aside and penetrates inside of the pipe (s. Figure 12).

To achieve better understanding of the relevant cavities between the spigot and the socket of a joint the engineers sliced several connection. They messured the size of the cavities (no substrate density) that could give roots a place to grow (s. Figure 13).

When roots „block“ their own way back.

The pipe connections excavated so far show, that a root can grow in the pipe connection for more than two years, before it grows through the seal into the pipe. We have proven this using the annual rings, which are also formed in roots. These findings confirm our hypothesis, that „Density traps“ - like the pipe connection cavity – lead the roots to the pipe connections. These results have been confirmed in model experiments. Growth areas in the substrate, e.g. pore spaces between the bedding and/or filling material seem to be primarily relevant for forming „Density traps“ and not primarily the degree of mechanical compression, as it is achieved with vibrating rollers or plates. The question of the pipe root fastness must therefore also be regarded in connection with bedding and backfilling. A further important starting point results from the root physiology. Since active transportation processes are carried out in the endodermis, oxygen is used there. Underground plant parts, which exhibit such transportation processes and live under oxygen deficiency, often form complicated aerification tissues. This is however not the case

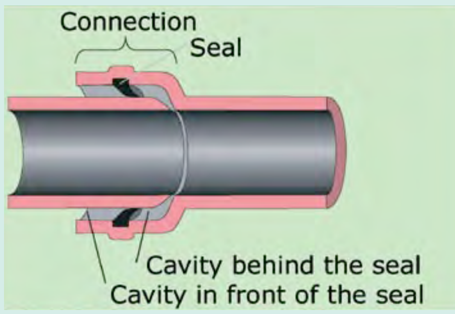


Figure 11: The pipe connection seal is a „Density trap“ for the root.

Figure 12: The root has „blocked“ its way back into the soil itself – the only way out is to push forwards. The root tip pushes the seal aside and grows into the pipe (s. arrow).

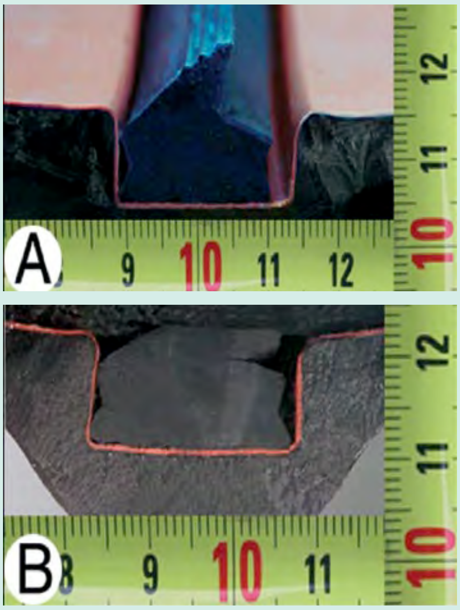


Figure 13: Example for a sliced joint. Socket and seal of a pipe (A). Compressed seal between socket and spigot (B).

for our wood compared to Mangrove plants. The root penetration of the substrate ends, where the oxygen supply falls below a critical limit.

We examined, whether roots perhaps also find pipe connections exclusively along oxygen gradients, since it is known from other investigations, that seals - even if no liquid leaks are present – become permeable for gases over time. The oxygen supply could play a important role by means of pipe systems, particularly in cities, where the gas exchange through the soil surface is strongly reduced by sealing (e.g. road surfaces). We have however so far found no appropriate clues during the excavations.

„Oxygen hypothesis" investigated

This hypothesis could also not be experimentally confirmed yet: We allowed cuttings rooted in clean water, to carry on growing in different waste water concentrations and provided them with oxygen over dialysis tubes. The damaging effect of the waste water could not be compensated and we also did not observe any root growth towards the oxygen source. The experiments do not allow to exclude the „oxygen hypothesis" fully, in case the gas supply of the root should play a role in further experiments, it is a minor one in comparison to the „Density trap model". The „Leak hypothesis" favoured so far could however not be confirmed in our investigations. Not only does the rooting process into the pipes oppose this, the quantities of leaking water also probably do not stimulate the roots sufficiently. Apart from that waste water pipe leaks usually close quickly again. The necessary pressures for noteworthy seeping losses are not achieved at water levels of usually less than 20 cm in the pipe. Penetrating ground water is more of a problem, because the groundwater pressure can considerably exceed the waste water pressure of deeply buried pipes. We are now looking for experimental alternatives to the natural processes, because the growth of roots into conduits takes ten and more years and our results - as in all research projects - have to be presented within approximately two years. We want to shorten the investigation period, using suitable model organisms plentifully available in the RUB Botanical Garden, and by model tests. This is absolutely necessary, because mistakes made in pipe construction during the next ten years will cause immense costs in the coming 50 years.

Consequences for laying pipes

A whole set of consequences for pipe laying can already be deduced from the present results. The rooting problem is not only a question of the seal contact pressure. Geometry and size of the cavity prior to the pipe connection seal play a crucial role, if the „Density trap model" can be further confirmed. The bedding and filling material for pipe trenches are however also of great importance according to this model. The whole pipe trench represents a „Density trap", if the grain size of the filling material offers sufficient pore channels, which roots can easily penetrate: The roots can then more or less grow parallel to the pipe and reach as a consequence nearly all pipe connections. Seal design, bedding and backfilling are therefore under the criterion of the independent variables in pipe laying, but closely inter-dependent factors. It seems justified to hope, that the results of the study will show us, how this pipe damages can be avoided in the future [2].

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IKT - Institute for Underground Infrastructure

ABOUT IKT

IKT - Institute for Underground Infrastructure is a research, consultancy and testing institute specialized in the field of sewers. It is neutral and independent and operates on a non-profit basis. It is oriented towards practical applications and works on issues surrounding underground pipe construction. Its key focus is centred on sewage systems. IKT provides scientifically backed analysis and advice.

IKT has been established in 1994 as a spin-off from Bochum University, Germany.

The initial funding for setting up the institute has been provided by the Ministry for the Environment of the State of North-Rhine Westphalia, Germany's largest federal state.

However, IKT is not owned by the Government. Its owners are two associations which are again non-profit organizations of their own:

a) IKT-Association of Network Operators: Members are about 100 cities, among them Berlin, Hamburg, Cologne and London (Thames Water). They hold together 66.6% of IKT.

b) IKT-Association of Industry and Service Providers: Members are about 60 companies. They hold together 33.3% of IKT.

You can find information on projects and services at:
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