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Roots and buildings

C. Mattheck, I. Tesari & K. Bethge
Institute for Materials Research II
Forschungszentrum Karlsruhe, Germany.

Abstract

Plants and especially trees enrich buildings. They give shade and improve the ambience, but also can cause damage to the buildings. Roots are biological soil anchorages. The wind load, which may amount to several metric tons and acts on lever arms that may exceed 50 meters in length, causes a high bending moment at the butt of the stem. This bending moment is distributed over the roots into the soil. Thereby, the roots often use structures in the surroundings of the tree like pipes, walls, etc., for anchoring and apply loads to these structures. Loading grows with tree height and root diameter, and when the loading caused by the roots exceeds the strength of the structure, it will fail. Structures of stone are especially sensitive against fatigue failure. In the present paper, examples of such root/building interactions will be given. Furthermore, results of a variant of the Soft Kill Option (SKO) will be presented. The method adapted to soil problems can be used for the optimization of technical soil anchors as well as for the simulation of mechanically stimulated root anchorage.

1 Introduction

It is well known that under certain conditions serious damage can be caused to buildings by neighbouring trees. It is easy to cut down the tree crown and to reduce the damage caused by wind thrown trees and broken branches. But the roots, the hidden part of the tree, have also to be taken into account. In addition to the subsidence of buildings by drying the soil [1], which is not discussed in this paper, roots can also harm buildings by direct interaction. For the appraisal of the endangerment of buildings by roots it is necessary to know their material properties, range and last but not least their growth principles. However, cracks in walls and buildings provide an insight into the kind and direction of the acting forces.

2 Root growth

2.1 Growth regulators

A tree collects the wind load with its leaves and branches and transfers it to the trunk via strong branches. The trunk conducts the wind load downwards. At the butt, the wind load is first transferred to the strong roots and then to the fine roots. At a certain distance from the tree, the small shear strength of the soil alone has to withstand the wind load. This shear strength determines the range of the mechanically active roots. Furthermore, it must be noted that various biological growth regulators influence the root distribution. Growth regulators of minor importance for this field of work, such as chemotropism, thermotropism, etc. [2] shall not be dealt with by the present paper. However, hydrotropism and mechanical control of the root growth play a major role. They are found to be in competition and sometimes even counteract each other. The hydrotropism which lets the roots grow in the direction of the moisture gradients, but avoids stagnant moisture is predominant. As a consequence, mechanically unfavorable or at least material-consuming root distributions develop.

2.2 Self-optimization of roots

Trees are characterized by a homogeneous stress distribution on the tree surface. They grow such that both local high stresses (potential points of rupture) as well as locally small stresses (excessive use of material) are avoided. This was demonstrated by Metzger [3] in 1893 already, based on the taper of spruce trunks. According to Mattheck and his co-workers [4], the cross-section of each root adapts to the load acting on it.
For instance, a root subjected to bending load only has an 8-shaped cross-section which is similar to that of an I-beam used for construction purposes.

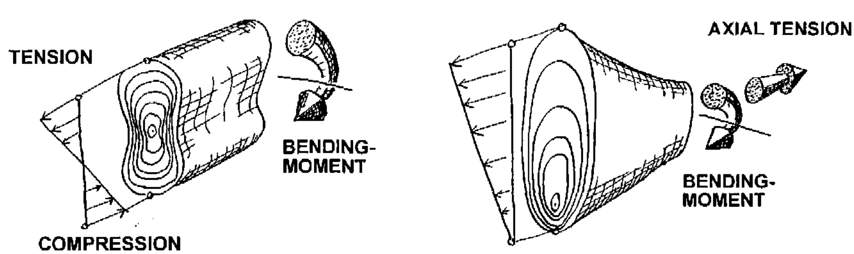

Figure 1: The about symmetrical 8-shape indicates a pure bending load, the combination of tension and bending load causes root growth to take place preferably on the upper side.

If, however, a combined tension and bending load acts on the tree root, root growth takes place on the upper side exclusively, where the tensile stresses add up. On the underside hardly any or no root growth occurs. Here, the tensile stresses are neutralized by the compressive stresses due to the bending load.

In addition to the optimization of the cross-section of each individual root, there is also an optimum distribution of the roots in the soil [4, 5]. This distribution is probably based on the Mohr-Coulomb law of soil mechanics, according to which compressed soil has a higher shear strength than uncompressed soil or soil which is subjected to a slight tensile load.

Matthias Teschner [5] calculated the influence of the load on the root morphology, i.e. on the root arrangement in the soil. He used the SKO-Method (Soft Kill Option) [6] adapted to soil problems. The Method can be used for the optimization of technical soil anchors as well as for the simulation of mechanically stimulated root anchorage. The modificated SKO-Method considers the special failing behaviour of soils. The shear stress required for slip depends on the cohesion and linearly upon the normal pressure on the slip surface (Mohr-Coulomb hypothesis). For the optimized design a constant equivalent stress is achieved in the soil close to the root-plate. In this favoured case there is no point at which failure is more probable than at another point.

The result is represented in the following figure and to be understood as qualitative and relative statement (due to the two-dimensional calculation model used).

Trees that are subjected to wind loads on one side only or leaning trees subjected to a one-side bending load due to gravitation form more, longer and stronger roots on the tension side of the bend with a view to reinforce the soil having a lower shear strength on this side. This illustrates, how sensitively the trees react to a reduction of the shear strength of the soil (Fig. 2).

For the same reason more and longer roots are required for reinforcing the soil on the windward side (main wind direction) of trees.

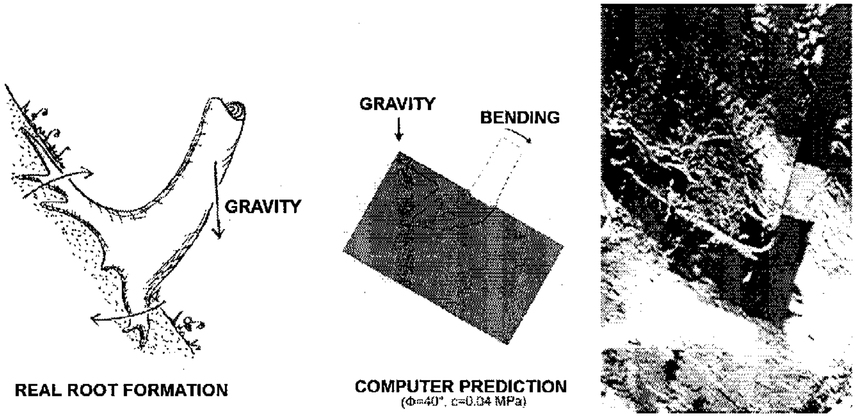

Figure 2: More and longer roots are required for reinforcing the soil with a lower shear strength. More roots are required uphill.

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2.3 Biological and mechanical root ranges

2.3.1 Root ranges of various trees according to Cutler and Richardson

Based on the statistical data of root-induced damage to buildings in England, Cutler and Richardson [7] determined the root ranges of various types of trees, which are represented more clearly by the bar chart below. The root ranges as measured in the cases of damages to buildings are shown in Fig. 3.

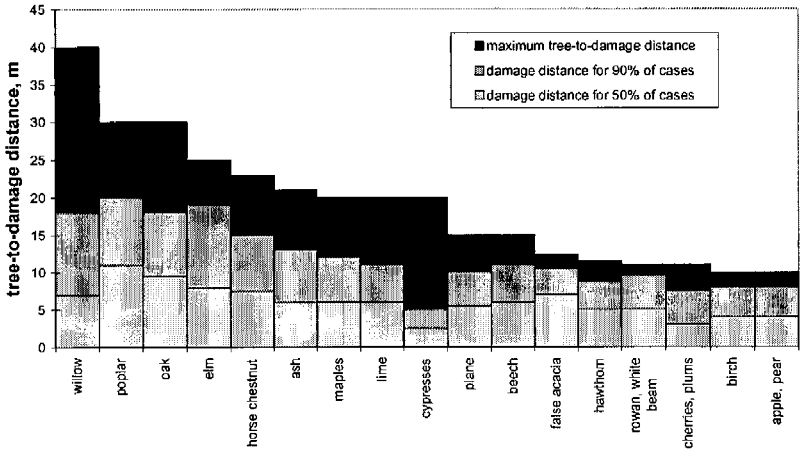

Figure 3: Distances between damaged buildings and the damage-causing trees [7].

The maximum ranges and varying percentages of the damage ranges are represented in a self-explaining manner. Maximum ranges of up to 40 m are reached for willows, for poplars the maximum ranges amount to up to 30 m. For limes damage ranges of up to 20 m were found. It must be noticed that these values represent damage ranges. The actual maximum ranges are supposed to be somewhat larger. Load introductions into pipelines are supposed to be limited above all to the range of the mechanically active root plate.

2.3.2 Mechanically active root plate and its modifications in urban areas

With an increasing distance from the trees, the root penetration intensity of the soil decreases. Finally, at a certain distance, the tree is surrounded by soil only.
There is, however, a certain critical root density, at which the soil is no longer reinforced sufficiently by the roots during stormy or stormy and rainy loads. The resulting circumferential windward soil cracks may eventually give rise to wind throw. With an increasing wind load, these soil cracks become the rupture edge of the root plate. According to a worldwide field study covering about 2500 thrown trees of various types, confirming about 1000 trees thrown by the Forestry Commission of England, there is a relationship between the trunk radius measured above the butt and the radius of the root plate turned out of the soil on the windward side (Fig. 4).

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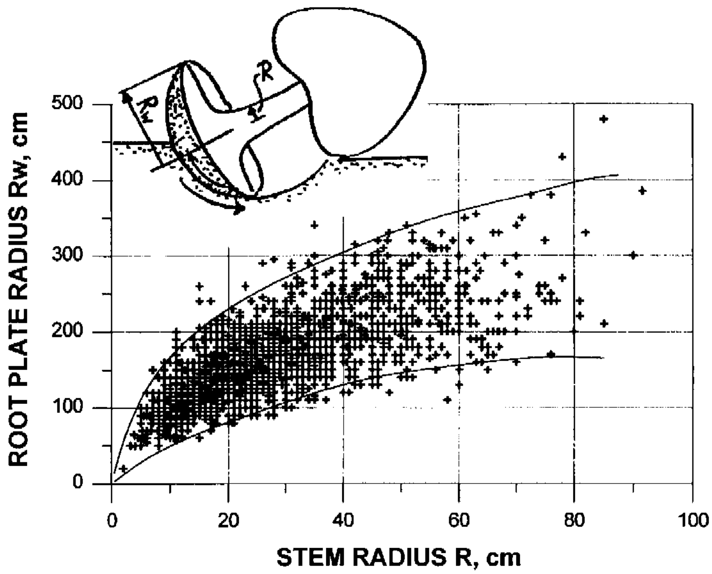

Figure 4: The mechanically active root plate as a function of the trunk radius.

Mechanical fatigue damage to pipelines may be limited to the close surroundings and probably even to the inside of this root plate. Unfortunately, no circular root plates develop in urban areas. Rectangular tree disks, curbstones etc. modify the root ranges. Lifted asphalt and cracks in adjacent walls may be indications of roots passing below.

2.4 Penetration potential and longitudinal and transverse forces of the root

One of the authors saw spruce roots breaking rocks in the Rocky Mountains and throwing rather heavy stones on the streets. The best and easiest-to-quantify experiment known to the authors, however, is the root in the neck of a beer bottle from the collection of the authors (Fig. 5).

With its mucous membrane which minimizes the friction of the root tip due to longitudinal growth, the root penetrates into the pre-compressed gap of the rubber seal and reaches the outside of the bottle. The subsequent thickness growth of the root spreads the pre-stressed spring catch of the bottle. An experimental analysis of the mechanical conditions prevailing indicates a transverse force of 114 N. This rather accidental beer bottle experiment was repeated by systematic experiments with living roots. The post-graduate student Gernot Bruder and Örjan Stal from the Swedish University of Arboricultural Sciences fixed spring-stressed screw clamps around tree roots and left them for two years with the living tree. The evaluation of spring compression yielded a surface pressure of the root of about 0.7 MPa. This is in good agreement with the beer bottle value which corresponds to a surface pressure of about 0.4 - 0.5 MPa.

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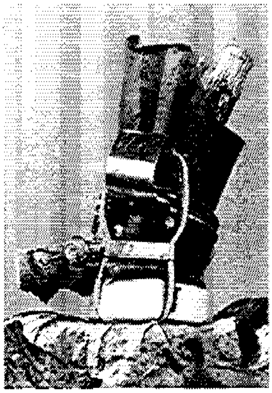

Figure 5: A root grows into the broken neck of a beer bottle, perforates the rubber seal and the spring catch and spreads it (Picture: [8]).

The longitudinal forces even of smaller roots should not be underestimated. In Fig. 6, the rupture load under tension is shown as a function of the root radius. A root of some 4 cm in thickness may lift about two elephants. Hence, trenching damage even of smaller roots may well be safety-relevant.

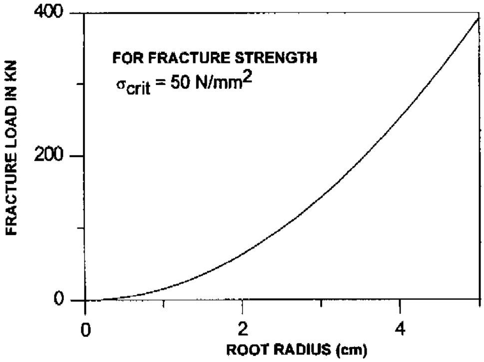

Figure 6: Root radius and breaking load under tension of a root of 50 MPa (50 N/mm^2) tensile strength.

3 Interaction between tree roots and pipes

Tree roots, as biological load carriers, tend to grow into a state of even stress distribution on the surface on a time average. If the constant stress state is disturbed, for instance by mechanical contact, the tree hurries to attach more material (locally thicker tree rings) in the overloaded places in order to restore the even load distribution.

A service pipeline brought into the soil close to a nearby tree is a welcome mechanical partner which makes anchorage much easier for the tree. The most dangerous interaction with respect to pipe failure is the tendril which grows under the pipe and lifts it at each wind gust. This tendril formation lead to a gas explosion in 1993 in a North German city. The SKO simulation shows the formation of tendrils which pass under the pipe when the pipe is situated on the windward side of the tree (Fig. 7). When the pipeline is on the lee side of the tree, the roots form a compression prop which pushes the pipe down (Fig. 8). Diggings at trees in the neighbourhood of the accident showed that the SKO computer predictions were correct also for the trees growing there.

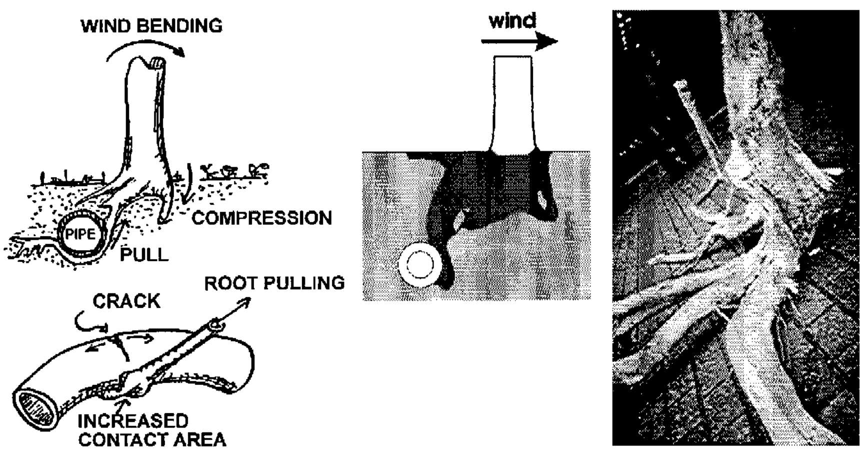

Figure 7: Tendril formation at a pipe located on the windward side of the tree.

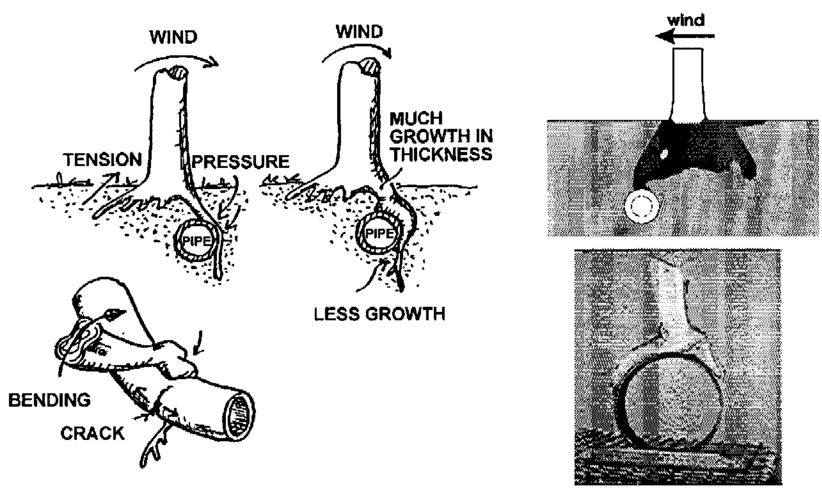

Figure 8: Pressure cushion formation at a pipe on the leeward side of the tree.

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In a situation as shown in Fig. 7, a sudden load is introduced into a pipeline located on the windward side of the tree by sagging (during relief) and tightening (during swaying in the wind direction). This sudden dynamic excess of the wind load introduced is generated by the acceleration of the tree crown by the wind with the root sling still sagging. This acceleration is suddenly delayed by the tightening of the sling – i.e., upon its contact with the pipeline. The forces of inertia of the wind-accelerated tree are transferred to the structure in addition to the wind load.

4 Interaction between tree roots and walls

Cracks caused by root growth can usually be distinguished from settlement cracks caused by soil drying [1], particularly by their distribution and because settlement produces a downward movement whereas roots lift the structure. The main cracks are located at the top, secondary cracks can occur at the bottom of the wall as it is shown in the drawing (Fig. 9). The cracks are located in areas which are loaded by tension.
As far as the interaction with buildings is concerned, the small fatigue strength of the brickwork against the fatigue loads introduced by the root also plays a major role. Even small roots may cause damage to the building by fatigue load.

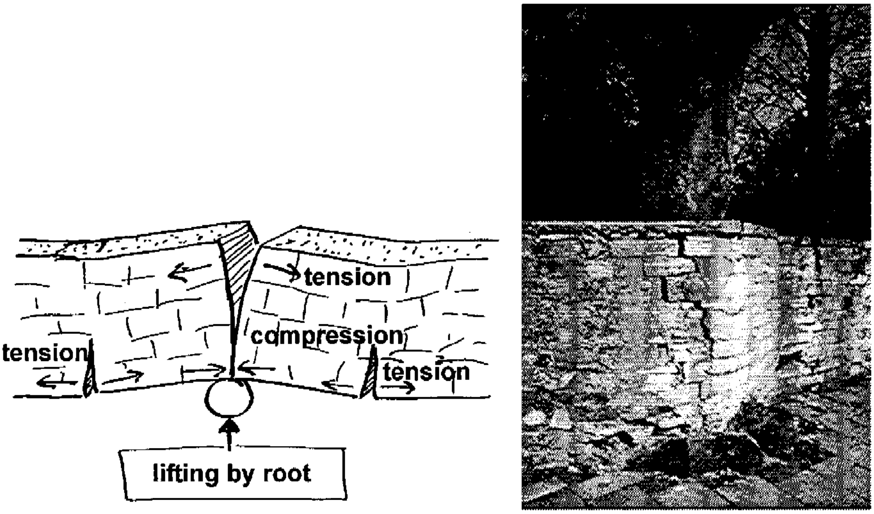

Figure 9: Roots can lift heavy loads. The induced bending stresses cause cracks.

Against a wall pressing roots (lateral force) can cause different crack formations. Vertical cracks on the outer side of the wall are easy to detect (Fig. 10 and Fig. 11 left side). But hidden damage (horizontal cracks, Fig. 11 right side) can also be caused by this roots.

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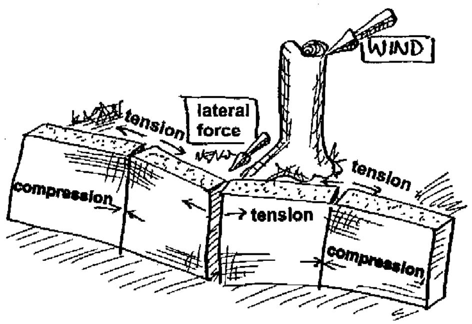

Figure 10: Vertical crack caused by a root pressing against the wall.

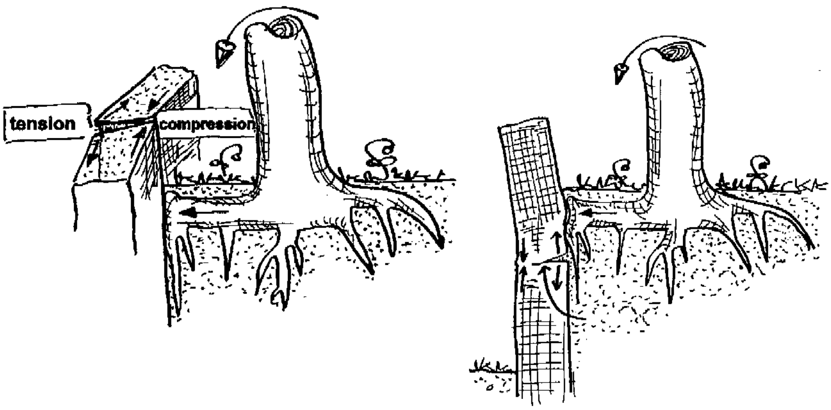

Figure 11: Easy to detect and hidden cracks caused by roots pressing against walls.

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