Biomimicry and Structural Analysis of Rooted Structures in Nature

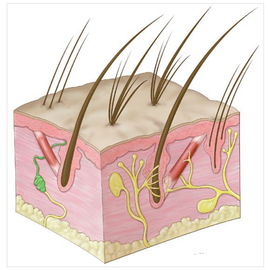
Subrata Deb Nath and Michael M Porter*

Dept. of Mechanical Engineering, Clemson University

Plant Root- Carrot

Bony Root- Tooth

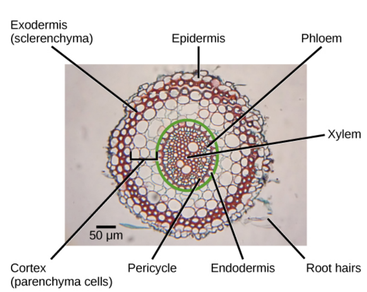
Keratinous Root- Hair



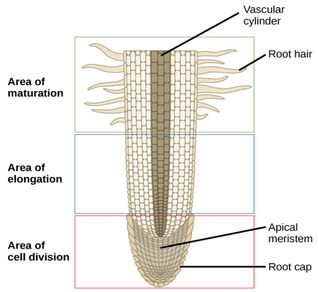
Source: wolfcreek family farm & Yesko

Abstract

- Biomimicry is a modern research area where designs in nature inspire engineers and scientists to come up with new ideas, solutions and innovations.
- We will attempt to mimic selected natural rooted structures, such as plant roots (plants to soil), horns, whiskers, and nails (keratinous structures to skin), and antlers, teeth, and ivory (bony tissue to bone and muscle).
- We are grouping material and geometric properties of natural rooted structures to categorize their relationships through root length, diameter, and elastic modulus and strength. We have studied different root structures and classified them according to their directional and physical position within the grounding substrate.
- Using computer-aided design software we modeled simplified root structures and plan to develop multi-material physical prototypes using a 3-D printer.
- We will compare the rooted structures via tension, shear, and bending test to determine the effect of geometric shape and mechanical properties on their anchorage properties.



Cross section of a Root



Parts of a Root

Source: cnx.org

Plant Root Anatomy

- Four different type of cells can be found in the cross section-
- Epidermis cells- Outermost layer, provide protection against dehydration and germ invasion.
- Cortex- The section is mainly a collection of parenchyma cells. There are extra and intracellular routes in the cortex zone so that water can reach from the epidermis to endodermis.
- Endodermis- It regulates the amount water and minerals in the vascular tissues of trees.
- Pericycle- Lateral roots starts from the pericycle by cell division and increase surface area of tree base.
- Xylem & Phloem- In the central zone of the root, there are tubules of xylem and phloem cells. Their main functions are to transport water, minerals and sugar throughout the tree.

Vertical Arrangement

By continuous cell division and maturation, roots tend to increase in size and length. The furthest part of the root from the seed is known as the area of cell division and nearest part is known as that of cell maturation. The middle section is known as area of cell elongation. Lateral roots and root hairs also proceed from here. The root cap is continuously replaced as root continues to grow.

Types of Plant Roots

We have classified the roots in two root systems according to their position-

- **Underground root system**
- **Aboveground root system**

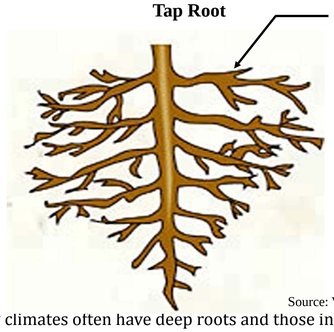
There are two main types of underground root systems-

- **Taproot system**
- **Fibrous root system**

The taproot system consists of one main longitudinal root and its several branches which grow across the soil. These smaller roots are known as lateral roots. Many woody trees and flowering plants have taproot systems. This type of root system is deeper than the fibrous root system which is highly branched and generally located closer to the soil surface. Many grasses and produce have fibrous or adventitious root systems. Some plants have a system of both tap and fibrous roots.

Fibrous Root

Tap Root



Source: Visual Dictionary

- From the biological view point, plants in dry climates often have deep roots and those in wet climates often have shallow roots.
- From the mechanical view point, bigger trees often have deeper or wider root systems to resist against bending.

Aerial Root- Bayan Tree

Props Root- Maize

Stilt Root- Walking Palm

Source: Wikipedia

Aboveground root systems stand above the ground; though they do not always start growing above the ground. Many aboveground roots collect water and nutrients directly from the air. For example, mangrove aerial roots help aerate the plant. Aboveground roots also have a structural function such as aerial, prop and stilt roots. They act as a column to support the stem to keep the plant upright.

Mechanical Aspects of Roots

Nicoll and Ray (1996) found that root systems are adaptive to wind action-

- Root systems are heavier on the leeward side than the windward side of the Sitka spruce.
- This uneven mass distribution gives the root cross section the shape of a T beam.
- Many roots also develop cross sectional shapes similar to I beams. This helps the tree resist flexure.

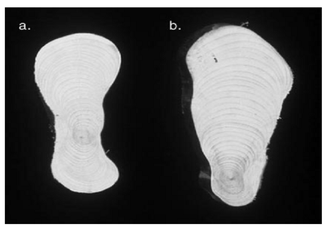
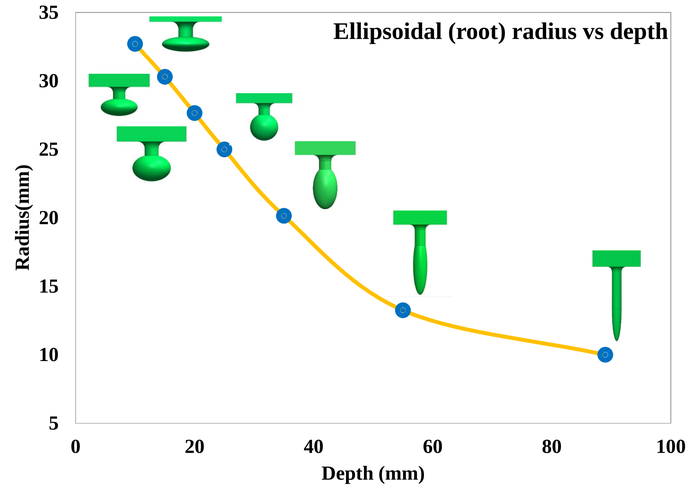
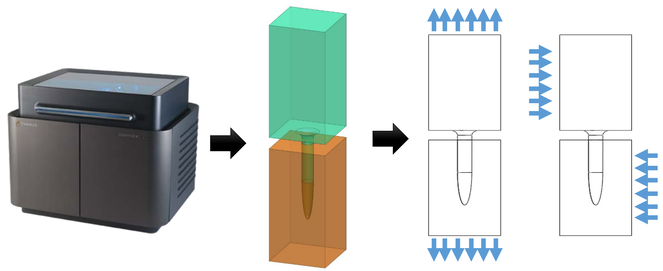


Figure- Roots shaped of a) T beam b) I Beam

Computer Aided Model

- Thus far, we have modeled the “plant root structure” as ellipsoids of varying the depth and radius.
- The surface area is constant for all root structures.
- The tensile, shear, and bending tests will be performed to find-relationships between geometrical and mechanical properties of the components.





3D Printer

Multi-Material Root Model

Tensile and Shear Experiments

Future Work

- Starting with simplified structures, we will eventually consider complex structures with numerous roots or ellipsoids.
- We will also consider different shapes, such as conical root structures.
- We will test various materials with different elastic moduli & yield strengths.

Potential Application

- New geometries might be introduced to anchor a structure into the ground. For instance, piles for bridges and electricity distribution towers might be designed to have rooted structures for more stability.
- New types of joining mechanisms can be introduced for multi-material joining where adhesives and nut-and-bolt fixtures are not effective.

References

- Kraehmer, H. and P. Baur "Vegetative Weed Reproduction." Weed Anatomy: 203-205
- Bergmann, D., et al. (2009). "Grass rhizosheaths: associated bacterial communities and potential for nitrogen fixation." Western North American Naturalist 69(1): 105-114.
- Nicoll, B. C. and D. Ray (1996). "Adaptive growth of tree root systems in response to wind action and site conditions." Tree physiology 16(11): 891-898.