Mathematical Statistician and Engineering Applications
ISSN: 2094-0343
2326-9865

Analysis of Crutches System to Select and Guide the Design of Crutches Suitable for Different Sizes of Siege Timber and Development of Tree Crutches

[1]Napassara Lattikapong, [2]Onvalee Amornleetrakul, [3] Sippawich Kambung

[1] [2] [3] King Mongkut's University of Technology North Bangkok.

[1]l.napas.d@gmail.com, [2]onvalee.a@archd.kmutnb.ac.th,
[3]sippawich.k@archd.kmutnb.ac.th

Article Info
Page Number: 6436-6448
Publication Issue:
Vol. 71 No. 4 (2022)

Article History
Article Received: 25 March 2022
Revised: 30 April 2022
Accepted: 15 June 2022
Publication: 19 August 2022

Abstract
Root system is the most important of trees for absorb nutrients and were anchorage to growth tree. But when the urban trees were transplanting, they always moved out the taproot affect to reduces tree anchorage. In some cases, severe wind loads can trigger uprooting affects the life and property of users. Therefore, the urban trees must be supported by crutches. However, about designing the crutches some users never know about how to install and usability as well as the duration of use. The results of this research show the difference in suitability for use of three varies tree crutches are the pavilion tree crutches, the implant crutches, and wire rope anchors. By calculating the size of the tree and bracing, the gravity of the tree, process and complexity of work, and sustainability of materials. In order that users can understand and apply and control the installation for various tree sizing to the design of their own landscape area.
Keywords: Bracing system, Landscape, Tree structure.

I. INTRODUCTION

The most of users tend to choose to install crutches out of their budget without knowing the actual suitability of the crutches in relation to the size of the tree, space for installation or even the safety of users. Mr. Tharadol Thunduan said that in fact the trees in the city had no taproots. By the nature of trees in a tropical climate when they grow to a certain point, the taproot will disappear. Another reason is the soil conditions in Bangkok are not favorable for the growth of taproots [10] When the taproot system is deep into the soil to meet the groundwater level, taproots will stop growing because they cannot breathe. When a tree grows to a perennial plant, the taproot disappears and it creates surface branches until it grows around the tree which the branch roots play an important role in helping the tree not to fall. Therefore, the real important function of the tree support system is supporting the plant until the roots are fully grown. This is because most of the perennial burrows are cut off the taproots during the siege. But for the trees along the public road, plaster will be poured over the tree until there is no space left for the roots to grow. The roots cannot grow completely. Therefore, it still has to install a long-term bracing system.

Pirone (1948) suggested that newly planted lumber should be supported immediately to prevent

the trunk from tilting or shifting in the presence of wind. This interferes with the root system and hinders the growth of the tree. Supporting the plant would help to stabilize the soil of the digging or planting tree, not to sway or be blown away by the wind on a windy day. The slightest movement of the soil bulge may cause the newly sprouted root capillary in the mound [14]

The degree of damage to trees in cities and forests was quite different. Falling urban trees will result in damage to the lives and property of people nearby. Causes of tree damage to uprooting are: the tree leaning towards the sunlight, moving clay, unbalanced leaf bushes from pruning, nearby trees were moved, the tree was hit by a vehicle or heavy machinery and the frequent winds caused the trees to bend or cause the center of gravity to move. Carpenter et al. [1] found that small burrowing plants with soil attached to their root system and potted plants did not need support. Except for siege timber with trunks larger than 6 inches.

Tree different support systems can be divided into 3 types: canopy tree support system, artificial tree support system and a sling-type tree support system. For perennials 6 months to 1 year old, no more than 6 inches diameter, the trunk is mostly bare-rooted making them extremely sensitive to the environment. Therefore, bracing should be carried out for 1 to 2 years until the root system is established and expanded. Trees with a trunk diameter of more than 6 inches are often perennial dug plants and is heavy enough to cause severe damage, especially during storms or fell from the weight of itself [2]. It can be noticed that trees are tilted for different reasons and factors. Therefore, having the right plant support system can reduce the risk of falling trees.

Brickell (2007) suggested that shrubs usually do not need support unless they have a large canopy. This must be supported during the first 1-2 years until the roots begin to spread and the tree is stable. The best method for low-branched shrubs should be supported by three columns around the canopy [13].

There is a lot of research described the forces acting on trees. Such forces affect trees in various way. Gravity force of the earth (Gravity Force) is the force that affects the balance or persistence of trees including the food conveying system which makes each tree species the highest height is 25 – 100 meters [5].

There was a several of researches described the forces acting on tree by such force affecting trees in various fields Gravity of the Earth (Gravity Force : CG) is the force that affects the balance or persistence of trees. Including the food conveying system which makes each tree species the highest height is 25 – 100 meters [5] If a tree is a pillar, the force acting until the tree is damaged can occur in 3 forms as shown in Figure 1.

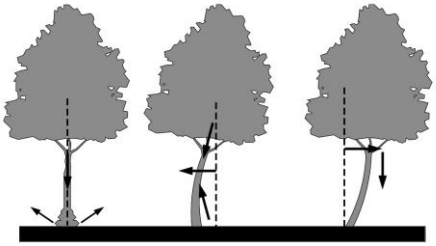

Fig.1 Damage of a tree from various forces

(a) Columns that fail with compression – compression

(b) Columns that failed by "Euler's deflection", a condition in which one side experiences a pulling force

(c) Columns that failed by gaining lateral force in the form of a cantilever which causes the beam to bend when bent, its own weight creates a rotating moment around the base.

Wood has a compressive strength of approximately 50 MPa and a density of approximately 500 kg/m^3 [5] which is better than brick. If considering the compressive strength alone according to Fig. 1a, the tree may be up to 10 km in height whereas the tree with the deflection in Fig. 1b follows the standard Euler Buckling equation [8] Trees can reach a height of 100 meters at a cross section of 1 meter. Gravity through the buckling equation has been found not to have much effect on buckling. The most probable damage to the tree, according to Fig. 1c, Greenhill's [3] analysis is the incidence of a particular force on the top of the tree and move the center of gravity to the side topple the tree. At the same time, there will be resistance to elastic recovery in the wood. This is the behavior of the self-loaded cantilever beam.

In practice, using the standard equation and the standard relationship between Young's modulus and density, a tree with a diameter of 1 meter may be up to 120 meters tall before the tree's wood undergoes the maximum tolerable stress. In real situations, gravity increases the damage faster when tilted away from the center of gravity [9]

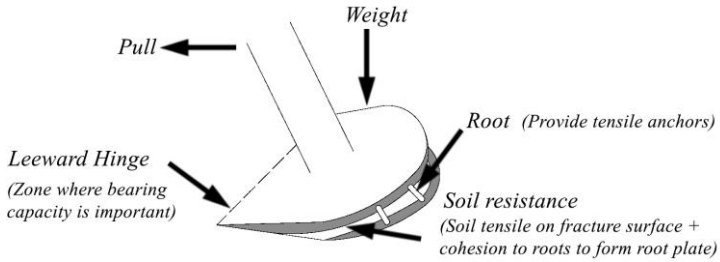

Fig.2 show shallow root system (Shallow-rooted) to hold the plant to the ground.

Jonathan Ramos Rivera [4] said there are four main components to the anchorage of such systems (Figure 2):

i) The bearing capacity of the soil.

ii) The resistance of the leeward hinge to bending.

iii) The resistance of the windward roots, especially the sinker, to uprooting.

iv) The mass of the root plate-soil plate.

All of the above explanations It describes a tree that exists naturally. It has a taproot, branching and capillary root system which can make the tree resistant to wind and stand tall. Including naturally occurring trees, if born in the forest, they will block each other's winds and have taproots including ground cover that acts as a support for the topsoil [9]

Vogel [7] said: Trees can stand upright to withstand the wind in many ways:

1.) With a long, hard taproot extending from the trunk down to the bottom trees can take advantage of the shear and compressive strength of the soil. And will work with the lateral roots to make the soil adhesion well.

2.) The entanglement of surrounding plants such as vines or other plants behaves like a diagonal cable from stem to root. Which will help support the tree Trees with such traction bracing tend to have thin trunks relative to their height.

3.) The lateral roots at ground level are very wide. And the canopy of many large temperate broadleaf trees is lower in temperate and the leaves are thicker. Which it will work with the pressure of its weight acting on the force of the earth's suction. These broad and heavy base trees usually have a dense trunk and do not bend when exposed to the wind. In this case, gravity performs another function which allows the tree to stand upright.

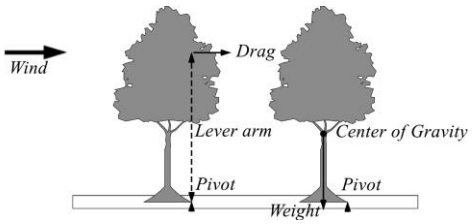

Fig.3 The Center of Gravity of the tree

In rooting, the firmly supported trees rotate around the horizontal axis to the side of the trunk axis as shown in Figure 3. The turning moment have to exceed the stabilizing moment – the product of drag force times the height of the center of canopy must exceed the product of the weight of tree times the distance from the stem to the pivot axis [6].

Jonathan Ramos Rivera [4] said there are three main factors causing tree damage: a) changes in soil shear strength, b) Damage from decay in trees and c) complex combination of root bonds in soil. To support the tree, the tree should not be held so tightly that it cannot be swayed by the wind. Because the trees are unable to adapt to the environment. If there is no support when the wind blows, the trees will be weak to the wind. cause the development of trees will have a larger and stronger trunk. Therefore, securing the stems at a distance so that they can sway slightly when exposed to the wind will make them stronger and grow faster [1]. If considering the perennial plants that are planted in the house, park or along the road nowadays, they are often dug around which has no taproot. This causes the root system attached to the soil to be

lost. And the countries in hot humid tropics and have a rainy season like Thailand can make the soil soft and causing the plants to cling to the soil very poorly. Using crutches or the root implant system is therefore very important to the trees in the city.

II. OBJECTIVES

(1) To analyze the guidelines for choosing a tree support system that is suitable for the size of the siege timber.

(2) To analyze the tree support system that is suitable for the installation area.

III. METHODOLOGY

This research project had four steps: 1) Study concepts and analyze problems about planting the urban perennials, damage caused by perennial trees, improper plant support system. 2) Collect relevant information and research such as the factors that cause trees to fall and 3 types of tree support system: marquee bracing, implant bracing and sling bracing. 3) Analyze and compare the data; the Center of Gravity of the trees, materials, the weight of the tree and the force acting, weight bearing of the tree support system. 4) Conclusion about suitability of the installation of bracing systems for perennial plants.

IV. RESULTS

The center of gravity of tree was analyzed in relation with the size of the siege timber. Calculation of the size of the soil digger of the excavated timber can be found from diameter of the trunk close to the soil is multiplied by 3 to get the radius of the cultivated soil. The depth of the cultivated soil is increased by 1 from 3 of radius of the cultivated soil [15]. When installing a tree bracing system, the center of gravity of the tree can be changed and help the tree grow better than before. Many research exposed that trees in the forest can reach the height of 10 kilometers due to the dense number of trees that compete for sunlight. But the canopy of the trees in the city was not so dense that it blocked the sunlight of the other trees which makes it grow more broadly than growing upwards. Generally planting the trees in the city will cut off the height of the trees when planted.

a) In the case of trees that height are 5 - 15 meters, the height will be cut off by 1/4 of the total height.

b) In the case of trees that height are 15 - 25 meters, the height will be cut off by 1/3 of the total height.

c) In the case of trees that height are 25 - 35 meters, the height will be cut off by 1/2 of the total height.

d) In the case of trees that are higher than 35 meters, the height will be cut off by 2/3 of the total height.

Most of the trees in the city or in the allotment project often used to planting the siege timber height of about 8 to 10 meters and trim the canopy to no more than 4 meters to make it convenient and safe for transportation and planting. Approximate dimensions are shown in Figure 4.

1. Guidelines for calculating force acting on crutches system.

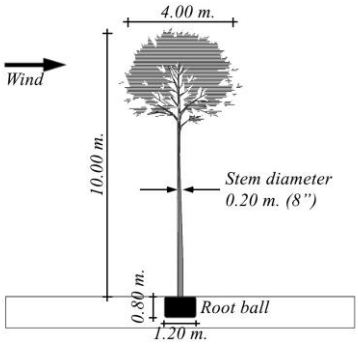

Fig.4 The size of the trees used as a guideline for calculations.

1.1 Determination of the weight of perennials. Average weight of hardwood is 900 kg/m^3.The volume of the trunk from the equation $\pi r_t^2 h$ when r_t is stem radius and h is tree height. It's was 288 kg. and the volume of the root ball from equation was 0.91 m^3. Moist loam weight is 1,280 kg/m^3.

The volume of the trunk

$$\pi r_t^{\,2} h$$

r_t stem radius

h tree height

= (3.142 x 0.12) x 10

= 0.32 m^3

= 0.32 x 900

= 288 kg.

The volume of the root ball

$$\pi r_r^{\,2} h$$

r_r root ball radius

= (3.142 x 0.62) x 0.8

= 0.91 m^3

Weight of the root ball = (0.455 x 900)+(0.455 x 1,280)

= 991.9 kg. ≈ 992 kg.

Wright of trunk+root ball= 288 + 992

= 1,280 kg.

Approximately the weight of branches, stem and leaves was 30 percent of perennials weight.

= 1,280 x 0.30

= 384 kg.

The total weight of tree = 1,280 + 384

= 1,664 kg.

Approximately that the root ball has a root weight to the soil weight of 1:1. So, the total trunk weight and the weight of the soil is 1,280 kg. And approximately the weight of branches, stem and leaves was 30 percent of perennials weight. Then the total weight of tree is 1,664 kg. and shown in Figure 5.

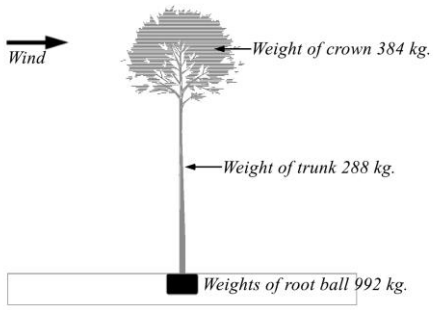

Fig.5 The weight of the tree in each section.

1.2 Analysis of the center of gravity and uprooting trees. Analysis of trees weight found that tree size as above The weight of the stem is greater than the weight of the stem and the leaf branches. Cause the center of gravity: CG. To be at the area of gravity as shown in Figure 6.

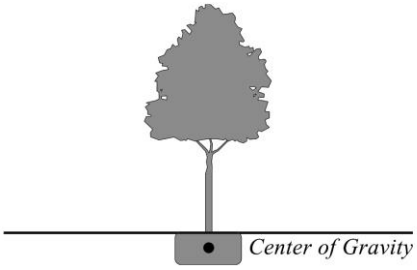

Fig.6 The center of gravity of tree high 10 m.

and diameter 0.20 m.

In fact, The tree has roots attached to the ground. This makes the tree look like a cantilever that extends perpendicular to the ground. And the wind is acting from the side causing the fall, as shown in Figure 7.

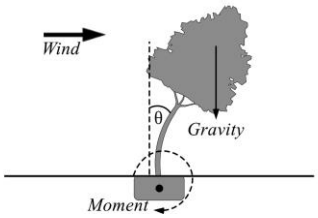

Fig.7 The behavior of trees when the wind acts from the side.

When the wind is acting from the side. The tree leans and the modulus of elasticity is formed in the trunk. A moment occurs that causes a flip at the soil bulge, and as the angle θ increases, the leaf bush area is subjected to more gravity to the point of collapse.

Where moment is the product of force multiplied by distance. If analyzing the existing crutches system, it was found that the implant system [14] is a system that increases the adhesion force and weight to the soil hopper area by hammering the wood into the soil 1.50 meters deep[13], but if calculating the moment the taller the tree. The moment can be increase, as shown in Figure 8a., the implant system can be used with a small tree. The crutches of the marquee system moves the anchor point (stiffness) higher. The resulting pivot point will be moved to the support point area, causing the distance l to be reduced, making it more suitable for larger trees as shown in Figure 8b. There is a risk that the tree will fall and uproot it. Therefore, canopy bracing has a better load-bearing capacity than implant type when supporting plants of the same size.

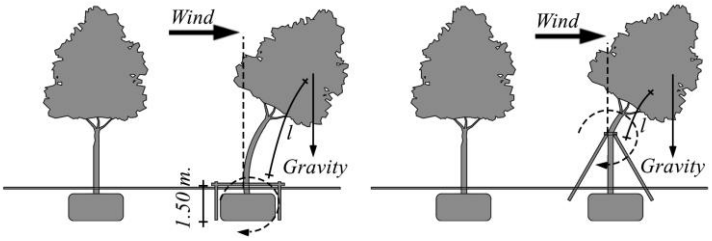

Fig.8 The behavior of marquee bracing and implant bracing

The behavior that caused the tilt of the tree is comparable to the behavior of the cantilever[4]. Slope-Deflection Equation for cantilever beam is $\delta_{max}=Pl^3/3EI$

From the formula, it can be seen that the smaller the distance l, the less the inclination distance (δ_{max}) will be. Therefore, the marquee bracing of tree support is more suitable for supporting large tall trees than the implant root system. And the distance of the crutches should not be less than one-fifth of the tree heights [4]

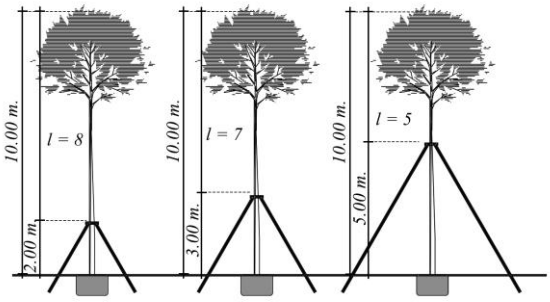

Fig.9 Bracing and the l distance of the tree

Table 1: Tree crutches suitable for 3 tree heights.

Support systems	Small trees (height not more than 9 meters)	Intermediate trees (height 9 to 15 meters)	Large trees (15 meters and above)
implant root bracing	✓	-	-
marquee bracing	✓	✓	✓
Sling bracing	✓	✓	✓

Medium height perennials (intermediate tree) are 9 - 15 meters height, while large trees are more than 15 meters in height. Trees at this level serve as the main structure in the garden because of their visible height and can be used to enclose the area above and on the sides to prevent wind. Small trees and ornamentals under 9 m in height are used to denote the boundaries of an area both above and on the sides, can peek through the trunk and suitable for small spaces [12]

2. Materials and installations of each type of bracing system currently available. The selection of materials for crutches affects many aspects including load-bearing capacity. Durability of the bracing system space for installation, beauty, steps and complexity of installation, including being environmentally friendly.

Table 2: Compare advantages and disadvantages each type of supports that is widely used today.

Materials	Support system	Installation	Functional life
Eucalyptus	Marquee bracing	Easy for general technicians, use nails or rope.	6 months – 1 year
	Implant bracing	Installed by an expert technician	6 months – 1 year
Steel	Marquee bracing	Expert technician welding required	Permanent
Wire rope	Marquee bracing	Installed by an expert technician	Must be careful to take care of the wire

Eucalyptus wood material is widely used to make crutches but the installation will have a problem when it comes to the rainy season, it must be maintained. Because when moisture causes mold in the wood, it has low durability. In addition, the peel is not beautiful and also food for termites. There are also research studies on the decomposition of eucalyptus leaves and changes in plant nutrients, including: potassium, calcium, magnesium, phosphorus and nitrogen. It was found that monocultures such as eucalyptus resulted in a negative change in the nutrient balance of plants and the diversity of benthic organisms tends to decrease. As a result, the quality of the soil and the environment gradually deteriorates in the end [11]

There is a significant difference between the root implant and marquee bracing in terms of installation space utilization. The root implant system occupies an area equal to the size of the enclosing timber. But the marquee bracing a 3 meters length crutches are used to install at a 30 degree angle to the trunk, the taller the tree, the more space it takes. Wire rope bracing It is more beautiful than using eucalyptus wood. But the user must be careful to take care of the wire that tightens the trunk. Due to the time the tree grows, it will be tightened until wounded and the tension must be adjusted. The sling is in a tight state. When the slack occurs, it is no longer useful. The wire rope should be installed at an angle of at least 45 degrees, which will take up more space than other types as shown in Figure 10.

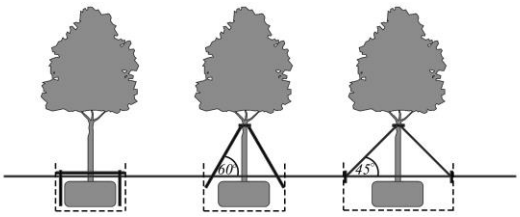

Fig.10 Installation area for each type of crutches: marquee bracing, implant bracing and sling bracing

The tree crutches was developed design to be a sustainable and test by a finite element based analysis with Ansys (CFD program) to examine the load and damage behavior.

A model of a tree crutches where the end of the model is buried in the ground and supported by the 4 members on the side, thus causing the bottom end to receive the fixed support force, the force acting on the four wooden bars will consist of the force of the wind and the weight of the skewed pole. In this case, we are interested, at the point of 5° tilt, the fixed support is on all four sides of the crutches and the base of the splice. Normally, the results of Equivalent Stress analysis in order to study the damage incurred at each point are also analyzed for Deformation, but the characteristics of the workpiece are intended to be related to strength. therefore no deformation analysis is required.

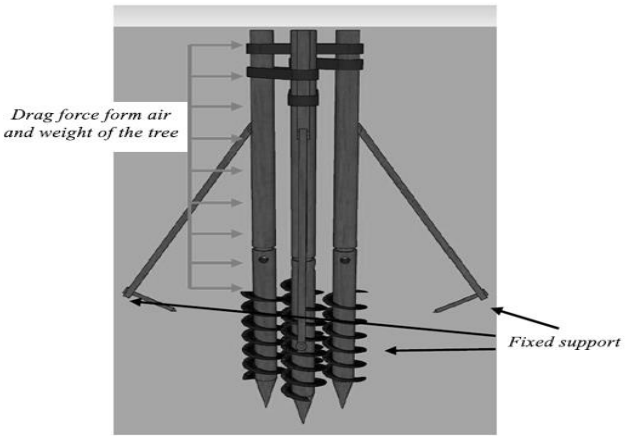

Fig.11 Boundary Conditions

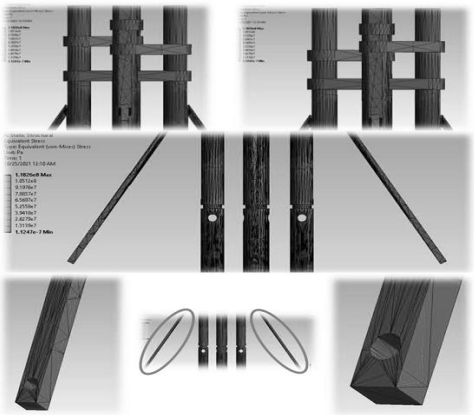

Fig.12 Result – Stress

Analyzing the Finite Element principle, it was found that the end of the crutches that touched the ground was the most damaged point. The set of optional tree crutches that the tree is tilted to do the most damage. The other sets were damaged, but they were reduced accordingly.

V. CONCLUSION

From all of the above analytical studies found that the factors causing the damage or the fall of a tree is the condition of the soil (root adhesion), the weight and height of the tree and canopy and the magnitude of the force acting on the tree. This does not include damage that may be caused by root-damaging insects or other fungi.

The behavior of trees falling often caused by forces acting from the side, such as wind forces, then the force will cause a moment at the root ball area and the fold (Hinge). When the tree is tilted, the weight and the canopy of the tree will have an effect, causing the tree to tilt beyond the CG (Center of Gravity) point and causing its topple.

There are two types of crutches to solve the problem:

1) Add weight or pressure to the root ball to achieve a firmer grip on the ground, such as an implant. This method does not change the pivot point position but makes the pivot point stronger.

2) Relocating pivot or momentum pivot points to a higher position for less tilt of the plant, such as a tent and sling system.

These concepts can be used as a guideline for choosing the right crutches for the tree together with other information to consider such as installation area material fastness and various advantages and disadvantages. In addition, it can also be used to build on the design of crutches suitable for different sizes of trees.

REFERENCES

1. Carpenter, P.L., T.D. Walker and F.O. Lanphear, (1975). Plants in the Landscape. W.H. Freeman and Co., San Francisco. 409 p.
2. Gilman, E.F. (1997). Trees for Urban and Suburban Landscapes. Delmar Publishers, New York. 647 p.
3. Greenhill A G. (1881). Determination of the greatest height consistent with stability that a vertical pole or mast can be made, and of the greatest height to which a tree of given proportions can grow (pp. 65-73). Cambridge Philos.
4. Johnatan Ramos Rivera. (2019). Tree-root anchorage : stability of trees based on real tree-root architecture (master's thesis). National university of Colombia, Medellin, Colombia.
5. Niklas K J. (1997). The evolutionary biology of plants (master's thesis). University of Chicago Press, Chicago.
6. Steven Vogel. (2015). Living in a physical world VII. Gravity and life on the ground (research report). USA. Duke University.

7. Vogel S. (1996). Blowing in the wind: storm-resisting features of the design of trees. Journal of Arboriculture, (22), 92-98.
8. Vogel S. (2003). Comparative biomechanics. Princeton, NJ: Princeton University Press.
9. Vogel S. (2006). Living in a physical world. VI. Gravity and life in the air. Journal of Biosci, (31), 12-25
10. Pang Prab Marn. (2017). misbelief “Life at Risk” Most urban trees are rootless. Retrieved January 6, 2022. From www.sanook.com/news/2239362
11. Suthipong Pongvorn. (2014). Eucalyptus, the serious benefit or harm to soil health. Institute for the Promotion of Teaching Science and Technology, Bangkok.
12. Sasiya Siripanich. (2015). Basic landscape. Nakhon Pathom: Faculty of Agriculture, Kasetsart University Kamphaeng Saen Campus.
13. Uamporn Weesommai, (2007). Supporting trees in landscape work, pp. 301-336. In Erb Kheaw Ruen, Editor's Office. Agricultural Manual. Tex and Journal Publication Company Limited, Bangkok.
14. Uamporn Weesommai, (2011). Digging around, planting and supporting trees for landscape work in Thailand. HN Group Printing House Co., Ltd., Bangkok. 444 pages.
15. Nopphorn Nonthapha. (Khun Dong ... free plants 24 hours). Techniques for how to surround large trees for quality. Retrieved January 24, 2022. From https://bit.ly/2VQKEBN