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Effect of Soil and Water on Tilted, Zig-Zag Patterned *Platanus orientalis* L. Trees in Tehran

Reza Mastouri[1*], Nozar Nozary[2] and Seyyed Mohammad Mirhosseini[1]

[1] Assist. Prof., Department of Civil Engineering, Faculty of Engineering, Arak Branch, Islamic Azad University, Arak, Iran

[2] Phd. Scholar, Department of Civil Engineering, Arak Branch, Islamic Azad University, Arak, Iran

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*Corresponding author's email: r-mastouri@iau-arak.ac.ir

Abstract

Various theories have been proposed about the tilted, zig-zag patterned *Platanus orientalis* L. trees in the center of Tehran. The increasing number of these trees has led to this study to determine the soil characteristics and distance parameters associated with this species. This research employs recent data from Tehran's District 11 Municipality. The District 11 Municipal Green Space Center is located in Razi Park, where the soil parameters were measured. We measured 170 tilted trees and examined more than 40 traffic signs in District 11 Municipality of Tehran. This study modeled one tree with various conditions of saturated soil using 2D Plaxis software to understand the influence of different factors on tilted *Platanus orientalis* L. and explain the mechanistic relationships that create the zig-zag growth pattern. In this research we realized in a creative way that the soil moisture and the distance of trees from each other are two effective reasons that trees and traffic signs tilt and sunlight and wind are not important in this pattern. The main cause of tilting zig-zag patterned in Tehran urban trees is the soil layer settlement and specific distance from each other which can occur to any kinds of trees.

Keywords: Settlement, Tilting, Urban trees, Water pipe burst, Zig-zag patterned.

INTRODUCTION

In the history of Tehran, this city is famous for its *Platanus orientalis* L. trees. Tehran has more than 160000 *Platanus orientalis* L. trees and one street of it, Valiasr, which is the longest street of Tehran and the Middle-East, has more than 9000 *Platanus orientalis* L. trees on both sides for 18 kilometers long. *Valiasr* Street is one of the tourist attractions of Tehran and has a special part of Iranian's memories. In another way *Platanus orientalis* L. has been used in traditional Persian medicine to treat allergic rhinitis (Maikhuri *et al.,* 2017) that shows it has been a long time usage. An important problem that has become prevalent in recent years at Tehran's District 11 (Fig. 1) is the tilted *Platanus orientalis* L. trees (Fig. 2). Studies show that 70 % of the damage to urban street facilities in District 11 is related to the tilted trees (Pourhashemi *et al*., 2012). Over time, the trees tilt either right or left (Fig. 3). Fig. 3 shows that trees on the right-hand side are tilted in a zig-zag pattern with less space from one another and trees on the other side of the street are tilted in one direction only with more distance between them. As can be seen in Figs. 2 and 3, this issue has become prevalent. Experts have speculated that the tilt is caused by the wind or by the tree crowns bending toward the sunlight. This research aims to understand the tilted zig-zag pattern by considering two parameters: Soil composition and the spacing distance between trees. The data will be analyzed using the Plaxis software.

Studies done by other researchers have shown that roots and soil have a significant effect on tilting trees depending on the soil moisture variation, soil parameters, and soil weight (Tanikawa *et al.*, 2021).

Fig. 1. Map showing District 11 of Tehran within the yellow border.

Fig. 2. Tilted *Platanus orientalis* L. trees to right side with an inter-tree distance more than 2 m.

Fig. 3. Tilted *Platanus orientalis* L. in a zig-zag pattern with an inter-tree distance less than 1 m.

MATERIALS AND METHODS

Research methodology

This research rejects the theory that traffic signs are tilted like the trees because of the sunlight angle; indeed, the only common parameter for both trees and traffic signs is the soil. This result has confirmed multiple experimental and theoretical studies and for the first time quantified these impacts. After reviewing and categorizing the information of the soil and trees, a single tree was modeled using PLAXIS software. The flooring near the trees and the type of ground cover varies, leading to variable water absorption and, hence, asymmetrical settlement and tilt. As studied in the Sitka spruce (*Picea sitchensis*), which has a shallow root system like here, the second-most important anchoring factor after lateral windward roots is RSP mass (the weight of the root-soil plate) (Coutts, 1983, 1986). The RSP represents the association between the root system and its adhering soils (Coutts, 1986). Root-architectural characteristics can have a significant influence on the anchorage of roots. The effects of some of these parameters, including the presence of lateral roots and branching angles, was investigated (Dupuy *et al.,* 2003) through numerical modeling. The relative results between the model and prototype show the mechanism of failure and tilting of the trees. The only factor among the trees grown in one street with the same condition and high moisture is the space between them. The trees with less space between them are tilted in the zig-zag pattern and the trees with more space between them are tilted in one direction.

For this study, a laser distance/slope meter (Fig. 4) was used with an accuracy of ±2 mm and working temperature 0–40 °C. The slope meter measured the vertical angle of the trunk tree. Non-rooted, non-saturated soil samples from within each stand were analyzed for soil moisture content, which was calculated as a percentage (grams of water per 100 g of dry soil) of the sample weight. The soil of the region has a sedimentary texture and composition of 74.6% sand, 20.2% silt, and 5.2% clay. The specific weight of dry soil is 1635.7 kg m^{-3}. The *Platanus orientalis* L. tree trunk weight which fallen in *Valiasr* street in car crashes and hazardous measured 470 kg/m^3.The trees and traffic signs and electric lamp posts with more than 10 degree slope are counted as tilted.

Fig. 4. Laser distance meter.

Tilted traffic signs in Tehran's district 11

Some of the causes of tree tilt that are frequently discussed are wind forces and pests that attack the trees, causing damage to the roots and subsequent uprooting. The cause of the trees' zig-zag growth pattern has been attributed to the tree canopy rotating to absorb sunlight. However, traffic signs and electric posts tilted in a zig-zag pattern do not require sunlight and also receive little force and momentum from wind due to their small front surface to the wind and height (Fig. 5). Traffic signs and electric posts (Fig. 6) are placed in the soil and then concreted to a depth of about 50 cm with a concrete collar circumference of 60 cm. The height of the light poles is six meters, which is usually at least 60 centimeters plus ten percent of the length in-ground with a concrete collar of circumference 140 cm.

Fig. 5. Zig-zag tilted trees, electric lamp post, and traffic signs.

Fig. 6. Tilted electric post.

Rainfall and irrigation

District 11 of Tehran Municipality is located in the south of Tehran. The ambient temperature of this district is higher than in other parts of the city due to being located in a hollow with a densely populated and compact urban texture. It rarely snows in this area and most precipitation is as rainfall. Importantly, the soil around the trees receives not only rainfall but also rainwater collected through a collection network in new buildings into wells near the *Platanus orientalis* L. (Fig. 7). The amount of collected rainwater is proportional to the size of the building's collection area. Due to the type of urban water collection structure in Tehran, the volume of water that reaches the trees is such that it is much more than can be absorbed by the soil. The soil absorbs some of the water while the rest remains on top of the ground. Soil drainage ceases once water has filled the empty spaces between soil particles, which is a measure of soil porosity. Variation in soil porosity is a reason for asymmetric soil settlement and, hence, tilting trees. For the *Platanus orientalis* L., a critical situation arises if it rains for several days due to the fact that there is no possibility of evaporation from the soil and the drainage is poor. Many trees have been cut down (Fig. 8) and new ones planted because of the danger created by tilting trees. Five incidents related to burst water pipelines were also examined. The buildings were restituted by the Water Organization because of the burst lines (Fig. 9). According to the regulations, water pipelines must be located at a minimum depth of 70 cm from ground level (General Specifications, 2005). The locations of the incidents were observed and the results showed that the trees were tilted and building settlement happened due to the high soil moisture content.

Fig. 7. *Platanus orientalis* L. tilting and water gutters.

Fig. 8. Water gutters placed above newly planted *Platanus orientalis* L. trees.

Fig. 9. Tilted trees and soil settlement due to burst water pipeline.

RESULTS AND DISCUSSION

Platanus orientalis L. roots and moisture

Estimating root depth and spread is a prerequisite for this study. The Tehran 11th district trees were planted simultaneously and, thus, have roughly the same diameter, weight, and height for comparison. What we focused on in this research is the increase of soil moisture in Region 11; this reduces sandy soil cohesion *c* and coefficient of friction *Φ*. This reduces the soil's water bearing capacity and causes settlement. Soil compaction not only reduces the available pore volume in which fluids are stored, but it alters the arrangement of soil constituents and pore geometry, thereby adversely impacting fluid transport and a range of soil ecological functions (Keller *et al.,* 2013). Keller showed the effect of tree roots and soil in response to wind force that causes tree tilt by setting plants at an artificial tilt of 45° and then naturally exposing them to wind. The wind affected the taper and the development of thickenings in the windward second-order roots, although the experienced winds were generally light. The straight-stemmed populations exhibited greater variability in the studied traits than the twisted-stemmed populations. This variability may reflect higher root responsiveness as well as various strategies to address mechanical stresses (Garrido *et al*., 2015). Around the trees there are usually different ground coverings at a short distance that can differ in porosity and void ratio (Eq. 1). As seen in Fig. 10, these factors cause the trees to uproot (Table 1):

$$e = \frac{\text{volume of void (volume of water+volume of air)}}{\text{volume (volume of water+volume of air+volume of soil)}} \quad (1)$$

Table 1. Trees average physical data.

Estimated age of trees (years)	Circumference of the tree trunk (cm)	No. of trees	No. of trees height between 12 to 15 m	No. of trees height > 15 m
40	47.1	6	6	0
50	75.3	37	26	11
60	86.4	84	61	23
80	107.4	43	14	29

In this study, the soil moisture was examined up to a depth of 60 cm deep because at depth greater than 60 cm the moisture is able to drain away. The trees that were tilted in the space around the soil showed that the roots were being pulled out from inside the soil, which, over time, caused further erosion and more water penetration and tilting (Table 2):

$$S = \frac{\text{volume of water}}{\text{volume of void}} \qquad (2)$$

Table 2. Soil depth and characteristics.

Depth (cm)	Cohesion *c* (KPa)	Coefficient of FrictionΦ (degrees)	Porositye (Volume Ratio)
10	60.3	6.7	0.39
35	4.14	36.9	0.26
70	3.30	36.3	0.37

Fig. 10. Roots of tilted *Platanus orientalis* L.

Zig-zag pattern of *Platanus orientalis* L. affected by distance and soil moisture

A major reason attributed by past experts for the zig-zag patterns on *Platanus orientalis* L. trees was wind or sunlight. The wind blowing in one direction cannot cause the trees tilt in a zig-zag pattern. The traffic signs tilt in a zig-zag pattern; the only common factor between the trees and the traffic signs is the soil. Moisture plays an important role in the settlement of sandy soil. When a tree is tilted due to moisture and soil settlement, it causes the tree roots to resist tilting and this resistance causes the roots to be stretched in the soil. When pulled, it empties the space caused by the soil moving with the roots, creating an empty space. This empty space reduces the water bearing capacity of the soil of the nearby tree and, therefore, the tree tilts toward the space where the soil is more porous, resulting in a zigzag tilt pattern. An increase of soil moisture can then cause the tree roots to come out of the soil. The inter-tree distances (measured as the distance between the outside of two tree trunks in line) show that the root systems interact with each other (see Table 3). In this research, 170 tilted trees were studied.

On the right-hand side of Fig. 11, trees with a distance of less than 1 m between them are tilted in the zig-zag pattern while on the left-hand side the trees with more than 1 m between them are tilted in one direction.

One of the areas where soil settlement has been studied a lot is around Tehran metro stations, so in many cases, tilting or cutting of trees is observed near metro stations Fig. 12, which shows that settlement is an important factor in tree tilting in Tehran. Nowadays, due to urbanization and population increase, need for metro tunnels, has been considerably increased in urban areas and block Qanat system and increase water level around metro stations. Common characterization of urban area tunnels is that they are excavated in very shallow depths and soft ground. Tunnel face instability and the potential surface settlement are the most hazardous factors that should be considered in all tunneling methods applied in urban areas. Incorrect estimation of the maximum surface settlement value can lead to irreparable damages to the buildings and other nearby structures. (Chakeri and Ünver, 2014).

Table 3. Tree and traffic sign tilted data.

Distance between trees or traffic signs (m)	Number in less than 1 m	Number in between 1 to 2 m	Number in more than 2m
Water burst pipe diameter(mm)	150	0	150
Trees	84	37	49
Tilted trees angle 35-55	49	16	21
Tilted trees angle 10-35	45	21	28
Zigzag pattern tilted	81	3	0
Tilted traffic signs	27	12	1
Water pipe burst	4	0	1
Trees up water pipe burst	14	0	3
Tilted trees up water pipe burst	14	0	3
Traffic signs up water pipe burst	2	0	1
Tilted traffic signs up water pipe burst	2	0	1

Fig. 11. Tilted trees' zig-zag pattern (left side).

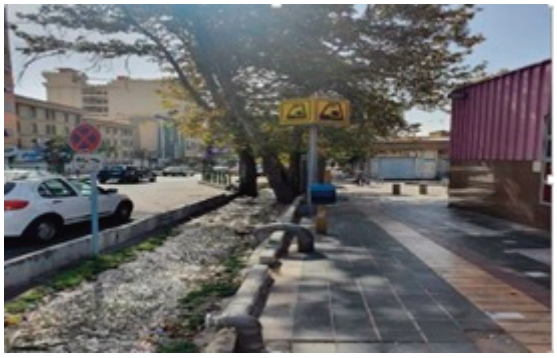

Fig. 12. Tilted trees due to soil settlement of Tehran metro.

Plaxis software

The finite element method is an approximation technique that uses the mathematical principles of stress and strain distribution estimates. For this purpose, in this method, the first is divided into similar smaller parts. The elements are divided so that in each element there are several specific nodes with a predetermined degree of freedom. Then, determine boundary conditions and geometric and resistance characteristics of the problem. This method is based on solving numerical partial differential equations to solve the unknowns in each node. The relation and the impact of each node is determined and calculated. The finite element program is based on PLAXIS Formulated, which is ideal for geotechnical applications.

Using the geogrid element, the tree trunk and roots were modeled with the Mohr Coulomb model in the 2D Plaxis software. In the model, the angle between the roots is 60 degrees, the center root height is 50 cm, the roots on both sides are 15 cm, and the diameter of each root is 10 cm.

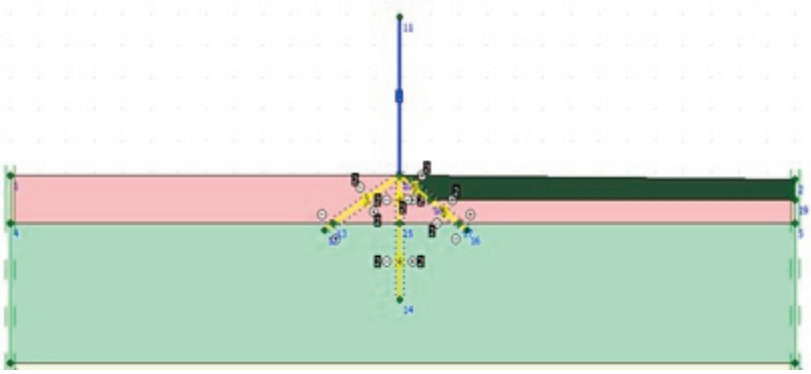

Fig. 13. Tree 2D Plaxis model.

As seen in Fig. 13, the dashed lines around the geogrid elements (yellow) demonstrate the interaction of the root with the surrounding soil. The value of the interaction coefficient is considered 0.67. Model boundary conditions are given that there is no dynamic load; simple boundaries are considered. We model a tree with concrete paving under the following conditions: 10 cm vegetable soil with 70 cm 100% saturated soil and 10 cm vegetable soil with 35 cm 100% saturated soil and 35 cm 80% saturated soil and the tree weight 5000 kg. Pavement can influence urban tree biomass and whole-tree transpiration, but the effect is minor, which is related to the water supply and varies with tree species. Pavement slightly increased leaf area and leaf biomass under sufficient water supply (Wang *et al*., 2020). The points numbered 12, 13, 14, 15, 16 and 17 in Fig. 12 were selected and their locations examined. The results reported in Table 4 show that tree tilted to the left side in both conditions and in the 100% saturated soil settlement is higher, meaning moisture content has an important role. The result is close to reality.

Although Zhang *et al*. (2020) measure and model the root anchorage strength in comparison of dry soil and saturated soil shows higher residence of root in dry soil than saturated soil which means that lateral force could tilt the trees. Also soil settlement create a force to tree roots the same as a wind force.

CONCLUSION

The effects of different parameters on the tilted zig-zag *Platanus orientalis* L. trees were studied. Ground spots with high moisture and where the distance between the trees is less than 1 m cause the trees to tilt in a zig-zag pattern. When the trees mature, their trunks become larger so

Table 4. Displacement of grid 12, 13, 14, 15, 16, 17.

ID	X_1	Y_1	X_2	Y_2
12	-2.06	+3.27	-1.97	+3.04
13	-2.01	+3.24	-1.93	+3.01
14	-0.17	+0.09	-0.07	+0.04
15	-0.15	+0.07	-0.06	+0.03
16	-1.04	-0.97	-0.94	-0.73
17	-1.01	-0.94	-0.91	-0.7

the distance between them decreases. As the distance between the trees decreases as the trunk grows and because of high moisture, the trees begin to tilt in a zigzag pattern. Such distance is considered appropriate to avoid the trees' tilted zigzag growth pattern as the trees grow, so does their trunk diameter, thus reducing the inter-tree distance. When the distance between tree trunks becomes 1 meter or less (distance of two tree trunks at 0.5 m), an increase of soil moisture triggers the tilting and zig-zag pattern. In order to reduce the risk of uprooting *Platanus orientalis* L. trees, their irrigation plans and surface water management should be reviewed. For example, it is better to (1) not irrigate the trees during continuous rain or for a few days before and (2) not to plant trees next to areas that need a lot of water, such as grass that must be irrigated although rate of settlement depends on soil profile. According to this research, tilted, zig-zag patterned *Platanus orientalis* L. trees in Tehran could be caused by the short inter-tree distance and soil moisture content that cause *Platanus orientalis* L. trees settlement and tilting. Water pipes burst reduces the adhesion between the roots and the soil and reduces the bearing capacity of the soil, which causes the trees to tilt. Experimental and numerical models confirm that moisture in sandy soil and soil settlement is the main cause of the tilting trees Tehran. It is suggested that, soil settlement layer for tilted trees can be studied more in the future researches and experiments and the trees near water pipe burst must have protect significantly to not tilted.

ACNOLEDGEMENT

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