

Uprooting of tree induced by typhoon: a case study of super typhoon Mangkhut in university town of Shenzhen

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Abstract. Super typhoon Mangkhut resulted a large number of fallen tree in form of uprooting in university town of Shenzhen (UTSZ), which hadn't happened for years. This study conducted a survey about tree uprooting induced by super typhoon Mangkhut in UT SZ, aiming to reveal main reasons for tree uprooting in UT SZ. Species of fallen trees were recognized. Fallen direction and height of fallen tree were measured. Also depth and diameter of root-soil plate and dry density of soil beneath root-soil plate were measured. The results showed that many fallen trees with uprooting in UT SZ had relatively small volume of root-soil plate which was not able to offer sufficient anchorage to tree during typhoon. One of solutions to avoid this phenomenon is not to select tree species with shallow root depth. Ponding was found in many places where uprooting occurred in UT SZ. Increase of degree of saturation of soil induced by ponding can significantly decrease soil strength which is a major component of anchorage of tree. Thus we recommend to modify the poor drainage condition of soil in UT SZ. Degree of compaction of soil may not be a main factor related to tree uprooting in UT SZ.

1 Introduction

Super typhoon Mangkhut was an extremely powerful tropical cyclone that brought severely damage to South China, including city of Shenzhen. It was the strongest typhoon to affect Shenzhen since Ellen in 1983. This typhoon resulted in around 11,680 fallen trees in Shenzhen [1]. Also this typhoon resulted in a large number of fallen tree in form of uprooting in university town of Shenzhen (UTSZ), which hadn't happened for years.

Uprooting of tree occurs when turning moment applied to the tree overcomes root anchorage and root anchorage is less than stem strength [2-3]. According to Coutts [4], the turning moment mainly consists of lateral force applied on tree and horizontally displaced weight of stem and crown. Uprooting is a sequential failure in different parts of root-soil system.

The root anchorage against the turning moment depends on many factors such as size or weight of root-soil plate [5], type and strength of soil [6-7]. The weight of root-soil plate is an essential component of anchorage of a tree, especially when the turning moment induced by force of wind reached its maximal value [4]. The weight of root-soil plate can give a resistant moment to the turning moment on the hinge on the leeward side of tree. Moreover, soil strength (i.e. shear strength and tensile strength) is an essential component of anchorage of a tree [6]. When a tree is under turning moment, shear strength of soil resist the movement of root-soil plate in the shear

plane. Tensile strength of soil can resist the lift of root-soil plate on the windward side of tree.

This study aims to (i) illustrate the situation of tree uprooting in UT SZ induced by super typhoon Mangkhut, to (ii) reveal main reasons for tree uprooting in UT SZ, and to (iii) give suggestions of modification from the lesson of this disaster.

2 Material and methods

2.1 Site description

Shenzhen is a coastal city in Guangdong Province, China. UT SZ is a university cluster, located near Xili Lake in the Nanshan District, Shenzhen. There are six higher education institutions located in the area, three of them are Harbin institute of technology, Shenzhen, Graduate school at Shenzhen, Tsinghua university and Graduate school at Shenzhen, Peking university. This study surveyed the situation of tree uprooting within the scope of these three education institutions, as shown in Fig. 1.

2.2 Measurement of parameters of fallen tree

Tree species was recognised by Xingse app, which take a photograph of the plant and recognised it in smartphone.

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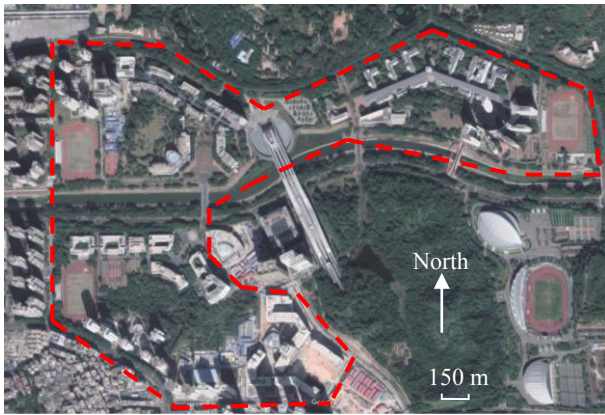


Fig. 1. Scope of survey of tree uprooting

Fallen direction of tree was measured by compass in smartphone. Fallen direction is defined as the direction from the roots base to crown along the main stem of fallen tree.

Height of fallen tree was measured by AR Ruler app, which uses augmented reality technology (AR) to tape measure the real world with smartphone's camera.

Depth and diameter of root-soil plate was measured by a measuring tape. Diameter of root-soil plate was twice the distance from the centre of the tree stem to the edge of the soil. Volume of root-soil plate was approximated by a cylinder shape of a given diameter and depth of root-soil plate.

2.3 Measurement of density of soil beneath root-soil plate

Soil in each pit of fallen tree in the campus of Harbin institute of technology in UTSZ was sampled by soil cutting ring with known volume. For each pit, three soil samples were sampled. Then the soil sample was dried in oven at 105°C for 8 hours to obtain the dry mass of soil sample. Dry density of soil was calculated by dividing dry mass of soil sample by the volume of cutting ring.

2.4 Measurement of meteorological parameters in UTSZ during typhoon Mangkhut

Hourly rainfall, 10-minute wind speed and wind direction during typhoon (i.e. from 0:00 16 September to 6:00 17 September) were measured by a meteorological station of Meteorological Bureau of Shenzhen Municipality located in UTSZ.

3 Results and discussions

Fig. 2 shows wind direction and 10-minute wind speed distributions in UTSZ during the period when super typhoon Mangkhut was close to Shenzhen. The wind came from the direction from north (N) to southwest (SE). This means the force of wind tend to blow down tree in direction from south (S) to northwest (NW). The maximum wind speed (i.e. 12.2 m/s) occurred at the range of direction from east-northeast (ENE) to east (E). This

means the strongest force of wind tend to blow down tree in direction from west-southwest (WSW) to west (W).

Fig. 2 also shows the fallen direction and number distributions of fallen tree with uprooting in UTSZ. The fallen direction of tree mainly distributed within the range of direction from south (S) to north (N), which is in accordance with the direction range of wind force applied on tree (i.e. from S to NW). In total, 125 fallen trees with uprooting were recorded in this study. Most trees fallen in the direction range from west-southwest (WSW) to west-northwest (WNW), which is also in accordance with the direction range of strongest wind force applied on tree (i.e. from WSW to W).

Fig. 3 shows the distribution of species of fallen trees with uprooting in percentage in UTSZ. In total, 39 tree species were recognized in this study. The main species of fallen tree were given in the figure. Many tree species (i.e. tree species with a superscript of a in the figure) were within the list of tree species which have shallow root depth or heavy crown [8]. According to Dupuy et al. [7], depth of root has strong positive correlation with anchorage of tree. Meanwhile, horizontally displaced weight of the crown would strengthen the turning moment applied on trees [4]. Thus many tree species recorded in this study are vulnerable to fall down upon typhoon.

Fig. 4 shows two typical cases of tree uprooting in UTSZ. The size of root-soil plate is relatively smaller than the size of stem and crown above ground surface. Fig. 5 shows the volume of root-soil plate and corresponding height of tree recorded in UTSZ. For a given height of tree, volume of root-soil plate varied significantly. For the trees with height between 10 m to 15 m, more than half in number has a volume of root-soil plate less than 2 m³. Relatively small volume of root-soil plate indicates relatively small weight of root-soil plate for tree. Thus resistant moment attributed by weight of root-soil plate against the turning moment on tree would be small.

Soil strength depends on degree of compaction (DOC) of soil. The measured average and standard deviation of dry density of the soil sampled from the pit of root-soil

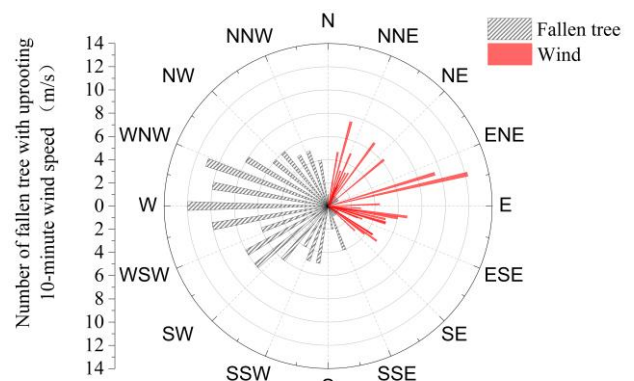


Fig. 2. Direction and speed distributions of wind (from 0:00 16 Sept to 6:00 17 Sept) together with fallen direction and number distributions of fallen tree with uprooting in UTSZ

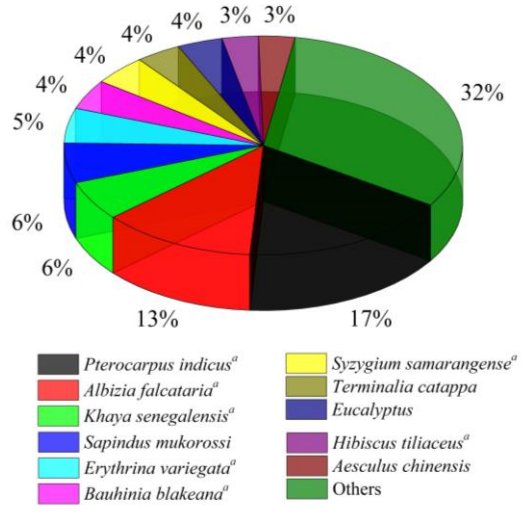


Fig. 3. Tree species distribution of fallen trees with uprooting in percentage in UTSZ (colour version of this figure is available online).

plate is 1.34 g/cm^3 and 0.13 g/cm^3 , respectively. The soil of surface soil layer of UTSZ is backfill soil. In appearance, the soil is similar to completely decomposed granite (CDG), which is widely distributed in surface soil layer in Shenzhen. Because the maximum dry density of CDG is approximately 1.66 g/cm^3 , the DOC of soil around fallen tree in UTSZ can be evaluated and the DOC is relatively high, i.e. around 85%. Therefore, it can be regarded that uprooting of tree in UTSZ is not due to low DOC of soil.

Soil strength also depends on degree of saturation of soil [9]. During survey of tree uprooting on the very next day of typhoon Mangkhut in UTSZ, ponding was found at a lot of places where tree uprooting occurred, as shown in Fig. 6. This means soil around roots was in high degree of saturation during tree uprooting, thus the contribution of suction to soil strength was limited. One



Fig. 4. Typical cases of tree uprooting in UTSZ

reason for the high degree of saturation of soil is the intensive precipitation upon the typhoon Mangkhut, as shown in Fig. 7. Another reason is the poor drainage of soil layer around the tree, which should be modified in future work.

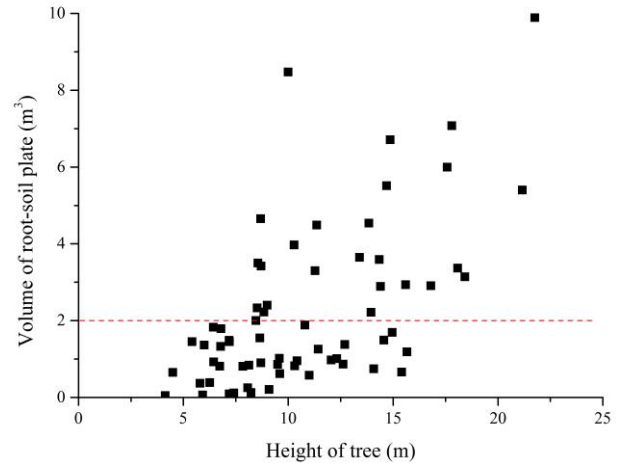


Fig. 5. Volume of root-soil plate and corresponding height of tree in UTSZ



Fig. 6. Ponding around tree uprooting

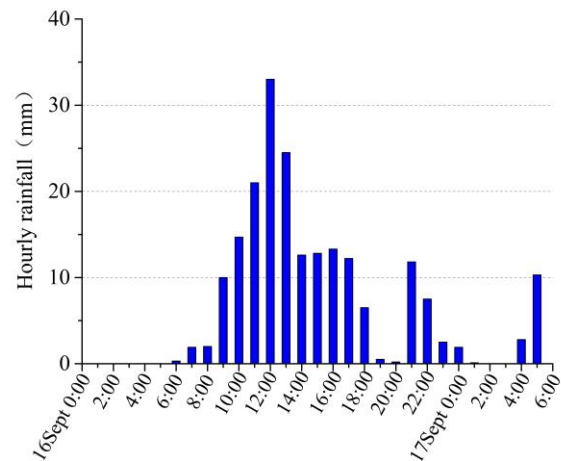


Fig. 7. Hourly rainfall in UTSZ during super typhoon Mangkhut.

4 Conclusions

In this study, a survey about the situation of tree uprooting induced by super typhoon Mangkhut in UTSZ was carried out, aiming to illustrate situation of tree uprooting in UTSZ and to reveal some main reasons for tree uprooting. Then suggestions of modification were given. The conclusions that can be drawn from this study are as follows:

1. Many fallen trees with uprooting in UTSZ had relatively small volume of root-soil plate which is not able to offer sufficient anchorage to tree against turning moment. One of solutions to avoid this phenomenon is not to select tree species with shallow root depth.
2. Ponding was found in many places where uprooting occurred in UTSZ. Increase of degree of saturation can significantly decrease soil strength which is a major component to anchorage of tree. We recommend to modify the poor drainage condition of soil in UTSZ.
3. DOC of soil beneath the root-soil plate is relatively high in UTSZ, thus DOC of soil may not be a main factor related to tree uprooting in UTSZ.

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