Dynamic analysis of a simple fruit tree structure model

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Summary: *The effect of shaker harvest on root damage was studied on a simple tree structure model. Equations were set up to be able to calculate the relation between shaking height and stress in the roots. To get the strain at break data field experiments were carried out. The acceleration versus time curves were recorded on different heights of the stem. Evaluating measured and calculated data it can be concluded, that the risk of root damage increases when*

- *the height of shaking is decreased,*
- *the stem diameter is smaller, and if*
- *the unbalanced mass of the shaker is increased.*

Key words: shaker, fruit harvesting.

Introduction

Fruit growers may experience root damages in their orchards due to misuse of their shaker harvester. The reason for the root ruptures is certainly the too large amplitude of shaking which follows from the oversize of the machine's eccentric mass(es) and/or the eccentricity of it(them). It is of interest to study how the roots behave during shaking, how large is the force reacting to the force generated by the shaker.

Láng (2003) has set up a simple tree structure model and carried out among others stress measurements on cherry tree root samples in the diameter range from 5–14 mm, and calculated some of their physical characteristics. His main findings were as follows: the Young's modulus changed between 216.3 and 228.8 N/mm^2, and the strain at break varied from 3.6 to 18.4%.

Materials and methods

To be able to decide weather the strain in roots during shaking reaches the critical value two kind of investigations had to be carried out: first the amplitude or displacement of the tree trunk itself must be measured, secondly it must be defined how this displacement acts on the strain of the roots.

Trunk displacement measurements

In ten-year-old cherry orchard accelerometers wer fixed on the stem of trees and acceleration was recorded during mechanical shaking.

The arrangement of the accelerometers was as follows *(Figure 1)*:

- at the ground level,
- at 30 cm above ground level,
- at 53 cm above ground level, and
- at 77 cm above ground level

each in the direction of shaking. The results below were recorded on a tree with 17 cm trunk diameter.

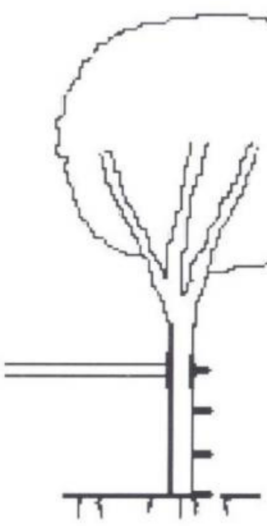

Figure 1 The position of accelerometers on the trunk

The shaker used was a Schaumann machine with the following parameters: shaking frequency: 14 Hz, eccentricity of the unbalanced mass: 22 mm, unbalanced mass: 135 kg.

To get the trunk displacement values at the heights mentioned earlier the acceleration versus time curves were twice geometrically integrated.

Modelling the trunk and rooting

From static point of view most of the fruit tree's rooting system may be replaced by a few main roots which join to the trunk in a rigid way. Their other end is anchored to the soil body at A and B *(Figure 2)* elastically, so they can stress and bend. During shaking the machine acts onto the trunk by a force *F*. The balance of acting and reacting forces can by written the following way *(Figure 3)*

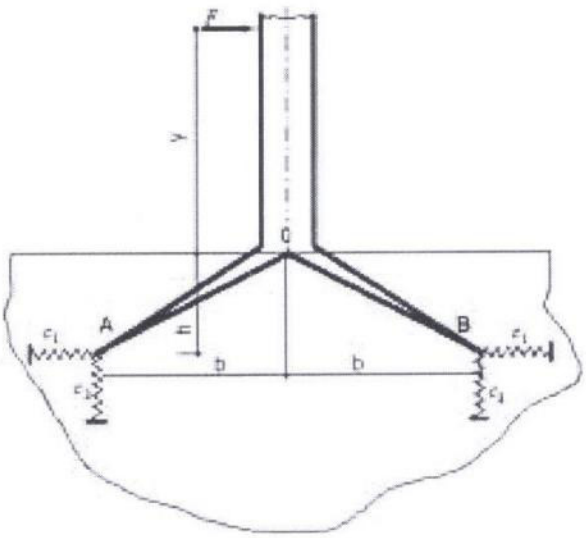

Figure 2 The simple model built of trunk

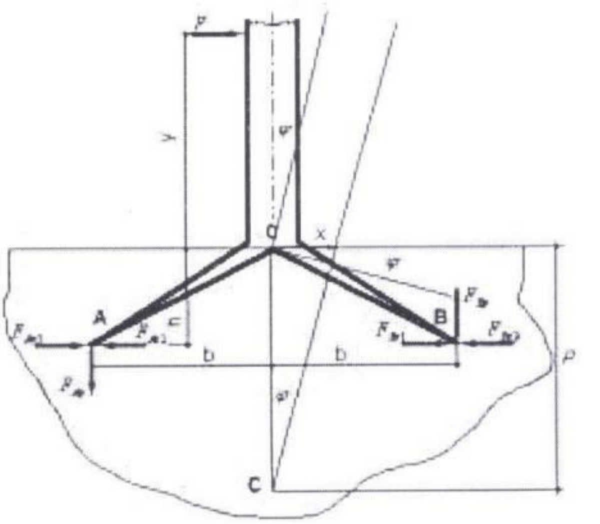

Figure 3 The static equilibrium of and main roots the model

$$F = F_{Ax2} + F_{Bx2} - F_{Ax1} - F_{Bx1} = 2\frac{x}{c} \qquad 1.$$

$$F \cdot y = b \cdot (F_{Ay} + F_{By}) + h \cdot (F_{Ax1} + F_{Bx1}) - h \cdot (F_{Ax2} + F_{Bx2}) \qquad 2.$$

Presuming that $F_{Ay} = F_{By}$, $F_{Ax1} = F_{Bx1}$ and $F_{Ax2} = F_{Bx2}$

$$2 \cdot h \cdot (F_{Ax1} - F_{Ax2}) = F \cdot y - 2 \cdot b \cdot F_{Ay} \qquad 3.$$

$$F_{Ax1} - F_{Ax2} = \frac{F \cdot y - 2 \cdot b \cdot F_{Ay}}{2 \cdot h} \qquad 4.$$

From the other hand:

$$2 \cdot b \cdot F_{Ay} = F \cdot (y + h) \qquad 5.$$

and from 4 and 5:

$$F_{Ax1} - F_{Ax2} = \frac{F}{2} \qquad 6.$$

Let x be the translation of 0. Presuming that $c_1 = c_2 = c$, than

$$x = \frac{c \cdot F}{2} \qquad 7.$$

The turning angle around 0:

$$\varphi \cong \frac{F_{Ay} \cdot c}{b} = \frac{F \cdot (y + h) \cdot c}{2 \cdot b^2} \qquad 8.$$

Finally the vertical distance of the virtual turning centre *C* from *0* is:

$$\rho \cong \frac{x}{\varphi} = \frac{c \cdot F}{2 \cdot \frac{c \cdot F \cdot (y + h)}{2 \cdot b^2}} = \frac{b^2}{y + h} \qquad 9.$$

For small displacements of the tree trunk, A0 will be deformed to A0' as shown in *Figure 4*. It means that A0 is mainly stressed, the strain can be calculated as the difference between A0' and A0 related to A0:

$$\Delta = \frac{A'0 - A0}{A0} \qquad 10.$$

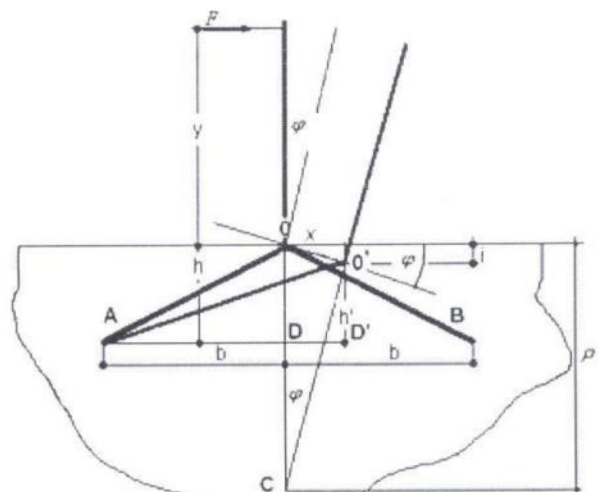

Figure 4 The deformation of the root A0

$$A0 = \sqrt{b^2 + h^2} \qquad 11.$$

$$A0' = \sqrt{(b + x)^2 + h'^2} \qquad 12.$$

For x different amplitude measured during harvest were replaced.

According *Figure 4*:

$$h' = h - i \quad \text{and} \qquad 13.$$

$$i = \rho - \rho \cdot \cos\varphi \qquad 14.$$

Results and discussion

The results of trunk displacement measurements and theoretical considerations are summarized in the diagrams on *Figure 5* and *6*.

Figure 5 shows the change of trunk amplitude at ground level, which is the x value in Equation 12. The curve of three measured values is extrapolated in both directions.

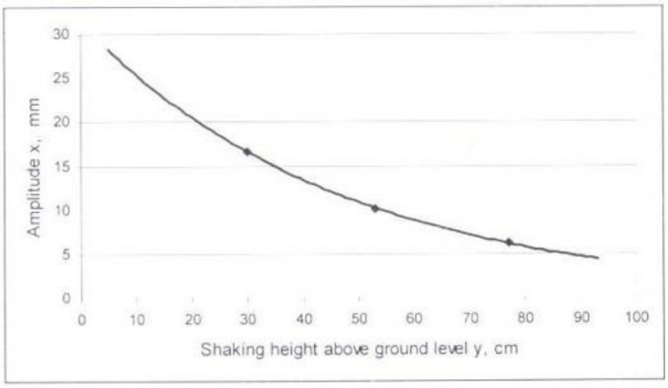

Figure 5 The change of trunk amplitude at ground level versus shaking height

The values of the diagram on Figure 6 were calculated using equations 9–14. Into Equation 9 the following constants were replaced: $h = 150$ mm, $b = 680$ mm. Both were matching the best with earlier measurements of Láng (2003).

From *Figure 6* it seems clear that the strain in the main roots increases when the shaking height is decreased.

As told in the introduction, roots can brake even at 3.6% strain. Normally the Schaumann shaker is used at about 80 cm above ground level. According Figure 6 there is no risk of damage as the strain at that height is about 0.8%. Shaking the same tree closer to ground level the risk of breakage increases. The 3.6% value would be reached when shaking would occur 10 cm above ground.

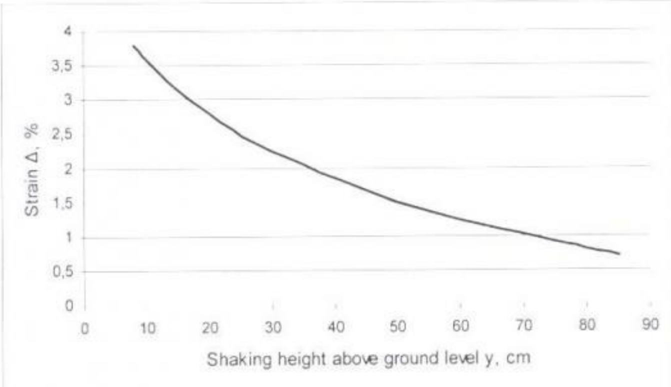

Figure 6. The change of root stress versus shaking height

Damage can happen also with the same machine and at the same height if the trunk diameter is much smaller. In that case the reduced mass of the tree is less, so the amplitudes are larger.

Root breakage can also happen if a shaker with much larger eccentric mass(es) is used. It also would lead to larger amplitudes and stress in the roots.

Note that these calculations do not apply exactly to all trees as large differences can be found between and within the varieties. However, the tendencies these diagrams suggest may be interesting both for machine designer and fruit grower.

Reference

Láng Z. (2003): A fruit tree stability model for static and dynamic loading. Byosystem Engineering. 85(4), 461–465.