

## Stability of the root plates of coniferous trees planted on surface water gley soils

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**ABSTRACT:** This paper presents details of a field study on the dynamic loading of mature coniferous tree stems planted on saturated mineral soils. The trees examined were planted in a narrow shallow layer of soil which had been deposited on the ground surface as a result of ploughing a furrow. The root plates are extremely shallow and the main roots tend to grow along the deposited aerated layer of soil. The unsymmetrical radial distribution of the main roots and the shallow root plates can render the trees unstable. In windy conditions the soil in the root plates can fail and as a result the trees can be blown over. This phenomenon is common in Ireland and in the United Kingdom and results in economic loss.

In this study a mechanical rocking device was constructed and placed on truncated tree stems 6m above ground surface. The force applied by the rocker was controlled. The behaviour of the rootplates and the trees were measured by transducers. The signals from these transducers were recorded on a fast microcomputer.

The selected test site has a history of tree instability. The mineral soil under the rootplates consists of a silty sand. The tree stems were rocked until the movements were excessive and the soil in the rootplates had fractured.

Results from the field tests showed that high pore water pressures in the soil were generated during the dynamic loading of the trees and these caused hydraulic fracturing of the soil. Trees which had main roots growing in the direction of rocking were stiffer in that direction than those which had main roots only at right angles to the direction of rocking. The above suggests that site preparation methods which encourage deep radially symmetrical root growth should be used on surface water gley soils.

## 1 INTRODUCTION

In windy conditions the soil under the root plates of trees can fail and as a result the trees can be blown over. This phenomenon is known as windthrow.

Windthrow is a major source of economic loss in Irish and United Kingdom forests and the risk of crop instability imposes important restrictions on silviculture.

This paper presents details of a field study on the dynamic loading of mature coniferous trees planted in a narrow shallow layer of soil which had been overturned and deposited on the ground surface as a result of ploughing a furrow with a double mouldboard plough.

The objectives of the study were:

1. To develop a mechanical rocking device and a high speed data logging system which could be used to assess the stability of trees in the field
2. To identify and measure the behaviour of trees and rootplates when subjected to dynamic loading
3. To identify soil properties which are important for tree stability.

## 2 SITE CHARACTERISTICS AND PREPARATION

The test site is at Castledaly Forest which is situated near the village of Ardrahan, 40km South East of Galway City in the West of Ireland. The trees on this site are Sitka spruce and were planted in 1967. Their present top heights are about 14m. This forest has experienced substantial windthrow in the past. The selected trees in the test plot did not show any signs of windthrow failure and were located some distance in from the edge of the forest.

The soils on the test site are classified as surface water gleys. The top soil layer, which is about 300mm to 400mm thick, consists of a dark mineral soil with a high organic matter content and this overlies a sandy loam. The water table is at or near ground surface throughout the year.

The site was prepared for planting using a double mouldboard plough. Double mouldboard ploughing causes a trench to be made and the displaced trench soil is overturned and deposited on the shoulders of the trench. Young trees are planted in the overturned soil. This overturned soil or ribbon is well aerated and the roots tend to follow the line of the ribbon (Figure 1). This causes an unsymmetrical root distribution with very few roots tending to grow at right angles to the ribbon. The tree roots usually only penetrate to the bottom of the top soil layer. This shallow rooting is probably due to the high water table.

### 3 FIELD EQUIPMENT

In order to measure the effects of dynamic loading on the trees a device for rocking the trees was designed and constructed. It was advantageous to have a mechanical method for rocking the trees so that field testing could proceed independently of suitable wind conditions. The tree rocker consisted of two disks with eccentric masses which were rotated by an hydraulic motor through gears, chains and sprockets. The rocker is illustrated in Figure 2. The motor was activated by an hydraulic pump which was driven by a petrol engine. The disk and eccentric mass arrangement enabled the tree to be rocked in one vertical plane only. The tree rocker was mounted on the truncated stems of the test trees 6m above ground surface.

Eight transducers were used to measure the effects of the dynamic loading induced by the tree rocker. These consisted of pore water pressure transducers, soil cells, linear variable displacement transducers and strain gauges. The pore water pressure transducers were used to monitor the behaviour of the pore water pressure in the soil as the trees were rocked over and back. The soil cells indicated how the stresses in the soil changed with loading. The displacement transducers measured the movement of the stem and the root plate. Strain gauges were attached to the tree 1.3m above ground surface. These consisted of linear displacement transducers which enabled the strain of the outer fibres of the stem to be calculated.

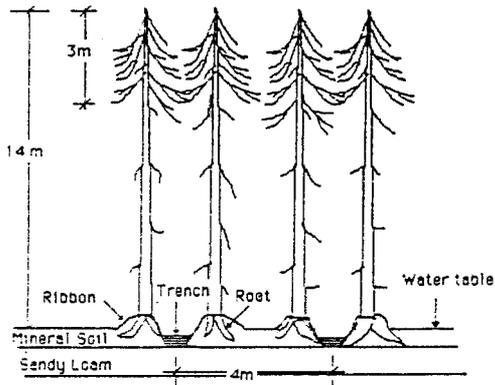
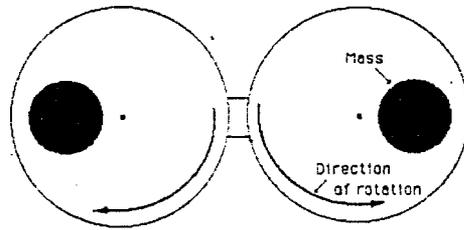
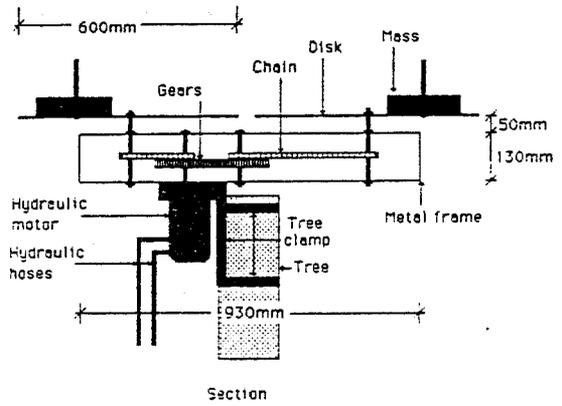


Figure 1. Tree development on double mouldboard ploughed land.



Plan

Figure 2. Tree rocker

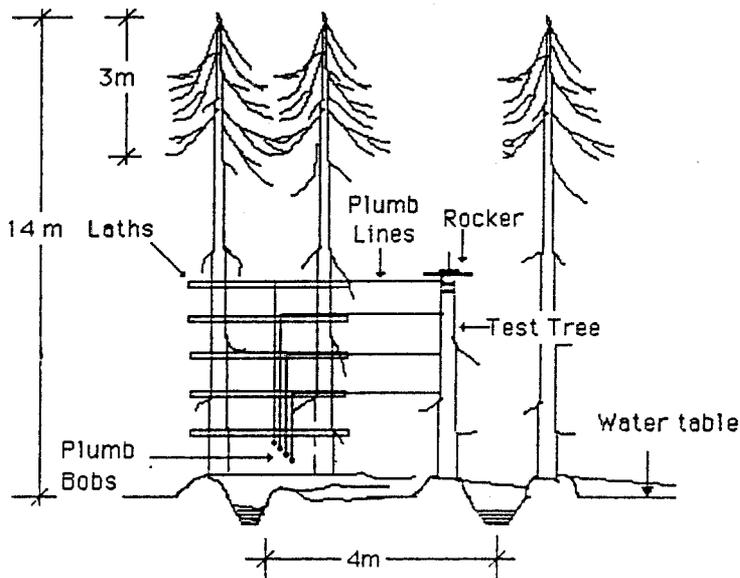


Figure 3. Lath arrangement for measuring the horizontal displacement of the tree stem

An Apple Macintosh II microcomputer was used to record the response of the transducers in the field. The signals from each of the eight transducers were sampled twenty times per second using a high speed 12-bit analog to digital converter in combination with Labview, a National Instruments software applications programme. Labview was also used in the field to plot transducer results as the test was proceeding in order to check the proper functioning of the transducers.

#### 4 FIELD TESTS

Field testing at Castledaly Forest was carried out on five trees. The test plot was flooded for at least three days prior to testing in order to fully saturate the soil in the rootplate. The pore water pressure transducers were inserted to a depth of 400mm below original ground surface. Great care was taken to ensure that these transducers were deaired. The soil cells were inserted at selected locations in the rootplate at the same depths as the pore water pressure transducers. The above two sets of transducers were inserted on the day prior to testing in order to allow any pressures that may have been generated on insertion to dissipate before loading began. The tree rocker was also mounted on the tree stem the day before testing commenced. The transducers which were used for measuring the displacement of the stem and root plate were placed in position using a support frame. This support frame ensured that measurements were not in error due to the movement of the tree and root plate. The strain gauges at 1.3m above ground surface enabled the extension and compression of the outer fibres of the tree stem to be calculated. A dial gauge was also attached to the tree to check the strain and to give a visual measure of the behaviour of the tree stem. An arrangement of horizontal timber laths and plumb bobs was used to monitor the horizontal displacement of the tree stem. The horizontal laths were attached at one metre vertical intervals to two trees which had a planting line at right angles to the direction of rocking. This planting line was offset about 2m from the test tree. The plumb bob lines were attached to the test tree at corresponding intervals of one metre and passed over the laths (Figure 3). The horizontal displacement of the tree stem was then found by measuring the vertical displacements of the plumb bobs.

The eccentric masses on the rocker were increased as the test proceeded. The maximum masses used on each disk was 41.5kg. The speed of rocking of the tree was controlled by a flow valve at the hydraulic pump. The disks were rotated at a maximum speed of 41 revolutions per minute during the tests.

## 5 FIELD RESULTS

The results from two tree tests are presented here, namely, Tree A and Tree B. Displacement, strain and pore water pressure measurements are presented for Tree A and strain and soil cell measurements are presented for Tree B. The roots of Tree A ran along the ribbon parallel to the trench with no roots at right angles to the trench. Test Tree B had one root in line with the direction of rocking of the tree and at right angles and away from the trench.

Figure 4 illustrates the behaviour of the pore water pressure transducer during the test on Tree A. This pressure transducer was inserted at a depth of 400mm below ground surface. The mass on the figure is the eccentric mass on one disk. The code for the disk rotational speeds is given at the side of the figure. The maximum pore water pressure attained had a value of about 15kPa. This pressure caused extremely high hydraulic gradients leading to liquefaction and hydraulic fracture of the soil.

For Tree A the maximum strains at 1.3m above ground surface, the maximum lateral movement of the tree and the maximum vertical movement of the roots increased with an increase in the maximum pore water pressure in the soil from about 130 minutes onwards (Figures 5,6 and 7). The increase in strain resulted from the increased inertial effect of the rocker and tree due to their large displacements, and the displacement of the centre of gravity of the rocker and tree from their equilibrium position. This strain increase occurred even though the loads on the rocker remained the same and the frequency of oscillation only changed slightly from 31 to 36 cycles per minute .

After Tree A was rocking with large amplitudes for a period of time it suddenly changed motion from a rocking motion to a loop motion in plan. This occurred at about 150 minutes and was sensed by all the transducers. The frequency of oscillation was increased but the rocking motion was not regained. However, the previous

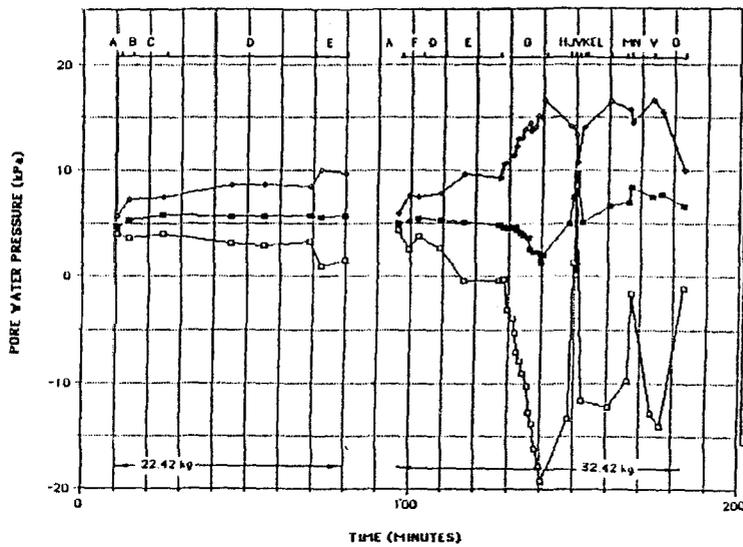


Figure 4

Tree A

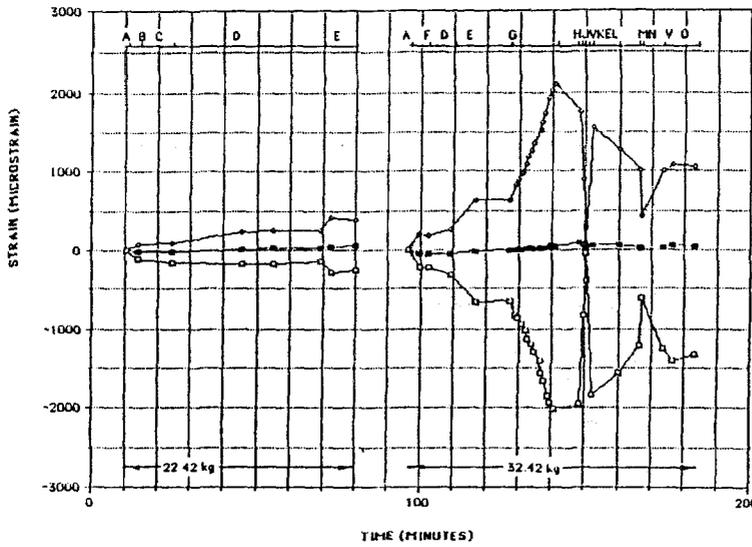


Figure 5

Tree A

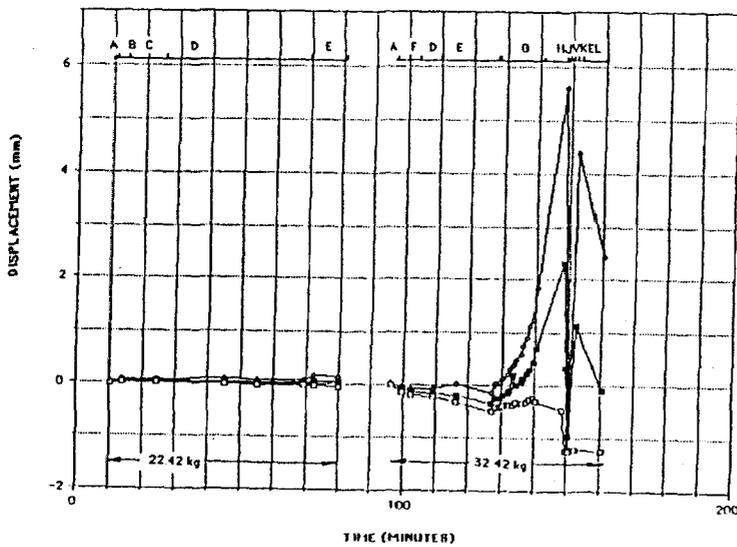


Figure 6

Tree A

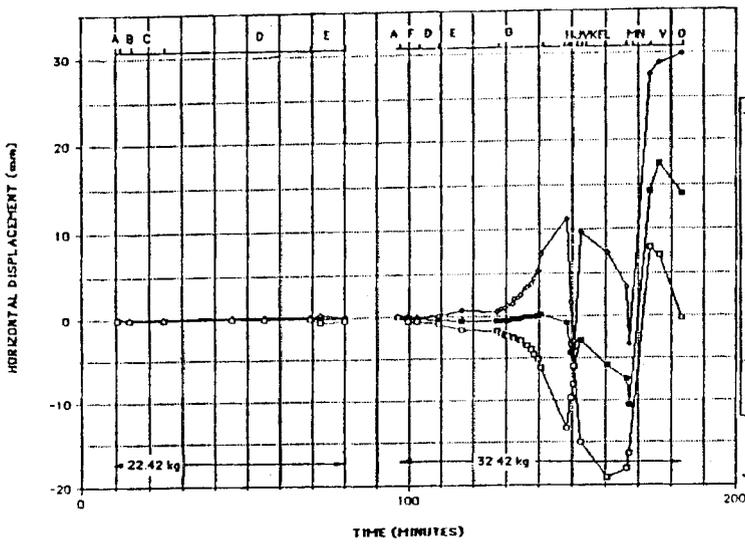


Figure 7

Tree A

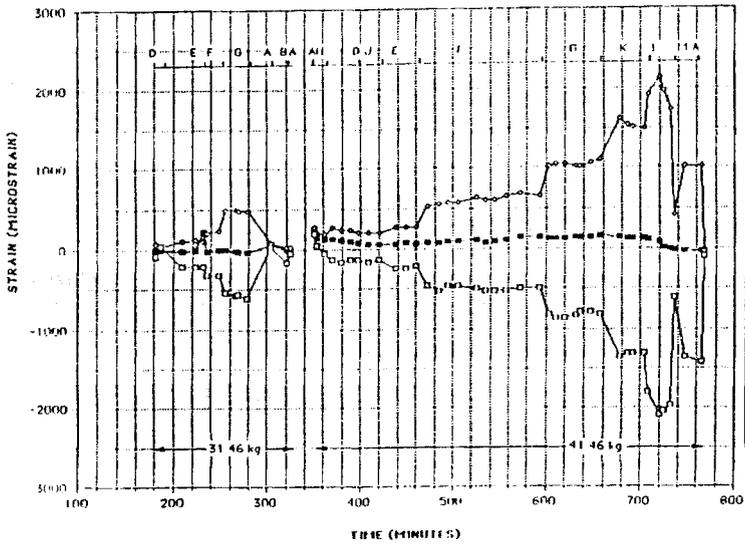


Figure 8

Tree B

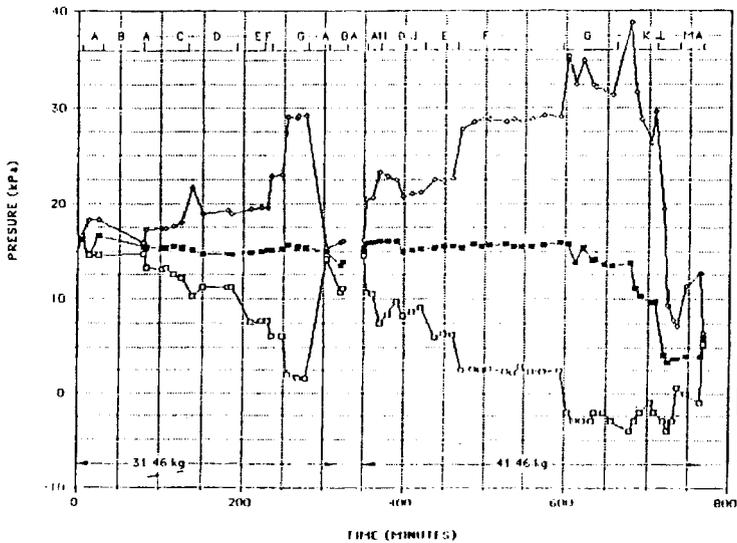


Figure 9

Tree B

amplitudes were subsequently achieved by reducing the frequency of oscillation. This phenomenon could indicate what occurs under conditions of natural dynamic loading. A strong storm could cause initial failure of the soil in the rootplate and the tree could be subsequently rocked with large displacements by winds of a lesser magnitude after this initial failure.

Test Tree B had a root in line with the direction of rocking. It was necessary to apply a larger force to Tree B than to Tree A to cause similar movement magnitudes (Table 1). The diameters of Tree A and Tree B at 1.3m above ground surface were 172.8 mm and 185mm respectively. Figures 8 and 9 illustrate the behaviour of the strain gauge and a soil cell respectively for Tree B

Tree	Mass per Disk (kg)	R.P.M	Height above ground surface (m)		
			3	5	6
			Horizontal displacement (mm)		
A	32.42	30	32.5	65	107.5
B	41.46	35	20	66.5	94.5

Table 1. Horizontal Displacements of Tree Stems

## 6 CONCLUSIONS

1. A methodology for the dynamic loading of trees in the field was successfully established. The equipment included a versatile tree rocker and a sophisticated computer data logging system for sampling outputs from measurement transducers.
2. High pore water pressures in the soil were generated during the dynamic loading of the trees. These pore water pressures caused liquefaction and hydraulic fracturing of the soil. This liquefaction and hydraulic fracturing seems to be a likely mechanism for rootplate failure on saturated surface water gley soils in windthrow conditions.
3. All the trees tested had shallow rootplates. This was possibly due to the high water table level. Lowering the water table could increase the root penetration which would in turn lead to greater tree stability. The lowering of the water table may also reduce the build up of pore water pressure.

4. Tree systems which had roots growing in the direction of rocking were stiffer in that direction than those which had roots only at right angles to the direction of rocking. This indicates that radially symmetrical root systems could give a more stable system than unsymmetrical ones.

The last two conclusions suggest that site preparation methods which encourage roots to grow deeper and radially should be adopted in surface water gley soils.

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