Breakability of Various Timber Species

Peter Chiang

School of Mechanical Engineering

CEED Partner: Main Roads WA

Abstract

Roadside accidents where a car crashes into a tree can lead to serious injury or death for its occupants. One way of addressing this problem is to limit the size of trees that are within close proximity to the road so that only those that will breakaway are kept. This project aims to investigate what the limiting sizes for breakability are for various native Western Australian species.

1.0 Introduction

Breakability is more commonly referred to as frangibility and it is the measure of how easily broken something is. In the context of this project, a frangible object is something that will breakaway within the occupant risk criteria of National Cooperative Highway Research Program Report 350 "Recommended Procedures for the Safety Performance Evaluation of Highway Features". Herein refered to as NCHRP350.

Existing guidelines suggest that all trees that have a diameter of greater than 100mm are not frangible and therefore warrants their removal if they are likely to be hit. This recommendation does not take into account of the fact that different trees will have different mechanical properties and therefore different limits of frangibility.

Removal of specific trees that are deemed to be hazardous has the advantage over clearing road reserves of all trees that are within close proximity to the road, because not only does it leave the land with greater aesthetic appeal, but it also helps preserve native vegetation. In certain areas within the wheatbelt of Western Australia, road reserves contain the only remnant native vegetation and the clearing of trees such as Salmon gum and Wandoo are restricted under environmental protection laws.

It is possible to achieve the objective of finding the threshold diameter at which a tree ceases to be frangible by comparing it with control frangibile objects and occupant risk criteria contained within NCHRP350.

1.1 Background

Information that relates directly to the topic of interest is uncommon. Most sources that have been used are primarily concerned with the design of wooden posts used for the end treatment of breakaway cable terminals, and it is known that these posts breakaway from crash test data and in-service evaluations. Information on the strength of some species of interest is also scarce since they are not commercial timbers and are either found within road reserves or used in roadside beautification projects.

1.1.1 Theory

All timber tested was kept as green as possible before testing to reflect as close as possible the insitu situation. It is also important to know that the strength of timber varies greatly depending on its moisture content. Seasoned timber, which have a moisture content of less than 15% can be twice as strong as unseasoned (green) timber. Therefore the use of seasoned timber would not have been an appropriate alternative.

When the testing is conducted the two sets of information that is of greatest interest are:

1. Change in velocity that results from the collision.
2. Maximum force that is exerted by the post in the impact.

Knowledge of the maximum force exerted during the impact is important because it tells us whether or not the structure of the vehicle is strong enough to resist the impact and prevent the tree from intruding into the passenger compartment. A research report conducted by (CASE 1999) suggests that the measurement of the change in velocity has little practical applications. However in this project, the change in velocity has been used to verify the acceleration data.

2.0 Methodology

Pendulum testing was conducted to determine the dynamic properties of the timber. In these tests the timber posts were rigidly clamped because it is assumed that this will provide the worst case scenario for analysis. The change in velocity was measured by using a high speed camera capable of capturing 500 frames per second. Peak acceleration was used to calculate the maximum force and this was taken directly from the tangential accelerometer attached to the pendulum mass.

In the analysis, the pendulum mass is modelled as free body travelling in the horizontal direction because the impact occurs very close to the bottom of the swing, any vertical component of the acceleration is considered to be negligible.

The diameters used for the calculations have been calculated from the circumference divided by π as this was found to give a better representation of the strength of the tree. Direct measurements of the diameter was subject to parallax error as well as error from the fact that the cross sectional area often wasn't round.

2.1 Species Tested

All species tested are native Western Australian trees obtained either from prunings or clearings.

Botanical Name	Common Name (If Applicable)	Sample Size
Acacia acuminata	Jam (raspberry) tree	7
Allocasuarina fraseriana		5
Banksia attenuata		24
Eucalyptus loxophleba	York gum	6
Eucalyptus marginata	Jarrah	24
Eucalyptus wandoo		7
Melaleuca lanceolata		2
Nuytsia floribunda	West Australian Christmas tree	7

For all species other than Banksia and Jarrah the nominal diameter tested was 140mm at the pendulum impact height. Whereas for Banksia and Jarrah the nominal diameter range was from 80mm to 200mm so that the effects of varying the diameter can be investigated. In reality there was a large amount variation in the sample sizes due mainly to limitations in the number of samples to select from, measurement errors and natural irregularities in the shapes of the specimens. Subsequently a least squares regression line was used as a means of averaging the data and producing a trend line.

3.0 Previous Results

Breakaway timber posts have been in use for some time, but pendulum test results for them are not always consistent. Test results from (CASE 1999) and test data from (Kapitola 2005) analysed gave average peak forces of 110KN and 90KN respectively. Results from (Michie 1971) conducted at the Southwest Research Institute in the US gave results of approximately 65KN when modified with equation A3.1 from the NCHRP350. This modification is required because the distance between the point of impact and the top of the clamp is greater in Michie's tests thus the bending moment produced is greater. Averaging these results provides 88KN as the maximum peak force value.

Equation A3.1 $F_y = D\left(\frac{\sigma_y Z_p}{H_r}\right)$

F_y = dynamic post yield force for a rigid anchor

Z_p = post elastic section modulus

D = dynamic magnification factor which is 1 for wood

H_r = height of the highest rail above the base of the post. This can also be called the impact height for greater clarity.

If D is omitted since it equals 1 Equation A3.1 can be rearranged to show that it is simply another way of writing the equation $\sigma_y = \frac{M \times y}{I}$ where the bending moment $M = F_y \times H_r$ so that:

$F_y = \frac{\sigma_y I}{H_r y}$ and since $\frac{I}{y} \equiv Z_p$ it is the same as the original equation.

4.0 Test Results

It was found that the change in velocity and therefore the change in energy that occurs due to the impact varied linearly with the post's area moment of inertia. This result is consistent with the findings of (Michie 1971).

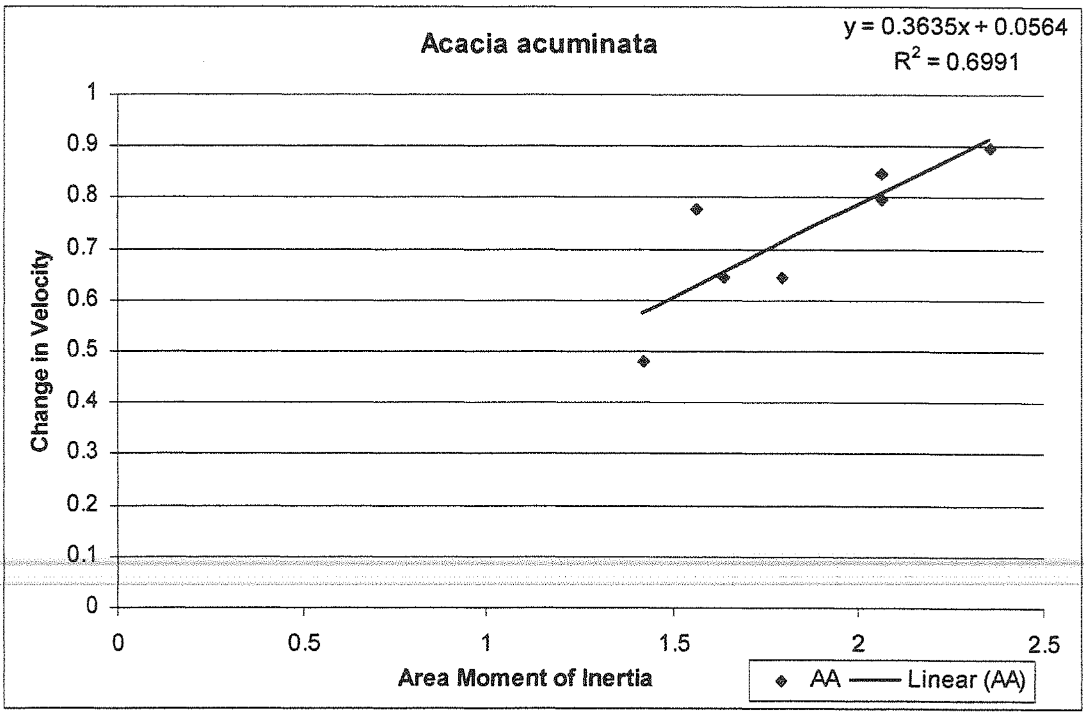

Figure 1 Results from Analysis of high speed video

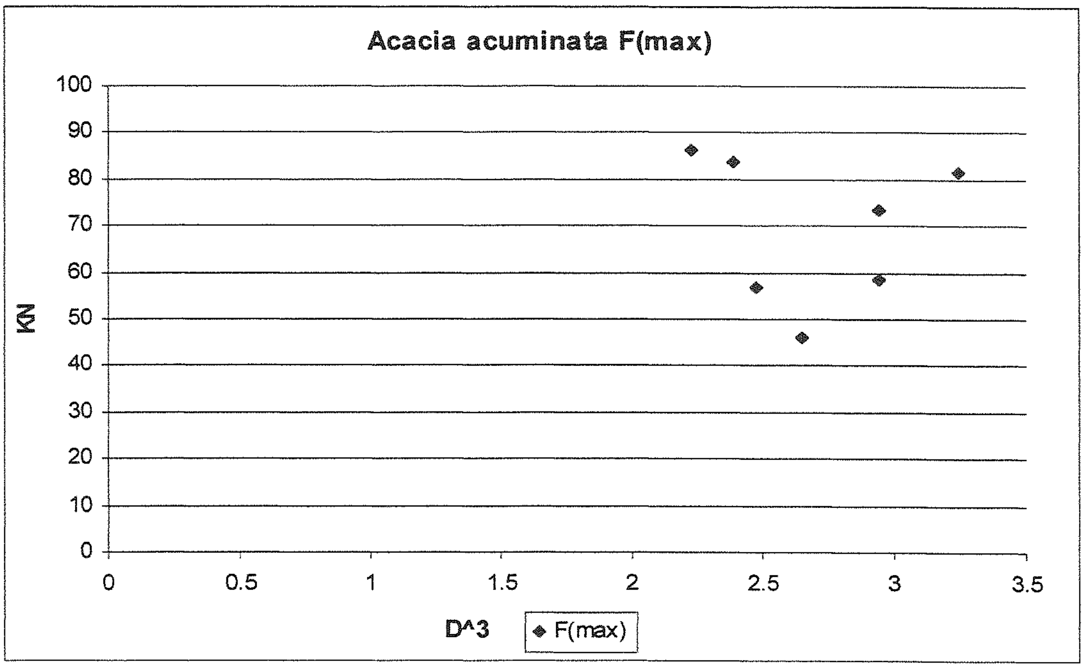

Figure 2 Results from Analysis of Accelerometer Data. D stands for the diameter at impact height

Plotting the force against I or D_ did not give good correlation. In fact it is quite puzzling as to why there was such an enormous degree of scatter that renders the data virtually unusable. Some of the scatter can be attributed to the fact the shape of the timber is not round and that the samples were far from the clear specimens used in standard timber tests. However the presence of imperfections does not explain why the maximum force is sometimes greater than predicted or the large variations seen in the results.

4.0 Discussion

Typically the plots of change in energy against area moment of inertia produced data points that followed a linear trend line. When these lines were extended down towards the origin all but one of these trend lines have a value greater than zero at an area moment of inertia value of zero. This is consistent with the findings of (Michie 1971) and can be explained partly by; the slight decrease in the velocity of the pendulum as a result of an increase in height as it swings through and friction forces that act on the pendulum arm.

Results also indicate that for the green timber posts tested the peak acceleration value does not exceed 4g for an impact mass of 2515kg and an impact velocity of 8.76m/s. Whereas in the analysis of Kapitola's data we see that peak accelerations can be as high as 5g for the breakaway wooden posts tested. Thus it seems at this point that the majority of posts tested are frangible.

4.1 Maximum Force

Michie's results predict a linear relationship between the area moment of inertia and F(max). However since the posts cross sectional area is approximated with a circle. Equation A3.1 from NCHRP350 appendix section A3.4.2.1 could be rearranged to give a linear relationship between the theoretical F(max) and D_. Subsequently all plots have been done this way.

There were also attempts to average the data so that an averaged acceleration was plotted instead of the maximum, but the end results were not much better. The expected reason for this is that the impact causes vibration of the pendulum arm and the whole test rig itself. This vibration can start to come into effect before the post is fully broken thus producing erroneous results.

4.2 Comparison between Analysis using Video and Accelerometer Data

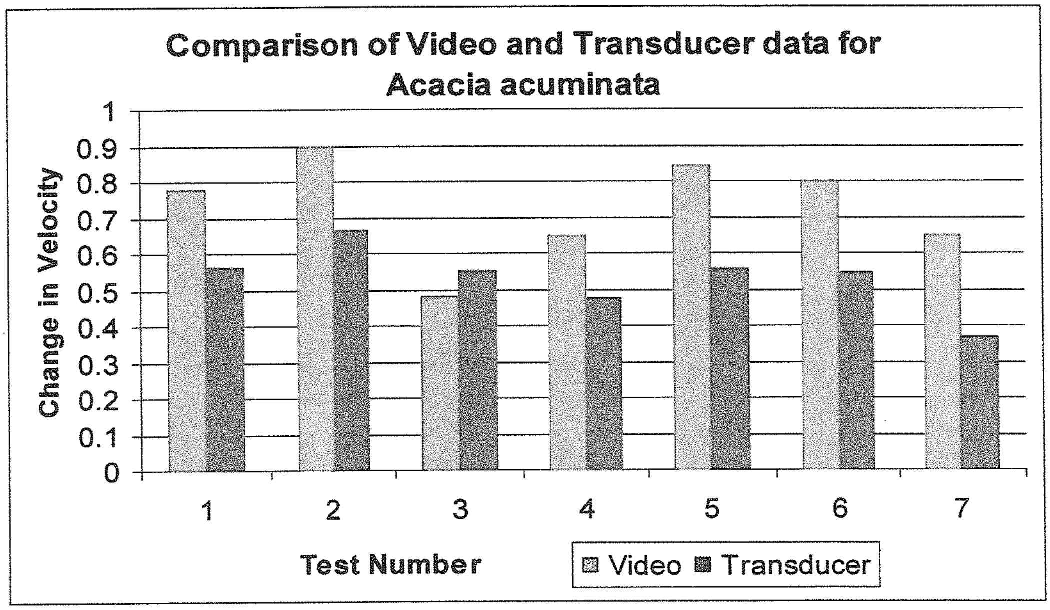

Figure 3 Plot of ΔV difference between the video and accelerometer data

Initial comparisons were made using Acacia acuminata and there were some similarities that can be seen between the results. A good correlation would place greater confidence in the quality of the acceleration data and its analysis. However further analysis of other data then showed that the correlation between the analysis of the video footage and the accelerometer data is often quite poor. The general trend is as shown above but there always appears to be some points that defy this trend.

5.0 Remaining Tasks

Actual figures on the recommended maximum diameters require some further work. Given that the Plots of F(max) do not provide accurate trends it will be necessary to investigate the use of other methods to predict the maximum diameter. These methods will rely on equation A3.1 from the NCHRP350, for example using the density of the timber as a measure its strength. Or alternatively the existing trendlines can be forced to take on a steeper gradient by making it pass through the origin. Therefore making estimates more conservative at higher diameters.

6.0 References

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