Tree Cable Loads During High Winds

Part 2 - Results of tests during wind storms.

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1. INTRODUCTION

In urban areas, the problem of trees and limbs falling, often during periods of high winds, is a cause of considerable concern to arborists. Steel cables are used to support limbs of trees in urban areas, in an attempt to provide support for tree limbs, but little knowledge exists of the loads and dynamic behaviour of these systems under the effects of high winds. A project that investigates the loads developed in tree cables during high winds has been commenced by the authors. This paper discusses the loads that have been monitored on tree cable systems, over a period of approximately one year. Some of the background and theoretical considerations have been presented in Part 1,[2].

2. EQUIPMENT DEVELOPED

A strain gauge load cell was developed which can measure the wind induced loads in a tree cable. The load cell consists of an accurately machined section of mild steel (200 mm long), plated with stainless steel, to minimise deterioration caused by the weather. Electronic strain gauges are attached to this steel section. Load signals from the gauge are sent via dedicated wires back to a fast data logging card in a computer where the analog signals are then converted to digital form and recorded using Labtech Notebook software. A signal scanning rate of 20 Hz has been found necessary to capture the peak loads that occur from rapid snap loading of the cable, during wind storms. The load cell is calibrated before being installed into the tree cable system. Figure 1 depicts a schematic of a typical arrangement using this equipment.

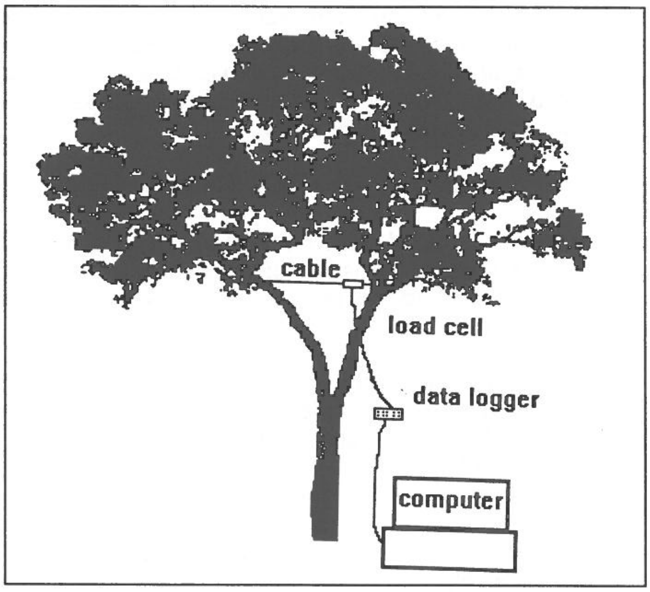


Figure 1. Tree cable monitoring system

3. TREE CABLE SYSTEMS

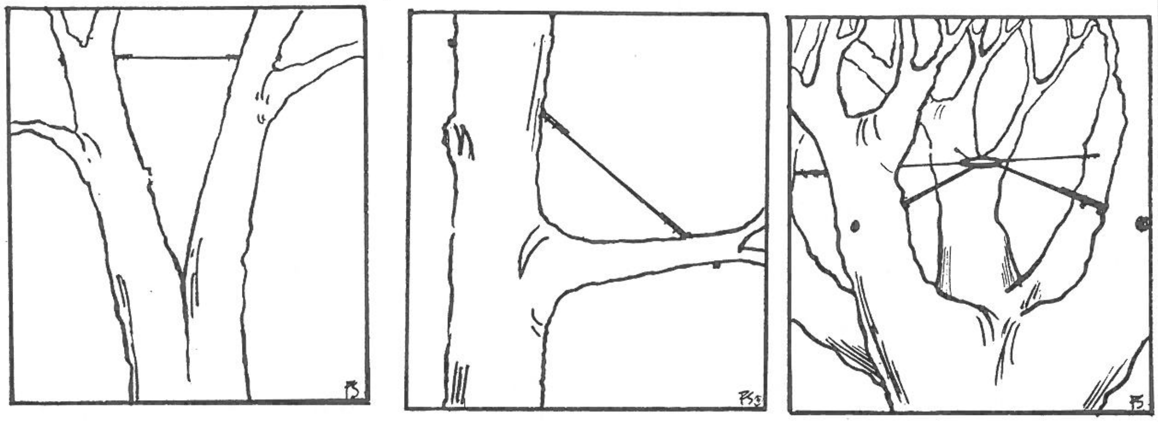
Three different tree cable configurations were monitored over a period of approximately one year in this pilot study, with recordings being made of cable loads which were developed during high winds. The cable configurations examined are shown in Figure 2, (a), (b), (c)and are:

(a) **straight cabling** between two codominant stems of about the same size (Fig 2a). This cable configuration was installed in a *Eucalyptus cladocalyx* of about 30 meters height which had three codominant stems.

(b) **a horizontal limb cabled** back to a main trunk for support (Fig 2b). This cable was located in a *Eucalyptus maculata* (spotted gum) of approximately 20 meters height.

(c) **a multi-cable system** connected back to a central ring (Fig 2c), in a *Cupressus macrocarpa* (Monterey cypress) that had many codominant stems. The overall height of this cypress was approximately 20 meters and the limbs were 300 - 600 mm at point of cable attachment.

The cable used was an 8mm, six strand steel cable rated at 31 kN breaking strain. It was secured at each end using three conventional cable clamps and after insertion of the load cell, was retightened to the original load.



(a) codominant stems (b) horizontal limb (c) multi-limb system

Figure 2 Tree cable configurations tested.

Wind speed and direction was measured using a cup anemometer and directional vane device and located in the canopy of the tree. This equipment used a hall effect sensor to measure speed and the TTL digital signal output was converted to give one second average speed values. The anemometer was located in the canopy of the tree, as near as possible to the cable, in order to give as representative a value of wind speed as possible.

4. MEASURED CABLE LOADS (RESULTS)

The maximum load recorded in the twelve month period occurred in the cable configuration between two codominant stems in the *Eucalyptus cladocalyx* during a period of high wind. The peak instantaneous load was measured at 4.3 kN and the load and corresponding wind record for this period is shown in Fig.3.

The peak load of 4 kN is approximately twice the normal peaks recorded during the wind storm and demonstrates that the cable is suddenly subjected to a high instantaneous loading situation. The results of cable load recordings over many storm periods indicate that during periods of high winds, only very few peak loads approached the value of 4 kN. It is difficult to predict when a peak load would occur even when the wind gusts were very strong. This can be seen in Figure 3, where one gust of wind results in a peak load, yet a similar gust, a few seconds later does not.

A different tree species, a *E maculata* with a cable installed between two codominant stems, was monitored and the maximum recorded load was 2.7 kN.

Results for one storm period, of loads in cables in a horizontally cabled limb on a *E maculata* show a peak of 2.18 kN occurring, which was the maximum value recorded over the twelve month period. This peak is lower than for codominant stem cable configuration and the dynamic response appears to be different, in that there was not the sudden extreme peak loading occurring in this cable attached to a horizontal limb.

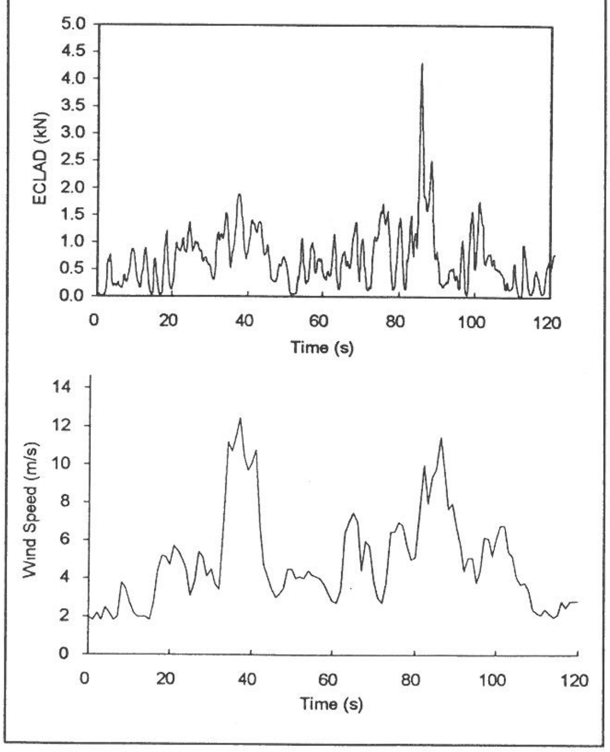


Figure 3 Cable loads and wind speed(*E cladocalyx*)

5. DISCUSSION

The peak cable loads developed in the codominant stem configuration of the *E cladocalyx* were generated during periods of high winds and are a result of the complex nature of the sway motion of large tree limbs. A large tree limb has a broad range of natural frequencies due to the sway of the main limb, sub limbs, branches and sub branches. There is also a damping effect due to the drag of the leaves in the air stream, and thus the resulting swaying motion is quite complex. Although the tree limb appears to sway backwards and forwards in a simple swinging motion, it does so at the same time as its subcomponents are swaying. Spectral analysis of the cable load records shows that the tree limbs have a broad natural frequency range, from 0.2 to 0.4 Hz, (Fig 4), ie. the limb sways back and forth approximately every two to five seconds. The spectrum curve in Figure 4 has been smoothed by averaging over one hour, but the results are similar to previous published results by Baker and Bell [1].

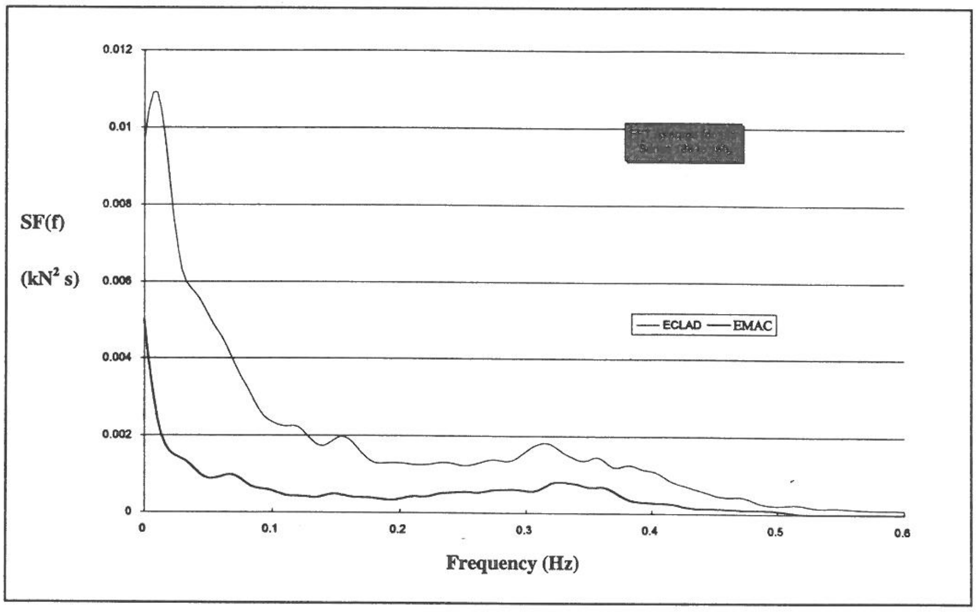


Figure 4. Spectrum analysis of sway frequencies of cabled limbs

When two large codominant stems sway in a strong wind, it appears that for most of the time the complex sway motion prevents any large build up of amplitude and only occasionally do the limbs get completely out of phase and sway apart, creating a sudden snap loading of the cable. This is a fortunate occurrence that minimises the limbs developing large amplitudes during high winds, however the peak snap loads will still occur very suddenly at some unpredictable moment. Thus the greatest limb movement and greatest stress generated occurs when two connecting limbs do not sway in unison [3].

The peak load of 4 kN developed in the cable contrasts with the more frequently occurring peaks of 2 kN during the same storm. The load rating of the 8 wire steel cable is 31 kN, well above any recorded peak and even the recommended safe working load of 10.3 kN for the cable appears conservative. However, the load capacity of some cable connection designs, specifically cable clamps, is often below the observed 4.3 kN peak load and thus these particular connections would be inadequate for this application. Static tests of cables confirmed that failure of the cable often occurred due to slippage at the cable clamps, at loads ranging from 0.9 kN to 9.0 kN. A new connector called a Eureka clamp is being tested and preliminary trials indicate that this design provides satisfactory anchorage for the tree cable.[4].

The results of horizontally cabled limbs in the *E maculata* show the load response is predominantly due to the sway of the single horizontal limb which is flexible when compared to the more rigid upright trunk. The cable has a preload of approximately 0.8 kN in order to support the limb, and the sway motion of the horizontal limb is both vertical and horizontal which results in less extreme peak loads being experienced by the cable, than for the codominant stem configuration.

In order to reduce the peak loading experienced by the cable (and hence the tree), especially in the case of a straight cable between codominant stems, it may be necessary to allow for more flexibility in the cable. This will result in simultaneously extending the period over which the load is applied, with a reduction in overall stiffness, and thus reduce the maximum load. Flexibility could be enhanced by installing a spring into the cable or may perhaps be achieved by changing the material from which the cable is made. Some developments in this area have already been tried with the introduction of polyester materials with the steel cable[6].

Another technique which could help reduce the peak load may be to absorb the energy developed in the cable by installing a damping device such as a shock absorber, much like a damper in a door which prevents it from slamming. Associated with the requirement to reduce the peak loads is the need to design a better cable clamping system, than the present wire rope clamps which have been found to fail by slipping at very low loads [4],

6. CONCLUSIONS

An electronic load cell has been developed that is capable of continuously monitoring the loads developed in tree cables during periods of high winds and storms. This system has been successfully used to continuously record and analyse loads in tree cables over a period of one year.

Loads have been measured in a range of tree cable configurations. The maximum recorded load during the tests, was 4.3 kN, measured in a cable located between two of three codominant stems in a 30m high *Eucalyptus cladocalyx*. The maximum recorded load in a horizontally cabled limb in a Eucalyptus maculata was 2.1 kN, over the same period.

The maximum measured load of 4.3 kN, recorded during wind storms in tree cables, is significantly less than the load capacity of the cables, such as 8 mm steel wire rope which has a breaking load of 30.9 kN. However these maximum loads exceed the failure loads of the wire rope cable connectors which slip at loads as low as 1 kN, depending on how they have been installed and tightened.

It is therefore concluded that there is a need to reassess the current design of the cable and clamping system so that more appropriate materials are used to adequately withstand the loads developed in tree cable systems. Some suggestions would be to use a more flexible cable material than steel wire rope, such as polyester, and stronger connectors such as the Eureka, rather than the present wire rope grips. There is also a need to investigate the use of damping devices that may reduce the peak loads that can be developed in the tree cable system.

The largest loads measured in this pilot study were generated in a straight cable system, installed between two codominant stems of a *E cladocalyx*. This occurred during high winds which caused a complex sway motion of the tree limbs to develop. At certain times, these limbs can sway apart from each other, causing a sudden shock loading to be developed in the tree cable. An analysis of the frequency spectrum of the tree cable load indicates that the tree limbs sway in a complex manner that has a broad period of motion ranging from 0.25 to 0.5 Hz. Further work to monitor tree limb movement during high winds will be needed to fully analyse this motion and the forces that are generated within the tree canopy. The longer term effects of cables on tree structures will also need to be investigated.

References

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