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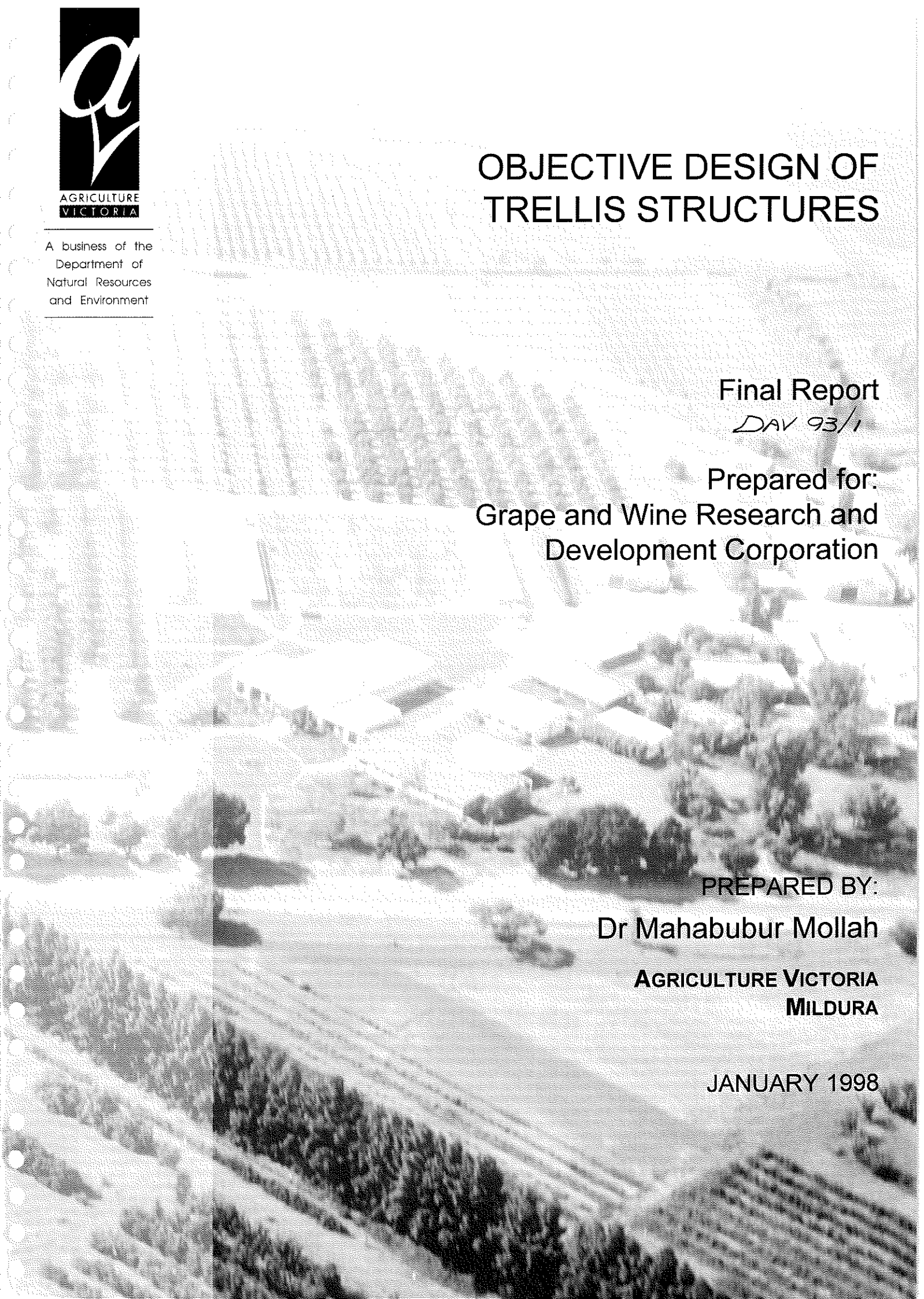
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# OBJECTIVE DESIGN OF TRELLIS STRUCTURES

Final Report

DAV 93/1

Prepared for:
Grape and Wine Research and Development Corporation




PREPARED BY:

Dr Mahabubur Mollah

**AGRICULTURE VICTORIA MILDURA**


JANUARY 1998

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# OBJECTIVE DESIGN OF TRELLIS STRUCTURES


| | |
|---|---|
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# SUMMARY

Trellis structures constitute a major portion of the cost of developing or redeveloping a vineyard. Therefore it is critical that wise choices are made regarding the purchase and installation of trellis components so that the trellis will be economical and long lasting. Grapes are grown on a wide range of trellis structures. Too often, a particular trellis configuration is selected because of tradition, or the preference of a region, contractor or neighbours, not always resulting in the best possible trellis. Trellises have failed resulting in significant repair costs and fruit loss, mainly due to the selection of the wrong type and size of components, such as posts and end assemblies for a particular task. Conversely, many of the structures that are functioning successfully are very expensive because of overdesign. No design data, particularly on the performance of end assemblies under loads or the strength of various components and soil have been available to assist with trellis design.

The loads that are placed on the end assembly can be classified as initial tension in the wire (force to keep the wire taut in the absence of any other loads); weight of fruit and canopy; and temporary increase in wire tension due to temperature reduction, wind gusts, weight of water from overhead sprinklers or rain and impact from vineyard machinery. Only the weight of fruit and canopy is well known. The presence and effect of other loads are not fully realised and often ignored during the design.

With the above issues in mind, studies were carried out on:

- strength of various trellis posts and soils,
- expected loads (static and dynamic) on a trellis end assembly, and
- mechanics of four common end assemblies.

Based on the studies carried out, the following conclusions and recommendations were made.

## Strength of posts

- The thicker the post, the higher its breaking force.
- The breaking force varies widely within each diameter class used to sell posts, mainly due to the variation in diameter amongst posts within the class and to the effect of knots.
- It is recommended that manufacturers should grade posts for trellising by estimated strength categories.

## Strength of soil

- The soil resistance to vertical lift and sideways loading of posts increased with increasing post diameter.
- There was no significant difference in compressive or cohesive strength of soils between the different areas (sites) of Victoria and South Australia that were investigated. This means that for a given installation method, load and soil condition, the average resistance applied to a post by soil, before it will move, will be similar at different test sites.

# BACKGROUND

Currently Australia has about 75,000 - 80,000 ha of land in grape production of which about 55,000 ha is devoted to wine grapes. This area is increasing at a rate of about 5,000 ha per year. Vineyards require a significant capital investment in vine trellising, estimated at $4,000 - $6,000 per hectare, a total investment for the current wine grape industry of $ 220 - $330 million. In addition, the typical annual maintenance costs are $200 - $400 per hectare.

Previous research has focussed on maximising wine grape production by developing improved canopy management systems. New trellis systems have been constructed to hold wires in ways that present the canopy in the desired form, however great variability exists in the costs of materials and erection methods commonly used. Detailed design methods which take into account the canopy style, soil type, crop loads, environmental factors etc., to minimise total cost did not exist. There was inadequate information on which to select structure types and component sizes in order to ensure a sound and cost-effective structure. No significant local or overseas research had been reported into the objective design of trellis structures for grape vines.

Failure of trellises has occurred resulting in considerable costs from fruit loss and trellis repair. Conversely, some successful trellises appear far stronger, and therefore more costly than necessary. Therefore data was needed to provide objective design of trellis structures.

# OBJECTIVES

The objectives of this project were to:

1. Reduce the capital and maintenance cost of vine trellising.
2. Optimise the mix of material and construction costs.
3. Improve the integrity, stability and effective life of trellis structures.

## Specific Objectives

### Strength of trellis posts:

- To test various trellis posts to destruction to assess their strength.

### Strength of soil:

- To assess the resistance to sideways loading and vertical lift of posts in various soil types located in different grape growing areas.
- To determine the effect of soil consolidation on the resistance of soil to vertical lift and sideways loading of posts.

### Expected loads on trellis end assembly:

- To measure static load caused by initial tension in the wires.
- To measure dynamic loads due to:
  -weight of fruit and canopy which increases during the season,
  -temperature reduction,
  -wind gusts,
  -weight of water from overhead sprinklers or rain and
  -impact from vineyard machinery.

### Mechanics of end-assemblies:

- To analyse commonly used trellis end assemblies and propose equations for static equilibrium.

### Post-graduate research:

- To determine the interaction of loads on post and soil deformation.

## Outcome

An information package for grape growers to design cost-effective trellises.

# 1. INTRODUCTION

Today's trellises vary in size and complexity, from single wire structures to multi-wire systems with special head designs, however, their purpose is the same. They must assist the vine to grow a straight trunk in its formative years then support the crop and canopy to produce the desired type of fruit and shape the vine to allow efficient spraying and harvesting. Trellis configurations are chosen to conform with local practice or the subjective preference of the trellis contractor. There are no objective design guidelines for vineyards.

A literature review on the AGRICOLA and CABABS databases revealed very little published information on structural design of trellises. Several articles have been published in an Australian journal and conference proceedings, however these did not answer the principal issues raised in this project.

The main aspects contributing to any successful trellis design guidelines were considered to be:

1. Strength of various trellis posts.

2. The load on an end assembly which is the combination of:

- initial tension in the wires,
- the weight of fruit and canopy which increases during the season, and
- temporary loads due to temperature reduction, wind gusts, weight of water from overhead sprinklers or rain and impact from vineyard machinery.

3. The interaction between the trellis end assemblies and the soil are not well understood. The geomechanics theory that relates to this area has been developed for large piles (eg. bridge pylons, power pylons etc.). End assemblies are somewhat different due to:

- their small scale and shallow depth,
- the soil undergoing many wetting and drying cycles as a result of irrigation,
- relatively high ratio of horizontal to vertical forces on the assemblies.

It was evident that experiments on post and soil strength and theoretical modelling would be required to predict the forces that an end assembly can sustain without failure.

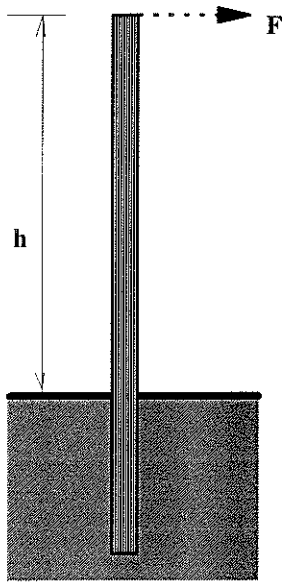
Once the three main aspects were assessed, the task remained to integrate this knowledge in a systematic way. This would then allow a grower or vineyard manager to design their own trellises. It was decided that this would be done by providing a design package in the form of computer software and a booklet.

# 2. RESEARCH METHODOLOGY AND MATERIAL USED

Initially a project team was formed comprising members from Agriculture Victoria; University of Melbourne; Waratah Wire Products, BHP Steel; and Alambie Property Management. This team provided direction and support for the project. This team formally met four times during the life of the project.

## 2.1 STRENGTH OF TRELLIS POSTS:

The simplest way to simulate a bending load on a trellis post in the vineyard and test it for strength, is to clamp a post at the bottom and apply a horizontal pull at the top (Figure 2.1).




**F = Pull**

**h = Height of pull**

**BM = F x h** **Bending moment**

$$Z = \frac{\pi D^3}{32}$$ **Section modulus (Round post)**

$$Z = \frac{b^3}{6}$$ **(Square post)**

**D = Post diameter**

**b = Side of a square post**

$$\sigma = \frac{BM}{Z}$$ **Maximum Stress in Timber**

**Figure 2.1 Schematic diagram of a loaded post, and formulae to calculate the maximum stress in the post.**

The bending strength of the material of posts can be defined as the value of the maximum stress, $\sigma$ (Figure 2.1), that occurs when the post breaks.

### 2.1.1 Test rig:

A portable test rig capable of applying horizontal loads of up to 10 tonnes at heights varying from 1 to 1.8 m, was used to test the load-carrying capacity of trellis end-assemblies in the field. This test rig consists of an L-shaped frame, which uses the dead weight of a tractor to provide anchorage and stability during the loading sequence (Figures 2.2 & 2.3). Horizontal pull is applied by a chain connected to a hydraulic cylinder. Load in the chain is measured by an STC load cell and displayed on a digital indicator.

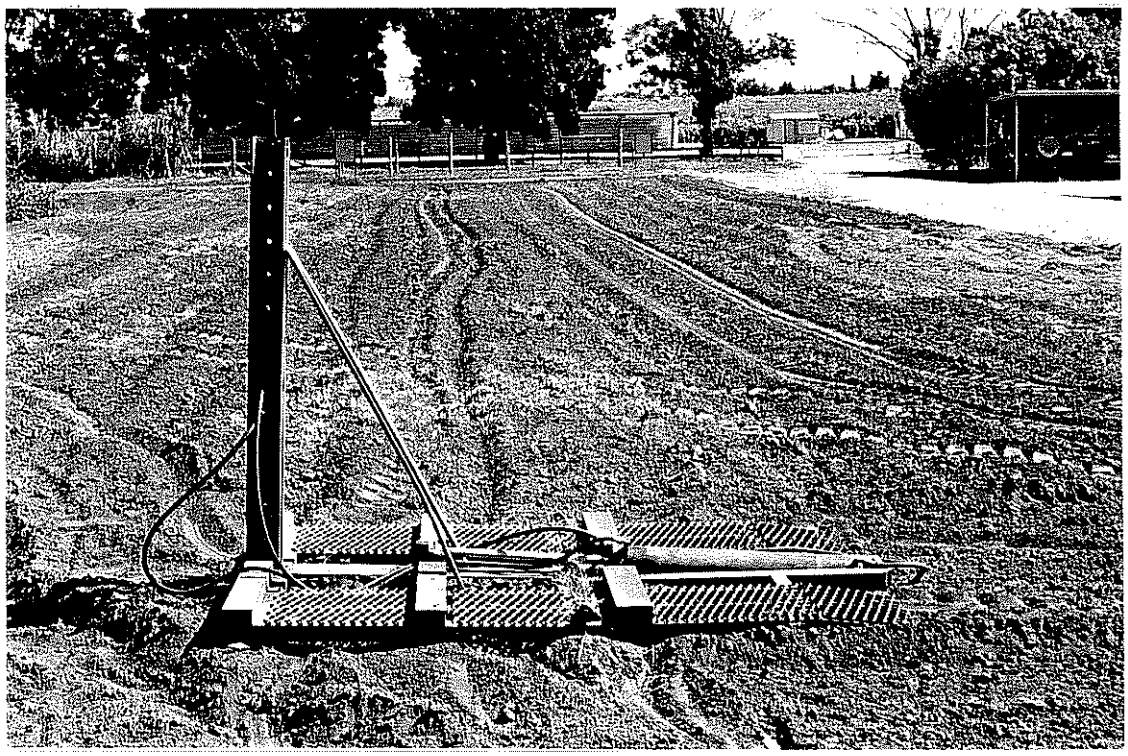


**Figure 2.2 Portable test rig.**

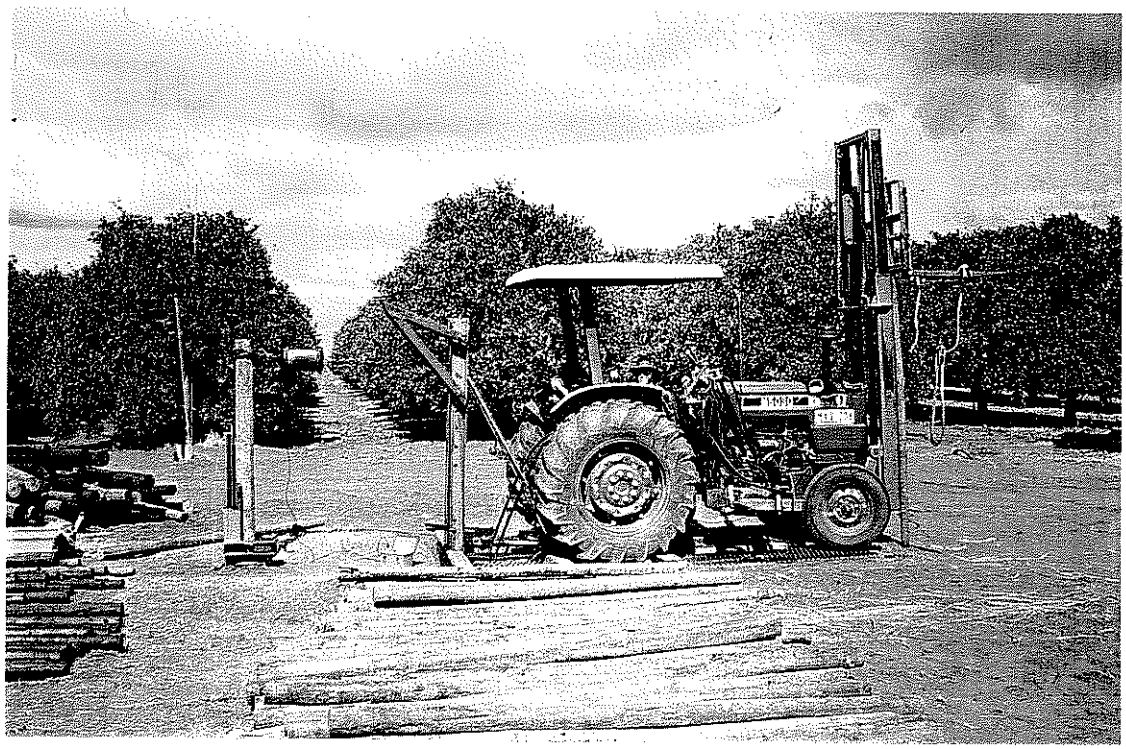


**Figure 2.3 The rigs being used to test breaking force of a post.**

## 2.1.2 Posts:

Two hundred and forty cambio (debarked) pine posts of two different types (treated with either creosote or CCA), in four diameter classes (50 - 75 mm, 75 - 100 mm, 100 - 125 mm and 125 - 150 mm), were tested for strength (Figure 2.4). The posts came from the same forest and received uniform preservation treatment for each diameter class.

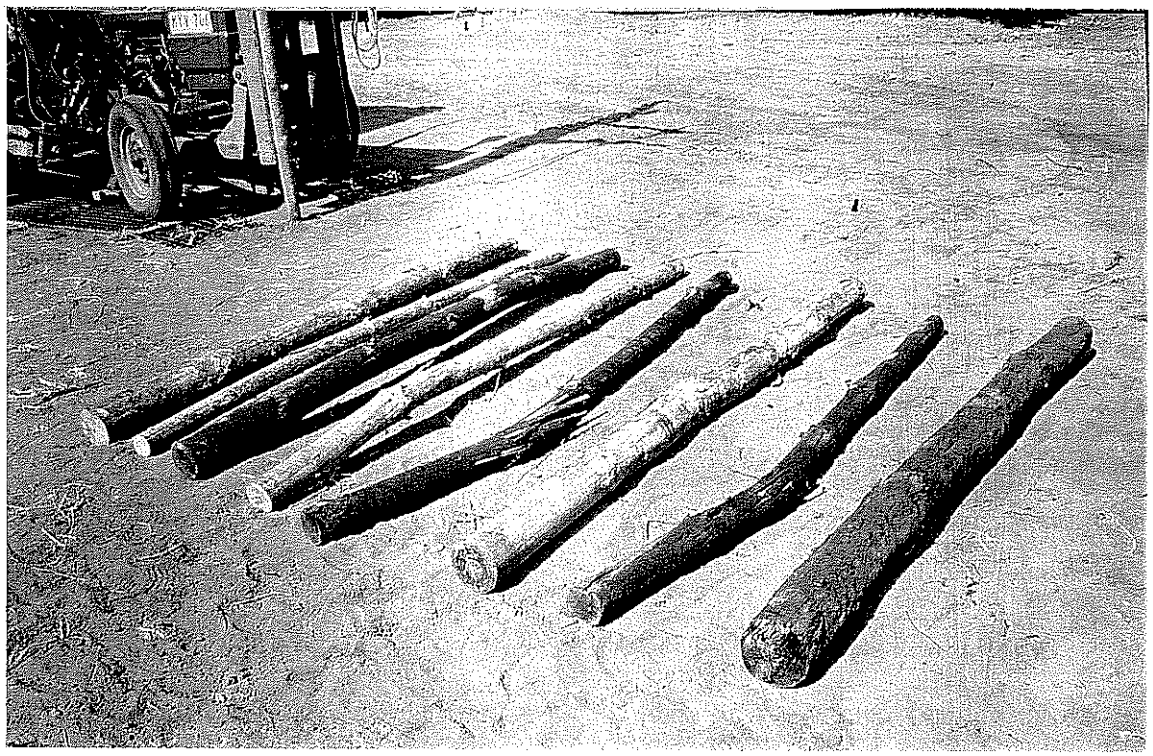


**Figure 2.4 Different types of posts tested.**

## 2.1.3 Test procedure:

For each run, the post to be tested was placed to a depth of 0.9 m in the fixed bed rig and held firmly by the clamp. The portable rig was placed against the concrete bed and the end of the chain was tied to the post at 1.4 m above the clamp of the fixed bed rig. The hydraulic cylinder was activated to apply a horizontal pull which gradually increased until the post broke. The peak pulling force at post breakage was read from the digital indicator.

The diameter of each post was measured. Its age was estimated by cutting a thin disc from the thicker end and counting the growth rings. The diameter at the base, tip and clamp height was recorded for each post. The presence of any knots close to the clamp height was noted.

## 2.2 STRENGTH OF SOIL:

Sets of different posts were installed (machine driven) at 7 different locations in Victoria and South Australia and left in the ground for 6 months before testing. A matching set of posts was installed at each location just prior to testing.

The location and soil type[1] of these test sites were as follows:

| Test site | Soil type |
|---|---|
| Mildura 1 | Clay loam (300 mm), descending into sandy clay loam (300 mm) then light medium clay |
| Mildura 2 | Loamy sand (300 mm), descending into sandy loam (600 mm) then into clay loam |
| Tatura | Clay loam |
| Great Western 1 | Brown loam |
| Great Western 2 | Clay loam with stones |
| Nuriootpa | White loam |
| Coonawarra | Hard bed of limestone under 400 mm of black clay |

The post categories used in the trials were:

- "Gripfast" steel posts
- 50 mm -75 mm CCA treated pine
- 75 mm - 100 mm CCA treated pine
- 125 mm - 150 mm CCA treated pine

To test the soil resistance to vertical pull, an extra attachment was placed on the portable rig, and the chain of the test rig was tied to the post near ground level (Figure 2.5). Soil samples were collected from each site for analysis of strength in the laboratory.

## 2.3 EXPECTED LOADS ON TRELLIS END ASSEMBLY:

The initial tension in trellis wires was measured using a pre-calibrated strain-gauged-beam and a digital load meter (Figure 2.6). The beam was held in position by friction by passing the wire over the end lugs and underneath the middle lug. The wire tension bent the beam, resulting in an electric signal. This was read by the digital load meter and the corresponding wire tension was read from a calibration graph.

[1] The description of soil type was adopted from a soil description handbook (Wetherby, 1992).

## 2.3.2 Dynamic loads

A data recording system comprising a computer, software, data acquisition cards, and sensors (Figure 2.7) was designed to record dynamic loads on trellis structures, particularly loads caused by fruit and canopy; temperature reduction; wind gusts and / or heavy rain. This system was used in a vineyard at the Sunraysia Horticultural Centre, Irymple. Loads imposed on the fruiting and foliage wires of Marshall and two-wire vertical trellises supporting Sultana vines on Ramsey rootstock, as well as wind speed, wind direction and temperature of wires were monitored. Normally the system scanned every 15 seconds and the data averaged every 5 minutes and then saved into a file every hour. However, the system had an option to log 4 readings per channel per second when wind speed exceeded a pre-set threshold value.

The data collected with this system was analysed to determine the loads imposed on trellises, such as wire tension and force exerted on end assemblies during: wind gusts or storms; temperature reduction; and increasing canopy and crop load.

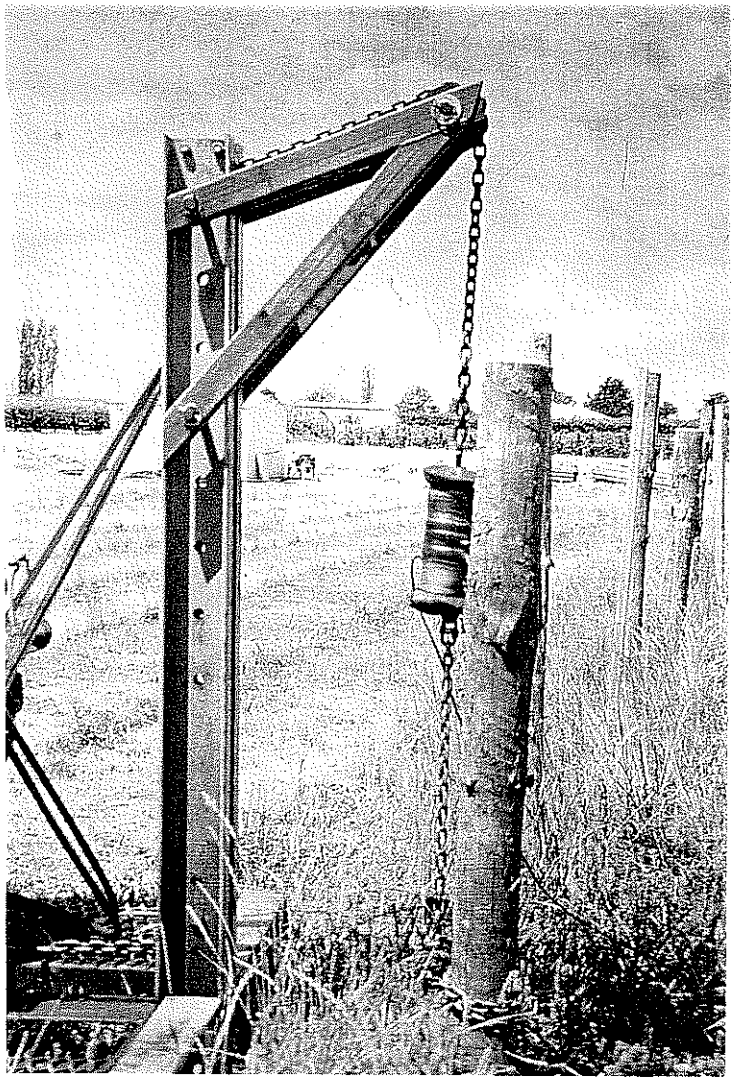


**Figure 2.5 A post being lifted vertically to test the resistance of soil.**

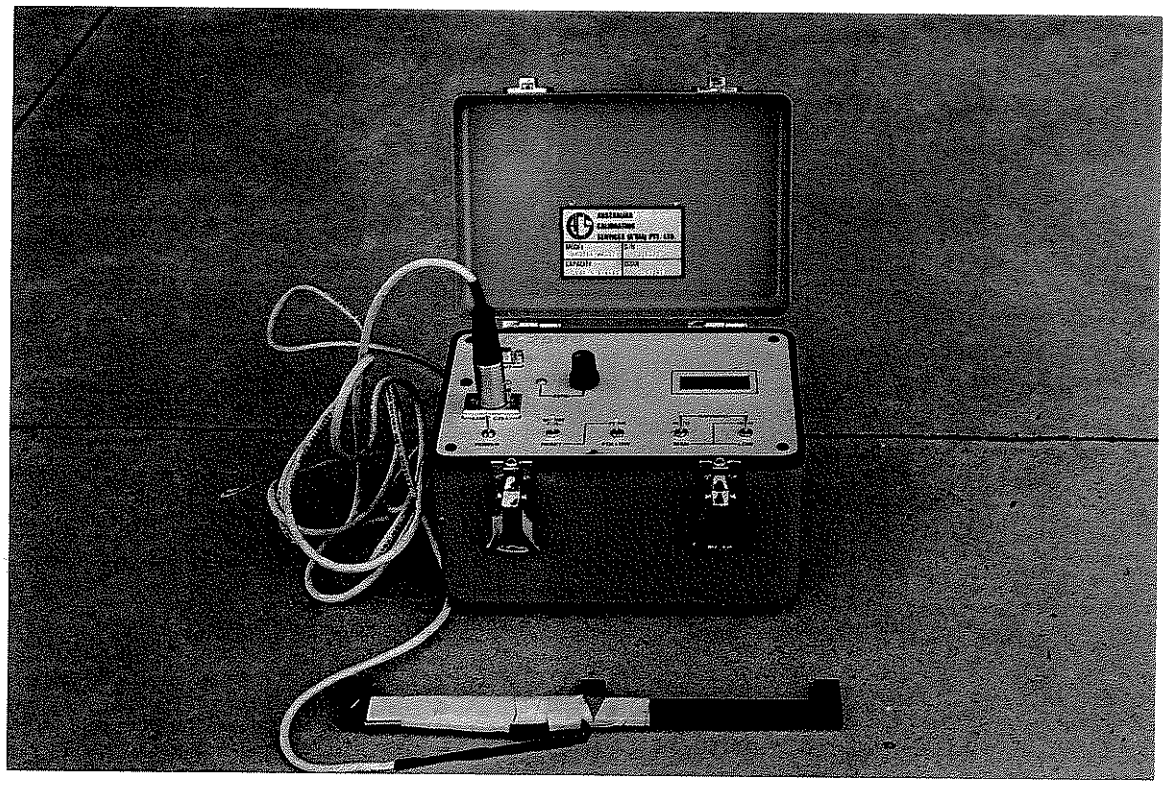


**Figure 2.6** **A strain-gauged-beam connected to a digital load meter.**

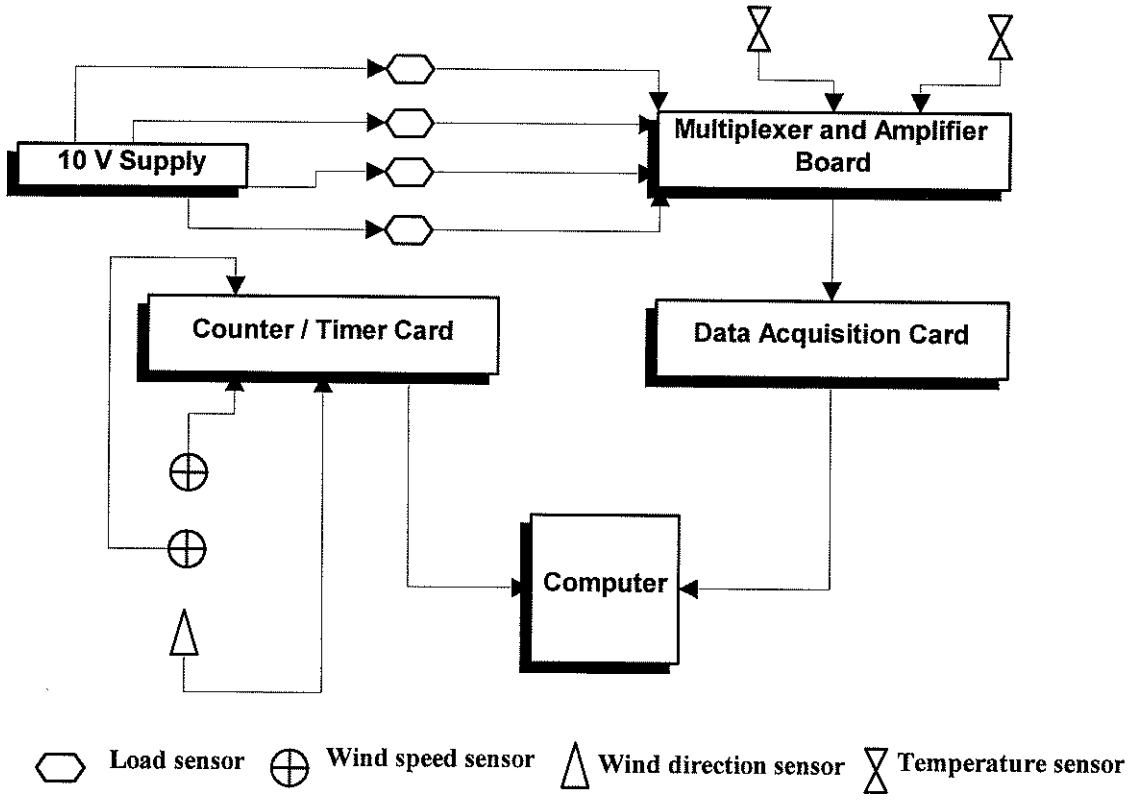



**Figure 2.7** **Schematic diagram of the data recording system.**

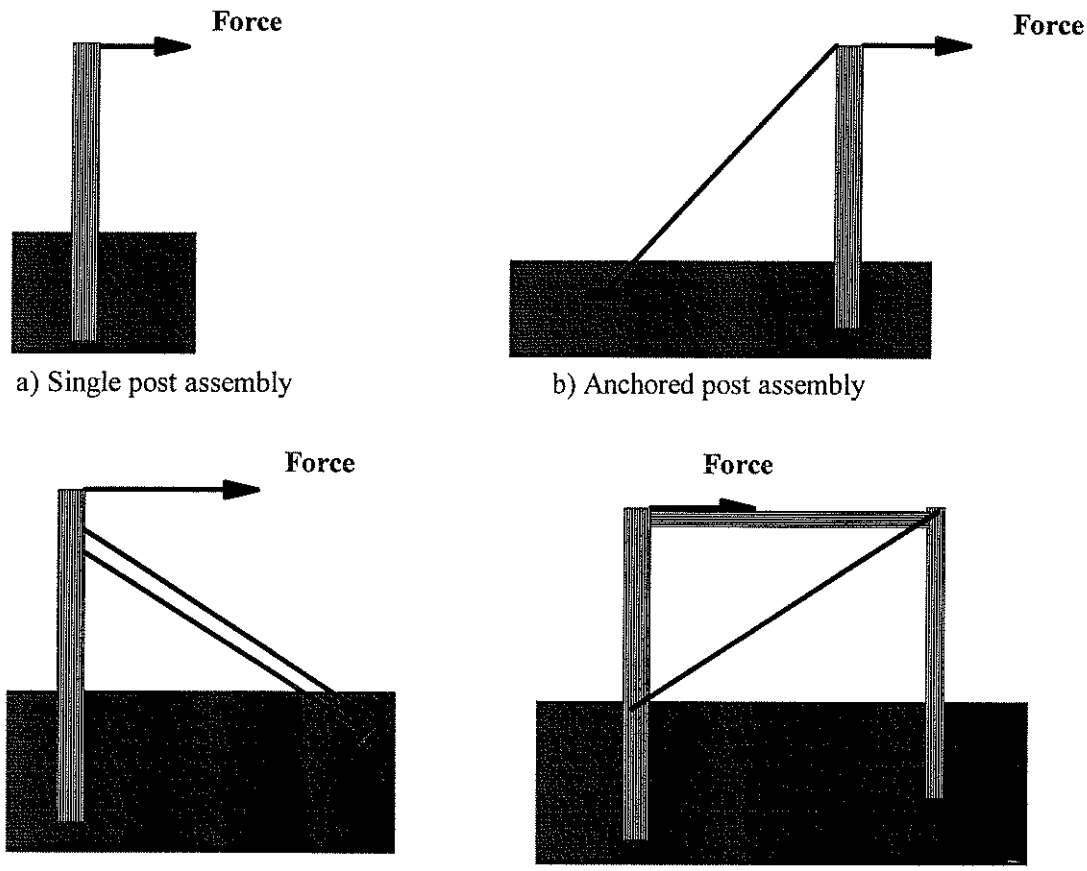
### 2.3.2.1 Impact of mechanical harvesting on trellis:

The impact from a mechanical harvester (beating in a horizontal plane) on a number of trellises in a commercial vineyard were monitored during harvesting using a strain-gauged-beam, data logger and a laptop computer.

## 2.4 MECHANICS OF END-ASSEMBLIES:

The engineering mechanics of four common end assemblies (Figure 2.8) were analysed using the following assumptions:

- Forces in trellis wires can be combined into a single force acting on the post at a known height above the ground.
- Most of the connections between posts, compression members and wires are considered to be pin joints.
- There is no ground movement, except for the single post. This means that all soil reactions can be resolved into vertical and horizontal forces.




a) Single post assembly

b) Anchored post assembly

c) Stayed post assembly

d) Post and rail assembly

**Figure 2.8 Four common end assemblies used for grapevine trellising.**

**Table 3.1** **Mean bending strength and breaking force of various posts used for grapevine trellising.**

| | | Bending Strength | | Measured Diameter | | Breaking Force | |
|---|---|---|---|---|---|---|---|
| **Post Type** | **Diameter Class / size (mm)** | **Mean (MPa)** | **Std. Dev. (MPa)** | **Mean (mm)** | **Std. Dev. (mm)** | **Mean (kg)** | **Std. Dev. (kg)** |
| **Creosote Treated Radiata Pine** | ***50-75*** | 63 | 23 | 83 | 7 | 247 | 91 |
| | ***75-100*** | 68 | 20 | 101 | 8 | 488 | 130 |
| | ***100-125*** | 57 | 10 | 128 | 11 | 888 | 256 |
| | ***125-150*** | 49 | 11 | 155 | 10 | 1304 | 308 |
| | **59** Mean Bending Strength | | | | | | |
| **CCA Treated Radiata Pine** | ***50-75*** | 44 | 15 | 82 | 10 | 181 | 84 |
| | ***75-100*** | 47 | 18 | 103 | 30 | 370 | 145 |
| | ***100-125*** | 46 | 9 | 121 | 10 | 580 | 113 |
| | ***125-150*** | 50 | 10 | 154 | 13 | 1274 | 245 |
| | **47** Mean Bending Strength | | | | | | |

***Note: A horizontal pulling force was applied at 1.4 m above the test rig clamp to evaluate the strength of each post.***

Referring to Figure 2.1, the breaking force of a post can be predicted as:

$$\textit{Breaking force} = \frac{\textit{(Bending strength x Section modulus)}}{\textit{(Height of the pull from the ground)}}$$

### 3.1.2 Effect of wood preservative used:

Posts treated with creosote withstood higher breaking forces, particularly in the 75-100 mm and 100-125 mm classes (Table 3.1) than CCA treated posts. This supports the previous observations by Mollah et al. (1995) that creosote treatment may provide extra strength to pine posts over CCA treatment. However creosote treated posts are more expensive, so when price is taken into consideration, CCA treated posts may be the preferred option. A 100 -125 mm CCA treated post can be bought for much the same price as a smaller 75 -100 mm creosote treated post. The larger CCA posts will withstand on average 92 kg more breaking force than 75 -100 mm creosote posts (Table 3.1) if the load is applied sideways at 1.4 m above the ground. Posts in the 125 - 150 mm class are generally used to construct end assemblies. Either a creosote or a CCA treated post in this class can be chosen for end assembly construction as the difference of 30 kg (Table 3.1) between their breaking forces is not significant at a 5% level of significance.

The current categories that posts are sold in give no indication of their breaking force. A post classification system that included the information needed to work out the expected breaking force would benefit growers by allowing them to better match posts to suit a specific need.

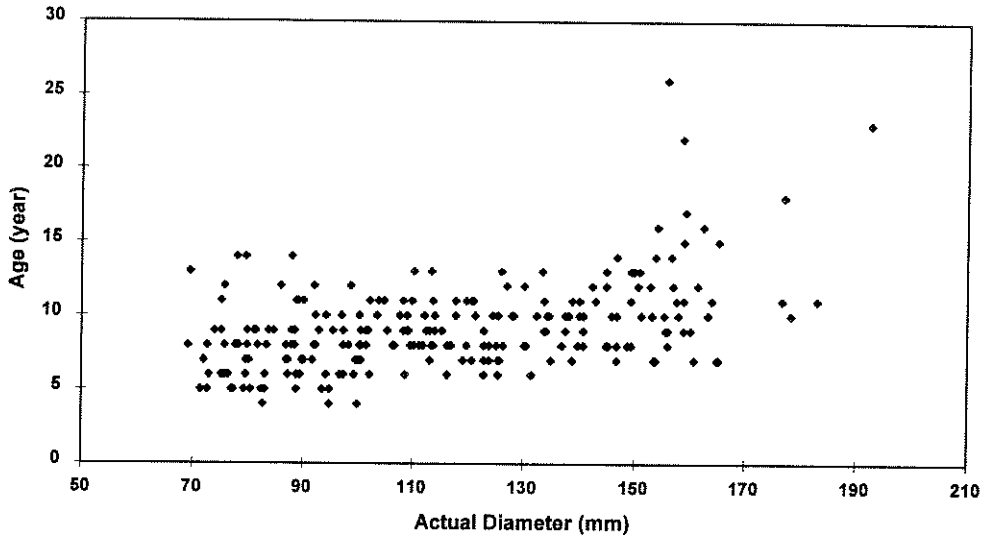



**Figure 3.2a** Age of post vs actual post diameter.

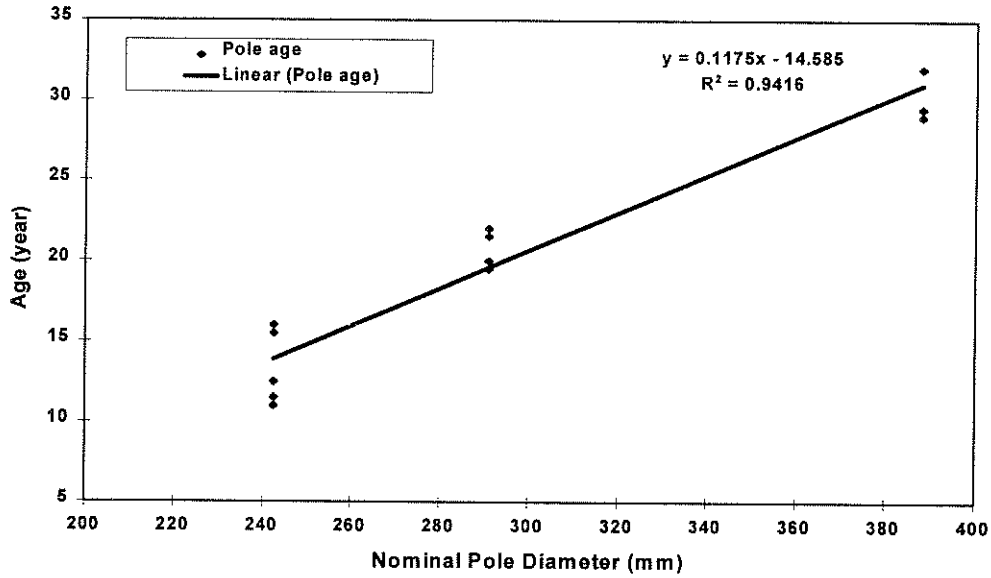



**Figure 3.2b** Age of post vs post diameter (adapted from Boyd 1964).

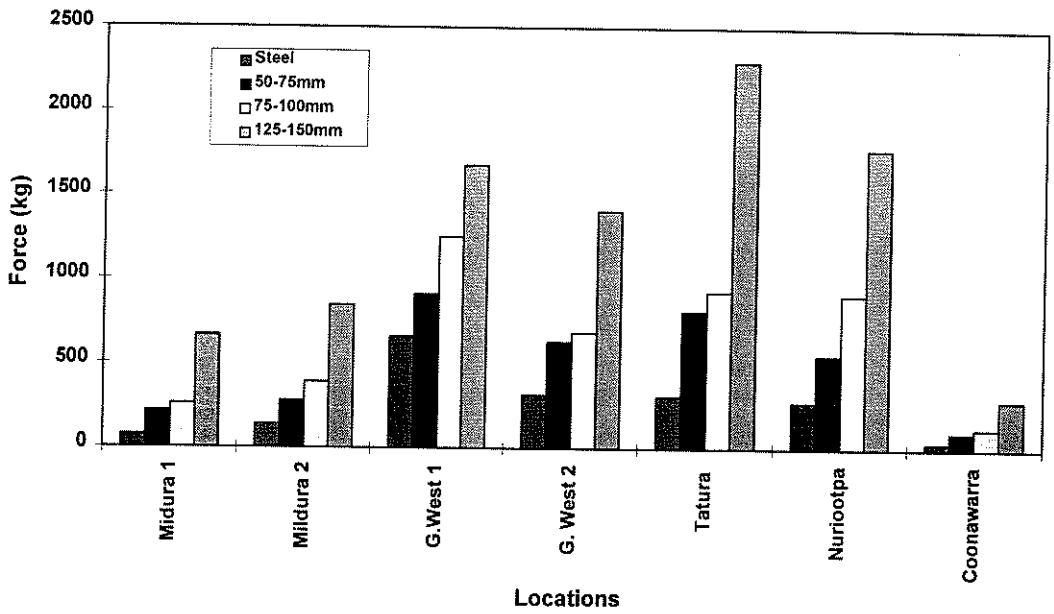



**Figure 3.4. Mean vertical lift withstood by different type of posts at different locations.**

Analysis of field data and soil samples at the University of Melbourne showed that there was no significant difference in compressive or cohesive strength of soils between the sites. This means that for a given installation method, load and soil condition, the average resistance applied to a post by soil, before it will move, will be similar at different test sites.

Clay loam at Tatura and brown loam at Great Western adhered strongly on posts in comparison to other soils. In these soils, 0.9 m depth of end posts and 0.6 m depth of in-line posts should be adequate for most situations.

Soil at the Coonawarra site had a low adhesive strength because it was ripped prior to installing the posts.

Drilling slightly undersized holes through limestone and installing posts by driving into the holes will improve the adhesive strength. This method is common in the Coonawarra area for the installation of end assemblies. In-line posts are rammed in ripped soil because they are mostly subjected to downward loads and not prone to pulling out of the ground. The typical depth of end posts is about 1.0 m and in-line posts 0.7 m in the Coonawarra area.

Soils from other sites were classified as of medium strength. In these soils the end posts are usually driven 1.2 m in the ground. The depth of in-line posts varies between 0.6 - 0.9 m depending on crop load and trellis type.

It was observed that high soil moisture content during post installation and testing resulted in a decrease in soil resistance to vertical lift and sideways loading of posts. End posts of end-assemblies are susceptible to pulling-out of the ground. It is recommended that they be installed when soil is drier to have more strength.

**Table 3.2.** **The effect of soil consolidation around posts on the soil resistance to sideways loading and vertical lift.**

| Locations | Type of resistance | Time in the ground | | Difference (p=0.05) |
|---|---|---|---|---|
| | | < 1 day | 6 months | |
| Mildura 1 | Side load (kg) | 220.9 | ***258.0*** | Significant |
| | Vert. lift (kg) | 288 | ***320.0*** | Significant |
| Mildura 2 | Side load (kg) | 270.1 | ***313.7*** | Significant |
| | Vert. lift (kg) | 377 | 448 | Not significant |
| G. West 1 | Side load (kg) | - | 436 | - |
| | Vert. lift (kg) | - | 1123 | - |
| G. West 2 | Side load (kg) | - | 362 | - |
| | Vert. lift (kg) | - | 758 | - |
| Tatura | Side load (kg) | 404 | 389 | Not significant |
| | Vert. lift (kg) | ***1707*** | 464 | Significant |
| Nuriootpa | Side load (kg) | ***389*** | 301 | Significant |
| | Vert. lift (kg) | ***1366*** | 387 | Significant |
| Coonawarra | Side load (kg) | 128.6 | 150.9 | Not significant |
| | Vert. lift (kg) | 104.1 | ***167.8*** | Significant |



**Figure 3.5** **High soil moisture during post installation at Tatura was responsible for deep tread marks by tractors.**

### 3.2.3 Determination of design curves

Experiments at SHC with posts of different diameters driven to varying depths, showed the resistance to vertical pull, $\mathbf{V_r}$ varies with the circumferential area of the post in contact with the saturated sandy soil (tensiometers indicated readings close to zero) [Figure 3.6]. The circumferential area, $\mathbf{A_c}$ is defined as:

$$\mathbf{A_c} = \pi \,.d\,.\,s \qquad [3.1]$$

Where,

- d = diameter of the post.
- s = depth of the post in the ground.

The lower boundary of experimental data has been taken as the design curve (Figure 3.6). Saturated sandy soil is expected to withstand a vertical pull, $\mathbf{V_r}$ as follows:

$$\mathbf{V_r} \quad = \quad 1.0 \times 10^{-7} \,.\, \mathbf{A_c}^{1.96} \qquad [3.2]$$

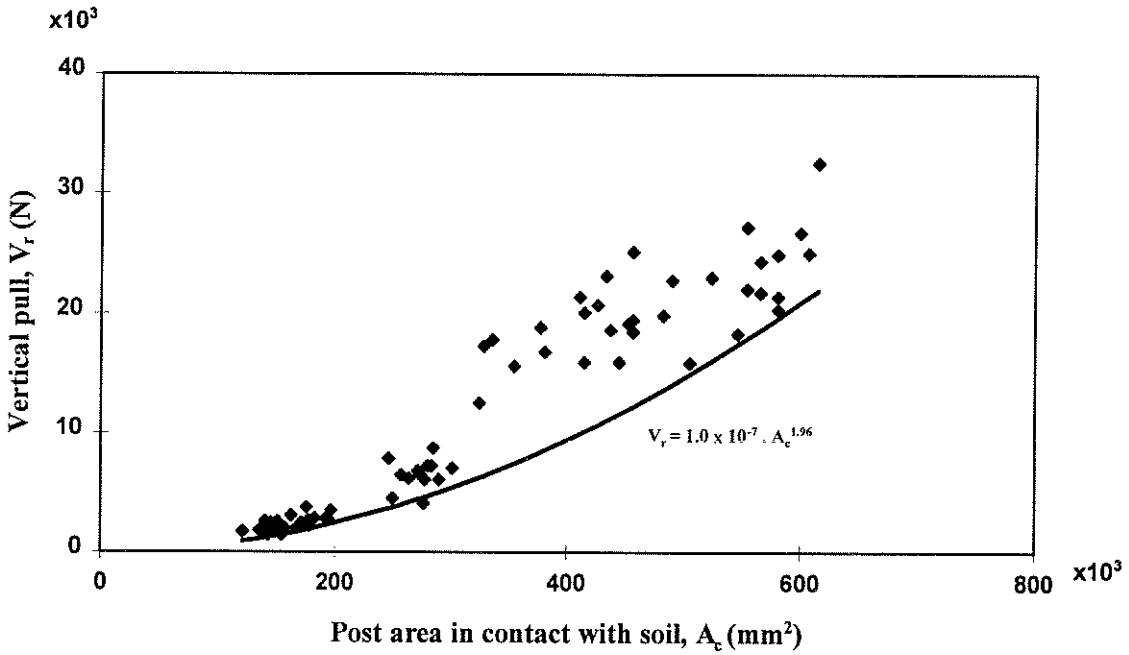



**Figure 3.6** **Resistance to vertical pull of posts in saturated sandy soil (depth range 0.6 1.2 m and post diameter 64 - 163 mm).**

In a similar manner, the relationship between the resisting moment, $\mathbf{M_r}$, caused by sideways pull of posts, and the circumferential area of the post in contact with the saturated sandy soil was developed (Figure 3.7).

### 3.3.2 The weight of the fruit, and canopy.

As the fruit and canopy grew during spring and summer, the tension increased significantly for wires that carried fruit (Figure 3.8).

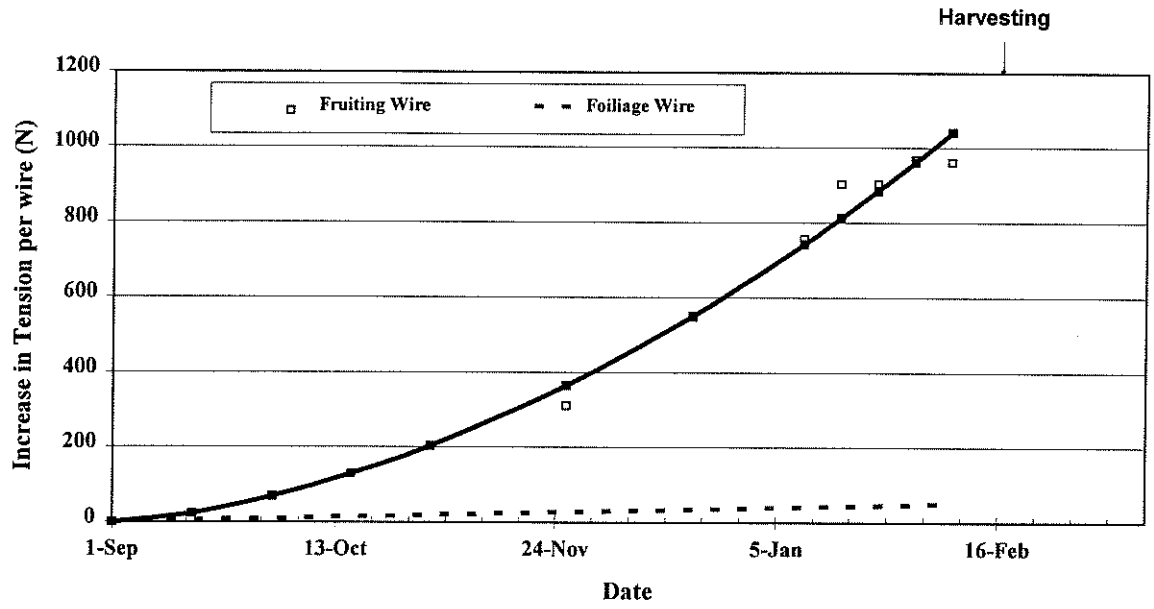



**Figure 3.8** **Change in wire tension of a trellis (2 fruiting and 2 foliage wires) over a growing season.**

Towards the end of February grapes were nearing full maturity and an increase in tension of up to 1,200 N could be expected per fruiting wire (vine spacing = 2.4 m and estimated fruit and canopy[2] weight per vine = 40 kg). Data from a separate trial indicated that the increase in tension per wire could be as high as 2030 N for high yielding vines producing 40 kg of fruit and 20 kg of canopy per vine (Benning, 1996).

### 3.3.3 TEMPERATURE EFFECT ON LOAD

Data from a trellis at Sunraysia Horticultural Centre showed that on a day during the growing season the wire tension varied by 250 N per wire as the wire temperature changed by 25°C (Figure 3.9).

For this 2.8 mm high tensile wire, an inverse temperature effect of 10 N per °C can be used to estimate the change in load.

If 25°C is considered to be the temperature at which the initial tension is estimated or measured, then any temperature reduction below this will increase the wire tension and add load to the end-assembly.

[2] The estimation of canopy weight was adopted from a study by Clingeleffer and Krake (1992).

- Canopy area between two posts is 4.8 m x 2.0 m.
- Air density = 1.25 kg/m$^3$

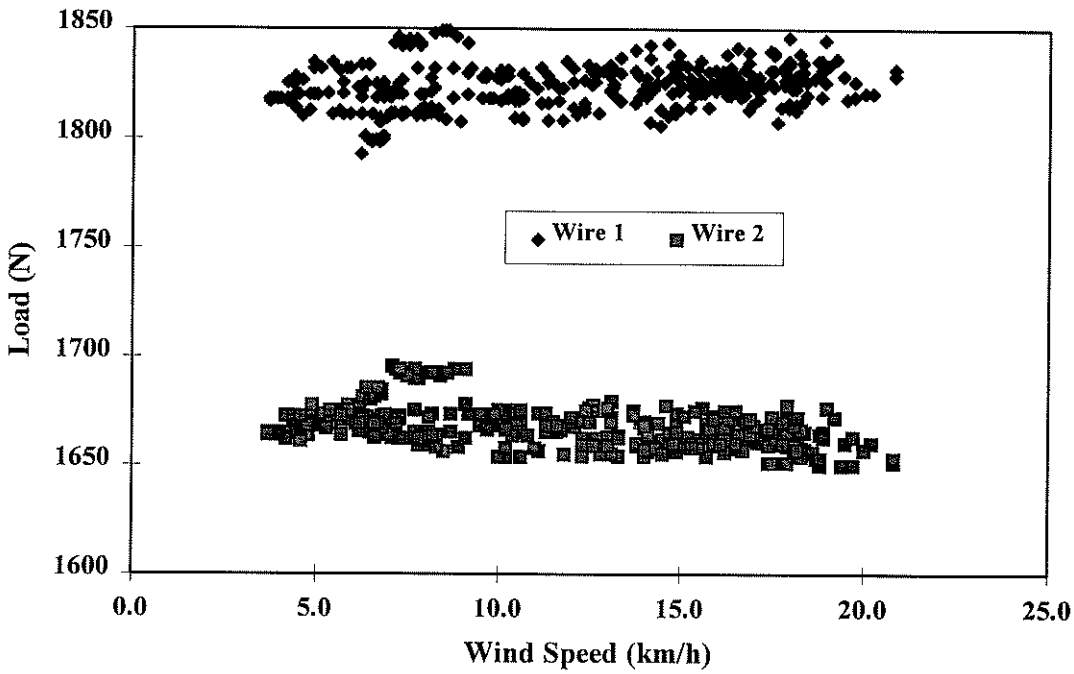



**Figure 3.10** **The effect of wind speed on wire tension**



**Figure 3.11** **Failed trellis due to high winds, Riverland (Photo Ben Vagnarelli)**

### 3.3.5 Impact load

Monitoring of the impact by a mechanical harvester (beating in a horizontal plane) on a number of trellises in Sunraysia area showed a temporary increase in tension of about 450 N per wire and an extra sideways load of about 1800 N (Figure 3.12) acts on a trellis post. However, the speed of beating and operator skill will influence these values.

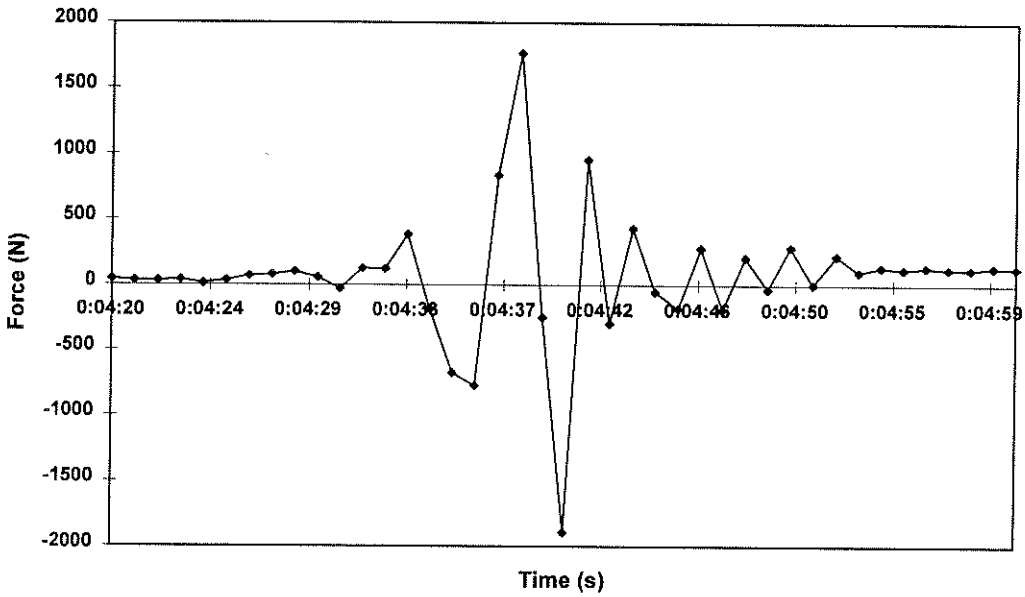



**Figure 3.12 Sideways impact on a trellis post from mechanical harvester.**

### 3.3.6 Weight of water

Drying grapes on trellises involves wetting of the fruit with an emulsion of water, potash and oil. In wetting experiments, vigorous Sultana vines with a large canopy and mature fruit were drenched with the emulsion and, on average, about 8 litres was retained per vine (Mollah, 1994). It is assumed that the vines will retain similar amounts of water from overhead sprinklers or rain.

An individual vine producing 40 kg of fruit and canopy, results in an increase in tension per wire of 1200 N (Figure 3.8). Adding the 8 kg (equivalent of 8 litres) per vine load of water will increase this tension by 240 N.

### 3.3.7 Estimated load on an end assembly

A two-wire vertical trellis is common in the Sunraysia area for wine grape production. Using the values given in Sections 3.3.1 - 3.3.6 the total load on the end-assembly of this trellis was estimated (Table 3.3).

Static equilibrium and forces in the directions shown (Figure 3.13) gives the following relationship:

$$\mathbf{M} = \mathbf{F} * h \quad [3.4]$$

$$\mathbf{H} = \mathbf{F} \quad [3.5]$$

Field tests on single posts did no more than verify that timber strength or the resisting moment of soil are the limiting factors for this end-assembly.

Analysis has shown that a single post of 125 - 150 mm diameter could safely carry a load of 6100 N at 1.5 m above the ground (based on 25 MPa bending strength) without risk of breaking. This obviously makes the single post end assembly unsuitable for most of the trellises used in Sunraysia region. This assembly may be used successfully in non-irrigated and low yielding vineyards.

## 3.4.2 Anchored Post

Tying the top of a post to a soil anchor (Figure 3.14) is an alternative favoured in some vineyards and increases the load carrying capacity compared with the single post. The tension tie of this assembly does not intrude into the vine canopy, which is an advantage for mechanical pruning and harvesting.

If there is no soil movement, then for the given layout (Figure 3.14), $\mathbf{H} = 0$, and the equations of equilibrium are:

$$\mathbf{V} = \mathbf{T} \cdot \cos(\alpha) \quad [3.6]$$

$$\mathbf{F} = \mathbf{T} \cdot \sin(\alpha) \quad [3.7]$$

$$\alpha = \arctan(p/h) \quad [3.8]$$

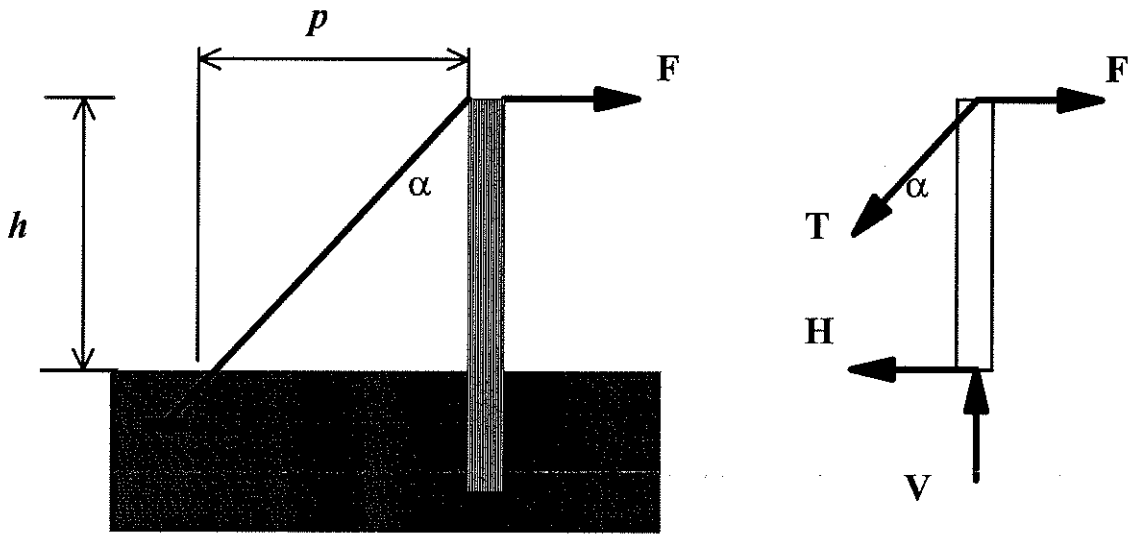



**Figure 3.14 Anchored post end-assembly and f.b.d.**

A number of stayed post assemblies with different configurations were tested (Table 3.4), and each failed in one of two ways:

1. The post broke with a measured load (column **g**, Table 3.4) well in excess of the design load (column **f**), suggesting that the bending strength of the posts exceeds 25 MPa. Using this value appears to give a safety factor of about 1.7.

2. Many assemblies pulled out of the soil (column **e**) under a greater load than the design values, with one exception. Dry soil at the time of testing is thought to be the reason for this observation. The one set of tests carried out in saturated sandy soil, marked with *, Table 3.4, gave a mean failure load lower than the design value, suggesting the design value of vertical pull (equation [3.2]) is too high. Until more is known about the mechanics of vertical pull out of posts, a further safety factor should be applied, reducing the design value by 25 %.

**Table 3.4 Design and measured values of F for different configurations of stayed post endssembly.**

| **Stay Position, *m* (mm)** | **Post Depth, *s* (mm)** | **Stay Angle, $\beta$ (°)** | **Based on Soil Failure:** | | **Based on post Breakage:** | |
|---|---|---|---|---|---|---|
| **a** | **b** | **c** | **Design F (kN) d** | **Mean of Measured F (kN) e** | **Design F (kN) f** | **Mean of Measured F (kN) g** |
| **0** | *600* | 43 | 4.8 | 12.7 | | |
| | | 57 | 8.0 | 17.8 | | |
| | *1200* | 43 | 18.8 | 26.0 | | |
| | | 57 | 31.0 | 36.7 | | |
| | | **** 59*** | ***33.0*** | ***27.6*** | | |
| | | 59 | 33.0 | 36.0 | | |
| **600** | *600* | 53 | 7.0 | 14.1 | | |
| | | 66 | 15.0 | 20.5 | | |
| | *1200* | 53 | | | 15.0 | 24.2 |
| | | 66 | 27.0 | 30.4 | | |
| **900** | *600* | 60 | 3.6 | 14.5 | | |
| | | 71 | | | 10.2 | 18.3 |
| | *1200* | 60 | | | 10.2 | 17.4 |
| | | 71 | | | 10.2 | 18.3 |

*Notes:*

*1. * Tested in saturated sandy soil.*

*2. Each measured value is the mean failure load of 6 assemblies*

ultimately they break. The breaking moment calculated from the measured **F** for post breakage (column **e**, Table 3.5) is consistent with post strength data (Table 3.1).

The results show that strength of wire (for staining) and post outweigh the theoretical benefits of this end assembly configuration.

**Table 3.5 Design and measured values of F for different configurations of *post and rail* assemblies (post depth in the ground is 1.2 m).**

| **Rail Length, *l* (m)** | **Tie Wire Angle, $\gamma$ (°)** | **Design F (kN) Based on:** | | | **Mean of Measured F (kN) Based on:** | | **Load in tension tie at Failure (kN)** | **Material Used for Tension Tie** |
|---|---|---|---|---|---|---|---|---|
| **a** | | **Soil Strength b** | **Wire Strength c** | **Timber strength d** | **Post breakage e** | **Wire breakage f** | **g** | **h** |
| *3.6* | *67* | *48* | *15.0* | *6.1* | | *18.8* | *20.0* | *2 strands of 2.8 mm wire.* |
| 2.4 | 58 | 32 | | 6.1 | 19.8 | | 23.4 | *8 mm chain was used as tension tie.* |
| 3.0 | 63 | 40 | | 6.1 | 20.2 | | 22.2 | |
| 3.6 | 67 | 48 | | 6.1 | 21.2 | | 22.6 | |

*Note:*
*T was taken as 16.0 kN, minimum breaking force of two strands of 2.8 mm high tensile wire (recommended by the manufacturer) for the estimation of design value for F.*

# 4.0 CONCLUSIONS

1. The thicker the post, the higher its breaking force.

2. The breaking force varies widely within each commercial diameter class mainly due to the variation in diameter amongst posts within the class and to the effect of knots.

3. It is suggested that the trellis structures be designed using a maximum of 25 MPa bending strength for posts.

4. The soil resistance to vertical lift and sideways loading of posts increased with increasing post diameter.

5. There was no significant difference in compressive or cohesive strength of soils between the sites. This means that for a given installation method, load and soil condition, the average resistance applied to a post by soil, before it will move, will be similar at different test sites.

6. The initial tension measured in wires of various trellises ranged from 400 to 1000 N with 650 N being a typical value.

7. An increase in tension of up to 1200 N could be expected per wire for a weight of 40 kg of fruit and canopy per vine.

8. An inverse temperature effect of 10 N per °C can be used to estimate the change in wire tension for 2.8 mm high tensile wire, commonly used for trellising.

9. Data from a 1.8 m tall trellis in the centre of a vineyard detected no effect of wind on wire tension, for wind speeds up to 20 km/h.

10. The impact by a mechanical harvester (beating in a horizontal plane) on a number of trellises showed a temporary increase in tension of about 450 N.

11. An individual vine with a large canopy and mature fruit may retain 8 litres of water from rain or overhead sprinkler, resulting in a predicted increase of wire tension by 240 N per wire.

12. Test data for single and anchored post assemblies agrees with design calculations.

13. Stayed post assemblies in saturated sandy soil carried a mean load lower than the design value. The discrepancy has not been investigated and a further safety factor is suggested for this end-assembly.

14. Post and rail end-assemblies did not carry design loads in situations even where the tension tie did not break. It would appear that the basic boxed structure does not retain its shape under load and large bending moments are transmitted to the posts. When this occurs, the end-assembly is no better than the single post assembly.

# 5.0 TANGIBLE OUTCOMES

A book on grapevine trellising:

The information generated from this and a number of other projects, resulted in the recent publication of a book titled **"practical aspects of grapevine trellising"** by Winetitles. This book has been produced to summarise results of relevant research and to present technical information from a practical perspective. The book was launched by Mr. Peter Hayes, Executive Director, GWRDC on 26 June 1997 at a seminar on trellis research which was part of the Viticulture Research Highlights- 1997 workshop held at the Sunraysia Horticultural Centre.

Information package:

In addition to the trellising book, work has begun to develop a simple and easy to use information package in the form of a booklet and a computer software for growers to design their own trellises. Discussion with AusVit is continuing and it is expected that the information package will be released as an AusVit module by the end of May 1998.

# 6.0 RECOMMENDATIONS

The estimated annual cost of fruit loss and trellis repair for the viticulture industry is between $1 and $2 million. As discussed earlier, most of the trellis failures in Australian vineyards could have been avoided by selecting posts of appropriate strength for a particular task. However, the existing post grading system by diameter classes does not provide information regarding the strength or expected breaking force of the posts. There is also a wide variation in post diameters within each class that causes wide variation in post breaking force.

Therefore, it is recommended that manufacturers should grade posts for trellising by estimated strength categories. To accomplish this, the following research is required:

- Determine the range and typical maximum expected loads on trellis posts for the different canopy management and harvesting strategies used by the grape industries.
- Develop a test procedure (for raw posts) that will predict the ultimate strength of treated posts.
- Develop a prototype machine to auto-grade raw posts according to their expected bending strength.
- Determine the effect of knot size and the distance of knot from ground on the bending strength of treated pine posts and recommend a grading method based on knot size and position of knot on the posts.

## STRENGTH OF POSTS

Two hundred and forty pine posts of various type and sizes were tested to destruction for strength, using two novel test rigs which were built for another project. The posts came from the same forest and received uniform preservation treatment for each diameter class.

## Findings:

- The mean bending strength of creosote treated posts was significantly higher than CCA treated posts at 5 % level of significance, suggesting the preservative treatments affect the strength of pine posts.

- Tests on individual posts found a wide variation in bending strength (20 to 100 MPa). To cater for this it is recommended that trellis structures be designed so that bending strengths of no more than 25 MPa are imposed on posts, because at this level of strength less than 2% of posts should break. The risk of post breakage increases if bending strengths of higher than 25 MPa are imposed.

## STRENGTH OF SOIL

A set of different size posts was installed at each of 7 different locations in Victoria and South Australia and left in the ground for 6 months before testing. A matching set of posts was installed at the same locations just prior to testing. The portable test rig was transported to each site for testing.

## Findings:

- Clay loam at Tatura and brown loam of Great Western adhered strongly on posts in comparison with other soils. In these soils 0.9 m depth of end posts and 0.6 m depth of in-line posts may be adequate for most of the situations.

- High soil moisture content during post installation and testing resulted in a decrease in soil resistance to vertical lift and sideways loading of posts. End posts of end-assemblies are susceptible to pulling-out of the ground. It is recommended that the end posts should be installed in dry soil to have more strength.

## LOADS ON A TRELLIS

The static and dynamic loads on a trellis were measured using a pre-calibrated strain-gauged-beam, a digital load meter, data logger, a lap top computer and a novel automatic data recording system.

## Findings:

- An increase in tension up to 1200 N could be expected per wire for a weight of fruit and canopy of 40 kg per vine.

- An inverse temperature effect of 10 N per °C can be used to estimate the change in wire tension for 2.8 mm high tensile wire, commonly used for trellising.

### TANGIBLE OUTCOMES:

The information generated from this and a number of other projects resulted in the recent publication of a book titled ***"practical aspects of grapevine trellising"*** by Winetitles.

It is expected that a simple and easy to use information package in the form of a booklet and a computer software will be developed in near future as AusVit module for growers to design their own trellises.

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