Report

Investigation into Stability of three Hill's Weeping Figs

Along Laman Street Newcastle

Prepared for

City of Newcastle

By

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1 Introduction

This report was commissioned by Mr Philip Hewett, City Arborist, of Newcastle City Council.

The brief for the assessment was to assess the stability of three nominated fig trees along Laman Street, Newcastle; provide comment as to the likely extent of the root-plate drawing upon past experience with investigations and other failures of fig trees in nearby suburbs; describe and assess evidence of root-plate movement in the subject trees; evaluate the hazard of each tree and advise on abatement options; comment on any implications that crown reduction pruning may have for root health; support the findings with photographic evidence and by reference to technical and scientific publications where appropriate.

The trees were assessed on 4 July 2007.

2 Methodology

The trees were visually assessed from ground level only. No drilling, probing, core sampling, excavation, or aerial assessment *etc* was carried out. Issues of stability were determined from directly observable root-plate characteristics plus signs in nearby infrastructure.

Each tree was rated for hazard using the method devised by Matheny & Clark. This assigns a numeric value based on the failure potential, the size of the defective part, and the target i.e. that which may be struck in the event of failure[i]. Each category has a maximum value of four points, giving an overall rating of 12 to the most hazardous of trees.

3 The Trees

The trees were three Hill's Weeping Fig *Ficus microcarpa* var. *hillii*, tree ID numbers 4818, 4796, and 4797. Tree #4818 is located outside 41 & 43 Laman Street, while trees numbered 4796 and 4797 are located opposite the Newcastle Region Art Gallery on the northern side of the street.

It was noted that two other Hill's Figs outside the Gallery on the southern side of the street had suffered partial windthrow during the storm of 8 June 2007 and had been removed or drastically reduced in preparation for removal by the time of inspection.

The location of the trees is indicated on the plan included in the appendix.

Tree #4818 was found to have been destabilised and undergoing gradual whole-tree failure. This finding was reported verbally to the City Arborist on 4 July 2007, with a recommendation that the tree be removed as soon as possible. We understand that the removal commenced on 6 July and was completed on the 9th.

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[i] Matheny, N. P and Clark, J. R (1994, 2nd ed) *'A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas'* International Society of Arboriculture, Champaign, Illinois.

4 Previous Investigations & Other Tree Failures

An investigation into the root-plate architecture of eight Hill's Figs outside the Newcastle Region Art Gallery was conducted over the weekend of 9 and 10 December 2006. The investigation was made to determine the lateral extent of the root-plate within Laman Street and extrapolate the findings to gauge root-plate stability.

This particular work was undertaken as part of the Development Application for the redevelopment of the Newcastle Region Art Gallery, with the results reported to the project manager Root Projects Australia P/L[ii].

Four trees outside the Art Gallery on either side of Laman Street were investigated. These were Tree #4802 and the three trees to the west (south side of the street), and Tree #4797 and the three trees to the west (north side of street).

Trenching was made within the street along a line that corresponded with the edge of the theoretical root-plate. Each trench was five metres in length, i.e. 2.5 metres to either side of the centre of the base, 60 centimetres wide and 1 metre depth.

The upper part of the road comprised a layer of asphalt 80mm deep underlain by 330mm of heavily compacted 'skulls', a by-product of steel mining and widely used as road-base throughout Newcastle precinct. Sandy fill to 1 metre depth was below this. A concrete saw and an excavator were used to cut and remove the top layers of the road. An 'air knife' eductor was used to remove the sub-grade and expose tree roots.

Photograph 1. Trench investigation 9 December 2006, looking west along Laman Street. Tree #4802 in foreground.

[ii] Marsden, D (2006) *'Investigation into Root-Plate Architecture of Hill's Weeping Figs along Laman Street outside Newcastle Region Art Gallery'* Report prepared by The Sugar Factory – *Arbor Advocate.*

The investigation found that no primary woody roots were present in any trench. The majority of trenches contained only a few woody roots, generally less than about 10mm in diameter, and few fibrous roots.

One trench only was found to contain woody roots, two roots of 20mm diameter and one of 60mm.

Photograph 2 (left) shows a typical completed trench.

From this it was concluded that the street did not provide an environment conducive to the development of roots, and that the trees had compromised root-plates. The observable characteristics suggested that the root-plates had developed mainly in a lineal orientation, with little lateral development.

Given that the proposal at that time was the removal of the existing Art Gallery and the construction of a new Gallery, the trees, growing as they were in the lee of the Gallery, would suddenly be exposed to strong southerly winds after the removal of the Gallery and were likely to undergo windthrow and/or large branch failure in a storm event.

The trees along the south of the street had no appreciable root-plate on the 'compression' side to resist southerly winds, whereas the trees on the north of the street had no root-plate on the 'tension' side. The trees on the northern side had very asymmetric crowns with a strong bias to the north, and were deemed to be at an increased risk of windthrow in the event that the Gallery plus the four trees on the south side of the street were removed.

A later study into the wind loading on the trees, which included modelling in a wind-tunnel, supported these conclusions[iii].

The investigation into root-plate architecture identified a number of unknowns as to the actual extent of the root-plate, nominating five factors as potential contributors to stability: root-grafts, root-slings, the planting pit ('wedge' effect of the root mass), crown mass, and wind-buffers.

The report recommended that if the proposed redevelopment of the Gallery were to proceed, that two of the fig trees scheduled for removal (one from either side of the street) be subjected to exploratory excavation to determine the full and actual extent of the primary and secondary woody root system.

[iii] Djenidi, L (2007) *'Wind Loading on Trees in Laman Street'* Report prepared for City of Newcastle by the University of Newcastle, School of Engineering, Discipline of Mechanical Engineering.

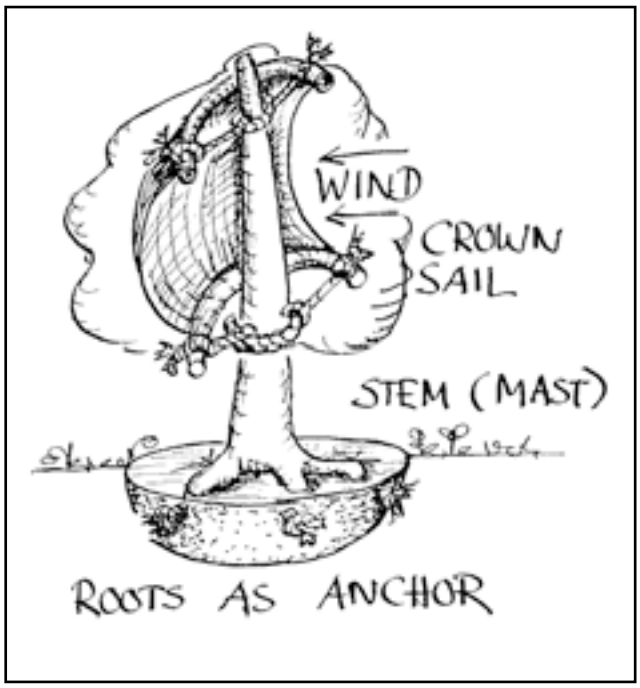
An earlier study into the whole-tree failure of two Hill's Figs on Tyrrell Street in 2004 concluded that poor root-plate architecture was a primary factor in the failures[iv]. It was found that the trees had developed restricted, lineal root-plates through a combination of inhospitable edaphic conditions, constriction by nearby infrastructure, and root severance in infrastructure repair and road works.

Several Hill's Figs along Bruce Street were windthrown in the storm of 8 June 2007. Photographs provided by City Arborist Mr Phil Hewett indicate that inadequate anchorage through impaired development of the root-plate allowed for the destabilisation of the trees when under wind load. The root-plates evident in the photographs closely correlate with the observed and suspected root-plates of the subject trees. Crown configurations were not given; hence it is not known to the author if crown imbalance was a factor in the failures.

Photograph 3, above. This Hill's Fig on Bruce Street had been planted in the footpath, with the kerb acting as a barrier to the development of the root-plate, preventing the extension of structural support roots on the 'tension' side. This mirrors the conditions on the northern side of Laman Street. What appears to be a large primary root has developed in a lineal direction, running along the inside edge of the kerb (large arrow). Note the lateral development of secondary woody roots (small arrows). Note also the diameter of the stem and the relatively small size of the root-plate tilted out of the ground.

[iv] Fakes, J (2004) *'Tree Management Options: Hill's Figs, Tyrrell Street Newcastle'* Report prepared by The Tree School for Newcastle City Council.

Photograph 4, above. Another of the Bruce Street figs. This tree had been planted within the street, which is identical to the situation on the southern side of Laman Street. Again, the kerb has acted as a barrier preventing the development of roots on the 'tension' side.



Mattheck & Breloer make the analogy of the main parts of the tree with a yacht, where the crown acts as a sail, the stem as mast, and the root-plate as a hull albeit in a very viscous sea. They describe the tree as being a chain of equally strong links, where the incoming wind load is transferred via the stem into the root ball and from there into the ground[v] (figure A, left).

[v] Mattheck, C, and Breloer, H (1994) *'The Body Language of Trees - A Handbook for Failure Analysis.'* HMSO, London.

While there can be some variations in modes of windthrow, root-plate failure generally follows the theme of the root-plate lifting on the side under tension, i.e. the windward side, and subsiding on the side under compression[vi] (figure B, below).

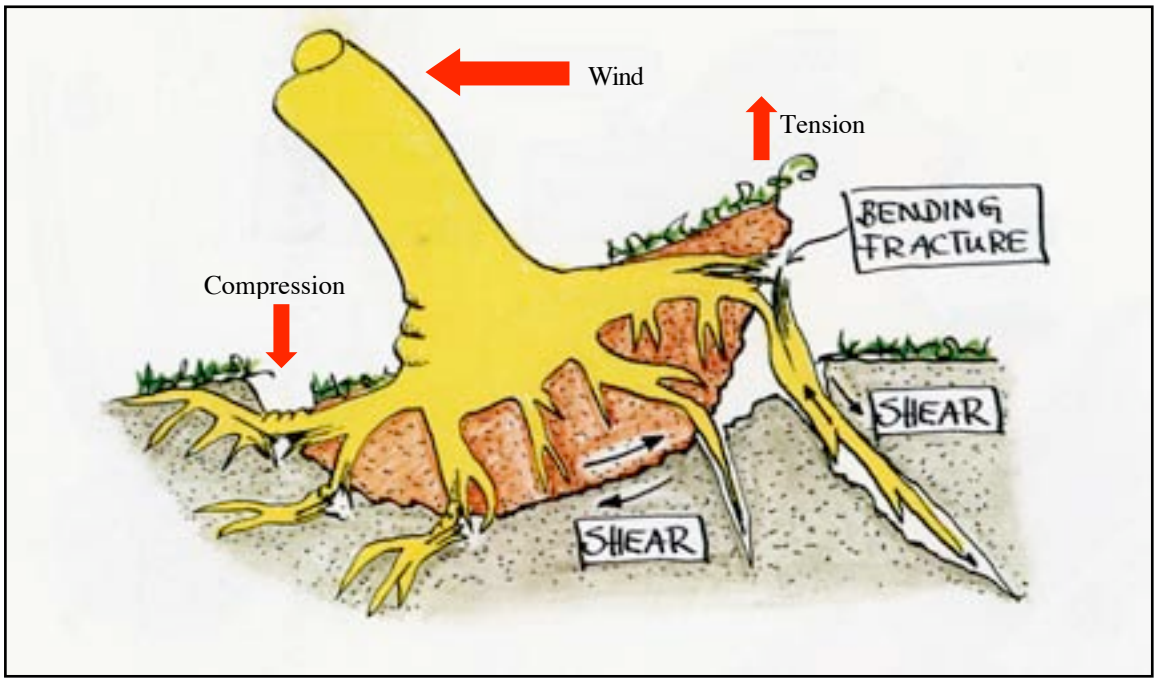


Figure B. Root-plate failure (Mattheck, 2004).

Research by Mattheck & Bethge found a correlation between stem diameter and root-plate diameter, which for trees growing in the open can be calculated as:

$$R_W = 64 \cdot (R)^{0.42}$$

Where R_W is the minimum root plate radius in centimetres to resist windthrow (that is, the mechanically-effective root-plate) and R is the radius of the stem in centimetres, measured above the buttress[vii].

The Hill's Figs on Laman Street, and judging by the photographs the Hill's Figs on Bruce Street too, have a stem diameter between 110cm to 140cm, giving a distance of for R_W ranging roughly 345 to 380 centimetres radius. Lonsdale (1999) states that in providing space for the development of root-plates of street trees, that the distance R_W should be the minimum distance provided for, preferably more, otherwise the development of an impaired root-plate could result.

What is clear is that the root-plates of the failed Bruce Street trees stop well short of the preferred range R_W, particularly on the kerb side. With no lateral development of tensile roots, the trees failed while under a tensile load.

[vi] Mattheck, C (2004) *'The Face of Failure in Nature and Engineering'* Karlsruhe Research Centre, Karlsruhe.
[vii] Mattheck, C, and Bethge, K (2000) *'Simple Mathematical Approaches to Tree Biomechanics'* Arboricultural Journal 24, pp. 307-326, ABB Academic Publishers, Great Britain.

5 Descriptions of Root-Plate Movement

5.1 Tree #4818

This tree is located outside 41 & 43 Laman Street (photograph 5, below) and has not been the subject of previous investigations by the author.

The tree has a fairly symmetrical crown spread although under-pruning to provide clearances of residences has left the crown with a pronounced bias to the north.

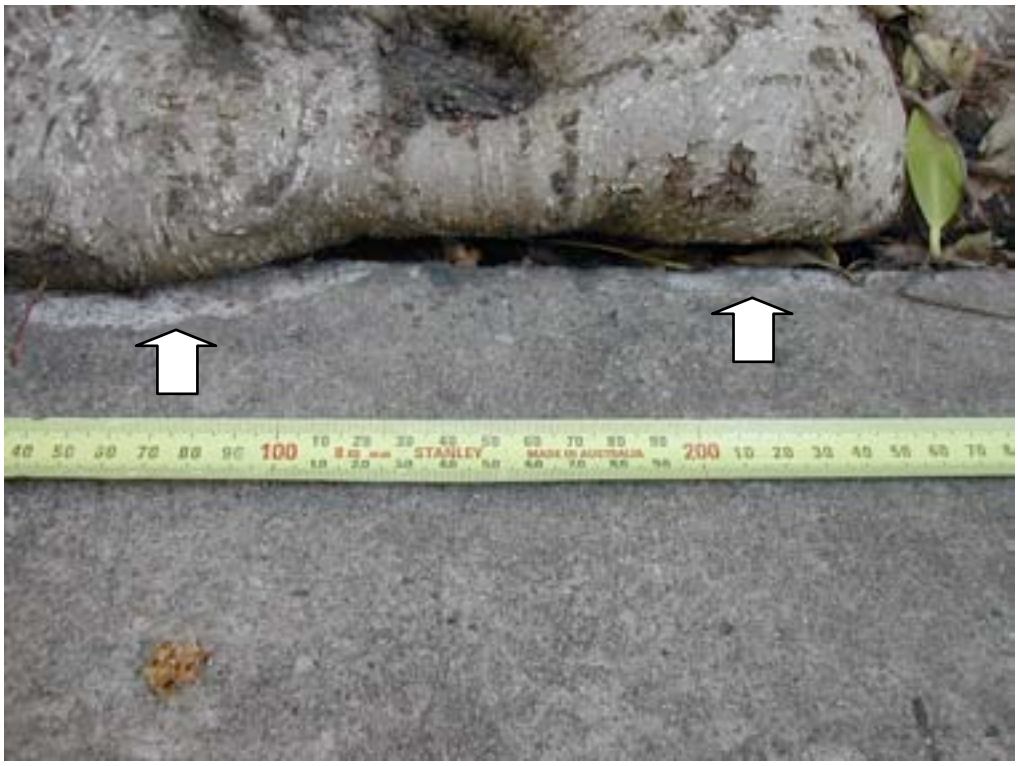
The tree is approximately 18 metres tall with an average spread of 22 metres, and a stem diameter above the buttress of 109cm.

The primary roots have buttressed along the gutter (photograph 6, left). Most of the surface roots across the remaining sides have been severed some years ago, no doubt to mitigate damage to the roadway.

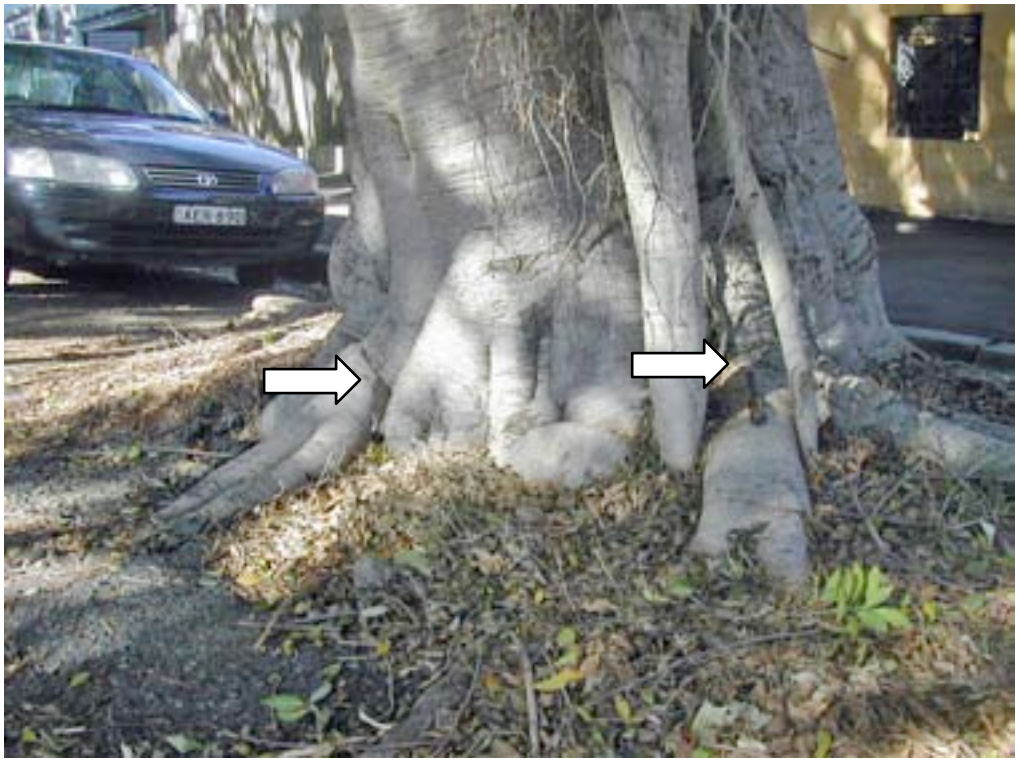
The root-plate appears to have a lineal orientation, with the main extension along an east-west axis. The south side is impeded by the kerb and the north side (towards the road) is unlikely to contain any appreciable extension of primary roots.

It was noted that a section of buttress on the southeast side of the tree had shifted up and away from the gutter, opening up a gap over a lineal distance of approximately one metre (photograph 7, left).

The gap along this section was 12 to 15mm wide (photograph 8, below). Note the light coloured patches on the concrete where the buttresses had previously rested (arrows).



Photograph 9, above. A surface root extending to the east had lifted by 50mm at the end nearest the tape. Freshly exposed soil was evident under the edge of the root. We understand from City Arborist Mr Phil Hewett that the lift was first measured as being around 20mm; hence, the tree has been gradually subsiding to the northwest since the time of the storm. A resident also noticed this gap.



Photograph 10, above. Fractures had developed on the sides of the stem under compression, i.e. the side opposite to the section that had separated from the gutter, and the side opposite the raised root. The gap and the fractures indicate a wind-load from the southeast.

Photograph 11. ‘Zigzag’ Fracture at base on north.

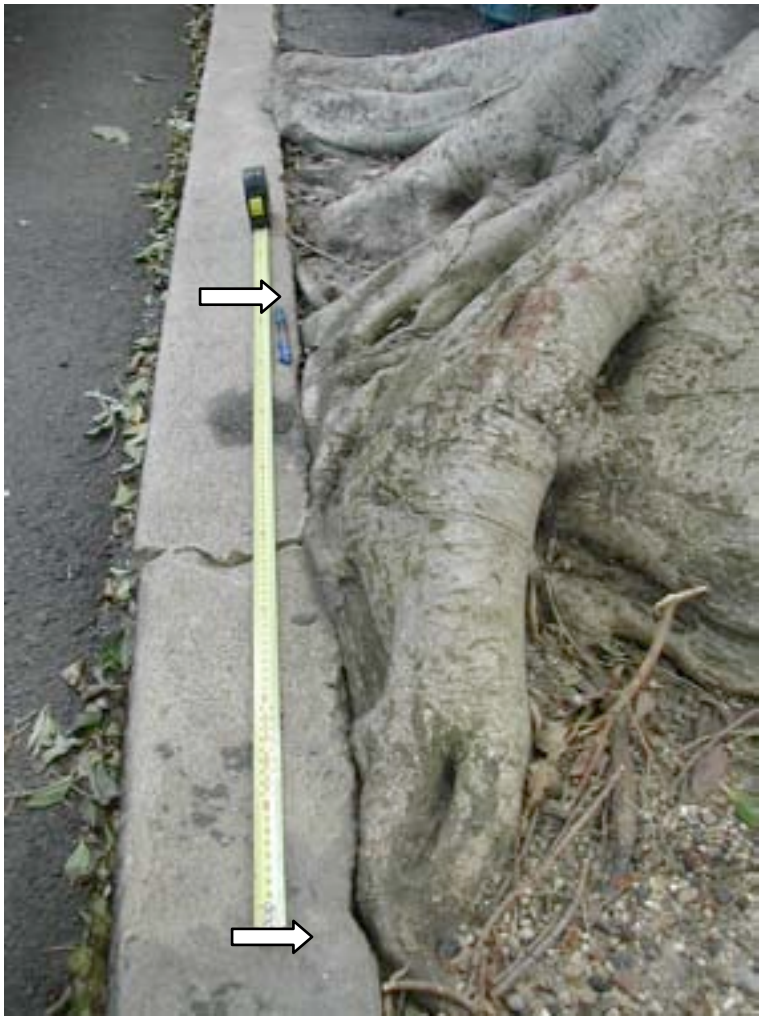
Photograph 12. Fractures at base on west.

5.2 Tree #4796

This tree is located towards the eastern end of Laman Street, on the northern side across from the Art Gallery. The tree has not been the subject of previous root investigations. This tree and the tree to the immediate east are not growing in the lee of the Gallery and are more or less fully exposed to southerly winds.

The tree has a well-balanced crown on the north-south axis, with each axis extending for around 12 to 14 metres. The east-west axes are suppressed by adjacent trees, each axis extending for some 6 metres.

A gap has recently opened up between the kerb and the buttressed roots, extending east from the approximate middle of the base (photograph 13, below). The gap is some 1 metre long and up to 5mm wide. Fractures are present in the kerb although the fractures are not fresh, predating the storm, and were presumably caused by the pressure of the roots expanding against the kerb. The kerb is displaced by 15mm. The gap indicates a wind-load from the southeast.



Root development is impeded on the southern side by the kerb. Previous investigations suggest that the tree has no appreciable extension of primary roots beyond the kerb and into the road. Some evidence of severance of primary roots is present across the remaining sides.

The root-plate is likely to be either lineal, spreading east and west only with little extension to the north, or rectangular and constrained by the planting pit.

Photograph 14. The gap is up to 5mm wide.

Photograph 15, below. The 'compression' side of the stem displayed no fractures or folds. Surface roots showed no signs of having been lifted by the wind. There were no signs of soil subsidence on the compressions side.

5.3 Tree #4797

This is the tree to the immediate west of Tree #4796. It was one of the trees subjected to the investigation of root-plate architecture in December 2006 and, like the other subject trees, was found to have an eccentric root-plate with no structural roots extending to the tensile or 'street side' of the root-plate. Previous root severance is evident. Resurfacing of the asphalt around the base of the tree may be masking other signs of root damage. It could be that the root-plate is contained by the planting pit with secondary woody roots having 'escaped' and growing into the garden at the edge of Civic Park.

It was anticipated that this tree (among others) would be at risk of windthrow in the event of the removal of the Art Gallery and the trees on the southern side of the street.

The crown of the tree is asymmetric and has a strong bias towards the north (photograph 16, left). The crown spread was physically measured at the time of the December 2006 inspection, with the axes being 15.5m (north), 6.3m (south), 9.3m (east), and 5.6m (west).

Photograph 17. The crown of the tree is carried on two vertical stems and one other stem growing on a lean of around 60^0 to the north.

Photograph 18. A gap had recently opened along the edge of the kerb. The gap extended for 1.5m and indicates a wind-load from the south or southeast. Fractures were present in the kerb although these did not appear fresh.

Photograph 19, below. The gap was up to 15mm wide.

Photograph 20. The ‘compression’ side of the stem displayed no fracturing or sudden fibre-buckling. Surface roots showed no signs of having been lifted when under wind load. There were no signs of soil subsidence on the compressions side.

6 Discussion

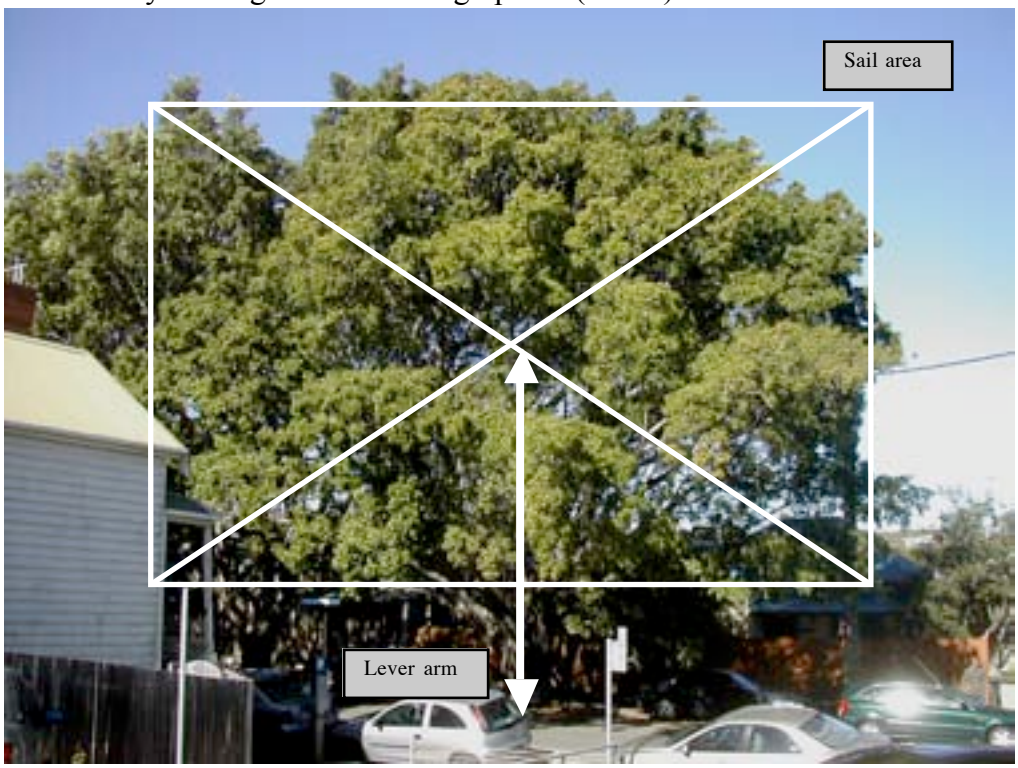
6.1 Tree #4818

The tree has suffered a partial wind-throw and now that the crown is imbalanced, the weight of the crown is gradually dragging the tree downwards to the north. Lonsdale states that trees that suffered partial windthrow can sometimes generate new roots over several years that will stabilise the tree[viii], although in this instance this is not an option that we would put forward to Council. Given that the root on the east of the tree has continued to lift, it can be argued that the tree is in the process of whole-tree failure and as such the options for retention are much more limited.

Lonsdale further states that a tree with a damaged root-plate may be likely to fail "unless it could be subjected to quite severe cutting so as to reduce the lever arm and sail area". Lonsdale does not define what degree of cutting constitutes 'quite severe'. Lever arm and sail area can however be determined from the crown shape.

According to Weber & Mattheck, the lever arm (that is, the leverage exerted by the crown through the stem and onto the root-plate when the crown is under wind load) is the vertical distance from the base of the tree to the centre of the crown.

The centre of the crown can be found by drawing a box around the perimeter of the crown when viewed in elevation, and joining up the diagonals. The crown centre is where the diagonals intersect[ix]. The sail area is simply the exposed side of the crown. The lever arm is indicated by the large arrow. Photograph 21 (below) illustrates this.



[viii] Lonsdale, D (1999) *'Principles of Tree Hazard Assessment and Management.'* HMSO, London.
[ix] Weber, K. and Mattheck, C (2003) *'Manual of Wood Decays in Trees'* The Arboricultural Association, Ampfield House, Ampfield.

Given that the tree is in the process of failure we shall proceed on the basis that the Safety factor of the root-plate is tending towards a value of 1.0 (down from 4.5).

In order to avert failure the lever arm and crown-sail area would then of necessity have to be reduced from the top of the crown downwards to the point where no or only very little leverage was exerted on the root-plate. Mathematically, this equates to a crown of roughly $35m^2$, or about 4m tall by 9m wide (photograph 22, below). Around 85% of the live crown area would be removed.

It should be noted that this is a simple theoretical exploration of a mechanical model based on the available literature; it does not account for impacts on tree health. Severe crown pruning can adversely affect the health of the tree, and is known to cause death in parts of the root system[x].

This would only be a short-term option to prevent the failure of the tree; it is not an acceptable treatment as a method of tree retention in other than exceptional circumstances, e.g. if the tree were especially valuable for reasons of culture, heritage, rarity, etc. Broadly speaking, it would involve lopping the tree back to a stump and then managing the regrowth. At best, this would result in an accelerated decline and at worst it could kill the tree outright.

In respect of a 'formal hazard rating' the tree receives maximum points for failure potential (4), maximum points for the size of the part at risk of failure (greater than 75cm diameter), and maximum points for target (year round use for a number of hours each day, residences), yielding a Hazard rating of 12.

[x] Shigo, A.L. (1986) *'A New Tree Biology'* Shigo & Trees, Associates, Durham, New Hampshire.

6.2 Tree #4796

The reasons for the formation of the gap along the kerb are not clear. The base of the tree and the infrastructure on the 'compression' side showed no signs of fracture or subsidence, and there were no signs of roots having lifted. This tends to suggest that movement of the roots displaced the kerb during the storm.

Lonsdale (1999) states that roots can flex while under tension without loss of anchorage. It can then be expected that objects in direct contact with roots will undergo movement or displacement when the roots flex[xi].

The precise configuration of the root-plate of this tree is unknown. The earlier investigation found that the Laman Street figs on the north side of the street had not developed structural roots on the street side to what would be considered a normal distance. Previous failures on Bruce Street and Tyrrell Street support this conclusion. The roots on this tree have buttressed along the edge of the kerb and it could be that roots are growing down the edge and possibly under the kerb. Loading these roots under tension could conceivably cause the kerb to shift.

The recent storm struck the tree from the south or southeast, which means that the kerb is on the tensile side. The kerb had a pre-existing fracture (caused by root pressure), and the displacement is to either side of the fracture.

Another possibility is that the displacement was caused by the tree and root-plate swaying back into position once a particular gust had ended. The tree possibly has a primary root growing below ground and along the inside edge of the kerb.

Key difference between Tree #4818 and Tree #4796 are that 4818 lifted up and away from the kerb, whereas 4796 did not lift; 4818 developed fractures on the compression sides unlike 4796; and 4818 continued to tilt downwards while 4797 appears stable.

Hence, it cannot be concluded from the available evidence that the tree has been destabilised by the recent storm. This tree will require monitoring before a Hazard Rating can be assigned.

Notwithstanding the requirement for monitoring, the evidence of compromised root-plate development from previous studies and other failures indicates that Hill's Figs in this type of planting environment are prone to windthrow. What cannot be predicted is the direction and speed of the wind and it could simply be that this tree survived the storm because the main wind gust passed to the side of the tree.

[xi] Roberts, J, Jackson, N, and Smith, M (2006) *'Tree Roots in the Built Environment'* London, The Stationery Office.

6.3 Tree #4797

This was one of the trees investigated during the Art Gallery proposal where it was established that the root-plate was eccentric, with no appreciable extension to the south. It was noted then that the tree was buffered to a degree by the trees on the opposite side of the street, which in turn were buffered by the Art gallery.

Like Tree #4796, the gap that opened up along the kerb was not accompanied by any signs of lifting at the buttresses on the tensile side, or any signs of subsidence or fracturing on the compression side. Again, it is probable that the gap was caused by the flexing of roots while under a tensile load, displacing the kerb. A conclusion that the tree was destabilised by the storm cannot be supported.

However, there are two crucial differences with this particular tree: the crown is extremely asymmetric with a pronounced bias to the north (a consequence of competition for light from nearby trees), and 'buffer' trees across the street have failed and been removed.

Lonsdale (1999) writes: "The strong asymmetry that develops in the crowns of trees along the edge of a group is usually no cause for concern, except in cases where one or more other trees in the group have fallen or have been removed. Such crowns can then become poorly balanced and exposed to unaccustomed loading from the wind… and have an increased risk of breakage in high winds."

As such, the tree now fulfils the conditions indicating a higher than normal risk of failure. Given that the tree overhangs Civic Park, the risk to persons of harm or injury associated with whole-tree failure cannot be overstated.

Crown reduction to reduce the lever arm would necessitate cutting the tree to a tall stump and other than to mitigate the immediate risk posed by failure, is not generally an acceptable method of tree management.

Under Matheny & Clark's Hazard rating System, the tree receives the maximum of 12 points.

7 Conclusions & Recommendations

Tree #4818 was found to have been destabilised by the storm and in the process of gradual whole-tree failure. The recommendation was made at the conclusion of the site inspection that the removal of the tree be prioritised, with the removal subsequently being carried out on 6 and 9 July.

Tree #4796 was not conclusively found on the available evidence to have been destabilised. The tree does carry deadwood and stubs, which should be promptly removed. Branch unions should be checked for fractures and such like during the course of pruning works and defective branches removed. The base of the tree and its surrounds should be checked for movement and the development of fractures at least once per week over an eight-week period commencing mid-July, or configured as necessary to include the traditional 'windy' season that occurs in or around August/September. It is further recommended that Council put in place a system that ensures that the inspections are carried out. Data including photographs from the inspections is to be recorded and retained in Council files. At the end of the inspection period if no signs of movement or fractures *etc* are found, it can be concluded that the tree has not been destabilised. If signs of movement or fracturing are found at any time during the inspections the tree is to be re-evaluated.

Tree #4797 was also not conclusively found to have been destabilised but was found to be at increased risk of failure due to severe crown imbalance and an increased exposure to wind loads. We recommend that the removal of this tree be prioritised.

The failure of the two trees outside the Art Gallery plus the removal of Tree #4797 will fragment the rows of figs, opening up gaps and will potentially expose other figs with imbalanced crowns to strong winds, increasing the risk of failure. We recommend that Council promptly assess adjacent trees in light of this potentiality.

Exploratory excavation to expose the root-plates of the figs proposed for removal would provide valuable information for assessing the stability of the remaining trees. It would be helpful to examine at least one tree from either side of the street, given the differing growing conditions. Ideally, this work would be done in the very near future before the root systems are badly affected by decay.

The evidence from the recent failures in Bruce Street and earlier failures in Tyrrell Street highlights the need for a contemporary approach to street tree selection, planting pit preparation, and tree maintenance.

Yours faithfully,

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Tree Location Plan (not to scale).
Plan provided by City of Newcastle. Trees marked with an X were partially windthrown in the storm of 8 June and have since been removed or drastically reduced in preparation for removal.