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Manual 4 – Decay above- ground

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MANUAL NO. 4

Decay Above-Ground

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This report has been prepared for Forest & Wood Products Australia (FWPA).

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Acknowledgments

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Contents

Executive Summary

- This report presents a service life prediction model for timber installed above-ground and attacked by decay fungi. The attack model is based on the assumption that significant decay occures only when the moisture content of timber is above that of the fibre saturation point, a moisture content of about 30%. The attack mechanism assumes that water is sucked into a wood base via a split or gap in a covering coating; the absorbed moistue cannot evaporate via the split; hence if the moisture cannot escape rapidly enough via another pathway it will accumulate and cause decay. Thus the two most important considerations are the wetting time and the geometry of the timber assemblage.
- This model described in this report was developed on the basis of two sets of data. The most important data set was that obtained from a series of 20-year L-joint field tests, conducted by the Queensland Department of Primary Industry and Fishery. In these tests specimens of nine wood species were installed at 11 test sites around Eastern Australia. Each species had two sets of L-joint specimens, one set painted and the other unpainted with 24 replicates in either set, installed at each site. In addition, 34 additional species were installed at the main site at Beerburrum, Queensland. At each site there were 24 replicates of each specimen type.
- The second set of data comprised panel tests undertaken by CSIRO. Each panel set comprised 10 test specimens. Two sets of tests were undertaken. The first tests were undertaken at 23 sites, lasted for 12 years and for these tests there were 10 different types of specimens at each location. There were no specimen replicates. The second tests were undertaken at 27 sites, lasted for 2.5 years and for these tests there were only two types of test specimens, i.e there were 5 replicates of each specimen.
- The field data used by previous researchers was in the form of score systems intended to reflect the severity of the decay. To develop the model, a conversion procedure was used to convert these scores into an estimate of the expected depth of surface decay that would occur under similat circumstances.
- It was assumed that the model of the progress of decay will follow an idealised bilinear relation over time. This model is characterised by two parameters: the time lag before decay commences, and the decay rate. It was also assumed that there is a relationship between the decay lag and decay rate so that effectively the decay characteristics of a specimen is described by a single parameter, namely the decay rate.
- The model for the progress of decay takes into account the wood species, the annual time of rainfall wetting, the effects of painting the wood surface, the dimensions and

oprientation of the timber and very importantly the geometric detail of the wood assembly.

- Following completion of the model, a series of ‘reality checks’ were undertaken by comparing the predictions of the model with observations on real outdoor structures such as fences and pergolas.
- To assist in reliability-based design, probability models for decay lag, decay rate, and decay depth were developed. A critical feature of this study has been to derive methods for quantifying the uncertainties associated with the application of the model. Both a first-order approximation and a Monte-Carlo simulation algorithm have been used to do this.
- The model for the progress of decay has been used to develop a service life computation procedure for an Engineering Design Code, a Design Guide for architects and builders, and ‘TimberLife’, a service life prediction software package intended for use as an educational tool.

1. Prediction Model

1.1. The Attack Mechanism

The attack mechanism of decay fungi is illustrated in Figures 1–6, based on the concept given by Zabel and Morrell (1992). Figure 1.1 shows the distribution of moisture within the cellular structure of wood. For moisture contents up to the fibre saturation moisture content (about 30%) the moisture is adsorbed into the walls of the cells and decay is minimal, because the decay fungi does not have enough suction strength to access the moisture. Above this value, the moisture is in a free form, easily accessible to the decay fungi, and as a result, decay proceeds rapidly as shown in Figure 1.2. When the cellular lumens are more than 80% full of water, there is inadequate oxygen for the decay fungi to survive and accordingly decay ceases.

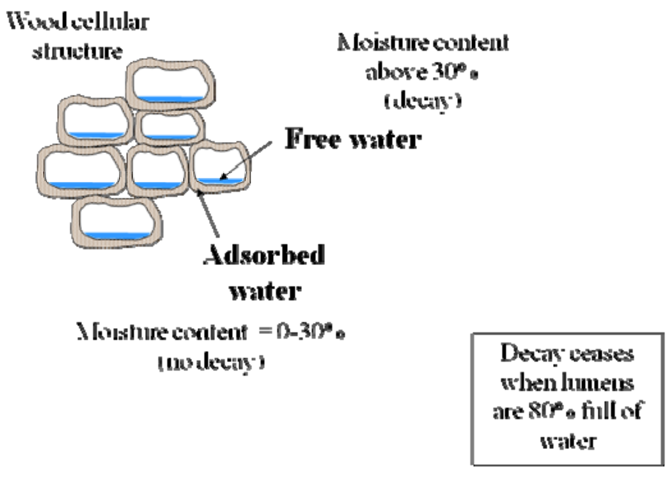


Figure 1.1 Definition of moisture in timber

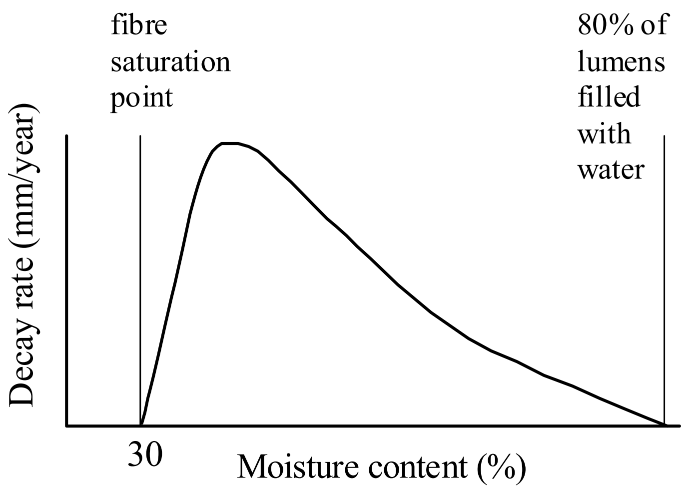
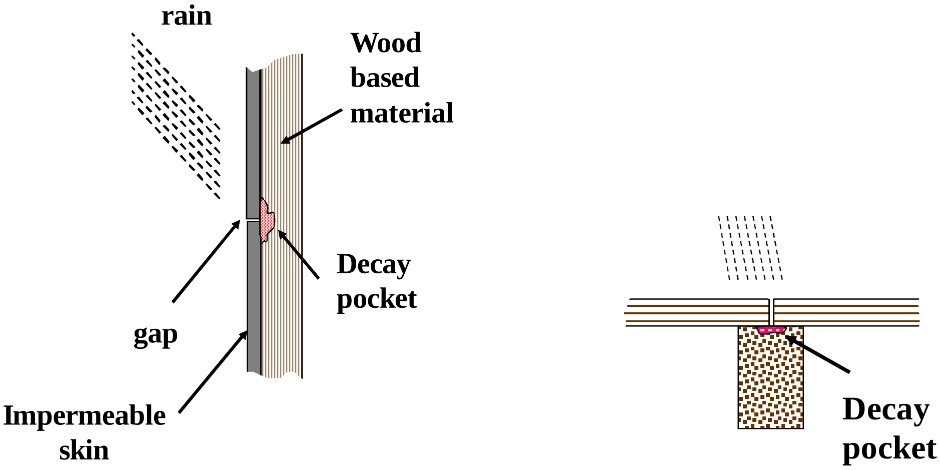


Figure 1.2 Schematic illustration of moisture content on rate of decay



(a) External cladding (b) External decking

Figure 1.3 Illustration of role of a gap on decay

Figure 1.3 illustrates a typical attack scenario for exposed timber construction. Typically a small slit or gap in a covering member will suck in rain water through capillary action and soak it into an underlying wood based substrate. This moisture cannot evaporate through the narrow slit. It must do so through some other face of the wood based substrate. If it cannot do so fast enough, then it accumulates in the wood based substrate where the moisture content may pass the 30% mark and decay will commence. The decayed wood substrate itself then forms a basin in which considerable moisture can be held.

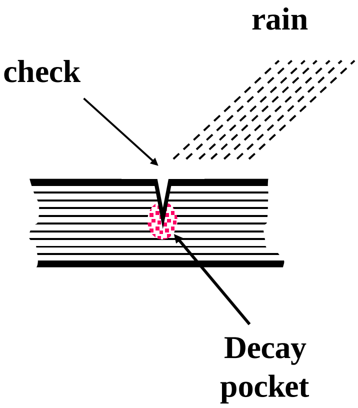
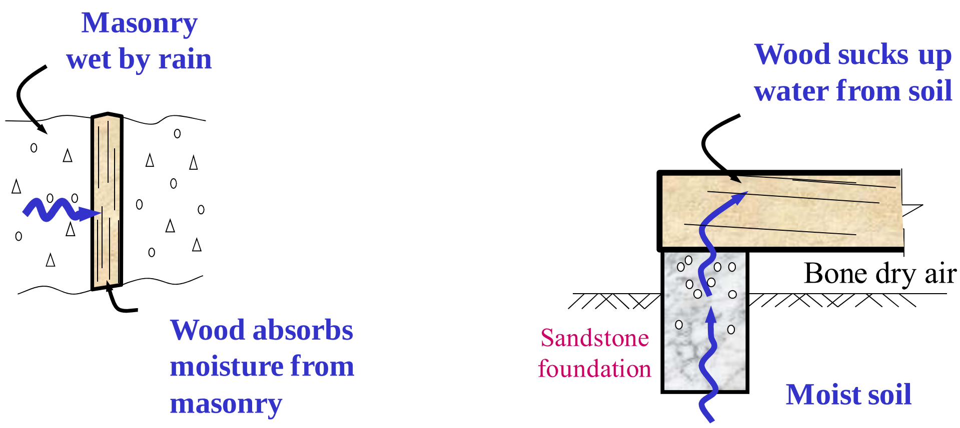


Figure 1.4 Illustration of scenario for decay of exposed members

Figure 1.4 illustrates the attack scenario for the case of an exposed timber element. Here it is necessary for wood to first develop a surface check through mechano-sorptive effects. Once a sufficiently deep check has developed, it can suck in rainwater and create a temporary well at the bottom of the check. Eventually this water may be enough to commence decay. As the pocket of decay increases in size, it holds more water and leads to increased decay for each rainfall episode.

Another potential cause of wetting wood to above the fibre saturation point is the placement of wood in contact with masonry that is wetted so that it attains a suction value less than that corresponding to that of wood above that attained at the fibre saturation point. Two typical examples of this are illustrated in Figure 1.5.

In terms of temperature, decay can occur once the wood temperature is above 5–10 °C. However once the temperature exceeds 60 °C for several hours, the decay fungi will be killed. Hence for some regions in the north of Australia, it is possible for timber to remain intact on the outside while decay occurs within a cross-section as shown in Figure 1.6.



(a) Timber sandwiched between wetted masonry

(b) Moisture conducted via masonry

Figure 1.5 Effect of masonry in contact with wood

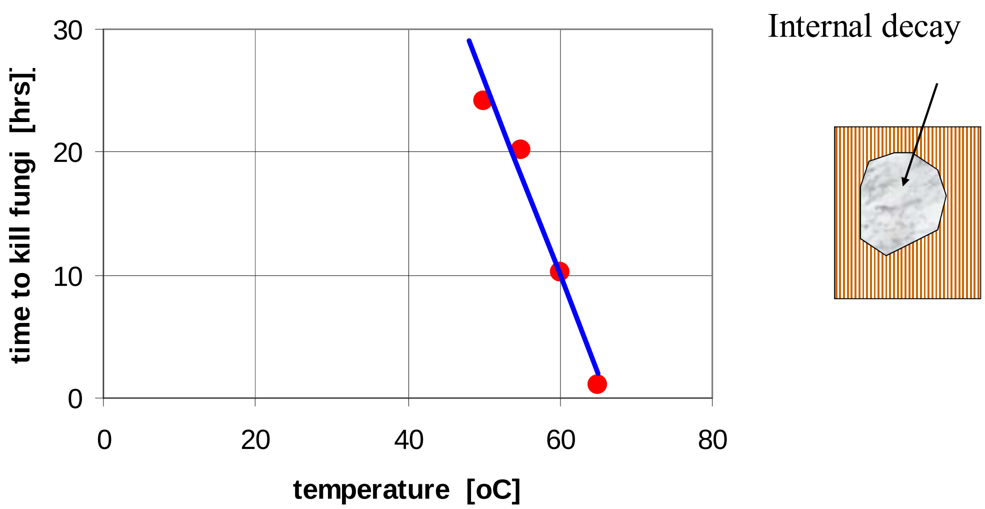


Figure 1.6 Effect of high temperatures on decay fungi

Based on the above considerations, it was decided to develop a model in which the climate parameter of interest is the time of wetting. Total annual rainfall and mean annual temperature were found to have a minimal practical effect for Australian climates. A highly significant parameter was the geometry of joint systems.

1.2. Prediction Model

A basic assumption for this model is that progress of decay depth with time t in a timber element can be approximated by an idealised bilinear relationship characterised by a decay lag, t_{lag} (years), and a decay rate, r (mm/year). Herein the notations r and t_{lag} are intended to denote median value estimates. A schematic illustration of this relationship is shown in Figure 1.7. Thus the decay depth after t years of installation, d_t (mm), is expressed as follows:

$$d_t = \begin{cases} ct^2 & \text{if } t \le t_{d_0}; \\ (t - t_{lag})r & \text{if } t > t_{d_0}. \end{cases} \tag{1.1}$$

in which

$$t_{d_0} = t_{lag} + \frac{d_0}{r} \tag{1.2}$$

$$c = \frac{d_0}{t_{d_0}^2} \tag{1.3}$$

The decay lag, t_{lag} (years), is given by

$$t_{lag} = 8.5r^{-0.85} \tag{1.4}$$

The expression for decay rate r is described in the next subsection.

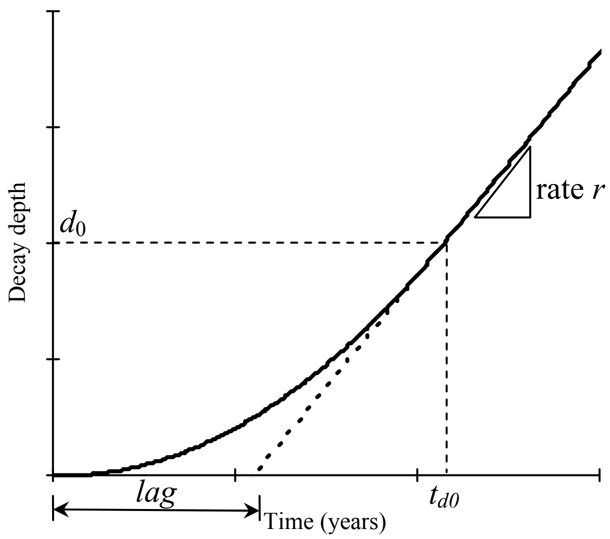


Figure 1.7 Idealised progress of decay depth with time.

1.3. Decay Rate

Decay rate r is assumed to be the product of multipliers that take into account the effects of material, construction, and environmental factors as follows:

$$r = k_{wood} k_{climate} k_p k_t k_w k_n k_g \tag{1.5}$$

where k_{wood} = wood parameter; $k_{climate}$ = climate parameter; k_p = paint parameter; k_t = thickness parameter; k_w = width parameter; k_n = fastener parameter; and k_g = geometry parameter.

1.4. Wood Parameter k_{wood}

The timber species are grouped into durability classes as shown in Table 1.1. Then for each class the value of k_{wood} is given by Eq. (1.6),

$$k_{wood} = \begin{cases} 0.50 & \text{for class 1;} \\ 0.62 & \text{for class 2;} \\ 1.14 & \text{for class 3;} \\ 2.20 & \text{for class 4;} \\ 6.52 & \text{for sapwood.} \end{cases} \tag{1.6}$$

Table 1.1 Natural durability classification for decay of timber above-ground

Trade Name	Botanical Name	Wood Type*	Durability Class
Ash, alpine	Eucalyptus delegatensis	E	3
Ash, Crow's	Flindersia australis	H	1
Ash, mountain	Eucalyptus regnans	E	3
Ash, silvertop	Eucalyptus sieberi	E	2
Balau (selangan batu)	Shorea spp.	H	1
Bangkirai	Shorea laevis	H	1
Beech, myrtle	Nothofagus cunninghamii	H	3
Belian (ulin)	Eusideroxylon zwageri	H	1
Blackbutt	Eucalyptus pilularis	E	1
Blackbutt, New England	Eucalyptus andrewsii	E	2
Blackbutt, WA	Eucalyptus patens	E	1
Blackwood	Acacia melanoxylon	H	3
Bloodwood, red	Corymbia gummifera	E	1
Bloodwood, white	Corymbia trachyphloia	E	1
Bollywood	Litsea reticulata	H	4
Box, brush	Lophostemon confertus	H	3
Box, grey	Eucalyptus moluccana	E	1
Box, grey, coast	Eucalyptus bosistoana	E	1
Box, long-leaved	Eucalyptus goniocalyx	E	2
Box, red	Eucalyptus polyanthemos	E	1
Box, steel	Eucalyptus rummeryi	E	1
Box, swamp	Lophostemon suaveolens	H	1
Box, yellow	Eucalyptus melliodora	E	1
Box,white	Eucalyptus albens	E	1
Brigalow	Acacia harpophylla	H	1
Brownbarrel	Eucalyptus fastigata	E	3
Bullich	Eucalyptus megacarpa	E	2
Calantas (kalantas)	Toona calantas	H	1
Candlebark	Eucalyptus rubida	E	3
Cedar, red, western	Thuja plicata	S	2
Cypress	Callitris glaucophylla	S	1
Fir, Douglas (Oregon)	Pseudotsuga menziesii	S	4
Gum, blue, southern	Eucalyptus globulus	E	2
Gum, blue, Sydney	Eucalyptus saligna	E	2
Gum, grey	Eucalyptus propinqua	E	1
Gum, grey, mountain	Eucalyptus cypellocarpa	E	2
Gum, Maiden's	Eucalyptus maidenii	E	2
Gum, manna	Eucalyptus viminalis	E	3
Gum, mountain	Eucalyptus dalrympleana	H	3
Gum, red, forest	Eucalyptus tereticornis	E	1
Gum, red, river	Eucalyptus camaldulensis	E	1
Gum, rose	Eucalyptus grandis	E	2

Gum, salmon	Eucalyptus salmonophloia	E	1
Gum, scribbly	Eucalyptus haemastoma	E	2
Gum, shining	Eucalyptus nitens	H	3
Gum, spotted	Corymbia maculata, incl. corymbia citriodora	E	1
Gum, sugar	Eucalyptus cladocalyx	E	1
Gum, yellow	Eucalyptus leucoxylon	E	2
Hardwood, Johnstone River	Backhousia bancroftii	H	2
Hemlock, Western	Tsuga heterophylla	S	4
Ironbark, grey	Eucalyptus paniculata	E	1
Ironbark, red	Eucalyptus sideroxylon	E	1
Ironbark, red (broad-leaved)	Eucalyptus fibrosa	E	1
Ironbark, red (narrow-leaved)	Eucalyptus crebra	H	1
Ironwood, Cooktown	Erythrophloeum chlorostachys	H	1
Jam, raspberry	Acacia acuminata	H	1
Jarrah	Eucalyptus marginata	E	2
Kapur	Dryobalanops spp.	H	2
Karri	Eucalyptus diversicolor	E	2
Keruing	Dipterocarpus spp.	H	3
Kwila (merbau)	Intsia bijuga	H	1
Mahogany, Philippine, red, dark	Shorea spp.	H	2
Mahogany, Philippine, red, light	Shorea, Pentacme, Parashorea spp.	H	3
Mahogany, red	Eucalyptus resinifera	E	1
Mahogany, white	Eucalyptus acmenoides	E	1
Mahogany, white	Eucalyptus umbra	E	1
Mahogany, southern	Eucalyptus botryoides	E	2
Mallet, brown	Eucalyptus astringens	E	1
Marri	Corymbia calophylla	E	3
Meranti, red, dark	Shorea spp.	H	3
Meranti, red, light	Shorea spp.	H	4
Mersawa	Anisoptera spp.	H	3
Messmate	Eucalyptus obliqua	E	3
Messmate, Gympie	Eucalyptus cloeziana	E	1
Oak, bull	Allocasuarina luehmannii	H	1
Oak, white, American	Quercus alba	H	3
Peppermint, black	Eucalyptus amygdalina	E	3
Peppermint, broad-leaved	Eucalyptus dives	E	2
Peppermint, narrow-leaved	Eucalyptus radiata	E	3
Peppermint, river	Eucalyptus elata	E	3
Pine, black	Prumnopitys amara	S	4
Pine, Caribbean	Pinus caribaea	S	4
Pine, celery-top	Phyllocladus aspleniifolius	S	2
Pine, hoop	Araucaria cunninghamii	S	4

Pine, Huon	Lagarostrobos franklinii	S	3
Pine, kauri	Agathis robusta	S	4
Pine, King William	Athrotaxis selaginoides	S	2
Pine, radiata	Pinus radiata	S	4
Pine, slash	Pinus elliottii	S	4
Ramin	Gonystylus spp.	H	4
Redwood	Sequoia sempervirens	S	1
Rosewood, New Guinea	Pterocarpus indicus	H	2
Satinay	Syncarpia hillii	H	1
Stringybark, Blackdown	Eucalyptus sphaerocarpa	E	1
Stringybark, brown	Eucalyptus baxteri	E	2
Stringybark, red	Eucalyptus macrorhyncha	E	2
Stringybark, white	Eucalyptus eugenioides	E	2
Stringybark, yellow	Eucalyptus muelleriana	E	2
Tallowwood	Eucalyptus microcorys	E	1
Taun	Pometia spp.	H	2
Teak, Burmese	Tectona grandis	H	1
Tingle, red	Eucalyptus jacksonii	E	3
Tingle, yellow	Eucalyptus guilfoylei	E	1
Tuart	Eucalyptus gomphocephala	E	1
Turpentine	Syncarpia glomulifera	H	1
Wandoo	Eucalyptus wandoo	E	1
Woolybutt	Eucalyptus longifolia	E	1
Yate	Eucalyptus cornuta	E	1
Yertchuk	Eucalyptus consideniana	E	1

1.5. Climate Parameter $k_{climate}$

Australia is divided into four hazard zones: A, B, C, and D, as shown in Figure 1.8. For each hazard zone, the value of $k_{climate}$ is given by Table 1.2.

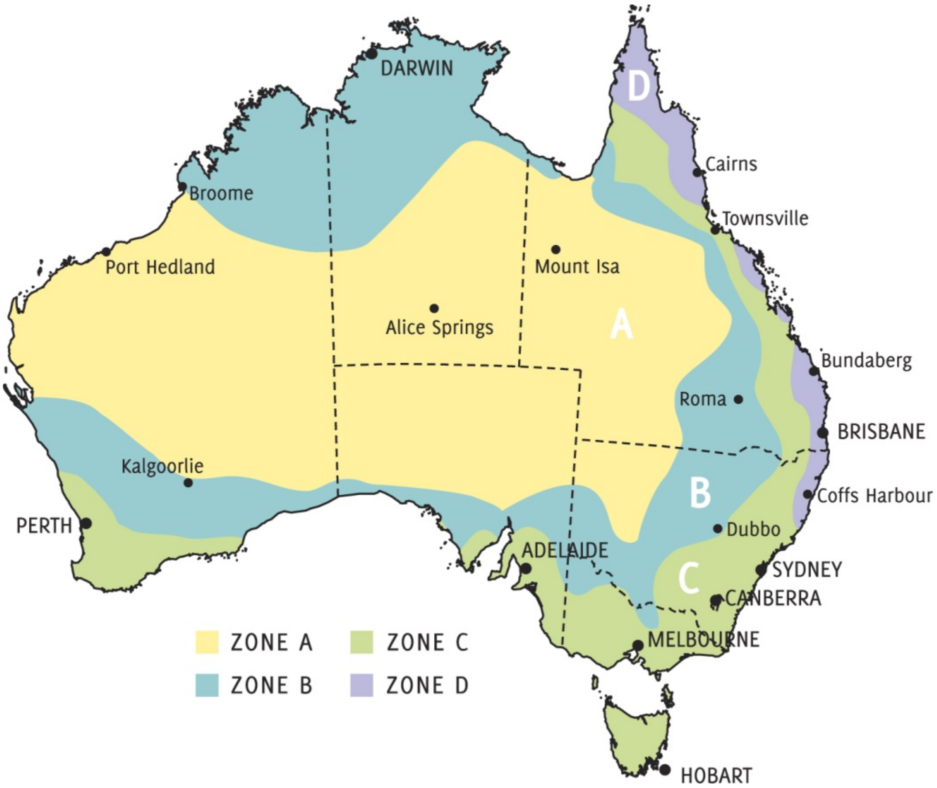


Figure 1.8 A hazard map of Australia for timber above-ground under attack of decay fungi (Zone D is the most hazardous).

Table 1.2 Representative climate index values for the 4 hazard zones of above-ground decay

Above-ground Decay Hazard Zone	**Representative $k_{climate}$**
A	0.40
B	0.50
C	0.65
D	0.75

1.6. Paint Parameter k_p

For unpainted wood, $k_p = 1$; for painted wood, use the values givien in Eq. (1.7).

$$k_p = \begin{cases} 3.5 & \text{for class 1;} \\ 2.0 & \text{for classe 2;} \\ 1.5 & \text{for classe 3;} \\ 1.1 & \text{for classe 4;} \\ 1.1 & \text{for sapwood.} \end{cases} \tag{1.7}$$

1.7. Thickness Parameters

This parameter is for the effects of drying in transverse direction to timber grain. If a part of a timber element is non-contact, i.e. it is not in contact with another element, it will tend to dry rapidly if it is sufficiently thin. Hence a thickness factor k_t is used to account for this effect. For non-contact surface of an element of thickness t,

$$k_t = \begin{cases} 1 & \text{for } t \geq 20 \text{ mm} \\ 0.5 & \text{for } t \leq 20 \text{ mm} \\ 0.05t & \text{otherwise} \end{cases} \tag{1.8}$$

For surfaces in contact with other elements, $k_t = 1.0$.

1.8. Width Parameter

This parameter takes into accounts the effect of specimen width (cross-grain) on the decay surface due to drying restraint. The bigger the width, the more restraints on the wood surface during drying, potentially causing larger and deeper checks on the surface and hence facilitating more severe decay. For contact surfaces, $k_w = 1.0$. For non-contact surfaces of width w,

$$k_w = \begin{cases} 1 & \text{for } w \leq 50 \text{ mm} \\ 1.5 & \text{for } w \geq 200 \text{ mm} \\ \dfrac{w}{300} + \dfrac{5}{6} & \text{otherwise} \end{cases} \tag{1.9}$$

Illustration of the width on member cross section is in Figure 1.9.

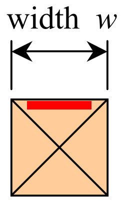


Figure 1.9 Illustration of the width w used to determine the width parameter

1.9. Connection Parameter

This parameter takes into accounts the effect of the presence of connector on the decay surface. The interface/gap between the connector and its hole would act as a path of moisture entry to enhance the decay progress. Provisionally, value of this parameter is set as follows,

- If there is connector, $k_n = 2.0$;
- If there is no connector, $k_n = 1.0$.

1.10. Geometry Parameter

The geometry parameter, k_g, is expressed as,

$$k_g = k_{g1}\, k_{g2} \tag{1.10}$$

where k_{g1} is contact factor and k_{g2} is position factor. These factors were originally derived as estimates by experts, and then modified in the light of limited small specimen and building construction field data. These factors are critical in the prediction of decay rates and are a potentially a rich field for future research.

1.10.1. Contact factor

This contact factor k_{g1} is determined depending on whether the assessed surface is in contact with other structural members or not.

(a) For a non-contact surface:

$$k_{g1} = 0.3$$

(b) For a contact surface:

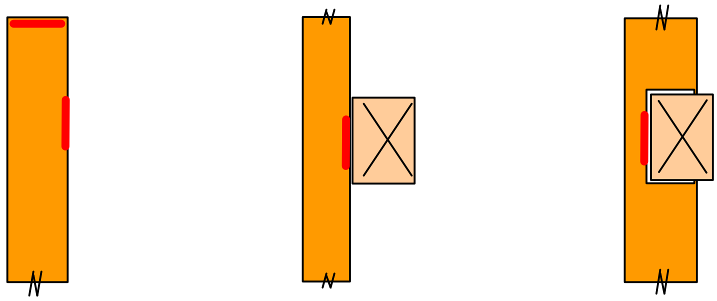
- Flat contact:

$$k_{g1} = 0.6$$

- Embedded contact: (reference to L-joint)

$$k_{g1} = 1.0$$

Illustration of the contacts is shown in Figure 1.10.



(i) Non-contact
$k_{g1} = 0.3$

(ii) Flat contact
$k_{g1} = 0.6$

(iii) Embedded contact
$k_{g1} = 1.0$

Figure 1.10 Illustration of non-contact, flat contact and embedded contact.

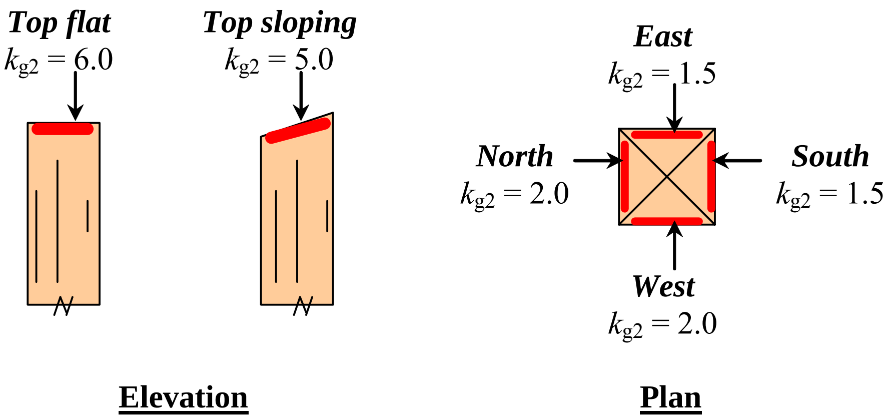
1.10.2. Position factor for non-contact surface

The position factor k_{g2} for non-contact surfaces takes into account the orientation of the member, orientation of the surface, and sheltering effect. It is noted that the surface orientation effect is due to the mechanical degradation caused by sun.

(a) For vertical members

The position factor k_{g2} for vertical member depends on the orientation of the decay-assessed surface. If the decay-assessed surface is

- *Top flat:* $k_{g2} = 6.0$
- *Top sloping:* $k_{g2} = 5.0$
- *Facing north:* $k_{g2} = 2.0$
- *Facing south:* $k_{g2} = 1.5$
- *Facing east:* $k_{g2} = 1.5$
- *Facing west:* $k_{g2} = 2.0$



Non-contact surfaces - Vertical member

Figure 1.11 Position factor k_{g2} for non-contact surface in vertical member.

(b) For horizontal members

The position factor k_{g2} *for horizontal member depends on the orientation of the decay-assessed surface. If the decay-assessed surface is*

- *Horizontal:*
    - *Top of member:* $k_{g2} = 3.0$
    - *Bottom of member:* $k_{g2} = 1.5$
- *Vertical sides of member (side grain):*
    - *Sheltered* (by decking):* $k_{g2} = 0.8$
    - *Exposed to north:* $k_{g2} = 2.0$
    - *Exposed to south:* $k_{g2} = 1.5$
    - *Exposed to east:* $k_{g2} = 1.5$
    - *Exposed to west:* $k_{g2} = 2.0$
- *Vertical ends of member (end grain):*
    - *Sheltered* (by decking):* $k_{g2} = 1.6$
    - *Exposed to north:* $k_{g2} = 4.0$
    - *Exposed to south:* $k_{g2} = 3.0$
    - *Exposed to east:* $k_{g2} = 3.0$
    - *Exposed to west:* $k_{g2} = 4.0$

It can be noted that the factor for vertical ends is twice that of vertical sides. This is to take into account the effect of grain orientation at the decay surface.

1.10.3. Position factor for contact surface

The position factor k_{g2} *for contact surfaces, including flat and embedded contacts, takes into account the type of material in contact, the presence of gap, and the gap size and location. The factor can be determined as*

$$k_{g2} = k_{g21}\, k_{g22}\, k_{g23} \tag{1.11}$$

Where k_{g21} is the contacted-material factor, k_{g22} is orientation factor, and k_{g23} is gap factor.

The contacted-material factor k_{g21} *depends on the type of contact material. If the contacted material is*

- *Wood* $k_{g21} = 1.0$
- *Steel* $k_{g21} = 0.7$
- *Concrete* $k_{g21} = 1.0$

The orientation factor k_{g22} *takes into account the orientation of the decay surface. It takes the following values*

- *For horizontal top surface (facing upward):* $k_{g22} = 2.0$
- *For others:* $k_{g22} = 1.0$

The gap factor k_{g23} *takes into account the effect of gap presence, gap size and gap location. Three cases are considered:*

(a) Continuous member in contact with a continuous member:

$$k_{g23} = 1.0$$

(b) Continuous member in contact with a butted member:

$$k_{g23} = 1.2$$

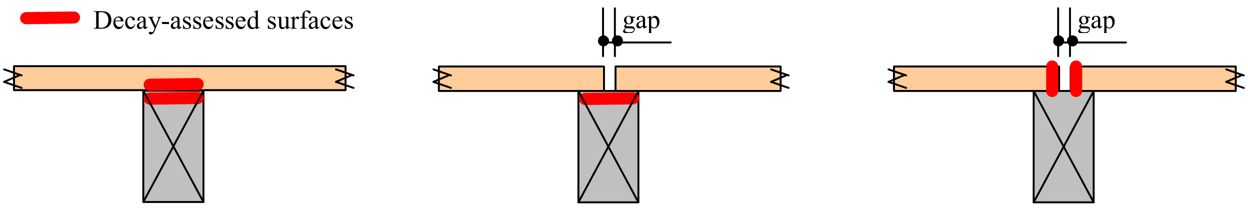
(c) A butted member:

If the gap size is

- ≤ 1.0 *mm* $k_{g23} = 2.0$
- ≥ 2.5 *mm* $k_{g23} = 1.3$

- $k_{g23} = \frac{3.7}{1.5} - \frac{0.7}{1.5} \times (\text{gap size})$ *otherwise*

Illustrations of these cases are given in Figure 1.12.



(a) Continuous members
$k_{g23} = 1.0$

(b) Continuous member in contact with a gapped member
$k_{g23} = 1.2$

(c) Butted member
k_{g23} depends on gap size

Figure 1.12 Illustration of 3 cases to determine gap factor k_{g23} for contact surfaces.

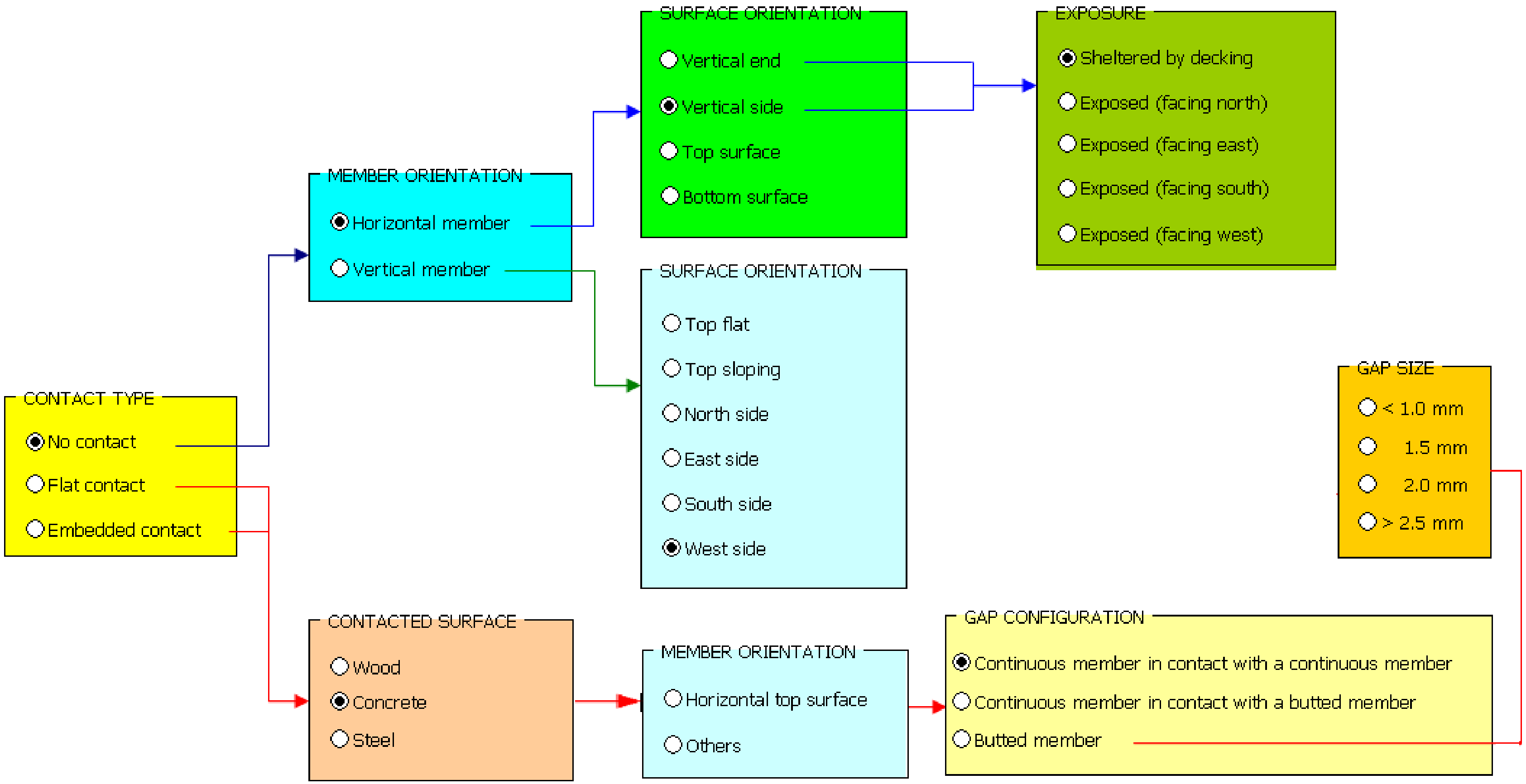


Figure 1.13 Generic scheme to determine the geometry parameter

2. Data Source

The data used for development of an aboveground decay prediction model are the test results from three field tests described in the following subsections.

2.1. Exposed L-Joint Test

A primary source of data for the aboveground decay prediction model is the series of L-joint field tests undertaken over a period of 20 years by the Department of Primary Industry and Fishery, Queensland. These data are based on the test results initiated in 1987 by Cause (1993) and after the first 11 years maintained by Francis and Norton (Francis and Norton 2006; Francis et al. 2007). The test specimens were mortice and tenon L-joints as shown in Figure 2.1. Detailed specifications for the construction and field installation of the L-joints were described in Francis and Norton (2005). The location of the test sites used are described in Table 2.1 and located as shown on the map in Figure 2.2. For each species, 24 painted and 24 unpainted replicates were installed at each site. It was noted that the paint of the painted specimens were broken at the interface of the mortise and tenon by pulling apart the two elements, thus creating a favourable condition for attack by decay fungi. Forty-three species of timber were used in this test, of which nine species (Table 2.2), referred to as 'reference species' were installed at all 10 test sites, and the other thirty-three (Table 2.3) at the Beerburrum site only.

Species No. 15 in Table 2.3, however, consisted of both heartwood and sapwood, its natural durability classification was not clear; and the assessed performance of Species No. 52 varied over a wide range and significantly below the level one would expect of durability class-one timber. Both of Species Nos. 15 and 52 were excluded from the analysis. The number of species used for analysis at Beerburrum for durability classes of 1 to 4 is 11, 6, 8, and 13, respectively. The locations of test sites are listed in Table 2.1 and shown in Figure 2.2. Half of the number of the joints was painted and the other half unpainted. Each type of joint (both painted and unpainted) was replicated 24 times at each site.

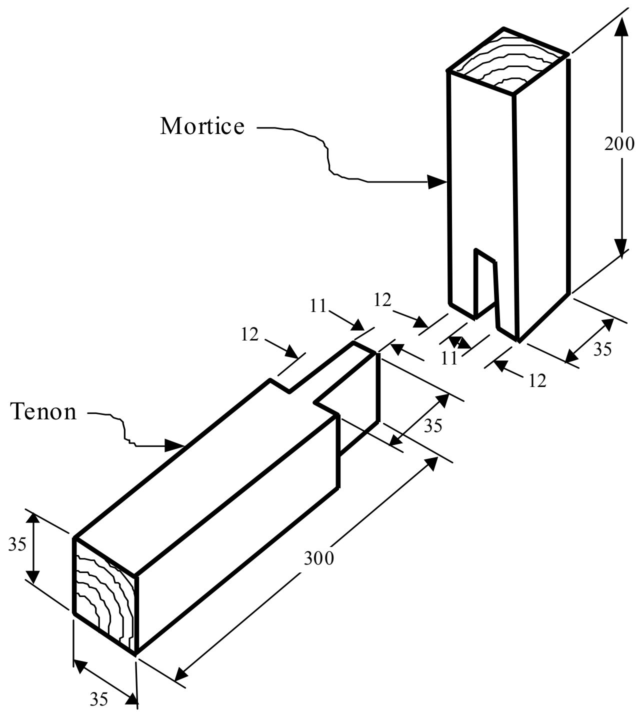


Figure 2.1 Dimensions of test specimens for exposed L-joint tests.

Table 2.1 Test sites for exposed L-joint test

Site ID	Place	Longitude	Latitude
1	Beerburrum	152.97	–26.97
2	Rockhampton	148.65	–20.08
4	Townsville	146.80	–19.30
5	South Johnstone	145.90	–17.35
6	Toowoomba	151.93	–27.58
7	Dalby	151.20	–27.53
8	Mt Isa	139.50	–20.70
9	Sydney	151.20	–33.86
10	Canberra	149.22	–35.28
11	Melbourne	144.97	–37.81

Figure 2.2 Location of test sites for exposed L-joint tests.

Table 2.2 L-joint test reference species installed at all sites

Species Name	Durability Class	Species No.
radiata pine (untreated sapwood)	sapwood	1
white cypress (untreated sapwood)	sapwood	2
Douglas fir (regrowth heartwood)	4	3
northern silky oak	4	4
brush box (outer heartwood)	3	5
western red cedar (regrowth heartwood)	2	6
spotted gum (Eucalyptus maculata)	1	7
grey ironbark	1	8
radiata pine (CCA treated sapwood)	CCA	9

Table 2.3 Supplementary L-joint test species installed at the Beerburrum site only

Species Name	Durability Class	Species No.
hoop pine (heartwood plantation)	4	10
hoop pine (heartwood native	4	11
slash pine (heartwood plantation)	4	12
Caribbean pine (heartwood plantation)	4	13
white cypress (heartwood native)	1	14
black cypress (sapwood & heartwood native)		15
radiata pine (heartwood plantation)	4	16
Douglas fir (mature heartwood)	4	17
western red cedar (mature heartwood)	2	18
spotted gum (Eucalyptus citriodora)	1	19
spotted gum (Eucalyptus henryi)	1	20
forest red gum (Eucalyptus tereticornis)	1	21
blackbutt (regrowth heartwood)	1	22
blackbutt (mature inner heartwood)	1	23
blackbutt (mature outer heartwood)	1	24
brush box (inner heartwood)	3	25
red mahogany	1	26
rose gum	2	27
Sydney blue gum	2	28
fishtail silky oak	1	29
white Eungella satinash	3	30
Queensland maple	4	31
Johnston River hardwood	2	32
rose alder	4	33
mountain ash	3	34
alpine ash	3	35
messmate	3	36
light-red meranti	4	37
malas	3	38
keruing	3	39

kapur	2	40
red balau	4	41
kamarere	4	42
white cypress (SPP = 52 hardwood)	1	52

Assessment of decay involved penknife probing of the tenon component and the flanking end grain of each joint to determine the extent of decay which was recorded by a five-point scale of severity (Francis and Norton 2006), as described in Table 2.4. The depth of decay at some inspections was also recorded.

Engineering consideration of timber construction is mainly on the strength of elements and structure. In this aspect, it is the decay depth, rather than the decayed surface area, that is of concern. Fortunately, during the last three inspections (occurring at 11, 16, and 20 years after installation) the decay depth along with the decay score of some tenons was recorded, which gave an indication of how the scores correspond to the expected decay depths.

The score–depth relationship at Beerburrum site was examined. A score of 3 or 4 always had a decay depth, if recorded, of zero. Figure 2.3 shows the estimates of cumulative distribution function (CDF) of the recorded decay depths when score readings are 1 or 2. The median depth for a score of 2 was between 1 and 2 mm and the median depth for a score of 1 was around 3 and 4 mm. Therefore, in this study a score of 2.5 was used as an indicator of the time at which decay initiated. The time at which a score of 2.5 was reached was assumed to be at the middle of the interval between the last time instant a score of 3 was recorded and the first instant a score of 2 was recorded. When either one or none of them was recorded, linear interpolation was used to estimate the time at which a score of 2.5 occurred. For example, when a score of 3 was assessed at the 6th year, and a score of 1 was assessed in the next, at the 9th year, inspection, then a score of 2.5 was assumed to occur at $6\frac{3}{4}$ years after installation; hence in this example the time lag to decay was estimated to be $6\frac{3}{4}$ years.

A summary of the score system used by the field researchers is given in Table 2.4. This Table also gives the value of one-sided decay depth assumed in this report for each decay score.

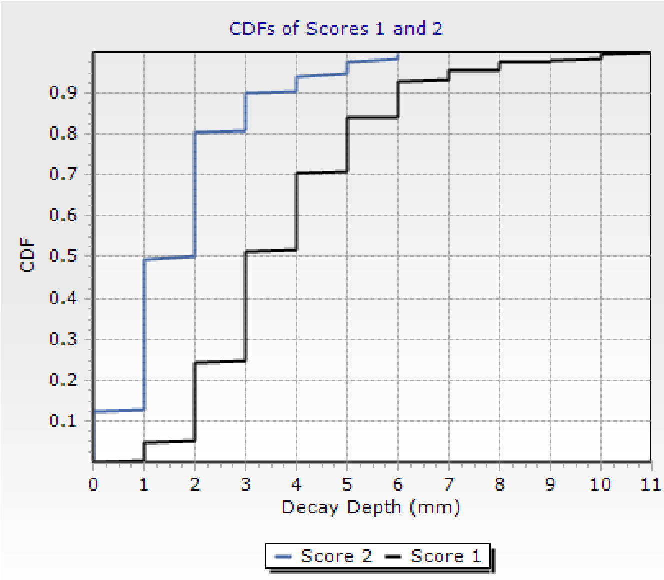


Figure 2.3 Cumulative distribution of decay depths corresponding to scores 1 and 2 measured at the Beerburrum site

Table 2.4 Criteria of score for L-joint decay assessment

Score	**Condition of tenon**	**Assumed decay depth* (mm)**
4	Sound	0
3	Signs of slight surface deterioration (incipient decay)	0
2	Small areas of obvious deterioration, < 25% of assessable tenon area deteriorated	1.5
1	Extensive deterioration, > 25% of assessable tenon area deteriorated	4.0
0	Joint failure (e.g. sufficient decay through entire 11 mm width of tenon to allow assessment probe to completely pass through	11.0

* depth relates to decay from one side

2.2. Exposed Painted Panel Test No. 1

The data are based on measurements obtained during above ground decay studies by Creffield, et al. (1992). The dimensions of the test specimens used are shown in Figure 2.4. The timber and treatments used are listed in Table 2.5. In the case of treated timber, the treatment was with CCA to a dry salt retention of 3.4–4.2 kg/m^3. The test site locations are listed in Table 2.6 and illustrated in Figure 2.5. Initially there was only one sample of each type of specimen at each site location. However as samples failed, they were sometimes replaced by new specimens, usually of untreated Radiata pine sapwood. However, data from these replacement specimens have not been used in this study. The decay scores assessed for the bottom area of a panel are used in the determination of decay lag and decay rate.

To assess the decay, the panels were first x-rayed to estimate the extent of the decay and a pen knife probe was then used to confirm the extent. The decay was evaluated as a proportion of the volume of wood lying within 12 mm of the top and bottom edges, and 6 mm above and below the saw cut. The data was given a score of 0 to 4 depending on the extent of the decay. The decay score was then converted to an effective depth of structural decay according to the following formulae.

- For decay at the top and bottom of panels:

$$\text{decay depth (mm)} = \left(\frac{8 - score}{8}\right) \times 12 \tag{2.1}$$

- For decay at the saw cut:

$$\text{decay depth (mm)} = \left(\frac{8 - score}{8}\right) \times 6 \tag{2.2}$$

The time to reach a score of 6 is taken to be the decay lag.

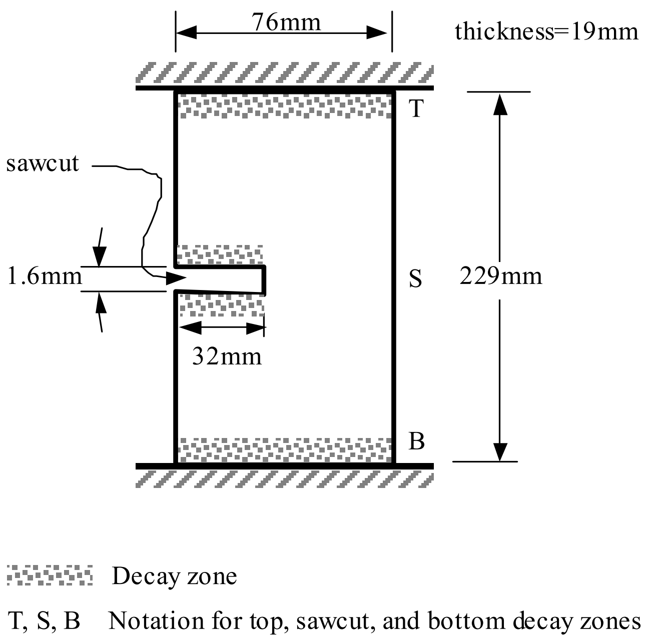


Figure 2.4 Dimensions of test specimens for exposed panel test No.'s 1 and 2.

Table 2.5 List of timber specimens and treatment

Specimen I.D.	**Species**	**Botanical Name**	**Sapwood/ Heartwood**	**Treated/ Untreated**
1	Radiata Pine	*pinus radiata*	sapwood	untreated
2	Radiata Pine	*pinus radiata*	sapwood	treated
3	Radiata Pine	*pinus radiata*	heartwood	untreated
4	Mountain Ash	*eucalyptus regnans*	heartwood	untreated
5	Mountain Ash	*eucalyptus regnans*	heartwood	treated
6	Ramin	*gonystylus* spp.	heartwood	untreated
7	Douglas fir	*pseudotsuga menziesii*	heartwood	untreated
8	Red Meranti	*shorea* spp.	heartwood	untreated
9	Messmate	*eucalyptus obliqua*	heartwood	untreated
10	Brush Box	*tristania conferta*	heartwood	untreated

Table 2.6 Test sites for exposed panel test No. 1

Site ID	Place		Longitude	Latitude
2	Lae	PNG	147.0	6.70
3	Kikori	PNG	144.22	–7.42
5	Brisbane	QLD	153.17	–27.47
6	Dalby	QLD	151.20	–27.53
7	Mackay	QLD	149.20	–21.10
8	Innisfail	QLD	146.03	–17.52
10	Dubbo	NSW	148.62	–32.25
11	Griffith	NSW	146.35	–34.23
12	Batlow	NSW	148.15	–35.53
13	Canberra	ACT	149.22	–35.28
14	Melbourne	VIC	144.97	–37.81
15	Creswick	VIC	143.90	–37.43
16	Horsham	VIC	142.10	–36.05
17	Powelltown	VIC	145.73	–37.87
18	Hobart	TAS	147.24	–42.08
20	Mount Gambier	SA	140.78	–37.08
21	Wirrabara	SA	138.27	–33.03
22	Adelaide	SA	138.60	–34.93
24	Katherine	NT	132.27	–14.44
26	Perth	WA	115.08	–31.92
28	Narrogin	WA	117.18	–32.93
29	Manjimup	WA	116.15	–34.25
30	Port Hedland	WA	118.60	–20.37

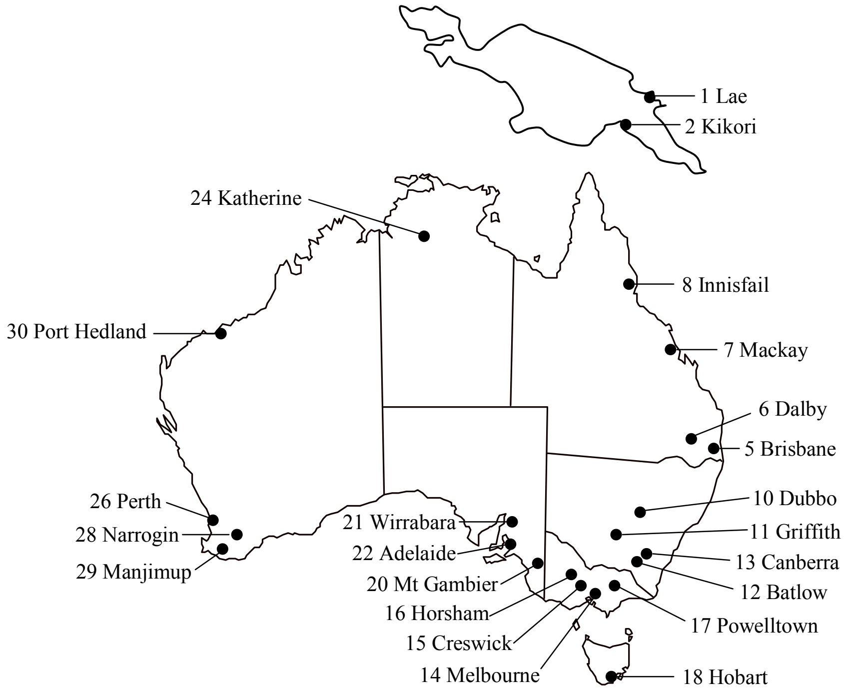


Figure 2.5 Site locations for exposed panel test No. 1

2.3. Exposed Unpainted Panel Test No. 2

These test results are based on unpublished data observed by Thornton and Johnson from a short-term field panel test. The site locations for these tests are listed in Table 2.7 and shown in Figure 2.6. As the primary purpose of this test was to compare the climate effects of various sites, only a limited number of species were used but several replicates were involved. The wood substrates used were

1. Eucalyptus regnans, untreated heartwood (id = 1)

2. Radiata pine, untreated sapwood (id = 2)

The dimensions of the test specimens are the same as those in test No. 1 shown in Figure 2.4. The test specimens were inspected only twice during the test period: 1 year and $2\frac{1}{2}$ years after installation.

The score system for this test was measured and interpreted in the same way as that of panel test No. 1.

Table 2.7 Test sites for exposed panel test No. 2

Site I.D.	Place		Longitude	Latitude
3	Taree	NSW	152.60	–31.83
4	Narrandra	NSW	146.55	–34.75
5	Brisbane(Salisbury)	QLD	153.10	–27.47
6	Dalby(Dunmore)	QLD	151.20	–27.53
7	Rockhampton(Mackay)	QLD	148.65	–20.08
8	Innisfail	QLD	146.03	–17.52
9	Pennant Hills(Sydney)	NSW	151.05	–33.68
10	Dubbo	NSW	148.62	–32.25
11	Griffith	NSW	146.35	–34.23
12	Batlow(Tumbarumba)	NSW	148.15	–35.53
13	Canberra	ACT	149.22	–35.28
14	Highett(Melbourne)	VIC	145.17	–37.98
15	Creswick	VIC	143.90	–37.43
16	Horsham(Wail)	VIC	142.10	–36.05
17	Powelltown	VIC	145.73	–37.87
18	Hobart	TAS	147.25	–42.08
19	Walpeup	VIC	142.03	–35.13
20	Mount Gambier	SA	140.78	–37.08
21	Wirrabara	SA	138.27	–33.03
22	Adelaide	SA	138.60	–34.93
23	Rowville(Melbourne)	VIC	145.30	–38.03
25	Beerburrum	QLD	152.97	–26.97
26	Perth(Como)	WA	115.08	–31.92
27	Frankston(Melbourne)	VIC	145.18	–38.10
28	Narrogin	WA	117.18	–32.93
29	Manjimup	WA	116.15	–34.25
30	Port Hedland	WA	118.60	–20.37

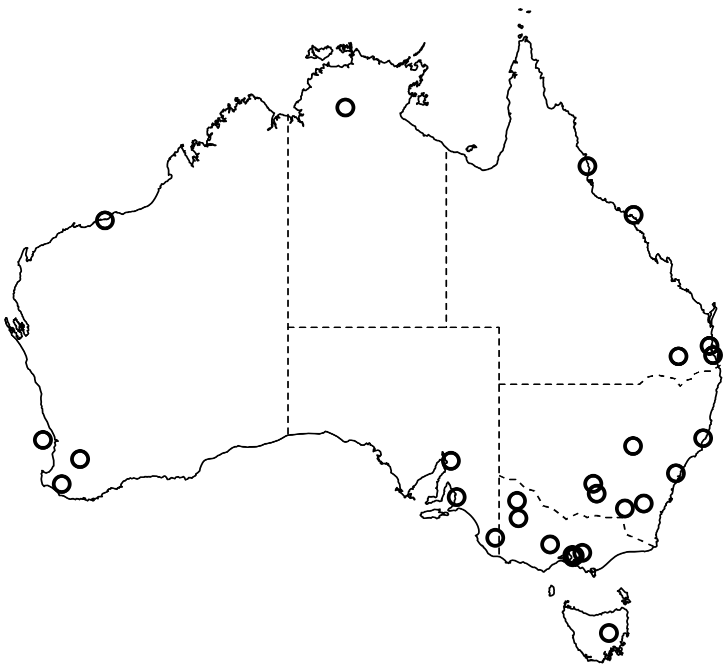


Figure 2.6 Site locations for exposed panel test No. 2.

3. Data Processing

3.1. Terminology used

In this Section it is the intention to compare the measured data with the decay model predictions. In doing this the equations used for the model predictions are those given in Section 1, except that the value of $k_{climate}$ used is not that for a hazard zone, but rather it is the value computed for the test site locations.

In this Section, the terminology used to denote the test data will be as follows:

- "Species data": For the case of L-joints and Panel Test No. 2, this will refer to the median or mean value obtained from the data of all specimens for a single species on a single test site. For the case of Panel Test No.1, this will refer to the median or mean value obtained from the data for the set of 10 specimens (each specimen being of a different species/treatment) used at each site.
- "Class Data": For the case of L-joints at the Beerburrum site, this will refer to the median or mean value obtained from the data of all specimens within a specific durability class or other grouping (such as for all sapwood specimens).

3.2. Processing Data from L-joints

The number of L-joint specimens available for the modelling is given in Table 3.1. Note that the CCA-treated specimens had not had a sufficient number of decayed specimens in 20 years to give satisfactory estimates of decay lags.

Table 3.1 Number of L-joint specimens for probabilistic modelling of decay lags

Paint	Durability Class				Sapwood
	1	2	3	4	
Unpainted	121	64	95	216	37
Painted	186	90	105	232	42

Assuming $k_g = k_t = k_w = k_n = 1$ for the L-joint test specimens, the decay rate is expressed as follows,

$$r = k_{wood} k_{climate} k_p \tag{3.1}$$

The value of k_{wood} for any particular species will be taken to be the median decay rate of the unpainted wood at the Beerburrum test site.

After the decay lag is determined, the other model parameter, the decay rate, is estimated by using the decay lag and the instant at which a score of 0, of which the corresponding decay depth was assumed to be 11 mm (Table 2.4), was first recorded. Because there were fewer specimens to reach a score of 0 than that to reach a score of 2, the number of estimated decay depths was less than the number of estimated decay lags.

The specimens, for which both estimated decay lag and rate were available at the Beerburrum test site, were used to estimate the median lag and rate of each species. A total of 20 species for unpainted, and 31 species for painted, L-joints had sufficient number of decayed specimens for this purpose. This data is shown plotted in Figure 3.1(a) as Species Data and on Fig 3.1 (b) as Class Data.

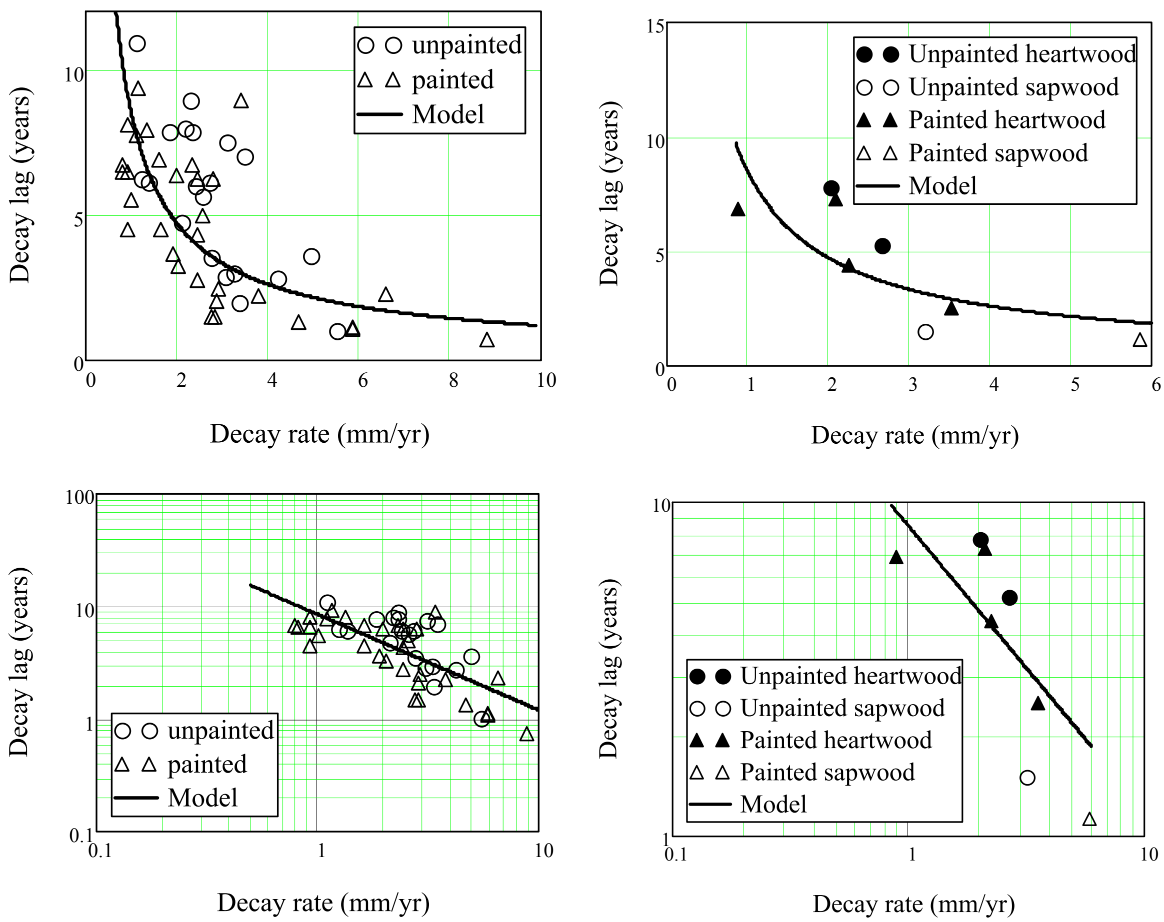
Also plotted is the regression relationship used for the decay model

$$l = 8.5 r^{-0.85} \tag{3.2}$$

where r is the median decay rate (mm/yr) and l is the median decay lag (yrs). Eq. (3.2) is the equation used for the model.

The correlation coefficient of the decay lag and rate was found to be 0.7.

Figure 3.2 shows measured values of the paint parameter k_p. Each point represents the median value of one species at one site. For convenience, the data have been grouped into durability classes.



(a) Species Data (b) Class Data

Figure 3.1 Median decay rate versus decay lag at the Beerburrum site only

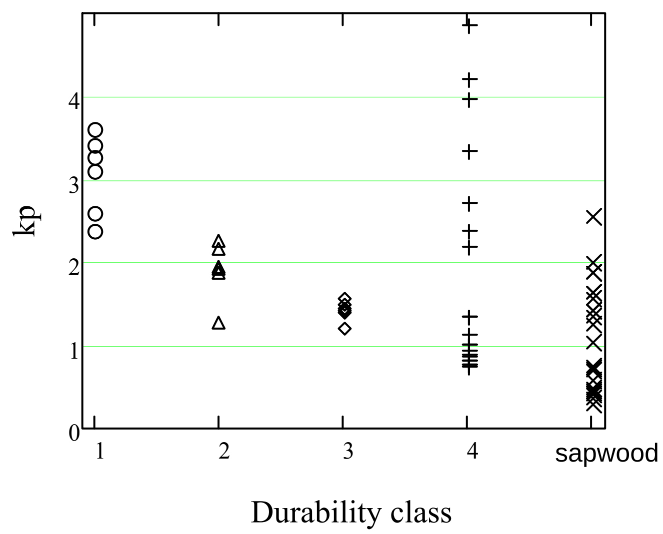


Figure 3.2 Relationship of the durability class to the paint parameter k_p (Species Data for all sites)

3.3. Climate Parameter

3.3.1. Derivation of $k_{climate}$

The specimens of the reference species assessed at the 11 test sites were used to investigate the effect of climate. Recall that nine species (Table 2.2) were installed at all sites; however, the specimens of treated radiate pine, spotted gum and grey ironbark had not decayed sufficiently after 20 years of exposure at Beerburrum to give a median estimate of decay lag, only the remaining 6 species were used to investigate the climate effect.

Assuming $k_g = k_t = k_w = k_n = 1$ for the L-joint test specimens, the decay rate is expressed as follows,

$$r = k_{wood} k_{climate} k_p \tag{3.3}$$

To estimate the effect of climate to all the 11 test sites, the *mean* decay rates of the 6 species of unpainted specimens at Beerburrum should be used as the wood parameter, denoted as $k_{wood,B}$, and listed in Table 3.2.

Table 3.2 $k_{wood,B}$ for normalisation of decay rates observed from the L-joint test sites

Species Name	Durability Class	$k_{wood,B}$	$\sigma_{\ln K}$
radiata pine (untreated sapwood)	sapwood	4.38	0.39
white cypress (untreated sapwood)	sapwood	4.38	0.39
Douglas fir (regrowth heartwood)	4	3.31	0.72
northern silky oak	4	2.78	0.72
brush box (outer heartwood)	3	1.37	0.52
western red cedar (regrowth heartwood)	2	1.60	0.41

The estimated decay rate, r_K, is computed from the observed decay lag, l_{obs}, as follows. If l_{obs} is assumed to follow a lognormal distribution, then

$$r_K = 5.5 l_{obs}^{-0.6} e^{\frac{1}{2}\sigma_{\ln K}^2} \tag{3.4}$$

in which $\sigma_{\ln K}$ is the standard deviation of $\ln k_{wood,B}$. The term $e^{\frac{1}{2}\sigma_{\ln K}^2}$ is needed as a multiplier to get the mean value of rate from the median, $5.5 l_{obs}^{-0.6}$. The estimated climate parameter, $k_{\mathrm{climate},K}$, thus becomes

$$k_{\text{climate},K} = \frac{r_K}{k_{wood,B}} \tag{3.5}$$

In order to obtain an estimate of annual rainfall wetting, a set of half-hour-interval data for the years 2000 and 2001 has been obtained from the Bureau of Meteorology for nine cities: Adelaide, Alice Springs, Brisbane, Canberra, Darwin, Hobart, Melbourne, Perth, and Sydney. As shown in Appendix B, this data leads to the following relationship between rainfall duration t_d and the 3-hourly rainfall quantity R_{3hr}

$$t_d = 1.2 + 0.3 \ln R_{3hr} \tag{3.6}$$

but not less than zero.

Using this relationship with the 3-hourly data R_{3hr} supplied by the Bureau of meteorology, the annual rainfall duration for has been computed for various cities in Australia and are given in Tables B.1, B.2 and B.3 in Appendix B. Using the values for the L-joint sites, the fitted value of $k_{climate}$ is given by

$$k_{climate} = \begin{cases} 0.15 t_{rain}^{0.5} & \text{if } t_{rain} \text{ is in days/yrs;} \\ 0.03 t_{rain}^{0.5} & \text{if } t_{rain} \text{ is in hrs/yrs.} \end{cases} \tag{3.7}$$

The correlation coefficient between t_{rain} and $k_{climate}$ is 0.62.

The relationship between annual duration of rainfall and the value of $k_{climate,K}$ is shown in Figure 3.3. It is seen that this follows the plot of Eq. (3.7) reasonably well. In Figure 3.4 it is seen that the value of $k_{climate,K}$ is not well correlated with mean annual temperature.

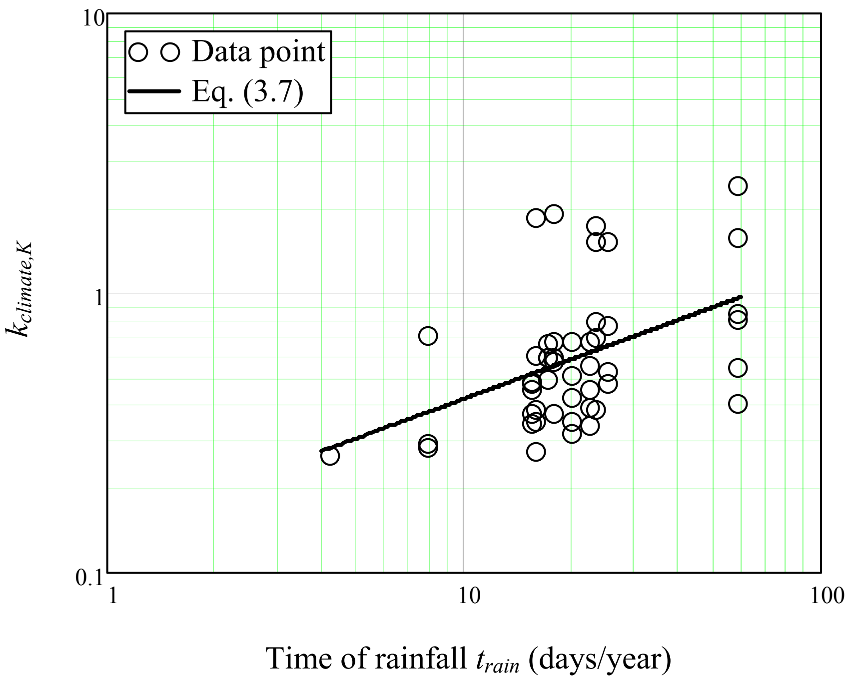


Figure 3.3 Time of rainfall versus decay rate normalised by $k_{wood,B}$ (Species Data, all sites)

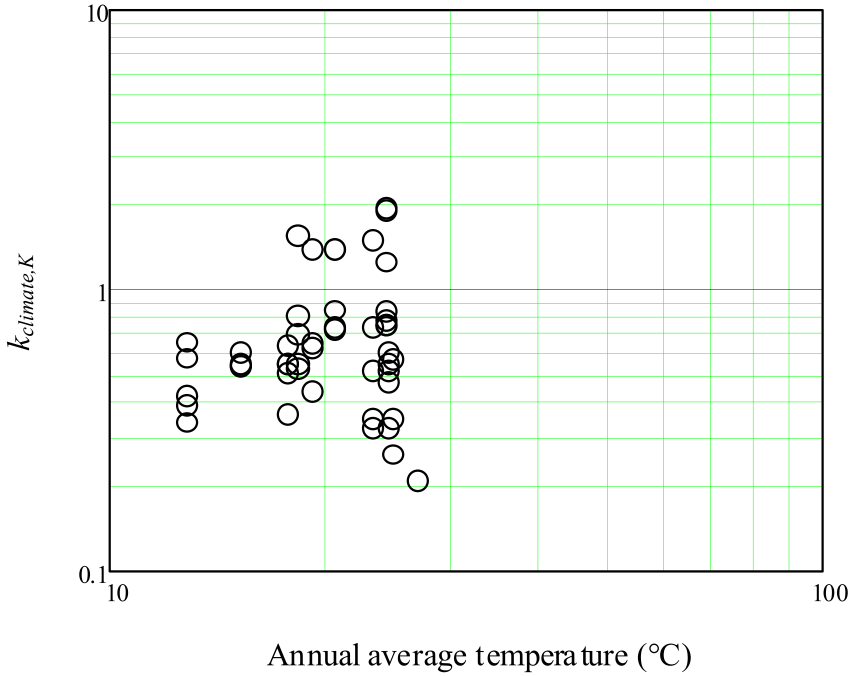


Figure 3.4 Dry-bulb temperature versus decay rate normalised by $k_{wood,B}$ (Species Data, all sites)

3.3.2. Class Data for the Beerburrum Site

Table 3.3 and Figs 3.5 show a comparison between the proposed model and measured Class Data for the Beerburrum test site. For this purpose the model predictions are taken as described in Section 1 except that the value of 0.73 has been used for $k_{climate}$, the 'exact' value for Beerburrum.

Table 3.3 Comparison between model and measured decay rate and lag at Beerburrum (Class Data)

Painting	Durability class	Median decay rate (mm/yr)		Median decay lag (years)	
		Model	Measured	Model	Measured
Unpainted	1	—	—	—	—
	2	—	—	—	—
	3	0.8	2.0	4.7	7.8
	4	1.6	2.7	3.7	5.2
	Sapwood	4.7	3.2	3.2	1.5
Painted	1	1.3	0.9	9.4	6.9
	2	1.0	2.1	4.5	7.3
	3	1.2	2.3	4.3	4.4
	4	1.7	3.5	2.9	2.5
	Sapwood	5.2	5.9	1.9	1.1

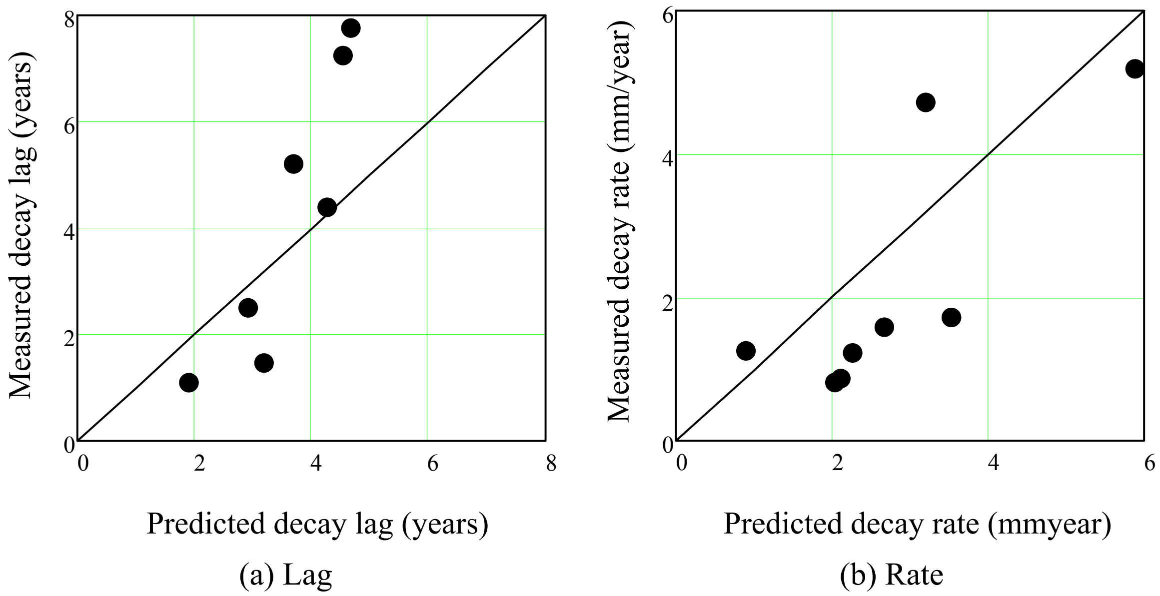


Figure 3.5 Comparison between model and measured decay rate and lag at Beerburrum (Class Data, i.e. each point represents the median values of a durability class as listed in Table 3.3)

3.3.3. Climate Zones for a Hazard Map

The climate parameter $k_{climate}$ could be used to produce an above-ground decay hazard map for Australia that delineates the continent of Australia according to the relative vulnerability of locations to fungal decay due to the climatic variation. To do this the value of $k_{climate}$ was evaluated for 135 weather sites around Australia as shown in Figure B.2 of Appendix B. Figure 3.6 shows a hazard map that divides the continent into four hazard zones defined by the boundary values quoted in Table 3.4.

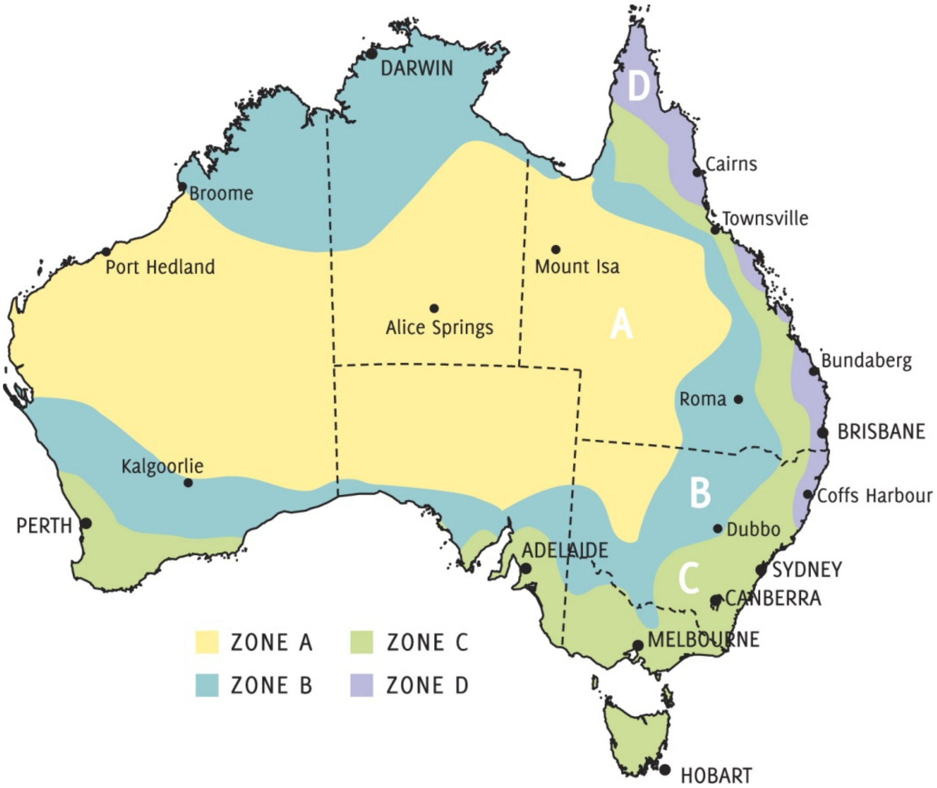


Figure 3.6 A hazard map of Australia for timber above-ground under attack of decay fungi (Zone D is the most hazardous).

Table 3.4 Test sites and 20-year 50-percentile decay depth for exposed L-joint test

Above-ground Decay Hazard Zone	**Representative** $k_{climate}$	**Boundary**
A	0.4	
		0.43
B	0.5	
		0.57
C	0.65	
		0.70
D	0.75	

3.3.4. The Scheffer Index

It is of interest to compare the derived hazard map shown in Figure 3.6 with one drawn on the basis of the Scheffer Index (Scheffer 1971). This index is defined as

$$\text{Scheffer Index} = \sum_{Jan}^{Dec} \frac{(T-2)(D-3)}{16.7} \tag{3.8}$$

where T (°C) is the mean monthly temperature, D is the mean number of days in the month with 0.25 mm or more o precipitation, and $\sum_{Jan}^{Dec}$ is the sum for the year of the products for each month.

The hazard map thus derived is shown in Figure 3.7. In many ways it is similar to the map shown in Figure 3.6.

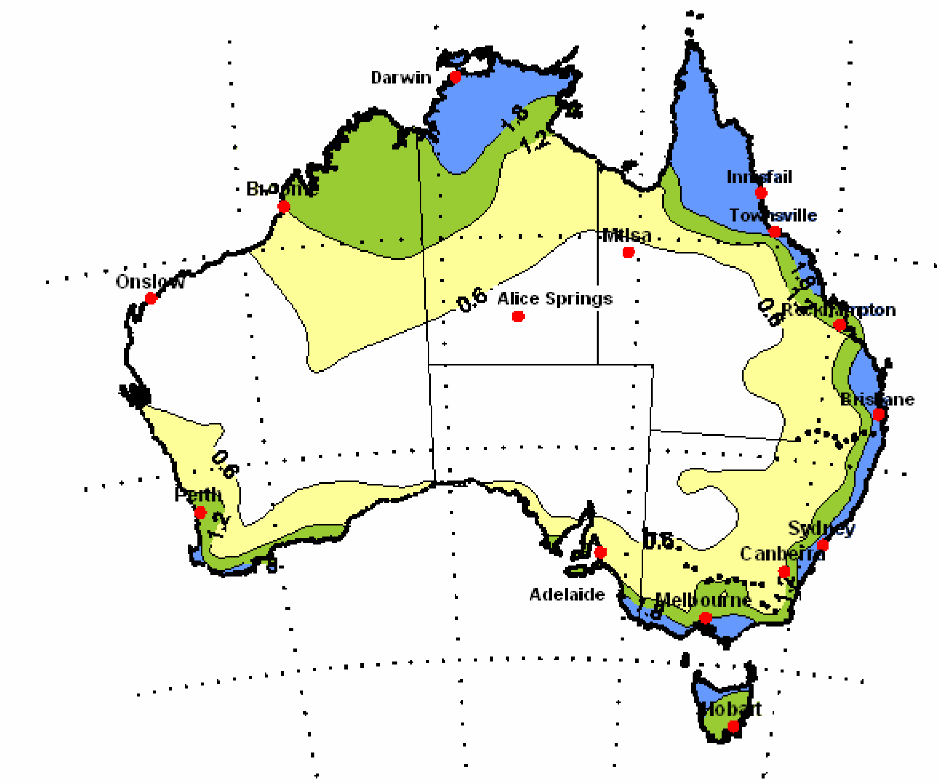


Figure 3.7 Contours of decay rate estimated by Scheffer Index (contour levels = 0.6, 1.2, and 1.8).

3.4. Processing Data from Panel Test No. 1

Each data point is the median value of all specimens at the bottom of a panel at a site. The data value used for each site is the median of the 10 test specimens. For this case it is reasonable to assume that $k_{wood} \times k_p = 1.6$. With this assumption and taking the value of $k_{climate}$ to be given by Eq. (3.7), a comparison between the measured and model prediction of effect of annual rainfall duration may be obtained as shown in Figure 3.8.

Figure 3.9 gives a comparison between the model prediction and the measured values of the relationship between decay rate and decay lag.

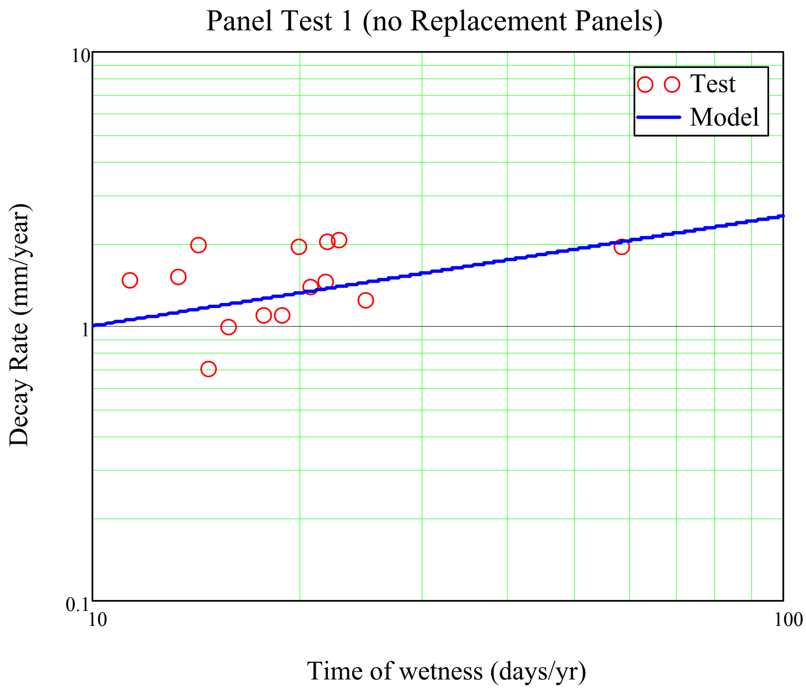


Figure 3.8 Comparison between the measured and model prediction of the effect of annual rainfall duration (Panel Test No. 1, Species Data)

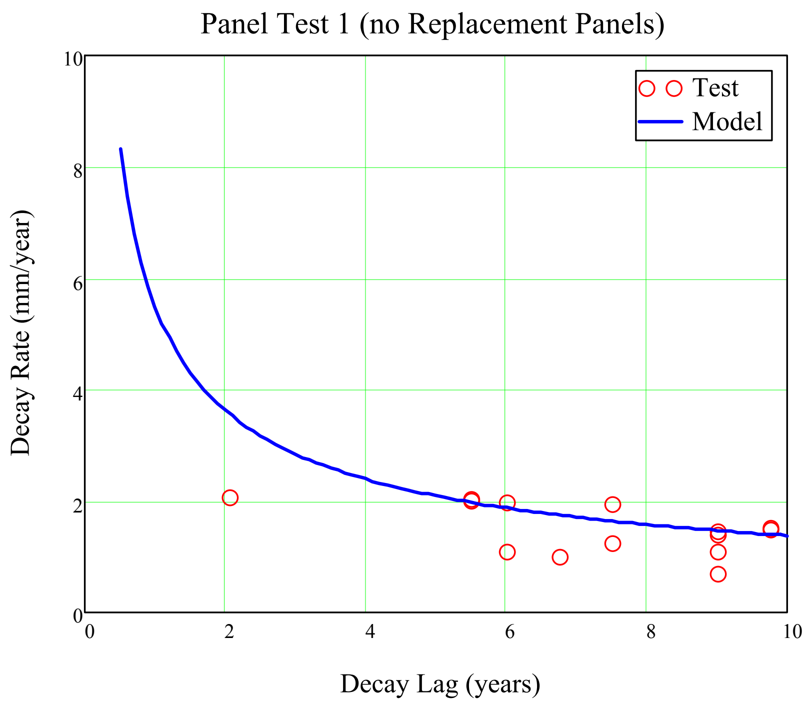


Figure 3.9 Comparison between the model prediction and the measured values of the relationship between decay rate and decay lag (Panel Test No. 1, Species Data)

3.5. Processing Data from Panel Test No. 2

Each data point is the median value of all specimens at a site. For each substrate, only one site (Batlow, NSW for E. regnan, Beerburrum, QLD for radiate pine) has shorter than 2.5 years of decay lag. A comparison between this limited data and the predictions of the model are shown in Figures 3.10 and 3.11.

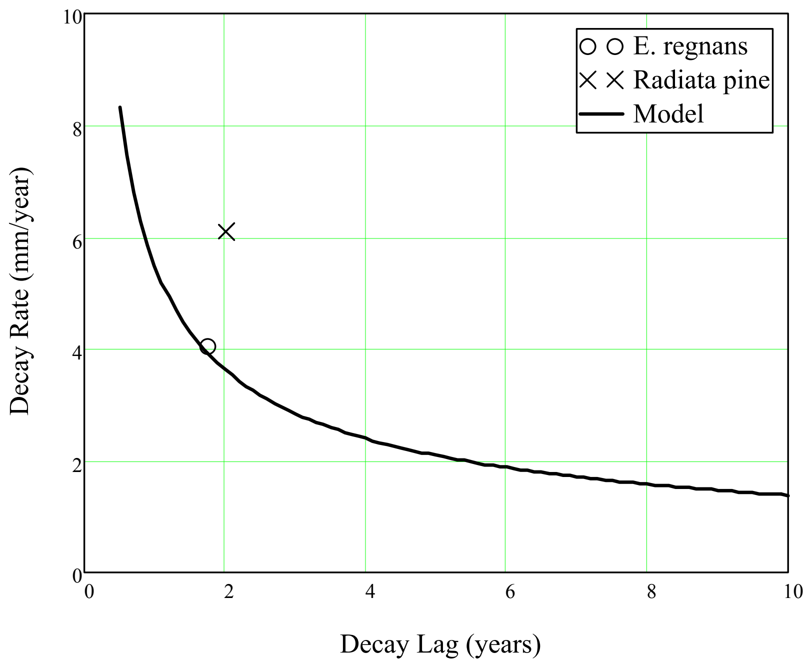


Figure 3.10 Comparison between the model prediction and the measured values of the relationship between decay rate and decay lag (Panel Test No. 2, Species Data)

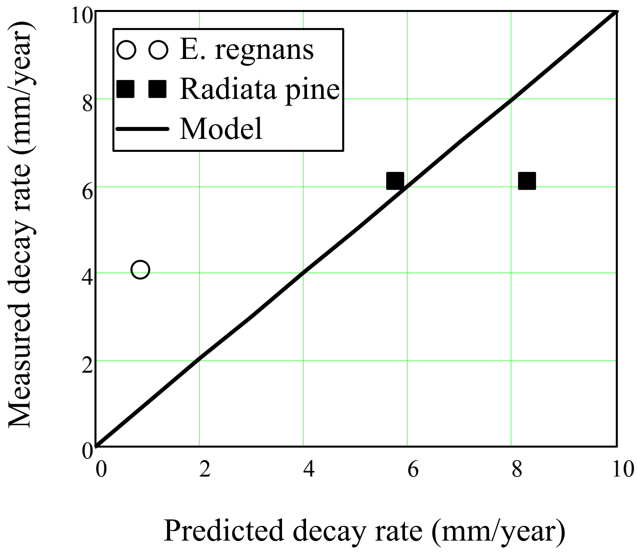


Figure 3.11 Predicted versus measured values of decay rate for Panel Test No. 2 (Species Data)

4. Reality Checks

Reality checks with the data collected from fences in Melbourne, from decks and stair treads in Brisbane, and from a pergola in Melbourne are performed in this section.

It is assumed that:

- All structures were made of heartwood
- All are unpainted
- Vertical surfaces without orientation information were facing north and therefore had the orientation factor of 1.5, where applicable.
- Connector parameter k_n = 1.0, which means that no connector at decay surfaces is assumed.

4.1. Climate Parameters

The annual time of rainfall in Melbourne is: t_{rain} = 453 hrs. Therefore, $k_{climate}$ = 0.62 (Melbourne)

The annual time of rainfall in Brisbane is: t_{rain} = 435 hrs.; therefore $k_{climate}$ = 0.707 (Brisbane)

d_0 in Eq. (1.2) is assumed to be 5 mm for reality checks.

4.2. Fences in Melbourne

Above-ground decay depths of fence rails, fence palings and fence posts obtained from 8 fences in Melbourne were used for calibration.

4.2.1. Fence Rails

Tables 4.1 to 4.3 present the predicted and measured decay depths for the fence rails. The locations of decay assessed on the fence rails are depicted in Figure 4.1. Comparative plots of predicted decay versus measured decay are provided in Figure 4.2 to Figure 4.4.

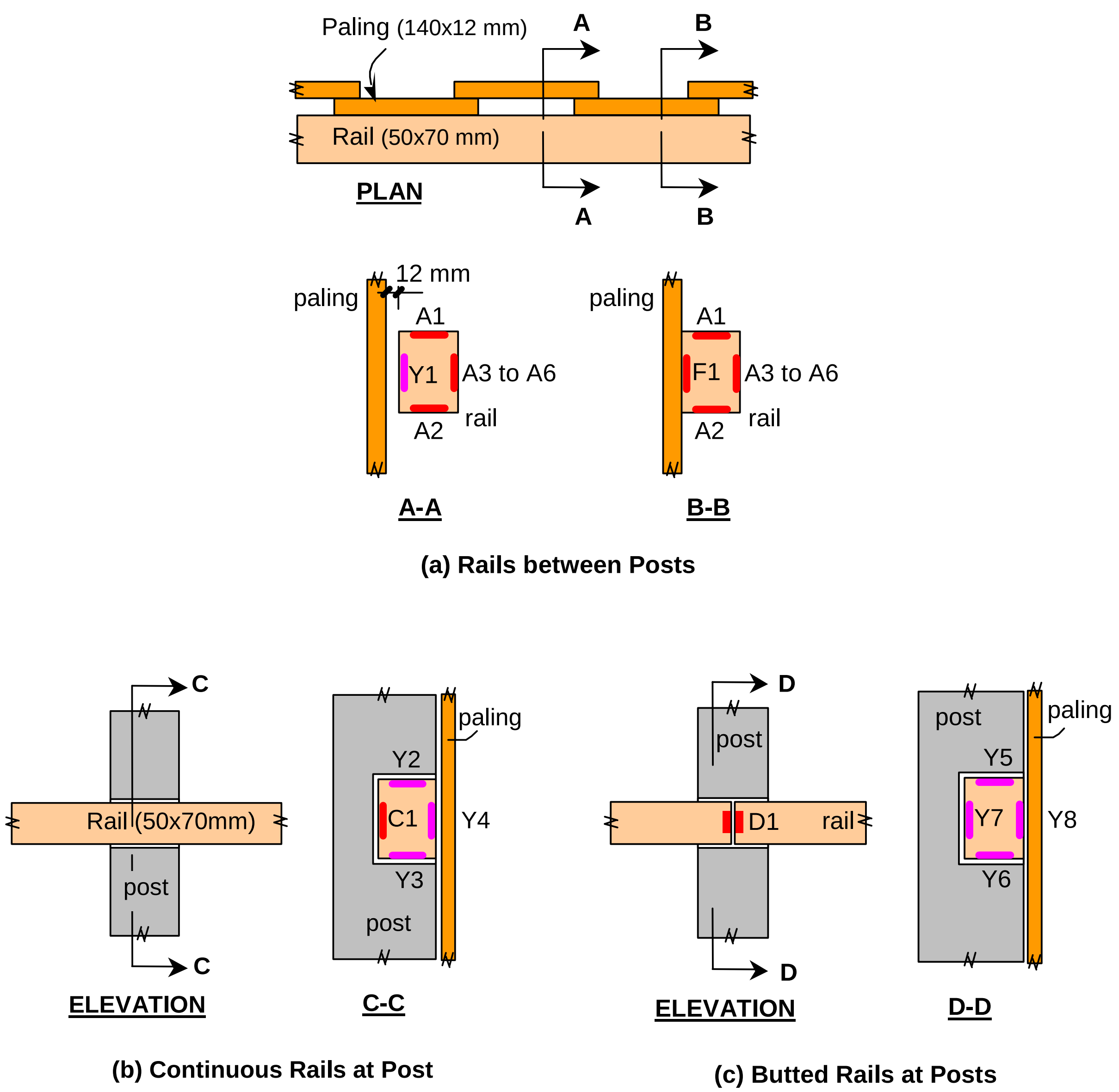


Figure 4.1 Locations assessed for decay on fence rails

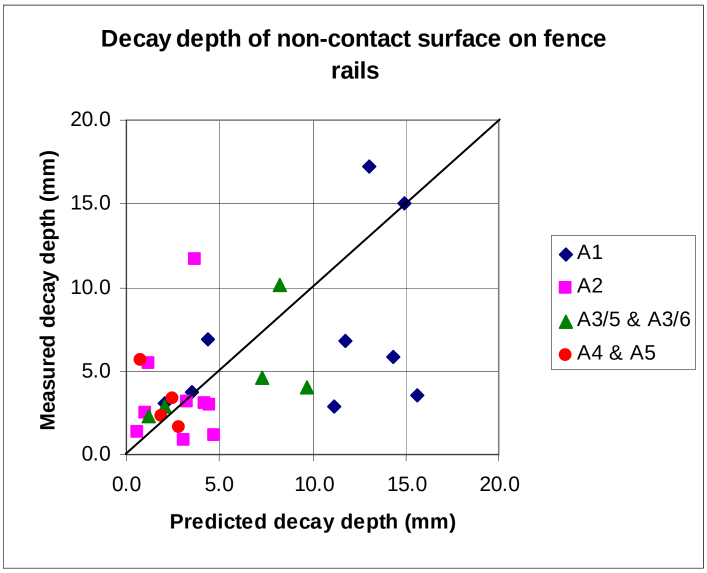


Figure 4.2 *Reality check with non-contact surfaces on fence rails*

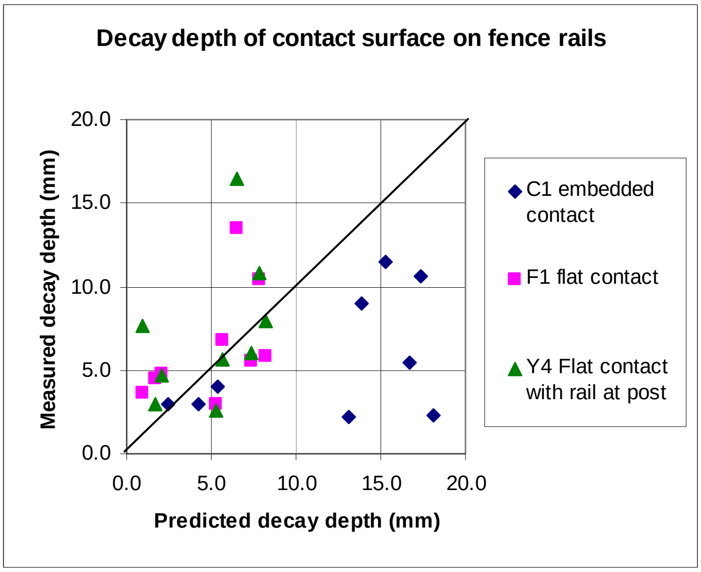


Figure 4.3 *Reality check with contact surfaces on fence rails*

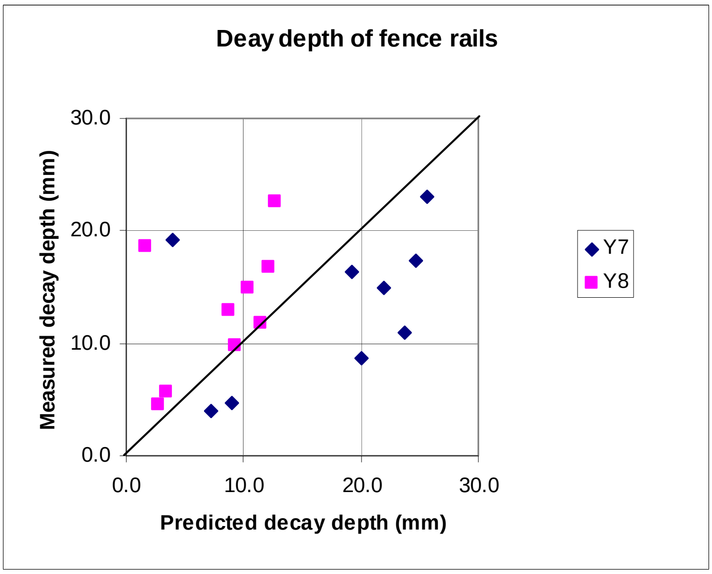


Figure 4.4 *Reality check with contact surfaces on fence rails*

Table 4.1 Prediction of decay of non-contact surfaces on fence rails and calibration data

Location (VIC)	Timber Species	Structure element	Dura-bility Class	Service Age (yrs)	Wood type	Size A (mm)	Size B (mm)	Decay surface	k_{dc}	k_{hw}	k_t	k_w	k_n	k_g	k_0	Rate	Lag	Predicted Decay (mm)	Measured Decay (Typical) (mm)
Beaconsfield	MA	Rails	3	13	Heartwood	50	70	A1	1.14	1.00	1.00	1.00	1.00	0.90	1.03	0.64	12.5	2.0	3.1
Mooroolbark	AA	Rails	3	17	Heartwood	50	70	A1	1.14	1.00	1.00	1.00	1.00	0.90	1.03	0.64	12.5	3.5	3.8
Bentleigh E.	MA	Rails	3	19	Heartwood	50	70	A1	1.14	1.00	1.00	1.00	1.00	0.90	1.03	0.64	12.5	4.4	6.9
Glen Waverley	MM	Rails	3	30	Heartwood	50	70	A1	1.14	1.00	1.00	1.00	1.00	0.90	1.03	0.64	12.5	11.1	2.9
Chelsea Heights	AA	Rails	3	31	Heartwood	50	70	A1	1.14	1.00	1.00	1.00	1.00	0.90	1.03	0.64	12.5	11.8	6.8
Mooroolbark	MM/MA	Rails	3	33	Heartwood	50	70	A1	1.14	1.00	1.00	1.00	1.00	0.90	1.03	0.64	12.5	13.0	17.2
Mt Waverley	MM/MA	Rails	3	35	Heartwood	50	70	A1	1.14	1.00	1.00	1.00	1.00	0.90	1.03	0.64	12.5	14.3	5.8
Doncaster E.	MA	Rails	3	36	Heartwood	50	70	A1	1.14	1.00	1.00	1.00	1.00	0.90	1.03	0.64	12.5	15.0	15.0
Blackburn S.	MA	Rails	3	37	Heartwood	50	70	A1	1.14	1.00	1.00	1.00	1.00	0.90	1.03	0.64	12.5	15.6	3.6
Beaconsfield	MA	Rails	3	13	Heartwood	50	70	A2	1.14	1.00	1.00	1.00	1.00	0.45	0.51	0.32	22.5	0.6	1.4
Mooroolbark	AA	Rails	3	17	Heartwood	50	70	A2	1.14	1.00	1.00	1.00	1.00	0.45	0.51	0.32	22.5	1.0	2.5
Bentleigh E.	MA	Rails	3	19	Heartwood	50	70	A2	1.14	1.00	1.00	1.00	1.00	0.45	0.51	0.32	22.5	1.2	5.5
Glen Waverley	MM	Rails	3	30	Heartwood	50	70	A2	1.14	1.00	1.00	1.00	1.00	0.45	0.51	0.32	22.5	3.1	0.8
Chelsea Heights	AA	Rails	3	31	Heartwood	50	70	A2	1.14	1.00	1.00	1.00	1.00	0.45	0.51	0.32	22.5	3.3	3.2
Mooroolbark	MM/MA	Rails	3	33	Heartwood	50	70	A2	1.14	1.00	1.00	1.00	1.00	0.45	0.51	0.32	22.5	3.7	11.7
Mt Waverley	MM/MA	Rails	3	35	Heartwood	50	70	A2	1.14	1.00	1.00	1.00	1.00	0.45	0.51	0.32	22.5	4.2	3.1
Doncaster E.	MA	Rails	3	36	Heartwood	50	70	A2	1.14	1.00	1.00	1.00	1.00	0.45	0.51	0.32	22.5	4.4	3.0
Blackburn S.	MA	Rails	3	37	Heartwood	50	70	A2	1.14	1.00	1.00	1.00	1.00	0.45	0.51	0.32	22.5	4.7	1.2
Beaconsfield	MA	Rails	3	13	Heartwood	70	50	A3/6 (NW)	1.14	1.00	1.00	1.13	1.00	0.60	0.78	0.48	15.8	1.2	2.3
Mooroolbark	AA	Rails	3	17	Heartwood	70	50	A3/5 (NE)	1.14	1.00	1.00	1.13	1.00	0.60	0.78	0.48	15.8	2.1	2.9
Chelsea Heights	AA	Rails	3	31	Heartwood	70	50	A3/6 (NW)	1.14	1.00	1.00	1.13	1.00	0.60	0.78	0.48	15.8	7.3	4.6
Mooroolbark	MM/MA	Rails	3	33	Heartwood	70	50	A3/5 (NE)	1.14	1.00	1.00	1.13	1.00	0.60	0.78	0.48	15.8	8.2	10.1
Doncaster E.	MA	Rails	3	36	Heartwood	70	50	A3/5 (NE)	1.14	1.00	1.00	1.13	1.00	0.60	0.78	0.48	15.8	9.7	4.0
Bentleigh E.	MA	Rails	3	19	Heartwood	70	50	A4 (S)	1.14	1.00	1.00	1.13	1.00	0.30	0.39	0.24	28.6	0.7	5.7
Blackburn S.	MA	Rails	3	37	Heartwood	70	50	A4 (S)	1.14	1.00	1.00	1.13	1.00	0.30	0.39	0.24	28.6	2.8	1.7
Glen Waverley	MM	Rails	3	30	Heartwood	70	50	A5 (E)	1.14	1.00	1.00	1.13	1.00	0.30	0.39	0.24	28.6	1.8	2.3
Mt Waverley	MM/MA	Rails	3	35	Heartwood	70	50	A4/5 (SE)	1.14	1.00	1.00	1.13	1.00	0.30	0.39	0.24	28.6	2.5	3.3

Table 4.2 Prediction of decay of contact surfaces on fence rails and calibration data

Location (VIC)	Timber Species	Structure element	Dura-bility Class	Service Age (yrs)	Wood type	Size A (mm)	Size B (mm)	Decay surface	k_{dc}	k_{hw}	k_t	k_w	k_n	k_g	k_0	Rate	Lag	Predicted Decay (mm)	Measured Decay (Typical) (mm)
Beaconsfield	MA	Rails	3	13	Heartwood	70	50	C1	1.14	1.00	1.00	1.00	1.00	1.00	1.14	0.71	11.4	2.5	3.0
Mooroolbark	AA	Rails	3	17	Heartwood	70	50	C1	1.14	1.00	1.00	1.00	1.00	1.00	1.14	0.71	11.4	4.2	3.0
Bentleigh E.	MA	Rails	3	19	Heartwood	70	50	C1	1.14	1.00	1.00	1.00	1.00	1.00	1.14	0.71	11.4	5.4	4.0
Glen Waverley	MM	Rails	3	30	Heartwood	70	50	C1	1.14	1.00	1.00	1.00	1.00	1.00	1.14	0.71	11.4	13.1	2.2
Chelsea Heights	AA	Rails	3	31	Heartwood	70	50	C1	1.14	1.00	1.00	1.00	1.00	1.00	1.14	0.71	11.4	13.8	9.0
Mooroolbark	MM/MA	Rails	3	33	Heartwood	70	50	C1	1.14	1.00	1.00	1.00	1.00	1.00	1.14	0.71	11.4	15.3	11.5
Mt Waverley	MM/MA	Rails	3	35	Heartwood	70	50	C1	1.14	1.00	1.00	1.00	1.00	1.00	1.14	0.71	11.4	16.7	5.5
Doncaster E.	MA	Rails	3	36	Heartwood	70	50	C1	1.14	1.00	1.00	1.00	1.00	1.00	1.14	0.71	11.4	17.4	***10.7***
Blackburn S.	MA	Rails	3	37	Heartwood	70	50	C1	1.14	1.00	1.00	1.00	1.00	1.00	1.14	0.71	11.4	18.1	2.3
Beaconsfield	MA	Rails	3	13	Heartwood	70	50	F1	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	1.0	3.7
Mooroolbark	AA	Rails	3	17	Heartwood	70	50	F1	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	1.7	4.5
Bentleigh E.	MA	Rails	3	19	Heartwood	70	50	F1	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	2.1	4.8
Glen Waverley	MM	Rails	3	30	Heartwood	70	50	F1	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	5.2	3.0
Chelsea Heights	AA	Rails	3	31	Heartwood	70	50	F1	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	5.7	6.8
Mooroolbark	MM/MA	Rails	3	33	Heartwood	70	50	F1	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	6.5	13.5
Mt Waverley	MM/MA	Rails	3	35	Heartwood	70	50	F1	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	7.4	5.6
Doncaster E.	MA	Rails	3	36	Heartwood	70	50	F1	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	7.8	10.4
Blackburn S.	MA	Rails	3	37	Heartwood	70	50	F1	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	8.2	5.8
Beaconsfield	MA	Rails	3	13	Heartwood	70	50	Y4	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	1.0	7.7
Mooroolbark	AA	Rails	3	17	Heartwood	70	50	Y4	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	1.7	3.0
Bentleigh E.	MA	Rails	3	19	Heartwood	70	50	Y4	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	2.1	4.7
Glen Waverley	MM	Rails	3	30	Heartwood	70	50	Y4	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	5.2	2.6
Chelsea Heights	AA	Rails	3	31	Heartwood	70	50	Y4	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	5.7	5.7
Mooroolbark	MM/MA	Rails	3	33	Heartwood	70	50	Y4	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	6.5	16.5
Mt Waverley	MM/MA	Rails	3	35	Heartwood	70	50	Y4	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	7.4	6.0
Doncaster E.	MA	Rails	3	36	Heartwood	70	50	Y4	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	7.8	***10.8***
Blackburn S.	MA	Rails	3	37	Heartwood	70	50	Y4	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	8.2	7.9

Table 4.3 Prediction of decay of contact surfaces on fence rails and calibration data

Location (VIC)	Timber Species	Structure element	Dura-bility Class	Service Age (yrs)	Wood type	Size A (mm)	Size B (mm)	Decay surface	k_{dc}	k_{hw}	k_t	k_w	k_n	k_g	k_0	Rate	Lag	Predicted Decay (mm)	Measured Decay (Typical) (mm)
Beaconsfield	MA	Rails	3	13	Heartwood	70	50	Y7	1.14	1.00	1.00	1.00	1.00	1.30	1.48	0.92	9.1	4.0	***19.2***
Mooroolbark	AA	Rails	3	17	Heartwood	70	50	Y7	1.14	1.00	1.00	1.00	1.00	1.30	1.48	0.92	9.1	7.2	4.0
Bentleigh E.	MA	Rails	3	19	Heartwood	70	50	Y7	1.14	1.00	1.00	1.00	1.00	1.30	1.48	0.92	9.1	9.1	4.7
Glen Waverley	MM	Rails	3	30	Heartwood	70	50	Y7	1.14	1.00	1.00	1.00	1.00	1.30	1.48	0.92	9.1	19.2	***16.3***
Chelsea Heights	AA	Rails	3	31	Heartwood	70	50	Y7	1.14	1.00	1.00	1.00	1.00	1.30	1.48	0.92	9.1	20.1	***8.7***
Mooroolbark	MM/MA	Rails	3	33	Heartwood	70	50	Y7	1.14	1.00	1.00	1.00	1.00	1.30	1.48	0.92	9.1	21.9	15.0
Mt Waverley	MM/MA	Rails	3	35	Heartwood	70	50	Y7	1.14	1.00	1.00	1.00	1.00	1.30	1.48	0.92	9.1	23.8	***11.0***
Doncaster E.	MA	Rails	3	36	Heartwood	70	50	Y7	1.14	1.00	1.00	1.00	1.00	1.30	1.48	0.92	9.1	24.7	***17.3***
Blackburn S.	MA	Rails	3	37	Heartwood	70	50	Y7	1.14	1.00	1.00	1.00	1.00	1.30	1.48	0.92	9.1	25.6	***23.0***
Beaconsfield	MA	Rails	3	13	Heartwood	70	50	Y8	1.14	1.00	1.00	1.00	1.00	0.78	0.89	0.55	14.1	1.6	***18.7***
Mooroolbark	AA	Rails	3	17	Heartwood	70	50	Y8	1.14	1.00	1.00	1.00	1.00	0.78	0.89	0.55	14.1	2.7	4.5
Bentleigh E.	MA	Rails	3	19	Heartwood	70	50	Y8	1.14	1.00	1.00	1.00	1.00	0.78	0.89	0.55	14.1	3.4	5.7
Glen Waverley	MM	Rails	3	30	Heartwood	70	50	Y8	1.14	1.00	1.00	1.00	1.00	0.78	0.89	0.55	14.1	8.8	***13.0***
Chelsea Heights	AA	Rails	3	31	Heartwood	70	50	Y8	1.14	1.00	1.00	1.00	1.00	0.78	0.89	0.55	14.1	9.3	***9.8***
Mooroolbark	MM/MA	Rails	3	33	Heartwood	70	50	Y8	1.14	1.00	1.00	1.00	1.00	0.78	0.89	0.55	14.1	10.4	15.0
Mt Waverley	MM/MA	Rails	3	35	Heartwood	70	50	Y8	1.14	1.00	1.00	1.00	1.00	0.78	0.89	0.55	14.1	11.5	***11.8***
Doncaster E.	MA	Rails	3	36	Heartwood	70	50	Y8	1.14	1.00	1.00	1.00	1.00	0.78	0.89	0.55	14.1	12.1	***16.8***
Blackburn S.	MA	Rails	3	37	Heartwood	70	50	Y8	1.14	1.00	1.00	1.00	1.00	0.78	0.89	0.55	14.1	12.6	***22.7***

4.2.2. Fence Palings

Table 4.4 presents the predicted and measured decay depths for the fence palings. The locations of decay assessed on the fence palings are depicted in Figure 4.5. Comparative plots of predicted decay versus measured decay are provided in Figure 4.6.

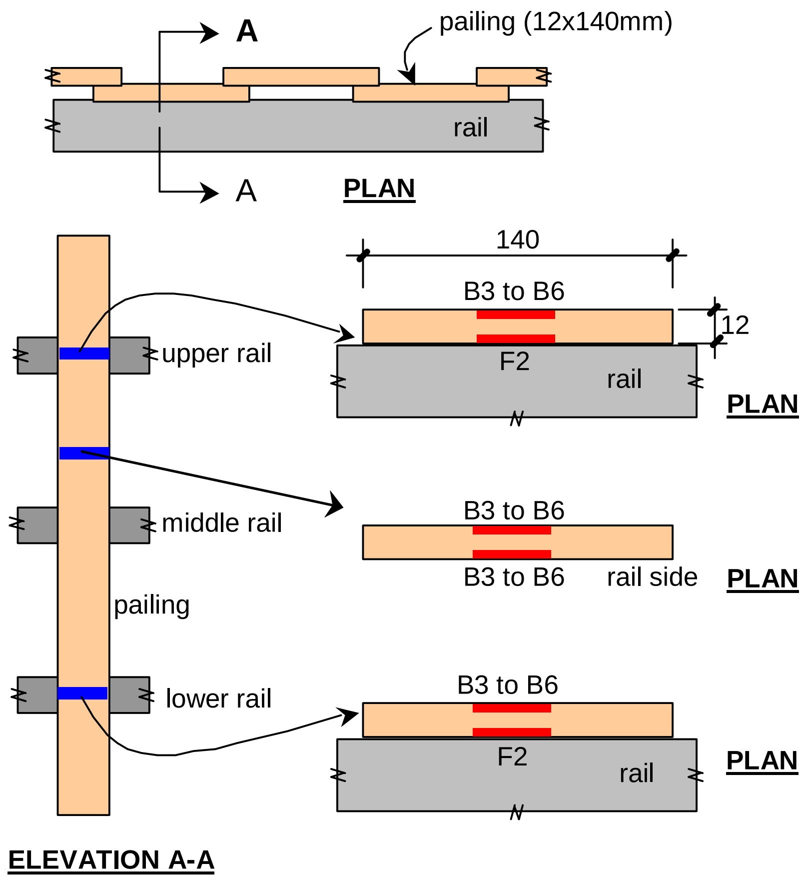


Figure 4.5 *Locations assessed for decay on fence palings*

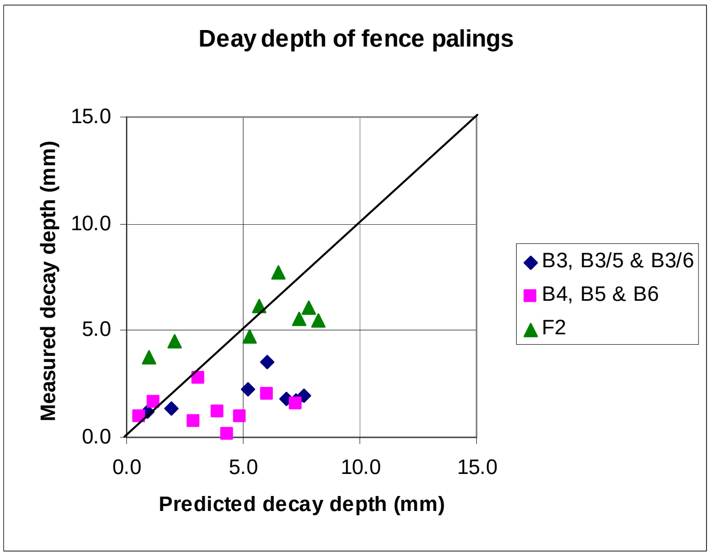


Figure 4.6 *Reality check with fence palings*

Table 4.4 Prediction of decay on fence palings and calibration data

Location (VIC)	Timber Species	Structure element	Dura-bility Class	Service Age (yrs)	Wood type	Size A (mm)	Size B (mm)	Decay surface	k_{dc}	k_{hw}	k_t	k_w	k_n	k_g	k_0	Rate	Lag	Predicted Decay (mm)	Measured Decay (Typical) (mm)
Bentleigh E.	MA	Palings	3	19	Heartwood	140	12	B3 (N)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	1.9	1.3
Blackburn S.	MA/MM/AA	Palings	3	37	Heartwood	140	12	B3 (N)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	7.6	1.9
Beaconsfield	AA	Palings	3	13	Heartwood	140	12	B3/6 (NW)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	0.9	1.2
Chelsea Heights	MA	Palings	3	31	Heartwood	140	12	B3/6 (NW)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	5.2	2.3
Mooroolbark	MM	Palings	3	33	Heartwood	140	12	B3/5 (NE)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	6.0	3.5
Mt Waverley	MA	Palings	3	35	Heartwood	140	12	B3/6 (NW)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	6.8	1.8
Doncaster E.	MA	Palings	3	36	Heartwood	140	12	B3/5 (NE)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	7.2	1.7
Bentleigh E.	MA	Palings	3	19	Heartwood	140	12	B4 (S)	1.14	1.00	0.60	1.60	1.00	0.45	0.49	0.31	23.3	1.1	1.7
Blackburn S.	MA/MM/AA	Palings	3	37	Heartwood	140	12	B4 (S)	1.14	1.00	0.60	1.60	1.00	0.45	0.49	0.31	23.3	4.3	0.2
Beaconsfield	AA	Palings	3	13	Heartwood	140	12	B4/5 (SE)	1.14	1.00	0.60	1.60	1.00	0.45	0.49	0.31	23.3	0.5	1.0
Chelsea Heights	MA	Palings	3	31	Heartwood	140	12	B4/5 (SE)	1.14	1.00	0.60	1.60	1.00	0.45	0.49	0.31	23.3	3.1	2.8
Mooroolbark	MM	Palings	3	33	Heartwood	140	12	B4/6 (SW)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	6.0	2.0
Mt Waverley	MA	Palings	3	35	Heartwood	140	12	B4/5 (SE)	1.14	1.00	0.60	1.60	1.00	0.45	0.49	0.31	23.3	3.9	1.2
Doncaster E.	MA	Palings	3	36	Heartwood	140	12	B4/6 (SW)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	7.2	1.6
Glen Waverley	MA	Palings	3	30	Heartwood	140	12	B6 (W)	1.14	1.00	0.60	1.60	1.00	0.60	0.66	0.41	18.2	4.8	1.0
Glen Waverley	MA	Palings	3	30	Heartwood	140	12	B5 (E)	1.14	1.00	0.60	1.60	1.00	0.45	0.49	0.31	23.3	2.9	0.8
Beaconsfield	AA	Palings	3	13	Heartwood	140	12	F2	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	1.0	3.8
Bentleigh E.	MA	Palings	3	19	Heartwood	140	12	F2	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	2.1	4.5
Glen Waverley	MA	Palings	3	30	Heartwood	140	12	F2	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	5.2	4.7
Chelsea Heights	MA	Palings	3	31	Heartwood	140	12	F2	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	5.7	6.1
Mooroolbark	MM	Palings	3	33	Heartwood	140	12	F2	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	6.5	7.8
Mt Waverley	MA	Palings	3	35	Heartwood	140	12	F2	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	7.4	5.6
Doncaster E.	MA	Palings	3	36	Heartwood	140	12	F2	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	7.8	6.1
Blackburn S.	MA/MM/AA	Palings	3	37	Heartwood	140	12	F2	1.14	1.00	1.00	1.00	1.00	0.60	0.68	0.42	17.6	8.2	5.5

4.2.3. Fence Posts

Table 4.5 and Table 4.6 present the predicted and measured decay depths for the fence posts. The locations of decay assessed on the fence posts are depicted in Figure 4.7. Comparative plots of predicted decay versus measured decay are provided in Figure 4.8 to Figure 4.10.

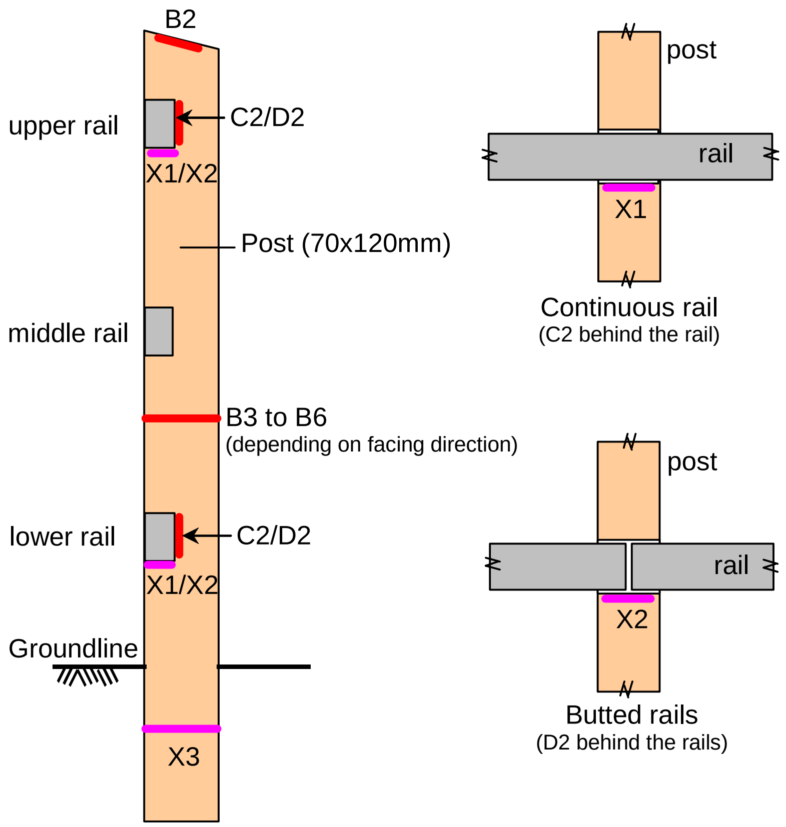


Figure 4.7 *Locations assessed for decay on fence posts*

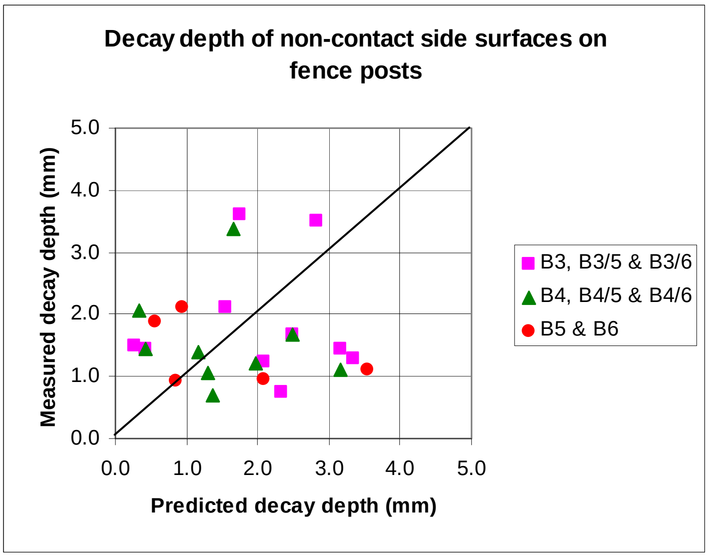


Figure 4.8 *Reality check with non-contact side surface on fence posts*

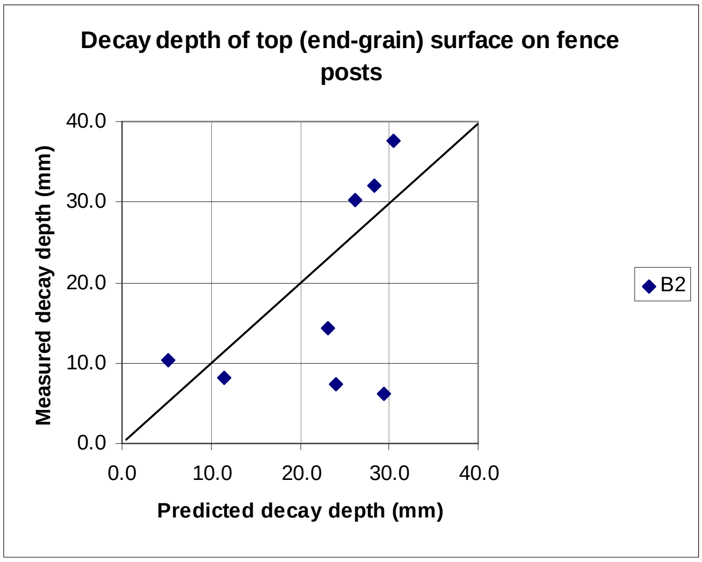


Figure 4.9 *Reality check with top surface on fence posts*

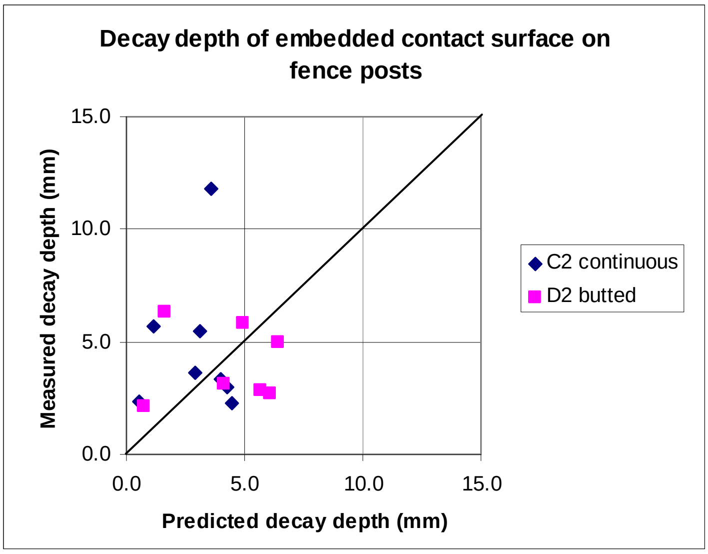


Figure 4.10 *Reality check with contact surface on fence posts*

Table 4.5 Prediction of decay of non-contact surface on fence posts and calibration data

Location (VIC)	Timber Species	Structure element	Dura-bility Class	Service Age (yrs)	Wood type	Size A (mm)	Size B (mm)	Decay surface	k_{dc}	k_{hw}	k_t	k_w	k_n	k_g	k_0	Rate	Lag	Predicted Decay (mm)	Measured Decay (Typical) (mm)
Beaconsfield	RRG	Posts	1	13	Corewood	70	120	B2	0.5	2.00	1.00	1.13	1.00	1.50	1.70	1.05	8.1	5.1	10.3
Bentleigh E.	RRG	Posts	1	19	Corewood	70	120	B2	0.5	2.00	1.00	1.13	1.00	1.50	1.70	1.05	8.1	11.5	8.2
Glen Waverley	RRG	Posts	1	30	Corewood	70	120	B2	0.5	2.00	1.00	1.13	1.00	1.50	1.70	1.05	8.1	23.1	14.3
Chelsea Heights	GG	Posts	1	31	Corewood	70	120	B2	0.5	2.00	1.00	1.13	1.00	1.50	1.70	1.05	8.1	24.1	7.3
Mooroolbark	RRG	Posts	1	33	Corewood	70	120	B2	0.5	2.00	1.00	1.13	1.00	1.50	1.70	1.05	8.1	26.2	30.2
Mt Waverley	RRG	Posts	1	35	Corewood	70	120	B2	0.5	2.00	1.00	1.13	1.00	1.50	1.70	1.05	8.1	28.3	32.0
Doncaster E.	RRG	Posts	1	36	Corewood	70	120	B2	0.5	2.00	1.00	1.13	1.00	1.50	1.70	1.05	8.1	29.4	6.2
Blackburn S.	RRG	Posts	1	37	Corewood	70	120	B2	0.5	2.00	1.00	1.13	1.00	1.50	1.70	1.05	8.1	30.4	37.6
Glen Waverley	RRG	Posts	1	30	Heartwood	120	70	B3 (N)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	2.3	0.8
Beaconsfield	RRG	Posts	1	13	Heartwood	120	70	B3/5 (NE)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	0.4	1.4
Beaconsfield	RRG	Posts	1	13	Heartwood	70	120	B3/6 (NW)	0.5	1.00	1.00	1.13	1.00	0.60	0.34	0.21	31.9	0.3	1.5
Chelsea Heights	GG	Posts	1	31	Heartwood	120	70	B3/5 (NE)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	2.5	1.7
Chelsea Heights	GG	Posts	1	31	Heartwood	70	120	B3/6 (NW)	0.5	1.00	1.00	1.13	1.00	0.60	0.34	0.21	31.9	1.6	2.1
Mooroolbark	RRG	Posts	1	33	Heartwood	70	120	B3/5 (NE)	0.5	1.00	1.00	1.13	1.00	0.60	0.34	0.21	31.9	1.8	3.6
Mooroolbark	RRG	Posts	1	33	Heartwood	120	70	B3/6 (NW)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	2.8	3.5
Mt Waverley	RRG	Posts	1	35	Heartwood	120	70	B3/5 (NE)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	3.2	1.4
Doncaster E.	RRG	Posts	1	36	Heartwood	70	120	B3/5 (NE)	0.5	1.00	1.00	1.13	1.00	0.60	0.34	0.21	31.9	2.1	1.2
Doncaster E.	RRG	Posts	1	36	Heartwood	120	70	B3/6 (NW)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	3.4	1.3
Bentleigh E.	RRG	Posts	1	19	Heartwood	70	120	B4 (S)	0.5	1.00	1.00	1.13	1.00	0.45	0.26	0.16	40.8	0.3	2.1
Glen Waverley	RRG	Posts	1	30	Heartwood	120	70	B4 (S)	0.5	1.00	1.00	1.47	1.00	0.45	0.33	0.20	32.7	1.4	0.7
Blackburn S.	RRG	Posts	1	37	Heartwood	70	120	B4 (S)	0.5	1.00	1.00	1.13	1.00	0.45	0.26	0.16	40.8	1.3	1.1
Beaconsfield	RRG	Posts	1	13	Heartwood	120	70	B4/6 (SW)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	0.4	1.4
Chelsea Heights	GG	Posts	1	31	Heartwood	120	70	B4/6 (SW)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	2.5	1.7
Mooroolbark	RRG	Posts	1	33	Heartwood	120	70	B4/5 (SE)	0.5	1.00	1.00	1.47	1.00	0.45	0.33	0.20	32.7	1.7	3.4
Mt Waverley	RRG	Posts	1	35	Heartwood	70	120	B4/5 (SE)	0.5	1.00	1.00	1.13	1.00	0.45	0.26	0.16	40.8	1.2	1.4
Mt Waverley	RRG	Posts	1	35	Heartwood	120	70	B4/6 (SW)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	3.2	1.1
Doncaster E.	RRG	Posts	1	36	Heartwood	120	70	B4/5 (SE)	0.5	1.00	1.00	1.47	1.00	0.45	0.33	0.20	32.7	2.0	1.2
Bentleigh E.	RRG	Posts	1	19	Heartwood	120	70	B5 (E)	0.5	1.00	1.00	1.47	1.00	0.45	0.33	0.20	32.7	0.6	1.9
Glen Waverley	RRG	Posts	1	30	Heartwood	70	120	B5 (E)	0.5	1.00	1.00	1.13	1.00	0.45	0.26	0.16	40.8	0.9	0.9
Blackburn S.	RRG	Posts	1	37	Heartwood	120	70	B5 (E)	0.5	1.00	1.00	1.47	1.00	0.45	0.33	0.20	32.7	2.1	0.9
Bentleigh E.	RRG	Posts	1	19	Heartwood	120	70	B6 (W)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	0.9	2.1
Blackburn S.	RRG	Posts	1	37	Heartwood	120	70	B6 (W)	0.5	1.00	1.00	1.47	1.00	0.60	0.44	0.27	25.6	3.5	1.1

Table 4.6 Prediction of decay of contact surface on fence posts and calibration data

Location (VIC)	Timber Species	Structure element	Dura-bility Class	Service Age (yrs)	Wood type	Size A (mm)	Size B (mm)	Decay surface	k_{dc}	k_{hw}	k_t	k_w	k_n	k_g	k_0	Rate	Lag	Predicted Decay (mm)	Measured Decay (Typical) (mm)
Beaconsfield	RRG	Posts	1	13	Heartwood	70	72	C2	0.5	1.00	1.00	1.00	1.00	1.00	0.50	0.31	23.0	0.6	2.3
Bentleigh E.	RRG	Posts	1	19	Heartwood	70	72	C2	0.5	1.00	1.00	1.00	1.00	1.00	0.50	0.31	23.0	1.2	5.7
Glen Waverley	RRG	Posts	1	30	Heartwood	70	72	C2	0.5	1.00	1.00	1.00	1.00	1.00	0.50	0.31	23.0	2.9	3.6
Chelsea Heights	GG	Posts	1	31	Heartwood	70	72	C2	0.5	1.00	1.00	1.00	1.00	1.00	0.50	0.31	23.0	3.1	5.5
Mooroolbark	RRG	Posts	1	33	Heartwood	70	72	C2	0.5	1.00	1.00	1.00	1.00	1.00	0.50	0.31	23.0	3.6	11.8
Mt Waverley	RRG	Posts	1	35	Heartwood	70	72	C2	0.5	1.00	1.00	1.00	1.00	1.00	0.50	0.31	23.0	4.0	3.3
Doncaster E.	RRG	Posts	1	36	Heartwood	70	72	C2	0.5	1.00	1.00	1.00	1.00	1.00	0.50	0.31	23.0	4.2	3.0
Blackburn S.	RRG	Posts	1	37	Heartwood	70	72	C2	0.5	1.00	1.00	1.00	1.00	1.00	0.50	0.31	23.0	4.5	2.3
Beaconsfield	RRG	Posts	1	13	Heartwood	70	72	D2	0.5	1.00	1.00	1.00	1.00	1.20	0.60	0.37	19.7	0.8	2.2
Bentleigh E.	RRG	Posts	1	19	Heartwood	70	72	D2	0.5	1.00	1.00	1.00	1.00	1.20	0.60	0.37	19.7	1.6	6.3
Glen Waverley	RRG	Posts	1	30	Heartwood	70	72	D2	0.5	1.00	1.00	1.00	1.00	1.20	0.60	0.37	19.7	4.1	3.1
Chelsea Heights	GG	Posts	1	31	Heartwood	70	72	D2	0.5	1.00	1.00	1.00	1.00	1.20	0.60	0.37	19.7		
Mooroolbark	RRG	Posts	1	33	Heartwood	70	72	D2	0.5	1.00	1.00	1.00	1.00	1.20	0.60	0.37	19.7	5.0	5.8
Mt Waverley	RRG	Posts	1	35	Heartwood	70	72	D2	0.5	1.00	1.00	1.00	1.00	1.20	0.60	0.37	19.7	5.7	2.8
Doncaster E.	RRG	Posts	1	36	Heartwood	70	72	D2	0.5	1.00	1.00	1.00	1.00	1.20	0.60	0.37	19.7	6.1	2.7
Blackburn S.	RRG	Posts	1	37	Heartwood	70	72	D2	0.5	1.00	1.00	1.00	1.00	1.20	0.60	0.37	19.7	6.4	5.0

4.3. Decking in Brisbane

Table 4.7 presents the predicted and measured decay depths for the decking. The locations of decay assessed on the fence posts are depicted in Figure 4.11. Comparative plots of predicted decay versus measured decay are provided in Figure 4.12.

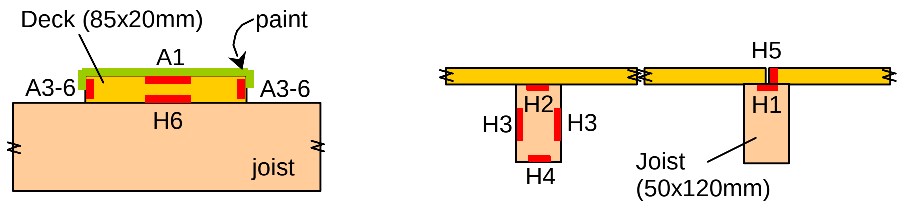


Figure 4.11 *Locations assessed for decay on Decking*

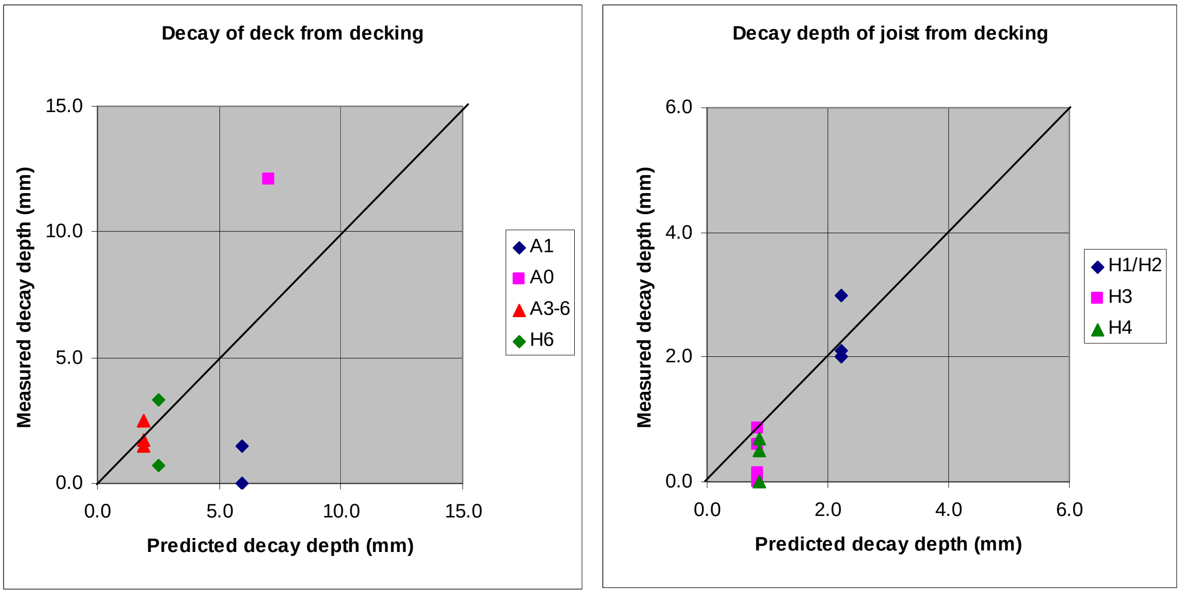


Figure 4.12 *Measured vs. predicted decay depth of deck (left) and joist (right) collected in Brisbane*

Table 4.7 Prediction of decay on decking and calibration data

Structure Element	Timber Species	Dura-bility Class	Service Age (yrs)	Wood Type	Size A (mm)	Size B (mm)	Gap width (mm)	In contact with	Shelter	Decay Surface	k_{dc}	k_{hw}	k_t	k_w	k_n	k_g	k_0	Rate	Lag	Predicted decay (mm)	Measured decay (Typical) (mm)
Deck	Brush Box	3	16	Heartwood	85	20	na	na	Exposed	A1	1.14	1.00	1.00	1.23	1.00	0.90	1.265	0.89	9.3	6.0	1.5
Deck	Brush Box	3	16	Heartwood	20	85	5	na	Exposed	A3-6	1.14	1.00	1.00	1.00	1.00	0.60	0.684	0.48	15.8	1.9	2.5
Deck	Brush Box	3	16	Heartwood	85	20	0	wood	Exposed	H6	1.14	1.00	1.00	1.00	1.00	0.70	0.798	0.56	13.8	2.5	3.3
Deck	Brush Box	3	16	Heartwood	20	85	5	na	Exposed	A3-6	1.14	1.00	1.00	1.00	1.00	0.60	0.684	0.48	15.8	1.9	1.7
Deck	Brush Box	3	16	Heartwood	85	20	na	na	Sheltered	A1	1.14	1.00	1.00	1.23	1.00	0.90	1.265	0.89	9.3	6.0	0.0
Deck	Brush Box	3	16	Heartwood	20	85	5	na	Sheltered	A3-6	1.14	1.00	1.00	1.00	1.00	0.60	0.684	0.48	15.8	1.9	2.5
Deck	Brush Box	3	16	Heartwood	85	20	0	wood	Sheltered	H6	1.14	1.00	1.00	1.00	1.00	0.70	0.798	0.56	13.8	2.5	0.7
Deck	Brush Box	3	16	Heartwood	20	85	5	na	Sheltered	A3-6	1.14	1.00	1.00	1.00	1.00	0.60	0.684	0.48	15.8	1.9	1.5
Deck	Brush Box	3	16	Heartwood	20	85	na	na	Exposed	A0	1.14	1.00	1.00	1.00	1.00	1.20	1.368	0.97	8.7	7.0	12.1
Joist	Blackbutt	1	16	Heartwood	50	120	0	wood	Exposed	H1/H2	0.50	1.00	1.00	1.00	1.00	1.50	0.750	0.53	14.6	2.2	2.0
Joist	Blackbutt	1	16	Heartwood	120	50	na	na	Exposed	H3	0.50	1.00	1.00	1.47	1.00	0.60	0.440	0.31	22.9	0.8	0.9
Joist	Blackbutt	1	16	Heartwood	50	120	na	na	Exposed	H4	0.50	1.00	1.00	1.00	1.00	0.90	0.450	0.32	22.5	0.9	0.7
Joist	Tallowwood	1	16	Heartwood	50	120	0	wood	Exposed	H1/H2	0.50	1.00	1.00	1.00	1.00	1.50	0.750	0.53	14.6	2.2	3.0
Joist	Tallowwood	1	16	Heartwood	120	50	na	na	Exposed	H3	0.50	1.00	1.00	1.47	1.00	0.60	0.440	0.31	22.9	0.8	0.2
Joist	Tallowwood	1	16	Heartwood	50	120	na	na	Exposed	H4	0.50	1.00	1.00	1.00	1.00	0.90	0.450	0.32	22.5	0.9	0.0
Joist	Grey Ironbark	1	16	Heartwood	50	120	0	wood	Exposed	H1/H2	0.50	1.00	1.00	1.00	1.00	1.50	0.750	0.53	14.6	2.2	2.1
Joist	Grey Ironbark	1	16	Heartwood	120	50	na	na	Exposed	H3	0.50	1.00	1.00	1.47	1.00	0.60	0.440	0.31	22.9	0.8	0.6
Joist	Grey Ironbark	1	16	Heartwood	50	120	na	na	Exposed	H4	0.50	1.00	1.00	1.00	1.00	0.90	0.450	0.32	22.5	0.9	0.5
Joist	Grey Ironbark	1	16	Heartwood	50	120	0	wood	Sheltered	H1/H2	0.50	1.00	1.00	1.00	1.00	1.50	0.750	0.53	14.6	2.2	2.0
Joist	Grey Ironbark	1	16	Heartwood	120	50	na	na	Sheltered	H3	0.50	1.00	1.00	1.47	1.00	0.60	0.440	0.31	22.9	0.8	0.0
Joist	Grey Ironbark	1	16	Heartwood	50	120	na	na	Sheltered	H4	0.50	1.00	1.00	1.00	1.00	0.90	0.450	0.32	22.5	0.9	0.0

4.4. Stair Treads in Brisbane

Table 4.8 presents the predicted and measured decay depths for the stair treads. The locations of decay assessed on the fence posts are depicted in Figure 4.13. Comparative plots of predicted decay versus measured decay are provided in Figure 4.14.

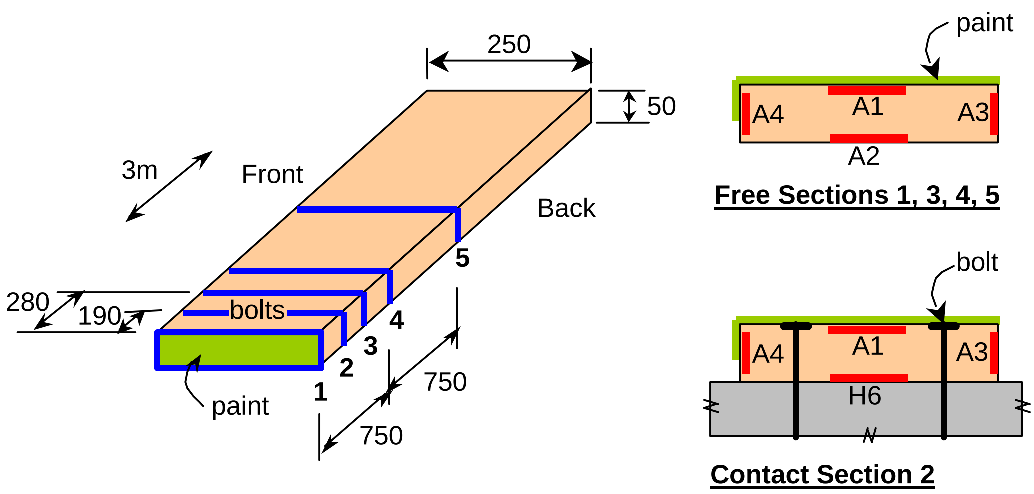


Figure 4.13 *Locations assessed for decay on stair treads*

Table 4.8 Prediction of decay on the stair and calibration data

Location	Structure Element	Timber Species	Dura-bility Class	Service Age (yrs)	Wood Type	Size A (mm)	Size B (mm)	Gap width (mm)	In contact with	Shelter	Decay surface	k_{dc}	k_{hw}	k_t	k_w	k_n	k_g	k_0	Rate	Lag	Predicted decay (mm)	Measured decay (Typical) (mm)
Brisbane	Stair tread top	Grey Ironbark	1	16	Heartwood	250	50	na	na	Sheltered & wetted	A1	0.50	1.00	1.00	2.00	1.00	0.90	0.90	0.64	9.5	4.2	8.1
Brisbane	Stair tread back	Grey Ironbark	1	16	Heartwood	50	250	na	na	Sheltered & wetted	A3	0.50	1.00	1.00	1.00	1.00	0.60	0.30	0.21	24.3	0.6	2.7
Brisbane	Stair tread bottom	Grey Ironbark	1	16	Heartwood	250	50	na	na	Sheltered & wetted	A2	0.50	1.00	1.00	2.00	1.00	0.45	0.45	0.32	17.2	1.2	0.6
Brisbane	Stair tread front	Grey Ironbark	1	16	Heartwood	50	250	na	na	Sheltered & wetted	A4	0.50	1.00	1.00	1.00	1.00	0.60	0.30	0.21	24.3	0.6	0.3

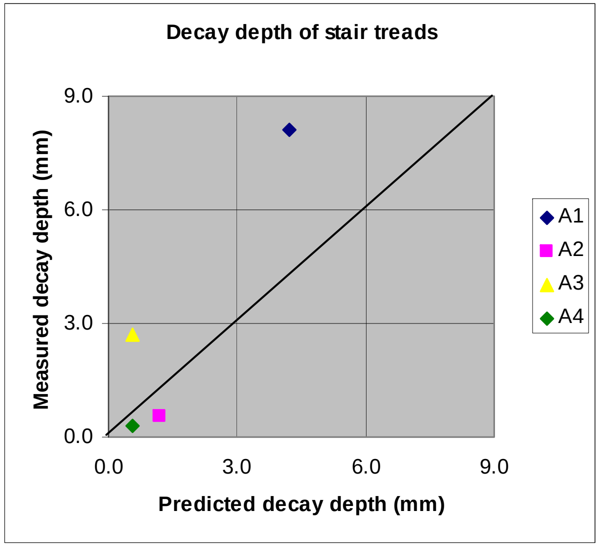


Figure 4.14 *Measured vs. predicted decay depth of the stair treads in Brisbane*.

4.5. Pergola in Melbourne

Table 4.9 presents the predicted and measured decay depths for the pergola. The locations of decay assessed on the fence posts are depicted in Figure 4.16 to Figure 4.18. Comparative plots of predicted decay versus measured decay are provided in Figure 4.15.

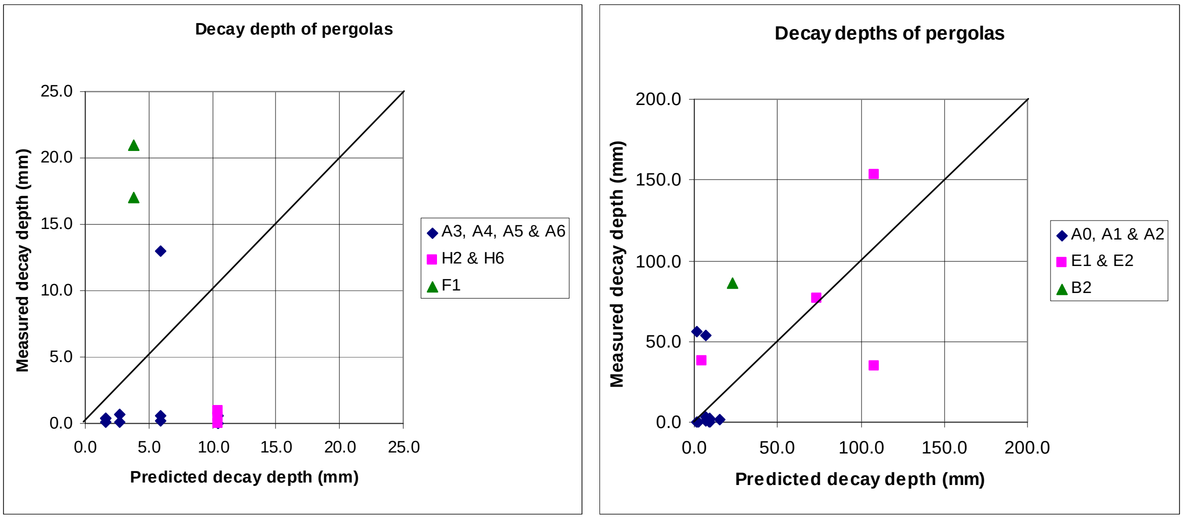
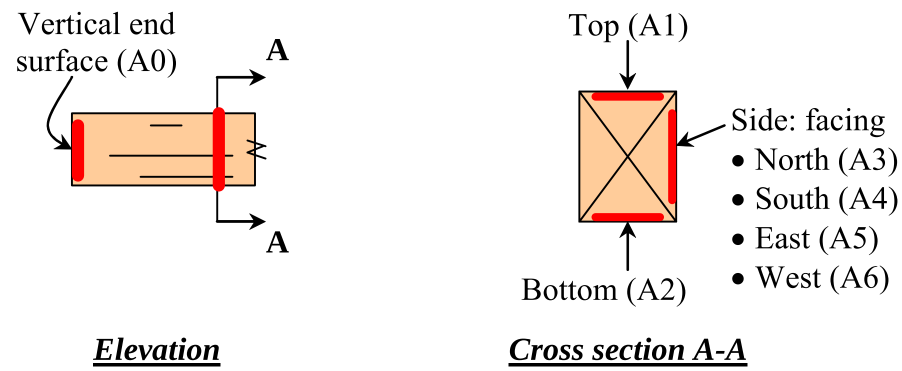


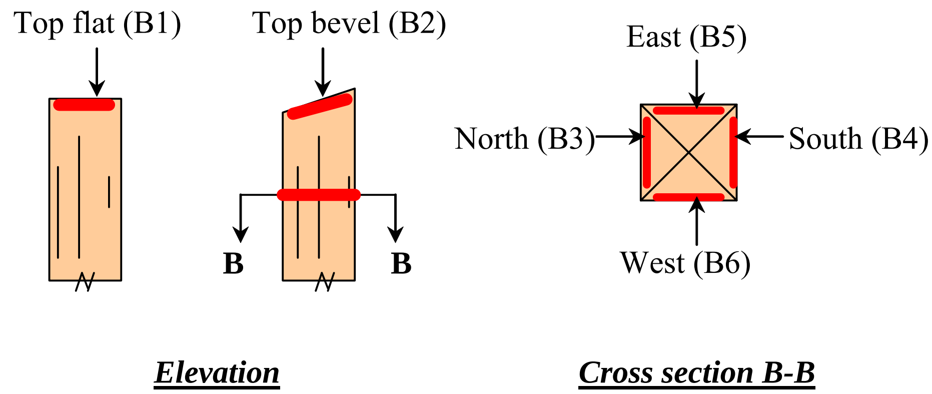
Figure 4.15 *Measured vs. predicted decay depth of the pergola in Melbourne*.

Table 4.9 Prediction of decay on the pergola and calibration data

Timber Species	Durability Class	Service Age (yrs)	Wood Type	Size A (mm)	Size B (mm)	Gap width (mm)	In contact with	Exposed to sun	Decay Surface	k_{dc}	k_{hw}	k_t	k_w	k_n	k_g	k_0	Rate	Lag	Predicted Decay (mm)	Measured Decay (Typical) (mm)
Oregon*	4	12	Heart/Sap	90	38	na	none	yes	A0 (W)	2.20	1.00	1.00	1.27	1.00	1.20	3.34	2.07	4.6	15.4	1.3
Oregon*	4	12	Heart/Sap	90	38	na	none	no	A0 (E)	2.20	1.00	1.00	1.27	1.00	0.90	2.51	1.55	5.8	9.6	0.2
Oregon*	4	12	Heart/Sap	90	38	na	none	yes	A1 (slope N)	2.20	1.00	1.00	1.27	1.00	0.90	2.51	1.55	5.8	9.6	2.0
Oregon*	4	12	Heart/Sap	90	38	na	none	yes	A2	2.20	1.00	1.00	1.27	1.00	0.45	1.25	0.78	10.5	2.5	0.0
Oregon*	4	12	Heart/Sap	38	90	na	none	yes	A4	2.20	1.00	1.00	1.00	1.00	0.45	0.99	0.61	12.9	1.6	0.4
Oregon*	4	12	Heart/Sap	38	90	na	none	yes	A3	2.20	1.00	1.00	1.00	1.00	0.60	1.32	0.82	10.1	2.7	0.7
Oregon*	4	12	Heart/Sap	90	38	na	none	no	A1 (slope N)	2.20	1.00	1.00	1.27	1.00	0.90	2.51	1.55	5.8	9.6	0.3
Oregon*	4	12	Heart/Sap	90	38	na	none	no	A2	2.20	1.00	1.00	1.27	1.00	0.45	1.25	0.78	10.5	2.5	0.0
Oregon*	4	12	Heart/Sap	38	90	na	none	no	A4	2.20	1.00	1.00	1.00	1.00	0.45	0.99	0.61	12.9	1.6	0.1
Oregon*	4	12	Heart/Sap	38	90	na	none	no	A3	2.20	1.00	1.00	1.00	1.00	0.60	1.32	0.82	10.1	2.7	0.1
Oregon*	4	12	Heart/Sap	45	195	0	wood	yes	H2	2.20	1.00	1.00	1.00	1.00	1.20	2.64	1.64	5.6	10.5	1.0
Oregon*	4	35	Heart/Sap	190	19	1.5	wood	yes	E1 (abuttment)	2.20	1.00	0.95	1.00	1.00	2.60	5.43	3.37	3.0	107.7	153.0
Oregon*	4	35	Heart/Sap	190	19	1.5	wood	yes	E1 (corner)	2.20	1.00	0.95	1.00	1.00	2.60	5.43	3.37	3.0	107.7	35.0
Oregon*	4	12	Heart/Sap	90	38	0	wood	yes	H6	2.20	1.00	1.00	1.00	1.00	1.20	2.64	1.64	5.6	10.5	0.5
Oregon*	4	12	Heart/Sap	90	38	0	wood	no	H6	2.20	1.00	1.00	1.00	1.00	1.20	2.64	1.64	5.6	10.5	0.0
Oregon*	4	12	Heart/Sap	90	38	na	none	yes	A1 (over H6)	2.20	1.00	1.00	1.27	1.00	0.90	2.51	1.55	5.8	9.6	1.2
Oregon*	4	12	Heart/Sap	38	90	na	none	yes	A4 (by H6)	2.20	1.00	1.00	1.00	1.00	0.45	0.99	0.61	12.9	1.6	0.4
Oregon*	4	12	Heart/Sap	38	90	na	none	yes	A3 (by H6)	2.20	1.00	1.00	1.00	1.00	0.60	1.32	0.82	10.1	2.7	0.7
Oregon*	4	12	Heart/Sap	60	240	na	none	partial	A1 (slope S)	2.20	1.00	1.00	1.07	1.00	0.90	2.11	1.31	6.8	6.9	1.1
Oregon*	4	12	Heart/Sap	60	240	na	none	partial	A2	2.20	1.00	1.00	1.07	1.00	0.45	1.06	0.65	12.2	1.8	0.0
Oregon*	4	12	Heart/Sap	240	60	na	none	partial	A5	2.20	1.00	1.00	2.00	1.00	0.45	1.98	1.23	7.1	6.0	0.2
Oregon*	4	12	Heart/Sap	240	60	na	none	partial	A6	2.20	1.00	1.00	2.00	1.00	0.60	2.64	1.64	5.6	10.5	0.0
Oregon*	4	12	Heart/Sap	240	60	0	wood	yes	H2 (end grain)	2.20	1.00	1.00	1.00	1.00	1.20	2.64	1.64	5.6	10.5	1.0
Oregon*	4	12	Heart/Sap	60	240	na	none	yes	A1 (by end grain)	2.20	1.00	1.00	1.07	1.00	0.90	2.11	1.31	6.8	6.9	3.0
Oregon*	4	12	Heart/Sap	240	60	na	none	yes	A6 (by end grain)	2.20	1.00	1.00	2.00	1.00	0.60	2.64	1.64	5.6	10.5	0.6
Oregon*	4	12	Heart/Sap	60	240	na	none	yes	A2 (by end grain)	2.20	1.00	1.00	1.07	1.00	0.45	1.06	0.65	12.2	1.8	0.0
Oregon*	4	12	Heart/Sap	240	60	na	none	yes	A5 (by end grain)	2.20	1.00	1.00	2.00	1.00	0.45	1.98	1.23	7.1	6.0	0.6
Oregon*	4	12	Heart/Sap	240	60	open	none	no	E1	2.20	1.00	1.00	2.00	1.00	2.60	11.44	7.09	1.6	73.7	77.0
Oregon*	4	12	Heart/Sap	60	240	na	none	no	A1 (by E1, E2)	2.20	1.00	1.00	1.07	1.00	0.90	2.11	1.31	6.8	6.9	54.0
Oregon*	4	12	Heart/Sap	240	60	0	wood	no	F1 (by end grain)	2.20	1.00	1.00	1.00	1.00	0.72	1.58	0.98	8.6	3.8	17.0
Oregon*	4	12	Heart/Sap	60	240	na	none	no	A2 (by E1, E2)	2.20	1.00	1.00	1.07	1.00	0.45	1.06	0.65	12.2	1.8	56.0
Oregon*	4	12	Heart/Sap	240	60	na	none	no	A5 (by E1, E2)	2.20	1.00	1.00	2.00	1.00	0.45	1.98	1.23	7.1	6.0	13.0
Oregon*	4	12	Heart/Sap	100	100	na	none	yes	B2	2.20	1.00	1.00	1.33	1.00	1.50	4.40	2.73	3.6	22.9	86.0
Oregon*	4	12	Heart/Sap	100	100	0	wood	no	E2 (no butted)	2.20	1.00	1.00	1.00	1.00	0.78	1.72	1.06	8.1	4.4	38.0
Oregon*	4	12	Heart/Sap	250	50	0	wood	no	F1	2.20	1.00	1.00	1.00	1.00	0.72	1.58	0.98	8.6	3.8	21.0

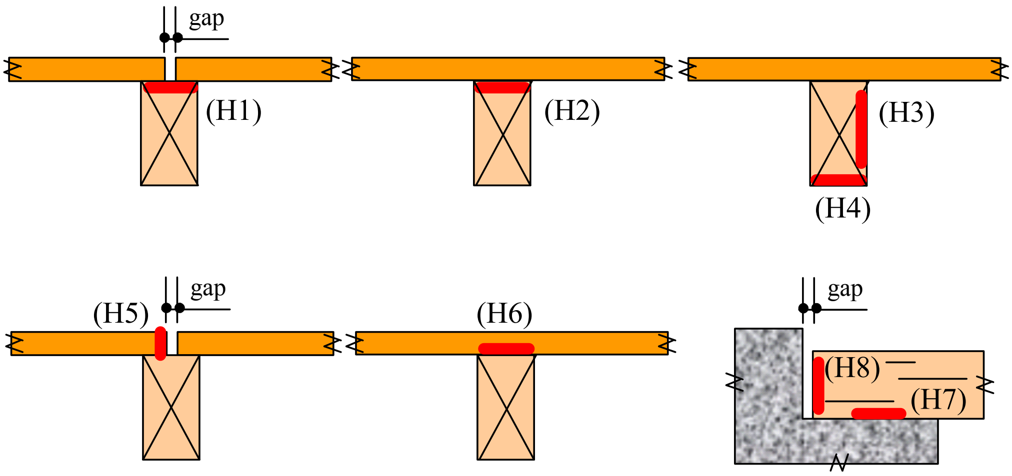


Horizontal Member
(*eg. pergola beams, fence rails*)

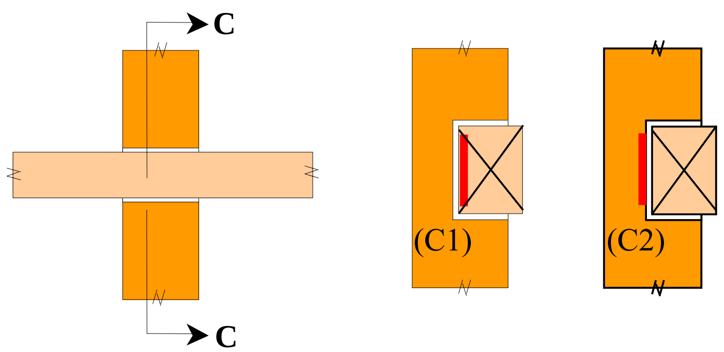


Vertical Member
(*eg. pergola columns, fence posts*)

Figure 4.16 *Decay configuration for non-contact surface*

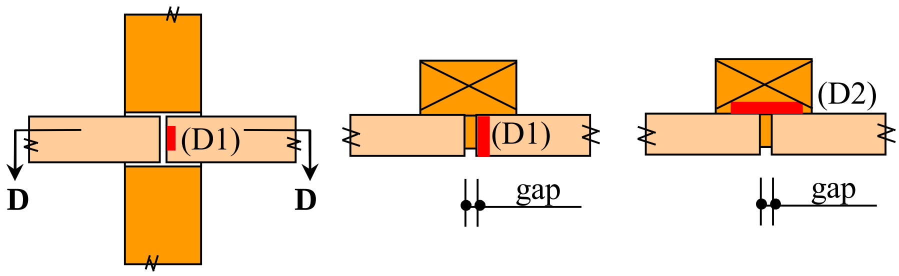


Elevation of Horizontal Structures
(*eg. decking*)



Elevation ***Cross section C-C***

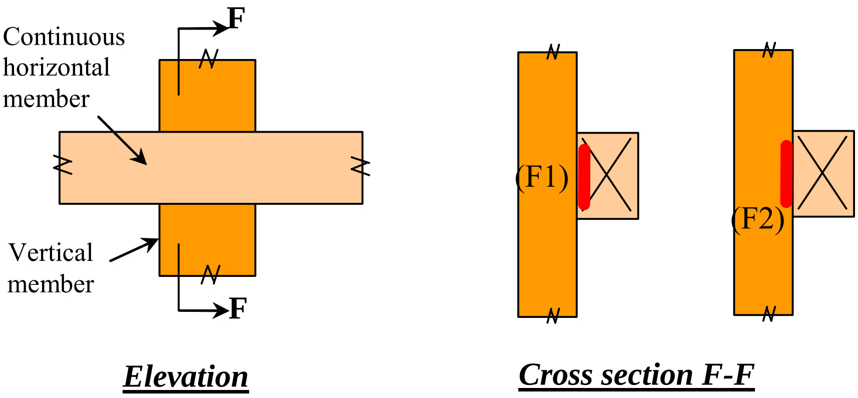
Vertical structures – Embedded contact – Continuous member
(*eg. fence posts and rails*)



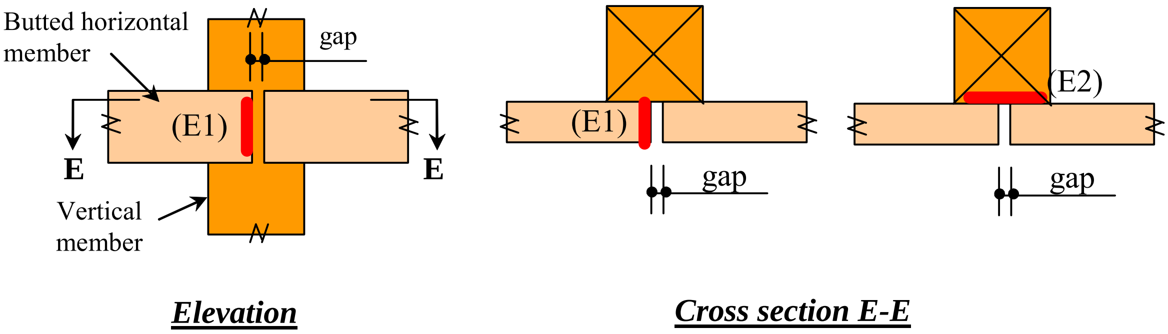
Elevation ***Cross section D-D***

Vertical structures – Embedded contact – Butted member
(*eg. fence posts and rails*)

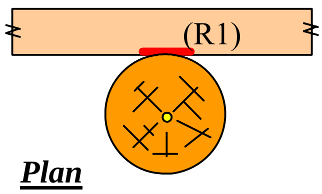
Figure 4.17 *Decay configuration for contact surface*



Vertical structures – Flat contact – Continuous member
(*eg. fence posts and rails*)



Vertical structures – Flat contact – Butted member
(*eg. fence posts and rails*)



Horizontal member – Flat contact with a round member
(*eg. cross-arms for power poles*)

Figure 4.18 *Decay configuration for contact surface*

5. Uncertainty and Probability Modelling

5.1. Notation

This section presents the probabilistic modelling of decay lag, decay rate, and decay depth based on the L-joint field test result collected from the Beerburrum site. The notation *R* and *L* will be used to denote the decay rates and lag as random variables. The following additional notation will also be used in this Section.

μ : mean value

σ^2 : variance

δ : coefficient of variation (COV)

ρ: correlation coefficient

$\ln(x)$: natural logarithm of x

For lognormal distributions, the mean and COV of *R*, denoted by μ_R and δ_R respectively, are given by

$$\mu_R = \exp\left(\mu_{\ln R} + \tfrac{1}{2}\sigma^2_{\ln R}\right) \tag{5.1}$$

and

$$\delta_R = \sqrt{\exp\left(\sigma^2_{\ln R}\right) - 1} \tag{5.2}$$

Similar relationships hold for the statistics of decay lag, *L*.

5.2. Probability Models for Decay Lag and Decay Rate

Except the CCA-treated woods, which had not had sufficient number of decayed specimens in 20 years to give satisfactory estimates of decay lags, the number of specimens available for the modelling of other types of wood is given in Table 5.1.

In Appendix A.1, it is shown that the distribution of the measured decay lags of each type of wood are then plotted on log-normal probability papers, as shown in Figure A.2, which show that the probability distribution of decay lag each of the wood type, both painted and unpainted, may be reasonably modelled as a log-normal distribution. Similar lognormal relationships can be shown for decay rates.

The median and mean values of decay lags estimated from log-normal distributions are presented in Table 5.2. If the decay lag is denoted by L, then its log-normal distribution parameters, $\mu_{\ln L}$ and $\sigma_{\ln L}$, and its coefficient of variation (COV), δ_L, could be estimated, as listed in Table 5.2.

Table 5.1 Number of L-joint specimens for probabilistic modelling of decay lags

Paint	**Durability Class**				**Sapwood**
	1	**2**	**3**	**4**	
Unpainted	121	64	95	216	37
Painted	186	90	105	232	42

Table 5.2 Log-normal distribution parameters and COV of decay lags

Wood Type		$\mu_{\ln L}$	$\sigma_{\ln L}$	δ_L
Paint	**Durability Class**			
Unpainted	1	2.70	0.58	0.64
	2	2.53	0.49	0.52
	3	2.02	0.61	0.67
	4	1.48	0.84	1.02
	Sapwood	0.58	0.46	0.48
Painted	1	1.98	0.35	0.36
	2	1.94	0.40	0.42
	3	1.35	0.59	0.65
	4	0.96	0.86	1.04
	Sapwood	0.25	0.21	0.22

Table 5.3 Log-normal distribution parameters and COV of decay rates

Wood Type		$\mu_{\ln R}$	$\sigma_{\ln R}$	δ_R
Paint	**Durability Class**			
Unpainted	1	0.091	0.496	0.53
	2	0.195	0.413	0.43
	3	0.496	0.519	0.56
	4	0.815	0.717	0.82
	Sapwood	1.350	0.389	0.40
Painted	1	0.522	0.296	0.30
	2	0.544	0.342	0.35
	3	0.893	0.504	0.54
	4	1.126	0.728	0.84
	Sapwood	1.546	0.181	0.18

If the lag–rate relationship is modelled by the power law relation, the correlation coefficient ρ of the measured decay lag and rate, as shown in Figure 3.1, is determined to be –0.7. Therefore, if the decay rate is denoted by *R*, then the log-normal distribution parameters of *R*, $\mu_{\ln R}$ and $\sigma_{\ln R}$, could be determined by the following equation derived from the regression of ln *R* on ln *L*,

$$\mu_{\ln R} = \ln(5.5) - 0.6\mu_{\ln L} \tag{5.3}$$

from which it follows that the standard deviation $\sigma_{\ln R}$ is (Ang and Tang 2007)

$$\sigma_{\ln R} = \frac{-0.6\sigma_{\ln L}}{\rho} \tag{5.4}$$

This standard deviation can be used to compute the coefficient of variation through Eq. (5.2)

5.3. Uncertainty Modelling for Decay Depth at Time *t*

When $t > L$, the decay depth, *D* (mm), is estimated by

$$D = (t - L)R \tag{5.5}$$

where *t* is exposure time after installation (years), *L* (years) and *R* (mm/yr) are the decay lag and decay rate, respectively. If *L* and *R* are log-normally distributed, there is no closed-form form for the distribution of *D*. Therefore, uncertainty of *D* may be estimated via Monte-Carlo simulation or approximate expression of Taylor expansion. For example, considering the correlation of *L* and *R*, the COV of *D* may be expressed by a first-order approximation (e.g. Ang and Tang 2007) as follows:

$$\delta_D = \frac{\sqrt{\left(\sigma_L \left.\frac{\partial D}{\partial L}\right|_{\mu_R,\mu_L}\right)^2 + \left(\sigma_R \left.\frac{\partial D}{\partial R}\right|_{\mu_R,\mu_L}\right)^2 + 2\rho\sigma_L\sigma_R\left(\left.\frac{\partial D}{\partial L}\right|_{\mu_R,\mu_L}\right)\left(\left.\frac{\partial D}{\partial R}\right|_{\mu_R,\mu_L}\right)}}{\mu_D} \tag{5.6}$$

Substituting Eq. (5.5) into Eq. (5.6) leads to

$$\delta_D = \frac{\sqrt{\sigma_L^2\mu_R^2 + \sigma_R^2(t-\mu_L)^2 + 2\rho\sigma_L\sigma_R\mu_R(t-\mu_L)}}{(t-\mu_L)\mu_R} \tag{5.7}$$

The standard deviations σ_L and σ_R are assumed to consist of contributions from the variability of wood property, climate effect, modelling uncertainty, and painting when painted wood is considered.

The COVs (i.e. δ_{wood}, $\delta_{cliamte}$, δ_{model}, δ_{paint}) for decay lag and rate are listed in Table 5.5 and Table 5.4, respectively. The correlation coefficient ρ is taken to be –0.7, as mentioned previously.

To determine σ_L, for example, we first use the COVs in Table 5.5 and Eq. (5.2) to obtain $\sigma_{\ln L,wood}$, $\sigma_{\ln L,cliamte}$, $\sigma_{\ln L,model}$, and $\sigma_{\ln L,paint}$. The standard deviation of ln*L*, $\sigma_{\ln L}$, is

$$\sigma_{\ln L} = \sqrt{\sigma^2_{\ln L,wood} + \sigma^2_{\ln L,climate} + \sigma^2_{\ln L,model} + \sigma^2_{\ln L,paint}} \tag{5.8}$$

The standard deviation of *L* can then be obtained from

$$\sigma_L = \mu_L \sqrt{\exp\left(\sigma^2_{\ln L}\right) - 1} \tag{5.9}$$

Table 5.4 Sources and values of contribution to the COV of decay rates for the Beerburrum site

Wood Type		$\mu_{\ln R}$	Coefficient of variation			
			$\delta_{R,wood}$ (1)	$\delta_{R,cliamte}$ (2)	$\delta_{R,model}$ (3)	$\delta_{R,paint}$ (4)
Paint	**Durab. Class**					
Unpainted	1	0.091	0.53	0.55	0.50	—
	2	0.195	0.43	0.55	0.50	—
	3	0.496	0.56	0.55	0.50	—
	4	0.815	0.82	0.55	0.50	—
	Sapwood	1.350	0.40	0.55	0.50	—
Painted	1	0.522	0.30	0.55	0.50	0.15
	2	0.544	0.35	0.55	0.50	0.15
	3	0.893	0.54	0.55	0.50	0.10
	4	1.126	0.84	0.55	0.50	0.10
	Sapwood	1.546	0.18	0.55	0.50	0.55

(1) Computed by Eq. (5.4) and the value of $\delta_{L,wood}$ given in Table 5.5

(2) Measured from Figure 3.1 (a)

(3) Estimated from reality checks in Section 4

(4) Estimated from the scatter shown in Figure 3.2

Table 5.5 Sources and values of contribution to the COV of decay lags for the Beerburrum site

Wood Type		$\mu_{\ln L}$	Coefficient of variation			
			$\delta_{L,wood}$ (1)	$\delta_{L,cliamte}$ (2)	$\delta_{L,model}$ (3)	$\delta_{L,paint}$ (4)
Paint	**Durab. Class**					
Unpainted	1	2.70	0.64	0.65	0.60	—
	2	2.53	0.52	0.65	0.60	—
	3	2.02	0.67	0.65	0.60	—
	4	1.48	1.02	0.65	0.60	—
	Sapwood	0.58	0.48	0.65	0.60	—
Painted	1	1.98	0.36	0.65	0.60	0.20
	2	1.94	0.42	0.65	0.60	0.20
	3	1.35	0.65	0.65	0.60	0.10
	4	0.96	1.04	0.65	0.60	0.10
	Sapwood	0.25	0.22	0.65	0.60	0.65

(1) Measured from the distributions graphed in Figure A.2.

(2) Computed by Eq. (5.4) and the value of $\delta_{R,cliamte}$ given in Table 5.4

(3) Computed by Eq. (5.4) and the value of $\delta_{R,model}$ given in Table 5.4

(4) Computed by Eq. (5.4) and the value of $\delta_{R,paint}$ given in Table 5.4

The following is the algorithm used for simulation of COV of decay depth at year *t*, given the distribution parameters $\mu_{\ln L}$ and $\sigma_{\ln L}$ for decay lag, $\mu_{\ln R}$ and $\sigma_{\ln R}$ for decay rate, and the correlation coefficient ρ of the decay lag and rate:

1. Generate an array of *N* log-normally distributed decay lags, $l_i, i = 1, \cdots, N$, using the distribution parameters $\mu_{\ln L}$ and $\sigma_{\ln L}$ (Ang and Tang 2007).
2. Compute $\lambda_{r_i|l_i} = \lambda_R\left(r_i \mid L = l_i\right) = \mu_{\ln R} + \rho\dfrac{\sigma_{\ln R}}{\sigma_{\ln L}}\left(\ln l_i - \mu_{\ln L}\right)$.
3. Compute $\zeta_{R|L} = \sigma_{\ln R}\sqrt{1-\rho^2}$.
4. Generate an array of *N* log-normally distributed decay rates, $r_i, i = 1, \cdots, N$, using the distribution parameters $\lambda_{r_i|l_i}$ and $\zeta_{R|L}$.
5. Compute an array of decay depths d_i at year *t* by Eq. (4), in which using l_i for *L* and r_i for *R*.
6. Compute the COV of decay depth at year *t* from the simulated values of d_i.

The COV of decay versus time after installation for unpainted wood of durability classes 1 to 4 and sapwood, evaluated by simulation and the first-order approximation, are shown in Figure 5.1, and that of painted wood in Figure 5.2. The sample size for simulation at each year is 5000. Similarly, the COV of decay versus decay depth for unpainted wood of durability classes 1 to 4 and sapwood, evaluated by simulation and the first-order approximation, are shown in Figure 5.3, and that of painted wood in Figure 5.4.

5.4. Probability Model for Decay Time at Decay Depth *d*

The period of time taken to reach a specific decay depth d could also be treated as a random variable, denoted by T. Then

$$T = L + \frac{d}{R} \tag{5.10}$$

Similar to the previous section for the uncertainty of D, the uncertainty of T may be estimated via Monte-Carlo simulation or approximate expression of Taylor expansion. A first-order approximation (e.g. Ang and Tang 2007) of δ_T is as follows:

$$\begin{aligned}\delta_T &= \frac{\sqrt{\left(\sigma_L \left.\frac{\partial T}{\partial L}\right|_{\mu_R,\mu_L}\right)^2 + \left(\sigma_R \left.\frac{\partial T}{\partial R}\right|_{\mu_R,\mu_L}\right)^2 + 2\rho\sigma_L\sigma_R\left(\left.\frac{\partial T}{\partial L}\right|_{\mu_R,\mu_L}\right)\left(\left.\frac{\partial T}{\partial R}\right|_{\mu_R,\mu_L}\right)}}{\mu_T} \\ &= \frac{\sqrt{\sigma_L^2 + \sigma_R^2\left(\frac{d}{\mu_R^2}\right)^2 + 2\rho\sigma_L\sigma_R\left(\frac{d}{\mu_R^2}\right)}}{\mu_L + \frac{d}{\mu_R}}\end{aligned} \tag{5.11}$$

The COV of time to reach a decay depth versus time for unpainted wood of durability classes 1 to 4 and sapwood, evaluated by simulation and the first-order approximation, are shown in Figure 5.5, and that of painted wood in Figure 5.6. The sample size for simulation at each year is 5000. Similarly, the COV of time versus decay depth for unpainted wood of durability classes 1 to 4 and sapwood, evaluated by simulation and the first-order approximation, are shown in Figure 5.7, and that of painted wood in Figure 5.8.

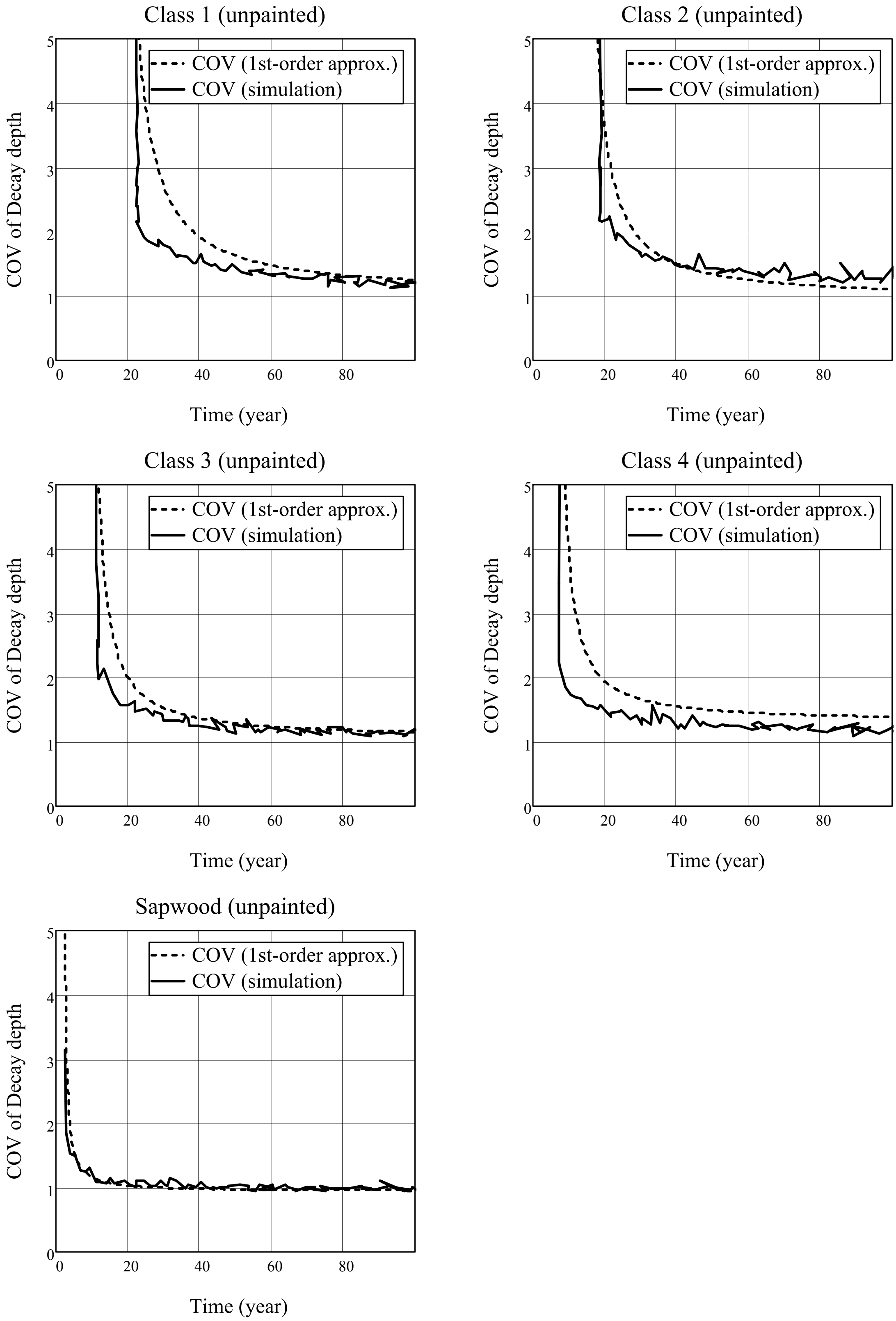


Figure 5.1 COVs of decay depth for unpainted wood

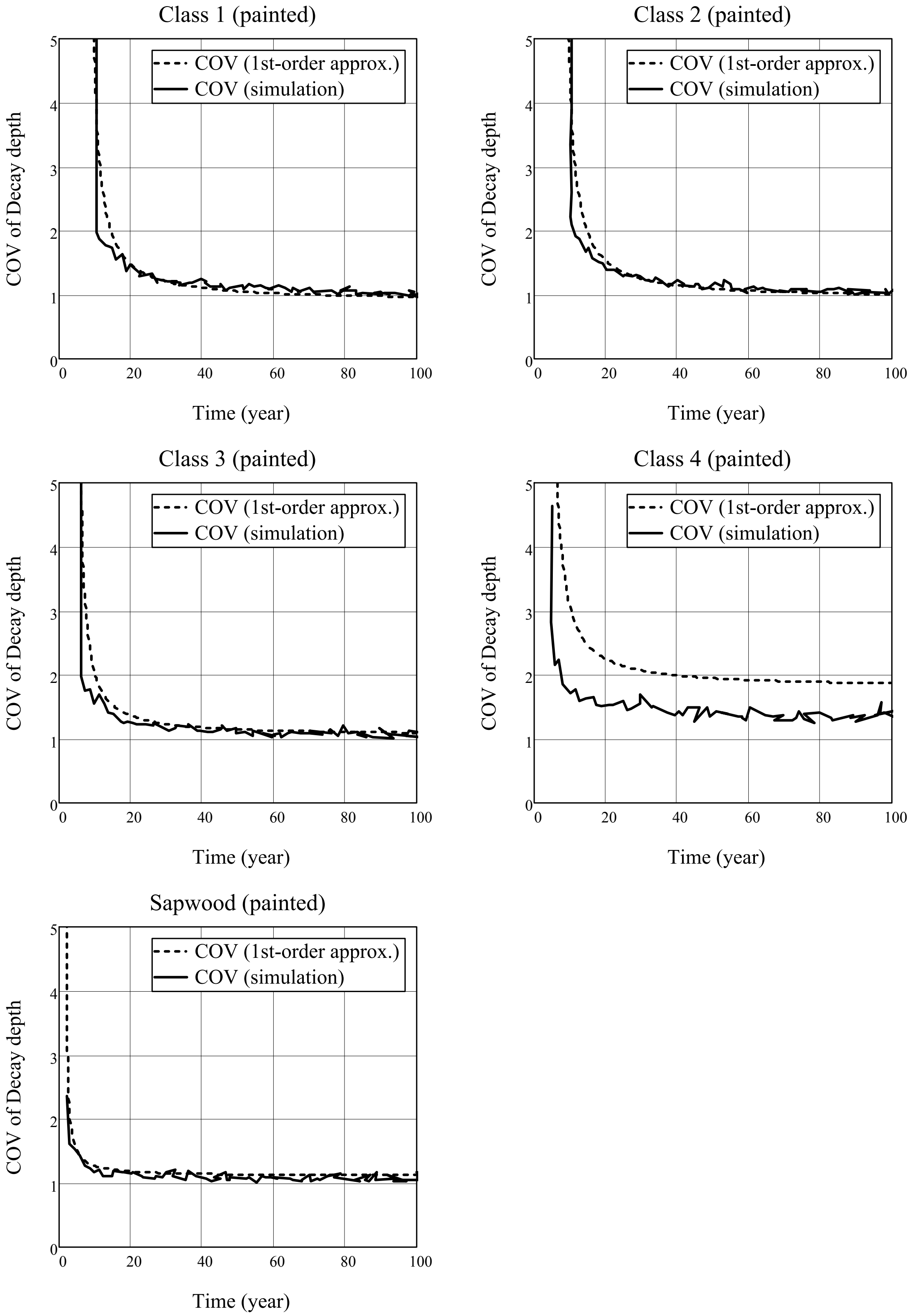


Figure 5.2 COVs of decay depth for painted wood

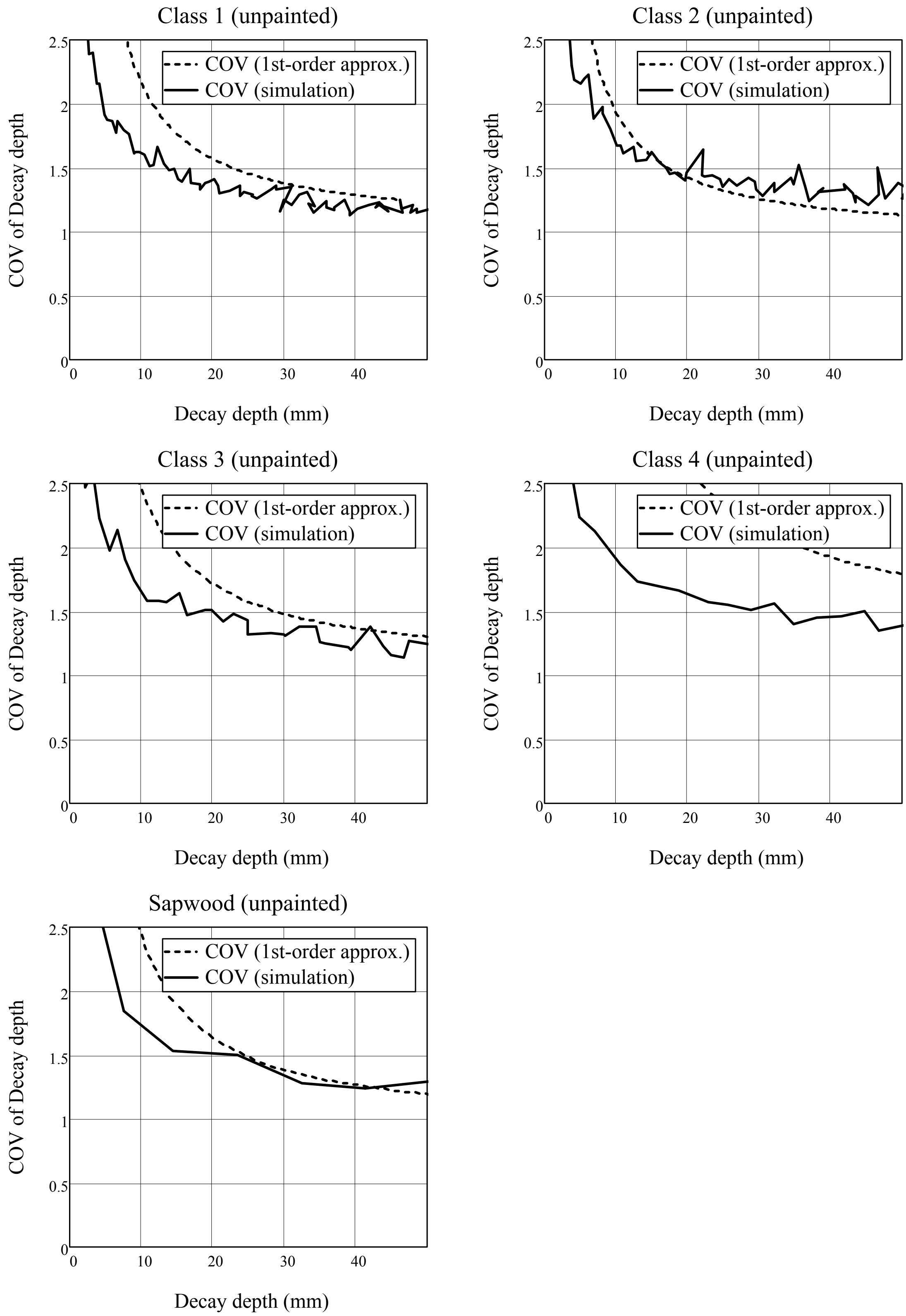


Figure 5.3 COVs of decay depth versus decay depth for unpainted wood

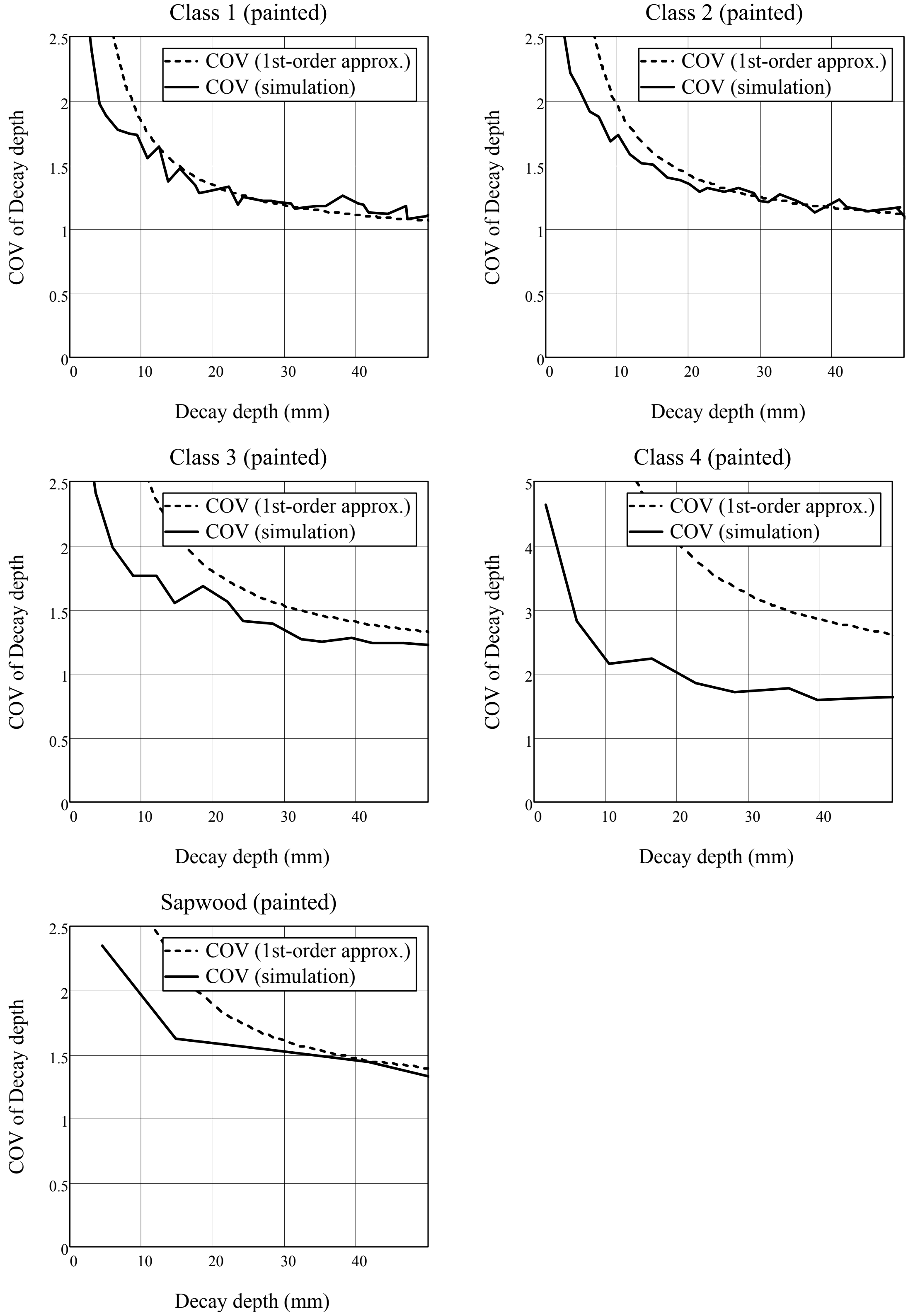


Figure 5.4 COVs of decay depth versus decay depth for painted wood

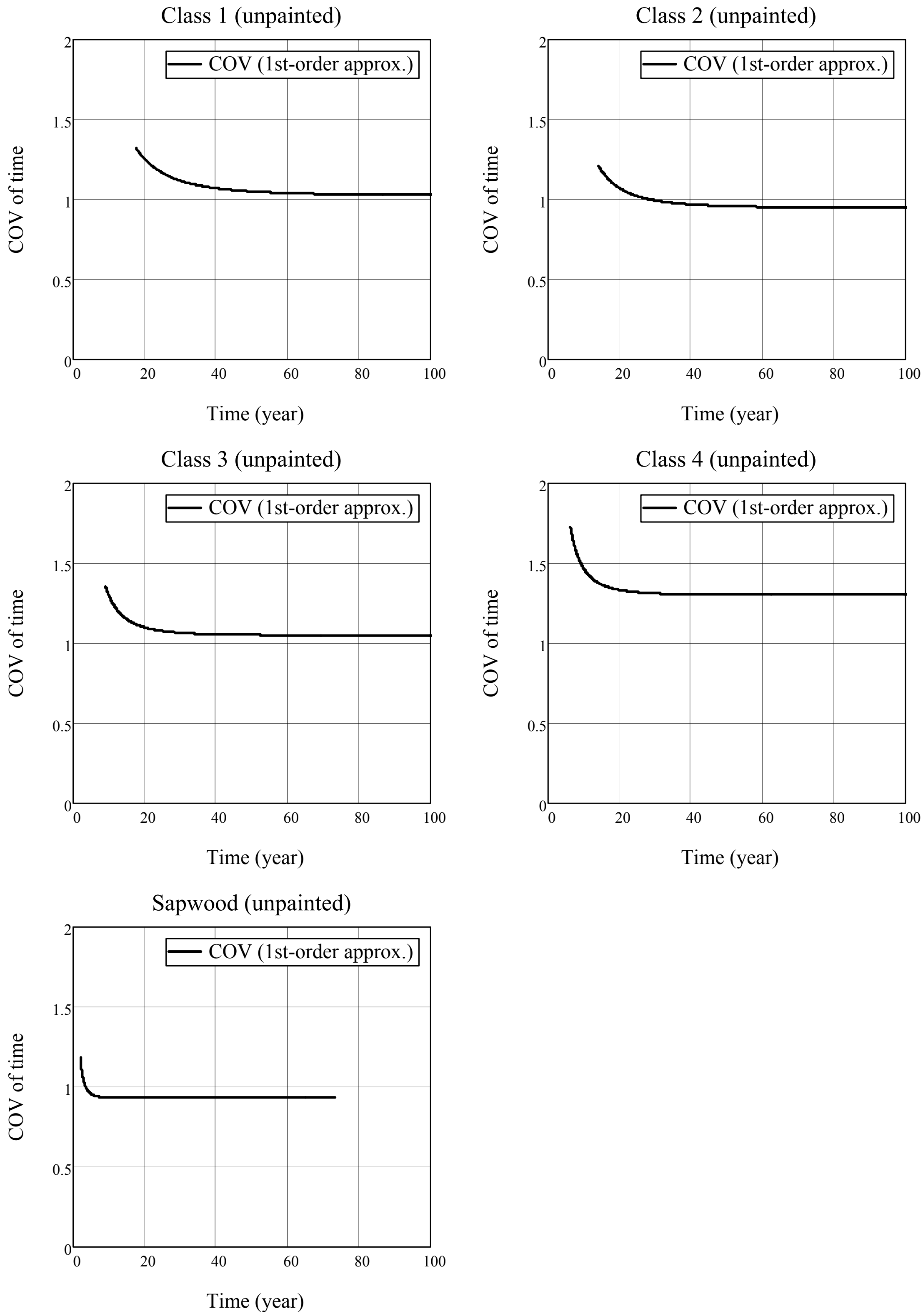


Figure 5.5 COVs of exposure time for unpainted wood

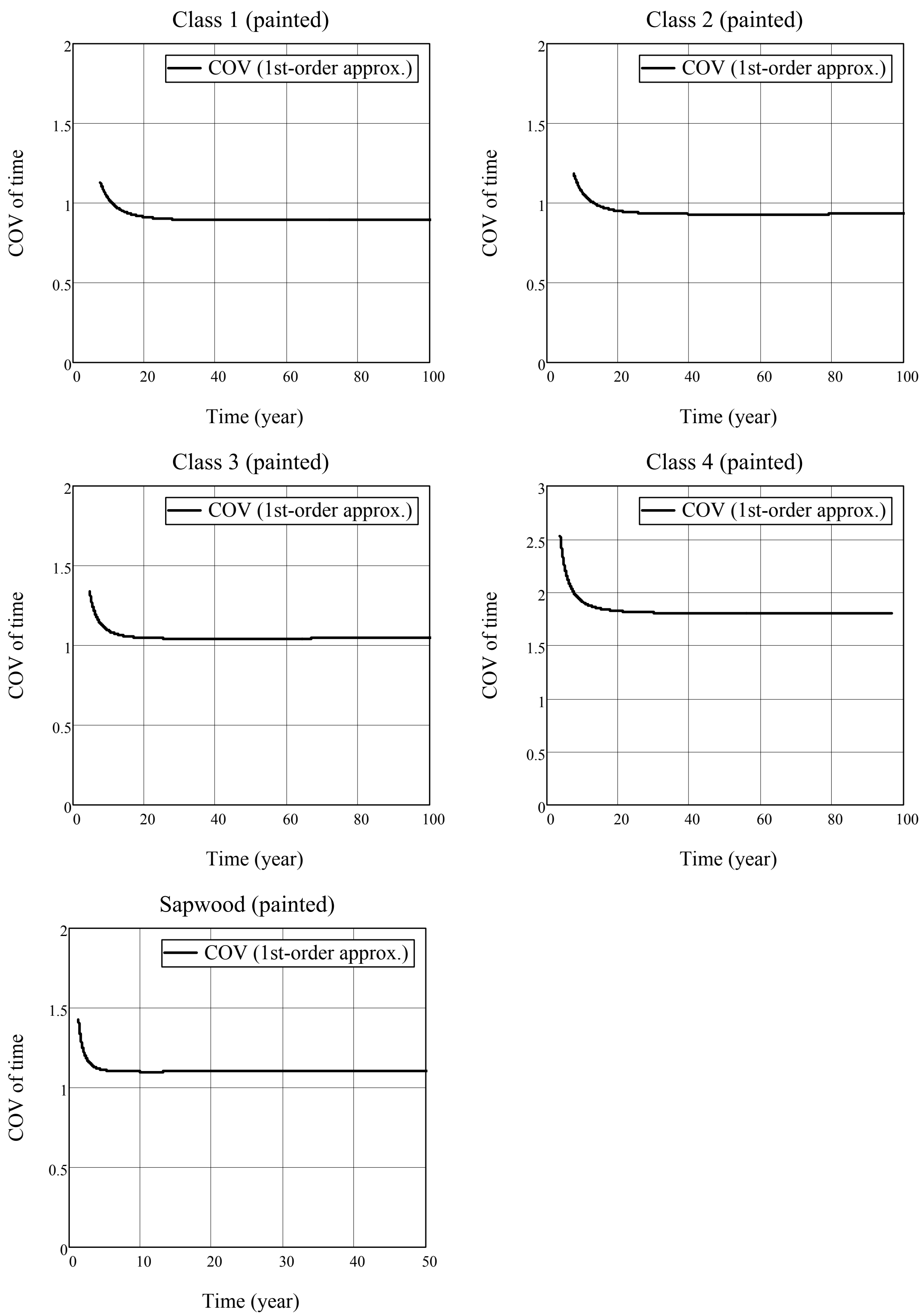


Figure 5.6 COVs of exposure time for painted wood

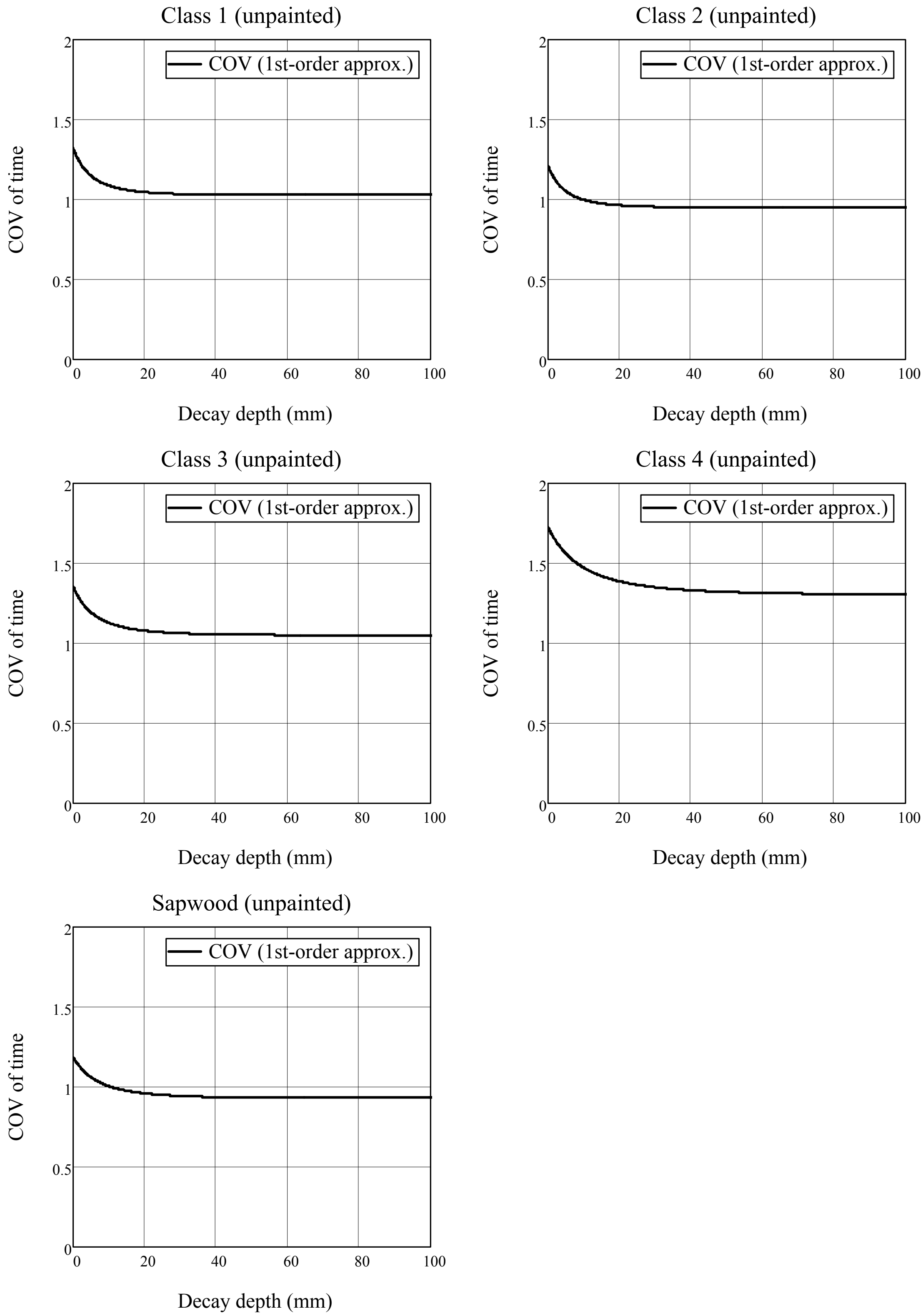


Figure 5.7 COVs of exposure time versus decay depth for unpainted wood

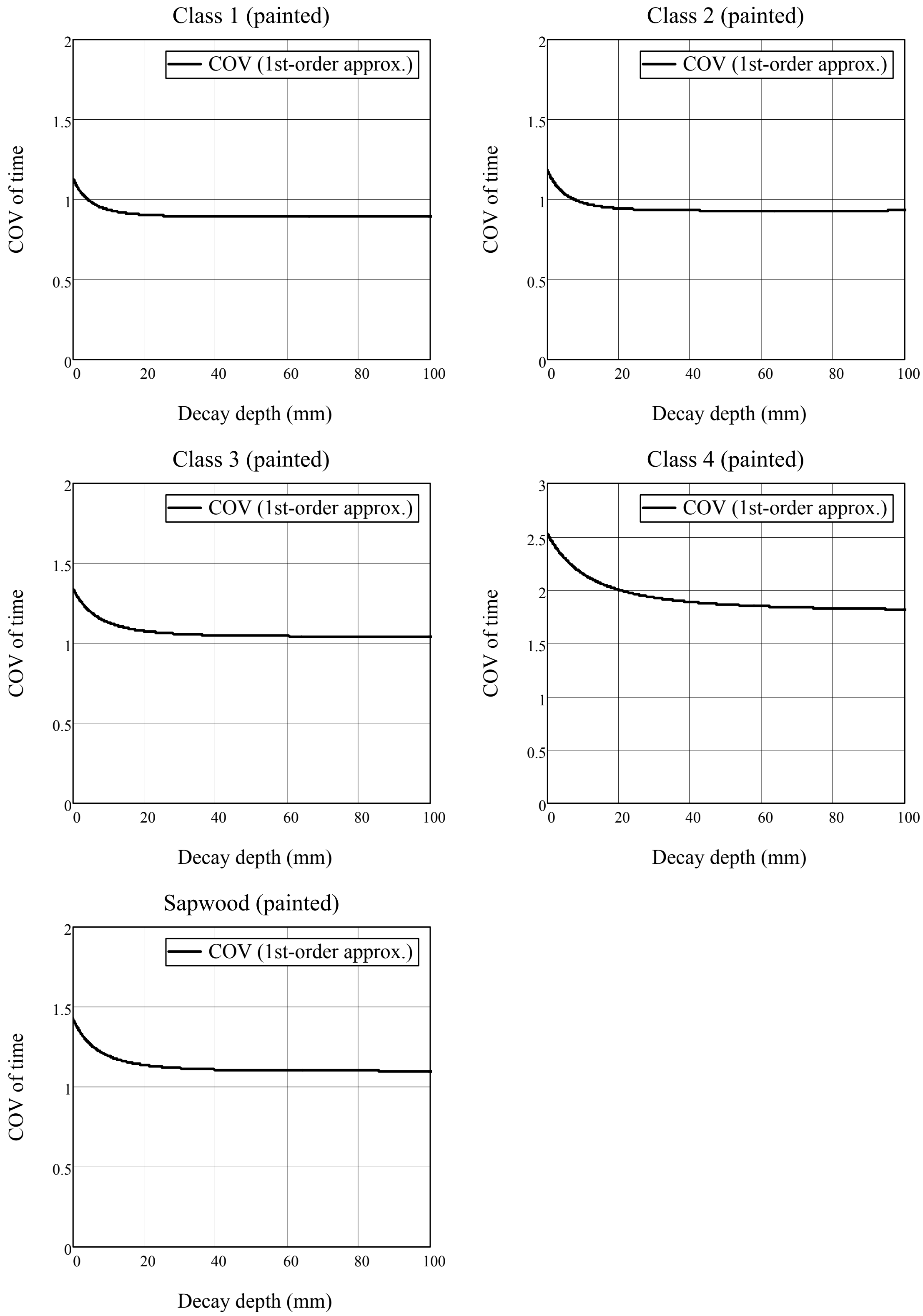


Figure 5.8 COVs of exposure time versus decay depth for painted wood

6. Equations for Use in Design Guide and TimberLife

The decay depth after *t* years of installation, d_t (mm), is expressed as follows:

$$d_t = \begin{cases} ct^2 & \text{if } t \le t_{d_0}; \\ (t - t_{lag})r & \text{if } t > t_{d_0}. \end{cases} \tag{6.1}$$

in which

$$t_{d_0} = t_{lag} + \frac{d_0}{r} \tag{6.2}$$

$$c = \frac{d_0}{t_{d_0}^2} \tag{6.3}$$

6.1. Decay Rate

Decay rate *r* is the product of multipliers that take into account the effects of material, construction, and environmental factors as follows:

$$r = k_{wood} k_{climate} k_t k_w k_n k_g \tag{6.4}$$

where k_{wood} = wood parameter; $k_{climate}$ = climate parameter; k_p = painting parameter; k_t = thickness parameter; k_w = width parameter; k_n = fastener parameter; and k_g = assembly parameter.

$$k_{wood} = \begin{cases} 0.25 & \text{for treated wood;} \\ 0.50 & \text{for class 1;} \\ 0.62 & \text{for class 2;} \\ 1.14 & \text{for class 3;} \\ 2.20 & \text{for class 4;} \\ 6.52 & \text{for sapwood.} \end{cases} \tag{6.5}$$

The climate parameter values for the four hazard zones are taken as shown in Table 6.1.

Table 6.1 $k_{climate}$ values used for service life computation

Above-ground Decay Hazard Zone	$k_{climate}$
A	0.40
B	0.50
C	0.65
D	0.75

6.1.1. Thickness Parameters

This parameter is for the effects of drying in transverse direction to timber grain. If a part of a timber element is non-contact, i.e. it is not in contact with another element, it will tend to dry rapidly if it is sufficiently thin. Hence a thickness factor k_t is used to account for this effect. For non-contact surface of an element of thickness t,

$$k_t = \begin{cases} 1 & \text{for } t \geq 20 \text{ mm} \\ 0.5 & \text{for } t \leq 20 \text{ mm} \\ 0.05t & \text{otherwise} \end{cases} \tag{6.6}$$

For surfaces in contact with other elements, $k_t = 1.0$.

6.1.2. Width Parameter

This parameter takes into accounts the effect of specimen width (cross-grain) on the decay surface due to drying restraint. The bigger the width, the more restraints on the wood surface during drying, potentially causing larger and deeper checks on the surface and hence facilitating more severe decay. For contact surfaces, $k_w = 1.0$. For non-contact surfaces of width w,

$$k_w = \begin{cases} 1 & \text{for } w \leq 50 \text{ mm} \\ 1.5 & \text{for } w \geq 200 \text{ mm} \\ \dfrac{w}{300} + \dfrac{5}{6} & \text{otherwise} \end{cases} \tag{6.7}$$

Illustration of the width on member cross section is in Figure 6.1.

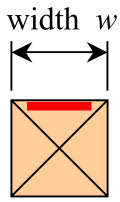


Figure 6.1 *Illustration of the width w used to determine the width parameter*

6.1.3. Painting Parameter

The effect of painting on decay is account for by the painting parameter, k_p, as follows:

$$k_p = \begin{cases} 2.0 & \text{for painted wood;} \\ 1.0 & \text{for unpainted wood.} \end{cases} \tag{6.8}$$

6.1.4. Connection Parameter

This parameter takes into accounts the effect of the presence of connector on the decay surface. The interface/gap between the connector and its hole would act as a path of moisture entry to enhance the decay progress. Provisionally, value of this parameter is set as follows,

- If there is connector, $k_n = 2.0$;
- If there is no connector, $k_n = 1.0$.

6.1.5. Geometry Parameter

The geometry parameter, k_g, is expressed as,

$$k_g = k_{g1}\, k_{g2} \tag{6.9}$$

where k_{g1} is contact factor and k_{g2} is position factor.

6.1.5.1. Contact factor

This contact factor k_{g1} is determined depending on whether the assessed surface is in contact with other structural members or not.

(a) For a non-contact surface:

$$k_{g1} = 0.3$$

(b) For a contact surface:

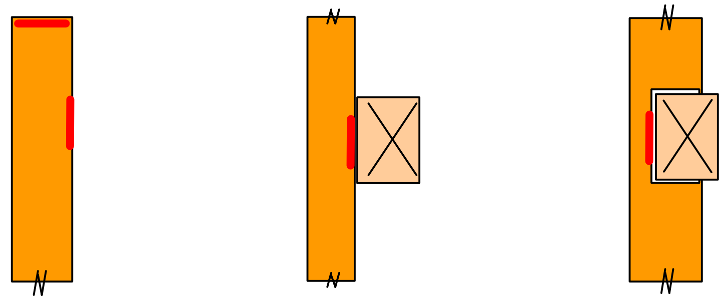
- Flat contact:

$$k_{g1} = 0.6$$

- Embedded contact: (reference to L-joint)

$$k_{g1} = 1.0$$

Illustrative examples of contact and non-contact surfaces are shown in Figure 6.2.



(i) Non-contact
$k_{g1} = 0.3$

(ii) Flat contact
$k_{g1} = 0.6$

(iii) Embedded contact
$k_{g1} = 1.0$

Figure 6.2 *Illustration of non-contact, flat contact and embedded contact.*

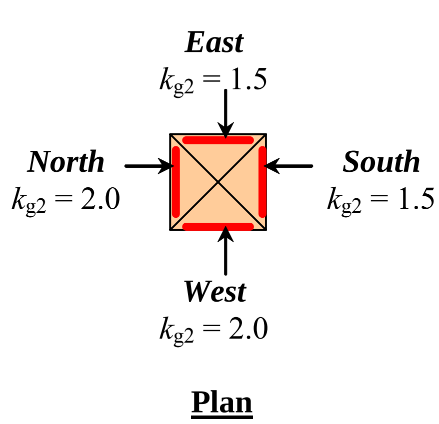
6.1.5.2. Position factor for non-contact surfaces

The position factor k_{g2} for non-contact surfaces takes into account of the orientation of the member, orientation of the surface, and sheltering effect. It is noted that the surface orientation effect is due to mechanical degradation caused by sunlight.

<u>(a) For vertical members</u>

The position factor k_{g2} for vertical member depends on the orientation of the decay-assessed surface. If the decay-assessed surface is

- *Top flat:* $k_{g2} = 6.0$
- *Top sloping:* $k_{g2} = 5.0$
- *Facing north:* $k_{g2} = 2.0$
- *Facing south:* $k_{g2} = 1.5$
- *Facing east:* $k_{g2} = 1.5$
- *Facing west:* $k_{g2} = 2.0$



Non-contact surfaces - Vertical member

Figure 6.3 *Position factor k_{g2} for non-contact surface in vertical member.*

(b) For horizontal members

The position factor k_{g2} for horizontal member depends on the orientation of the decay-assessed surface. If the decay-assessed surface is

- Horizontal:
    - *Top of member:* $k_{g2} = 3.0$
    - *Bottom of member:* $k_{g2} = 1.5$
- Vertical sides of member (side grain):
    - *Sheltered* (by decking):* $k_{g2} = 0.8$
    - *Exposed to north:* $k_{g2} = 2.0$
    - *Exposed to south:* $k_{g2} = 1.5$
    - *Exposed to east:* $k_{g2} = 1.5$
    - *Exposed to west:* $k_{g2} = 2.0$
- Vertical ends of member (end grain):
    - *Sheltered* (by decking):* $k_{g2} = 1.6$
    - *Exposed to north:* $k_{g2} = 4.0$
    - *Exposed to south:* $k_{g2} = 3.0$
    - *Exposed to east:* $k_{g2} = 3.0$
    - *Exposed to west:* $k_{g2} = 4.0$

It can be noted that the factor for vertical ends is twice that of vertical sides. This is to take into account the effect of grain orientation at the decay surface.

6.1.5.3. Position factor for contact surface

The position factor k_{g2} for contact surfaces, including flat and embedded contacts, takes into account of the type of contacted material, and the presence of gap, its size and location. The factor can be determined as

$$k_{g2} = k_{g21}\, k_{g22}\, k_{g23} \tag{6.10}$$

Where k_{g21} is contacted-material factor, k_{g22} is orientation factor, and k_{g23} is gap factor

The contacted-material factor k_{g21} depends on the type of contact material. If the contacted material is

- *Wood* $k_{g21} = 1.0$
- *Steel* $k_{g21} = 0.7$
- *Concrete* $k_{g21} = 1.0$

The orientation factor k_{g22} takes into account the orientation of the decay surface. It takes the following values

- For horizontal top surface (facing upward): $k_{g22} = 2.0$
- For others: $k_{g22} = 1.0$

The gap factor k_{g23} takes into account the presence of gap, gap size and location. Three cases are considered:

<u>(a) Continuous member in contact with a continuous member:</u>

$k_{g23} = 1.0$

<u>(b) Continuous member in contact with a butted member:</u>

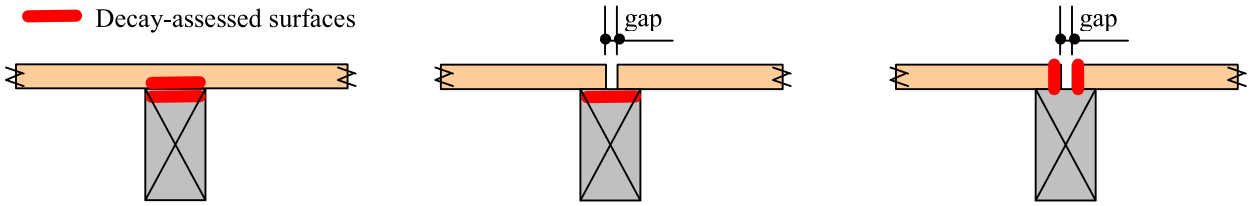
$k_{g23} = 1.2$

<u>(c) A butted member:</u>

The gap factor k_{g22} depends on the gap size. If gap size is

- ≤ 1.0 *mm* $k_{g23} = 2.0$
- ≥ 2.5 *mm* $k_{g23} = 1.3$
- $k_{g23} = \frac{3.7}{1.5} - \frac{0.7}{1.5} \times (\text{gap size})$ *otherwise*

Illustrations of these cases are given in Figure 1.4.3.1.



(a) Continuous members
k_{g23} = 1.0

(b) Continuous member in contact with a gapped member
k_{g23} = 1.2

(c) Butted member
k_{g23} *depends on gap size*

Figure 6.4. *Illustration of 3 cases to determine gap factor k_{g23} for contact surfaces*.

6.2. Decay Lag

The decay lag, t_{lag} (years), is given by

$$t_{lag} = 8.5r^{-0.85} \tag{6.11}$$

6.3. Service Life

For a give time lag, t_{lag}, and decay rate, r, the life for serviceabilityis determined by

$$L_S = \left(t_{lag} + \frac{5}{r} \right) \sqrt{\frac{2}{5}} \tag{6.12}$$

which can be derived from Eq. (6.1) by assuming $d_0 = 5$ mm and $d = 2$ mm. Similarly, the life for replacement, L_R, is determined by

$$L_R = t_{lag} + \frac{10}{r} \tag{6.13}$$

by assuming $d = 10$ mm in Eq. (6.1).

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Appendix A L-Joint Data

A.1 Data from the Beerburrum Site

The CDF estimates of decay lag, in terms of Class Data, for sapwood, and the untreated heartwood of durability classes of 1 to 4, both painted and unpainted, are shown in Figs A.1 and A.2. The decay lags are assumed to follow lognormal distribution. Derivation of the distribution parameters is described in Section 5.2. The probability distributions of decay lag are determined by the relationship between the decay lag and decay rate, also described in Section 5.2. Table A.1 gives the means and the medians of decay lags, and Table A.2 that of decay rates, determined from the assumed probability distributions.

For the Beerburrum site, the measured median decay lag and rate, in terms of Species Data, are listed in Table A.3.

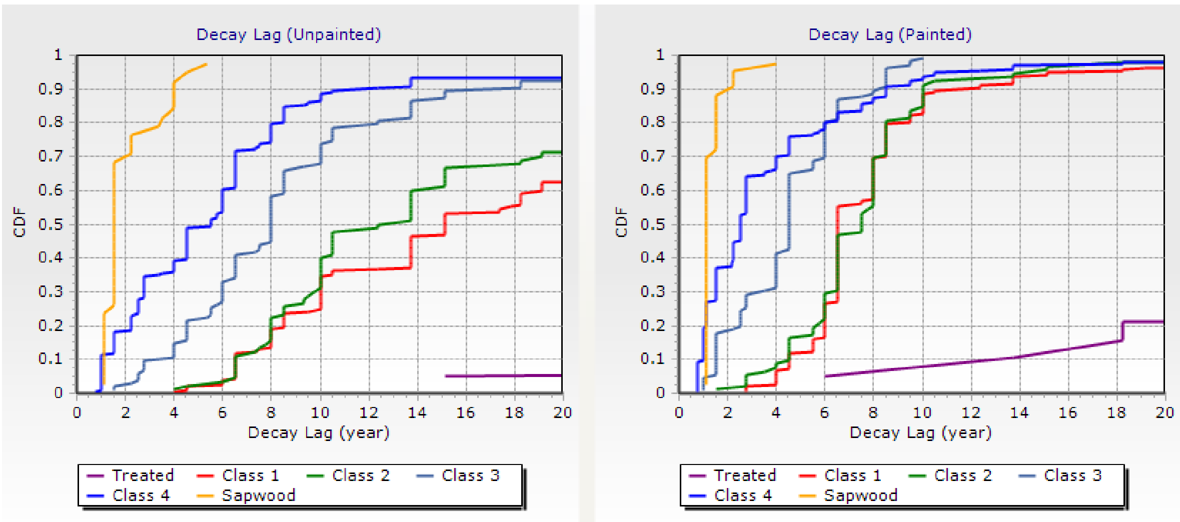
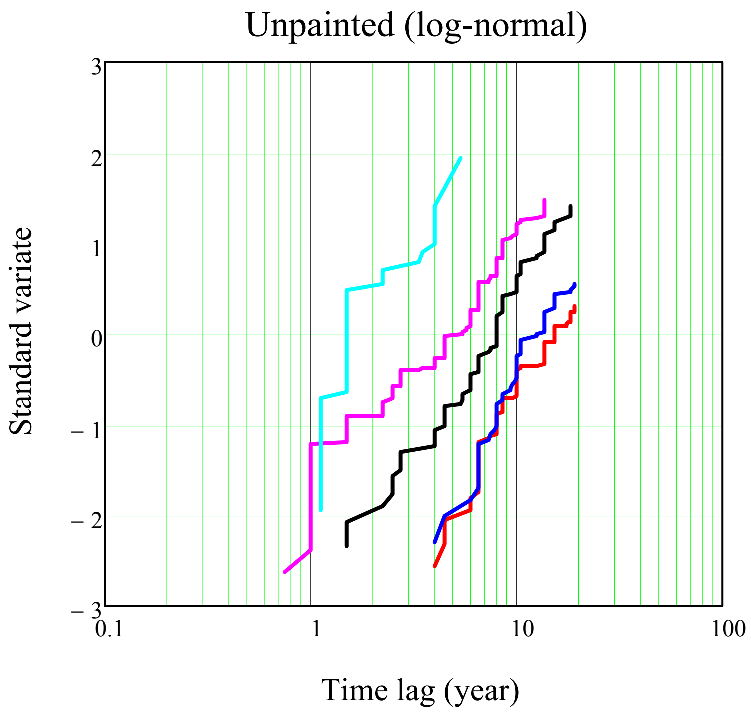
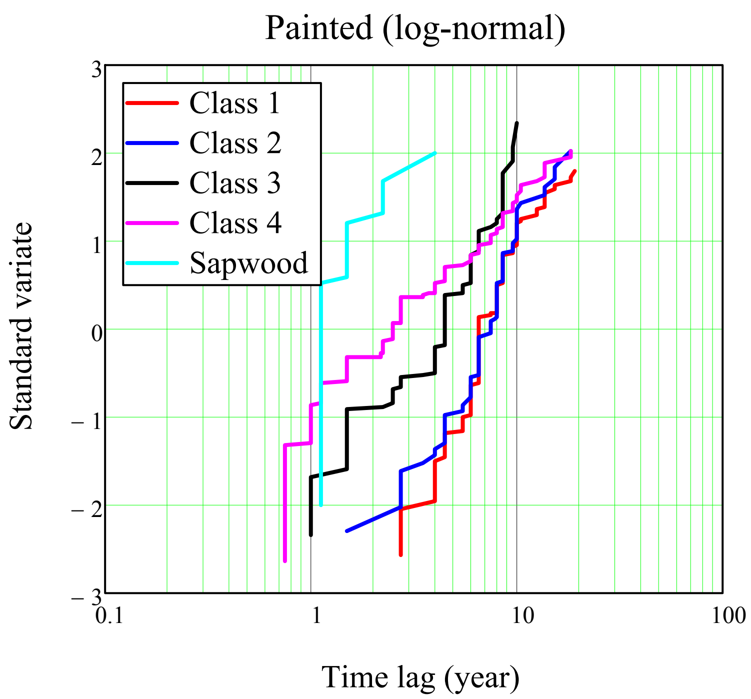


Figure A.1 Cumulative distribution of decay lags for painted and unpainted specimens



(a) unpainted specimens



(b) painted specimens

Figure A.2 Measured decay lags plotted on log-normal probability papers: (a) unpainted specimens; (b) painted specimens

Table A.1 Median and mean decay lag, determined from assumed lognormal distribution, of L-joint specimens at Beerburrum test site (Class Data)

Wood Type		**Median (yrs)**	**Mean (yrs)**
Paint	**Durability Class**		
Unpainted	1	14.9	17.7
	2	12.5	14.1
	3	7.5	9.1
	4	4.4	6.3
	Sapwood	1.8	2.0
Painted	1	7.2	7.7
	2	7.0	7.5
	3	3.9	4.6
	4	2.6	3.8
	Sapwood	1.3	1.3

Table A.2 Measured median and mean decay rate, determined from assumed lognormal distribution, of L-joint specimens at Beerburrum test site (Class Data)

Wood Type		**Median (mm/yr)**	**Mean (mm/yr)**
Paint	**Durability Class**		
Unpainted	1	1.10	1.23
	2	1.22	1.32
	3	1.64	1.88
	4	2.26	2.92
	Sapwood	3.86	4.16
Painted	1	1.69	1.76
	2	1.72	1.83
	3	2.44	2.76
	4	3.08	4.02
	Sapwood	4.69	4.77

Table A.3 Measured median decay lag and rate for the Beerburrum site (Species Data)

Species Number	Species Name	Painting	Dura. Class	Lag (years)	Rate (mm/yr)
7	spotted gum (Eucalyptus maculata)	1	1	> 20	-
7	spotted gum (Eucalyptus maculata)	2	1	6.875	1.615079
8	grey ironbark	1	1	> 20	-
8	grey ironbark	2	1	8.125	0.916667
14	white cypress (heartwood native)	1	1	> 20	-
14	white cypress (heartwood native)	2	1	16.6875	0
19	spotted gum (Eucalyptus citriodora)	1	1	> 20	-
19	spotted gum (Eucalyptus citriodora)	2	1	7.75	1.1

Species Number	Species Name	Painting	Dura. Class	Lag (years)	Rate (mm/yr)
20	spotted gum (Eucalyptus henryi)	1	1	7.833333	2.322222
20	spotted gum (Eucalyptus henryi)	2	1	5.5	1.006905
21	forest red gum (Eucalyptus tereticornis)	1	1	> 20	-
21	forest red gum (Eucalyptus tereticornis)	2	1	6.5	
22	blackbutt (regrowth heartwood)	1	1	9.625	0
22	blackbutt (regrowth heartwood)	2	1	7.25	
23	blackbutt (mature inner heartwood)	1	1	10.71875	0
23	blackbutt (mature inner heartwood)	2	1	6.5	0.814815
24	blackbutt (mature outer heartwood)	1	1	10.9375	1.1
24	blackbutt (mature outer heartwood)	2	1	7.875	
26	red mahogany	1	1	> 20	-
26	red mahogany	2	1	6.875	
6	western red cedar (regrowth heartwood)	1	2	8.958333	2.317857
6	western red cedar (regrowth heartwood)	2	2	8.9375	3.422222
27	rose gum	1	2	13.75	0
27	rose gum	2	2	7.9	1.333333
28	Sydney blue gum	1	2	13.1	0
28	Sydney blue gum	2	2	6.75	2.322222
32	Johnston River hardwood	1	2	> 20	-
32	Johnston River hardwood	2	2	6.375	1.986667
40	kapur	1	2	14.09375	0
40	kapur	2	2	6.75	0.785714
5	brush box (outer heartwood)	1	3	12.59375	0
5	brush box (outer heartwood)	2	3	6.25	2.444444
25	brush box (inner heartwood)	1	3	8	2.2
25	brush box (inner heartwood)	2	3	4.333333	2.444444
34	mountain ash	1	3	5.645833	2.563996
34	mountain ash	2	3	1.5	2.846032
35	alpine ash	1	3	7.5	3.098013
35	alpine ash	2	3	3.6875	1.906667
36	messmate	1	3	6.25	1.237678
36	messmate	2	3	4.5	1.631868
3	Douglas fir (regrowth heartwood)	1	4	3.5625	2.777109
3	Douglas fir (regrowth heartwood)	2	4	1.125	5.866667
4	northern silky oak	1	4	4.75	2.113135
4	northern silky oak	2	4	2.0625	2.867168
10	hoop pine (heartwood plantation)	1	4	1	5.5
10	hoop pine (heartwood plantation)	2	4	0.75	8.8
11	hoop pine (heartwood native	1	4	1.958333	3.357143
11	hoop pine (heartwood native	2	4	1.083333	5.866667
12	slash pine (heartwood plantation)	1	4	2.866667	3.079832
12	slash pine (heartwood plantation)	2	4	2.25	3.785714
13	Caribbean pine (heartwood plantation)	1	4	3.625	4.95

Species Number	Species Name	Painting	Dura. Class	Lag (years)	Rate (mm/yr)
13	Caribbean pine (heartwood plantation)	2	4	2.305556	6.6
16	radiata pine (heartwood plantation)	1	4	3	3.266106
16	radiata pine (heartwood plantation)	2	4	1.333333	4.661905
17	Douglas fir (mature heartwood)	1	4	7.875	1.850122
17	Douglas fir (mature heartwood)	2	4	6.25	2.807773
31	Queensland maple	1	4	6	2.410893
31	Queensland maple	2	4	3.25	2.04
33	rose alder	1	4	6.125	1.369963
33	rose alder	2	4	2.75	2.444444
37	light-red meranti	1	4	6.125	2.73254
37	light-red meranti	2	4	2.483333	2.921008
41	red balau	1	4	> 20	-
41	red balau	2	4	9.375	1.155651
42	kamarere	1	4	7	3.494118
42	kamarere	2	4	5	2.552288
9	radiata pine (CCA treated sapwood)	1	CCA	> 20	-
9	radiata pine (CCA treated sapwood)	2	CCA	> 20	-
1	radiata pine (untreated sapwood)	1	s	1.5	3.588095
1	radiata pine (untreated sapwood)	2	s	1.125	5.866667
2	white cypress (untreated sapwood)	1	s	1.5	3.142857
2	white cypress (untreated sapwood)	2	s	1.125	5.866667
15	black cypress (sapwood & heartwood native)	1		2.8	4.216667
15	black cypress (sapwood & heartwood native)	2		1.5	2.76746
29	fishtail silky oak	1	1	17.35938	0
29	fishtail silky oak	2	1	6.5	0.916667
30	white Eungella satinash	1	3	11.1875	0
30	white Eungella satinash	2	3	4.5	0.916667

A.2 Data from sites other than Beerburrum

For sites other than Beerburrum, the measured median decay lag and rate, in terms of Species Data, are listed in Table A.4.

Table A.4 Measured median decay lag and rate for sites other than Beerburrum

Site No.	Species No.	Species Name	Painting	Dura. Class	No. of specimens for Lag	Lag	No. of specimens for Rate	Rate
1	7	spotted gum (Eucalyptus maculata)	1	1	18	> 20	11	-
1	7	spotted gum (Eucalyptus maculata)	2	1	18	6.875	2	1.615079
1	8	grey ironbark	1	1	18	> 20	16	-
1	8	grey ironbark	2	1	18	8.125	1	0.916667
1	6	western red cedar (regrowth heartwood)	1	2	18	8.958333	14	2.25641
1	6	western red cedar (regrowth heartwood)	2	2	18	8.9375	9	3.422222
1	5	brush box (outer heartwood)	1	3	18	13.125	4	0
1	5	brush box (outer heartwood)	2	3	18	6.25	1	2.444444
1	3	Douglas fir (regrowth heartwood)	1	4	20	3.125	15	2.777109
1	3	Douglas fir (regrowth heartwood)	2	4	20	1.125	18	5.866667
1	4	northern silky oak	1	4	18	4.75	16	2.113135
1	4	northern silky oak	2	4	19	2.1	13	2.867168
1	9	radiata pine (CCA treated sapwood)	1	CCA	18	> 20	17	-
1	9	radiata pine (CCA treated sapwood)	2	CCA	18	> 20	14	-
1	1	radiata pine (untreated sapwood)	1	s	18	1.5	18	3.588095
1	1	radiata pine (untreated sapwood)	2	s	21	1.125	19	5.866667
1	2	white cypress (untreated sapwood)	1	s	19	1.5	18	3.142857
1	2	white cypress (untreated sapwood)	2	s	21	1.125	19	5.866667
2	7	spotted gum (Eucalyptus maculata)	1	1	18	> 20	16	-
2	7	spotted gum (Eucalyptus maculata)	2	1	18	8.875	5	0.956522
2	8	grey ironbark	1	1	18	> 20	15	-
2	8	grey ironbark	2	1	18	10.125	2	0.478261
2	6	western red cedar (regrowth heartwood)	1	2	18	10.5	8	1.65
2	6	western red cedar (regrowth heartwood)	2	2	18	10.25	13	1.65873
2	5	brush box (outer heartwood)	1	3	18	> 20	9	-
2	5	brush box (outer heartwood)	2	3	18	8	6	2.311594
2	3	Douglas fir (regrowth heartwood)	1	4	20	3.208333	15	2.367251

Site No.	Species No.	Species Name	Painting	Dura. Class	No. of specimens for Lag	Lag	No. of specimens for Rate	Rate
2	3	Douglas fir (regrowth heartwood)	2	4	20	1.875	19	3.247619
2	4	northern silky oak	1	4	18	10.125	5	1.571429
2	4	northern silky oak	2	4	19	5.2	12	2.793651
2	9	radiata pine (CCA treated sapwood)	1	CCA	18	> 20	13	-
2	9	radiata pine (CCA treated sapwood)	2	CCA	18	> 20	15	-
2	1	radiata pine (untreated sapwood)	1	s	18	4.3125	18	4.2
2	1	radiata pine (untreated sapwood)	2	s	19	1.5	19	3.314286
2	2	white cypress (untreated sapwood)	1	s	19	1.8	17	4.746667
2	2	white cypress (untreated sapwood)	2	s	19	1.5	18	4.635714
3	7	spotted gum (Eucalyptus maculata)	2	1	17	6.3	0	
3	8	grey ironbark	2	1	18	8	0	
3	6	western red cedar (regrowth heartwood)	1	2	9	9.5	1	4.4
3	6	western red cedar (regrowth heartwood)	2	2	10	8.666667	7	4.888889
3	5	brush box (outer heartwood)	1	3	6	9	0	
3	5	brush box (outer heartwood)	2	3	18	8.125	0	
3	3	Douglas fir (regrowth heartwood)	1	4	17	5.6	11	3.666667
3	3	Douglas fir (regrowth heartwood)	2	4	20	3.208333	17	2.863492
3	4	northern silky oak	1	4	15	6.4	7	2.677249
3	4	northern silky oak	2	4	18	4.75	9	2.591479
3	9	radiata pine (CCA treated sapwood)	2	CCA	2	10	0	
3	1	radiata pine (untreated sapwood)	1	s	18	6	15	3.561905
3	1	radiata pine (untreated sapwood)	2	s	21	1.95	18	2.793651
3	2	white cypress (untreated sapwood)	1	s	19	3.95	17	3.561905
3	2	white cypress (untreated sapwood)	2	s	20	2.430556	15	3.174603
4	7	spotted gum (Eucalyptus maculata)	1	1	18	> 20	17	-
4	7	spotted gum (Eucalyptus maculata)	2	1	17	11.1	1	0
4	8	grey ironbark	1	1	18	> 20	14	-
4	8	grey ironbark	2	1	18	13.75	9	0

Site No.	Species No.	Species Name	Painting	Dura. Class	No. of specimens for Lag	Lag	No. of specimens for Rate	Rate
4	6	western red cedar (regrowth heartwood)	1	2	16	10.5	0	
4	6	western red cedar (regrowth heartwood)	2	2	17	13.7	5	0
4	5	brush box (outer heartwood)	1	3	16	> 20	8	-
4	5	brush box (outer heartwood)	2	3	18	9.125	0	
4	3	Douglas fir (regrowth heartwood)	1	4	19	7.1	7	2.851852
4	3	Douglas fir (regrowth heartwood)	2	4	20	5.666667	11	3.142857
4	4	northern silky oak	1	4	18	14	5	0
4	4	northern silky oak	2	4	19	6.5	3	2.444444
4	9	radiata pine (CCA treated sapwood)	1	CCA	18	> 20	14	-
4	9	radiata pine (CCA treated sapwood)	2	CCA	18	> 20	15	-
4	1	radiata pine (untreated sapwood)	1	s	19	6.35	10	3.833333
4	1	radiata pine (untreated sapwood)	2	s	21	1.5	19	3.419048
4	2	white cypress (untreated sapwood)	1	s	19	3.95	18	3.75
4	2	white cypress (untreated sapwood)	2	s	21	1.425	18	4.719048
5	7	spotted gum (Eucalyptus maculata)	1	1	18	5.75	7	1.309524
5	7	spotted gum (Eucalyptus maculata)	2	1	18	4.5	3	0.709677
5	8	grey ironbark	1	1	18	6.5	5	0.709677
5	8	grey ironbark	2	1	18	5.875	1	0.785714
5	6	western red cedar (regrowth heartwood)	1	2	18	8.25	15	4.253333
5	6	western red cedar (regrowth heartwood)	2	2	18	6.0625	16	3.666667
5	5	brush box (outer heartwood)	1	3	18	6	8	0.865741
5	5	brush box (outer heartwood)	2	3	18	3.75	16	1.846154
5	3	Douglas fir (regrowth heartwood)	1	4	19	1.8	18	3.719048
5	3	Douglas fir (regrowth heartwood)	2	4	21	1.5	18	2.315789
5	4	northern silky oak	1	4	19	4.4	16	2.924603
5	4	northern silky oak	2	4	18	3.5625	13	2.358674
5	9	radiata pine (CCA treated sapwood)	1	CCA	17	> 20	17	-
5	9	radiata pine (CCA treated sapwood)	2	CCA	18	> 20	15	-
5	1	radiata pine (untreated sapwood)	1	s	20	2.25	19	4.08

Site No.	Species No.	Species Name	Painting	Dura. Class	No. of specimens for Lag	Lag	No. of specimens for Rate	Rate
5	1	radiata pine (untreated sapwood)	2	s	21	1.5	18	3.833333
5	2	white cypress (untreated sapwood)	1	s	21	1.125	20	5.866667
5	2	white cypress (untreated sapwood)	2	s	20	1.25	19	5.866667
6	7	spotted gum (Eucalyptus maculata)	1	1	17	> 20	14	-
6	7	spotted gum (Eucalyptus maculata)	2	1	18	7.25	0	
6	8	grey ironbark	1	1	18	> 20	17	-
6	8	grey ironbark	2	1	18	8.5	0	
6	6	western red cedar (regrowth heartwood)	1	2	16	9	9	3.911111
6	6	western red cedar (regrowth heartwood)	2	2	18	> 20	7	-
6	5	brush box (outer heartwood)	1	3	18	> 20	8	-
6	5	brush box (outer heartwood)	2	3	18	7.875	0	
6	3	Douglas fir (regrowth heartwood)	1	4	19	4.3	17	2.828571
6	3	Douglas fir (regrowth heartwood)	2	4	20	1.5	17	4.655238
6	4	northern silky oak	1	4	18	6.375	14	2.095752
6	4	northern silky oak	2	4	20	1.875	15	2.495238
6	9	radiata pine (CCA treated sapwood)	1	CCA	18	> 20	16	-
6	9	radiata pine (CCA treated sapwood)	2	CCA	18	> 20	17	-
6	1	radiata pine (untreated sapwood)	1	s	20	3.125	18	3.535714
6	1	radiata pine (untreated sapwood)	2	s	21	1.125	21	5.866667
6	2	white cypress (untreated sapwood)	1	s	21	1.425	19	4.232381
6	2	white cypress (untreated sapwood)	2	s	21	1.125	20	5.866667
7	7	spotted gum (Eucalyptus maculata)	1	1	18	> 20	10	-
7	7	spotted gum (Eucalyptus maculata)	2	1	18	6.125	1	2.2
7	8	grey ironbark	1	1	18	> 20	9	-
7	8	grey ironbark	2	1	18	6.875	0	
7	6	western red cedar (regrowth heartwood)	1	2	18	10.5	6	6.6
7	6	western red cedar (regrowth heartwood)	2	2	18	11.375	1	2.444444
7	5	brush box (outer heartwood)	1	3	18	10.5	3	0

Site No.	Species No.	Species Name	Painting	Dura. Class	No. of specimens for Lag	Lag	No. of specimens for Rate	Rate
7	5	brush box (outer heartwood)	2	3	18	7.875	0	
7	3	Douglas fir (regrowth heartwood)	1	4	18	5	17	3.107937
7	3	Douglas fir (regrowth heartwood)	2	4	20	1.5	16	3.82381
7	4	northern silky oak	1	4	18	6.5	8	3.404762
7	4	northern silky oak	2	4	19	4.5	8	2.315789
7	9	radiata pine (CCA treated sapwood)	1	CCA	18	> 20	15	-
7	9	radiata pine (CCA treated sapwood)	2	CCA	18	> 20	16	-
7	1	radiata pine (untreated sapwood)	1	s	19	1.95	18	2.586884
7	1	radiata pine (untreated sapwood)	2	s	21	1.275	20	4.95873
7	2	white cypress (untreated sapwood)	1	s	19	3.25	17	3.352381
7	2	white cypress (untreated sapwood)	2	s	21	1.2	21	5.866667
8	6	western red cedar (regrowth heartwood)	1	2	5	10.5	0	
8	6	western red cedar (regrowth heartwood)	2	2	4	14	0	
8	5	brush box (outer heartwood)	1	3	9	11.16667	0	
8	5	brush box (outer heartwood)	2	3	6	10.25	0	
8	3	Douglas fir (regrowth heartwood)	1	4	18	9.625	0	
8	3	Douglas fir (regrowth heartwood)	2	4	15	10.4	0	
8	4	northern silky oak	1	4	17	10.3	0	
8	4	northern silky oak	2	4	9	12.83333	3	4.4
8	9	radiata pine (CCA treated sapwood)	1	CCA	5	14	0	
8	9	radiata pine (CCA treated sapwood)	2	CCA	1	15.5	0	
8	1	radiata pine (untreated sapwood)	1	s	17	10.4	0	
8	1	radiata pine (untreated sapwood)	2	s	12	9.4375	9	5.866667
8	2	white cypress (untreated sapwood)	1	s	6	8.875	4	6.233333
8	2	white cypress (untreated sapwood)	2	s	9	7	6	3.3
9	7	spotted gum (Eucalyptus maculata)	1	1	18	> 20	10	-
9	7	spotted gum (Eucalyptus maculata)	2	1	18	6.125	5	2.2
9	8	grey ironbark	1	1	18	> 20	10	-
9	8	grey ironbark	2	1	18	6.75	5	2.2

Site No.	Species No.	Species Name	Painting	Dura. Class	No. of specimens for Lag	Lag	No. of specimens for Rate	Rate
9	6	western red cedar (regrowth heartwood)	1	2	17	9.65	6	4.033333
9	6	western red cedar (regrowth heartwood)	2	2	18	9.6875	8	2.793651
9	5	brush box (outer heartwood)	1	3	18	10.125	3	0
9	5	brush box (outer heartwood)	2	3	18	6.25	6	1.286154
9	3	Douglas fir (regrowth heartwood)	1	4	19	6.366667	13	3.666667
9	3	Douglas fir (regrowth heartwood)	2	4	17	6.966667	14	3.535714
9	4	northern silky oak	1	4	18	6.5	9	2.444444
9	4	northern silky oak	2	4	18	6.375	7	2.067669
9	9	radiata pine (CCA treated sapwood)	1	CCA	17	> 20	14	-
9	9	radiata pine (CCA treated sapwood)	2	CCA	17	> 20	14	-
9	1	radiata pine (untreated sapwood)	1	s	19	5.5	18	3.85
9	1	radiata pine (untreated sapwood)	2	s	20	4.166667	18	3.666667
9	2	white cypress (untreated sapwood)	1	s	19	4	18	3.535714
9	2	white cypress (untreated sapwood)	2	s	20	2.875	17	3.419048
10	7	spotted gum (Eucalyptus maculata)	1	1	18	> 20	17	-
10	7	spotted gum (Eucalyptus maculata)	2	1	18	7.75	0	
10	8	grey ironbark	1	1	18	> 20	14	-
10	8	grey ironbark	2	1	18	8.875	1	0
10	6	western red cedar (regrowth heartwood)	1	2	18	9.875	7	5.866667
10	6	western red cedar (regrowth heartwood)	2	2	18	10.25	6	0
10	5	brush box (outer heartwood)	1	3	18	10.5	5	0
10	5	brush box (outer heartwood)	2	3	18	7.5	1	3.666667
10	3	Douglas fir (regrowth heartwood)	1	4	17	6.3	11	3.666667
10	3	Douglas fir (regrowth heartwood)	2	4	19	7.4	10	2.380117
10	4	northern silky oak	1	4	18	7.625	5	2.444444
10	4	northern silky oak	2	4	18	6.375	9	2.498765
10	9	radiata pine (CCA treated sapwood)	1	CCA	18	> 20	16	-
10	9	radiata pine (CCA treated sapwood)	2	CCA	18	> 20	17	-
10	1	radiata pine (untreated sapwood)	1	s	18	6.125	18	4.3

Site No.	Species No.	Species Name	Painting	Dura. Class	No. of specimens for Lag	Lag	No. of specimens for Rate	Rate
10	1	radiata pine (untreated sapwood)	2	s	20	4.597222	14	3.619048
10	2	white cypress (untreated sapwood)	1	s	19	5.35	18	3.666667
10	2	white cypress (untreated sapwood)	2	s	19	4.75	17	3.88
11	7	spotted gum (Eucalyptus maculata)	1	1	18	> 20	8	-
11	7	spotted gum (Eucalyptus maculata)	2	1	18	8	0	
11	8	grey ironbark	1	1	18	> 20	11	-
11	8	grey ironbark	2	1	18	10	2	0
11	6	western red cedar (regrowth heartwood)	1	2	18	15.5	10	1.762821
11	6	western red cedar (regrowth heartwood)	2	2	17	9.6	14	1.728571
11	5	brush box (outer heartwood)	1	3	18	> 20	10	-
11	5	brush box (outer heartwood)	2	3	18	6.5	3	2.444444
11	3	Douglas fir (regrowth heartwood)	1	4	18	5.375	15	3.073016
11	3	Douglas fir (regrowth heartwood)	2	4	19	6.916667	18	2.380117
11	4	northern silky oak	1	4	18	6.5	15	1.731941
11	4	northern silky oak	2	4	19	4.9	14	2.269006
11	9	radiata pine (CCA treated sapwood)	1	CCA	18	> 20	18	-
11	9	radiata pine (CCA treated sapwood)	2	CCA	18	> 20	17	-
11	1	radiata pine (untreated sapwood)	1	s	19	3.6	18	3.666667
11	1	radiata pine (untreated sapwood)	2	s	21	2.25	17	2.977444
11	2	white cypress (untreated sapwood)	1	s	20	4.083333	18	3.75
11	2	white cypress (untreated sapwood)	2	s	18	6.958333	18	4.3

Appendix B Processing Climate Data

The following indicates the development of a procedure to obtain the duration of a rainfall from R_{3hr}, the 3-hour rainfall recorded by the BOM.

To do this, a set of half-hour-interval data for the years 2000 and 2001 has been obtained from the BOM for nine cities: Adelaide, Alice Springs, Brisbane, Canberra, Darwin, Hobart, Melbourne, Perth, and Sydney. For rainfall duration estimation, it is assumed that whenever there is rainfall in a half-hour interval, the rainfall intensity is constant over the interval. Hence for each value of 3 hourly rainfall R_{3hr}, there is an effective rainfall duration t_d (hr) that is either 0, 0.5, 1.0, 1.5, 2.0, 2.5 or 3.0 hours.

For each city, the values of the rainfall duration, t_d (hr) were grouped according to R_{3hr} intervals and then averaged to produce the points shown in Fig. B.1.

The averages of the groupings are then used for determination of relationship between three-hour rainfall and its duration as follows:

$$t_d = 1.2 + 0.3 \ln R_{3hr} \tag{B.1}$$

but not less than zero.

The location of the BOM weather recording sites used to develop map are shown in Fig. B.2. Tables B.1-B.3 give the annual rainfall duration for all test sites, computed with the use of equation (B.1).

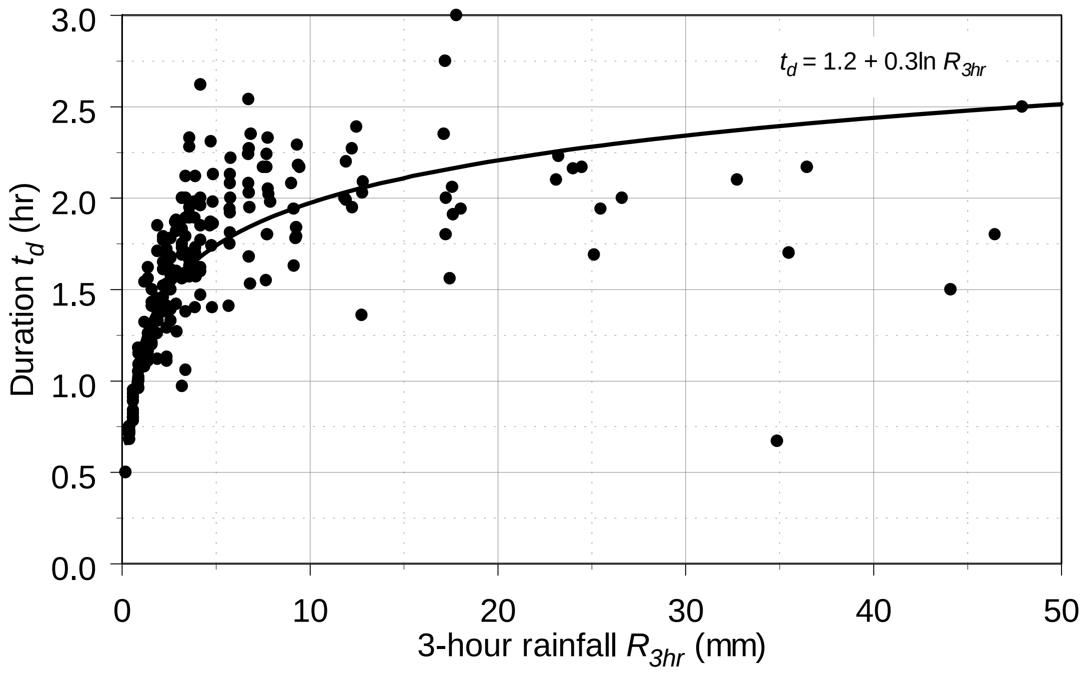


Figure B.1 Duration vs. three-hourly rainfall derived from half-hourly rainfall data.

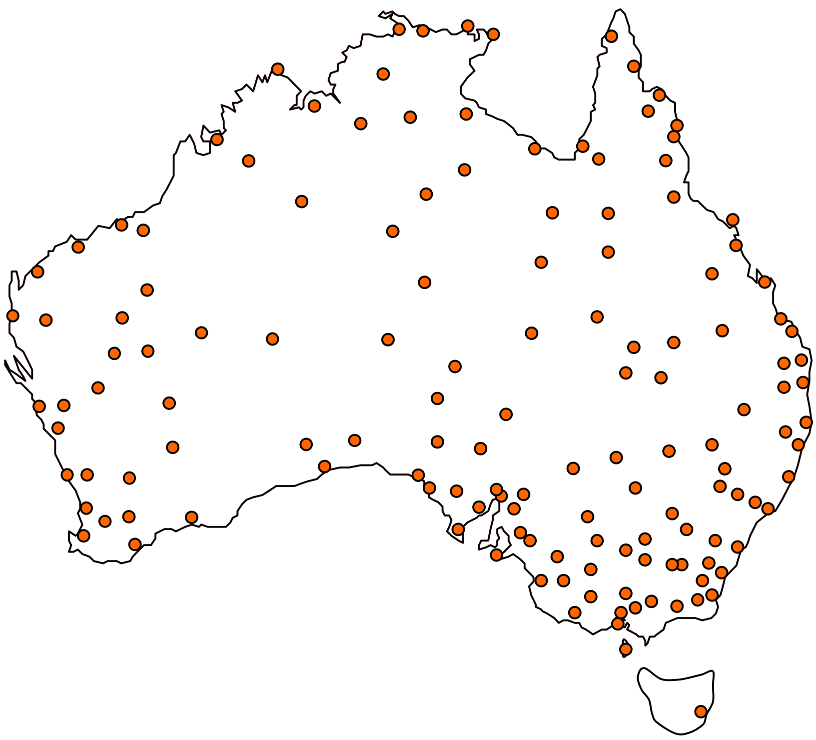


Figure B.2 Location of meteorological sites for the Bureau of Meteorology data

Table B.1 Time of rainfall at the test sites for L-joint Tests

Site Name	Longitude	Latitude	Time of rainfall (days/yr)
Beerburrum	152.97	-26.97	23.4
Rockhampton	150.53	-23.33	15.8
Mackay	149.134	-21.19	19.9
Townsville	146.8	-19.22	7.85
Sth Johnstone	145.9	-17.35	58.2
Toowoomba	151.9	-27.58	17.8
Dalby	151.2	-27.18	25.2
Mt Isa	139.48	-20.83	4.16
Sydney	151.17	-33.92	22.4
Canberra	149.13	-35.3	15.4
Melbourne	144.97	-37.75	17.1

Table B.2 Time of rainfall at the test sites for Panel Test No. 1

Site Name	Longitude	Latitude	Time of rainfall (days/yr)
Adelaide (SA)	138.6	-34.93	13.3
Batlow (NSW)	148.17	-35.53	15.7
Brisbane (QLD)	153	-27.67	24.8
Canberra (ACT)	149.13	-35.3	17.7
Creswick (VIC)	143.97	-37.45	18.8
Dalby (QLD)	151.2	-27.18	25.2
Dubbo (NSW)	148.68	-32.27	11.3
Griffith (NSW)	146.07	-34.3	10.4
Hobart (TAS)	147.3	-42.9	18.6
Horsham (VIC)	142.25	-36.75	14.7
Innisfail (QLD)	146	-17.5	58.2
Katherine (NT)	132.33	-14.48	14.2
Mackay (QLD)	149.33	-21.17	19.9
Manjimup (WA)	116.1	-34.23	25.8
Melbourne (VIC)	144.97	-37.75	21.8
Mount Gambier (SA)	140.83	-37.85	22.7
Narrogin (WA)	117.17	-32.97	15
Perth (WA)	115.82	-31.93	20.6
Port Hedland (WA)	118.6	-20.4	5.7
Powelltown (VIC)	145.73	-37.87	21.7
Wirrabara (SA)	138.3	-33.05	6

Table B.3 Time of rainfall at the test sites for Panel Test No. 2

Site Name	Longitudinal	Latitude	Time of rainfall (days/yr)
Adelaide (SA)	138.6	-34.93	13.3
Batlow(Tumbarumba) (NSW)	148.15	-35.53	15.7
Beerburrum (QLD)	152.97	-26.97	23.4
Brisbane(Salisbury (QLD)	153.1	-27.47	21.6
Canberra (ACT)	149.22	-35.28	17.7
Creswick (VIC)	143.9	-37.43	18.8
Dalby(Dunmore) (QLD)	151.2	-27.53	25.2
Dubbo (NSW)	148.62	-32.25	11.3
Frankston(Melbourne) (VIC)	145.18	-38.1	19.5
Griffith (NSW)	146.35	-34.23	10.4
Highett(Melbourne) (VIC)	145.17	-37.98	19.8
Hobart (TAS)	147.25	-42.08	18.6
Horsham(Wail) (VIC)	142.1	-36.05	14.7
Innisfail (QLD)	146.03	-17.52	58.2
Manjimup (WA)	116.15	-34.25	25.8
Mount Gambier (SA)	140.78	-37.08	23.3
Narrandera (NSW)	146.55	-34.75	13.4
Narrogin (WA)	117.18	-32.93	15
Pennant Hills(Sydney) (NSW)	151.05	-33.68	22.4
Perth(Como) (WA)	115.08	-31.92	20.6
Port Hedland (WA)	118.6	-20.37	5.7
Powelltown (VIC)	145.73	-37.87	21.7
Rockhampton(Mackay) (QLD)	148.65	-20.08	15.5
Rowville(Melbourne) (VIC)	145.3	-38.03	19.8
Taree (NSW)	152.6	-31.83	22.9
Walpeup (VIC)	142.03	-35.13	11.8
Wirrabara (SA)	138.27	-33.03	6