Forest&Wood Products Australia
Knowledge for a sustainable Australia

USP2007/049

MANUAL NO. 12

Equations for Use in TimberLife

C-H. Wang, R.H. Leicester, and M. Nguyen

April 2008

CSIRO

Please address all enquiries to:
Urban Systems Program
CSIRO Sustainable Ecosystems
P.O. Box 56, Highett, Victoria 3190

Acknowledgments

This Manual is one of a series of Manuals that have been produced as part of a project titled 'Design for Durability'. The authors are deeply indebted to the Forest and Wood Products Australia for their funding and collaboration in this project over the past 10 years. The authors would especially like to thank Colin MacKenzie (Timber Queensland) for the major role that he has played in managing and guiding this project to completion. Thanks go to Greg Foliente, Craig Seath, Sandra Roberts and numerous other CSIRO personnel for their assistance and contribution to this project.

Contents

Executive Summary

- This report documents the equations used in the development of the educational software package, TimberLife. That Windows-based computer program is intended as an educational tool that gives estimates of average or typical attack consequences on timber construction. The background documents for development of the service life prediction models and equations are given in References section.

1. Decay in Ground Contact

Equation Section (Next)

The following assumptions were made in computing the service lives of timber poles and posts in the design guide:

- Progress of decay depth with time t in a timber element follows an idealised bilinear relationship characterised by a decay lag, t_{lag} (years), and a decay rate, r (mm/year).
- The corewood diameter is 1/3 of the overall
- For treated softwood, the CCA penetration area is 80% of the cross-section
- For treated hardwood, the CCA penetration is 15 mm for decay classes 1 & 2, 20 mm for classes 3 & 4

1.1. Model Assumptions

A schematic illustration for decay progress is shown in Figure 1.1. For given d_0, t_{lag}, and r, 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 expression for decay rate r is described in the next subsection.

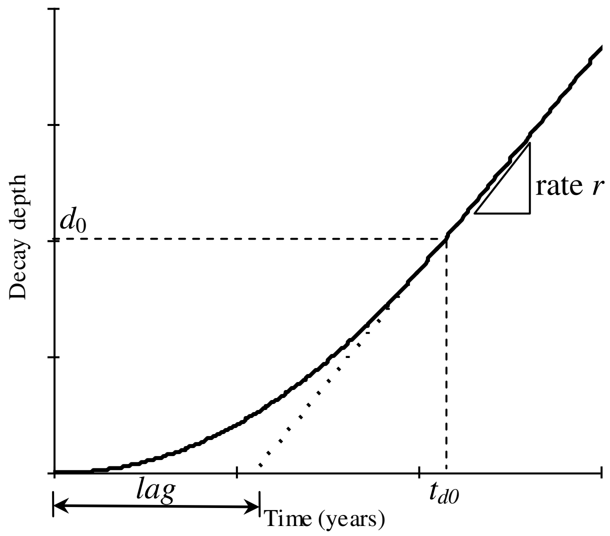


Figure 1.1 Idealised progress of decay depth with time.

1.2. Decay Rate for Untreated Wood Stakes

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:

$$r_{un,stake} = k_{wood} k_{climate} \tag{1.4}$$

where k_{wood} = wood parameter and $k_{climate}$ = climate parameter.

1.2.1. Wood Parameter for Heartwood

$$k_{wood,heart} = \begin{cases} 0.23 & \text{for class 1;} \\ 0.48 & \text{for class 2;} \\ 0.76 & \text{for class 3;} \\ 1.36 & \text{for class 4.} \end{cases} \tag{1.5}$$

1.2.2. Wood Parameter for Sapwood

$$k_{wood,sap} = \begin{cases} 2.72 & \text{for hardwood;} \\ 5.44 & \text{for softwood.} \end{cases} \tag{1.6}$$

1.2.3. Wood Parameter for Corewood

$$k_{wood,core} = 2k_{wood,heart} \tag{1.7}$$

1.2.4. Decay Rate for Treated Wood Stakes

It is assumed that in a treated timber log, the sapwood is the only type of wood treated with preservative, whilst the heartwood remains untreated.

To facilitate computation, the retention a preservative is converted into a CCA equivalent. For creosote retention, C_{creosote} (in %kg/kg), its CCA equivalent, $C_{\text{CCA-equiv}}$ (in %kg/kg), is

$$C_{\text{CCA-equiv}} = \begin{cases} 0.07C_{\text{creosote}} & \text{for softwoods;} \\ 0.01C_{\text{creosote}} & \text{for hardwoods;} \end{cases} \tag{1.8}$$

If retention is given in kg/m^3, the conversion between %kg/kg and kg/m^3 may be done by (David Gardner, 2001)

$$\text{kg/kg}(\%) = \begin{cases} \dfrac{0.36\times\ \text{kg/m}^3}{D}\times 100 & \text{for CCA treatment,} \\ \dfrac{\text{kg/m}^3}{D}\times 100 & \text{for creosote treatment.} \end{cases} \tag{1.9}$$

in which D is the air-dry density of timber (kg/m^3).

The decay rate of treated sapwood, $r_{\text{tr,sap,stake}}$, is determined by

$$r_{\text{tr,sap,stake}} = \frac{r_{\text{un,sap,stake}}}{1 + B\times C_{CCA-equiv}} \tag{1.10}$$

where $r_{\text{un,sap,stake}}$ is the decay rate of untreated sapwood from Eqs. (1.4) and (1.6); B is given by

$$B = \begin{cases} 45 & \text{for softwoods,} \\ 12 & \text{for hardwoods.} \end{cases} \tag{1.11}$$

1.3. Climate Parameter

The climate parameter values used for the design guide service life computation is shown in Table 1.1.

Table 1.1 Climate parameter values used for service life computation

Hazard Zone	$k_{climate}$
A	0.5
B	1.5
C	2.5
D	3.0

1.4. Decay Lag

The decay lag and decay rate are correlated; therefore, given a decay rate r determined as described in the previous subsection, the decay lag, t_{lag} (years), is given by

$$t_{lag} = 5.5r^{-0.95} \tag{1.12}$$

1.5. Decay Progress and Parameters of Round Poles

1.5.1. Decay Patterns

Decay in a timber pole can initiate both from the perimeter progressing inwards and from the pith zone progressing outwards, as illustrated in Figure 4.5.1. It is observed also that both the lag time and decay rate of treated perimeter sapwood as well as corewood of a timber pole are different from that observed from small stake tests.

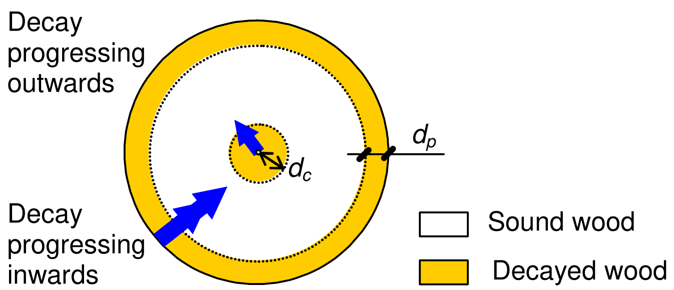


Figure 1.2 Decay patterns of round poles.

1.5.2. Model parameters for decay progressing inwards

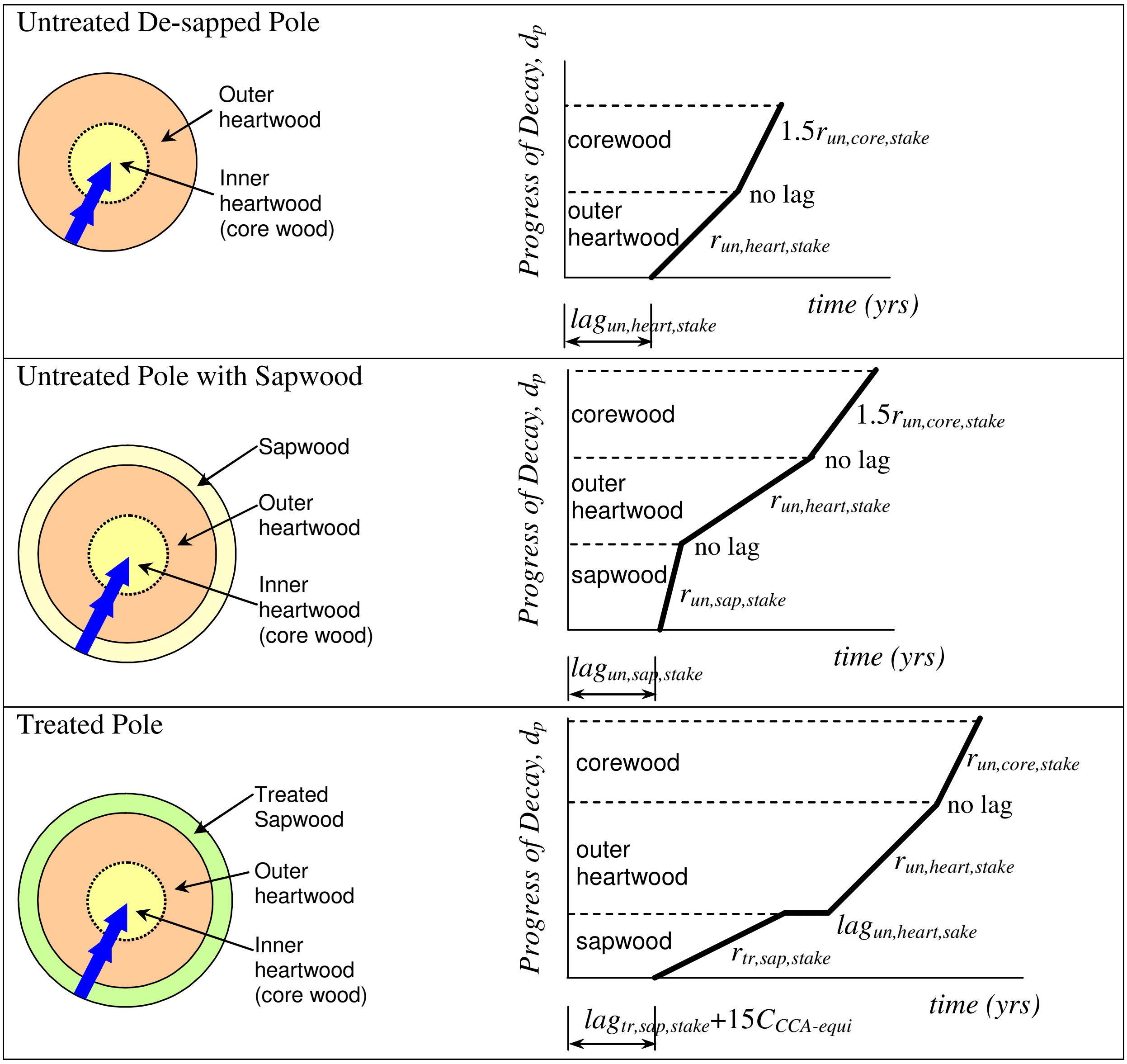


Figure 1.3 Decay of poles progressing inwards

1.5.3. Model parameters for Decay Progressing Outwards

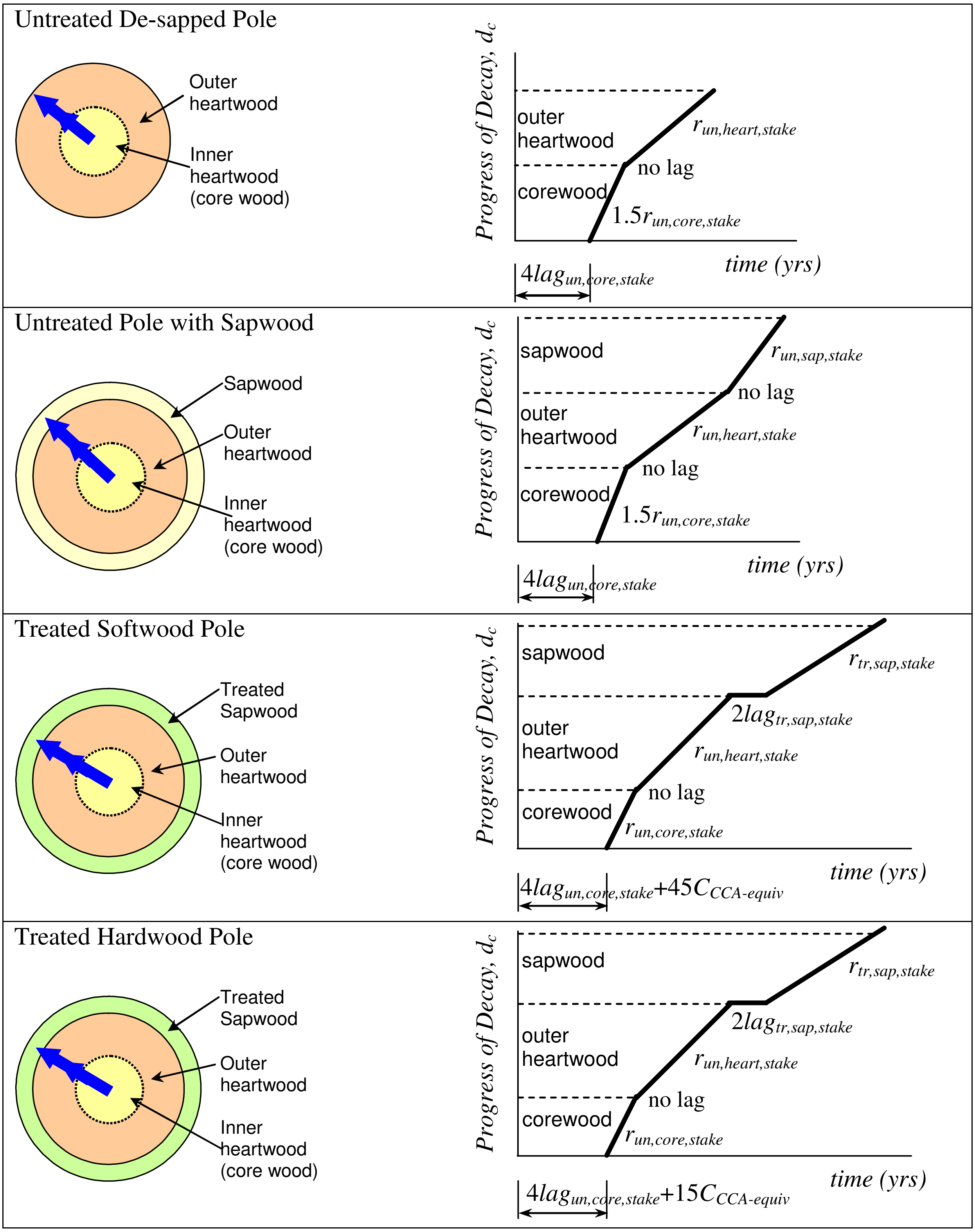
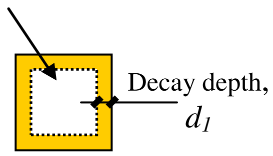
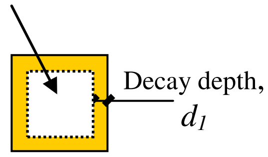
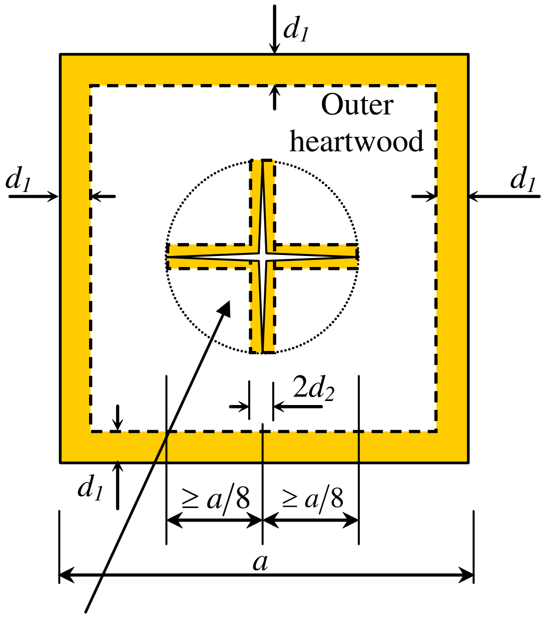
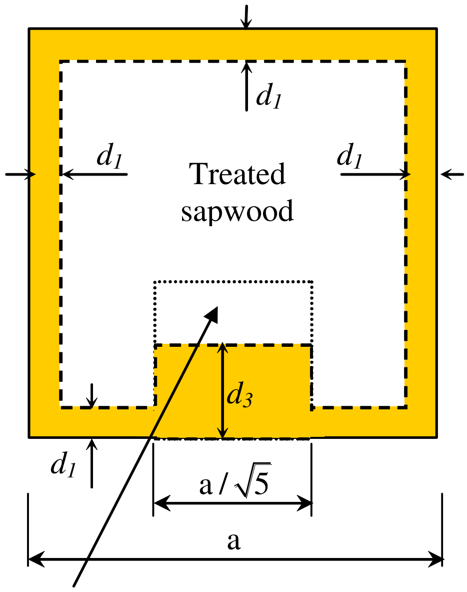


Figure 1.4 Decay of poles progressing outwards

1.6. Decay parameters of Square Posts

Table 4.6.1 Cross-sections of square posts and decay paterns

	UNTREATED HARDWOOD	TREATED SOFTWOOD
Small size 100x100 150x150	Outer heartwood 	Treated sapwood 
Large size 200x200 250x250	 Corewood	 Outer heartwood (20% of total section area)

2. Decay Above-Ground

Equation Section (Next)

The following assumptions were made in computing the time for serviceability and replacement of timber elements above-ground:

- Progress of decay depth with time t in a timber element is characterised by a decay lag, t_{lag} (years), and a decay rate, r (mm/year).
- The life for serviceability is reached when surface decay depth exceeds 2 mm
- The life for replacement is reached when surface decay depth exceeds 10 mm

2.1. Decay Depth

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

$$d_t = \begin{cases} ct^2 & \text{if } t \le t_{d_0}; \\ (t - t_{lag})r & \text{if } t > t_{d_0}. \end{cases} \tag{2.1}$$

in which

$$t_{d_0} = t_{lag} + \frac{d_0}{r} \tag{2.2}$$

$$c = \frac{d_0}{t_{d_0}^2} \tag{2.3}$$

2.2. Decay Lag

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

$$t_{lag} = 8.5r^{-0.85} \tag{2.4}$$

2.3. Decay Rate

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

$$r = k_{wood} k_{climate} k_t k_w k_n k_g \tag{2.5}$$

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.

$$k_{wood} = \begin{cases} 0.25 & \text{for treated wood;} \\ 0.50 & \text{for class 1;} \\ 0.62 & \text{for class 2;} \\ 1.14 & \text{for class 3;} \\ 2.20 & \text{for class 4;} \\ 6.52 & \text{for sapwood.} \end{cases} \tag{2.6}$$

The climate parameter values for the four hazard zones are taken as shown in Table 2.1.

Table 2.1 $k_{climate}$ 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

2.3.1. 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,

$$k_t = \begin{cases} 1 & \text{for } t \geq 20 \text{ mm} \\ 0.5 & \text{for } t \leq 20 \text{ mm} \\ 0.05t & \text{otherwise} \end{cases} \tag{2.7}$$

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

2.3.2. *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,

$$k_w = \begin{cases} 1 & \text{for } w \le 50 \text{ mm} \\ 1.5 & \text{for } w \ge 200 \text{ mm} \\ \dfrac{w}{300} + \dfrac{5}{6} & \text{otherwise} \end{cases} \tag{2.8}$$

Illustration of the width on member cross section is in Figure 2.1.

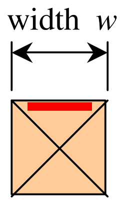


Figure 2.1 Illustration of the width w used to determine the width parameter

2.3.3. *Paint Parameter*

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

$$k_p = \begin{cases} 2.0 & \text{for painted wood;} \\ 1.0 & \text{for unpainted wood.} \end{cases} \tag{2.9}$$

2.3.4. *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, $k_n = 1.0$.

2.3.5. *Geometry Parameter*

The geometry parameter, k_g, is expressed as,

$$k_g = k_{g1}\, k_{g2} \tag{2.10}$$

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

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:

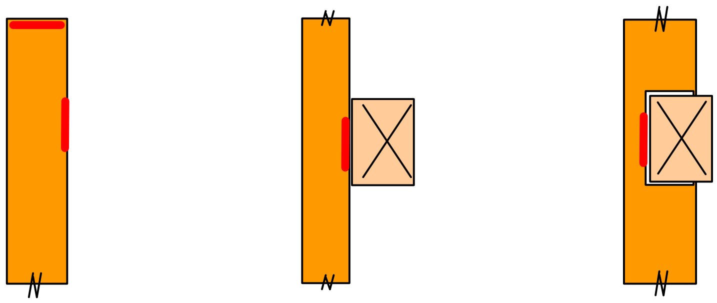
- Flat contact:

$$k_{g1} = 0.6$$

- Embedded contact: (reference to L-joint)

$$k_{g1} = 1.0$$

Illustration of the contacts is shown in Figure 2.2.



(i) Non-contact $k_{g1} = 0.3$ (ii) Flat contact $k_{g1} = 0.6$ (iii) Embedded contact $k_{g1} = 1.0$

Figure 2.2 Illustration of non-contact, flat contact and embedded contact.

Position factor for non-contact surface

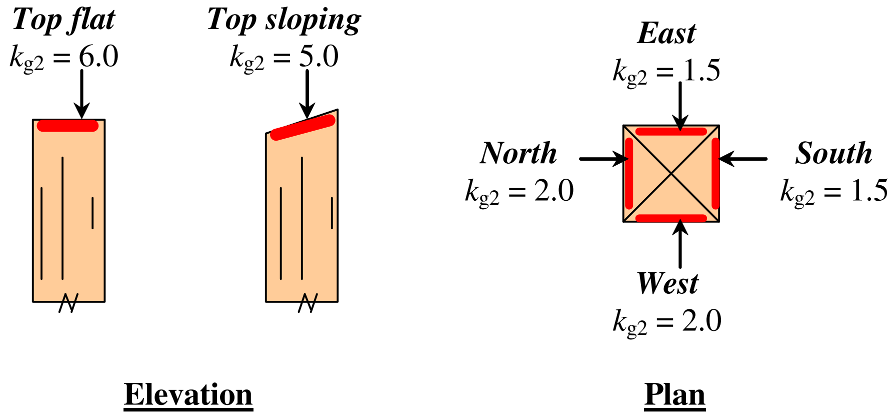
The position factor k_{g2} for non-contact surfaces takes into account of the orientation of the member, orientation of the surface, and sheltering effect. It is noted that the surface orientation effect is due to the mechanical degradation caused by sun.

(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 2.3 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: $k_{g2} = 4.0$

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

$$k_{g2} = k_{g21}\, k_{g22}\, k_{g23} \tag{2.11}$$

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:

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

$k_{g23} = 1.0$

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

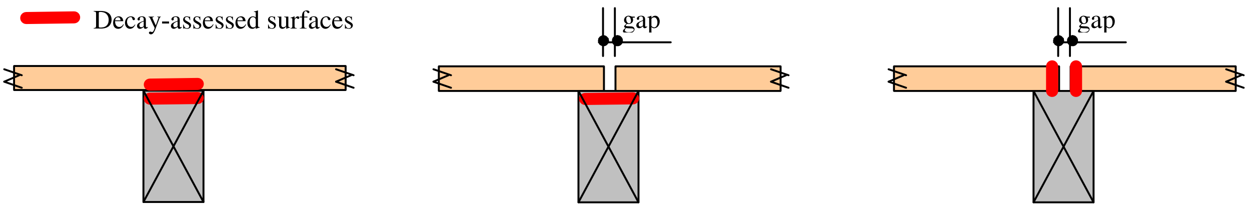
$k_{g23} = 1.2$

(c) A butted member:

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

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

Illustrations of these cases are given in Figure 2.4.



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

2.4. Failure Criteria

For serviceability, decay depth = 2 mm.

For replacement, decay depth = 10 mm.

3. Atmospheric Corrosion Exposed to Weather

Equation Section (Next)

3.1. Notations

c_0 : the first-year corrosion depth (µm)
c_b : corrosion depth near the neck of the bolt
D_{rain} : number of raindays (days)
L_{coast} : distance to coast (km)
L_{indus} : distance to the industry (km)
P_{air}: airborne pollution agent (µg/m^3)
S_{air} : airborne salinity (mg/m^2/day)
t : time (years)
t_{wet} : time of wetness (%)
λ_b: enhancement factor for bolts
λ_r: enhancement factor for fasteners under corrugated roofing of an open space

3.2. Corrosion of Fasteners

3.2.1. Corrosion of Zinc

The corrosion depth of zinc over time, c_z (µm), is determined by the following power-law equation,

$$c_z = c_{0,z} t^{0.6} \tag{3.1}$$

where t (year) is the time in service. $c_{0,z}$ is the basic corrosion depth dependent on the presence of pollution agents,

$$c_{0,z} = 0.025\, t_{\mathrm{wet}}^{0.6} S_{\mathrm{air}}^{0.5} + 0.006 t_{wet}^{0.2} P_{air} \tag{3.2}$$

where t_{wet} is time of wetness, which is defined as the percentage of time in a year when the relative humidity is above 80% and the temperature above 0°C. S_{air} (mg/m^2/day) is the salt concentration in the air (airborne salinity). P_{air} is the pollution of air due to the concentration of SO_x ($\mu g/m^3$).

3.2.2. Corrosion of Steel

The corrosion depth of steel over time, c_s (μm), is determined by the following power-law equation,

$$c_s = c_{0,s} t^{0.8} \tag{3.3}$$

where t (year) is the time in service. $c_{0,s}$ is the basic corrosion depth dependent on the presence of pollution agents,

$$c_{0,s} = 0.5 t_{wet}^{0.8} S_{air}^{0.5} + 0.1 t_{wet}^{0.5} P_{air} \tag{3.4}$$

where t_{wet} is time of wetness, which is defined as the percentage of time in a year when the relative humidity is above 80% and the temperature above 0°C. S_{air} (mg/m^2/day) is salt concentration in the air (airborne salinity). P_{air} is the pollution of air due to the concentration of SO_x ($\mu g/m^3$).

3.2.3. Air Salinity

The salinity in the air at a site, S_{air} (mg/m^2 per day), is estimated by the following equation,

$$S_{\mathrm{air}} = \max \begin{cases} \alpha_{\mathrm{exp}} \alpha_{\mathrm{micro}} \left[\alpha_{\mathrm{coast}} \beta_{\mathrm{coast}} \left(0.9 e^{-10 L_{coast}} + 0.1 e^{-L_{coast}} \right) + \alpha_{\mathrm{ocean}} e^{-0.02 L_{\mathrm{coast}}} \right] \\ 1.0 \end{cases} \tag{3.5}$$

in which L_{coast} is the distance to the coast in kilometres; the parameters α_{coast} and α_{ocean} take into account the effect of coastal zoning (Table 3.1); β_{coast} the effect of coastal exposure (Table 3.2); α_{exp} the effect of site exposure (Table 3.3); and α_{micro} the effect of local shelter factors (Table 3.4).

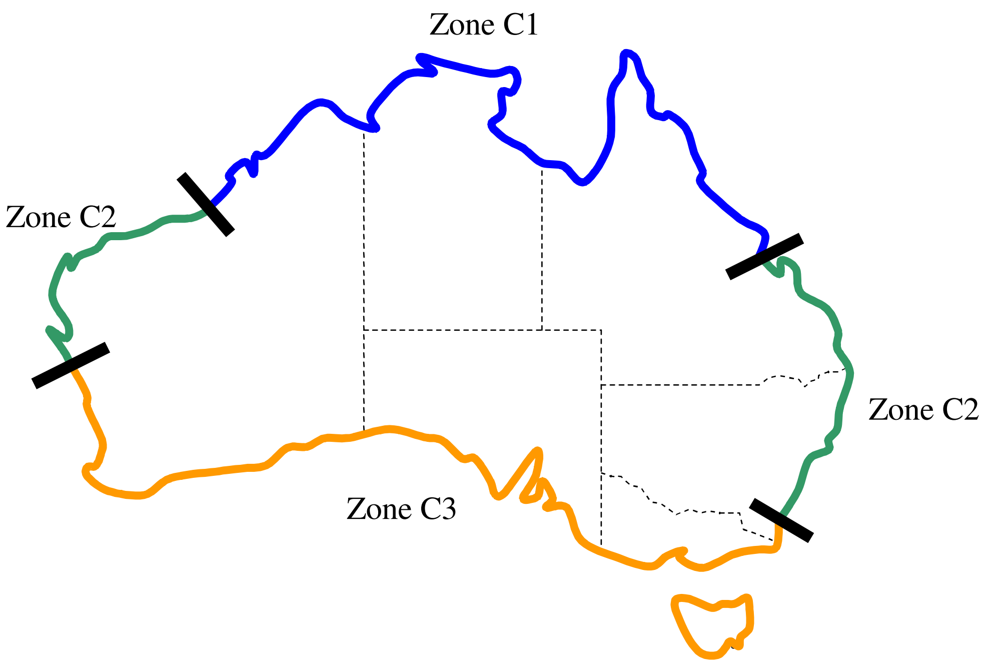


Figure 3.1 *Definition of coastal zones.*

Table 3.1 Parameters for the effect of coastal and ocean surf

Coastal zone*	α_{coast}	α_{ocean}
C_1	50	2
C_2	150	6
C_3	500	20
* See Figure 3.1.		

Table 3.2 Parameter for the effect of coastal exposure

Coastal exposure condition*	β_{coast}
Closed bay	0.05
Partially closed bay	0.10
Open bay	0.35
Open surf	1.00
* See Figure 3.2.	

Table 3.3 Parameters for the effect of site classification

Site classification	α_{exp}
Open to sea	2.00
Urban (suburbs)	0.50
Urban (city centre)	0.25
Other sites	1.00

Table 3.4 Parameter for the effect of shelter (rain protection)

Local Shelter	α_{micro}
Sheltered from rain	2.0
Exposed to rain	1.0

The coastal exposure condition is dependent on the opening angle, θ (degrees), and the radius, R (km), of the bay. By using an exposure factor for the idealised bay, α_{bay}, calculated as follows for a given θ and R,

$$\alpha_{\mathrm{bay}}^2 = \left(\frac{\theta}{85}\right)^2 + \left(\frac{R}{20}\right)^2 \tag{3.6}$$

then the coastal exposure condition is determined by the α_{bay} value:

$$\text{Coastal exposure condition} = \begin{cases} \text{Closed bay,} & \text{if } \alpha_{bay} < 1; \\ \text{Partially closed bay,} & \text{if } 1 \le \alpha_{bay} < 1.5; \\ \text{Open bay,} & \text{if } 1.5 \le \alpha_{bay} < 2.5; \\ \text{Open surf,} & \text{if } \alpha_{bay} \ge 2.5. \end{cases} \tag{3.7}$$

The definition of Eq. (3.7) is schematically shown in Figure 3.2.

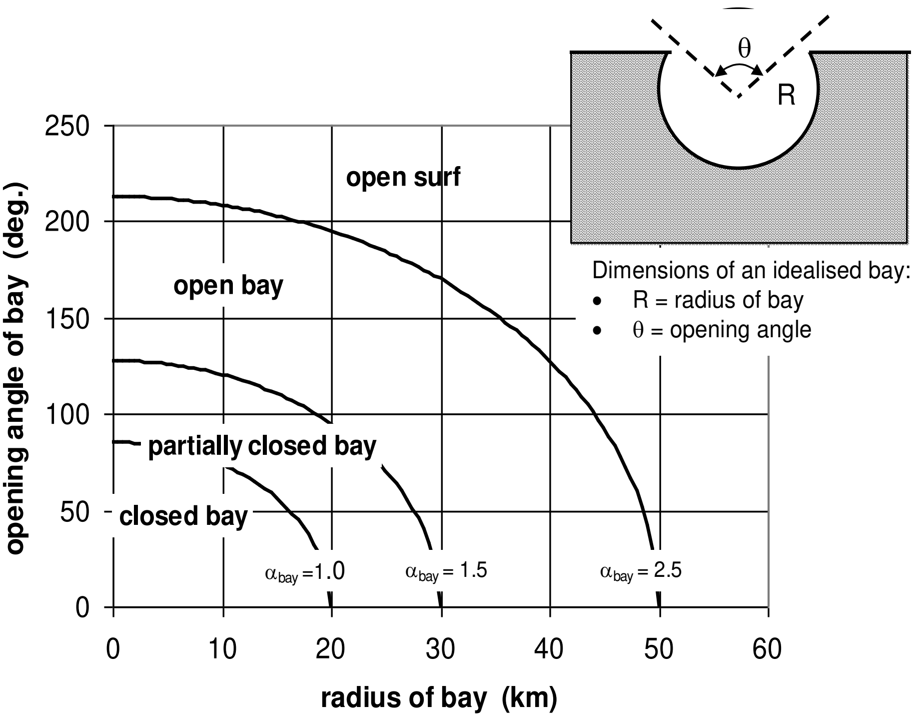


Figure 3.2 Definition of coastal exposure condition.

3.2.4. Pollution

An estimate of the pollution parameter, P_{air}, which is the pollution of air due to the concentration of airborne SO_x ($\mu g/m^3$), can be made by,

$$P_{\text{air}} = \frac{\alpha_{\text{indus}}}{L_{indus} + 1} \tag{3.8}$$

where L_{indus} (km) the distance to the nearest industrial complex; α_{indus} is defined in Table 3.5.

Table 3.5 Parameter for the effect of industrial exposure

Industry Type	α_{indus}
Heavy industry (steel works, petrochemical)	110.0
Moderate industry (paper mills, large manufacturing)	22.0
Light industry (assembly plants)	5.5

3.2.5. Climate Related Parameters — Time of Wetness (t_{wet})

The climate parameter considered in the prediction of corrosion depth is the time-of-wetness, t_{wet} (%), defined as the percentage of time in a year when the relative humidity is above 80% and the temperature is above 0°C. t_{wet} is estimated by

$$t_{wet} = 0.22 D_{rain} \tag{3.9}$$

where D_{rain} is the number of rain days per year (days/year). A rain day is defined as a day in which there is at least 0.2 mm of rain. For a site near the coast, D_{rain} takes a representative value found in Table 3.6, which depends on the hazard zones shown in Table 3.3. For an inland site, D_{rain} is computed by

$$D_{rain} = D_{rain-inland} + \left(D_{rain|L_{coast}=0} - D_{rain-inland} \right) e^{-0.004 L_{coast}} \tag{3.10}$$

where L_{coast} is the distance to the nearest coast (km); $D_{rain\text{-}inland}$ = 30 days/year, a representative value of D_{rain} for inland locations about 1000 km or more from the coast.

Figure 3.3 Hazard Zones related to corrosion due to airborne salt (Zone E is the most hazardous).

Table 3.6 Hazard zones and corresponding coastal zones and numbers of rain days

Hazard Zone	Coastal zone (Figure 8.1)	Representative D_{rain} (No. of rain days / year)
A	C1	70
B	C2	40
C	C1	100
D	C2	130
E	C3	130

3.3. Corrosion of Bolts

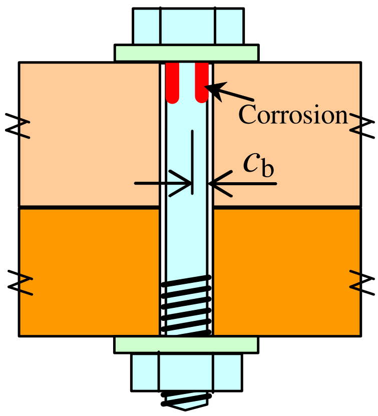


Figure 3.4 Corrosion of bolt

Corrosion of bolts in wood construction is unique because bolts are often placed in oversized holes pre-drilled into the timber, thus allowing moisture/water, salt and oxygen to ingress, a situation that does not occur with other fasteners. The most corroded part often occurs near the neck of the bolt, as shown in Figure 3.4. This is either due to the embedded corrosion mechanism enhanced by water entering the bolt hole or due to atmospheric corrosion that is enhanced when the site is near a beach. Therefore, the prediction of bolt corrosion is implemented as follows,

A. Compute the corrosion depth due to the embedded corrosion mechanism by following the procedure in Section 2.5 of Manual No. 6.

B. Compute the corrosion depth due to atmospheric corrosion mechanism by first following the procedure in Section 3.2 of this Manual to compute the basic corrosion depth ($c_{0,z}$ for zinc and $c_{0,s}$ for steel), which is then multiplied by an enhanced corrosion factor; i.e.

$$c_{0,zb} = \left(1 + 2e^{-\frac{L_{coast}}{2}}\right) c_{0,z} \tag{3.11}$$

$$c_{0,sb} = \left(1 + 2e^{-\frac{L_{coast}}{2}}\right) c_{0,s} \tag{3.12}$$

where $c_{0,zb}$ and $c_{0,sb}$ are the basic corrosion depths of the zinc coating the bolt steel, respectively, and L_{coast} (km) is the distance to coast. Then $c_{0,zb}$ is substituted into Eq. (3.1), and $c_{0,sb}$ into Eq. (3.3), to determine the bolt corrosion depth due to atmospheric corrosion mechanism.

C. Choose the greater of the corrosion depths determined in Steps A and B as the bolt corrosion depth near the neck of the bolt.

3.4. Corrosion of Fasteners under Corrugated Roof

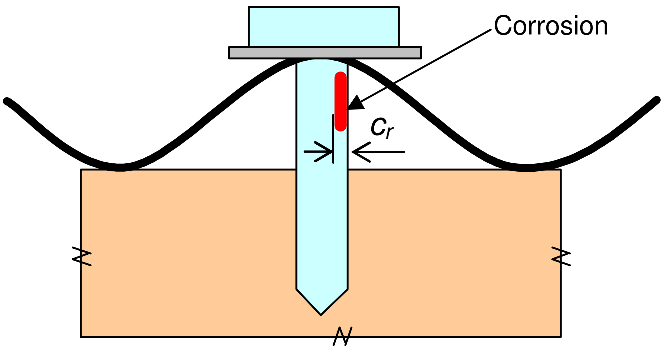


Figure 3.5 Depth of corrosion on exposed part of fasteners under a corrugated roof

A corrugate roof may be used to cover an open space (e.g. car port, open walk way) or an enclosed space (e.g. house). To predict the corrosion depth of fasteners used under corrugated roofs, first follow the procedure in Section 3.2 of this Manual to compute the basic corrosion depth ($c_{0,z}$ for zinc and $c_{0,s}$ for steel), which is then multiplied by an enhanced corrosion factor; i.e.

- If installed in an open space:

$$c_z = c_{0,z} \times \left(0.5 + e^{-\frac{L_{coast}}{14}}\right) \tag{3.13}$$

$$c_s = c_{0,s} \times \left(0.5 + e^{-\frac{L_{coast}}{14}}\right) \tag{3.14}$$

- If installed in a closed space:

$$c_z = c_{0,z}\left(0.2 + 0.6e^{-\frac{L_{coast}}{9}}\right) \tag{3.15}$$

$$c_z = c_{0,z}\left(0.2 + 0.6e^{-\frac{L_{coast}}{9}}\right) \tag{3.16}$$

where L_{coast} (km) in Eqs. (3.13) to (3.16) is the distance to coast.

4. Embedded Corrosion Exposed to Weather

Equation Section (Next)

This Section describes the prediction models for the corrosion depth of metal fasteners embedded in wood, such as the shank of nails, screws, and the teeth of nail-plates, as the nail shown in Figure 4.1.

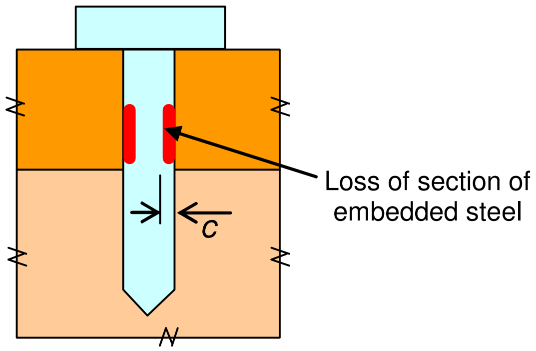


Figure 4.1 Embedded corrosion depth

4.1. Hazard Zones

The content of Australia is divided into three embedded corrosion hazard zones, as shown in Figure 4.2. The hazard map is developed based on the mean annual seasonal equilibrium moisture content (*SEMC*). The representative SEMC values for the hazard zones are listed in Table 4.1.

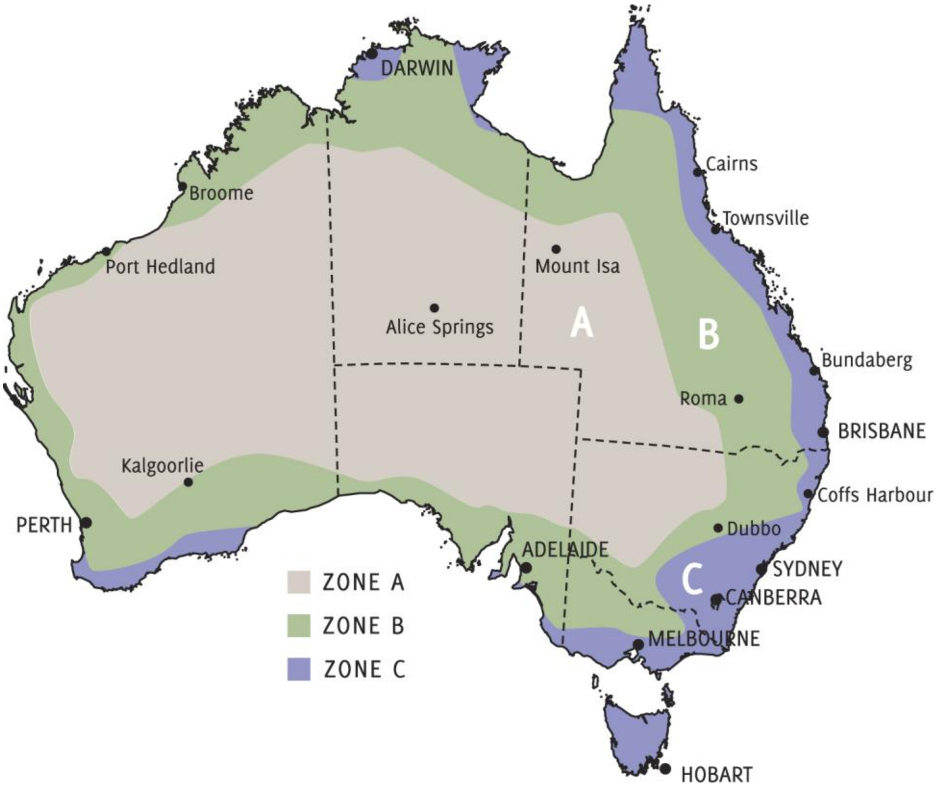


Figure 4.2 Embedded corrosion hazard map (Zone C is the most hazardous)

Table 4.1 Annual mean *SEMC* values for the hazard zones and boundaries

Zone	**Representative Zone *SEMC***	**Boundary *SEMC***
A	9	
		10
B	12	
		13
C	15	

4.2. Climate Zones

The continent of Australia is divided roughly into two climate zones:

- Marine, if the distance to coast < 1 km
- Other (i.e. non-marine)

4.3. Timber Acidity Classification

Table 4.2 lists the timber acidity, if available, and its classification for commonly used wood species.

Table 4.2 Timber Acidity classification

Standard Australia index	Trade name	Botanical name	Type	Density	Design pH	Natural acidity class
22	Ash, alpine	Euc. delegatensis	E	650	3.6	3
25	Ash, Crow's	Flindersia australis	H	950	5.1	1
30	Ash, mountain	Euc. regnans	E	640	4.7	2
37	Ash, silvertop	Euc. sieberi	E	862	3.5	3
-	Balau (selangan batu)	Shorea spp.	H	900	-	2
-	Bangkirai	Shorea laevifolia	H	850	-	2
65	Beech, myrtle	Nothofagus cunninghamii	H	705	-	2
-	Belian (ulin)	Eusideroxylon zwageri	H	1000	-	2
84	Blackbutt	Euc. pilularis	E	884	3.6	3
86	Blackbutt, New England	Euc. andrewsii	E	850	-	3
87	Blackbutt, WA	Euc. patens	E	849	-	3
88	Blackwood	Acacia melanoxylon	H	650	-	2
97	Bloodwood, red	Euc. gummifera	E	900	3.6	3
90	Bloodwood, white	Euc. trachyphloia	E	1023	-	3
109	Bollywood	Litsea reticulata	S	532	3.9	3
121	Box, brush	Lophostemon confertus	H	900	4.5	2
126	Box, grey	Euc. moluccana	E	1105	3.5	3
127	Box, grey, coast	Euc. bosistoana	E	1110	3.4	3
134	Box, long leaved	Euc. goniocalyx	E	873	-	3
138	Box, red	Euc. polyanthemos	E	1064	-	3
144	Box, steel	Euc. rummeryi	E	0	-	3
145	Box, swamp	Lophostemon suaveolens	H	850	-	2
150	Box, yellow	Euc. melliodora	E	1075	-	3
148	Box,white	Euc. albens	E	1112	-	3
162	Brigalow	Acacia harpophylla	H	1099	-	2
165	Brownbarrel	Euc. fastigata	E	738	3.3	3
167	Bullich	Euc. megacarpa	E	640	-	3
-	Calantas (kalantas)	Toona calantas	H	500	-	2
178	Candlebark	Euc. rubida	E	750	-	3
73	Cedar, red, western	Thuja plicata	S	448	3.3	3
544	Cypress	Callitris Glaucophylla	S	680	5.4	1
114	Fir, Douglas	Pseudotsuga menziesii	S	520	3.5	3
253	Gum, blue, southern	Euc. globulus	E	900	-	3
254	Gum, blue, Sydney	Euc. saligna	E	843	3.6	3
266	Gum, grey	Euc. propinqua	E	1050	3.8	3
267	Gum, grey, mountain	Euc. cypellocarpa	E	961	3.6	3
268	Gum, maiden's	Euc. maidenii	E	992	-	3
269	Gum, manna	Euc. viminalis	E	814	-	3
272	Gum, mountain	Euc. dalrympleana	E	700	-	3
281	Gum, red, forest	Euc. tereticornis	E	737	4.2	2
281	Gum, red, river	Euc. camaldulensis	E	913	-	3

284	Gum, rose	Euc. grandis	E	753	5.1	1
286	Gum, salmon	Euc. salmonophloia	E	1070	-	3
288	Gum, scribbly	Euc. haemastoma	E	907	-	3
289	Gum, shining	Euc. nitens	E	530	-	3
293	Gum, spotted	Euc. maculata	E	988	4.5	2
294	Gum, sugar	Euc. cladocalyx	E	1105	-	3
305	Gum, yellow	Euc. leucoxylon	E	1008	-	3
310	Hardwood, Johnstone River	Backhousia bancroftii	H	950	-	2
-	Hemlock, western	Tsuga heterophylla	S	500	4.9	2
322	Ironbark, grey	Euc. paniculata	E	1110	4.0	3
325	Ironbark, red	Euc. sideroxylon	E	1086	-	3
326	Ironbark, red (broad-leaved)	Euc. fibrosa	E	1116	-	3
327	Ironbark, red (narrow-leaved)	Euc. crebra	E	1046	4.0	3
336	Ironwood Cooktown	Erythrophleum chlorostgchys	H	1220	-	2
340	Jam, raspberry	Acacia acuminata	H	1038	-	2
341	Jarrah	Euc. marginata	E	823	3.3	3
-	Kapur	Dryobalanops spp.	H	750	3.3	3
344	Karri	Euc. diversicolor	E	905	4.2	2
	Keruing	Dipterocarpus spp.	H	750	5.1	1
173	Kwila	Intsia bijuga	H	825	-	2
-	Mahogany, Philippine, red, dark	Shorea spp.	H	650	-	2
-	Mahogany, Philippine, red, light	Shorea, Pentacme, Parashorea spp.	H	550	-	2
384	Mahogany, red	Euc. resinifera	E	955	3.0	3
391	Mahogany, white	Euc. acmenoides	E	993	3.5	3
391	Mahogany, white	Euc. umbra	E	887	-	3
387	Mahonany, southern	Euc. botryoides	E	919	-	3
411	Mallet, brown	Euc. astringens	E	974	-	3
432	Marri	Euc. Calophylla	E	855		3
-	Meranti, red, dark	Shorea spp.	H	650	3.9	3
-	Meranti, red, light	Shorea spp.	H	400	5.0	2
226	Mersawa (Garawa)	Anisoptera thyrifera	H	630	4.5	2
434	Messmate	Euc. obliqua	E	722	3.2	3
435	Messmate, Gympie	Euc. cloeziana	E	996	-	3
458	Oak, bull	Allocasuarina luehmannii	H	1050	-	2
240	Oak, white, American	Quercus alba	H	750	-	2
509	Peppermint, black	Euc. amygdalina	E	753	-	3
510	Peppermint, broad leaved	Euc. dives	E	811	-	3
512	Peppermint, narrow leaved	Euc. radiata	E	822	3.2	3
515	Peppermint, river	Euc. elata	E	804	-	3
529	Pine, black	Prumnopitys amara	S	500	-	2
533	Pine, caribbean	Pinus caribaea	S	550	3.9	3
534	Pine, celery-top	Phyllocladus asplenifolius	S	646	-	2
545	Pine, hoop	Araucaria cunninghamii	S	550	5.2	1
546	Pine, Huon	Lagarostrobos franklinii	S	520	4.6	2
548	Pine, kauri	Agathis robusta	S	503	-	2
549	Pine, King William	Athrotaxis selaginoides	S	400	-	2
559	Pine, radiata	Pinus radiata	S	540	4.8	2
561	Pine, slash	Pinus elliotii	S	650	-	2

-	Ramin	Gonystylus spp.	H	650	5.2	1
326	Redwood	Sequoia sempervirens	S	400	-	2
332	Rosewood, New Guinea	Pterocarpus indicus	H	577	-	2
635	Satinay	Syncarpia hillii	H	838	-	2
668	Stringybark, Blackdown	Euc. sphaerocarpa	E	1000	-	3
671	Stringybark, brown	Euc. capitellata	E	838	-	3
676	Stringybark, red	Euc. macrorhyncha	E	899	-	3
680	Stringybark, white	Euc. Eugenioides 2	E	856	-	3
680	Stringybark, White (Wilkinson's)	Euc. Eugenioides 1	E	856	-	3
681	Stringybark, yellow	Euc. muelleriana	E	884	4	3
688	Tallowwood	Euc. microcorys	E	990	3.5	3
-	Taun	Pometia pinnata	H	700	-	2
369	Teak, Burmese	Tectona grandis	H	600	4.5	2
713	Tingle, red	Euc. jacksonii	E	772	-	3
714	Tingle, yellow	Euc. guilfoylei	E	900	-	3
720	Tuart	Euc. gomphocephala	E	1036	-	3
723	Turpentine	Syncarpia glomulifera	H	945	3.5	3
747	Wandoo	Euc. wandoo	E	1099	-	3
774	Woolybutt	Euc. longifolia	E	1068	-	3
780	Yate	Euc. cornuta	E	1100	-	3
788	Yertchuk	Euc. consideniana	E	939	-	3

4.4. Moisture Content of Wood

The moisture content of wood exposed outdoors, TM_{mean}, is estimated from the mean surface equilibrium moisture content of the site location, $SEMC_{mean}$,

$$TM_{mean} = exp[1.9 + 0.05\ SEMC_{mean}] \tag{4.1}$$

$SEMC_{mean}$, is given in Table 4.1. The maximum and mean seasonal moisture contents of wood in building envelope, $BTM_{\max}$ and BTM_{mean}, are,

$$BTM_{\text{mean}} = TM_{\text{mean}} + \Delta_{\text{climate}} + \Delta_{\text{rain}} \tag{4.2}$$

$$BTM_{\max} = BTM_{\text{mean}} + 0.1\, D \times TM_{\text{mean}} \tag{4.3}$$

where the damping factor D and Δ_{climate} are given in Table 4.3, and Δ_{rain} is given in Table 4.4.

Table 4.3 Damping factor and adjustment factor for climate

Climate zone	***D***	$\boldsymbol{\Delta_{\text{climate}}}$
Marine*	6.0	2.5
Other	2.0	0.5

* Choose marine if the distance to coast < 1 km

Table 4.4 Adjustment factor Δ_{rain}

Outdoor (Facades)	Δ_{rain}		
	Hazard zone A	**Hazard zone B**	**Hazard zone C**
Sheltered / partly sheltered from rain	0	1	2
Vertical surface exposed to rain	1	4	8
Horizontal surface exposed to rain	3	9	17

4.5. Model Equations for Embedded Corrosion

The corrosion depth at 120 days, denoted by $f_{120}(M)$, is a function of the moisture content of the timber, M. The functional form of $f_{120}(M)$ for fasteners embedded in untreated timber is shown schematically in Figure 4.3, and expressed mathematically by

$$f_{120}(M) = \begin{cases} 0 & \text{if } M \le M_0; \\ 0.2\ C_{120}(M - M_0) & \text{if } M_0 < M < (M_0 {+} 5\%); \\ C_{120} & M \le (M_0 {+} 5\%) \end{cases} \tag{4.4}$$

where M (%) is the wood moisture content. The parameters C_{120} (μm) and M_0 are given in Table 4.5.

For fasteners embedded in CCA treated wood, $f_{120}(M)$ is shown schematically in Figure 4.4, and expressed mathematically by

$$f_{120}(M) = \begin{cases} 0 & \text{if } M \le M_0; \\ 0.7\ (M - M_0) & \text{if } M > M_0; \end{cases} \tag{4.5}$$

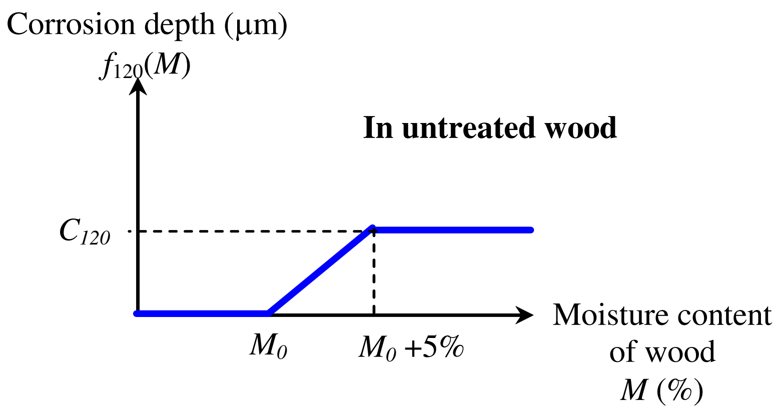


Figure 4.3 Function of $f_{120}(M)$ for fasteners embedded in untreated wood

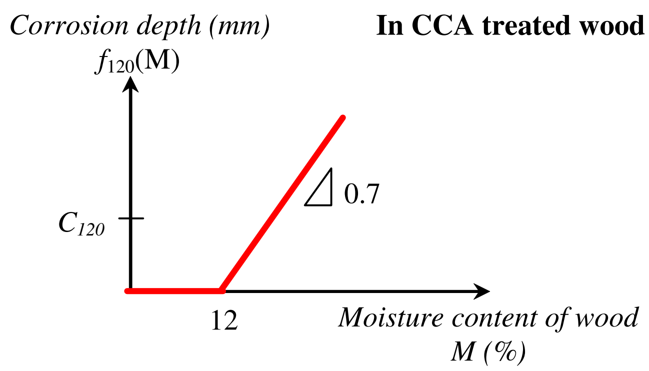


Figure 4.4 Function of $f_{120}(M)$ for fasteners embedded in CCA-treated wood

Table 4.5 Parameters of the corrosion model of embedded fasteners in untreated wood

Material	Wood type	C_{120}			M_0 (%)
		Acidity class 1	Acidity class 2	Acidity class 3	
Zinc	Hardwood	2.0	7.0	12.0	10
	Softwood	4.0	5.0	6.0	15
Steel	Hardwood	2.0	8.0	14.0	15
	Softwood	2.0	6.0	10.0	15

For fasteners embedded in untreated wood in building envelope, the first-year corrosion depth, c_o (μm), is computed as follows,

$$c_o = \frac{1}{2}[f_{120}(BTM_{\max}) + 0.3 f_{120}(BTM_{\text{mean}})] \tag{4.6}$$

The corrosion depth, c, of fasteners embedded in untreated wood after t years is computed by

$$c = c_o\, t^n \tag{4.7}$$

where n= 0.5 for zinc and n = 0.6 for steel.

For fasteners embedded in CCA-treated wood, c_o is computed as follows,

For zinc: $$c_o = 1.3 f_{120}(BTM_{\text{mean}}) \tag{4.8}$$

For steel: $$c_o = 2.1 f_{120}(BTM_{\text{mean}}) \tag{4.9}$$

The corrosion depth, c, of fasteners embedded in CCA-treated wood after t years is computed by

$$c = c_o\, t^n \tag{4.10}$$

where n= 0.6 for zinc and n = 1.0 for steel.

4.6. Corrosion of Bolts

Corrosion of bolts follows the procedure described in Section 3.3.

5. Marine Borer Attack

Equation Section (Next)

The following assumptions were made in computing the service lives of timber piles:

- Progress of attack depth with time t in a timber element is characterised by an attack time lag, t_{lag} (years), and an attack rate, r (mm/year).

5.1. Timber Classification for Outer Heartwood

Durability classification of timber is listed in Table 5.1.

Table 5.1 Natural durability classes of outer heartwood for marine borer attack

Trade name	**Botanical name**	**Marine Borer Durability Class**	**Source (see text)**
Alder, blush	Sloanea australis	4	H
Alder, brown	Caldcluvia paniculosa	4	H
Alder, pink	Gillbeea adenopetala	4	H
Alder, rose	Caldcluvia australiensis	4	H
Amberoi	Pterocymbium spp.	4	H
Apple, rough-barked	Angophora floribunda	4	H
Apple, smooth-barked	Angophora costata	4	G
Ash, alpine	Eucalyptus delegatensis	4	G
Ash, Blue Mountains	Eucalyptus oreades	4	G
Ash, Crow's	Flindersia australis	4	G
Ash, mountain	Eucalyptus regnans	4	A
Ash, pink	Alphitonia petriei	4	H
Ash, silver	Flindersia bourjotiana, Flindersia schottiana	4	H
Ash, silvertop	Eucalyptus sieberi	4	A
Ash, white	Eucalyptus fraxinoides	4	H
Baltic, red (pine, Scots)	Pinus sylvestris	4	H

Baltic, white (spruce, Norway)	Picea abies	4	H
Beech, myrtle	Nothofagus cunninghamii	4	H
Beech, negrohead	Nothofagus moorei	4	H
Beech, silver	Nothofagus menziesii	4	H
Belian	Eusideroxylon zwageri	1	J
Birch, white, Australia	Schizomeria ovata	4	H
Blackbutt	Eucalyptus pilularis	3	A
Blackbutt, New England	Eucalyptus andrewsii, Eucalyptus campanulata	2	A
Blackbutt, Western Australian	Eucalyptus patens	3	E
Blackwood	Acacia melanoxylon	4	C
Bloodwood, red	Corymbia gummifera, Eucalyptus intermedia Eucalyptus polycarpa	3	D
Bollywood	Cinnamomum baileyanum, Litsea spp.	4	H
Box, brush	Lophostemon confertus	2	A,D
Box, grey	Eucalyptus macrocarpa, Eucalyptus moluccana Eucalyptus woollsiana	2	A
Box, grey, coast	Eucalyptus bosistoana	3	B
Box, ironwood	Choricarpia leptopetala Choricarpia subargentea	4	H
Box, kanuka	Tristania exiliflora, Tristania laurina	4	H
Box, long-leaved	Eucalyptus goniocalyx	4	H
Box, swamp	Lophostemon suaveolens	2	D
Brownbarrel	Eucalyptus fastigata	4	G
Bullich	Eucalyptus megacarpa	4	H
Calophyllum	Calophyllum spp.	4	H
Candlebark	Eucalyptus rubida	4	H
Carabeen, yellow	Sloanea woolsii	4	H
Cedar, red	Toona australis	4	G
Cedar, western red	Thuja plicata	4	H
Cheesewood, white	Alstonia scholaris	4	H
Coachwood	Ceratopetalum apetalum	4	H
Cypress, black	Callitris endlicheri	3	C,G
Cypress, white	Callitris glaucophylla	2	B,C,D
Fir, amabilis	Abies amabilis	4	H
Fir, Douglas (oregon)	Pseudotsuga menziesii	4	C
Geronggang	Cratoxylon arborescens	4	H
Gum, blue, southern	Eucalyptus globulus	4	A
Gum, blue, Sydney	Eucalyptus saligna	3	A

Gum, grey	Eucalyptus canaliculate, Eucalyptus major Eucalyptus propinqua, Eucalyptus punctata	2	A
Gum, grey, mountain	Eucalyptus cypellocarpa	4	A
Gum, Maiden's	Eucalyptus maidenii	4	H
Gum, manna	Eucalyptus viminalis	4	H
Gum, mountain	Eucalyptus dalrympleana	4	G
Gum, pink	Eucalyptus fasciculosa	4	H
Gum, poplar	Eucalyptus alba	4	H
Gum, red, forest	Eucalyptus blakelyi, Eucalyptus tereticornis	2	D
Gum, red, river	Eucalyptus camaldulensis	2	A
Gum, rose	Eucalyptus grandis	4	A
Gum, round-leaved	Eucalyptus deanei	4	H
Gum, shining	Eucalyptus nitens	4	H
Gum, spotted	Corymbia maculate, Corymbia citriodora Eucalyptus henryi	4	A,D
Gum, swamp	Eucalyptus camphora	4	H
Gum, white, Dunn's	Eucalyptus dunnii	4	H
Gum, yellow	Eucalyptus leucoxylon	4	H
Hardwood, Johnston River	Backhousia bancroftii	4	H
Hemlock, western	Tsuga heterophylla	4	4
Iroko	Chlorophora excelsa	1	A
Ironbark, grey	Eucalyptus drepanophylla, Eucalyptus paniculate, Eucalyptus siderophloia	3	A
Ironbark, red	Eucalyptus sideroxylon	2	A
Jam, raspberry	Acacia acuminata	2	E
Jarrah	Eucalyptus marginata	3	A,B
Jelutong	Dyera costulata	4	H
Kamarere	Eucalyptus deglupta	4	H
Kapur	Dryobalanops spp.	4	H
Karri	Eucalyptus diversicolor	4	A,B
Kauri, New Zealand	Agathis australis	4	G
Kauri, Queensland	Agathis atropurpurea, Agathis microstachya Agathis robusta	4	G
Kempas	Koompassia malaccensis	4	H
Keruing	Dipterocarpus spp.	4	H
Kwila (merbau)	Intsia bijuga	3	C
Lumbayau (mengkulang)	Heritiera spp.	4	H
Mahogany, African	Khaya spp.	4	H

Mahogany, American	Swietenia mahogani	4	H
Mahogany, brush	Geissois benthamii	4	H
Mahogany, red	Eucalyptus pellita, Eucalyptus resinifera	2	C
Mahogany, red, Philippine,	Shorea spp.	4	H
Mahogany, southern	Eucalyptus botryoides	4	H
Mahogany, white	Eucalyptus acmenoides, Eucalyptus tenuipes Eucalyptus umbra subsp. Carnea	2	A,G
Malas	Homalium foetidum	4	H
Mallet, brown	Eucalyptus astringens	4	H
Malletwood	Rhodamnia argentea, Rhodamnia costata	4	H
Malletwood, brown	Rhodamnia rubescens	4	H
Malletwood, silver	Rhodamnia acuminata	4	H
Mangrove, grey	Avicennia marina	4	D
Maple, Queensland	Flindersia brayleyana	4	H
Maple, rose	Cryptocarya erythroxylon	4	H
Maple, scented	Flindersia laevicarpa	4	H
Maple, sugar (rock)	Acer saccharum	4	H
Marri	Corymbia calophylla, Eucalyptus calophylla	4	A
Meranti, bakau	Shorea spp.	4	H
Meranti, dark-red	Shorea spp.	4	H
Meranti, light-red	Shorea spp.	4	H
Meranti, white	Shorea spp.	4	H
Meranti, yellow	Shorea spp.	4	H
Mersawa	Anisoptera spp.	4	H
Messmate	Eucalyptus obliqua	4	A,B
Nyatoh	Palaquium and Payena spp.	4	H
Oak, silky, northern	Cardwellia sublimis	4	H
Oak, tulip, blush	Argyrodendron actinophyllum	4	H
Oak, tulip, brown	Argyrodendron polyandrum Argyrodendron trifoliolatum	4	H
Oak, tulip, red	Argyrodendron peralatum,	4	H
Oak, white, American	Quercus alba	4	H
Paulownia	Paulownia spp.	4	H
Penda, brown	Xanthostemon chrysanthus	2	F
Penda, red	Xanthostemon whitei	2	F
Penda, southern	Xanthostemon, oppositifolius	2	F
Penda, yellow	Ristantia pachysperma	2	D
Peppermint, black	Eucalyptus amygdalina	4	H
Peppermint, broad-leaved	Eucalyptus dives	4	H

Peppermint, narrow-leaved	Eucalyptus Australiana, Eucalyptus radiata Eucalyptus robertsonii	4	H
Peppermint, river	Eucalyptus elata	4	H
Peppermint, white	Eucalyptus pulchella	4	H
Pine, brown	Podocarpus elatus	3	D
Pine, bunya	Araucaria bidwillii	4	H
Pine, Canary Island	Pinus canariensis	4	H
Pine, Caribbean	Pinus caribaea	4	H
Pine, celery-top	Phyllocladus asplenifolius	4	H
Pine, Corsican	Pinus nigra	4	H
Pine, hoop	Araucaria cunninghamii	4	G
Pine, Huon	Lagarostrobos franklinii	4	C,D
Pine, King William	Athrotaxis selaginoides	4	C
Pine, klinki	Araucaria hunsteinii	4	H
Pine, loblolly	Pinus taeda	4	H
Pine, longleaf	Pinus palustris	4	H
Pine, maritime	Pinus pinaster	4	H
Pine, NZ white (kahikatea)	Dacrycarpus dacrydioides	4	H
Pine, patula	Pinus patula	4	H
Pine, ponderosa	Pinus ponderosa	4	H
Pine, radiata	Pinus radiata	4	B,C
Pine, Scots	Pinus sylvestris	4	H
Pine, slash	Pinus elliottii	4	H
Pine, white, western	Pinus monticola	4	H
Planchonella	Planchonella chartacea	4	H
Poplar, balsam	Populus spp.	4	H
Poplar, pink	Euroschinus falcata	4	H
Quandong, silver	Elaeocarpus angustifolius, Elaeocarpus grandis	4	H
Ramin	Gonystylus spp.	4	H
Redwood	Sequoia sempervirens	4	G
Rimu	Dacrydium cupressinum	4	H
Rosewood, New Guinea	Pterocarpus indicus	4	H
Sassafras	Daphnandra dielsii, Daphnandra micrantha Daphnandra repandula, Doryphora aromatica Doryphora sassafras	4	G
Satinash, grey	Syzygium claviflorum,, Syzygium gustavioides	4	H
Satinash, rose	Syzygium crebrinerve, Eugenia francisii	4	H
Satinay	Syncarpia hillii	1	D

Sepetir	Copaifera spp., Pseudosindora spp., Sindora spp.	4	H
Sheoak, beach	Allocasuarina equisetifolia	4	H
Sheoak, black	Allocasuarina littoralis	4	G
Silkwood, maple	Flindersia pimenteliana	4	H
Spruce, Norway	Picea abies	4	H
Spruce, Sitka	Picea sitchensis	4	H
Stringybark, blue-leaved	Eucalyptus agglomerata	4	H
Stringybark, brown	Eucalyptus baxteri, Eucalyptus blaxlandii Eucalyptus capitellata	4	H
Stringybark, diehard	Eucalyptus cameronii	4	H
Stringybark, red	Eucalyptus macrorhyncha	3	C
Stringybark, silvertop	Eucalyptus laevopinea	4	H
Stringybark, white	Eucalyptus eugenioides, Eucalyptus globoidea Eucalyptus phaeotricha	3	A,G
Stringybark, yellow	Eucalyptus muelleriana	3	A
Sycamore, silver	Cryptocarya glaucescens	4	H
Tallowwood	Eucalyptus microcorys	3	A
Taun	Pometia spp.	4	H
Tea-tree, broad-leaved	Melaleuca leucadendron, Melaleuca quinquenervia, Melaleuca viridiflora	3	D
Tea-tree, river	Melaleuca bracteata	4	H
Tingle, red	Eucalyptus jacksonii	4	H
Touriga, red	Calophyllum costatum	4	H
Tuart	Eucalyptus gomphocephala	4	E
Turpentine	Syncarpia glomulifera	1	A,B
Walnut, New South Wales	Endiandra virens	4	H
Walnut, Queensland	Endiandra palmerstonii	4	H
Walnut, yellow	Beilschmiedia bancroftii	4	H
Wandoo	Eucalyptus wandoo	3	E
Yate, swamp	Eucalyptus occidentalis	4	E

5.2. Hazard Zones

The marine borer attack hazard map for Australia is shown in Figure 5.1. The representative value for the factor k_{water} in each of the seven hazard zones are given in Table 5.2. These values have been calibrated to field data and expert opinions.

Figure 5.1 Marine borer hazard zones. Zone G is the most hazardous.

Table 5.2 Definition of hazard coastal zones and water climate index

Hazard Coastal zone	Approximate coastline range		k_{water}
	from (longitude, latitude)	to (longitude, latitude)	
A	Latitude < –40°	Latitude < –40°	0.7
B	(140°, –37°)	(150°, –37°)	0.9
C	(120°, –34°)	(140°, –37°)	1.2
D	(120°, –34°)	(114°, –27°)	1.6
E	(150°, –37°)	(153°, –27°)	2.0
F	(114°, –27°)	(143°, –11°)	3.0
G	(143°, –11°)	(153°, –27°)	3.8

5.3. Attack Patterns

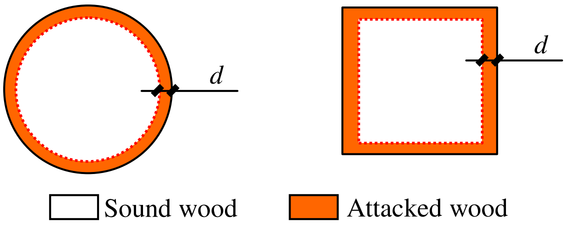


Figure 5.2 Marine borer attack patterns

5.4. Attack Model

A schematic illustration for the assumed progress of marine borer attack is shown in Figure 5.3. It comprises of a time lag (*lag*) and a constant attack rate (*r*). The attack depth of timber, denoted by *d*, after *t* years is given by:

$$d = \begin{cases} 0 & \text{if } t \le lag \\ (t - lag)r & \text{if } t > lag \end{cases} \tag{5.1}$$

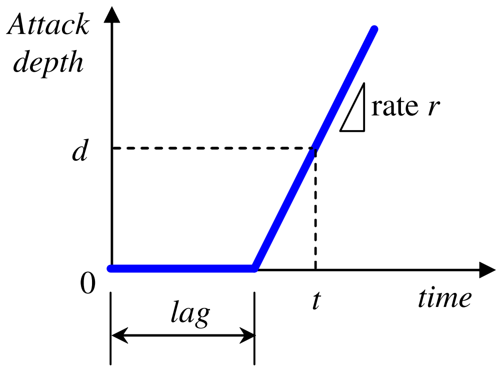


Figure 5.3 Marine borers attack model

The marine borer attack rate (*r*) is determined as follows,

$$r = k_{water} k_{wood} k_{salt} k_{shelter} k_{protect} k_{contact} k_{knot} \tag{5.2}$$

where,

- k_{water}, given in Table 5.2, is dependent on the coastal zone where the timber is installed.
- k_{wood}, given in Table 5.3, is dependent on types/classes of materials (timber).
- k_{salt}, given in Table 5.4, is dependent on the salinity level of the sea water.
- $k_{shelter}$, given in Table 5.5,is dependent on whether the water is exposed to or sheltered from strong current or surf.

- $k_{protection}$, given in Table 5.6, is dependent on the type of timber protection measures.
- $k_{contact}$, given in Table 5.7, is dependent on the existence of surface contact with other timber elements.
- k_{knot}, given in Table 5.8, is dependent on the existence of big knots and the associated protective plates.

The time lag is determined as a function of the rate by the following equation,

$$lag = \begin{cases} 0 & \text{if } r \geq 20 \\ 2.0 - 0.1r & \text{if } r < 20 \end{cases} \tag{5.3}$$

For double treated timber, an extra lag of 10 years is added to that given by Eq. (5.3).

Table 5.3 Wood Parameter k_{wood}

Material		Notation	k_{wood} Zones A to C	k_{wood} Zones D to G
Heartwood*	Class 1	HW1	1.1	1.3
	Class 2	HW2	1.7	5.2
	Class 3	HW3	3.4	8.8
	Class 4	HW4	17.0	25.0
		Notation (treatment level)	**All zones**	
Sapwood of softwood	Untreated	SAPs	40	
	Creosote-treated			
	24 %kg/kg	CR1s (H5)	1.7	
	40 %kg/kg	CR2s (H6)	1.0	
	CCA-treated			
	0.6 %kg/kg	CC0s (H4)	4.7	
	1 %kg/kg	CC1s (H5)	3.0	
	2 %kg/kg	CC2s (H6)	1.8	
	5 %kg/kg	CC3s (>H6)	1.0	
	Double-treated			
	CC2s+CR2s	DBTs (H6)	0.9	
Sapwood of hardwood	Untreated	SAPh	25	
	Creosote-treated			
	13 %kg/kg	CR1h (H5)	0.8	
	22 %kg/kg	CR2h (H6)	0.6	
	CCA-treated			
	0.7 %kg/kg	CC0h (H4)	3.2	
	1.2 %kg/kg	CC1h (H5)	1.8	
	2.4 %kg/kg	CC2h (H6)	1.1	
	Double-treated			
	CC2h+CR2h	DBTh (H6)	0.5	

(*) Heartwood classification is in Section 8.2

Table 5.4 Parameter k_{salt} and salinity classification

Salinity Class	**Salinity** (ppt)	k_{salt}	
		Zones A to D	**Zones E to G**
1	1-10	0.7	1.0
2	11-25	0.8	1.0
3	26-35	1.0	1.0

Table 5.5 Parameter k_{wav} for different water zones

Shelter	$k_{shelter}$
Sheltered from strong current or surf (eg. behind breakwaters, harbour, river, etc.)	1.0
Exposed to strong current and/or surf	0.6

Table 5.6 Parameter $k_{protect}$ for maintenance measures

Protection measure	$k_{protect}$
Floating collar or plastic wrap in tidal zone	0.5
None	1.0

Table 5.7 Parameter $k_{contact}$ for contact with other timber members

Contact	$k_{contact}$
Contact with other timber member (e.g. X-brace) in tidal zone	2.0
None	1.0

Table 5.8 Parameter k_{knot} for presence of knots

Knot presence	$\boldsymbol{k_{knot}}$
Having knots without protective plate	2.0
Having knots with protective plate	1.0
None	1.0

The equations in this section determines the following attack rates and time lags, which are the parameters needed to estimate attack depth over time:

$r_{\mathrm{un,HWi}}$: attack rate on timber of outer heartwood class *i* (mm/year)

$lag_{\mathrm{un,\ HWi}}$: attack time lag on timber of outer heartwood class *i* (years)

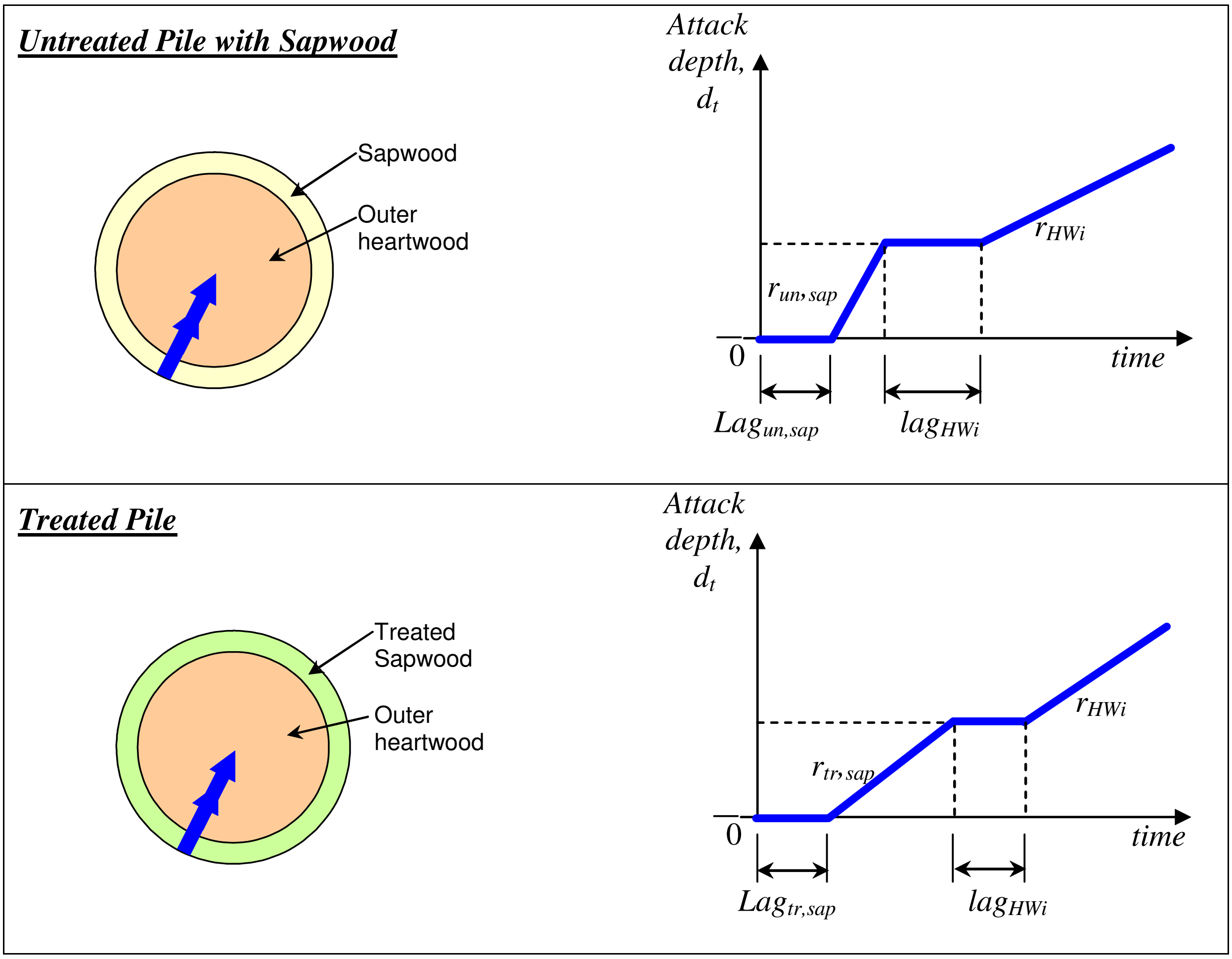
$r_{\mathrm{un,sap}}$: attack rate of a clear stake of untreated sapwood (mm/year)

$lag_{\mathrm{un,sap}}$: attack time lag of a clear stake of untreated sapwood (years)

$r_{\mathrm{tr,sap}}$: attack rate of a clear stake of treated sapwood (mm/year)

$lag_{\mathrm{tr,sap}}$: attack time lag of a clear stake of treated sapwood (years)

5.5. Progress of Attack on Round Piles



6. Termite Management

Equation Section (Next)

6.1. Procedure to Compute Risk

First the Hazard score H is evaluated using Tables 6.1–6.8. Then, using these hazard scores, the value of $risk(50)$, the probability of an attack in 50 years is evaluated using the following equation

$$risk(50) = 20 + m^*[H - H(20)] \tag{6.1}$$

where $risk(50)$ denotes the probability of a termite attack within 50 years, and $H(20)$ denotes the hazard score total for which $risk(50) = 20\%$.

The risk can also be combined with the costs associated with the termite management strategy and the cost of failure, should such a failure occur according to Eq. (6.2) given in Section 6.5.

Details of the derivation of the procedure, and explanations of the various parameters cited can be found in "Manual No. 8 Termite Attack" by R.H. Leicester, C-H Wang and M.N. Nguyen (April 2008).

6.2. Hazard Score Components

Table 6.1 *Hazard score for location Zone*

Location Zone*	Hazard score
B	0
C	2
D	4

Table 6.2 *Hazard score for age of suburb**

Age of suburb	Hazard score
<10 yrs	0
10-70 yrs	2
>70 yrs	4

* Suburb refers to area within which at least 20% of the land is covered by buildings.

Table 6.3 *Hazard score for distance to nearest property boundary*

Distance to nearest boundary	Hazard score
>8 m	0
2—8 m	0.5
<2 m	1.0

Table 6.4 *Hazard score for wood in Garden (and under house)*

Quantity of wood in garden and under house*	Hazard score
low	0
medium	0.5
high	1.0

Table 6.5 *Hazard score for contact of house with ground*

Hazard related to ground contact*	Hazard score
low	0
medium	1
high	2

Table 6.6 *Hazard score for type of construction material*

Hazard related to type of construction materials*	Hazard score
low	0
medium	1
high	2

Table 6.7 *Hazard score for exposure conditions of timber*

Hazard related to exposure of material*	**Hazard score**
low	0
medium	1
high	2

6.3. The Hazard Score Total

Table 6.8 *Evaluation of hazard score total*

Hazard factor	**Hazard score**
Location zone	
Age of suburb	
Distance to boundary	
Wood in garden	
Ground contact	
Construction material	
Timber exposure	

Hazard score total H = $\boxed{}$

6.3.1. Comment on Hazard Zone A (Tasmania)

Currently, Tasmania does not have subterranean termites, which damage houses and accordingly termite management measures are not warranted.

6.4. Parameters for Evaluating the Risk Equation

As an example, Table 6.9 shows the inspection and maintenance regimes that must be put in place to ensure that the risk of termite attack is no greater than 20% in a 50 year period.

Table 6.9 Parameters for the Risk equations

Barrier type	**Maintenance quality**	**Inspection quality**	***H*(20)***	***m*****
Physical barrier		high	9.407	10
		med	8.573	10
		low	4.039	10
Toxic Chemical	high	high	no limit	8
		med	13.299	8
		low	6.764	8
	medium	high	no limit	8
		med	10.362	8
		low	5.908	8
	low	high	10.917	8
		med	7.963	8
		low	4.292	8
Repellent chemical	high	high	13.443	8.5
		med	9.439	8.5
		low	5.639	8.5
	medium	high	11.124	8.5
		med	8.211	8.5
		low	4.61	8.5
	low	high	9.068	8.5
		med	6.934	8.5
		low	3.939	8.5
No barrier		high	5.871	11.5
		med	4.402	11.5
		low	2.417	11.5

* $H(20)$ denote the total hazard parameter that will cause a risk of attack of 20% in 50 years

** m denotes the inverse slope of the risk-hazard relationship of the type shown in Figures C3–C5.

6.5. Risk Management procedure

6.5.1. Cost Components

In assessing the cost of various protection strategies, the following assumptions are made for costs over a 50 year period.

The cost of good quality inspection is assumed to be $500 every 2 years. Combining this information with the classifications given in Table 4 leads to the following total costs over a 50 year period:

- cost for high quality inspection = $25,000
- cost for medium quality inspection = $6,000
- cost for low quality inspection = $2,000

The cost of good quality maintenance for chemical treatments is assumed to be $2,000 every 5 years. Combining this information with the classifications given in Table 5 this leads to the following total costs over a 50 year period:

- cost for high quality maintenance = $20,000
- cost for medium quality maintenance = $10,000
- cost for low quality maintenance = $2,000

The cost of installing a physical barrier such as Granitgard or Termimesh is taken to be $1,000.

Should a termite attack occur, the cost of the potential damage is classified as follows:

- cost of low damage = $2,000
- cost of medium damage = $5,000
- cost of high damage = $20,000

6.5.2. Effective Cost of Termite Protection Strategies

The effective cost of a protection strategy is taken to be given as follows:

Cost of strategy = cost of installation of physical barriers + cost of maintenance of chemical barriers + cost of inspection + (probability of attack)*(costs incurred if an attack occurs) (6.2)

7. Decay within Building Envelope

Equation Section (Next)

7.1. Model Assumptions

A schematic illustration for decay progress is shown in Figure 1.1. For given d_0, t_{lag}, and r, the decay depth after t years of installation, d_t (mm), is expressed as follows:

$$d_t = \begin{cases} ct^2 & \text{if } t \le t_{d_0}; \\ (t - t_{lag})r & \text{if } t > t_{d_0}. \end{cases} \tag{7.1}$$

in which

$$t_{d_0} = t_{lag} + \frac{d_0}{r} \tag{7.2}$$

$$c = \frac{d_0}{t_{d_0}^2} \tag{7.3}$$

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

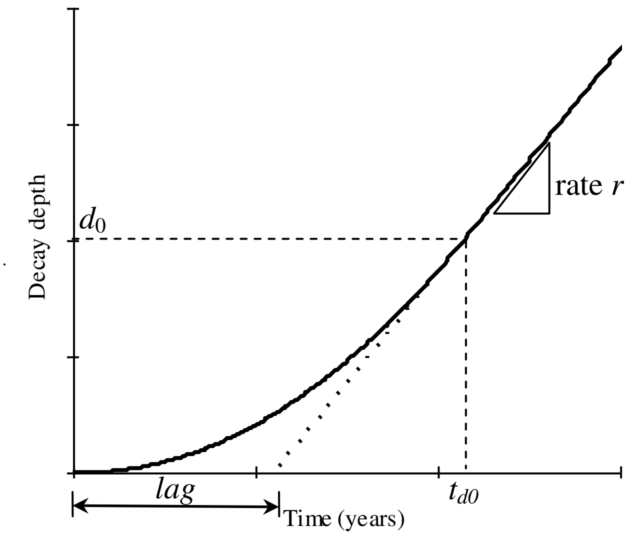


Figure 7.1 Idealised progress of decay depth with time.

7.2. Decay Rate and Decay Lag

The rate of decay is taken to be given by

$$r = k_{wood}\, k_{geometry}\, k_{climate} \tag{7.4}$$

where k_{wood} is related to the species of timber used, the zone of the tree from which it has been taken and the type of preservative. The term $k_{geometry}$ is related to the orientation and configuration of the structural element.

Using the annual value of time of wetness t_{wet}, which is the time that the timber is wetted by liquid water, as the climate indicator of decay rate, a climate factor $k_{climate}$ can be chosen as

$$k_{climate} = \begin{cases} 0.15 t_{wet}^{0.5} & \text{if } t_{wet} \text{ is in days/yrs;} \\ 0.03 t_{wet}^{0.4} & \text{if } t_{wet} \text{ is in hrs/yrs.} \end{cases} \tag{7.5}$$

For structures fully exposed to weather, $t_{wet} = t_{rain}$, where t_{rain} is the mean annual time of rainfall, which can be computed from BOM data.

The decay lag is assumed to be related to the decay rate as follows,

$$lag = 8.5 r^{-0.85} \tag{7.6}$$

In the following sections, the model parameters, particularly t_{wet}, are presented for prediction of decay in microclimates of building envelop, including roof-space, wall cavity, and subfloor.

7.3. Decay in Roof Space

7.3.1. Time of Wetness

It is assumed that leakage in the roof-space occurs when rain water, driven by strong wind speed of more than 4m/s, enters through the gaps between the ridge cap and the roof sheeting.

The annual time of wetness of timber (hrs/year) at the decay spots is then estimated as

$$t_{wet} = \sum_{i}^{N} (\alpha t_{rain,\ V \geq 4m/s} - t_{delay})_i \quad \text{with } (\alpha t_{rain,\ V \geq 4m/s} - t_{delay})_i > 0 \tag{7.7}$$

where:

- N is the number of occasions of rain during one year, i signifies the i^{th} occasion of rain
- $t_{rain,\ V \geq 4\text{m/s}}$ is the time of rain during which the wind speed is equal or more than 4m/s in one occasion of rain.
- t_{delay} is the time needed for the leaking water travelling from the ridge cap to the decay spots in each occasion of rain. This time is set as 0.2 hour (12 min).
- α is the wind direction adjustment factor. For a gable house,
  - α = 1.0, if the wind direction is within the range from –45° to +45° to the direction perpendicular to the ridge
  - α = 0.2, if the wind direction is within the range from –45° to +45° to the direction parallel to the ridge

7.3.2. Wood Parameters

Wood parameter k_{wood} is assumed to be

Durability Class	k_{wood}	
	Outer heartwood	Untreated sapwood
Class 1	0.5	6.52
Class 2	0.62	
Class 3	1.14	
Class 4	2.20	

Assume flat contact geometry at decay spots, then $k_{geometry}$ = 0.6

7.3.3. Failure Criteria

For serviceability, decay depth = 2 mm.

For replacement, decay depth = 10 mm.

7.4. Decay of Wall Panels

7.4.1. Time of Wetness

It is assumed that leakage in the wall occurs when rain water, driven by strong wind speed, hits and enters through cracks in the external skin of the wall, as depicted in Figure 7.2.

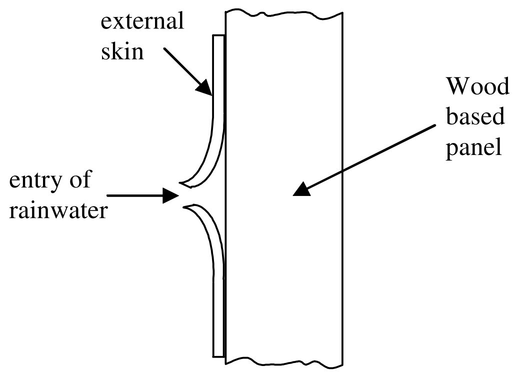


Figure 7.2 Entry of rainwater via a crack in the external skin.

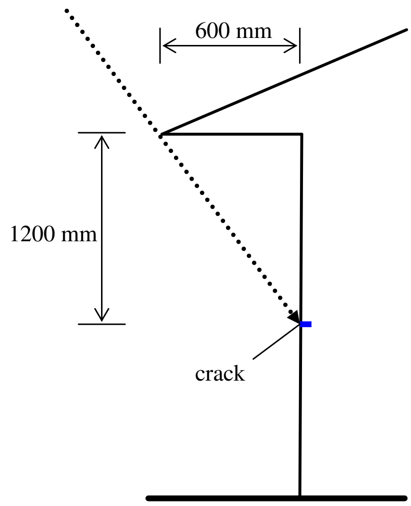


Figure 7.3 Wind driven rain drops wetting a wall under eaves.

It is assumed that the crack is at the mid-height of the wall, and the dimension of the eaves is shown in Figure 7.3. The dominant size of rain drops is assumed to be 1 mm in diameter.

The annual time of wetness of timber at the decay spots on the panel is then estimated as

$$t_{wet} = \sum_{i}^{N} (t_{raindrop,crack} - t_{drying})_i \quad \text{with } (t_{raindrop,crack} - t_{drying})_i > 0 \tag{7.8}$$

where:

- N is the number of occasions of rain during one year, i signifies the i^{th} occasion of rain
- $t_{raindrop,crack}$ is the time of rain during which the rain drops hits the crack on the wall being considered in each occasion of rain.
- t_{drying} is the adjustment time to take into account the extent of ventilation of the wall,
    - t_{drying} = 1.0 hour for cavity wall with both ends open and $S_{house} > 25$
    - t_{drying} = 0.2 hour (12 min) for cavity wall with both ends open and $S_{house} \leq 25$
    - t_{drying} = 0.0 hour for cavity wall with both ends close
    - t_{drying} = 0.0 hour for non-cavity wall
- S_{house} is the whole house ventilation score determined by Table 7.1.

Table 7.1 Determination of S_{house} for whole house ventilation

Roof ventilation	**Options**	***Score***
Sarking	Yes	0
	No	12
Eave ventilation	Yes	5
	No	0
Gable ventilation	Yes	10
	No	0
Ceiling ventilation	Yes	3
	No	0
Wall cavity	Yes, ends open	5
	Yes, ends close	1
	No	0
Subfloor ventilation	Large	15
	Standard	10
	No	0
	Total	S_{house}

7.4.2. Wood and Geometry Parameters

Material factor k_{wood} depends on the panel material:

- k_{wood} = 13.4 for OSB (assume decay rate is twice that of plywood)
- k_{wood} = 6.52 for untreated plywood (assume decay rate is the same as that of sapwood)
- k_{wood} = 0.0 for fibre cement sheet (no decay)

The geometry at decay spots is assumed to be similar to that of L-joint, then $k_{geometry}$ = 1.0.

7.4.3. Failure Criteria

For replacement, decay depth = 2/3 thickness. In Timberlife, replacement decay depth = 10 mm because the panel thickness is assumed to be 15 mm.

7.5. Decay of Wall Studs

7.5.1. Time of Wetness

The annual time of wetness of wall studs is determined by

$$t_{wet} = \sum_{i}^{N} (t_{raindrop,crack} - t_{drying})_i \quad \text{with } (t_{raindrop,crack} - t_{drying})_i > 0 \tag{7.9}$$

where:

- N is the number of occasions of rain during one year, i signifies the i^{th} occasion of rain
- $t_{raindrop,crack}$ is the time of rain during which the rain drops hits the crack on the wall being considered in each occasion of rain.
- t_{drying} is the adjustment time to take into account the extent of ventilation of the wall,
  - $t_{drying} = \infty$ for cavity wall. In other words, stud does not decay in this case.
  - t_{drying} = 0.5 hour for non-cavity wall with vapour barrier
  - t_{drying} = 0.0 hour for non-cavity wall without vapour barrier

7.5.2. Wood and Geometry Parameters

Wood parameter k_{wood}

Durability Class	k_{wood}	
	Outer heartwood	Untreated sapwood
Class 1	0.5	6.52
Class 2	0.62	
Class 3	1.14	
Class 4	2.20	

If the geometry of wall studs is assumed to be of flat contact, then $k_{geometry}$ = 0.6, in accord with the decay model for timber above ground exposed to weather.

7.5.3. Decay Lag

Decay lag for wall studs is

$$lag = 3\beta \times \left(\frac{t_{rain,\ Melbourne}}{t_{rain}} \right) + 8.5 r^{-0.85} \tag{7.10}$$

where $t_{rain,Melbourne}$ (≈ 450 hours) is the annual time of rainfall in Melbourne; t_{rain} is the annual time of rainfall at the location of the house under study; β is the adjustment factor taking into account the durability of the panel material. The factor β is determined as follows,

- β = 1.0 for OSB
- β = 2.0 for untreated plywood

7.5.4. Failure Criteria

For replacement, decay depth = 10 mm.

7.6. Decay in Subfloor

7.6.1. Time of Wetness

It is assumed that leakage in the subfloor occurs when water leaks through cracks or construction gaps in the floor, often in the bathroom, laundry room or kitchen. The annual time of wetness of timber (hrs/year) at the decay spots in the subfloor is then estimated as

$$\begin{gathered} t_{wet} = 365\ (t_{leakage} - t_{drying}) \\ \text{with } (t_{leakage} - t_{drying}) > 0 \end{gathered} \tag{7.11}$$

where:

- $t_{leakage}$ is the time of leakage per day (hrs/day), divided into 4 levels as follows,
  - No leakage, then $t_{leakage}$ = 0 (no problem)
  - Minor leakage, then $t_{leakage}$ = 1 hour
  - Medium leakage, then $t_{leakage}$ = 6 hours
  - Major leakage, then $t_{leakage}$ = 24 hours
- t_{drying} is the adjustment time. t_{drying} is computed by

$$t_{drying} = t_{drying,mean} \prod_{i=1}^{n} (1 + k_i a_i) \tag{7.12}$$

For a typical subfloor, $t_{drying,mean}$ = 3.34. The factors a_i and k_i are determined as in Table 7.2.

Table 7.2 Determining a_i and k_i for subfloor to estimate t_{drying}

i	Parameters	Options			a_i
		High risk $k_i = +1$	Medium risk $k_i = 0$	Low risk $k_i = -1$	
1	Subfloor ventilation	No vent	Standard	Large	-0.446
2	Whole house ventilation(1)	$S_{\text{house}} < 15$	$S_{\text{house}} = 15 - 30$	$S_{\text{house}} > 30$	-0.167
3	Annual local external wind speed (2)	<2 m/s	2 to 5 m/s	> 5 m/s	-0.223
4	Annual external temperature	<15°C	15 – 25°C	>25°C	-0.223
5	Soil type	Loam	Sand	Clay	-0.111
6	Water table depth	≤ 3m	–	> 3m	-0.223
7	Membrane	No	–	Yes	-0.223

(1) Determination of S_{house}, is given in Table 7.1.

(2) Procedure for local external wind speed is presented in the next subsection.

7.6.2. Local External Wind Speed

The local external wind speed used is the wind speed at the eaves of 3 m in height estimated by

$$V_{H=3m} = C_s C_{H=3m} V_{met} \tag{7.13}$$

where

V_{met} = wind speed measured at MET station

C_s = shelter factor depending on site classification as in Table 7.3.

$C_{H=3m}$ = terrain and height adjustment coefficient, determined by Eq. (7.14)

$$C_{H=3m} = \left(\frac{270}{10.0}\right)^{0.14} \left(\frac{3.0}{\delta}\right)^{a} \tag{7.14}$$

where the constants a and δ depending on the local terrain category are taken from Table 7.4.

Table 7.3 Shelter factor C_s

Shelter class	C_s	Description of local shelter
1.	1.0	No obstructions or local shielding
2.	0.9	Typical shelter for an isolated rural house
3.	0.7	Typical shelter caused by other buildings across the street from the building under study
4.	0.5	Typical shelter for urban buildings on larger lots where sheltering obstacles are more than one building height away
5.	0.3	Typical shelter produced by buildings or other structures that are immediately adjacent (closer than one house height): e.g. neighbouring houses on the same side of the street, trees, bushes, etc.

Table 7.4 Atmospheric boundary layer parameters

Terrain category	Description	Exponent a	Layer thickness δ (m)
1	Large city centres, in which at least 50% of buildings are higher than 21 *m*, over a distance of at least 2000 *m* or 10 times the height of the structure upwind, whichever is greater	0.33	460
2	Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger, over a distance of at least 2000 *m* or 10 times the height of the structure upwind, whichever is greater	0.22	370
3	Open terrain with scattered obstructions having heights generally less than 10 *m*, including flat open country typical of **meteorological station** surroundings	0.14	270
4	Flat, unobstructed areas exposed to wind flowing over water for at least 1.6 *km*, over a distance of 500 *m* or 10 times the height of the structure inland, whichever is greater	0.10	210

7.6.3. Wood and Geometry Parameters

Wood parameter k_{wood}

Durability Class	k_{wood}	
	Outer heartwood	Untreated sapwood
Class 1	0.5	6.52
Class 2	0.62	
Class 3	1.14	
Class 4	2.20	

Assume the geometry at decay spots to be of flat contact, then $k_{geometry} = 0.6$.

7.7. Failure Criteria

For serviceability, decay depth = 2 mm

For replacement, decay depth = 10 mm

8. Atmospheric Corrosion within Building Envelope

Equation Section (Next)

8.1. Model Assumptions

Since the model for fasteners in building envelope was developed based on the model for fasteners exposed outdoor, the model equations for fasteners exposed outdoor will be presented in this section.

8.1.1. Corrosion of Zinc

The corrosion depth of zinc over time, c_z (μm), is determined by the following power-law equation,

$$c_z = c_{0,z} t^{0.6} \tag{8.1}$$

where t (year) is the time in service. $c_{0,z}$ is the basic corrosion depth dependent on the presence of pollution agents,

$$c_{0,z} = 0.025\, t_{\mathrm{wet}}^{0.6} S_{\mathrm{air}}^{0.5} + 0.006 t_{wet}^{0.2} P_{air} \tag{8.2}$$

where t_{wet} is time of wetness, which is defined as the percentage of time in a year when the relative humidity is above 80% and the temperature above 0°C. S_{air} (mg/m^2/day) is the salt concentration in the air (airborne salinity). P_{air} is the pollution of air due to the concentration of SO_x (μg/m^3).

8.1.2. Corrosion of Steel

The corrosion depth of steel over time, c_s (μm), is determined by the following power-law equation,

$$c_s = c_{0,s} t^{0.8} \tag{8.3}$$

where t (year) is the time in service. $c_{0,s}$ is the basic corrosion depth dependent on the presence of pollution agents,

$$c_{0,s} = 0.5 t_{wet}^{0.8} S_{air}^{0.5} + 0.1 t_{wet}^{0.5} P_{air} \tag{8.4}$$

where t_{wet} is time of wetness, which is defined as the percentage of time in a year when the relative humidity is above 80% and the temperature above 0°C. S_{air} (mg/m^2/day) is salt concentration in the air (airborne salinity). P_{air} is the pollution of air due to the concentration of SO_x (μg/m^3).

8.1.3. Air Salinity

The salinity in the air at a site, S_{air} (mg/m^2 per day), is estimated by the following equation,

$$S_{\text{air}} = \max \begin{cases} \alpha_{\text{exp}} \alpha_{\text{micro}} \left[\alpha_{\text{coast}} \beta_{\text{coast}} \left(0.9 e^{-10 L_{coast}} + 0.1 e^{-L_{coast}} \right) + \alpha_{\text{ocean}} e^{-0.02 L_{\text{coast}}} \right] \\ 1.0 \end{cases} \tag{8.5}$$

in which L_{coast} is the distance to the coast in kilometres; the parameters α_{coast} and α_{ocean} take into account the effect of coastal zonation (Table 8.1); β_{coast} the effect of coastal exposure (Table 8.2); α_{exp} the effect of site exposure (Table 8.3); and α_{micro} the effect of local shelter factors (Table 8.4).

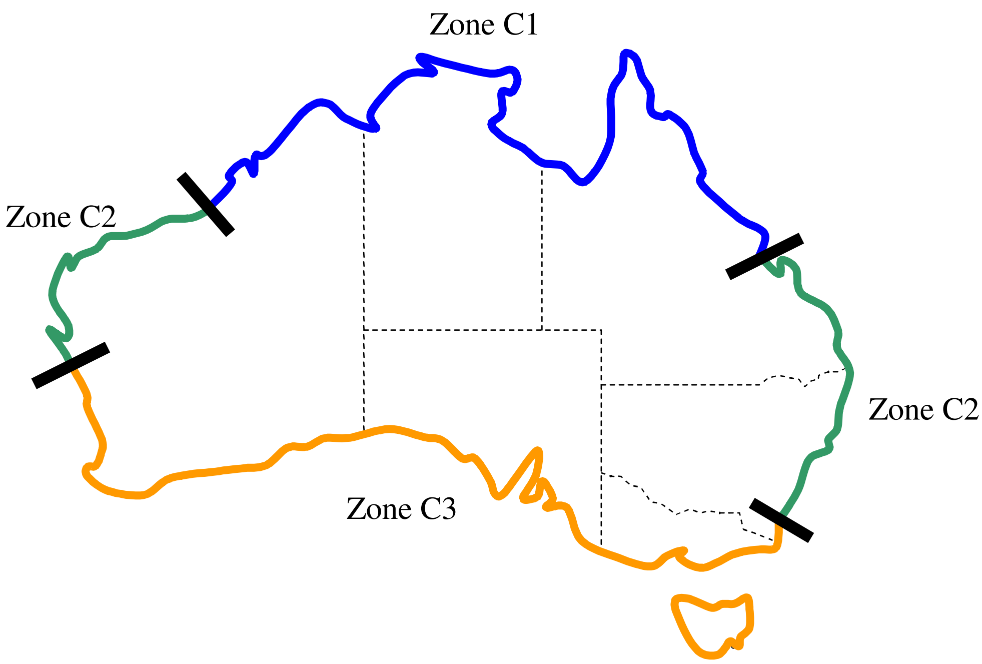


Figure 8.1 *Definition of coastal zones.*

Table 8.1 Parameters for the effect of coastal and ocean surf

Coastal zone*	α_{coast}	α_{ocean}
C_1	50	2
C_2	150	6
C_3	500	20
* See Figure 8.1		

Table 8.2 Parameter for the effect of coastal exposure

Coastal exposure condition*	β_{coast}
Closed bay	0.05
Partially closed bay	0.10
Open bay	0.35
Open surf	1.00
*See Figure 8.2	

Table 8.3 Parameters for the effect of site classification

Site classification	α_{exp}
Open to sea	2.00
Urban (suburbs)	0.50
Urban (city centre)	0.25
Other sites	1.00

Table 8.4 Parameter for the effect of shelter (rain protection)

Local Shelter	α_{micro}
Sheltered from rain	2.0
Exposed to rain	1.0

The coastal exposure condition is dependent on the opening angle, θ (degrees), and the radius, R (km), of the bay. By using an exposure factor for the idealised bay, α_{bay}, calculated as follows for a given θ and R,

$$\alpha_{\mathrm{bay}}^2 = \left(\frac{\theta}{85}\right)^2 + \left(\frac{R}{20}\right)^2 \tag{8.6}$$

then the coastal exposure condition is determined by the α_{bay} value:

$$\text{Coastal exposure condition} = \begin{cases} \text{Closed bay,} & \text{if } \alpha_{bay} < 1; \\ \text{Partially closed bay,} & \text{if } 1 \le \alpha_{bay} < 1.5; \\ \text{Open bay,} & \text{if } 1.5 \le \alpha_{bay} < 2.5; \\ \text{Open surf,} & \text{if } \alpha_{bay} \ge 2.5. \end{cases} \tag{8.7}$$

The definition of Eq. (8.7) is schematically shown in Figure 8.2.

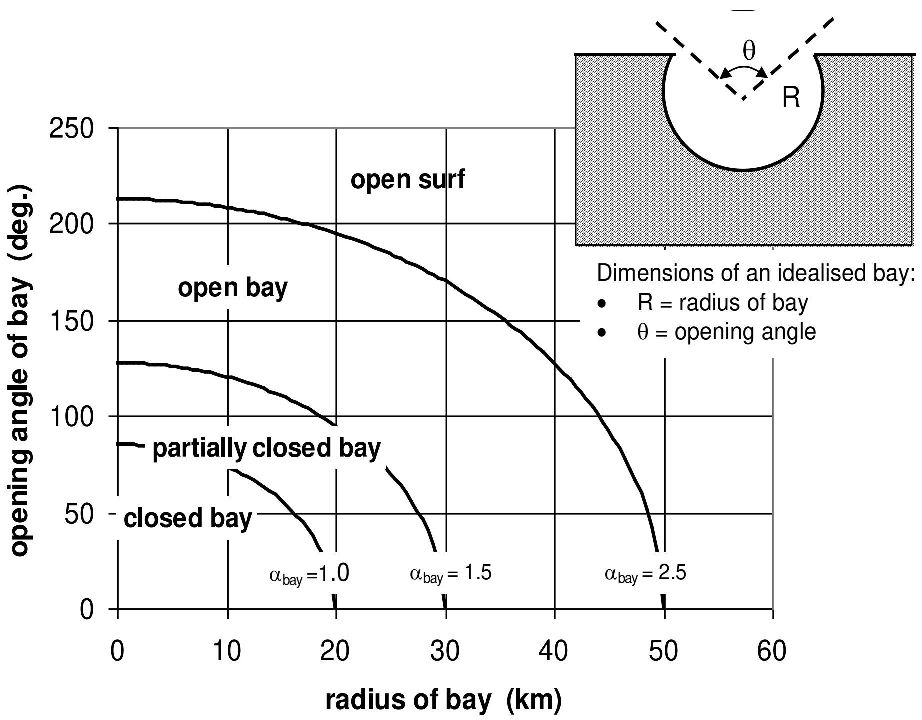


Figure 8.2 Definition of coastal exposure condition.

8.1.4. Pollution

An estimate of the pollution parameter, P_{air}, which is the pollution of air due to the concentration of airborne SO_x ($\mu g/m^3$), can be made by,

$$P_{\mathrm{air}} = \frac{\alpha_{\mathrm{indus}}}{L_{indus} + 1} \tag{8.8}$$

where L_{indus} (km) the distance to the nearest industrial complex; α_{indus} is defined in Table 8.5.

Table 8.5 Parameter for the effect of industrial exposure

Industry Type	α_{indus}
Heavy industry (steel works, petrochemical)	110.0
Moderate industry (paper mills, large manufacturing)	22.0
Light industry (assembly plants)	5.5

8.1.5. Climate Related Parameters — Time of Wetness (t_{wet})

The climate parameter considered in the prediction of corrosion depth is the time-of-wetness, t_{wet} (%), defined as the percentage of time in a year when the relative humidity is above 80% and the temperature is above 0°C. t_{wet} is estimated by

$$t_{wet} = 0.22 D_{rain} \tag{8.9}$$

where D_{rain} is the number of rain days per year (days/year). A rain day is defined as a day in which there is at least 0.2 mm of rain. For a site near the coast, D_{rain} takes a representative value found in Table 8.6, which depends on the hazard zones shown in Figure 8.3. For an inland site, D_{rain} is computed by

$$D_{rain} = D_{rain-inland} + \left(D_{rain|L_{coast}=0} - D_{rain-inland}\right)e^{-0.004 L_{coast}} \tag{8.10}$$

where L_{coast} is the distance to the nearest coast (km); $D_{rain\text{-}inland}$ = 30 days/year, a representative value of D_{rain} for inland locations about 1000 km or more from the coast.

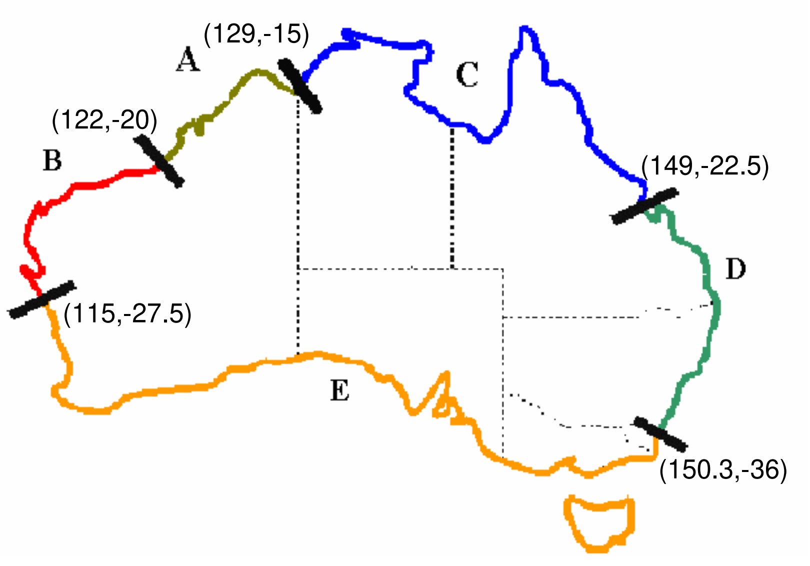


Figure 8.3 Hazard Zones related to corrosion due to airborne salt (Zone E is the most hazardous).

Table 8.6 Hazard zones and corresponding coastal zones and numbers of rain days

Hazard Zone	Coastal zone (Figure 8.1)	Representative D_{rain} (No. of rain days / year)
A	C1	70
B	C2	40
C	C1	100
D	C2	130
E	C3	130

8.2. Model for Metal Fasteners in Building Envelope

The corrosion prediction models for fasteners in building envelope take the same forms as those for fasteners outdoors; i.e. Eqs (8.1) and (8.2) for zinc, and Eqs (8.3) and (8.4) for steel. The parameters S_{air}, t_{wet}, and P_{air}, needs to be adjusted, as described in subsections 8.3, 8.4, and 8.5, respectively.

8.3. Air Salinity in Building Envelope

The air salinity in building envelope, $S_{air,\text{indoors}}$, is related to the air salinity outside the building, $S_{air,\text{outdoors}}$, by the following equation

$$S_{\text{air,indoors}} = \alpha\, S_{\text{air,outdoors}} \tag{8.11}$$

where α is given by

$$\alpha = \alpha_{\text{mean}} \prod_{i=1}^{n} (1 + k_i a_i) \tag{8.12}$$

The air salinity outdoors $S_{\text{air,outdoors}}$ is described in Section 8.1.3. The parameters α_{mean}, α_i, and k_i for salinity in subfloor, wall cavity, and roof space are described in the following subsections.

8.3.1. Salinity in Subfloor

For a typical subfloor space, $\alpha_{\text{mean}} = 0.253$. a_i and k_i are given in Table 8.7.

Table 8.7 a_i and k_i for salinity estimation in subfloor

i	Parameters	Risk level			a_i
		High risk $k_i = +1$	Medium risk $k_i = 0$	Low risk $k_i = -1$	
1	Subfloor ventilation	Large	Standard	No vent	0.843
2	Whole house ventilation[(1)]	$S_{house} > 30$	$S_{house} = 15 - 30$	$S_{house} < 15$	0.316
3	Annual local external wind speed [(2)]	> 5 m/s	2 to 5 m/s	<2 m/s	0.632

(1) Determination of the score for whole house ventilation, S_{house}, is given in Section 8.6.

(2) Determination of the local external wind speed is given in Section 8.7.

8.3.2. Salinity in Wall Cavity

For a typical wall, $\alpha_{mean} = 0.207$. a_i and k_i are given in Table 8.8.

Table 8.8 a_i and k_i for salinity estimation in wall cavity

i	Parameters	Risk level			a_i
		High risk $k_i = +1$	Medium risk $k_i = 0$	Low risk $k_i = -1$	
1	Wall ventilation	Cavity, ends open	Cavity, ends close	Non-cavity	0.752
2	Whole house ventilation[(1)]	$S_{house} > 30$	$S_{house} = 15 - 30$	$S_{house} < 15$	0.282
3	Annual local external wind speed [(2)]	> 5 m/s	2 to 5 m/s	<2 m/s	0.376
4	Orientation of wall to sea	Facing direction to sea	Other directions	Facing opposite direction to sea	0.564

(1) Determination of the score for whole house ventilation, S_{house}, is given in Section 8.6.

(2) Determination of the local external wind speed is given in Section 8.7.

8.3.3. Salinity in Roof space

For a typical roof space, α_{mean} = 0.253. a_i and k_i are given in Table 8.9.

Table 8.9 a_i and k_i for salinity estimation in roof space

i	Parameters	Risk level			a_i
		High risk $k_i = +1$	Medium risk $k_i = 0$	Low risk $k_i = -1$	
1	Roof ventilation[3]	$S_{roof} > 20$	$S_{roof} = 10 - 19$	$S_{roof} < 10$	0.843
2	Whole house ventilation[1]	$S_{house} > 30$	$S_{house} = 15 - 30$	$S_{house} < 15$	0.316
3	Annual local external wind speed [2]	> 5 m/s	2 to 5 m/s	<2 m/s	0.632

(1) Determination of the score for whole house ventilation, S_{house}, is given in Section 8.6.

(2) Determination of the local external wind speed is given in Section 8.7.

(3) Determine of the score for roof ventilation S_{roof} is given in Table 8.10.

Table 8.10 Score for roof ventilation

Roof ventilation	**Options**	**Score**
Sarking	Yes	0
	No	12
Eave ventilation	Yes	5
	No	0
Gable ventilation	Yes	10
	No	0
Ceiling ventilation	Yes	3
	No	0
Wall cavity	Yes, ends open	5
	Yes, ends close	0
	No	0
	Total	S_{roof}

8.4. Time of Wetness of Timber in Building Envelope

The time-of-wetness of timber located within building envelope, $t_{\text{wet,indoors}}$, is related to the time-of-wetness of timber located outside the building, $t_{\text{wet,outdoors}}$,

$$t_{\text{wet,indoors}} = \beta\ t_{\text{wet,outdoors}} \tag{8.13}$$

where β is given by

$$\beta = \beta_{\text{mean}} \prod_{i=1}^{n} (1 + k_i a_i) \tag{8.14}$$

The time-of-wetness of timber outside the building $t_{\text{wet,outdoors}}$ is describe in Section 8.1.5. The parameters β_{mean}, α_i, and k_i for that in subfloor, wall cavity, and roof space are described in the following subsections.

8.4.1. Time of Wetness of Timber in Subfloor

For a typical subfloor, $\beta_{\text{mean}} = 1.18$. a_i and k_i are given in Table 8.11.

Table 8.11 a_i and k_i for time-of-wetness estimation in subfloor

i	Parameters	Risk level			a_i
		High risk $k_i = +1$	Medium risk $k_i = 0$	Low risk $k_i = -1$	
1	Subfloor ventilation	No vent	Standard	Large	0.220
2	Whole house ventilation(1)	$S_{\text{house}} < 15$	$S_{\text{house}} = 15 - 30$	$S_{\text{house}} > 30$	0.083
3	Annual local external wind speed (2)	<2 m/s	2 to 5 m/s	> 5 m/s	0.110
4	Annual external temperature	<15°C	15 – 25°C	>25°C	0.110
5	Soil type	Loam	Sand	Clay	0.055
6	Water table depth	1m	–	5m	0.110
7	Membrane	No	–	Yes	0.110

(1) Determination of the score for whole house ventilation, S_{house}, is given in Section 8.6.

(2) Determination of the local external wind speed is given in Section 8.7.

8.4.2. Time of Wetness of Timber in Wall Cavity

For a typical wall, $\beta_{mean} = 0.73$. a_i and k_i are given in Table 8.12.

Table 8.12 a_i and k_i for time-of-wetness estimation in wall cavity

i	Parameters	Risk level			a_i
		High risk $k_i = +1$	Medium risk $k_i = 0$	Low risk $k_i = -1$	
1	Wall Ventilation	Non-cavity	Cavity, ends close	Cavity, ends open	0.374
2	Whole house ventilation[(1)]	$S_{house} < 15$	$S_{house} = 15 – 30$	$S_{house} > 30$	0.140
3	Annual local external wind speed [(2)]	<2 m/s	2 to 5 m/s	> 5 m/s	0.187
4	Annual external temperature	<15°C	15 – 25°C	>25°C	0.187
5	Orientation of wall to sun	South	East/West	North	0.234

(1) Determination of the score for whole house ventilation, S_{house}, is given in Section 8.6.

(2) Determination of the local external wind speed is given in Section 8.7.

8.4.3. Time of Wetness of Timber in Roof space

For a typical roof space, $\beta_{mean} = 0.51$. a_i and k_i are given in Table 1.4.3.1.

Table 8.13 a_i and k_i for time-of-wetness estimation in roof space

i	Parameters	Risk level			a_i
		High risk $k_i = +1$	Medium risk $k_i = 0$	Low risk $k_i = -1$	
1	Roof ventilation[(3)]	$S_{roof} < 10$	$S_{roof} = 10 - 19$	$S_{roof} > 20$	0.537
2	Whole house ventilation[(1)]	$S_{house} < 15$	$S_{house} = 15 - 30$	$S_{house} > 30$	0.201
3	Annual local external wind speed [(2)]	<2 m/s	2 to 5 m/s	> 5 m/s	0.268
4	Annual external temperature	<15°C	15 – 25°C	>25°C	0.268

(1) Determination of the score for whole house ventilation, S_{house}, is given in Section 8.6.

(2) Determination of the local external wind speed is given in Section 8.7.

(3) Score for roof ventilation S_{roof} is determined in Table 8.14.

Table 8.14 Score for roof ventilation

Roof ventilation	**Options**	**Score**
Sarking	Yes	0
	No	12
Eave ventilation	Yes	5
	No	0
Gable ventilation	Yes	10
	No	0
Ceiling ventilation	Yes	-3
	No	0
Wall cavity	Yes, ends open	5
	Yes, ends close	0
	No	0
	Total	S_{roof}

8.5. Pollution of Air in Building Envelope

In the absence of direct measurements, the pollution of air in building envelope, $P_{air,indoors}$, is assumed to be related to the pollution of air outside the building, $P_{air,outdoors}$, similar to that of the air salinity, by the following equation,

$$P_{\mathrm{air,indoors}} = \alpha\, P_{\mathrm{air,outdoors}} \tag{8.15}$$

where α is described in Section 8.3. The air pollution outdoors, $P_{air,outdoors}$ is describe in Section 8.1.4.

8.6. Score for whole house ventilation — S_{house}

Table 8.15 Score for whole house ventilation

Roof ventilation	Options	Score
Sarking	Yes	0
	No	12
Eave ventilation	Yes	5
	No	0
Gable ventilation	Yes	10
	No	0
Ceiling ventilation	Yes	3
	No	0
Wall cavity	Yes, ends open	5
	Yes, ends close	1
	No	0
Subfloor ventilation	Large	15
	Standard	10
	No	0
	Total	S_{house}

8.7. Local External Wind Speed

The local external wind speed considered is at the height of 3 m, a typical eaves height. It is determined by

$$V_{H=3m} = C_s C_{H=3m} V_{met} \tag{8.16}$$

where

V_{met} = wind speed measured at a nearby MET station

C_s = shelter factor dependent on the site classification defined in Table 8.16.

$C_{H=3m}$ = terrain and height adjustment coefficient, determined by Eq. (8.17)

$$C_{H=3m} = \left(\frac{270}{10.0}\right)^{0.14} \left(\frac{3.0}{\delta}\right)^{a} \tag{8.17}$$

where a and δ are dependent on the local terrain category, defined in Table 8.17.

Table 8.16 Shelter factor C_s

Site classification	Shelter factor C_s
Open to sea	1
Urban (suburbs)	0.7
Urban (city centre)	0.4
Other site	0.9

Table 8.17 Atmospheric boundary layer parameters a and δ

Terrain category	Description	Exponent a	Layer thickness δ (m)
1	Large city centres, in which at least 50% of buildings are higher than 21 *m*, over a distance of at least 2000 *m* or 10 times the height of the structure upwind, whichever is greater	0.33	460
2	Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger, over a distance of at least 2000 *m* or 10 times the height of the structure upwind, whichever is greater	0.22	370
3	Open terrain with scattered obstructions having heights generally less than 10 *m*, including flat open country typical of **meteorological station** surroundings	0.14	270
4	Flat, unobstructed areas exposed to wind flowing over water for at least 1.6 *km*, over a distance of 500 *m* or 10 times the height of the structure inland, whichever is greater	0.10	210

9. Embedded Corrosion within Building Envelope

Equation Section (Next)

9.1. Model Assumptions

Since the model for fasteners in building envelope was developed based on the model for fasteners embedded in timber exposed outdoors, the model equations for fasteners exposed outdoor will be presented in this section

9.2. Hazard Zones

The content of Australia is divided into three embedded corrosion hazard zones, as shown in Figure 9.1. The hazard map is developed based on the mean annual seasonal equilibrium moisture content (*SEMC*). The representative SEMC values for the hazard zones are listed in Table 9.1.

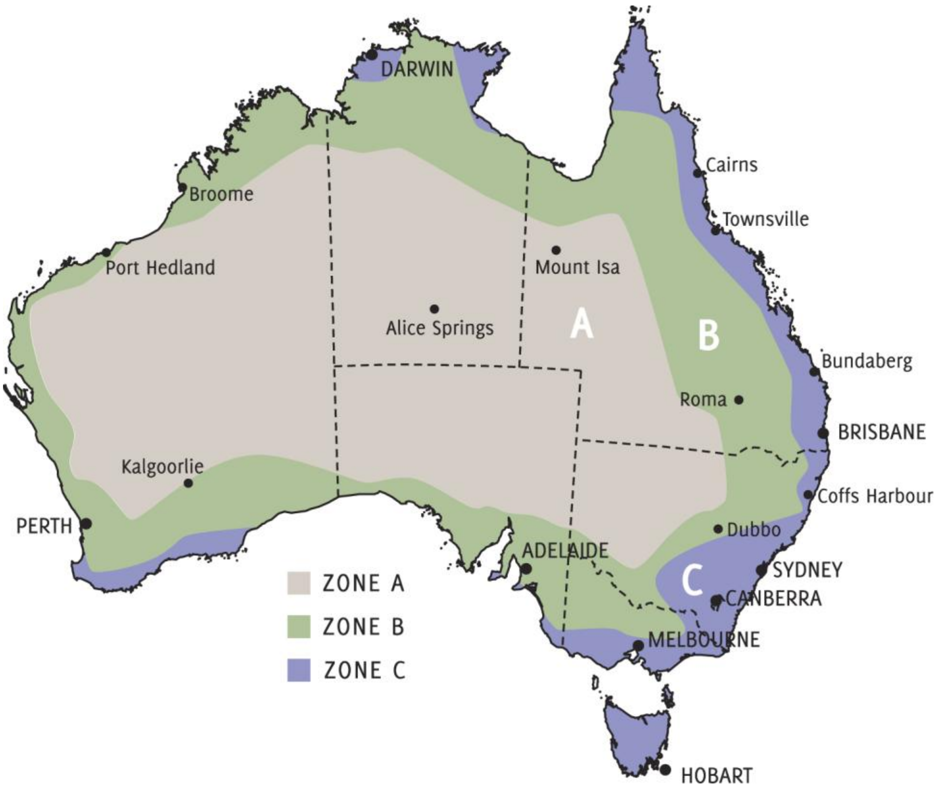


Figure 9.1 Embedded corrosion hazard map (Zone C is the most hazardous)

Table 9.1 Annual mean *SEMC* values for the hazard zones and boundaries

Zone	**Representative Zone *SEMC***	**Boundary *SEMC***
A	9	
		10
B	12	
		13
C	15	

9.3. Climate Zones

The continent of Australia is divided roughly into two climate zones:

- Marine, if the distance to coast < 1 km
- Other (i.e. non-marine)

9.4. Timber Acidity Classification

Table 9.2 lists the timber acidity, if available, and its classification for commonly used wood species.

Table 9.2 Timber Acidity classification

Standard Australia index	Trade name	Botanical name	Type	Density	Design pH	Natural acidity class
22	Ash, alpine	Euc. delegatensis	E	650	3.6	3
25	Ash, Crow's	Flindersia australis	H	950	5.1	1
30	Ash, mountain	Euc. regnans	E	640	4.7	2
37	Ash, silvertop	Euc. sieberi	E	862	3.5	3
-	Balau (selangan batu)	Shorea spp.	H	900	-	2
-	Bangkirai	Shorea laevifolia	H	850	-	2
65	Beech, myrtle	Nothofagus cunninghamii	H	705	-	2
-	Belian (ulin)	Eusideroxylon zwageri	H	1000	-	2
84	Blackbutt	Euc. pilularis	E	884	3.6	3
86	Blackbutt, New England	Euc. andrewsii	E	850	-	3
87	Blackbutt, WA	Euc. patens	E	849	-	3
88	Blackwood	Acacia melanoxylon	H	650	-	2
97	Bloodwood, red	Euc. gummifera	E	900	3.6	3
90	Bloodwood, white	Euc. trachyphloia	E	1023	-	3
109	Bollywood	Litsea reticulata	S	532	3.9	3
121	Box, brush	Lophostemon confertus	H	900	4.5	2
126	Box, grey	Euc. moluccana	E	1105	3.5	3
127	Box, grey, coast	Euc. bosistoana	E	1110	3.4	3
134	Box, long leaved	Euc. goniocalyx	E	873	-	3
138	Box, red	Euc. polyanthemos	E	1064	-	3
144	Box, steel	Euc. rummeryi	E	0	-	3
145	Box, swamp	Lophostemon suaveolens	H	850	-	2
150	Box, yellow	Euc. melliodora	E	1075	-	3
148	Box,white	Euc. albens	E	1112	-	3
162	Brigalow	Acacia harpophylla	H	1099	-	2
165	Brownbarrel	Euc. fastigata	E	738	3.3	3
167	Bullich	Euc. megacarpa	E	640	-	3
-	Calantas (kalantas)	Toona calantas	H	500	-	2
178	Candlebark	Euc. rubida	E	750	-	3
73	Cedar, red, western	Thuja plicata	S	448	3.3	3
544	Cypress	Callitris Glaucophylla	S	680	5.4	1
114	Fir, Douglas	Pseudotsuga menziesii	S	520	3.5	3
253	Gum, blue, southern	Euc. globulus	E	900	-	3
254	Gum, blue, Sydney	Euc. saligna	E	843	3.6	3
266	Gum, grey	Euc. propinqua	E	1050	3.8	3
267	Gum, grey, mountain	Euc. cypellocarpa	E	961	3.6	3
268	Gum, maiden's	Euc. maidenii	E	992	-	3
269	Gum, manna	Euc. viminalis	E	814	-	3
272	Gum, mountain	Euc. dalrympleana	E	700	-	3
281	Gum, red, forest	Euc. tereticornis	E	737	4.2	2
281	Gum, red, river	Euc. camaldulensis	E	913	-	3

284	Gum, rose	Euc. grandis	E	753	5.1	1
286	Gum, salmon	Euc. salmonophloia	E	1070	-	3
288	Gum, scribbly	Euc. haemastoma	E	907	-	3
289	Gum, shining	Euc. nitens	E	530	-	3
293	Gum, spotted	Euc. maculata	E	988	4.5	2
294	Gum, sugar	Euc. cladocalyx	E	1105	-	3
305	Gum, yellow	Euc. leucoxylon	E	1008	-	3
310	Hardwood, Johnstone River	Backhousia bancroftii	H	950	-	2
-	Hemlock, western	Tsuga heterophylla	S	500	4.9	2
322	Ironbark, grey	Euc. paniculata	E	1110	4.0	3
325	Ironbark, red	Euc. sideroxylon	E	1086	-	3
326	Ironbark, red (broad-leaved)	Euc. fibrosa	E	1116	-	3
327	Ironbark, red (narrow-leaved)	Euc. crebra	E	1046	4.0	3
336	Ironwood Cooktown	Erythrophleum chlorostgchys	H	1220	-	2
340	Jam, raspberry	Acacia acuminata	H	1038	-	2
341	Jarrah	Euc. marginata	E	823	3.3	3
-	Kapur	Dryobalanops spp.	H	750	3.3	3
344	Karri	Euc. diversicolor	E	905	4.2	2
	Keruing	Dipterocarpus spp.	H	750	5.1	1
173	Kwila	Intsia bijuga	H	825	-	2
-	Mahogany, Philippine, red, dark	Shorea spp.	H	650	-	2
-	Mahogany, Philippine, red, light	Shorea, Pentacme, Parashorea spp.	H	550	-	2
384	Mahogany, red	Euc. resinifera	E	955	3.0	3
391	Mahogany, white	Euc. acmenoides	E	993	3.5	3
391	Mahogany, white	Euc. umbra	E	887	-	3
387	Mahonany, southern	Euc. botryoides	E	919	-	3
411	Mallet, brown	Euc. astringens	E	974	-	3
432	Marri	Euc. Calophylla	E	855		3
-	Meranti, red, dark	Shorea spp.	H	650	3.9	3
-	Meranti, red, light	Shorea spp.	H	400	5.0	2
226	Mersawa (Garawa)	Anisoptera thyrifera	H	630	4.5	2
434	Messmate	Euc. obliqua	E	722	3.2	3
435	Messmate, Gympie	Euc. cloeziana	E	996	-	3
458	Oak, bull	Allocasuarina luehmannii	H	1050	-	2
240	Oak, white, American	Quercus alba	H	750	-	2
509	Peppermint, black	Euc. amygdalina	E	753	-	3
510	Peppermint, broad leaved	Euc. dives	E	811	-	3
512	Peppermint, narrow leaved	Euc. radiata	E	822	3.2	3
515	Peppermint, river	Euc. elata	E	804	-	3
529	Pine, black	Prumnopitys amara	S	500	-	2
533	Pine, caribbean	Pinus caribaea	S	550	3.9	3
534	Pine, celery-top	Phyllocladus asplenifolius	S	646	-	2
545	Pine, hoop	Araucaria cunninghamii	S	550	5.2	1
546	Pine, Huon	Lagarostrobos franklinii	S	520	4.6	2
548	Pine, kauri	Agathis robusta	S	503	-	2
549	Pine, King William	Athrotaxis selaginoides	S	400	-	2
559	Pine, radiata	Pinus radiata	S	540	4.8	2
561	Pine, slash	Pinus elliotii	S	650	-	2

-	Ramin	Gonystylus spp.	H	650	5.2	1
326	Redwood	Sequoia sempervirens	S	400	-	2
332	Rosewood, New Guinea	Pterocarpus indicus	H	577	-	2
635	Satinay	Syncarpia hillii	H	838	-	2
668	Stringybark, Blackdown	Euc. sphaerocarpa	E	1000	-	3
671	Stringybark, brown	Euc. capitellata	E	838	-	3
676	Stringybark, red	Euc. macrorhyncha	E	899	-	3
680	Stringybark, white	Euc. Eugenioides 2	E	856	-	3
680	Stringybark, White (Wilkinson's)	Euc. Eugenioides 1	E	856	-	3
681	Stringybark, yellow	Euc. muelleriana	E	884	4	3
688	Tallowwood	Euc. microcorys	E	990	3.5	3
-	Taun	Pometia pinnata	H	700	-	2
369	Teak, Burmese	Tectona grandis	H	600	4.5	2
713	Tingle, red	Euc. jacksonii	E	772	-	3
714	Tingle, yellow	Euc. guilfoylei	E	900	-	3
720	Tuart	Euc. gomphocephala	E	1036	-	3
723	Turpentine	Syncarpia glomulifera	H	945	3.5	3
747	Wandoo	Euc. wandoo	E	1099	-	3
774	Woolybutt	Euc. longifolia	E	1068	-	3
780	Yate	Euc. cornuta	E	1100	-	3
788	Yertchuk	Euc. consideniana	E	939	-	3

9.5. Model Equations for Fasteners in Wood Exposed Outdoors

The corrosion depth at 120 days, denoted by $f_{120}(M)$, is a function of the moisture content of the timber, M. The functional form of $f_{120}(M)$ for fasteners embedded in untreated timber is shown schematically in Figure 9.2, and expressed mathematically by

$$f_{120}(M) = \begin{cases} 0 & \text{if } M \le M_0; \\ 0.2\ C_{120}(M - M_0) & \text{if } M_0 < M < (M_0{+}5\%); \\ C_{120} & M \le (M_0{+}5\%) \end{cases} \qquad (9.1)$$

where M (%) is the wood moisture content. The parameters C_{120} (μm) and M_0 are given in Table 9.3.

For fasteners embedded in CCA treated wood, $f_{120}(M)$ is shown schematically in Figure 9.3, and expressed mathematically by

$$f_{120}(M) = \begin{cases} 0 & \text{if } M \le M_0; \\ 0.7\ (M - M_0) & \text{if } M > M_0; \end{cases} \qquad (9.2)$$

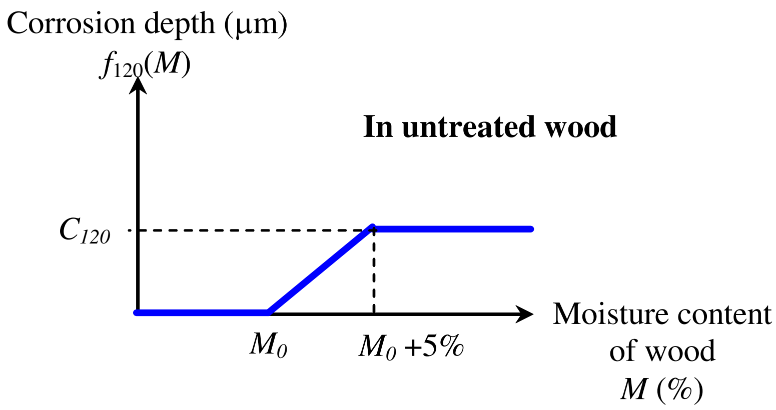


Figure 9.2 Function of $f_{120}(M)$ for fasteners embedded in untreated wood

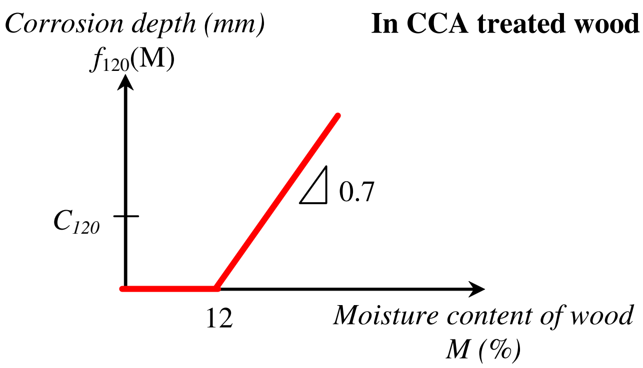


Figure 9.3 Function of $f_{120}(M)$ for fasteners embedded in CCA-treated wood

Table 9.3 Parameters of the corrosion model of embedded fasteners in untreated wood

Material	Wood type	C_{120}			M_0 (%)
		Acidity class 1	Acidity class 2	Acidity class 3	
Zinc	Hardwood	2.0	7.0	12.0	10
	Softwood	4.0	5.0	6.0	15
Steel	Hardwood	2.0	8.0	14.0	15
	Softwood	2.0	6.0	10.0	15

9.6. Moisture Content of Wood

The moisture content of wood exposed outdoors, TM_{mean}, is estimated from the mean surface equilibrium moisture content of the site location, $SEMC_{mean}$,

$$TM_{mean} = exp[1.9 + 0.05\ SEMC_{mean}] \tag{9.3}$$

$SEMC_{mean}$, is given in Table 9.4. The maximum and mean seasonal moisture contents of wood in building envelope, $BTM_{\max}$ and BTM_{mean}, are,

$$BTM_{\text{mean}} = TM_{\text{mean}} + \Delta_{\text{enviroment}} \tag{9.4}$$

$$BTM_{\max} = BTM_{\text{mean}} + 0.1\, D\ TM_{\text{mean}} \tag{9.5}$$

where the damping factor D is given in Table 9.5. Determination of $\Delta_{\text{environment}}$ is described in the following subsections.

9.7. $\Delta_{\text{environment}}$ for Subfloor

$\Delta_{\text{environment}}$ for subfloor is determine by

$$\Delta_{\text{enviroment}} = \Delta_{\text{microclimate}} + \Delta_{\text{SFvent}} + \Delta_{\text{soil}} \tag{9.6}$$

where $\Delta_{\text{microclimate}}$ is given in Table 9.5, Δ_{SFvent} in Table 9.6, and Δ_{soil} in Table 9.7.

9.8. $\Delta_{\text{environment}}$ for Roof Space

$\Delta_{\text{environment}}$ for roof space is determine by

$$\Delta_{\text{enviroment}} = \Delta_{\text{microclimate}} + \Delta_{\text{sarking}} + \Delta_{\text{eaves}} + \Delta_{\text{gable}} + \Delta_{\text{ceiling}} \tag{9.7}$$

where $\Delta_{\text{microclimate}}$ is given in Table 9.5. Δ_{sarking}, Δ_{eaves}, Δ_{gable}, and Δ_{ceiling} are all given in Table 9.8.

9.9. $\Delta_{\text{environment}}$ for Wall Cavity

$\Delta_{\text{environment}}$ for wall cavity is determine by

$$\Delta_{\text{enviroment}} = \Delta_{\text{microclimate}} + \Delta_{\text{WCvent}} \tag{9.8}$$

where $\Delta_{\text{microclimate}}$ is given in Table 9.5 and Δ_{WCvent} in Table 9.9.

Table 9.4 Mean surface equilibrium moisture content

Hazard zone	$SEMC_{mean}$
A	9
B	12
C	15

Table 9.5 Damping and microclimate parameters

Microclimate	D		$\Delta_{\text{microclimate}}$	
	Marine(1)	**Other**	**Marine**	**Other**
Sub-floor	2.0	0.8	2.5	0.9
Wall cavity	1.5	1.1	0.5	0.6
Roof space	2.0	1.3	-0.5	-3.8

If distance to coast < 1km, the climate zone is 'Marine'; otherwise, it is 'Other.'

Table 9.6 Subfloor ventilation parameter

Extent of Ventilation	Δ_{SFvent}	
	Marine	**Other**
None	4.0	1.5
Standard	0.0	0.0
Large	-1.0	-0.5

Table 9.7 Soil moisture parameter

Membrane use and water table level	Δ_{soil}		
	Loam	**Sand**	**Clay**
Without membrane:			
1 m	1.5	1.0	0.5
5 m	0.2	0.1	0.0
With membrane installed:	0.0	0.0	0.0

Table 9.8 Roof space ventilation parameters

Option	$\Delta_{sarking}$	Δ_{eaves}	Δ_{gable}	$\Delta_{ceiling}$
Yes	0.0	0.0	0.0	0.0
No	-2.0	0.2	2.0	-1.5

Table 9.9 Wall ventilation parameter

Wall configuration	Δ_{WCvent}		
	North wall	**East/west wall**	**South wall**
Wall with 19mm-wide cavity:			
* Opening at both ends	-1.5	0.0	1.5
* Not opening	0.5	2.0	3.5
Non-cavity wall	1.0	2.5	4.0

9.10. Model Equations for Fasteners in Wood Installed in Building Envelope

For fasteners embedded in untreated wood in building envelope, the first-year corrosion depth, c_o (μm), is computed as follows,

$$c_o = \frac{1}{2}\left[f_{120}(BTM_{max}) + 0.3 f_{120}(BTM_{mean})\right] \tag{9.9}$$

The corrosion depth, c, of fasteners embedded in untreated wood after t years is computed by

$$c = c_o\, t^n \tag{9.10}$$

where n= 0.5 for zinc and n = 0.6 for steel.

For fasteners embedded in CCA-treated wood, c_o is computed as follows,

For zinc: $$c_o = 1.3 f_{120}(BTM_{mean}) \tag{9.11}$$

For steel: $$c_o = 2.1 f_{120}(BTM_{mean}) \tag{9.12}$$

The corrosion depth, c, of fasteners embedded in CCA-treated wood after t years is computed by

$$c = c_o\, t^n \tag{9.13}$$

where n= 0.6 for zinc and n = 1.0 for steel.

References

Leicester, R. H., Wang, C-H. and Nguyen, M. N. (2008). "Manual No. 8: Termite Attack." http://www.timber.org.au/, April 2008.

Nguyen, M.N., Leicester, R.H. and Wang, C-H. (2008) "Manual No. 5: Atmospheric corrosion of fasteners in exposed timber structures." http://www.timber.org.au/, April 2008.

Nguyen, M.N., Leicester, R.H. and Wang, C-H. (2008) "Manual No. 6: Embedded corrosion of fasteners in exposed timber structures." http://www.timber.org.au/, April 2008.

Nguyen, M.N., Leicester, R.H. and Wang, C-H. (2008) "Manual No. 7: Marine borer attack." http://www.timber.org.au/, April 2008.

Wang, C-H., Leicester, R.H. and Nguyen, M.N. (2008) "Manual No. 3: Decay in ground contact." http://www.timber.org.au/, April 2008.

Wang, C-H., Leicester, R.H. and Nguyen, M.N. (2008) "Manual No. 4: Decay above-ground." http://www.timber.org.au/, April 2008.