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Prediction Models For Engineered Durability Of Timber In Australia

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Summary: This paper gives an overview of a major Australian project to develop an engineered approach to the design for durability of timber construction. The focus of this research has been to develop probability based prediction models for the effect of durability on the strength of timber structures. These models may be used for risk estimates of building performance. To date, models of attack by decay fungi, termites and corrosion agents have been developed. These models have been derived on the basis of expert opinion combined with data derived from tests on small clear specimens of wood and metal. The models are now undergoing calibration through the use of data from in-service structures. When calibrated, the models will be useful for the development of engineering design procedures, design optimisation and asset management strategies.

Keywords: durability, timber, structural, model, decay, termite, corrosion.

1 INTRODUCTION

When a timber construction fails through structural collapse, the event is unexpected and the typical response is to sue the structural engineer concerned. However, should a timber construction fail because of a loss of durability, the general public perception is that this is a consequence to be expected in the use of wood. The reason for this difference in perceptions is that while structural designs are undertaken by the application of design codes based on predictive models of structural performance, design against durability is undertaken by a mixture of experience and adherence to good building practice. The expected performance in designs for durability is rarely stated.

To remedy this situation, the Australian timber industry (through FWPRDC) has sponsored a large national project to develop engineered design procedures for timber construction. Progress to date is described in detail in a summary paper by Leicester (2001) and in several CSIRO laboratory reports (Leicester *et al.* 2001b, 2001c, 2001d and 2001e). The procedures developed are based on probabilistic prediction models. It is important to appreciate that in using probabilistic models, all outcomes can be stated in terms of risk, the single most significant measure of building performance. The models can include consideration of both the natural variability of relevant parameters and the uncertainty in our modelling concepts. Moreover the models can be formulated to include data from any source, including expectations originating from engineering experience. With the use of these probabilistic models, performance stated in risk terms can be used as criteria for

- engineering procedures
- cost-optimised design
- asset management strategies

The first and most important task of the project has been to develop probabilistic prediction models of the effects of various durability hazards on the performance of timber construction. Typical examples of the required model outputs are shown schematically in Fig.1. To date the durability hazards considered have been

- decay
- termite attack
- corrosion (of connectors)

In the future it is planned to include other hazards such as attack by marine borers, insects, and chemical and mechanical degradation.

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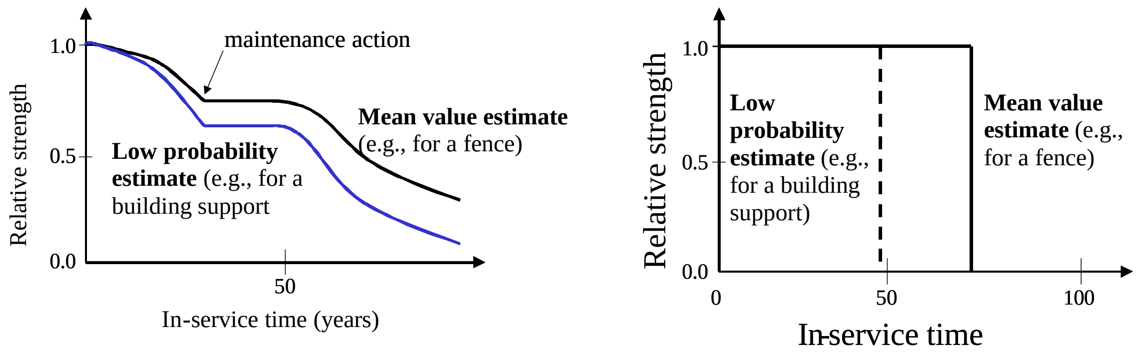

(a) Attack by decay fungi or corrosion agents **(b) Attack by termites**

Figure 1. Schematic illustration of the effects of durability hazards on the strength of timber construction.

2 MODELS

2.1 Concepts

The basic components of the models developed are shown in Fig. 2. Here an attack model is used to predict the performance of a timber construction on the basis of a set of input parameters that define the problem. The most difficult part of the project has been to develop attack models in quantitative terms. Although there is extensive literature on hazard attack scenarios, very little of this is quantitative. Moreover it is obviously not possible to initiate experiments that last for more than about 3 years duration as part of this project. Accordingly it has been necessary to develop the format of models on the basis of limited experimental studies and information gleaned from the scientific literature, and then to calibrate these models on the basis of long-term quantitative data derived from in-service real constructions. In general the attack models require the following components to be defined:

- the attack pattern and/or attack scenario
- the rate of attack

2.2 Environment Factors

In order to quantify the effects of environment factors it is convenient to subdivide timber construction according to exposure conditions as follows:

- in-ground
- exposed
- protected

For protected conditions, the important locations of a house are

- sub-floor
- wall cavity
- roof space

These locations are illustrated schematically in Fig. 3. Figure 4 shows locations in Australia where the climate within the building envelopes of houses have been monitored.

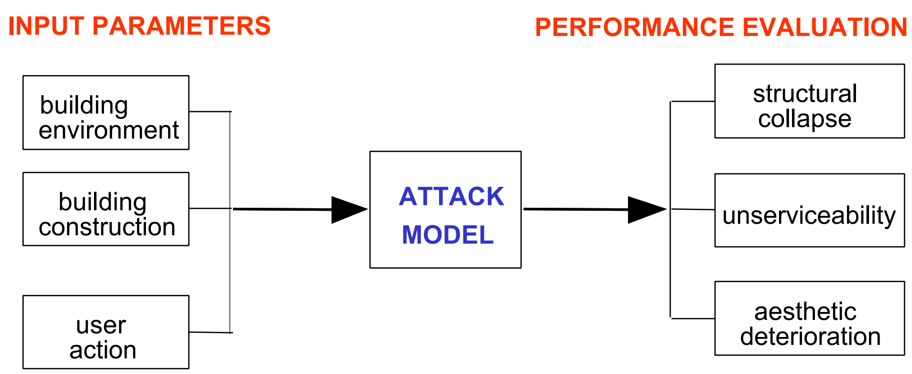

Figure 2. Components of a probabilistic prediction model.

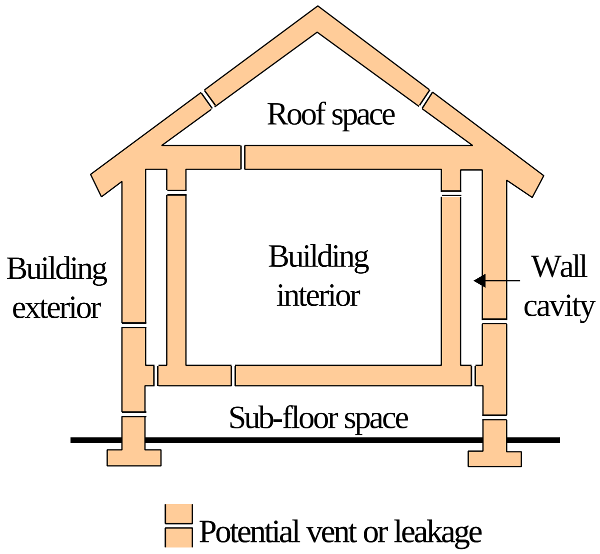

Figure 3. Locations within the building envelope of a house.

Figure 4. Locations used for monitoring the climate within the building envelope of houses.

Global environment parameters are derived by interpolating climate data from about 130 Meteorological Bureau stations scattered around Australia. This data, combined with local terrain and shelter effects, are used to derive local climate conditions for fully exposed construction. For exposed construction the effects of sheltering, such as illustrated in Fig. 5, have a significant effect on material degradation and must be evaluated quantitatively.

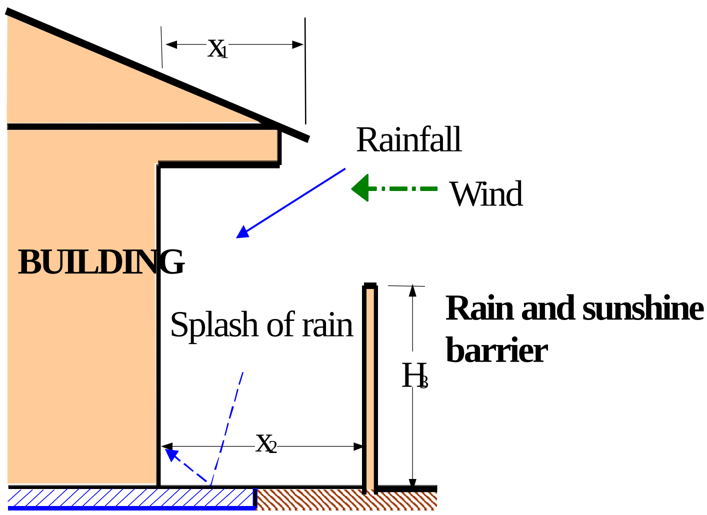

Figure 5. Illustration of the effects of sheltering on the time of wetness of exposed construction.

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From the climate of exposed locations, the climate conditions within a building envelope of typical Australian housing may be derived through the use of empirical formulae such as (McGeachie *et al* 1999)

$$T_{cavity}(t) = 7.9 + 0.13\,T_{exterior}(t) + 0.41\,T_{exterior}(t\text{-}2) \qquad (1)$$

$$H_{cavity}(t) = 28.4 + 0.24\,H_{exterior}(t) + 0.35\,H_{exterior}(t\text{-}2) \qquad (2)$$

where T denotes temperature (deg.C), H denotes relative humidity (%), t denotes the time (hrs), and the subscripts 'cavity' and 'exterior' denote conditions in the wall cavity and outside the house as shown in Fig. 3.

From temperature and humidity values, most of the environment parameters that affect durability can be derived. In addition to this, it is also necessary to have procedures for estimating the concentration of salt and other pollutants in the air.

2.3 Decay

The models for decay are based on data obtained from tests described elsewhere (Beesley 1978, Creffield *et al.* 1992, Thornton *et al*, 1994 Cause 1993) on small clear wood specimens of the types shown in Fig. 6. The locations at which these specimens were tested are shown in Fig. 7. The in-ground specimens were monitored for about 30 years and the exposed above-ground specimens for about 10 years. Most of the specimens were from outer heartwood timber. All told the studies involved about 80 species and 5 preservatives, although not all species or preservatives were used for every test. In addition, the effects of several maintenance treatments were assessed from a study of 60 in-ground poles located at the Wedding Bells test site near Coffs Harbour in New South Wales (Gardner *et al.* 1998); these poles had been under test for 15-25 years.

From the data, idealised but quantified models for the rate of decay, as shown in Fig. 8, were derived. The strength capacity of a structural element is then obtained using the assumption that decayed wood has no strength, while undecayed wood has its full initial strength. This assumption is still under investigation. Models of decay rates were derived for corewood, outer heartwood and treated and untreated sapwood as shown schematically in Fig. 9. These models were then combined with an assumed attack scenario and attack pattern to estimate the effective residual structural cross-section and hence load capacity with time. Examples of assumed attack patterns are shown in Fig. 10.

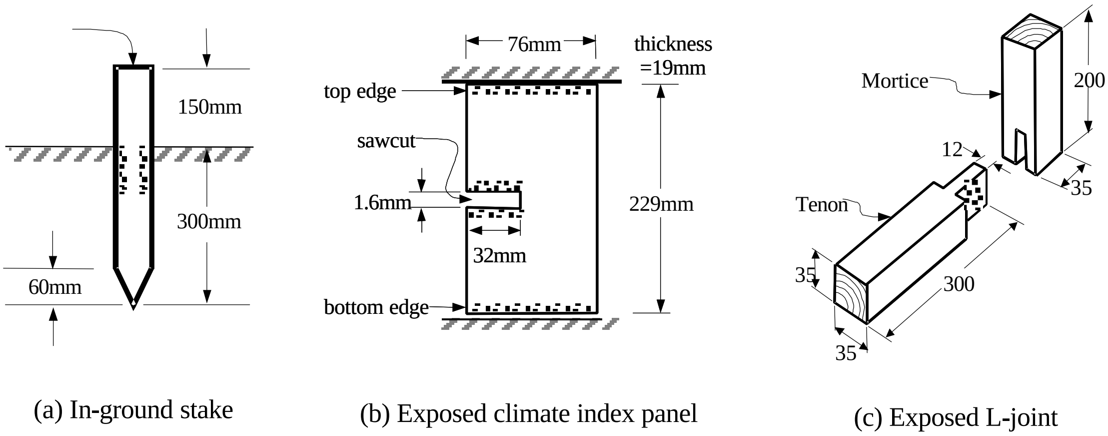

Figure 6. Small clear wood specimens used to develop the models for decay.

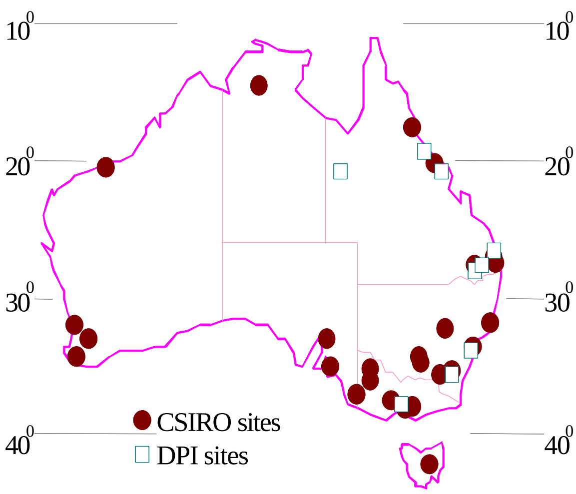

Figure 7. Locations of test sites used to measure decay

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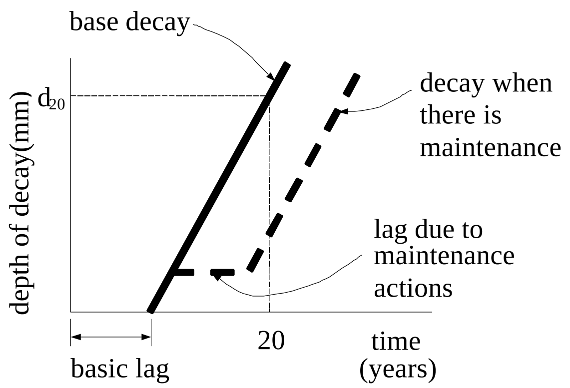


Figure 8. Idealised model for attack by decay

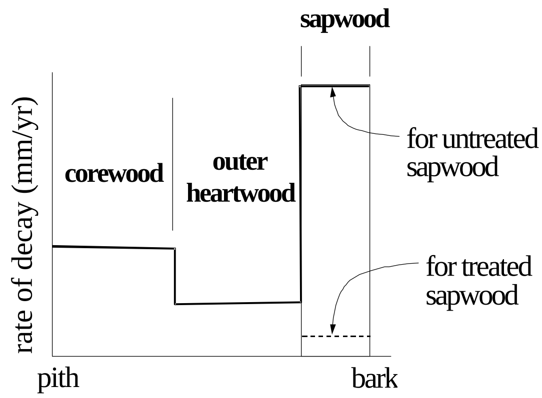


Figure 9. Schematic illustration for the relative rates of decay within a pole

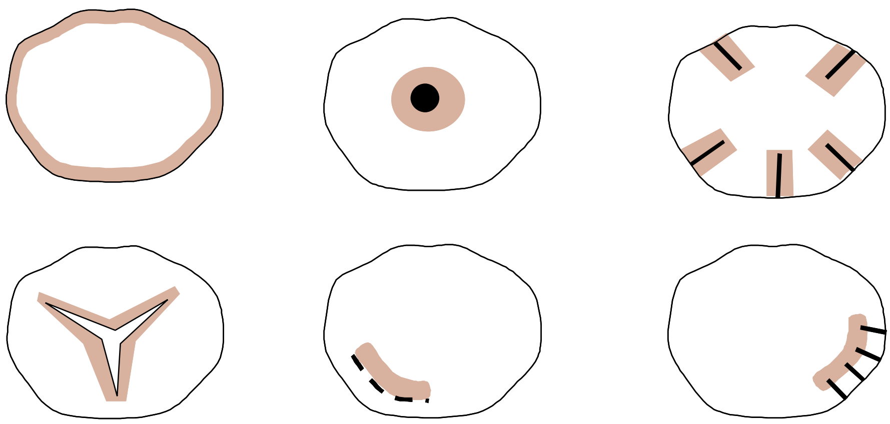
From the field data from small clear wood specimens, the effect of climate on in-ground decay was found to be reasonably well related to an index that is a function of the following parameters:

- annual rainfall
- number of months per year that have a rainfall less than 5mm
- mean annual temperature

Similarly a climate index for the decay of exposed timber was found to be related to the following parameters:

- mean annual temperature
- annual time-of wetness
- mean annual vapour pressure deficit

The computed climate zones for in-ground and exposed timber in Australia are shown in Fig. 11. No direct measurements have been made for the case of decay in a protected environment. However from microbiological considerations it would appear that decay cannot initiate without the effects of wetting by free moisture; i.e. high humidity alone is not enough to commence decay (Zabel and Morell 1992). Within a building envelope, free moisture may arise from rainwater ingress, leakage from domestic sources or condensation. In the absence of other information, the decay equations developed for exposed construction would appear to be a useful starting point.



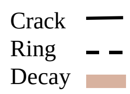


Figure 10. Examples of assumed attack patterns for in-ground poles

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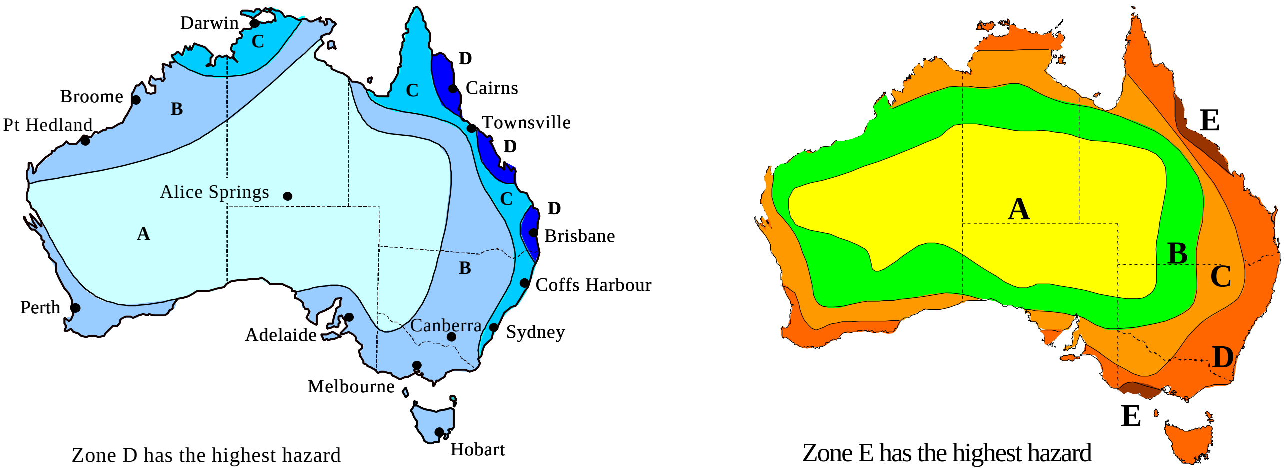


(a) In-ground timber (b) Exposed timber

Figure 11. Climate zones for fungal decay of timber.

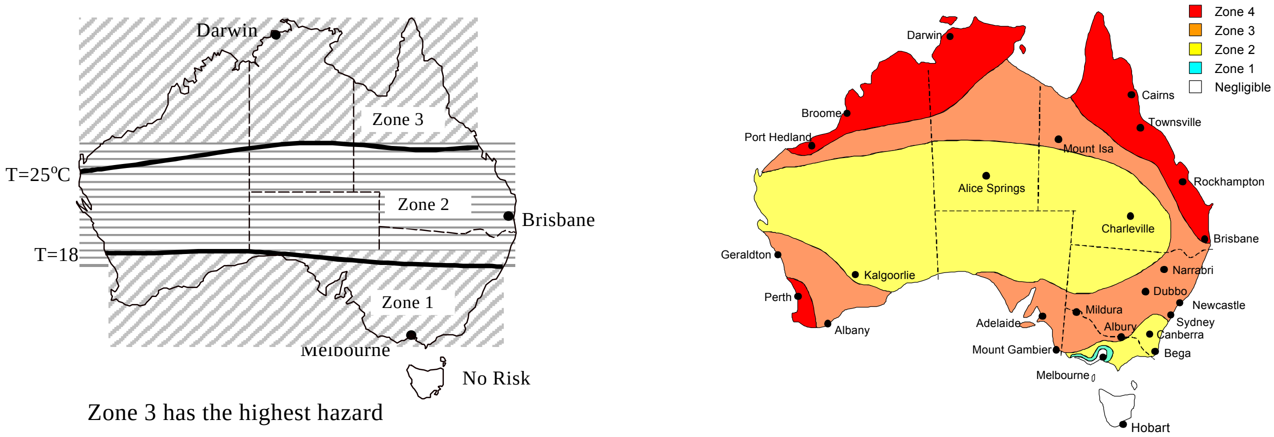
2.4 Termite Attack on Houses

The model for termites was developed initially as a model to reflect the opinions of experts such as researchers and pest controllers (Leicester and Wang 2001, Leicester *et al* 2001d). This model takes into account the following parameters in predicting the time to attack a house;

- mean annual temperature
- age of suburbs
- building construction
- type of termite barrier, if any
- inspection frequency
- number of potential nest sites
- food sources
- soil type

From this model an average estimate of the time to attack destructively is derived. This mean estimate is then used in a probabilistic model that predicts the probability of attack depending on the age of the house. The model has been calibrated with data obtained from a termite survey of 5000 houses chosen at random around Australia (Cookson 1999). One important aspect in using the data from this survey was to assume that the memory of the occupants surveyed was limited to events that occurred no earlier than 20 years before the survey date. This observed risk will be termed the "apparent risk'.

Using the data from the housing survey, it was found possible to relate the termite hazard either to agro-ecological zones or to temperature zones. The derived hazard zones are shown in Fig. 13. Figure 14 shows the good agreement obtained between the model predictions and the observed apparent risk of attack for average conditions. Figure 15 shows that the possible range in the risk predicted by the model is extremely great, depending on the choice of input parameters used, and cannot be ignored in practical applications.



(a) Temperature zonation (b) Agro-ecological zonation

Figure 13. Climate zones for termite attack.

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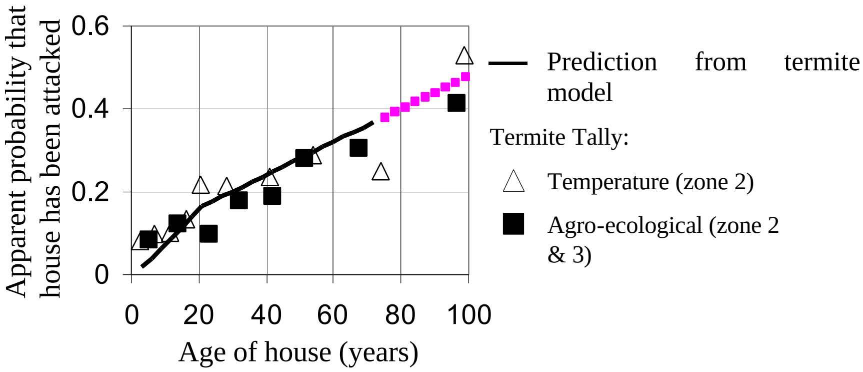

Figure 14. The apparent risk of attack for average conditions.

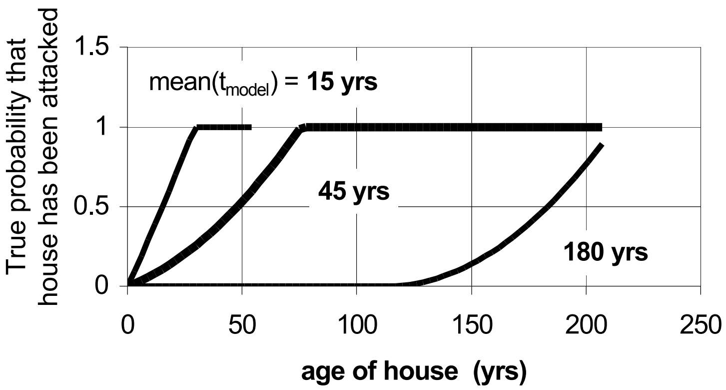

Figure 15. The range of predicted true risks for Australia.

2.5 Corrosion of Metal Fasteners

The model for corrosion of metal fasteners is focussed on estimating the loss of metal with time. Once this loss is known, the effect on the strength capacity of a connector can be calculated from basic mechanics concepts. It is assumed that metal lost is defined in terms of a depth of corrosion depth *c* given by

$$c = c_o t^n \qquad (3)$$

where c_o is a parameter that depends on the type of metal and the environment conditions, and *t* denotes the in-service time. The two types of metal that have been investigated to date are bright steel and zinc coating.

For the case of metal embedded in wood, the relevant parameters in the model are

- the timber substrate (including the type of preservative, if any)
- the moisture content of the timber.

The moisture content of the timber depends on the location of the connector and it is loosely related to the mean annual moisture content of wood in outdoor sheltered conditions. The distribution within Australia of this moisture parameter is shown in Fig. 16.

For the case of metal exposed to air, such as occurs with the plate of toothed-plate connectors, the relevant corrosion parameters are

- the salt or pollution concentration in the air
- time of metal surface dampness.

Pollutant concentration depends on the type of pollutant and the distance of the construction from the pollutant source. Salt concentration depends on the distance from the sea coast and the sea-state activity near that coast (Cole *et al.* 1999, Leicester *et al.* 2001c). The coastal zonation of the Australian coastline for this purpose is shown in Fig. 17.

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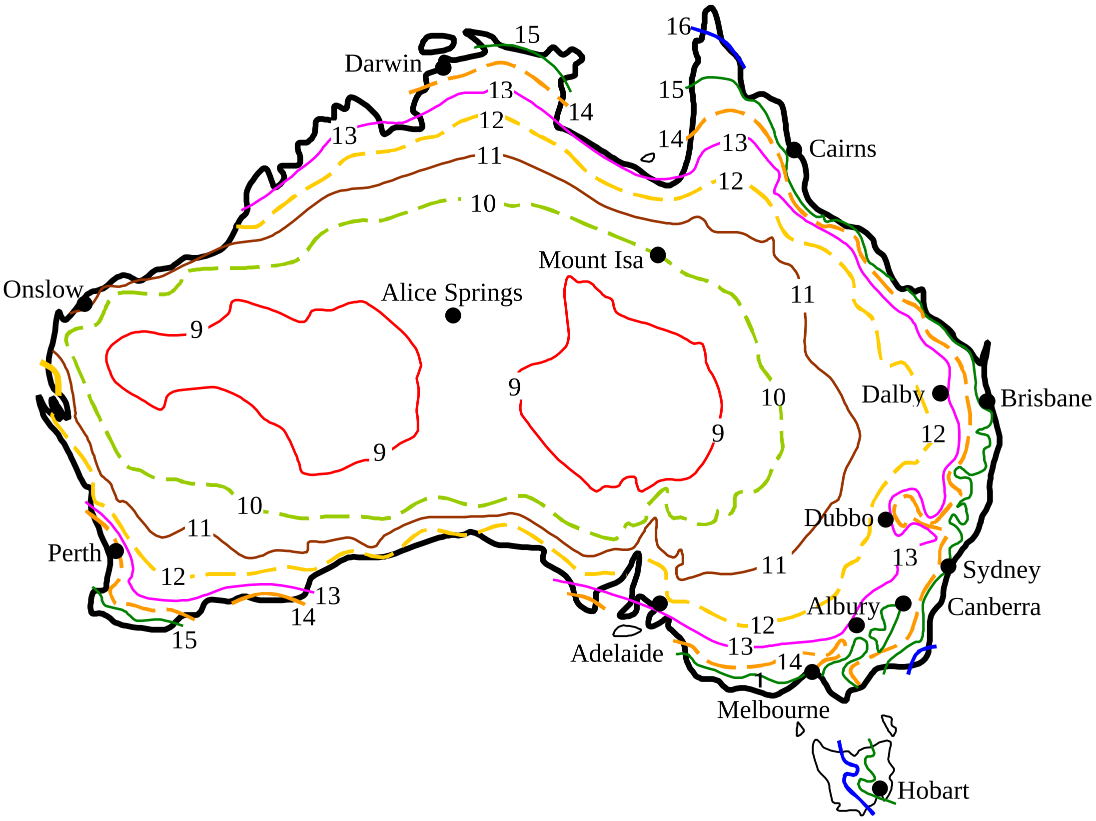
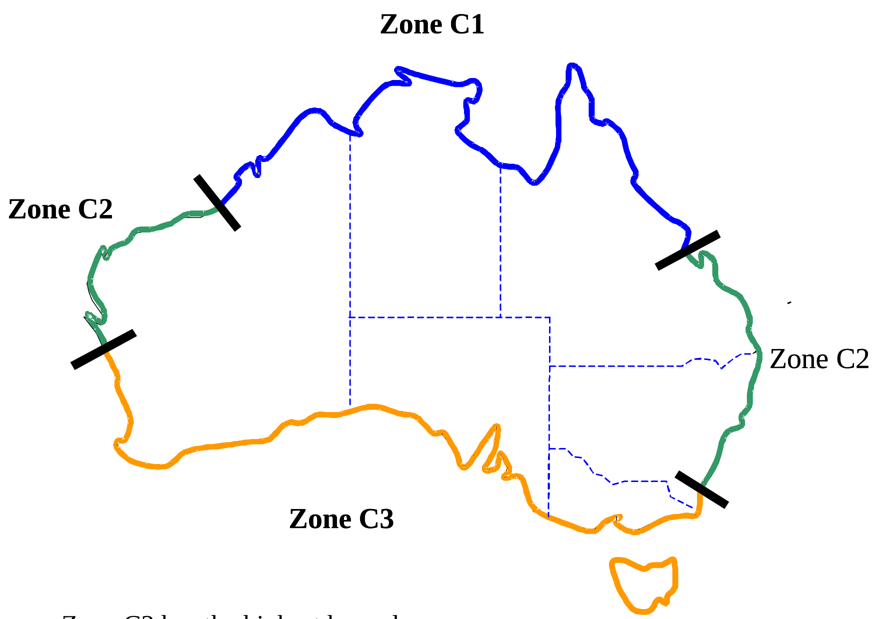


Higher moisture contents indicate higher hazards

Figure 16. Mean annual moisture content of wood in sheltered conditions (per cent).



Zone C3 has the highest hazard

Figure 17. Coastal zones for computing the corrosion of exposed connector surfaces.

3 MODEL CALIBRATION

As indicated in the Introduction, the basis for the development of models has been based largely on a mixture of data obtained from tests on small clear pieces of wood and/or expert opinion. However before the models are used for practical applications, they must first be calibrated with data obtained from in-service construction. This data is essential to derive and/or verify assumed attack patterns and long duration effects. Thus the full range of data to be considered are derived from the following sources:

- expert opinion
- laboratory tests on small wood or metal specimens
- field tests on small wood or metal specimens
- field tests on full size constructions
- in-service measurements on real construction

Currently, a major effort is in progress to collect in-service data. Table 1 gives a summary of the data that has been obtained to date.

Table 1. Summary of project data samples

Hazard type	*Number of data items*			
	Lab studies	*Field studies*		*In-service studies*
	Small specimens	*Small specimens*	*Full size specimens*	
In-ground decay	—	5000	150*	200
Exposed decay	—	4000	—	1500
Termite attack	—	—	—	5000
Corrosion	200	700	300**	20

* Poles at Wedding Bells site.

** Gang-nail plates.

4 CONCLUDING COMMENT

At this time useful working models and associated software have been derived for predicting the structural performance of timber construction subjected to attack by decay fungi, termites and corrosion agents. However the model of attack within a building envelope by decay fungi needs further investigation. Calibration of these models with data from in-service construction is in progress.

Future work will focus on the use of these models for engineering design and asset management purposes. Models for attack by other hazards will be developed. The scope of the models will be extended to include the prediction of non-structural effects such as for example aesthetic and serviceability considerations.

5 ACKNOWLEDGEMENTS

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