THE DEVELOPMENT OF RELIABILITY BASED DURABILITY DESIGN METHODS FOR TIMBER STRUCTURES

GEOFF STRINGER

1993 GOTTSTEIN FELLOWSHIP REPORT

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Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

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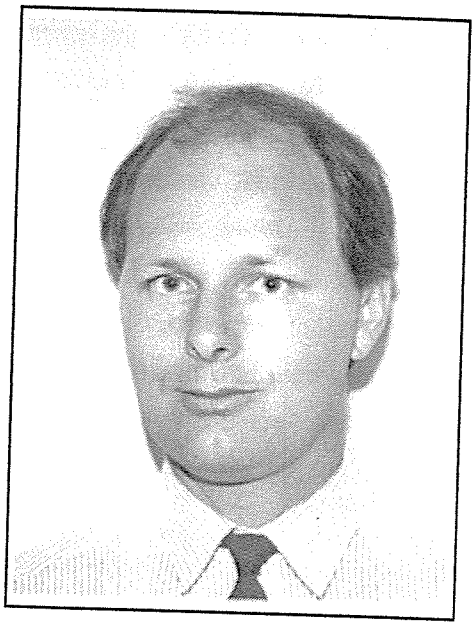
AUTHOR PROFILE



Geoff Stringer is a Queensland based timber engineer, employed by Hyne & Son in Maryborough as their Product Development Officer. Currently he is involved with improving the performance of existing products and the development of new timber based products. At the time of applying for the Gottstein Fellowship he worked for the Timber Research and Development Advisory Council (TRADAC) of Queensland where he managed their research and development program and was actively involved in a wide range of timber utilisation projects.

He has a Bachelor of Engineering Degree with honours from the Queensland University of Technology and is particularly interested in the grading, connection and durability of timber products. He has had experience as a carpenter, civil engineering technician, fabricated timber products manager and quality control officer for the Queensland timber industry.

The Gottstein Fellowship has allowed Geoff to pursue his interest in durability and to document the challenge facing the forest products industry.

ABSTRACT

Durability design methods are a useful means of conveying durability knowledge to the designers of timber structures. Existing methods used in Australia are generally unco-ordinated and have a basis which does not satisfactorily meet the changing needs of durability designers, particularly engineers. An increased appreciation of the needs of durability designers together with improved knowledge about environmental agents, timber resistance and the many factors influencing their effect on timber structures, will result in the development of more acceptable durability design methods.

Durability design principles, environmental agents and the existing durability design methods are summarised in this report. A review of durability design methods and options for future development, indicates that the use of reliability principles in durability design will result in the more efficient use of forest products. An alternative durability design method is proposed and when calibrated has the potential to allow engineers to reliably estimate the effect of environmental agents on the strength and stiffness of timber members and joints.

If timber is to be used in an increasingly environmentally acceptable way it is essential that timber producers, designers, researchers and users participate in a national debate on durability issues, aimed at accelerating the evolution of durability design. A Durability Co-ordinating Group is recommended to facilitate such a debate and to synthesise priorities and future action.

ACKNOWLEDGMENTS

Undertaking a project such as the one reported herein requires the involvement and support of many people. I would like to express my sincere gratitude to the following people.

- Bob Leicester and John Barnacle, for having the vision to write the paper which inspired the pursuit of this project.
- Col Mackenzie, for helping me see the durability "big picture" and encouraging me to change it.
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PREFACE

This report is intended to stimulate and even provoke the increased consideration of durability issues among timber producers, researchers and designers. As a result it is hoped that a wide ranging debate on the future direction of durability related matters will be initiated. Such a debate should encourage a re-appraisal of durability fundamentals and critically review the past, present, and possible future development of durability related technology. Only from such a debate can a clear, co-ordinated and beneficial approach be developed.

In part, this report is also an attempt to implement a number of the recommendations identified from the study. These recommendations relate to the following,

- the need for timber producers and researchers to be aware of the changing needs of designers. Refer Section 2. Design Principles.

- the need for timber designers to have a comprehensive summary of environmental agents and strategies to reduce their effect on timber. Refer Section 3. Environmental Agents.

This report provides an overview of durability matters, particularly as they relate to the designers of timber structures. In doing so, the report seeks to act as a catalyst for the development of innovative timber products and related technology which ultimately will lead to timber structures which better satisfy society's needs.

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LIST OF ABBREVIATIONS

AQIS	Australian Quarantine and Inspection Service
BCA	Building Code of Australia
CSIR	Council for Scientific & Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EMC	Equilibrium Moisture Content
FIFWA	Forest Industries Federation of Western Australia
FPL	Forest Products Laboratory - USA
IEAust	The Institution of Engineers of Australia
ISO	International Standards Organisation
LSD	Limit States Design
MC	Moisture Content
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
NAFI	National Association of Forest Industries
NSWFC	New South Wales Forestry Commission
NWPC	Nordic Wood Preservation Council
NZBC	New Zealand Building Code
PAA	Plywood Association of Australia
QDPI	Queensland Department of Primary Industry
QFS	Queensland Forest Service
TABMA	Timber and Building Materials Association
TMA	Timber Marketing Act - NSW
TPC	Timber Promotion Council - Victoria
TRADAC	Timber Research and Development Advisory Council
TUMA	Timber Utilisation & Marketing Act - Qld
WSD	Working Stress Design

1. INTRODUCTION

1.1 Background

As the human race strives to achieve a balance between the quality of our life on earth and the sustainability of that existence, the wise use of our earth's resources is becoming increasingly important. In particular the use of our limited vegetative resources to create structures necessary for human survival, requires ongoing improvement to ensure that structures of maximum utility are achieved through the efficient utilisation of these resources. The ability of structures made from timber products to withstand the many environmental agents that can reduce a structure's utility, is one aspect of that improvement process and is the subject of this report.

Prior to utilising timber products in a structure it is necessary to formulate a plan detailing the structure's construction. This process is called design. In designing a timber structure the needs and expectations of those people using the structure should be considered. Fundamentally these are:

- **Cost**, including initial, ongoing and recovery costs as well as any costs associated with the failure of a structure.
- **Design Life**, which depends on the current and future use of a structure.
- **Reliability**, which is the probability of a structure performing as intended.
- **Function**, which is the degree of useability of a structure.

These needs are inter-related and when coupled with the unique loadings and environmental agents acting on a structure, together with the varying abilities of the available timber, human and associated resources, sets an imposing challenge to the designers of timber structures.

To simplify the decision making involved in this design process a number of design rules or guidelines have evolved. Within this report these rules or guidelines are referred to as design methods. Most formalised durability design methods have been developed by wood technologists, chemists or building regulators. The primary designers of timber structures have had little input and as such this investigation very much adopts a designer's viewpoint, particularly an engineering viewpoint.

Professional designers of timber structures are generally confused by the existing prescriptive design methods and are often unnecessarily paranoid about the risks and consequences of durability failure. The lack of reliable information on which to base durability design decisions for timber structures, either discourages the use of timber or encourages conservative designs that lead to the inefficient use of forest products.

Professional designers generally have an ethical requirement to serve the community's interest and in doing so often chose materials in which they have maximum confidence, i.e. steel and concrete, even though this may conflict with environmental principles for engineers (I.E. Aust 1992) relating to sustainable development.

The general lack of confidence in the ability of timber products to perform is detrimental to achieving an environmentally sustainable future and needs to be urgently addressed by timber producers, researchers and designers.

Reliability principles have been usefully applied to the strength design of structures regarding their abilities to perform under imposed loads. However such principles have not been formally applied to the performance of timber structures against environmental agents. The development of durability design methods based on reliability principles is an obvious way of redressing the current lack of confidence in timber durability performance.

The assumption adopted by the author and underlying the investigation reported herein is that

> "The development of reliability based methods for the durability design of timber structures will result in the more efficient utilisation of forest products."

1.2 Study Objectives

The development of fully calibrated and accepted reliability based durability design methods is a substantial undertaking and this investigation can realistically only lay a foundation of ideas out of which may grow a pragmatic design method which can benefit society well into the next century. The limitations of the work undertaken are described in the following primary objectives of the study.

(i) To identify and summarise the needs of structural designers regarding durability design.

(ii) To identify and summarise the environmental agents which act on timber structures.

(iii) To identify and summarise the factors which influence the effect of environmental agents on timber structures.

(iv) To review current durability design methods.

(v) To discuss a number of options for development of durability design methods.

(vi) To provide an uncalibrated example of a durability design method.

1.3 Study Methods

The method of investigation used to examine this matter has primarily been a review of appropriate literature together with the formulation of ideas which may benefit Australian timber users. The development of these ideas was greatly assisted by interviewing a number of selected people involved with the durability performance of timber structures. A list of these people is given in Appendix A. Many were formally interviewed while some were consulted on specific matters.

1.4 Terminology

A number of terms used throughout this report require some clarification as they may differ from standardised meanings promoted through Australian Standards or are not defined elsewhere in a context relevant to timber.

Durability - The fitness of a timber product, system or structure to reliably perform its intended function for a specified period of time when exposed to environmental agents which may cause deterioration.

This definition is modified from that given by C.E. Mackenzie (NAFI 1989). The definition varies considerably from the AS1604-1993 definition which is limited to outer heartwood and to two environmental agents.

The definition given above implies that the environmental agents should be nominated to give the term any real meaning. C.S.I.R. made a similar observation (Boas 1947). In

general the term when used absolutely should be qualified by indicating the specific environmental agent, function, performance period and even reliability, e.g.

> "..... unmaintained timber bridges in North Queensland have a termite durability which achieves a 20 year service life with a probability of failure of 5%."

Currently "durability" is not used in this way but rather in a relative way, using relative adjectives like high and low or numbers indicating a relative performance class.

Durability Design - The process of making decisions about a timber product, system or structure regarding its durability.

Durability Design Method - A set of rules or guidelines which assist designers of timber structures to make decisions about durability.

Natural Durability - As for Durability above, except that the term is applied to the non-chemically treated timber of a specific timber product.

Preservation - Any action taken to improve the durability of a timber product, system or structure.

This word is used quite loosely in Australia and often is used to imply a chemical treatment of a timber product. This has come about through the preferred use of the word "preservative" in lieu of chemical as promoted by AS1604.

Environmental Agent - Any action which occurs either naturally or as part of a structure's normal function and has the potential to cause a detrimental effect on either the material or geometric properties of the timber products within a structure. The load effects due to the action of snow, wind, earthquakes, dead and live loads are not included within this term.

Geometric Properties - The properties of a timber section which relate to the size and shape of a member and are used in structural design, e.g. section modulus, cross-sectional area, shear modulus, etc.

Mechanical Properties - The inherent strengths and stiffness characteristics of timber which are used in structural design, e.g. bending, tension, shear and compression strengths, modulus of elasticity, etc.

Durability Limit State - A limit state of collapse, loss of structural integrity or loss of acceptable in-service condition due to a durability failure.

The specific environmental agent may be nominated to give a more accurate indication of the limit state being referred to, e.g. Decay Limit State, Termite Limit State.

2. DESIGN PRINCIPLES

2.1 General

The aim of timber structure designers is to provide adequate information about an intended structure so that it can be efficiently constructed and is fit for its intended use.

The design task can be quite complex where the structure has many elements and a large number of potential failure scenarios may need to be considered.

The structure designer needs the following to begin the design process.

(i) An understanding of the clients performance requirements for the structure. This will include
- financial limitations
- target service life
- reliability of performance
- functional requirements
- health & safety requirements

Many of these items may not be clearly defined by the designer's client and in most cases legislative performance requirements may be accepted as the default minimum performance requirements for the structure. It is not always desirable to rely on these minimum requirements as a particular client may have specific performance requirements which vary from these legislative requirements. Good designers are in tune with their client's expectations of a structure's performance.

(ii) Accurate and reliable information about the resources which will be used to construct and maintain the structure. Information on how these resources perform during construction or service conditions is also required.

The designers task can be simply expressed as achieving a balance between the client's requirements and the abilities of the available resources to meet those requirements.

A design method which rationalises client requirements and resource capabilities can be used by designers to simplify the design task. The overall efficiency of resource utilisation can vary considerably depending on the quality of the chosen design method. The particular design method selected by a designer is generally dependent on the degree of resource utilisation

improvement that can be gained by using the method.

The design of a structure can be subdivided into a number of areas, i.e.

(a)	Structural	-	The selection of members, connections and other systems to adequately resist construction and inservice load effects.
(b)	Fire	-	The selection of active and passive fire protection systems to ensure human safety and minimise property damage in the event of a fire.
(c)	Health & Amenity	-	Selection of services and systems appropriate to the structure's function, e.g. aesthetic, sanitary, lighting, acoustic, weather-proofing.
(d)	Durability	-	Selection of materials and systems which ensure the structure performs reliably over a period of time when exposed to inservice environmental agents.

Some of these design tasks are inter-dependent, such as structural performance which can be influenced by fire or durability performance, e.g. a durability failure may result in a reduction of a member's ability to adequately resist load effects.

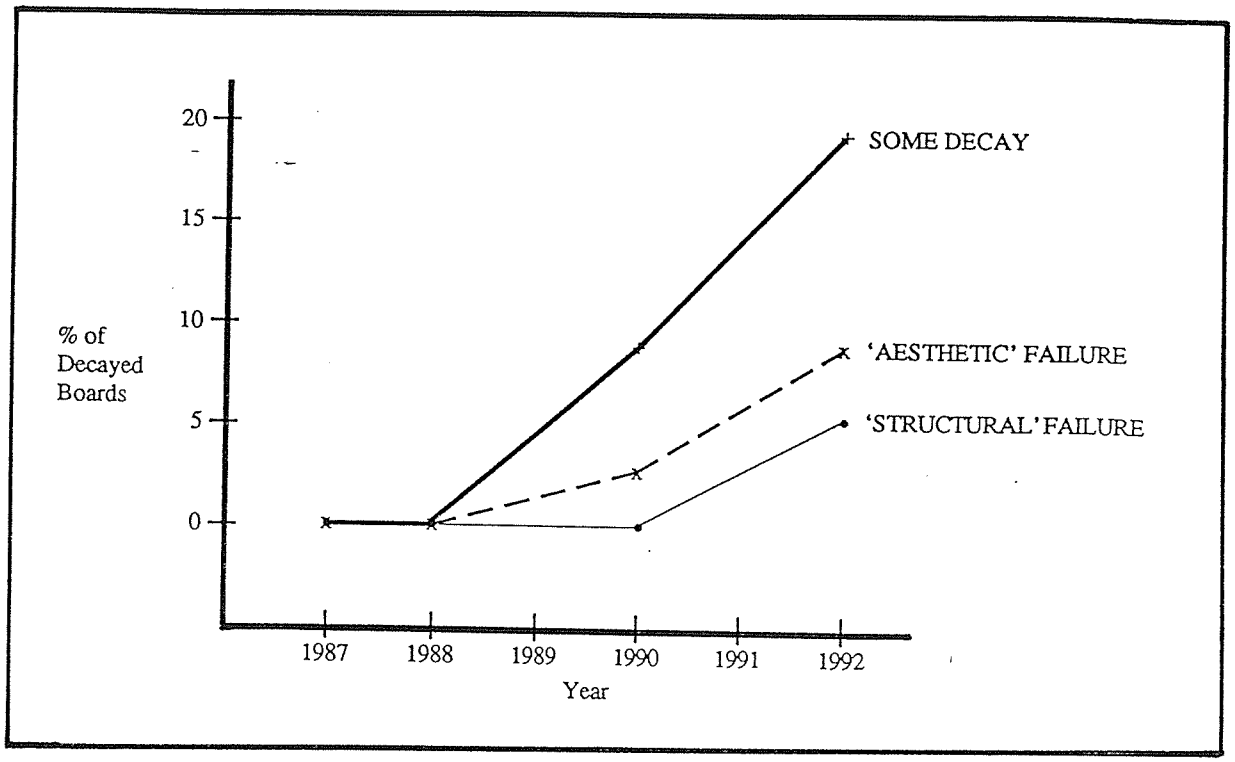
2.2 Durability Design

2.2.1 Durability Failure

Depending on the intended function of a timber product, system or structure, a durability failure may take many forms. For instance, the magnitude of an environmental agent's effect on timber could be quite minor and yet fail to satisfy aesthetic performance requirements. Alternatively, the nature of other deterioration may adversely influence the weatherproofness performance of a structure. From a human safety point of view the most serious durability failure is one that has the potential to lower the structural performance of structure. This failure scenario is most important to structural designers and is the focus of the design method proposed later in this report. A durability failure of this significance is often preceded by noticeable signs of deterioration in the structure. Indeed, deterioration due to environmental agents often progresses over time from minor effects to more serious effects. The results of a cypress decking trial in Queensland (Cause and Stringer 1993) shows this progressive nature. Figure 1 extracted from this work highlights this point, where "aesthetic" failure indicates visually

unacceptable boards and "structural" failure indicates boards that most consumers would seek to replace for safety reasons.

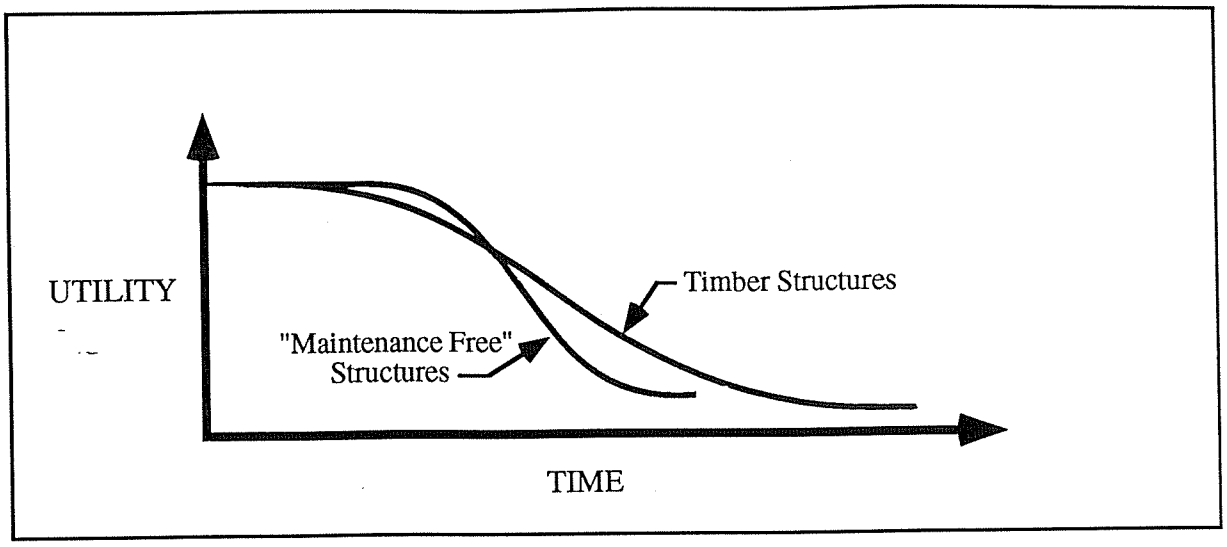
FIGURE 1 TIME VERSUS PERCENTAGE OF BOARDS WITH VARIOUS FAILURE SCENARIOS



This progressive nature of deterioration in timber structures is actually a desirable feature as it provides warning signs to a trained observer that a structural limit state may be approaching. In the same way that a steel structure can exhibit a noticeable yield stage prior to ultimate failure, a timber structure also provides noticeable warning signs of imminent failure. As a result collapse of timber structures is relatively rare as appropriate action is nearly always taken to either enhance the structure's durability or to decommission it.

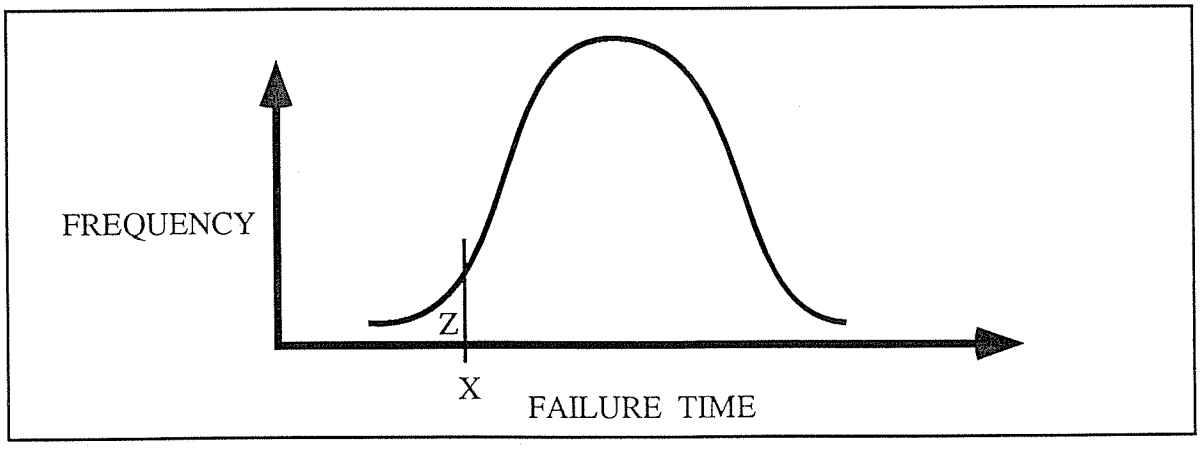
In considering the ageing of a timber structure it has been suggested (Van der Molen 1985) that structures constructed of materials like timber which exhibit this perceptible degradation are more cost effectively maintained, relative to structures of supposedly "maintenance free" materials. This suggested relationship between the nature of construction materials and the loss of a structure's utility is shown graphically in Figure 2.

FIGURE 2 TIME VERSUS THE UTILITY OF A STRUCTURE



The criteria for a durability failure needs to be clear in the designers mind. The definition of durability suggests that a failure occurs when a timber product, system or structure, becomes unfit for its intended use. Figure 3 provides a diagrammatic representation of durability failure by showing a hypothetical failure time distribution of a large number of timber structures similarly constructed and exposed to the same environmental agent.

FIGURE 3 FAILURE TIME DISTRIBUTION OF SIMILAR TIMBER STRUCTURES EXPOSED TO A SIMILAR LEVEL OF ENVIRONMENTAL AGENT ACTIVITY



The variation in failure time is due to the variability of the structure's resistance to the particular agent and to variation in the occurrence and activity of the environmental agent. X indicates the minimum failure time selected for the particular structure. Z is the selected percentage of failures appropriate to the structure. A durability failure occurs when either X falls below or correspondingly Z exceeds the specified levels for acceptable durability performance, i.e. service life, reliability.

2.2.2 Designer's Role

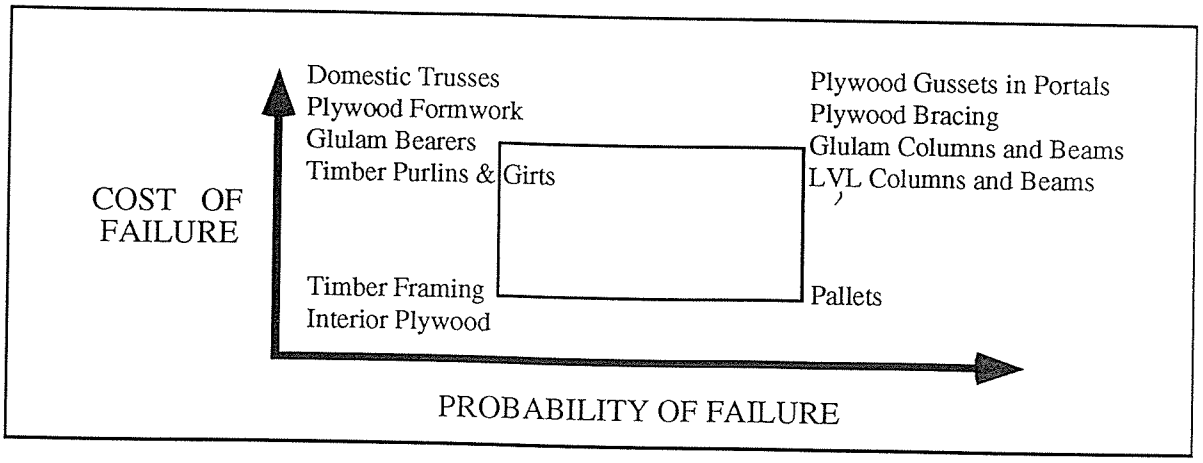
The role of the durability designer is to move the distribution in figure 3 to the right or the left so that it satisfies the client's requirements.

In general the designer has two options, to either increase the service life or decrease the probability of failure, i.e. increase the resistance of the timber to the environmental agent or decrease the level of environmental agent activity which may act on the structure. The emphasis on chemically treated timber since World War 2 has focused designers attention on material resistance and away from methods of reducing environmental agent activity, which have been the traditional methods adopted by tradesmen and craftsmen.

Usually the action involved in increasing the service life or reducing the probability of failure means increasing the financial resource requirements for the structure, i.e. the structure's cost. A common durability design strategy is to focus on keeping the structure's initial cost to a minimum without decreasing the service life or increasing the probability of failure.

An alternative approach (Lyngcoln 1992) to the durability design of a timber structure is to focus on the cost of failure of a structure or product, and to balance this against the risk or probability of that failure. The ultimate cost of failure is loss of human life, while loss of property is minor by comparison. This approach when applied to durability design aims to achieve a risk of durability failure appropriate to the consequences of failure. The Plywood Association of Australia (Lyngcoln 1990) have successfully used this approach to establish levels of quality control for various plywood products. Figure 4 (Lyngcoln 1990) shows the probability and cost of failure relationship for a range of timber products.

FIGURE 4 EXAMPLES OF PROBABILITY AND COST OF FAILURE RELATIONSHIPS FOR TIMBER PRODUCTS



Regardless of the design strategy used the durability designers task can be broken into a number of steps i.e.

(i) Establish and understand the clients requirements for a structure.

(ii) Obtain and review information about the range of environmental agents likely to act on the structure.

(iii) Obtain and review information about available timber performance and factors which can influence that performance.

(iv) Evaluate trial designs to ensure that selected material and construction options are balanced against the activity of the environmental agents to which the structure is exposed.

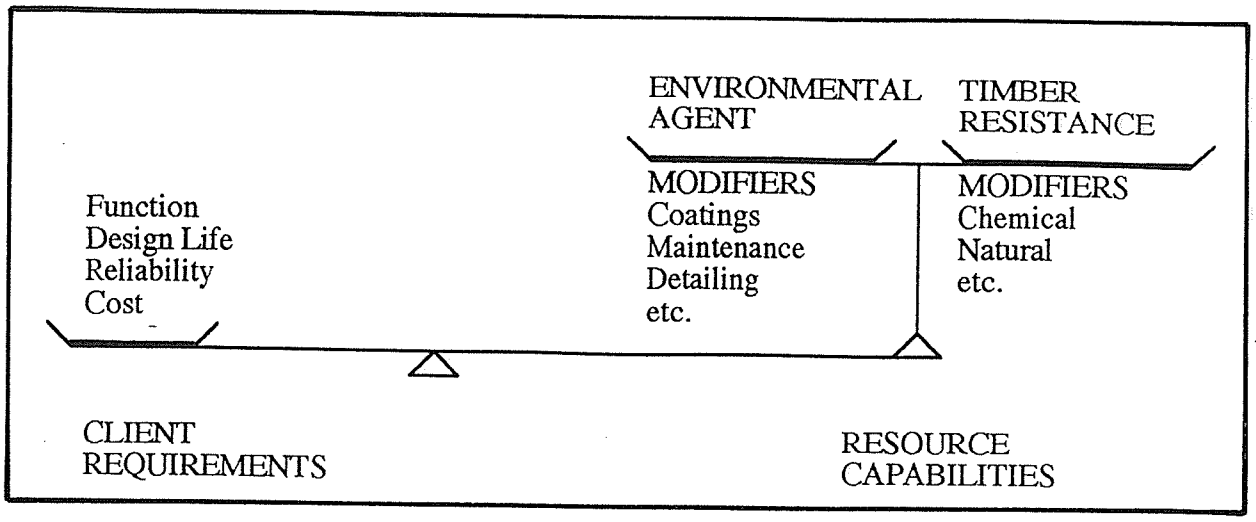
(v) Evaluate a chosen design against the client requirements regarding cost, service life, reliability and function.

(vi) Where client requirements are not satisfied obtain further information, modify the design and evaluate trial designs until the clients requirements are satisfied. If this can't be achieved it may be necessary to renegotiate client requirements or undertake structure specific durability research.

The designer may need to use all available information to achieve a balanced design, i.e. a design which efficiently utilises available resources to the satisfaction of the client. Poor durability design comes into two categories, (i) excessively liberal designs where the resulting structure will not perform as intended, and (ii) excessively conservative designs where resources are wasted, e.g. H5 chemical treatment where H3 would suffice, or costly termite protection where minimal termite activity exists. Durability designers in the past have been overwhelmed by the complexity of the durability design task and have adopted a "better safe than sorry" approach which has generally resulted in the inefficient use of resources associated with durability performance.

The balancing act which the durability designer must perform is shown diagrammatically in Figure 5.

FIGURE 5 DIAGRAMMATIC REPRESENTATION OF DURABILITY DESIGN



Anyone with even limited knowledge can design a timber structure which will perform satisfactorily regarding service life and function. However this will more than likely be a costly structure and wasteful of available resources. The real challenge for designers is to design a structure which optimises the available resources so they provide maximum benefit to the client and minimal environmental impact.

2.2.3 Who are the Designers?

A durability designer is anyone who makes decisions about a structure which may effect its ability to resist the activity of environmental agents. It may be a homeowner choosing a paint system for timber weatherboards, a builder selecting the gap size and nail type for a deck, a draftsman specifying a particular species for a pergola, an architect deciding the level of underfloor ventilation required in a building or an engineer evaluating a marine organism protection system for piles in a wharf.

The decisions made are all based on the designers experience and training, which should be appropriate to the nature of the timber structure being designed. The information used by designers to make such decisions usually involves any number of the following sources.

(a) **Personal Knowledge**, based on first hand experience and trial and error.

(b) **Knowledge of Colleagues**, neighbours, friends or family who may be asked to assist.

(c) **Legislative Requirements**, which may require particular action to be undertaken or prohibit other actions.

(d) **Durability Design Methods**, usually given in appropriate publications or handed down as "rules of thumb".

(e) **Documented Research Results**, which may give very detailed information about durability performance under controlled conditions.

Durability design methods when targeted at the needs of a particular group of designers, provide an excellent means of encouraging the efficient use of societies resources. Each designer will have their own needs and require a design method appropriate to their expertise and the needs of their client. Of course in many simple structures the designer and client may be the same person.

Designers can be grouped into the following categories which generally reflect structure type, responsibility level and expertise.

A. Homeowners and handymen generally involved with small low cost structures. Information requirements are quite general and simple design methods are usually adequate.

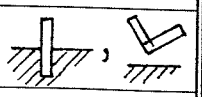
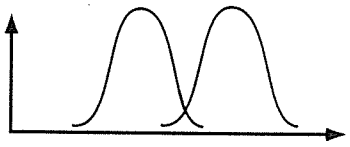
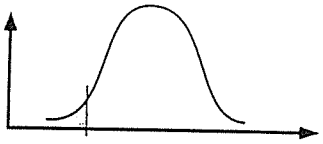
B. Builders, draftsmen and tradesmen who are involved with more substantial structures. They generally possess considerable information about the practical means of influencing durability. Their information needs are greater as they are striving for increased resource efficiency relative to category A.

C. Engineers, architects and others who may be involved with substantial timber structures and need to achieve maximum resource utilisation efficiency. Their information needs may be quite sophisticated and be at the limit of durability knowledge.

2.3 Structural Design

As most engineers are familiar with the structural design of timber structures it would seem beneficial to develop durability design principles which are analogous with structural design principles. Table 1 shows the potential parallels that could exist between the structural design approach and a durability design approach.

TABLE 1 ANALOGY BETWEEN STRUCTURAL AND DURABILITY DESIGN

Item	Structural Design	Durability Design
Basic material resistance tests (under controlled conditions)	small clear, or "ingrade" 	graveyard or above ground 
Design resistance values	Adjust test results for D.O.L., variation and factor of safety Published in AS1720	Adjust results for test site conditions, variation and factor of safety Published?
Potential failure scenarios	Collapse, excessive deflection, unstable	Aesthetic, functional, structural (i.e. collapse)
Agents causing failure	Imposed loads, i.e. wind, dead, live, snow, earthquake. Quantified in AS1170	Environmental Agents. see section 3 of report. Quantified in ?
Adjust design resistance values to be structure specific	e.g. Reliability K_2, Load sharing K_8, Stability K_{12}, and J_2, etc. Based on testing and quantified in AS1720	e.g. coatings, maintenance, product size and shape influence. Limited tests. Quantified in ?
Balance agent effect and resistance to achieve required performance	Load Effect(S) Resistance(R)  stress $R \geq S$ for given design life and reliability	 X failure time $X \geq$ design life for given reliability

Note: DOL means Duration of Load. K_2, K_8, K_{12} and J_2 are factors from AS1720.

The information and design methods included in AS1720 allows the evaluation of structural performance to be quantified. The uncertainty associated with the design method and the load and resistance information is catered for by using load and resistance factors.

Structural design is usually an evaluation of a structure's performance at any instant in time, i.e. a design based on the initial characteristics of a structure is not necessarily a valid analysis of a structure's performance at say 30 years, when material and geometric properties of members in the structure may have altered considerably due to environmental agents. Structural design does consider DOL and fatigue effects on material properties but not the many effects caused by external (non stress inducing) agents acting on a structure.

2.4 Reliability Based Design

The primary goal of all designers is to achieve a structure or product that does not fail. Reliability is the term used to express the degree of confidence that failure will not occur. A formal definition is,

> Reliability is the probability of a product or structure performing an intended function, without failure under given conditions for a specified period of time.

Reliability or its converse "probability of failure" can be used as the basis for fairly assessing the quality of a design. As such, the use of a design method which is based on achieving a uniform level of structural reliability is likely to result in the more efficient use of societies resource.

Design methods in the past have largely used conservative "safety factors" to achieve some token level of reliability. The problem with relatively arbitrary "safety factors" is that reliability is not always uniform and in some cases may lead to early failures or gross waste of resources.

The major difficulty with developing a reliability based design method is obtaining sufficient information to quantify reliability. The reliability approach to design is being increasingly accepted by engineers, who throughout the world are now encouraging and undertaking testing to better quantify structural reliability. The recent ingrade testing of radiata pine framing in Australia is an example (Bolden et al 1993). Reliability analysis provides a rational means of examining the variability and uncertainty of material performance and design methods.

The adoption of reliability principles in structural design codes can take many forms and is generally related to the level of available information. Examples of formats for reliability based structural design codes are shown in Table 2 (Leicester 1990). Currently AS1720 is a level I code and is moving towards level II.

TABLE 2 EXAMPLES OF FORMATS FOR RELIABILITY BASED CODES

Code Level	Code		Specified parameters for committee decisions
	Type of code	Specified parameters	
I	WSD	R_{norm}, S_{norm}	ß
II	LSD	$R_k, S_k, ø, \gamma$	ß, p_F
III	First order reliability	ß	p_F
IV	Full reliability	p_F, design life	socio-economic factors

WSD = working stress design
LSD = limit states design
Rnorm, Snorm = working stress values of strength and load
Rk, Sk = characteristic values of strength and load
p_F = probability of failure
ß = reliability index, directly related to p_F
$ø, \gamma$ = resistance and load factors

2.5 Limit States Design

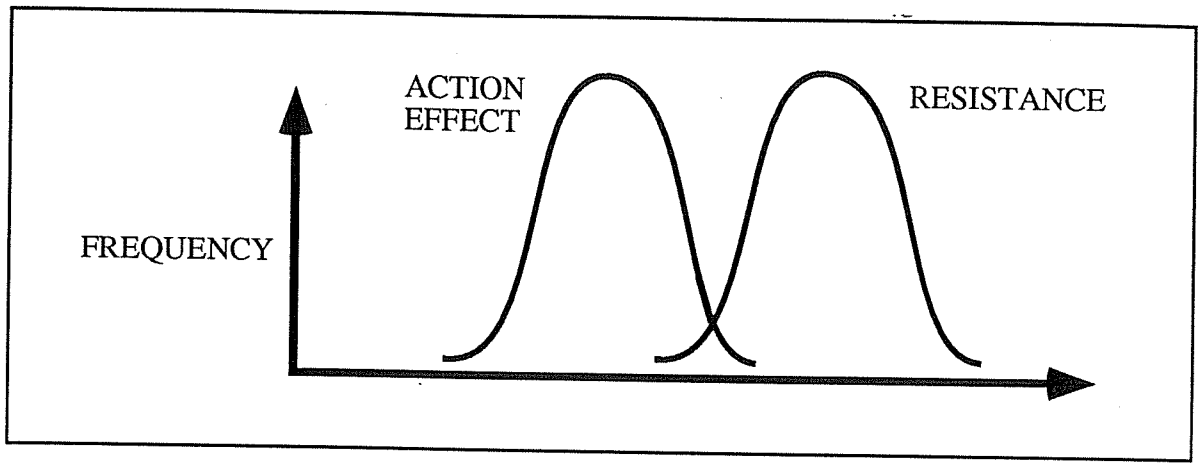
The current policies of Standards Australia and the International Standards Organisation (ISO) are for structural design standards to be presented in a limit states format. A "limit state" is any limiting condition beyond which the structure ceases to fulfil its intended function. This term is often qualified using adjectives indicating the particular intended function, limiting condition or the cause of any limiting condition, e.g. fire, serviceability, stability, strength (AS1170.1-1989). Table 3 provides a brief summary of some of the terms used in qualifying the "limit state".

TABLE 3 SUMMARY OF LIMIT STATES TERMS

Intended Function of Structure	Serviceable & Structurally Adequate		
Limiting Condition - General	Unserviceable	Collapse	Unstable
Limiting Condition - Specific	Aesthetic, Health & Amenity, Static member deflection, Dynamic member response	Strength	Equilibrium, Buckling
Actions with potential to cause limiting conditions (examples only)	Fire, Decay, Termites, Chemical agents, Mechanical agents, Physical agents, Loading (dead & Live, Wind, Snow, Earthquake) etc.		

Designing a structure with the aim of ensuring an identified limiting condition has an acceptable probability of occurrence, is called limit state design. The design process requires the effect of an action on a structure to be quantified and compared with the ability of the structure to resist the specific action. This principle is often expressed diagrammatically and is shown in Figure 6.

FIGURE 6 RELIABILITY MODEL FOR FIRST ORDER APPROXIMATIONS OF SAFETY INDEX



In the Limit States Design formats adopted by Australian Standards, factors to account for the uncertainty associated with the resistance and action effect are used.

The design of a structure for a specific durability limit state can be considered using this principle, i.e. The capacity of a structure to resist the effect of an environmental agents must be greater than the effect of the environmental agent on the structure. To reduce the probability of a limiting condition occurring the two strategies suggested by this approach are,

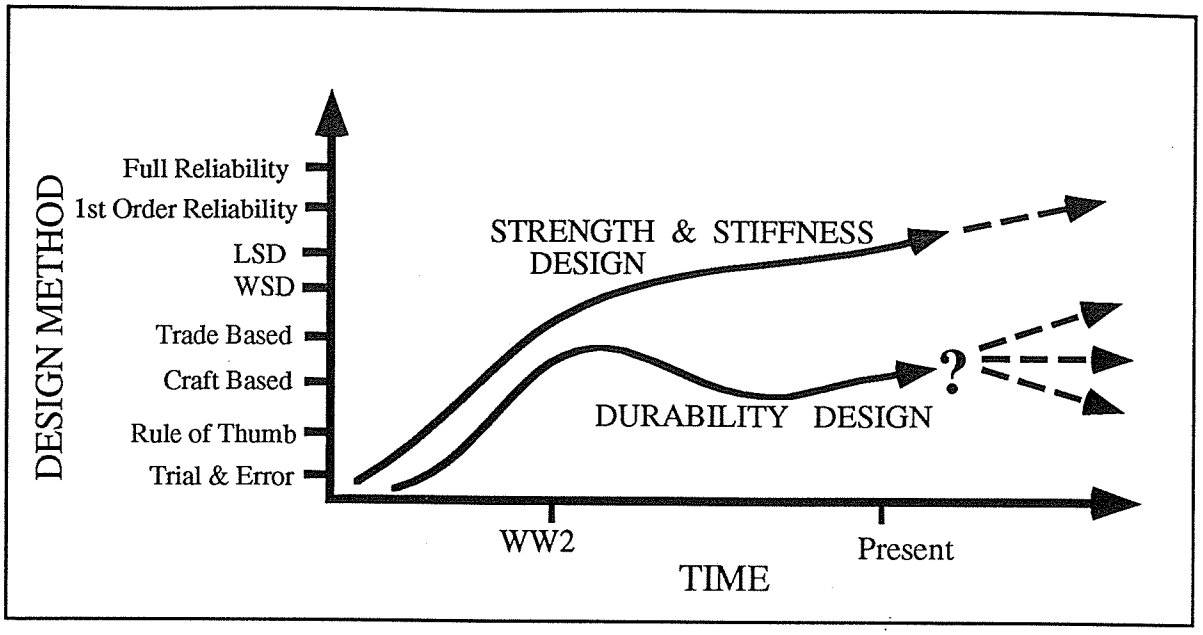
(i) Increase the timbers resistance to the environmental agent , and/or

(ii) Reduce the effect of the environmental agent.

2.6 Evolution of Design

The ongoing quest for improving a timber structures performance is reflected in the evolution of structural design methods. As designers seek better information and methods for modelling structural performance, design methods have evolved to reflect the changing needs of designers. Figure 7 shows graphically the evolution of design methods for durability and structural performance.

FIGURE 7 GRAPHICAL REPRESENTATION OF DESIGN METHOD EVOLUTION



Structural design has been progressively improving with major advances in the past due to the development of structural analysis theory and the improved knowledge of timbers mechanical properties. The application of reliability principles to structural design is the latest generation of improvements to be pursued by engineers. By comparison the durability of timber structures has not progressed beyond trade based methods. The main reasons for this have probably been twofold.

(i) The lack of appropriate information to quantify durability performance.

(ii) The overwhelming complexity of the durability design task and the advances in structural design which distracted the attention of engineers away from durability matters.

Many of the people interviewed during the study tour stage of this project have suggested that since World War 2 and even as early as World War 1, there has been a decline in the durability of timber structures because of the substantial loss of craft and trade skills. This significant decline in the durability knowledge base seems to have largely been brought about by the loss of craft knowledge through the retirement of specialist tradesmen and the increased focus on a structures initial cost rather than long term performance. The general breakdown and considerable changes in tradesmen training has meant that the knowledge of timber tradesmen skilled in durability related practices has not been adequately conveyed to the younger

generations of "tradesmen".

Unfortunately many of the skills of these timber tradesmen have not been adequately documented and the many interesting and effective techniques they developed to increase a structure's durability will undoubtedly need to be rediscovered by following generations.
Recent multi-skilling approaches to trade training also have the potential to further erode the durability knowledge base, i.e. "Jack of all trades, master of none". For efficient timber utilisation more masters are needed.

In some ways the tremendous technology improvements, post World War 2, regarding the chemical treatment of timber to improve its resistance against biological agents, has also contributed to the knowledge decline in non-chemical methods of durability enhancement. The promotion of chemical methods as being a cure all to timber durability performance was often believed by timber designers and users. The result was a general perception that non-chemical means of improving durability were not as important and were therefore not emphasised or were forgotten.

This report is concerned with the future evolution of durability design, which is currently lagging well behind the advancements made in structural design.

2.7 Joint Design and Member Design

Timber structures can generally be considered as an arrangement of members and joints. A joint being any point within a structure where two members are connected together for the purposes of transferring forces within the structure or provided stability. The joint may be as simple as one member bearing on another with no connecting elements or as complex as a bolted and metal plated joint where many members meet at a range of angles.

The design strategy used by designers concerned with the structure's ability to resist imposed load is to separate member and joint design. This is compatible with the general structural failure modes associated with "real" timber structures, i.e. joints usually fail before members and should therefore be the focus of the designers attention.

The consequence of environmental agents acting on a joint is not quantified in AS1720. However for fire AS1720.4 provides advice to designers. The methods used to physically connect members together are generally metal connectors or adhesives. These additional materials used in conjunction with timber can have an effect on the environmental agent's activity on timber, e.g. corrosion of metals can cause timber breakdown as a result of chemical

action, the effects of moisture content changes on timber can be accentuated by the presence of a rigid (non-shrink, non-swell) glueline.

In addition to these connector induced durability consequences on the timber, the connectors themselves must have sufficient durability to resist any environmental agents which may act on them. This report does not cover the durability of such materials alone which should be confirmed separately. General advice about such matters is usually found in prescriptive durability design methods.

From a strength point-of-view, the consideration of joint durability separately from member only durability would seem desirable. This is particularly the case where joint configuration or the connectors themselves may adversely contribute to the activity of an environmental agent. For instance, joints with large horizontal interfaces between bolted or nailed members, exposed to direct moisture, are more likely to decay due to the enhanced decay activity conditions at the member interfaces.

3. ENVIRONMENTAL AGENTS

3.1 Overview

The various environmental agents which can potentially effect a timber structure can be classified based on the type of action which causes deterioration of the wood in the product or structure, i.e. Table 4 summarises these environmental agents and provides a description of their effect on timber. The usual effect of the agent on geometric and material properties is also shown. The five categories of environmental agent considered herein are,

A. Thermal
B. Chemical
C. Physical
D. Mechanical
E. Biological

This section of the report discusses the various environmental agents, the nature of their effect on timber and the means of modifying wood resistance and the agents activity. Many of the ways of modifying the wood or agents have not been adequately quantified for design purposes. Also no attempt has been made in this section to document all possible sources of data regarding environmental agents and factors which influence them. Reference to a good wood technology library should be made where additional information is required.

3.2 Thermal Agents

3.2.1 Temperatures - Above Combustion

Sustained combustion of timber products or structures generally occurs at temperatures above 250°C. The carbonisation of the wood results in wood loss and consequently altered geometric properties. There are a number of means of influencing the effect of combustion on timber. Table 5 highlights the actions which can be taken.

TABLE 4 SUMMARY OF ENVIRONMENTAL AGENTS

Environmental Agents Acting on Timber	Effect on Timber		
	Descriptive	Reduced Structural Properties	
		Material Properties	Geometric Properties
A.THERMAL			
1. Temperatures above combustion point	Burning	X	X
2. Temperatures below combustion above normal	Delignification	X	X
3. Temperatures & UV in normal environment	Delignification	X	X
B.CHEMICAL			
1. Special environments	Wood breakdown	X	X
2. Normal environments, e.g. sea, air, soil	Wood breakdown	X	X
C.PHYSICAL			
1. Initial changes in MC%	Splits, checks & heart shake	-	X
2. Ongoing cycling of MC%	Surface checks	-	X
D.MECHANICAL			
1. Application induced, e.g. rubbing on fender piles	Grooves, surface abrasion, splits, etc.	-	X
2. Natural agents, i.e. water, wind	Abraded surface	-	X
E.BIOLOGICAL			
1. Plant			
(i) FUNGI			
(a) Brown Rot	Cubical decay	X	X
(b) White Rot	Fibrous decay	X	X
(c) Soft Rot	Brash Fracture	X	X
(ii) BACTERIA	Wood breakdown	X	X
2. Animal			
(i) INSECTS			
(a) Termites - Subterranean	Irregular Galleries	-	X
- Drywood	Irregular Galleries	-	X
(b) Borers - Lyctus	Many small holes	-	X
- Anobuim	Many small holes	-	X
- Calymmaderus	Many small holes	-	X
(ii) MOLLUSCS			
(a) Teredinid	Medium holes	-	X
(b) Martesia	Large Holes	-	X
(iii) CRUSTACEANS			
(a) Limnoria	Many small holes	-	X
(b) Sphaeroma	Many medium holes	-	X

Note: An "X" indicates these properties are usually reduced by the agent whereas a "-" indicates a negligible effect.

TABLE 5 REDUCING THE EFFECT OF COMBUSTION ON TIMBER

Reduce Agent Activity	Increase Timber Resistance
• Adopt fire protection practices recommended in building codes • Use both active and passive systems • Encourage users to adopt fire safety practices • Keep potential fire fuel levels to a minimum • Insulate members likely to be exposed	• Use higher density species • Use fire resistant species • Treat timber with fire retardant chemicals • Use larger sizes or sacrificial members • Avoid chemical treatments of timber which reduce resistance • Use sections with minimum surface area exposed

3.2.2 Temperatures - Combustion to Normal

Wood exposed to this temperature range will suffer some loss of geometric properties and more significantly will lose material properties. Timber exposed to such temperatures can appear darkened, brittle and even show cross grain checking. the wood under the charcoal in a burnt timber member is usually affected in this way. While fire is the main way that timber members are exposed to such temperatures, particular conditions of use may also expose timber to such temperatures, e.g. timber in foundries, low temperature kilns, members adjacent to boilers, etc. The changes which occur in timber at these temperatures are summarised in Table 6. (Schaffer 1992)

The methods for reducing the effects of these temperatures on timber are similar to those in Table 5, except that where the elevated temperatures are due to an industrial process, specific coating or shielding systems may be most appropriate to reduce the effect of these temperatures.

TABLE 6 THERMALLY INDUCED CHANGES IN DRY WOOD IN AN INERT ATMOSPHERE.

Temperature °C	Change
>50	
55	Natural lignin structure is altered. Hemicelluloses begin to soften.
70	Transverse shrinkage of wood begins.
>100	
110	Lignin slowly begins weight loss.
120	Hemicellulose content begins to decrease, *a* -cellulose begins to increase. Lignins begin to soften.
140	Bound water is freed.
>150	
160	Lignin is melted and begins to reharden.
180	Hemicelluloses begin rapid weight loss after losing 4 percent weight. Lignin in torus flows.
≥200	
200	Wood begins to lose weight rapidly. Phenolic resin begins to form. Cellulose dehydrates above this temperature.
210	Lignin hardens, resembles code. Cellulose softens and depolymerises. Endothermic reaction changes to exothermic.
225	Cellulose crystallinity decreases and recovers.
>250	
280	Lignin has reached 10 percent weight loss. Cellulose begins to lose weight.
288	Assumed wood charring temperature.
≥300	
300	Hardboard softens irrecoverably.
320	Hemicelluloses have completed degradation.
>350	
370	Cellulose has lost 83 percent of initial weight.
400	Wood is completely carbonised.

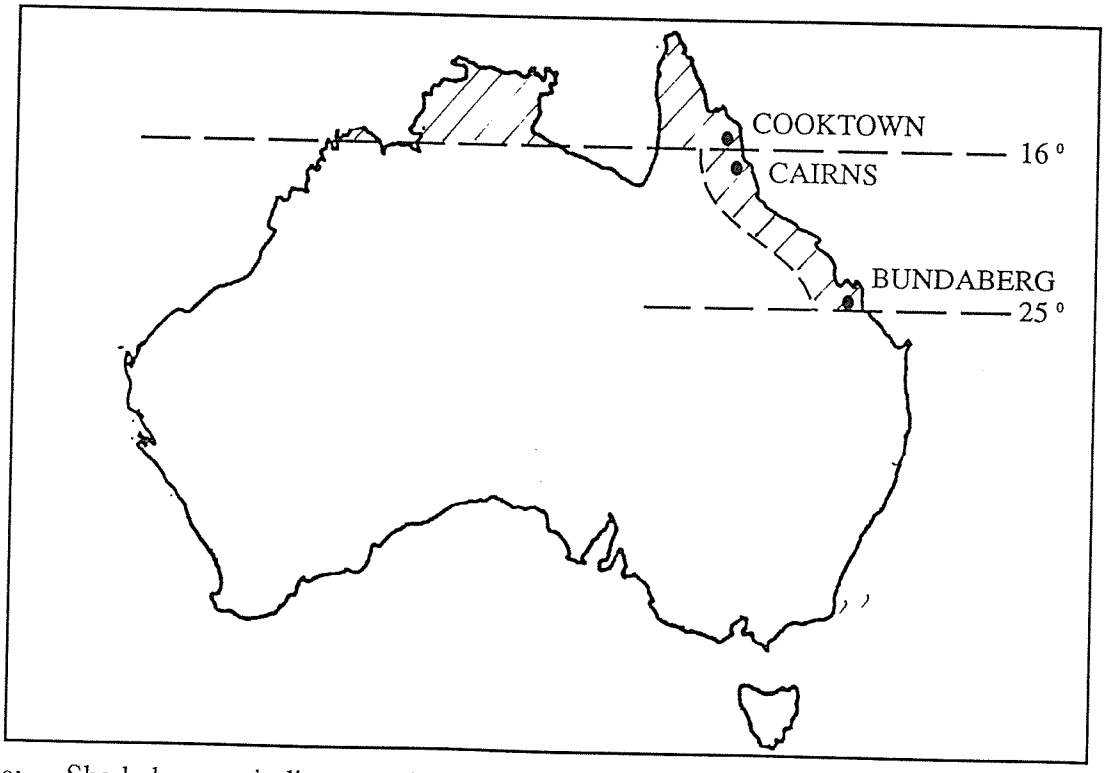
3.2.3 Temperatures - Normal

In general the effect on timber of temperatures less than 50°C and natural radiation is relatively negligible. The effect on protective chemical coatings (e.g. paint) may however be quite significant. Mechanical properties may be slightly affected by temperatures, while ultra violet radiation may cause oxidative degradation on exposed surfaces leading to a slight reduction in geometric properties. Affected surfaces, particularly when exposed to rain, are typically a silvery colour and slightly fibrous in nature. Some of the ways of reducing low level

temperature effects on timber are to provide some shade to the structure, use finish systems which reflect the heat (i.e. light colours), coating systems providing some insulative benefit and/or use species which are less susceptible to temperature effects. The best way to reduce ultra violet radiation effects is to use a pigmented coating system which is resistant to radiation effects i.e. use a material (paint) with superior durability to protect the material (timber) with lower durability against the particular agent.

In practice, apart from specifying a coating system for aesthetic performance, very few designers considering structural performance will need to specifically design for temperature or UV degradation of timber as action taken regarding other environmental agents will usually also provide adequate protection against this agent. The design method suggested in AS1720.1 for adjusting design properties for temperature, K_6 is intended to apply to specific climatic conditions where high ambient temperatures occur simultaneously with high equilibrium moisture contents (EMC). Refer Figure 8 based on AS1720.1. In other conditions the loss in strength due to temperature is usually compensated for due to the strength increase from a reduction in EMC. (Leicester 1988)

FIGURE 8 REGIONS OF AUSTRALIA WHERE NORMAL TEMPERATURES ADVERSELY AFFECT TIMBER



Note: Shaded areas indicate regions where normal temperature effects on timber require designer action.

3.3 Chemical Agents

Chemical solutions and fumes are a part of everyday life and timber being an assembly of organic chemicals can react with a range of chemicals causing degradation in the wood structure and substance, leading to affected mechanical and geometric properties. From a designer's viewpoint the chemical agents which have potential to act on timber can be categorised into two types of environments, i.e. special and normal.

3.3.1 Special Environments

Chemical degradation of timber can occur where timber, because of its application in a structure, is exposed to chemical substances of concentrations not normally found in nature. In general wood is quite resistant to mild acidic conditions, relative to metals. However it is generally inferior to metals regarding resistance to alkaline conditions. (Bootle 1983)

Applications can vary from cooling towers exposed to water with high chlorine concentration to timber in foundries exposed to sulphur dioxide fumes.

The effect of chemical reactions on the wood can vary. However colour changes and a general breaking of wood bonds can occur. The detrimental effects of chemical environments can be reduced by taking action specific to the chemical in question. In general there are a number of actions which can be taken to reduce the effect of chemicals on timber products and structures. These are summarised in Table 7.

TABLE 7 REDUCING THE EFFECT OF CHEMICAL AGENTS ON TIMBER

Reduce Agent Activity	Increase Timber Resistance
• Reduce concentrations of adverse chemicals in environment. • Use coating or sheeting systems which reduce chemical/timber contact. • Reduce moisture content of environment. • Use detailing which reduces settling or precipitation of chemicals. • Use neutralisers to reduce the action of the chemical.	• Use chemically resistant species. • Avoid treatment of timber which chemicals which may reduce resistance. • Use larger sizes or sacrificial members. • Use sections or products with minimum exposed surface area • Use timber which is free of voids.

3.3.2 Normal Environments

Naturally occurring chemicals in the air, water and ground can adversely effect timber. The chemical substances in each of these environments can react with the organic chemicals in timber causing wood breakdown. The chemicals associated with other materials used in timber structures can also facilitate chemical reactions which may cause degradation, e.g. iron salts from corroding steel fasteners can be strongly acidic and have a hydrolysing action on the wood. The degradation of timber exposed to a seaside atmosphere can occur due to high levels of salts. The effect of these normal chemical environments is generally quite negligible and will usually be exceeded by the actions of other environmental agents, except where unique environmental conditions exist in the ground, water or atmosphere to which the structure is exposed. The reduction actions given in Table 7 would also generally apply to normal chemical environments.

3.4 Physical Agents

Physical changes in timber products may occur due to changes in the moisture content (MC) of timber products. Changes in moisture content within a piece of timber can result in changes in cell dimension (shrinkage or swelling). These dimensional changes can induce significant stresses within pieces and between regions of different dimensional change, which in turn can cause breakage of the timbers. These minor breaks usually manifested as longitudinal separation between fibres can adversely influence the geometric properties of a structure and can also detrimentally affect the strength of connections where joint design does not accommodate such dimensional change. Moisture content changes in timber occur as a direct result of normal environmental changes in temperature and humidity. Physical agents acting on timber can be considered in two ways, the initial change in MC and the ongoing changes in MC.

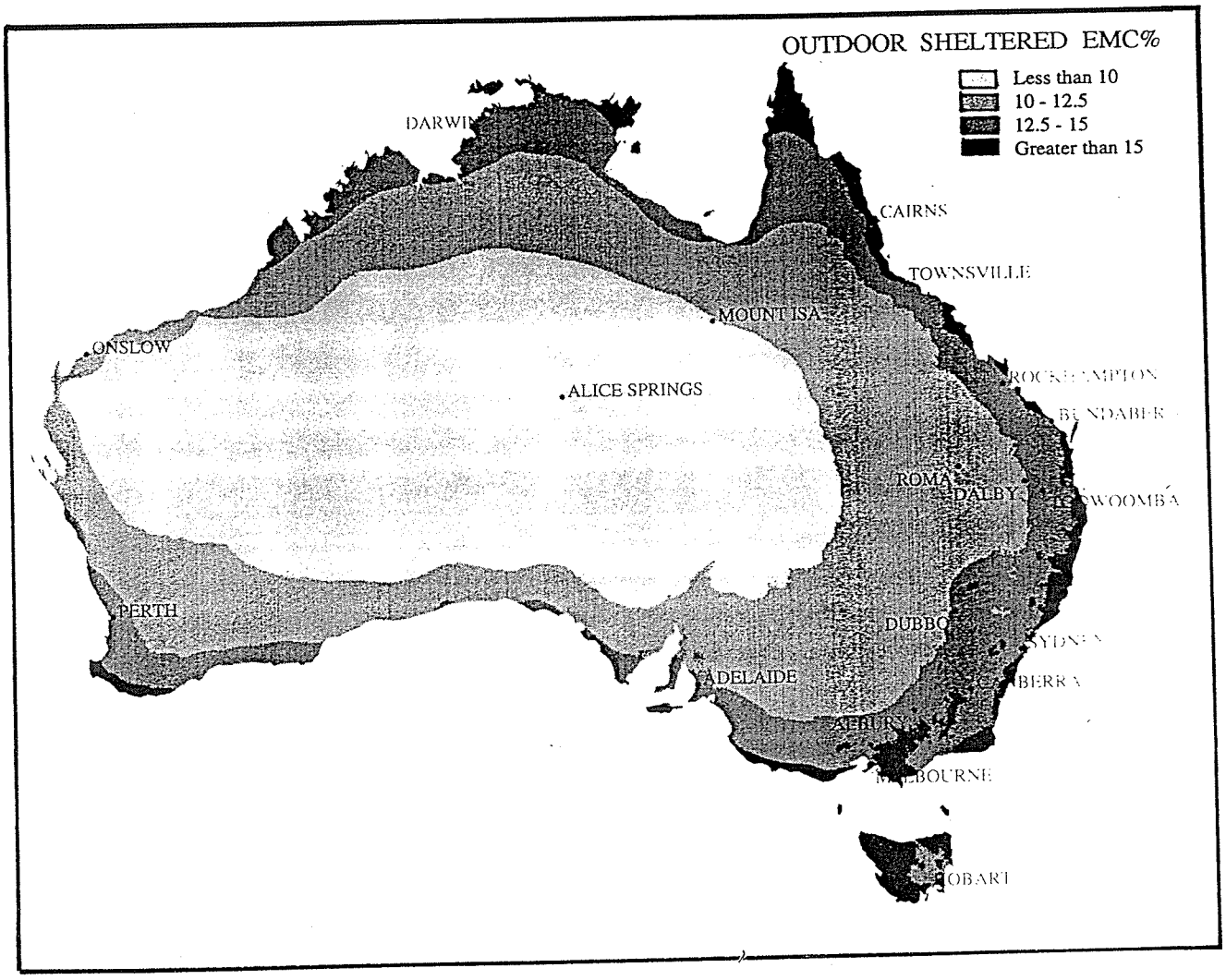
3.4.1 Initial Changes in Moisture Content

The service environment in which a timber member may be used can be quite different from the environment in which it was produced. Initially the timber member will lose or gain moisture in an attempt to reach a stable moisture content level compatible with the service conditions. This initial change can result in a detrimental effect, particularly where the magnitude of the change is large and it occurs over a relatively short period, e.g. unseasoned timber used in the arid interior of Australia in the middle of summer.

The initial moisture content change in the timber can cause the following structural effects on timber. Splits, checks, heart and other shakes which reduce the geometric properties of the member.

The service moisture conditions vary geographically in Australia. Figure 9 shows the average EMC values for various parts of Australia. (Based on QDPI-Forest Service Model (Bragg 1986). Map prepared by QDPI (Palmer 1994)).

FIGURE 9 EMC ZONES IN AUSTRALIA



Action to reduce the effect of initial moisture content changes on timber is summarised in Table 8.

TABLE 8 REDUCING THE EFFECT OF INITIAL MC% CHANGES ON TIMBER

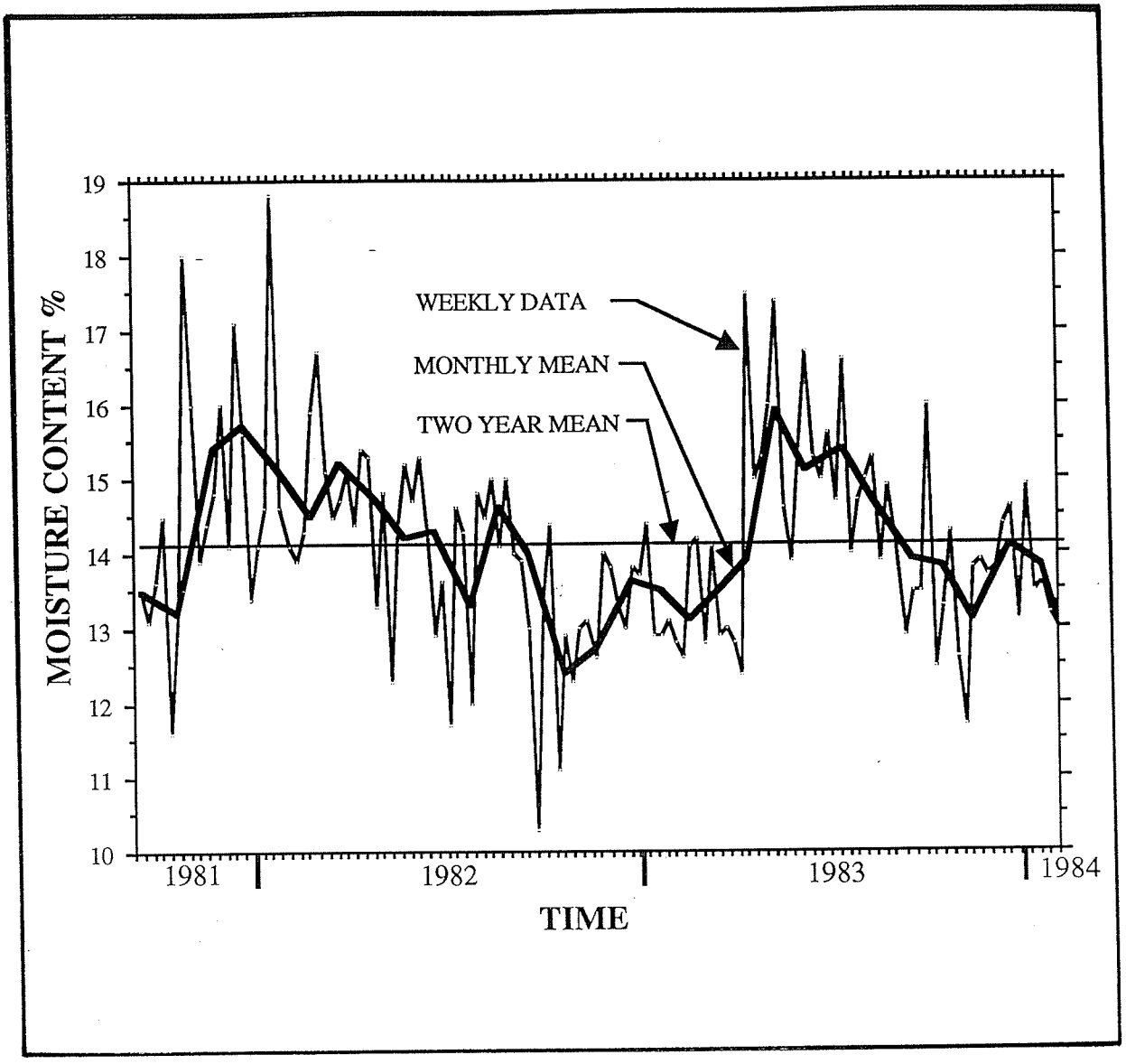
Reduce Agent Activity	Increase Timber Resistance
• Use on-site pre-seasoning methods prior to installation in service. • Coat timber to slow down moisture flow and even out gradients, particularly at exposed end grain. • Monitor MC changes and take action as required. • Modify on-site conditions through architectural detailing or suitable landscaping to provide shade. • Detail structure so that initial movement does not induce additional stress.	• Use species less susceptible to longitudinal breaks. • Use timber shapes which reduce surface stress concentrations, i.e. round in lieu of square. • Use product types which have increased resistance to cross grain stress. • Specify initial product MC as near to service conditions as possible. • Avoid timber products with features which have weak gross grain strength, e.g. loose gum veins. • Use control joints in locations which minimise the effect on geometric properties.

3.4.2 Ongoing Changes in Moisture Content

After a timber member has stabilised to an inservice moisture content it is still subject to ongoing environmental changes which cause moisture content fluctuations. These fluctuations in moisture content will induce stresses in the timber which, if sufficiently large, can cause longitudinal breaks in the timber. Where the moisture in the timber is subject to freeze-thaw cycling the resulting damage to the timber can be accentuated. This is only relevant where timber is used in relatively cold climates.

The inservice moisture content fluctuations generally have a cyclic nature. A long term cycle which corresponds with seasonal change and a shorter term cycle which corresponds to variations in weekly weather conditions. This is shown graphically in Figure 10 below based on data collected by QDPI-Forest Service (Bragg 1986) for a single 198 x 92 x 19mm hoop pine board placed outside but protected from direct wetting.

FIGURE 10 MOISTURE CONTENT FLUCTUATIONS FOR A HOOP PINE BOARD IN BRISBANE.



Species and climatic differences between sites have a significant influence on the magnitude of the moisture content fluctuations, as can be seen in Table 9 which is extracted from a QFS Report. (Bragg 1986)

TABLE 9 EMC RESULTS FOR FOUR SPECIES AT SIXTEEN SITES THROUGHOUT QUEENSLAND

Site	Hoop pine			White cypress pine		
	Mean	Range	S.D.	Mean	Range	S.D.
Brisbane	14.0	12.3-15.8	0.87	13.2	12.3-14.2	0.51
Toowoomba	14.2	11.1-18.7	1.87	13.5	11.6-16.0	1.20
Dalby	12.1	8.8-16.0	1.98	11.6	9.4-14.1	1.34
Yuleba	10.8	7.2-14.4	2.01	10.6	8.0-13.2	1.53
Charleville	9.4	5.8-14.5	2.34	9.0	6.7-12.9	1.81
Passchendaele	14.5	11.5-18.0	1.62	13.4	11.6-15.2	0.91
Gympie	13.8	11.3-16.7	1.21	13.0	11.6-14.7	0.80
Elliott	14.5	11.8-18.1	1.46	13.5	11.7-15.6	0.97
Rockhampton	12.8	10.5-15.4	1.19	12.3	11.2-13.7	0.66
Mackay	14.8	12.7-17.4	1.03	13.9	12.7-15.3	0.56
Emerald	10.9	7.7-15.9	1.94	10.8	8.6-13.5	1.43
Townsville	14.1	12.4-16.0	1.12	13.6	12.6-14.6	0.62
Cairns	16.1	13.1-18.8	1.53	14.8	13.0-16.4	0.87
Sth Johnstone	17.4	15.4-19.2	1.19	15.8	14.6-17.0	0.72
Atherton	15.1	12.5-18.4	1.80	14.2	12.4-16.1	1.10
Mareeba	13.7	11.4-15.5	1.02	13.1	118.-14.1	0.63

NOTE: * The mean, range and standard deviation are based on monthly average observations.

The main methods of reducing the effect of these fluctuations on timber's geometric properties are summarised in Table 10.

TABLE 10 REDUCING THE EFFECTS OF ONGOING MC CHANGES ON TIMBER

Reduce Agent Activity	Increase Timber Resistance
• Coat timber to reduce hygroscopic effect. • Maintain coating system as required. • Detail structure so agent effect is minimised.	• Use species which are less responsive to MC fluctuations. • Use products which are not susceptible to damage as a result of MC fluctuations.

3.5 Mechanical Agents

The deterioration of timber products or structures as a result of another object moving against it, over a relatively lengthy period of time can be considered to be the action of a mechanical agent. From a designer's point of view two different types of environmental agents can be considered, i.e. application induced and natural.

3.5.1 Application Induced

Some timber products by their very nature are subject to deterioration as a result of normal function, e.g. rubbing of fender piles, high point load shoes on timber floors. Typically the wood is broken off or dislodged in small quantities due to quite high localised stresses acting on the surface of timber members. Large longitudinal splitting of fender piles is not classified herein as being due to mechanical agents but is considered as a load capacity matter which may be exacerbated by lost cross-section due to rubbing.

Application induced mechanical agent effects on timber can be reduced by the methods shown in Table 11.

TABLE 11 REDUCING THE EFFECTS OF APPLICATION INDUCED MECHANICAL AGENTS ON TIMBER

Reduce Agent Activity	Increase Timber Resistance
• Increase member sizes to reduce movement. • Modify the use of the structure. • Use surface strengthening treatments, i.e. metal sheeting or coats. • Use surface lubricants or other devices to minimise the effect.	• Use sacrificial timber members. • Chemically treat to improve surface properties. • Use more resistant species.

3.5.2 Natural

Wind and water can carry small particles which when impacted against timber in these environments can cause minor surface abrasion. Continuation of such action over a long period of time can have a substantial effect on the geometric properties of a timber product or structure. An example of such action can be seen in the timber used in Mawsons Hut in Antarctica (Chester 1986) where particles carried in the wind have ice-blasted the timber. Other examples are sand carried by wind or silt or rocks carried by water, e.g. scouring of bridge piles near the bed of a water course. A number of practices are capable of reducing the effect of

these natural mechanical agents on timber and are shown in Table 12.

TABLE 12 REDUCING THE EFFECTS OF NATURAL MECHANICAL AGENTS ON TIMBER.

Reduce Agent Activity	Increase Timber Resistance
• Reduce availability of particles. • Detail structure so primary direction of particle impact causes less degradation. • Use flow channelling and disturbing devices to reduce impact. • Use protective systems with improved durability against such agents, e.g. concrete sleeves.	• Use more resistant species. • Use sacrificial timber members. • Use product types and shapes which are less susceptible to damage. • Use timber which is free of voids that could be exploited by the agent. • Improve resistance through surface treatment.

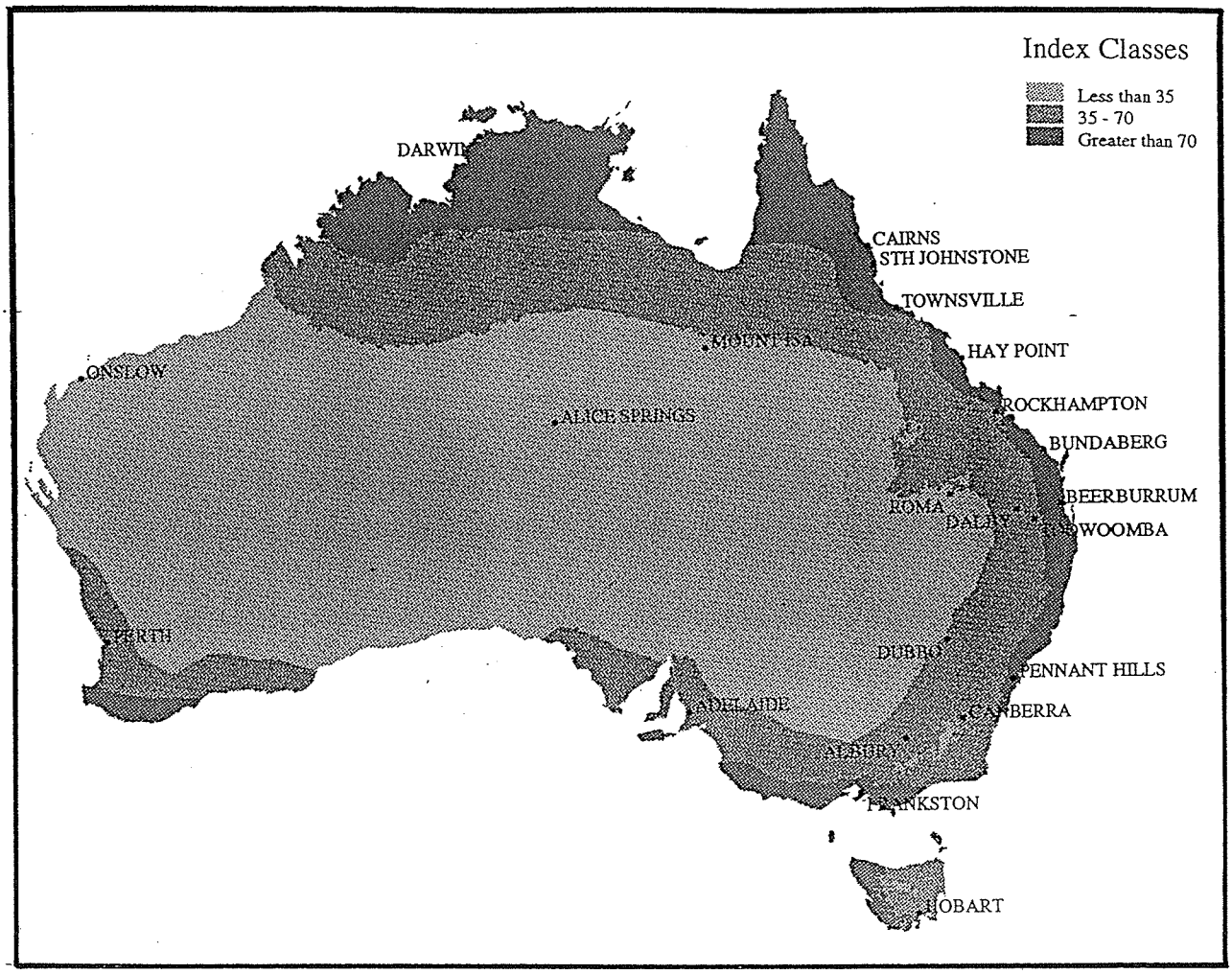
3.6 Biological Agents

The enormous number of individual biological species which have the potential to adversely affect timber necessitates a rationalisation of similar species into five broad groupings, i.e. fungi, bacteria, termites, borers and marine organisms. Each of these groups are discussed herein. The biological organisms focussed on in this report are those commonly found in Australia, e.g. the effect of woodpeckers on timber is not discussed. The activity of biological agents is undoubtedly the area of greatest concern for producers, designers and users of timber products and structures. The potential damage done by such organisms is the usual focus of durability designers.

3.6.1 Fungi

In nature fungi play a vital role in the carbon cycle by helping degrade biological debris. However when the biological material is timber, and it is in a functional structure the activity of such agents must be minimised so that the structure can perform adequately. Fungal activity is influenced by climatic parameters like temperature and the presence of moisture. A map (shown in Figure 11) reflecting the level of activity of fungi in above ground timber elements has been prepared by the QDPI-Forest Service (Cause et al 1993) based on an index developed by FPL (Scheffer 1971). While these decay zones have not been calibrated against field results, they do generally reflect relative above ground decay activity in Australia.

FIGURE 11 ABOVE-GROUND WOOD DECAY INDEX MAP OF AUSTRALIA



CSIRO (Leicester & Barnacle 1989) have developed a series of maps indicating the general durability hazards to which timber is exposed, dependent on the timber's placement above or in ground or in water. These maps are reproduced below in Figures 12 a, b & c. These maps generally reflect decay, insect and marine organism attack.

Apart from regional climatic influences, the microclimates associated with a structure can also have a significant influence on the level of fungal activity to which the timber product may be exposed. Figure 13 shows a number of microclimates which could be associated with a structure and indicates on a relative scale of 1 (low) to 10 (high) the degree of fungal activity associated with the type of application.

FIGURE 12a. IN WATER HAZARD ZONES (H= high, M= medium, L= low).

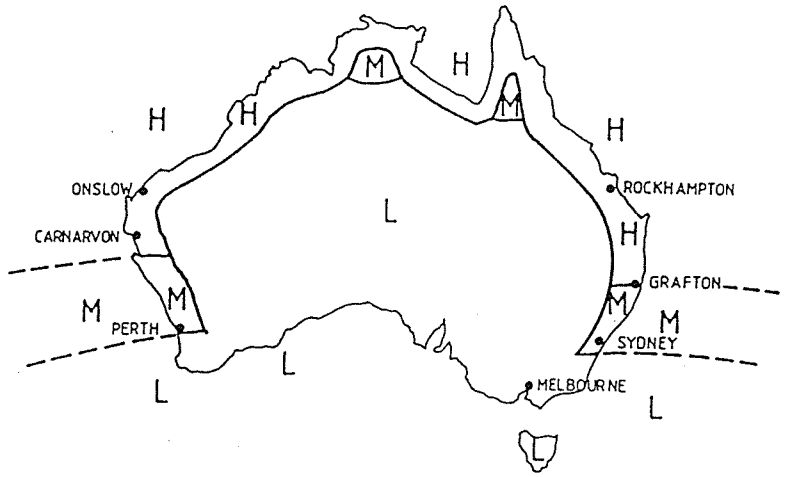


FIGURE 12b. ABOVE GROUND HAZARD ZONES (H= high, M= medium, L= low).

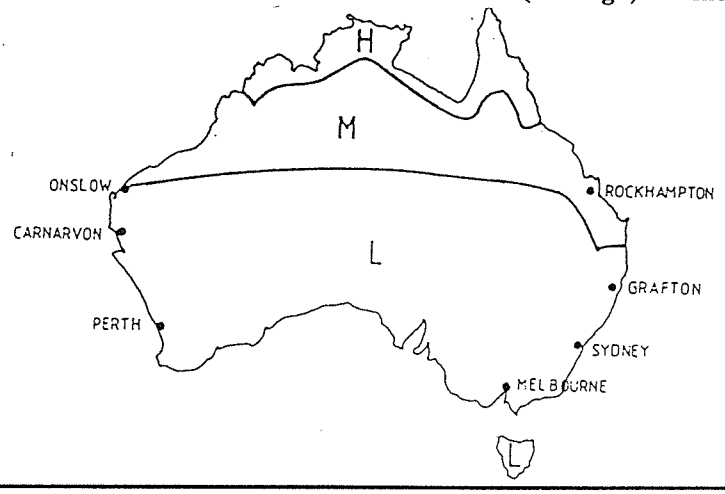


FIGURE 12c. GROUND CONTACT HAZARD ZONES (H= high, M= medium).

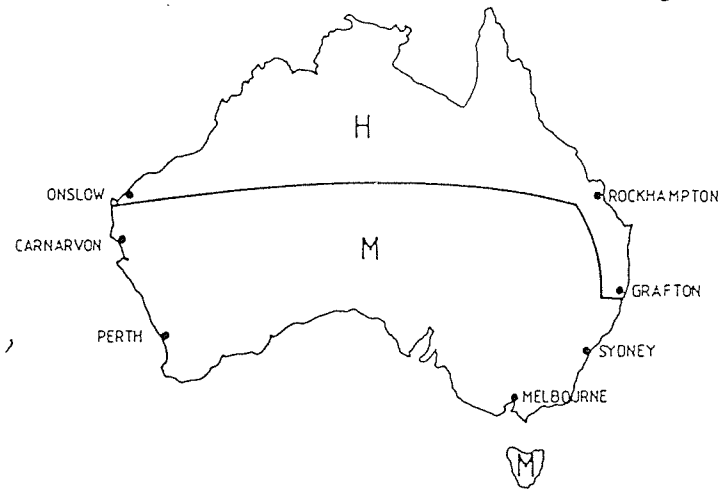
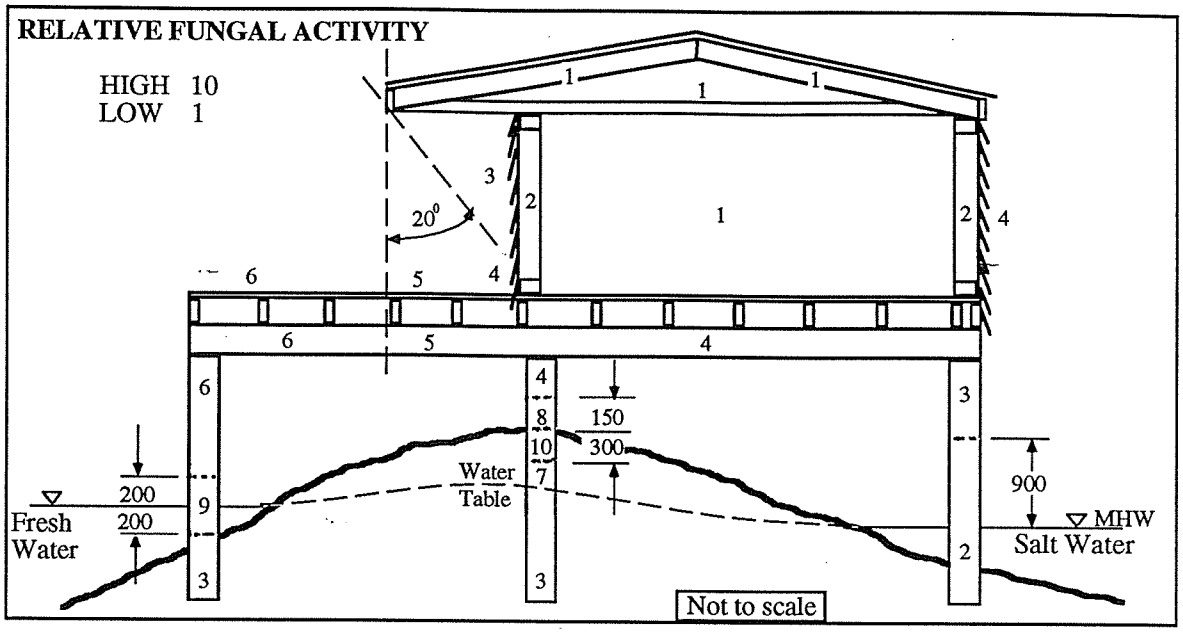


FIGURE 13 MICROCLIMATIC INFLUENCES ON WOOD ATTACKING FUNGAL ACTIVITY IN TIMBER STRUCTURES



These microclimate influences can also vary depending on the orientation of the structure and the direction of the prevailing wind. The three major types of fungi which cause decay in timber are:

- **Brown rot,** which generally attacks the cellulose in wood and eventually causes darkening and cuboidal type cracking. Softwoods are particularly susceptible.
- **White rot**, which attacks both the lignin and cellulose leaving the timber a bleached fibrous mass. Hardwoods are generally more susceptible than softwoods.
- **Soft rot,** which causes a softening of the timber and fine surface cracking when dry. The soft rot can extend right through the timber.

Fungi usually affect both geometric and mechanical properties. Even partially affected wood can exhibit increased brittleness and loss of strength with no visible sign of decay activity.

The reduction of fungal effects on timber products and structures can be achieved in a number of ways. A summary of practices aimed at enhancing the durability of weather exposed hardwoods was given by TRADAC (Stringer 1992) and is reproduced in Table 13. These practices are primarily aimed at reducing fungal effects and to a lesser degree physical agents. The principles behind the guidelines generally apply also to other species.

TABLE 13 GUIDELINES FOR CONSTRUCTION WITH HARDWOODS IN WEATHER EXPOSED SITUATIONS

(Based on Hardwood use in Queensland)

Item	Requirement	Recommendation
End Grain	- Prevent end splitting and/or water penetration.	- Seal end grain with Bitumastic or Petroleum Oil type finish e.g. (Mobil Cer M Wax Emulsion) - Provide mechanical restraint eg. nail plates or straps.
Member Orientation	- Enhance performance i.e. reduce splitting & probability of decay.	- Orientate heart away from exposure where juvenile wood is present, otherwise orientate sapwood away, particularly if untreated.
Fasteners	- Prevent corrosion. - Prevent decay near fasteners. - Avoid splitting of wood.	- All fasteners to be hot dip galvanised or stainless steel. - Avoid excessive oversizing of holes. - Use multiple screws/nails where possible. - Coat bolts with grease or similar product. - Stagger fixings where possible. - Install nails at slightly opposing angles.
Shrinkage	- Avoid shrinkage induced stresses which could have a detrimental effect on structural adequacy.	- Use seasoned wood where possible. - Oversize bolt holes. - Stagger fasteners where possible. - Allow for differential shrinkage when using timber in conjunction with other materials. - Use hardwoods with similar shrinkage rates. - Use volute washers.
Finishing	- Reduce surface deterioration. - Prevent water entry. - Reduce staining effects.	- Use good quality paint systems, preferably oil based. - Select light coloured finishes. - Use seasoned or low staining hardwoods.
Grading	- Improve decay resistance. - Reduce splitting.	- Develop application specific grading rules. - Avoid open defects on exposed faces. - Exclude heart wherever possible and if used restrict it to centre 1/3 of cross-section.
Profile	- Improve finish performance. - Reduce surface checking.	- Use rounded or arrised edges. - Round sections generally show less heart shake development than square or rectangle sections.
Joint Detailing	- Improve durability.	- Keep horizontal contact areas to a minimum and avoid if possible, in favour of self draining vertical surfaces. - Ensure joint surfaces are well ventilated.
Workman-ship	- Ensure correct installation.	- Use qualified tradesmen. - Supervise all critical elements.
Maintenance	- Ensure ongoing performance.	- Develop a maintenance plan. - Appoint someone to carry out regular evaluation.
Specification	- Ensure specification is achievable.	- Where availability of hardwood is uncertain adopt a performance specification approach.

In general the ways of reducing fungal effects on timber products or structures are summarised in Table 14.

TABLE 14 REDUCING THE EFFECT OF FUNGI ON TIMBER

Reduce Agent Activity	Increase Timber Resistance
• Modify microclimate to reduce activity e.g. shielding, orientation. • Use non-corrosive fasteners. • Ensure all joints and member surfaces are free draining and ventilated. • Provide roof cover wherever possible. • Seal end grain and surfaces with suitable moisture resistant coatings. • Use light coloured paints in preference to dark colours. • Provide ongoing inspections and maintenance.	• Use species more resistant to fungi. • Use chemically treated timber products. • Use product types and shapes which are less susceptible. • Use grades of timber which are free of decay prone natural characteristics. • Use larger sections to allow for timber loss. • Use seasoned timber. • Orientate product to provide maximum resistance. • Use chemical protection.

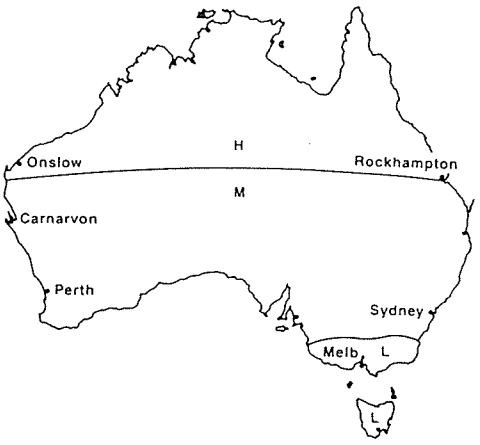
3.6.2 Bacteria

The effect on timber of bacterial activity is generally quite negligible relative to other biological agents. As a result durability designers do not usually need to take specific action to reduce bacterial activity, as practices to reduce other agents will generally also be effective with bacterial agents. Bacterial activity on timber is usually seen where timber has been exposed to anaerobic environments for considerable periods of time.

3.6.3 Insects - Termites

Two major groups of wood destroying termites exist in Australia, i.e. Subterranean termites which are the greatest insect concern for durability designers and drywood termites which are of less commercial significance. Considerable information is available on the major species and their distribution within Australia. Maps indicating the relative level of activity of termites have been suggested (Leicester & Barnacle 1987). These maps are reproduced in Figures 14 a & b. An exotic drywood termite, *Cryptotermes brevis,* at this stage only needs to be considered where structures are located in known hazard areas, i.e. Brisbane, Maryborough and Bundaberg. This introduced drywood termite is considered to be the world's most destructive and is the subject of a major eradication campaign in Queensland to prevent its increased distribution.

FIGURE 14a. SUBTERRANEAN TERMITE HAZARD ZONES



REGION		HAZARD LEVEL
H	= high	= H3
M	= medium	= H2
L	= low	= H1

FIGURE 14b. CRYPTOTERMITES (DRYWOOD) HAZARD ZONES

REGION		HAZARD LEVEL
H	= high	= H3
M	= medium	= H2
L	= low	= H1

The effect of termite agents on timber is usually a reduction in geometric properties, caused by the loss of timber associated with the formation of irregular galleries.

The pest control industry is actively involved in both curative and preventative actions to reduce the effect of termites on timber structures. Durability designers are interested primarily in designing durability into a structure and therefore focus more on preventative actions. A summary of preventative control practices is shown in Table 15. (Stringer 1992)

TABLE 15 PREVENTATIVE TERMITE CONTROL

	PREVENTATIVE ACTION			
Strategies	**Reduce Termite Hazard**		**Improve Timber Resistance**	
Methods	Chemical Systems	Physical Systems	Natural Resistant	Chemically Treated
Specifics	Organochlorins Organophosphates Pyrethroids Others	Elevated Const. Ant Caps Ventilation Others	Cypress Dense Eucalypts Brush Box Others	CCA Creosote LOSP Others
References	AS2057, AS3660	AS1694, AS3660	AS3660 App.B.	AS1604

In general the actions to reduce the effect of termites on timber products and structures are shown in Table 16.

TABLE 16 REDUCING THE EFFECT OF TERMITES ON TIMBER.

Reduce Agent Activity	Increase Timber Resistance
• Chemically poison the soil adjacent to or under the structure. • Use construction practices or termite aggregation devices which expose any termite activity. • Reduce moisture levels under or in structures through increased ventilation. • Undertake regular termite inspection and carry out maintenance where necessary. • Reduce available wood substance in the area of structure.	• Use resistant species. • Use chemically treated timber. • Use product types with increased resistance. • Use larger section sizes to allow for timber loss.

Although not investigated, it has been suggested that termites have inherent durability design skills, i.e. an ability to sense increasing stress in wood fibres, which is driven by the termite's self-preservation needs. After all, it is not in the termite's interest to eat a structure to the point of collapse, as they are also residents of the structure.

3.6.4 Insects - Borers

The larval stage of a number of borers is of importance to the durability designers as they can reduce the geometric properties of timber products or structures. The main borers of concern are:

(i) Lyctus species (Powder Post Beetles) which attack only the sapwood of certain hardwood species, reducing the sapwood eventually to a mass of holes and powdery frass. The activity of this agent is generally greater in wetter warmer climates. Despite the legislative significance (i.e. Qld & NSW Acts) of this insect no maps showing varying activity of the insect have been made.

(ii) *Calymmaderus incisus* (Queensland Pine Beetle) which attacks the sapwood of hoop pine in the coastal region from Murwillumbah to Bundaberg. It honeycombs the timber with small holes.

(iii) *Anobuim punctatum* (Furniture Beetle) which attacks many softwood species, particularly when they have aged in service for at least 20 years. It is active mainly in areas of high humidity in southern Australian States. Its effect on timber is similar to Calymmaderus.

While these insects have some albeit quite minimal potential to structurally weaken timber products, the damage they cause is generally of more concern from an aesthetic point of view. The public paranoia about such insects has been sufficient in the past to cause action by governments, e.g. Qld & NSW for Lyctus, NZ for Anobium. Most legislation regarding such insects has generally been introduced as a result of a knee jerk reaction to unscrupulous building and timber supply practices by a few suppliers, at times of high timber demand. For instance, the Qld legislation originated in the post World War 2 building boom when 979 sawmills existed in Queensland, many of which were cutting "scrubwoods" with wide sapwood and high starch contents in an attempt to meet the unprecedented demand for timber. Prior to the legislation the real public risks and consequences of lyctus attack were never adequately investigated or quantified and the legislation was developed with conservative assumptions of very high risks and very severe consequences. Houses of the time had generally higher timber contents and more exposed timber elements and as such were more likely to be affected by lyctus. Today there are about 250 sawmills in Queensland, reduced demand, a completely different resource base which is less susceptible, i.e. pines, no "scrubwoods", houses which have less timber exposed to the insect and a high level of timber and building industry self regulation, yet the legislation survives 45 years hence. This is

probably because of the crutch it provides in protecting the timber industry's investment in chemical treatment plants and the zealous altruism of the legislation's human infrastructure.

The effect of these insects on timber products can be reduced by the general methods shown in Table 17.

TABLE 17 REDUCING THE EFFECT OF BORERS ON TIMBER

Reduce Agent Activity	Increase Timber Resistance
• Reduce the availability of susceptible near the structure. • Modify environment conditions near structure to reduce activity e.g. increase temperatures. • Use non penetrable coatings, screens or shields to prevent agent access to timber. • Use insect repellent coatings.	• Use resistant species. • Use chemically treated timber. • Reduce the MC% of timber below acceptable thresholds. • Grade the timber to limit the proportion of susceptible timber. • Use older timber which has dissipated starch levels. • Use timber which has been leached to reduce starch content.

3.6.5 Molluscs and Crustaceans

The activity of these agents is confined to marine environments and is not noticeable between the mud line and high tide levels. These animals cause the loss of geometric properties as a result of the holes they create. The type of animal and its activity varies with water salinity and its geographic location. Marine borer hazard zones have been proposed by CSIRO (Cookson 1986). These are shown in Figure 15 and Table 18.

These hazards have been further rationalised. (Barnacle & Leicester 1989). Figure 12(a) shows this further simplification.

Table 19 shows the methods of reducing the effect of marine organisms on timber products and structures.

FIGURE 15 MARINE BORER HAZARD ZONES OF AUSTRALIA. GENERALISED ESTUARINE RIVER (ZONES 6 & 7) NOT TO SCALE.

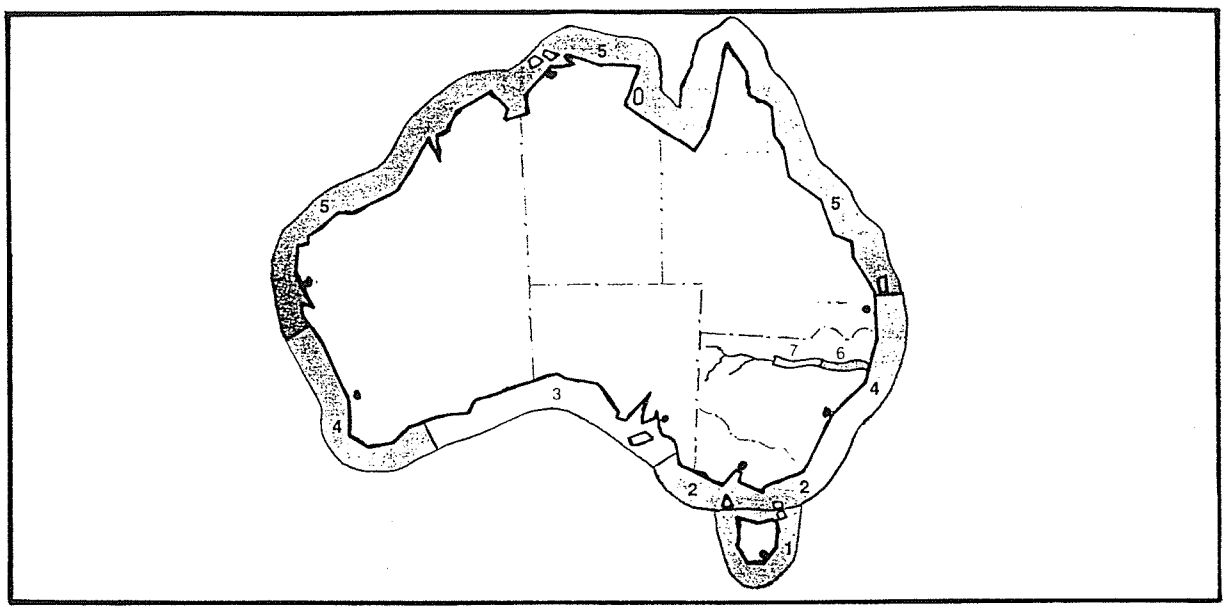


TABLE 18 TENTATIVE LIST OF MARINE BORER HAZARDS

	Hazard Zone						
	1	2	3	4	5	6	7
Salinity $^0/00$	**30-35**	**30-35**	**30-35**	**30-35**	**30-35**	**10-30**	**1-10**
Approximate Location	**Tas**	**Vic**	**SA**	**Sth WA NSW**	**Nth WA Qld NT**	**Port Stephens**	**Brisbane River**
Marine Borer :							
Limnoria tripunctata	-	low	mod	ext	mod	low	-
L. quadripunctata	mod	mod	mod	high	-	-	-
L. indica		-	-	high	high	-	-
L. unicornis	-	-	-	-	mod	-	-
L. insulae	-	-	-	-	mod	-	-
Sphaeroma terebrans	-	-	-	high	ext	ext	mod
S. quoyanum	low	low	mod	high	low	ext	-
S. triste		-	-	-	low	-	-
Ptyosphaera alata	-	-	-	-	-	low	low
High salinity teredinids	mod	mod	mod	high	ext	high	-
Nausitora spp	low	low	low	low	low	mod	ext
Martesia striata	-	-	-	mod	ext	low	-

mod = moderate, ext = extreme

TABLE 19 REDUCING THE EFFECT OF MARINE ORGANISMS ON TIMBER

Reduce Agent Activity	Increase Timber Resistance
• Alter environment around the timber, ie. plastic wrapping or concrete sleeves prevents fresh sea water entry. • Provide mechanical barriers. • Monitor activity and take action when necessary.	• Use resistant species. • Use chemically treated timber. • Increase size to allow for loss. • Use less susceptible shapes.

3.6.6 Potential Biological Agents

Australia, as an island continent, has been relatively isolated from the activities of some notable overseas organisms which can significantly affect timber structures. Introduced species like the West Indian Termite have only been controlled through the significant efforts of the Queensland Government. There are a number of species which, if they become established, could adversely affect susceptible timber structures. These are summarised in a Plant Quarantine Leaflet (AQIS 1992).

The most significant of these organisms are insects, namely

(i) *Hylotrupes bajulus* (European House Borer), although not established is Australia because of prompt treatment of reported infestations, the potential consequences of this insect should it become established are quite significant. A number of entomologists believe it is only a matter of time until it gets established, assuming of course it is not already established. The consequences in South Africa where it is now established have been considerable damage to existing buildings and mandatory chemical treatment of pines used for structural purposes. It attacks predominantly softwood species causing holes of about 5mm diameter.

(ii) *Coptotermes formasonus* (Formosan termite) is established in South Africa and many of the Pacific rim countries. It is a subterranean termite with minimal moisture requirements and develops large nests. In the countries where it is established it is the most commercially important termite species.

(iii) *Stromatium* species, are longicorn beetles like *Hylotrupes* which can attack seasoned timber.

(iv) *Heterobostrichus aequalis* and *Sinonylon anale* are both of the family bostrichidae and have the potential to attack seasoned timber.

(v) Carpenter Ants from North America also have the potential to attack seasoned timber. In the north west of the USA they are considered to be of equal importance to termites.

Apart from these insects which attack finished structures, a range of insects which could also threaten our exotic pine plantations also have potential to become established. The first line of defence in protecting Australia from these pests is the Australian Quarantine and Inspection

Service. Many of the above insects are regularly detected in timber imported into Australia. This Government service is changing in response to trade liberalisation moves and increasing financial restraint. The implications on the forestry and forest industries in Australia and New Zealand have been summarised by the Queensland Forestry Department (Wylie 1989).

Many of the entomologists working with forest and forest products in Australia are deeply concerned about the possible establishment of these insects in Australia and believe increased attention and resources need to be given to preventing and dealing with such a scenario. The development of contingency plans has been considered (Wylie & Peters 1986). The risk of establishment is difficult to determine as is the possible consequences. As a country which is sensitive to introduced species it would seem prudent to implement procedures which would reduce the risk of establishment to an acceptable level.

3.7 Agents In Combination

It is possible that any of the agents mentioned previously in this section could act on a timber product or structure simultaneously with other agents. These agents in combination may act independently of each other or may in fact have some interaction causing an acceleration of deterioration. In most cases there will be some interaction between agents. Table 20 shows a number of examples of applications where agents may interact.

TABLE 20 INTERACTION OF ENVIRONMENTAL AGENTS - EXAMPLES

Application	Interacting Agents	Consequences
Decking	Mechanical & Physical	Small surface checks can weaken surface fibres which are more easily dislodged by foot traffic.
Bridge Girders	Physical & Biological	Heart shake and split development can provide desirable conditions for fungal attack.
Marine Piles	Mechanical & Biological	The development of grooves or splits as a result of mechanical agents may increase the surface area available to marine organisms.

Some interaction between different biological agents even seems to be symbiotic. For example, the moisture associated with termite attack increases the likelihood of fungal activity which can modify the timber to make it more attractive to termites and thus increase their activity.

The most common interaction of agents is generally referred to as weathering, which can be considered as the combination of thermal, chemical, mechanical and physical agents which occur naturally. The form of weathering which occurs will vary depending on the different levels of individual agents acting on the structure. The reduction of weathering effects on timber is most commonly achieved using the methods given for each agent. The usual reduction method is the use of suitable coatings. Durability designers need to be aware of agents in combination and their combined effect on the performance of the structure.

3.8 Influencing Agent Activity - General

In previous pages advice on practices which can reduce the effect of agents on timber has been given. These durability enhancement strategies are intended to provide guidance to designers, to help them meet their durability design objectives for a particular structure. General strategies regardless of the agent or structure are summarised in Table 21.

TABLE 21 GENERAL STRATEGIES FOR ENHANCING DURABILITY

Reduce Agent Activity	Increase Resistance of Timber
• Modify geography or microclimates to reduce hazard. • Adopt construction practices which minimise activity. • Change functions of structure to improve durability • Use coatings, screens, shields and other devices which effectively separate the agent from the timber. • Reduce or control moisture content movement.	• Use naturally durable species. • Use chemical treatments which enhance durability. • Use products which are of a particular type, shape, grade, moisture content and/or size which are less susceptible to agent activity.

4. DURABILITY DESIGN METHODS - EXISTING

4.1 General

Durability designers have a range of formal durability design methods to choose from in Australia. This choice to some degree is governed by legislative requirements which may specifically relate to the structure being designed. Most of the design methods, legislative or otherwise, have been prepared by different groups who generally have different objectives and make different assumptions about the expectations and needs of timber designers and/or the users of timber structures.

TABLE 22 SUMMARY OF CURRENT AUSTRALIAN DURABILITY DESIGN METHODS FOR TIMBER STRUCTURES

Method	Legal Status (excluding Contractual Specification)	Agents Covered	Where Used	Other Details
AS1720.4	Via BCA, Spec. A2.3	Fire	Aust	Single element design only
Timber Utilisation and Marketing Act (TUMA)	Queensland Act	Lyctus	Qld	Treated timber similar to AS1604
Timber Marketing Act (TMA)	NSW Act	Lyctus	NSW	Aust Stds called up
AS1604	None except via TMA-NSW	Biological	Aust	Treated timber only
AS3660 (formerly AS1694 & AS2057)	Via BCA, B1.3	Sub Termites	Aust	Physical & chemical barrier systems
NAFI Datafile P4	None	All	Aust	Part of NAFI Timber Manual
AS1684	Via BCA, B1.3	Biological some Mech	Aust	Aust Stds called up
Tech Pamphlet 1	Via BCA, Qld B1.3	Biological some Mech	Qld	Extensive species schedule
Cookson 1986	None	Marine borers	Aust	Specific to piles
CSIRO, TRADAC, TPC, NSWFC, QFS, TABMA, FIFWA & other Industry Publications (Not referenced)	None, unless called up in registered products or state variation to BCA	Generally as above	Aust	Generally based on the above design methods

A summary of the main methods used by Australian designers is shown in Table 22. A number of alternative design methods which have either been used in the past or suggested for the future are summarised in Table 23.

TABLE 23 ALTERNATIVE DURABILITY DESIGN METHODS

Method	Agents Covered	Other Details
Langlands & Thomas (1939) Pearson et al (1958) AS1720-1975	Biological and weathering, except marine	Integrates durability and structural design, using Exposure Factors to adjust working stresses. Recently calibrated for bridge girders (Law and Morris 1992).
Cokley (1973)	Biological, except marine	Improved geographical and climatic identification of agents proposed. To be based on survey of existing structures and reliability principles
Leicester & Barnacle (1990)	Biological	Prediction method for determining beam and joint strength performance is proposed. Reliability approach suggested.
Stringer (1992) (See Appendix B)	Termites	Proposed formalisation of cypress use in structures to reduce probability of structural failure.
Sato (1990)	Termites & fungi	A prediction method given by a series of expressions is suggested to determine the service life of dwellings in Japan.
Schaffer (1992)	Thermal, chemical, biological	Kinetic models are proposed to predict the effect of aggressive environments on timber.
Bodig (1985)	Biological, mechanical	A model based on field evaluation of in-service poles is proposed to estimate a lower bound rate of deterioration.

4.2 Legislative Based Methods

4.2.1 Building Legislation

The rationalisation of local and state building requirements into a single publication, the "Building Code of Australia" (BCA) has unified building requirements across Australia. However it has not adequately provided requirements which should be met over the life of the structure. Requirements are given which are aimed at ensuring that acceptable standards of structural sufficiency, fire safety, health and amenity are maintained for the benefit of the community now and in the future. Despite this objective, regarding future performance, only general requirements relating to the design and construction stage of a building are provided. It is generally implied that the materials and structure should have adequate durability for the life of the structure. By comparison, the New Zealand Building Code (NZBC) tackles this issue front-on with a durability clause which outlines the durability performance requirements for a structure and any structural element thereof. The reliability associated with the nominated

service life requirements is however not stated. The handbook (1992) to the NZBC provides guidance on durability evaluation in order to verify compliance with the stated requirements. The relevant extract from the NZBC is shown in Appendix C. The legal consequences of these requirements have been identified (NZ TDJ 1993) and it seems that the legislation will prompt increased consideration of durability matters by suppliers and builders. An increase in durability research and the provision of improved product literature will be a direct consequence of these durability requirements.

The BCA seems to rely more on the requirements in material standards to address durability related matters. The Health and Amenity section within BCA has a number of requirements which inadvertently improve the durability of timber elements within the structure, e.g. weatherproofing, sub-floor ventilation. The main area of BCA which calls up documents concerned with timber durability is Part B1 "Structural Provisions". It references AS1720.1, AS1684, AS1694 & AS2057 (replaced by AS3660) and Technical Pamphlet No1 (Queensland only). AS3660 is somewhat out of place in clause B1.3 as it is an environmental agent specific code rather than structure or material specific as are the other codes referred to in this clause.

The timber structures code, AS1720.1 which is deemed to satisfy the BCA structural provisions is quite inadequate regarding its advice to designers on durability matters. No requirements to ensure the durability of timber structures are included, which is incongruous considering the most common failure modes for timber structures are durability related. In fact, AS1720.1 by referencing the corrosion protection standard, AS2312 provides better advice about the durability of metal connectors used in timber, than it does about timber exposed to adverse environments.

The durability design methods referred to in BCA are summarised individually below.

(i) **AS1720.4** provides a design method for predicting the magnitude of wood adversely affected by a standard fire. This method is called up in the Specification A2.3 of BCA. The method relates to individual members and through the use of post fire event loading requirements and the structural design procedures of AS1720.1 has a reliability basis. Requirements for the protection of joints are also included.

(ii) **AS3660,** which replaces AS1694 and AS2057 provides requirements for protecting buildings from subterranean termites. The requirements are based on traditional physical barrier building practices, chemical barrier systems as well as other novel physical barrier systems. Appendix B of AS3660 gives an indication of the relative

termite resistance of some species. It is a prescriptive document with a reasonable amount of useful information. It has no formal reliability basis, does not adequately distinguish between the various regional and local levels of termite activity in Australia, makes only general statements about the ability of the prescriptive practices to protect a structure and is primarily targeted at pest controllers and builders.

(iii) **AS1684** primarily provides design and construction information relevant to the structural performance of conventionally framed timber buildings. It is very much a formalisation of conventional building practice and outlines a number of requirements which relate to durability performance, i.e. AS1604, AS2057 and AS1694 are referenced, durability classes are given for various applications, practices relevant to durability against fungi and termite attack are provided. Durability requirements for materials during storage and handling are also given, as well as specific requirements for platform floor protection. In general durability is treated haphazardly in the document and is by no means complete for this type of structure. The environmental agents acting on such structures are not well defined. Construction practice requirements conducive to durability performance are also quite limited.

(iv) **Technical Pamphlet No. 1** "Building Timbers - Properties and Recommendations for Use in Queensland" only applies in Queensland via the BCA state variations. It provides a wealth of practical information to assist the durability designer regarding fungi, termite, borer and some mechanical agents which act on domestic and light commercial timber buildings. A range of applications are defined and species suitability to each application are given. It is a prescriptive document and is based on assumptions of good building practice, including reasonable maintenance activities. The document claims to satisfy the "suitability of materials" requirements of the BCA. Only minimal recognition of variations in regional and local environmental agent activity and the range of factors influencing that activity is provided. Construction practice conducive to suitable performance is also quite minimal. The document relies strongly on the chemical treatment of timber as the cure-all for achieving acceptable durability performance.

4.2.2 Other Legislation

Apart from legislation which attempts to control building practices, a number of other pieces of legislation relevant to timber durability exist. These were generally enacted to control undesirable marketplace practices in the timber industry or address some perceived major durability threat to society's timber infrastructure. The current relevant Australian legislation is:

Timber Marketing Act - NSW
Timber Utilisation and Marketing Act - Qld
Diseases in Timber Act - Qld

The first two of these relate to lyctus borer attack in susceptible timber. The Queensland Act also provides mandatory requirements regarding the chemical preservation of timber and its utilisation. These are similar to the provisions of AS1604. The Queensland durability class system and lyctus susceptibility ratings for individual species is enshrined within the legislation. Both of these systems differ slightly from the systems adopted in other states which are usually based on CSIRO proposed systems.

Durability designers in Queensland and New South Wales need to be familiar with these pieces of legislation as decisions relating to durability can have well defined legal consequences.

The Diseases in Timber Act came about in response to West Indian Termite infestation in Queensland. The Act requires notification of the insects detection. Durability designers working on existing structures in hazard areas should be aware of the Act as it could adversely influence a project, e.g. The Treasury Building redevelopment project in Brisbane recently required total fumigation.

4.3 Non-Legislative Based Methods

Various groups involved in timber production, utilisation or research, have seen fit over the years to publish documents which provide advice about durability matters. The most notable of these are discussed below.

(i) **AS1604**. This document is not called up in Building legislation or AS1720.1, however it is referred to in the Timber Marketing Act of NSW. It forms the basis for the production and use of treated timber in Australia and often attains legal status through contractual specifications. It focuses on biological agents and standardises chemical retention and penetration requirements into six levels which are then recommended for six rationalised levels of exposure. These levels of exposure are then associated with specific service conditions, biological hazard and typical uses. A listing of durability ratings is provided which differs from other Australian Standards, i.e. AS1720.2. The method is not reliability based and makes no statement which quantifies the expected performance of structures which use the design method. This document is actively promoted by the chemical supply and treated timber research industries in Australia.

The standardisation of retention and penetration requirements can unintentionally discourage the use of non-standard requirements which may be more appropriate to a particular hazard or applications, e.g. surface penetration through brush on applications, are not recognised despite their beneficial effect on improving the durability of structures. As a design method it does not adequately consider the wide variation of environmental agents acting on Australian timber structures. The controllable factors influencing the activity of these agents is also not considered within the standard despite the forward to the document acknowledging that such factors do influence the performance of timber. The method rationalises sapwood durability to a non-durable status which is inconsistent with sapwoods known performance in many structures. Other methods of improving durability performance are completely ignored to the point that the document, when written into a contractual specification, requires all interior framing timber to be chemically treated to a H2 level. It seems that many of the retention and penetration requirements of the code are based on conservative extrapolation of limited research data, assuming minimum processing abilities, maximum variation in the treatability characteristics of the timber species and the existence of maximum biological agent activity. The document focuses on chemicals which make the timber poisonous to biological agents and makes no provision for alternative chemical treatments which may use more environmentally acceptable protection strategies such as repellency. The document is relatively immature and seems to have been prepared with a "blinkered" view of broader durability issues.

Concern about the data upon which some of the code requirements are based has been raised (Campbell 1993, 1994). Such concern seems to be driven by the need to have reliable prescriptive requirements which can be used with confidence in the design of timber structures.

(ii) **Timber - Design for Durability**. This NAFI (1989) publication, included as datafile P4 within the NAFI Timber Manual, is targeted directly at professional designers and as such adopts an approach which encourages designers to consider the impact of their durability decisions on the performance requirements of a structure. In this regard it is more performance orientated than prescriptive. All environmental agents are presented, with a good summary of the various actions which can be taken to improve durability. The section on design is particularly valuable as it highlights many desirable practices. The principle author of the document, C E MacKenzie of TRADAC, has attempted with relative success to broaden the designer's approach to durability and to provide a good overview of issues which need to be addressed by designers.

(iii) **Marine Borers and Timber Piling Options** by L. Cookson (1986). The information presented in this publication which appears to be targeted directly at engineers, allows reasonably accurate decision making about the durability of timber piles in Australian marine environments. It is agent and application specific. The information provided about the variation and extent of agent activity in Australian waters is most excellent. The emphasis put on explaining the agents and their activity is unprecedented in other Australian design methods and greatly assists designers. The publication is on the verge of allowing reliability based principles to be used by designers. The publication is a fine example of how good science can be presented to an engineering audience. The honest approach to the uncertainty associated with some of the data presented allows engineers to better evaluate the risks associated with their design. The document is slightly bias towards chemical treatments and would be even more valuable if further information about the performance benefits of non-chemical protection systems were included. It is an essential design resource for any engineer using timber in a marine environment.

(iv) **Other Methods.** A large number of simplified prescriptive durability design publications are available in Australia. These are generally published by organisations who have a role to encourage the improved durability of timber structures, e.g. CSIRO, State Forest Services, State & National timber promotion organisations, Building Associations or regulators. Most of these publications are usually agent, application, product and/or species specific in nature. They generally summarise the information from the more formalised design methods previously discussed. As a vehicle for conveying design information they have the benefit of brevity. However they often promote conservative recommendations which flow from worse-case assumptions made about environmental agents and the practices of structure users.

4.4 Alternative Methods

Other researchers have attempted to develop durability design methods and have proposed various alternative design approaches which are not currently used. It is worth discussing these as they provide interesting ideas about how durability design methods may be improved.

(i) **Langlands and Thomas (1939).** This method proposed that an exposure factor should be used by engineers to adjust the mechanical properties used in design calculations so as to allow for biological and weathering deterioration of a structure over time. This method was accepted by the authors of the Timber Engineering Design Handbook (Pearson et al 1958)

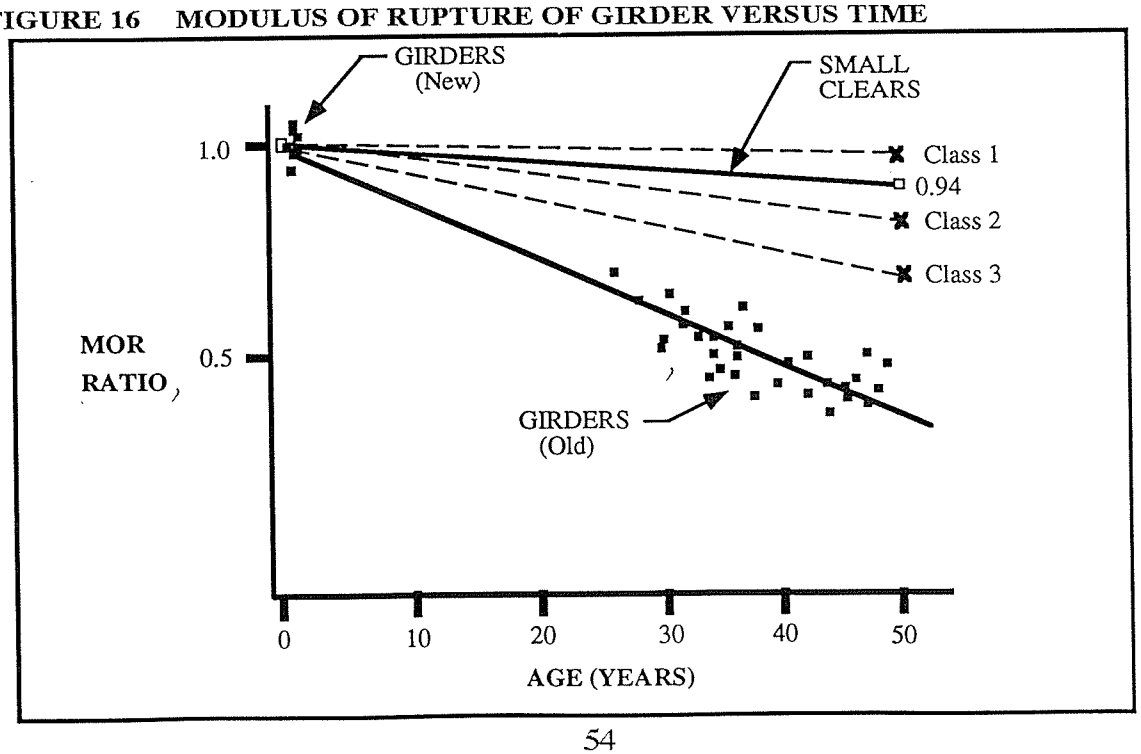
and the Timber Structures Code AS1720-1975 (Standards Australia 1975). However the method was withdrawn from the 1988 AS1720 revision (Standards Australia 1988) as a result of concerns about its accuracy and application to existing structures. These exposure factors allowed designers to quantify the effect of biological agents on structures. The exposure factors are related to rationalised conditions of use and the natural durability of the timber. Table 24 extracted from AS1720-1975 shows the magnitude of these exposure factors.

TABLE 24 EXPOSURE FACTORS AS1720-1975

Property	Condition of use*	Timber durability class			
		Class 1	Class 2	Class 3	Class 4
Bending and tension	a	1.00	1.00	1.00	1.00
	b	1.00	0.95	0.85	0.80
	c	1.00	0.90	0.70	-
Modulus of elasticity	a, b, c	1.00	1.00	1.00	1.00
Shear	a	1.00	1.00	1.00	1.00
	b	1.00	0.95	0.85	0.80
	c	1.00	0.90	0.70	-
Bearing parallel and perpendicular to grain	a	1.00	1.00	1.00	1.00
	b	0.95	0.85	0.75	0.60
	c	0.90	0.70	0.50	-
Columns	a	1.00	1.00	1.00	1.00
	b	1.00	0.95	0.85	0.80
	c	1.00	0.90	0.70	-

Note: a - completely protected from weather with no decay hazard;
b - structures exposed to weather; c - severe decay hazard.

FIGURE 16 MODULUS OF RUPTURE OF GIRDER VERSUS TIME



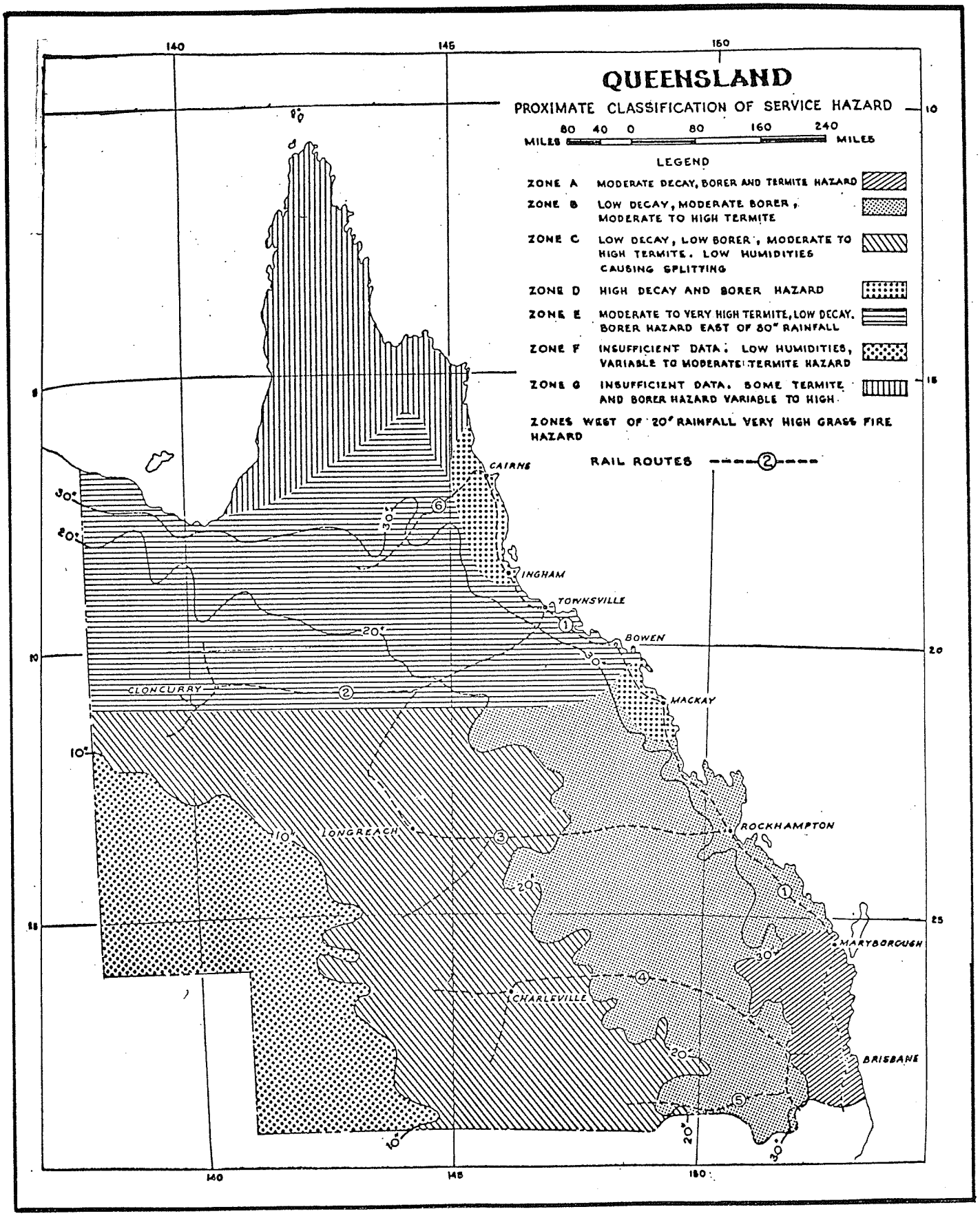
In a major study on bridge girders (Law & Morris 1992), the exposure factors for bending (MOR) and modulus of elasticity (MOE) were calibrated for 50 years. The modulus of rupture versus time relationship reported in this study is shown in Figure 16. Also shown on the figure is the exposure factors suggested in AS1720-1975. AS1720.1-1988 with an absence of such exposure factors encourages the designer to believe no change in properties occurs over time.

The deterioration of the girders in this study was primarily due to an altered cross-sectional shape, the consequences of which are reflected in Figure 16 in terms of reduced mechanical properties. Other reasons which may be involved in causing the deterioration of the girder are an ageing effect and a fatigue effect. The method is limited to biological agents and provides no data to the designer about the nature of the wood loss effect on geometric properties. The method when calibrated against the performance of real structures has the potential to allow defined levels of reliability to be achieved. The method also provides a stress focussed engineer with an incentive for improving the durability of the structure, i.e. design stresses can be increased where high durability class timbers are used. Further development of the system may allow stress increases where other durability enhancement practices are undertaken.

(ii) **Cokley (1973)** suggested an approach to durability design which was never adopted. He suggested that more accurate assessments of an environmental agents activity (in his case decay hazard) would enable the effective and maximum utilisation of timber. He was aware of the limitations of the natural durability classification system and the effect of microclimates and construction methods on the decay hazard. He suggested the Queensland Forest Service was intending to undertake a performance survey of different species in different applications and hazard levels. He suspected that correlations of the results would help explain the satisfactory performance of low durability species in some exposed situations. He considered that advisers to the timber using industry should not require 100% service. The development of an accelerated test procedure for structural components was also suggested. He suggested that correlations between service performance and climatic conditions should be used to predict the service life associated with 95% performance. A hazard map for Queensland was also proposed and is shown in Figure 17. Apart from biological hazards this figure also defines a thermal hazard zone (i.e. bushfires).

The best trial of a timbers performance is in-service use and the suggestion of evaluating existing structures is extremely worthy, as astute observations can help identify the factors associated with improving performance. The improved evaluation of hazards is also warranted particularly as reliability principles are increasingly introduced into durability design. Cokley has identified a clear need to obtain better information about durability performance and to use this to reliably design durable timber structures.

FIGURE 17 PROPOSED HAZARD MAP OF QUEENSLAND (COKLEY 1975)



(iii) **Leicester and Barnacle (1990)** proposed a formal design process for timber structures exposed to biological agents. Five levels of performance are defined for the two types of structural elements, i.e. beams and joints. Also proposed is a simple method for predicting the durability performance of a structure based on the

- natural durability of the species concerned.
- zone of the tree from which the timber is cut.
- relative classification of the biological hazards.
- location of the timber beam or joint relative to the ground or water.
- chemical treatment of the timber.

Calibration of this prediction method is suggested, after which it is proposed that design rules be developed. The following additional factors are suggested for improving the prediction method.

- structure orientation
- structural detailing, particularly at joints
- thickness of timber elements
- the use of coatings
- the use of inspection and maintenance activities

The design rules which eventuate can then have a reliability basis. This proposed method is significant in that it has prompted many Australian engineers to think about how timber durability design could be improved. The method itself relies on the inaccuracies associated with the current durability class system and as suggested by the authors may lead to conservative design rules unless many additional factors influencing durability performance are included.

(iv) **Stringer (1992)**. In a previously unpublished proposal to the Cypress Division of the Queensland Timber Board a design method formalising the traditional use of cypress in houses as a termite control system was suggested. A copy of the proposed system is included in Appendix B. The system is species, agent and structure specific. Unlike other termite systems, drywood termite hazards are considered, as are regional and local variations in termite activity. The system is not exclusion orientated like AS3660 but structural performance orientated. A formal field evaluation of cypress dwellings would help calibrate the system and establish the level of reliability associated with it. The system uses both hazard reduction practices and species resistance data to achieve structural performance. It is claimed that the system provides equivalent performance to traditional termite control systems.

(v) **Sato (1990)** suggested a design method for determining the service life of wooden dwellings in Japan. He developed an expression

$$Y=[Ys]x[B]x[C]x[D]+[M]$$

where,
- [Y] : planned service life time
- [Ys]: service life time of materials
- [B] : conditions of structural systems
- [C] : construction condition
- [D] : deterioration environments
- [M] : maintenance conditions

Each of the elements in this expression, in turn has an expression with a number of parameters. Various parameter options are allocated points depending on the unique characteristics of the structure and it is then simply a matter of calculating all the expressions and determining an estimate of the service life which can be compared to the required service life. The parameters considered in the design are

- natural durability of timber
- size of timber members
- chemical treatment of timber
- height of foundations and roof pitch
- drying possibilities of structural members
- water protection of members
- level of construction inspections
- termite and fungal hazard zones
- part of building, water use in dwelling and presence of gutter
- service inspections of structural members
- accessibility of structural members
- preservative re-treatment intervals

It is claimed the system is suitable for new buildings. The method allows the designer to study the sensitivity of various durability enhancement options on the service life of the dwelling. The method is confined to termite and fungal activity on the dwelling and recognises the benefits of desirable design construction and maintenance systems. This method was the outcome of a major five year project by the Japanese Ministry of Construction (Takebayashi et al 1983). The method has recently been used to predict wood building service lifes for different wood sheathing options available in Japan (Falk & Sato, 1994).

(vi) **Schaffer (1992)** suggests that kinetic models, based on reaction rate theory of

physical chemistry can be useful in modelling the response of wood-based materials in aggressive environments. Accelerated testing to determine the specific equations needs to be undertaken with extreme care. The rate of thermal, chemical and biological deterioration of wood can be explained by the use of such models. The form of the thermal degradation models proposed is

$$\frac{dw}{dt} = -wAe^{(-\Delta E/RT)}$$

where, $\frac{dw}{dt}$ = the rate of weight loss

A & E = material constants dependent on heating levels

R = a constant

T = absolute temperature

W = current weight

t = time

e = base of natural logarithm

Similar forms were presented for the hydrolysis of wood based materials and for the growth of biological organisms. A model to predict the change in strength of fire retardant treated plywood was developed. Further development accounting for cyclic service conditions is continuing.

(vi) **Bodig (1985)** reported an approach used by the US Electric Power Research Institute, to determine the rate of deterioration of poles due to biological and mechanical agents. Figure 18 shows the modulus of rupture at ground line for southern pine poles with various in-service ages. An equation of the following form was used to model the deterioration.

$$Y_T = Y_O e^{-bT}$$

where Y_T = property at time T

Y_O = property of the new product at time zero

e = base of natural logarithm

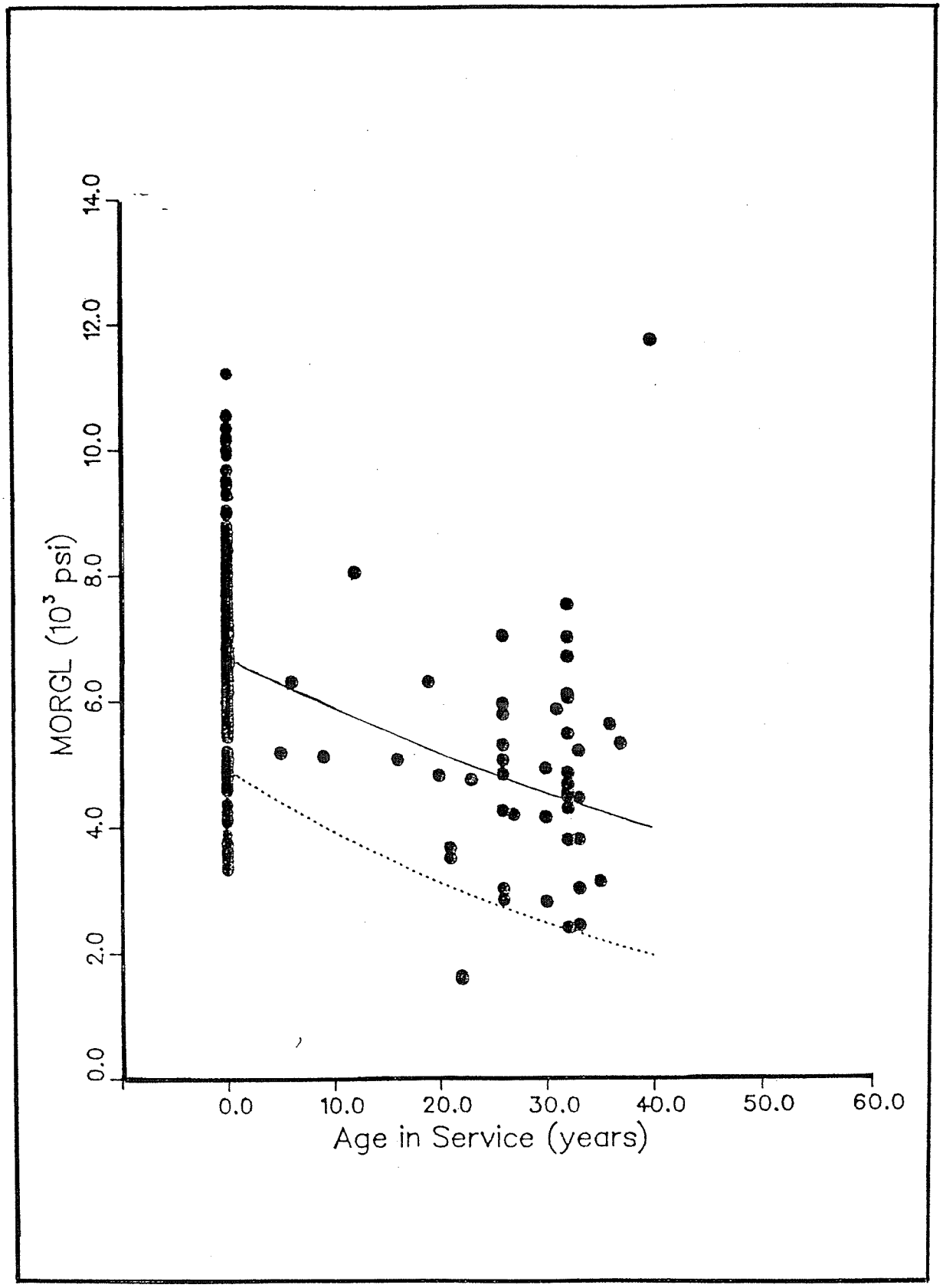
b = constant

A model for design purposes was developed from the data shown in Figure 18 and represents the lower 5% exclusion limit, shown by the dotted line. The model is

$$Y_{T5\%} = 4924e^{-0.023T}$$

Such an expression allows reliability principles to be applied to the design of southern pine poles.

FIGURE 18 BENDING STRENGTH DETERIORATION OF IN-SERVICE SOUTHERN PINE POLES WITH AGE IN SERVICE

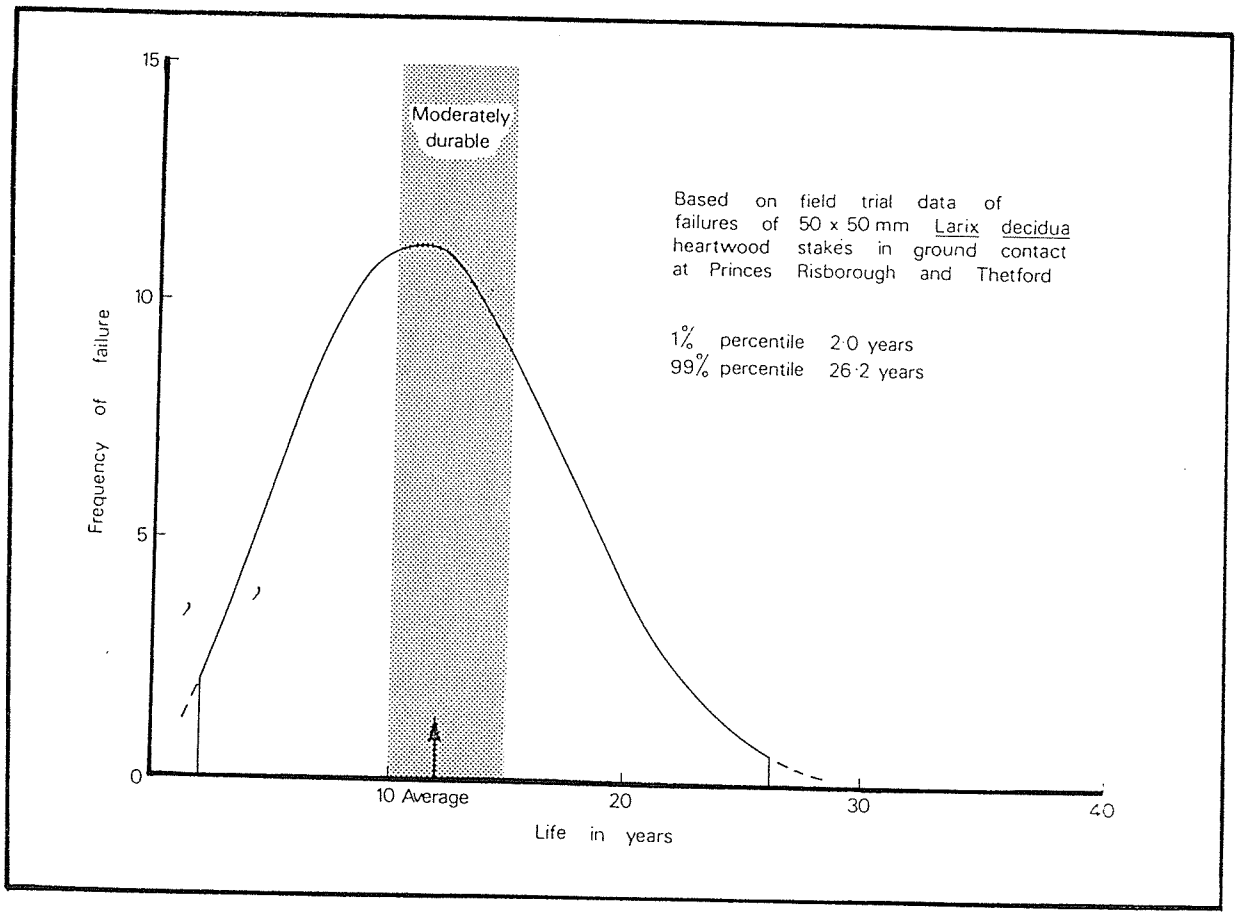


4.5 General Review of Methods

4.5.1 Natural Timber Resistance

Most design methods rely on some measure of the timbers inherent resistance to the environmental agent concerned. The most common measure of natural durability is the durability class system which provides mainly relative information about the resistance of heartwood to fungi and some termite activity. This system has been widely promoted and misrepresented over the years to the point that most durability designers, industry and some researchers genuinely believe, for instance that if they use class 1 timbers in the ground then 100% of them will last more than 25 years and possibly up to 50 years or more. Research results (Thornton et al 1993) show that this is simply not the case. The poor promotion of the durability class system is quite dangerous as it generally ignores the large variations in natural resistance, agent activity and the other construction and service factors which have a significant influence on the in-service performance of timber. The variation within species alone can be quite large and was highlighted diagrammatically by the Building Research Establishment (Cockcroft 1977). This diagram is shown below in Figure 19.

FIGURE 19 THE NATURAL DURABILITY OF EUROPEAN LARCH (LARIX DECIDUA)



The results of CSIRO's significant inground trial (Thornton et al 1991) also show considerable variation within species and between sites. A selected summary of some species from this work is shown in Table 25.

TABLE 25 SUMMARY OF INGROUND DATA RESULTS FOR SELECTED SPECIES

Site	Specimen Life (years) (Q_1 is 1st Quartile)							
	Turpentine		Jarrah		Messmate		Mountain Ash	
	Q_1	Median	Q_1	Median	Q_1	Median	Q_1	Median
Brisbane - Qld	8.5	10.3	3.1	6.8	1.0	3.1	1.0	2.0
Innisfail - Qld	8.5	8.5	8.5	8.5	1.1	1.1	1.1	1.1
Pennant Hills - NSW	8.6	16.1	12.0	12.0	4.7	8.6	4.7	8.6
Walpeup - Vic	14.8	N.A	16.8	20.5	8.8	8.8	3.3	5.3
Mulgrave /Rowville - Vic	N.A	N.A	14.0	N.A	4.3	8.3	1.1	6.3
Current Durability rating & expected service life	Class 1 25+ years		Class 2 15 to 25 years		Class 3 5 to 15 years		Class 4 Less than 5 years	

N.A indicates the results are not yet available due to insufficient failures.

Variation between sites and within sites is also showing up in the results of the QDPI - Forest Service above ground trial (Cause 1993). This real life variation in the inherent resistance of timber to decay and termites is not compatible with the current service life data presented in existing durability class systems. The move by Thornton & Johnson (1991) towards 1st quartile presentation of the data seems to be compatible with a reliability approach to durability design, i.e. just as engineers use lower 5 percentile mechanical properties to indicate how weak the timber is, lower quartile natural durability results could be used to indicate how perishable the timber is to a particular agent or in a particular service environment.

Many of the existing durability design methods adopt a simple approach to sapwood durability, i.e. it is non-durable. This generalisation of sapwood durability is disproven by examining many of society's structures which contain non-chemically treated sapwood, e.g. fencing, pergolas, claddings, cypress decking (Cause & Stringer 1993). It seems the approach towards sapwood has come about by researchers interested in promoting chemical treatment of all sapwood as the only means to reduce the supposedly great risk to which sapwood is exposed. Prior to chemical treatment, timber structures containing sapwood were built and have lasted hundreds, even thousands of years.

While design methods continue to rely on over-rationalised data and in some cases inaccurate data about natural resistance, the reliability associated with the end structure will be difficult to determine and may lead to inefficient resource use or premature failure of the structure.

4.5.2 Environmental Agent Activity

None of the existing methods quantify the activity of an agent sufficiently to allow the reliability of a structure to be determined. In general, biological activity is assumed in most methods to be present everywhere and at a high level, e.g. a designer considering fungal effects on timber in Innisfail compared to Alice Springs makes no distinction between the different levels of activity which exist. In Innisfail a durability class 1 species may be unsuitable while in Mount Isa a durability class 4 species may be suitable. An evaluation of an agents activity is an integral part of the durability design process and the lack of information given in design methods reflects the lack of research in this area. While relative levels of agent activity can be estimated, durability designers require absolute estimates of an agents activity so that their effect on a timber product or structure can be quantified.

The only existing method which quantifies the effect of an agent on structural performance is AS1720.4 where both the loss of timber through burning and the loss of material properties of adjacent timber through elevated temperatures is rationalised to a thickness of timber on the affected surfaces. This allows post fire event geometric properties to be determined and used in structural calculations to determine the structures performance under post fire event loads.

No other existing methods provide a means for determining either the reduction in geometric or material properties as a result of the environmental agents. Quantification of such effects is essential if reliable structure performance over time is to be estimated.

Most methods do not recognise the wide range of factors which can influence the activity of agents on the timber, e.g. there is no advice given on the geographic or climatic influences of an agent occurrence or level of activity. There appears to be an assumption, probably based on the wide variation in durability performance, that factors apart from basic material resistance have a relatively negligible influence on performance. This is disproven by examination of the performance of real structures. The Queensland decking trial highlights the importance of sapwood orientation, sun exposure and brush on preservatives (Cause and Stringer 1993) all of which currently receive no recognition in existing design methods.

4.5.3 Performance Criteria

A prescriptive design method will result in a particular performance being achieved. The authors of the design methods should have had some level of performance in their mind as they

developed the method. This level of performance may be a service life with a certain level of reliability. The durability designer when using a prescriptive durability design method needs to be aware of the performance criteria that the method is intended to satisfy. If this differs from the client or structure specific performance requirements then the designer can adjust the details of the structure to better utilise resources.

The absence of stated performance criteria in design methods are probably a reflection of the author's discomfort with the data on which the method is based and resulting concern about liability in the event of structure failure. It could be argued that without stated performance criteria a prescriptive design method has no meaning to a designer trying to achieve a defined performance.

Apart from performance criteria not being stated there also seems to be some implied and in some cases stated assumptions underlying many of the methods, i.e.

(i) "Good building practice, based on the traditional use of timber" (QFS 1991).

(ii) Timber structures should provide very high levels of durability performance.

(iii) Owners of timber structures should not be faced with extensive maintenance.

(iv) Agents causing an effect on timber will occur everywhere and at their most extreme regardless of the presence of influencing factors.

In particular, none of the methods state the expected structural reliability or design life which will result from using a method. Most methods use a relative rather than an absolute approach to this issue, i.e. the performance of one species or specific factors influencing durability is higher or lower than another option. AS1720.4 however in conjunction with AS1720.1 does allow the AS1720.1 level of reliability to be achieved.

The magnitude of safety factors used to determine say, chemical retention levels in timber is not stated in AS1604, although such information would allow designers to better understand the prescriptive requirements of the code and better estimate the risk of a structural failure.

4.5.4 Efficient use of Resources

The result of inadequate timber resistance and agent activity information coupled with the absence of any stated performance criteria will ultimately lead to cautious designers who will adopt designs which are conservative and wasteful of resources.

The inherent conservatism of some of the existing design methods is undoubtedly a direct consequence of trying to achieve a simple design method, e.g. AS1604 and the rationalisation of hazards, retentions and penetrations. The result of such conservatism is that resources, be they timber, chemical or human, are not always efficiently used, e.g. the labour involved on a Victorian building site (low termite risk) to install physical termite barriers capable of protecting buildings in tropical Australia (high termite risk) is wasteful, because AS1694 does not distinguish between the different agents on either site. The legislative endorsement of design methods, either directly or indirectly, effectively makes it difficult for any innovative durability system to be approved. In this regard the current methods effectively discourage the pursuit of ideas that help improve durability performance or resource utilisation, e.g. AS1604 and TUMA by establishing minimum retention and penetration levels discourage specific customisation of treatments for particular applications exposed to particular agents.

4.5.5 Risks and Consequences of Failure

The provision of advice to timber structure designers should be based on accurate assessment of the risks of durability failure and in the event of such a failure, an assessment of the resulting consequences. It seems many of the current design methods are based simply on anecdotal reports of the level of risk and the resulting consequences. Indeed, in the absence of this basic data on which to develop a design method, the authors of a method naturally make conservative assumptions about these matters. As a result the design advice included in design methods is correspondingly conservative and ultimately has the potential to lead to wasted resources. Formalised surveys of existing structures is probably the most reliable way to accurately estimate the real risks of durability failure and to quantify the likely real consequences of such failures. Geographic, construction and other factors which may influence the risks and consequences could be identified from such surveys. It is encouraging that these basic assessments have been suggested for termites by NAFI. (MacKenzie 1992)

4.5.6 Research Basis for Design Methods

Many of the currently used design methods do have some research basis supporting the stated requirements. In most cases however the research work has been carried out in controlled conditions which may not necessarily reflect the real conditions to which a structure may be exposed. The work of CSIRO and state forest services, most notable the Queensland, New South Wales and West Australian services, provides the major research basis for the methods currently in use. The interest in chemical preservation techniques has created a relatively large research infrastructure focussing primarily on increasing timber resistance through the use of chemicals. As most research work is undertaken in very controlled conditions the conversion of research results to useable design information can require assumptions about the uncertainties involved in applying the results to real structures. While durability researchers can

provide excellent scientific knowledge their skills in applying the results are often quite limited relative to engineers who are specifically trained to interpret science and apply it to the real world with due consideration of the uncertainties involved.

Unfortunately many of our current design methods have been scientist rather than engineer driven and consequently the design methods reflect the conservative assumptions adopted by cautious scientists. There are of course exceptions to this generalisation. For instance, AS1720.4 was engineer driven and Cookson's (1986) method regarding marine organisms provides an excellent example of scientific work presented to an engineer audience.

Industry support for durability research has over the years been quite poor, except for the chemical industry through companies like Koppers, who have invested heavily in research to the benefit of both the timber and building industries. The timber industry has very much relied on government research organisations to provide necessary durability research. The building industry in general seems to perceive durability matters as issues for the material industry sector concerned, and not construction practice related. As such building industry supported durability research activities have been quite limited. The reduction in government funding for research activities has eroded the research infrastructure and as such industry wide durability research projects necessary to advance the utilisation of timber products may be increasingly difficult to initiate and maintain. An example of this is the current above ground durability project (Cause 1993) whose continuation is threatened by limited support funding both from the government and non-government sectors.

The quality of durability design methods is dependent on continued durability research. The improvement of current durability design methods requires both an increase in the current level of durability research and a substantial refocussing of current research activities.

4.5.7 Product Influences

Timber products can have a range of characteristics which may influence their durability performance. In general many of the design methods ignore the influence of these product characteristics, probably because of the limited research work in this area. Some of the product characteristics which can influence durability are

(i) **Shape**. Timber products which have a minimal surface area exposed to an environmental agent are likely to have increased durability. Round sections used as poles for instance would be expected to have increased durability over say square or rectangular sections, which have a higher surface area for the same cross-sectional area.

(ii) **Size**. The micro-environment within timber products may vary depending on the section size, creating conditions which may be more susceptible to agent activity. Larger diameter poles in Western Australia have been observed to exhibit different decay patterns than smaller diameter poles. Roof shingles which are relatively thin in section and generally of a relatively low fungal resistant species can provide considerable service lifes. It has been suggested (Moffat 1992) that the thin section results in a rapid drying out of the timber which in turn reduces the occurrence of conditions conducive to fungal activity.

(iii) **Grade**. The natural characteristics in timber are usually the focus of sorting processes within sawmills and other timber product operations. Some of these natural characteristics can influence the effect of environmental agent activity, i.e.

- insipient decay or doze can be re-initiated in certain in-service conditions or be attractive to termites.

- gum veins, shakes and other longitudinal breaks can increase the surface area exposed to the agent. They may also create planes of weakness which are more susceptible to damage by physical agents.

- knots and overgrowth of injury can also create conditions which may increase the activity of agents.

- pith and immature wood are also features which can influence durability performance.

(iv) **Moisture Content**. The activity of some environmental agents is influenced by the presence of moisture within the timber products, i.e. chemical, physical and particularly biological activity.

(v) **Type**. Traditionally most timber products have been solid sections of the same species. As timber processing has improved a range of composite wood products have developed, each of which can respond differently to environmental agents. The presence of glue and other substances in the various products can influence durability performance. Most composite product manufacturers or their associations provide excellent advice to designers about improving the durability performance of their products when exposed to various environmental agents.

4.6 Non Timber Methods

The other primary building materials, i.e. steel and concrete, also have a number of environmental agents which act on them and reduce their ability to perform as intended. The two design codes for these materials provide information which the designer can use to achieve suitable durability performance.

(i) **Steel**. AS4100 provides an informative appendix on corrosion protection. It recommends two systems of protection, AS2311 for structures not exposed to rain or sun and AS2312 for steel structures exposed to exterior atmospheric corrosion. Both documents provide information which assists the designer to specify a protective coatings suitable to the end use. The parameters used to design an exterior coating are:

- the climatic conditions
- the proximity to coast and/or industrial activity
- the structural detailing characteristics

Corrosivity maps for Australia are also being developed.

(ii) **Concrete**. AS3600 provides a design method for reinforced concrete structures which allows designers to select a concrete strength and reinforcement cover appropriate to the environmental agent. A service life of 40-60 years is suggested if the design method is followed. The parameters used in the design are the:

- climate zones
- surface and exposure environments
- member type, i.e. plain, reinforced or pre-stressed
- traffic type causing abrasion
- concrete strength
- reinforcement cover.

Like timber, both of these materials can be seriously affected by the action of environmental agents. The concerns of designers and users of such structures have prompted the inclusion of durability design methods within the material codes. These methods will undoubtedly improve with time as the steel and concrete durability researchers obtain better information. Timber by comparison with its susceptibility to a large number of environmental agents, has no design method in its primary structural code, i.e. AS1720.1-1988.

5. DURABILITY DESIGN METHODS - FUTURE OPTIONS

5.1 Satisfying Customer Needs

Successful business organisations all have one thing in common, they supply goods and/or services which satisfy the needs and expectations of their customers. The development of a useful durability design method must be undertaken with an understanding of the needs and expectations of those people who may use the method. A durability design method from a designer's point of view should have the following features.

- Simplicity of use, i.e. simple procedures requiring minimal time.
- Provision of durability designs which are reliable, environmentally beneficial, cheap to implement and efficiently use the available resources.
- Be fully applicable to the specific product, structure or environmental agent under consideration.

In practice any design method can only achieve these desirable features to a certain level as some of the features can and usually do conflict with each other, e.g. simple design methods do not always provide the cheapest or most efficient utilisation of resources. The needs of designers may also change over time due to financial or resource restraints.

The individual needs of the various types of durability designers also requires consideration in the development of a durability design method, e.g. some designers are satisfied with prescriptive methods while other designers seek more performance orientated methods where a standard performance is not assumed and the designer has sufficient information to develop a specific prescription aimed at achieving a specific performance.

Durability design involves the consideration of three primary items.

- the timber product
- the structure in which the product is used
- the environmental agent being considered

Many of the existing methods tend to focus on specific combinations of these items, e.g.

AS1720.4	Fire, single members, joints, buildings
AS3660	Subterranean termites, buildings

AS1604	Chemical treated timber, biological agents
Cookson 1986	Marine pile, crustacean and molluscs

A universal design method which applies to all products, all structures and all environmental agents is probably not warranted as durability designers generally focus on specific combinations of product, structure and agent.

A design method likely to satisfy the changing needs of durability designers concerned with the effects of environmental agents on the structural performance of a timber structure would probably require the following features.

- primary structural members are covered
- the primary environmental agents are covered
- the effect on geometric or mechanical properties can be quantified
- the main factors which can influence the timber resistance or agents activity are included and quantified

The only methods which currently have these features to some degree are AS1720.4, Langlands & Thomas (1939), Leicester & Barnacle (1990), Sato (1990) and Bodig (1988). Apart from AS1720.4 none of the design methods currently used by Australian designers have these desirable features, which highlights the need for the development of a more acceptable method.

5.2 Developing Current Methods

The current design methods listed in Table 22 all have the potential to be improved to better satisfy the needs of the user groups at which they are aimed. The main ways they could be improved are through

- improving the research basis for the methods
- stating the performance which the design method was developed to achieve, i.e. service life & reliability
- providing increased information about the range of factors influencing timber resistance and agent activity, and thus performance
- ensuring all methods are presented within a common framework and with a similar set of underlying principles
- ensuring all prescriptive methods are based on a calibrated performance orientated design method
- ensuring no method is restrictive of alternative practices which may achieve the required performance

- re-writing the methods to better satisfy the specific types of designer and their needs, i.e. simplification of prescriptive methods for Type A designers (refer section 2.2.3) and increased information about the reliability associated with the requirements for Type C designers
- field calibration or confirmation that the methods are achieving the intended levels of performance.

5.3 Developing Alternative Methods

The alternative design methods listed in Table 23 although not currently used, have the potential to also be developed to account for other factors influencing performance and to improve the accuracy of the performance estimate from the method.

Many timber structures which are extremely similar regarding the timber used and the active environmental agent would suit a method similar to Bodig (1985). Applications in Australia where a co-ordinated field survey of existing structures would lead to the development of a very structure specific and reliable design method are:

- power poles
- cross arms
- bridge members, e.g. girders, Law & Morris (1992)
- sleepers
- fence posts
- marine piles
- domestic cladding, decking, stumps
- house poles
- landscape timbers

Government instrumentalities responsible for timber structures, with their extensive record keeping practices would be in an excellent position to develop reliable design methods for their specific use.

The Bodig (1985) method is an example of Cokley's (1973) suggestions implemented and also represents a development of Langlands and Thomas' (1939) method for a specific structure.

Sato's (1992) method is an excellent example of a structure specific design method with considerable potential for further development as the influence of further factors on performance is quantified.

Leicester and Barnacles' (1990) method also has potential for further development as performance knowledge increases. A number of factors which could improve the method are suggested in their paper, i.e. orientation of structure, detailing, coatings, member thickness, inspection and maintenance practices.

5.4 Developing Innovative Methods

Progress is often inhibited by the professional conditioning that a potential innovator may be exposed too. The development of durability design methods and indeed practices which may enhance durability needs to be as innovative as possible, particularly because of the complex nature of the timber deterioration process. In general, innovative development has been reasonably limited due to bureaucratic supporting infrastructures which generally tend to pursue politically correct activities for enhancing durability, e.g. "chemical treatment is the main way to improve durability performance". Examples of innovative durability enhancement research are

- colour and density selection methods to improve durability in Shorea species (Smith & Orsler 1991)
- paint systems, based on cayenne pepper, which repel marine organisms (Kingsmill 1993)

The innovative approaches suggested by some CSIRO scientists (French 1992) are also encouraging signs for the future development of durability enhancement strategies.

Innovative durability design methods should also be encouraged and investigated wherever they show promise. The development of innovative methods may be initiated in response to the changing tools of designers, e.g. the increased use of computers provide an opportunity to develop a knowledge based durability design method which uses an extensive data base of durability performance information to guide a durability designer in his decision making.

5.5 Developing the Durability Infrastructure

5.5.1 Research

The improved utilisation of timber products will only occur if a quality research infrastructure is created and maintained. The steady increase in durability knowledge coming from such research is essential to the development of existing, alternative, and innovative design methods as well as durability enhancement strategies. A balanced infrastructure, capable of following a multi-disciplined approach will ultimately provide information which benefits the consumers of the research services, be they individual companies, industry sectors and/or the public at large. Current research bodies are not as multi-disciplined as they should be, particularly when it

comes to the involvement of applied scientists e.g. engineers. Increased engineering involvement in durability research is essential if research results are to provide maximum benefit. The consideration of end user needs should be paramount in deciding on research topics and setting research properties associated with these projects.

The future funding of durability research projects also requires careful consideration. With governments increasingly obviating their responsibility to public good research, an increasing onus is being directed toward individual companies and industry sector organisations. The formation of the Forest and Wood Products Research and Development Corporation (Bain 1993) is an excellent example of an industry sector accepting their responsibility to support research. Individual companies have also shown a commitment to support research work, e.g. Koppers in the highly research dependent area of chemical treatment. Many other companies have formalised their in-house research programs and are contributing increased resources to their implementation. One sector which is noticeably absent from the direct support of durability research activities is the building sector. Other timber user groups have invested in durability research, e.g. State & Road authorities, however the building industry has largely passed their responsibilities in this area to material suppliers. This may be reasonable for something like chemical treatment of timber which is a product development, but for research on, say construction practices conducive to improving durability, it would seem obvious to involve the beneficiaries of modifications to construction practices, i.e. the builders. It is perhaps the concentration of research activities on the chemical treatment of timber since World War II that has deterred the building industry from pursuing such research.

The relatively rapid reduction in funds by some governments for major timber durability research organisations has resulted in professional staff reductions and consequently loss of human expertise essential to providing a quality research service. For instance, if the real significance of existing and potential insect agents on Australian timber structures were rationally considered then the existing 6 entomologists, Australia wide, working full time on timber related insects would seem totally inappropriate.

The development of research methods and analysis compatible with a reliability based durability design method are also required. The quartile presentation of the in-ground durability trial data (Thornton et al 1993) and the development of a reliable accelerated field simulator (Cookson et al 1993) are good examples of valuable durability research analysis and methods. The accelerated field simulator in particular as it is correlated with longer field studies has the potential to provide timber resistance data, in a relatively short period for minimal expenditure.

As reliability principles are increasingly used by durability designers, it will be necessary for researchers to provide absolute performance information rather than results which relate performance to another species, treatment or practice which is equally less defined.

The information that will be increasingly required by structural designers is the quantified influence of an environmental agent on timber's mechanical properties. A good example of this is the evaluation requirements of the "graveyard" trial specimens in the Nordic region of Europe (NWPC 1992). The guidelines require a bending test to be carried out on certain stakes to assess if they have reached a pre-determined failure point. By comparison, the CSIRO "graveyard" trials establish failure based on residual cross section alone, (Thornton 1993), i.e. when the condition of the specimen has a 60% to 75% loss of cross section due to either decay and/or termites. Engineers designing a structure to resist imposed loads and environmental agents need to know the magnitude of an agents effect on mechanical properties and geometric properties. A re-analysis of the CSIRO graveyard trial results based on an amended failure definition which corresponds to a loss of section modulus of say 25% may be beneficial, i.e. failure occurs where a loss of cross section of 10% occurs. The current failure definition results in a theoretical reduction in section modulus to between 13% and 25% of the original section modulus. Such a large reduction may not be appropriate on which to base calculations of real structure performance.

5.5.2 Legislation and Standards

Currently there is very little co-ordination between legislation and standards. The presence of legislation such as TUMA-Qld, TMA-NSW and Technical Pamphlet No.1-Qld all seem to reflect this poor referencing of standards within building legislation. The abovementioned NSW and Queensland state acts all existed prior to the formalisation of building legislation and would not be required if adequate requirements regarding timber utilisation were to be adequately referenced in building legislation, particularly now that building legislation has been unified under a national code.

A desirable framework which would better cater for timber durability matters is shown in Table 26.

These design method standards, be they national, industry or company standards, represent the culmination of knowledge on these matters. The knowledge provided in the design methods needs to be collected in a standardised way so that it has a wide application. Table 27 provides a proposed suite of standards which could be used as the basis for obtaining this necessary information.

TABLE 26 A PROPOSED FRAMEWORK FOR DURABILITY LEGISLATION AND STANDARDS

Designer Type (Refer 2.2.3)	Structure	Buildings	Other: ie bridges, wharves	
	Legal Reqs.	State Acts calling up BCA with a durability clause	Contractual specifications	
A	**Performance Standards**	AS1720.4-Fire, AS1720.5-Durability Design? called up in BCA or contract specification		
A,B	**Prescriptive Standards**	Product Codes	Structure Codes	Agent Codes
		AS1604 (chemically treated timber) PAA reqs (Plywood) Others?	AS1684 (Houses) Road & Rail authority stds. (Bridges) Others?	AS3660 (Sub.Termites) Others?
B,C	**Simple Prescriptive Standards**	e.g. TRADAC Tech. data sheets, Timberfacts Handyman Sheets, CSIRO Information Sheets, NSW-FC Tech. Publications, Koppers Design Guides, Qld Forest Service Timber Notes, etc., etc., etc.		

TABLE 27 PROPOSED EVALUATION STANDARDS TO SUPPORT DESIGN METHODS

Evaluation Topic	Details
In-service Environmental Agent Evaluation	The in-service risk of agent activity and consequences of any activity should be quantified for each of the following agents. Thermal, chemical, physical, mechanical, biological, i.e. fungi, bacteria, termites sub. and dry, lyctus, anobium, calymmaderus, molluscs and crustaceans. The test standards for each of these species should ideally use the same control species. Surveys may be coupled with test data to extend the application of the results. Analysis procedures of test and survey results should be defined. The test results should allow hazard maps to be prepared.
Factors influencing agent activity	For the range of factors which may influence each of the above agents activity, standard test methods are required, e.g. physical barrier assessment for sub. termites.
Timber Resistance Evaluation	The inherent resistance of natural timber (sapwood, heartwood, mature and immature) and chemically treated timber needs to be evaluated for each of the environmental agents indicated above.
Timber factors influencing the agents effect	The range of factors associated with the product which may influence the effect of an agent on a timber product or structure, e.g. product type, size, shape, grade, moisture content, etc.

Many of the standard evaluation procedures proposed in this table may already be drafted and in use in other countries. If so, they should be reviewed, amended where necessary, and adopted. The European Standards Committee are currently reviewing their durability standard requirements (Caston 1990, Hue 1993). In all test standards, an evaluation of the effect on a product's geometric or mechanical properties should be determined. Test methods based on in-service performance, field trials, accelerated field trials and laboratory trials, should also be included. The uniform analysis and interpretation procedures of the results should be defined for all tests. In-service evaluation methods of timber performance are largely unstandardised currently and if reliable performance information is to be obtained the development of such methods is essential. The results of in-service evaluations will help provide confirmation that current design methods are providing satisfactory results as well as indicating areas for optimising performance while achieving efficient resource utilisation.

6. PROPOSED DURABILITY DESIGN METHOD

6.1 Background to Method

The durability design method proposed in section 6.2 of this report has been developed for the specific use of engineers who may be concerned with the strength and stiffness characteristics of timber structures. The method provides an incentive for designers to specify desirable durability enhancement practices. The incentive is an increase in member and/or joint strength and stiffness.

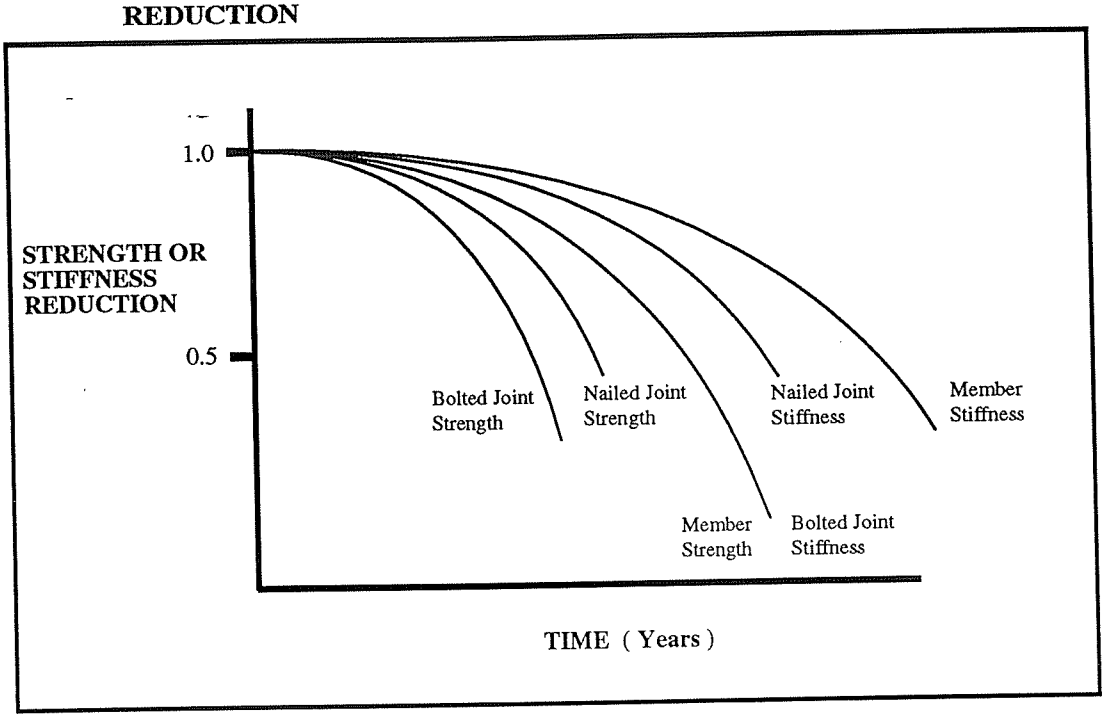
The method has been kept relatively simple and extends on the methods proposed by Langlands & Thomas (1939), Leicester & Barnacle (1990), Sato (1990) and Bodig (1985). The method includes many factors which are not included in prescriptive durability design methods. Only termite and fungal environmental agents are covered as these are the main agents to which most timber structures are exposed. The timber products covered by the method are sawn or round timber sections. The only glued products covered are gluelaminated beams. Plywood, particleboard and other composite timber products are not covered as these products can have their own unique resistance to termites and fungi which may not be related to inherent species resistance. Prescriptive durability design information is generally provided for such products by producers or industry associations.

The proposed method estimates the reduction in strength and stiffness due to the action of fungi and termites. An assumption behind the extended use of this data in structural design calculations is that the variation in strength and stiffness remains constant throughout the life of the structure. This assumption allows design strength and stiffness values to be similarly reduced by the value determined from the design. This assumption is not totally valid, particularly when the variation of an agents action on timber is considered. The resulting increase in strength and stiffness variation would further reduce the design values. While this assumption may seem to threaten the use of the method in structural design, it is further assumed that the uncertainty associated with the change in strength and stiffness variation will be catered for in the calibration of the method by amending the proposed structural element and property factor (D_1), or introducing a further factor for such purposes.

The expression used to estimate the reduction in strength and stiffness over time is based on the deterioration models suggested by Blakey (1985) and extended by Van der Molen (1985). It is most probably conservative for reduction values less than 0.5.

The expression gives equal weighting to the timber resistance and the magnitude of the fungal or termite activity. For any given set of resistance and hazard conditions the reduction in member or joint performance will vary. This is shown in Figure 20.

FIGURE 20 SUMMARY OF MEMBER/JOINT STRENGTH OR STIFFNESS REDUCTION



The relative relationships shown in Table 28 are not based on any substantial data, except that Law & Morris (1992) found member stiffness did not reduce to the same magnitude as member strength.

The basic data used to quantify fungi resistance is from Thornton et al (1993). Because of site differences it was decided to use a mean value determined from the first quartile values at each site. Further analysis of this data may result in a more reliable lower bound estimate of the inherent fungal resistance. Separation of fungal and termite activities may also help. The aboveground durability trial (Cause 1993) may also be useful for establishing some measure of basic resistance. As CSIRO's data is primarily fungal resistance related it was decided to increase the value for species known to have inherent termite resistance. The application of this data to real timber members requires consideration of the various types of wood, including chemically treated wood and the typical combinations of different wood types which may occur within pieces. Shape, size and grade influences on resistance also require consideration. It has been assumed that timber members with high proportions of treated sapwood are not influenced by such factors.

The evaluation of the hazard to which the structure or member is exposed relies on maps of known variations in fungal and termite activities. The fungi are influenced strongly by microclimate and reference to a typical section of a structure is used to estimate such influences. Detailing, construction, finishing and maintenance practices also have a significant influence on fungal activity and are ranked into various levels for consideration by the designer. The practices suggested in AS3660 for preventing subterranean termite activity are quantified and used to adjust the termite hazard.

The proposed method quantifies many factors for which no or limited research data exists. The basis for such quantification lies in the author's personal observations and knowledge of a wide range of timber structures. Scientists will generally be unsettled by such an approach, due to concerns about the uncertainty associated with individual elements of the method. Engineers however will appreciate that the absence of extensive research work needed to fully substantiate such a method, is not a barrier to its use providing the method is based on sound durability principles with an understanding of the uncertainties involved.

The uncertainties associated with the method can be evaluated through the trialing of the method. The trial results will provide evidence to improve the reliability associated with the method. This process is referred to as calibration and is discussed in section 6.4.

6.2 Proposed Durability Method

(i) **Scope and Application**. This proposed design method is intended to be used by structural engineers who wish to quantify the strength and stiffness effects of environmental agents on a timber structure. The method applies only to timber products which are either sawn, gluelaminated or in pole form, and are used in environments where fungi or termites may cause deterioration. The actions of chemical, mechanical, physical, thermal and other biological environmental agents are not covered by the method and should be considered separately. The method is not intended to restrict the use of alternative design methods which may be more appropriate. The method should be used in conjunction with local performance knowledge and all calculations adjusted accordingly.

(ii) **Interpretation**. The values provided in this proposed design method have been selected to allow designers to estimate the reduction in structural properties due to the action of fungal and termite agents. The estimated strength property reductions are expressed as the ratio between lower five percentile properties after a nominated time period and the initial five

percentile properties. The reductions in stiffness are based on the mean stiffness values at each of these times. The estimates of property reduction can be used as an additional K or J factor in AS1720.1 member and joint design. This will assist in determining member and joint details which will meet satisfactory performance requirements. Loads should be modified appropriately to account for structures which may be partway through their intended service lives rather than as new.

(iii) **Referenced Documents.**

- AS1720 SAA Timber Structures Code
- AS1720.1 Part 1 : Design Methods
- Thornton J D, Johnson G C and Nam-Ky Nguyen 1993. Condition of Natural Durability Specimens from the CSIRO In-Ground Field Test after 23 years of exposure. 24th Forest Products Research Conference, November 1993, CSIRO Division of Forest Products, Victoria, Australia
- AS1604-1993 Preservative Treated Timber
- AS3660-1993 Protection of buildings from subterranean termites - prevention detection and treatment of infestation.
- AS2311-1980 Painting of buildings

(iv) **Definitions**. Refer Clause 1.4 of this report

(v) **Notation.**

K_d	=	durability modification factor for member and joint strength
J_d	=	durability modification factor for member and joint stiffness
D_1	=	Structural element and mechanical property factor for durability design
D_2	=	Timber Resistance score for durability design
D_3	=	Environmental agent score for durability design
X	=	Design service life chosen by designer
H	=	Intermediate environmental agent score used with subscripts D to indicate geographical fungi hazard, M to indicate microclimate adjustment of H_D; F to indicate overall fungal score; I to indicate geographical termite score and T to indicate overall termite score.
T	=	Intermediate timber resistance score used with subscript D to indicate mean first quartile values; T to indicate

termite adjustment of T_D and W to indicate wood type adjustment to T_T.

(vi) **Design Procedure**

A. MECHANICAL PROPERTY REDUCTION. The reduction of mechanical properties due to the action of fungi, termites and physical agents shall be determined from the following:

Strength: $K_d = 1 + D_1 (1 - \exp.(X/(D_2 + D_3)^{1.5}))$

Stiffness: $J_d = 1 + D_1 (1 - \exp.(X/(D_2 + D_3)^{1.5}))$

where the procedures for determining D_1, D_2 and D_3 are given below.

(i) D_1 shall be determined from Table 28

TABLE 28 STRUCTURAL ELEMENTS AND MECHANICAL PROPERTY FACTOR D_1

Mechanical Property	Structural Element		
	Member	Joint - Connection Type	
		Nails, Screws	Bolts, Split Rings, Shear Plates
Strength	0.5	0.6	0.7
Stiffness	0.3	0.4	0.5

Note: Strength includes bending, tension, shear and compression strength as well as joint capacity, while stiffness includes the bending modulus of elasticity and joint stiffness.

(ii) D_2 shall be determined from the procedure described in Table 29.

TABLE 29 PROCEDURE FOR DETERMINING THE TIMBER RESISTANCE SCORE D_2

Step	Procedure	Notation
1	Determine mean first quartile value T_D for the heartwood of the species from Table 3 of Thornton et al (1993) using all site data	T_D
2	Adjust the mean quartile value Q_D for natural termite resistance by increase T_D by 20% if the species is classified as termite resistant in Appendix B of AS3660.	T_T
3	Adjust T_T for the presence of other natural wood types and/or chemically treated wood by either multiplying T_W by the factor given in Table 30 or adopting a new score from the table as indicated	T_W
4	For timber which is greater than 30% in heartwood adjust T_W for shape, grade and size effects by multiplying T_W by the factor given in Table 31.	D_2

TABLE 30 ADJUSTMENT FOR WOOD TYPE AND CHEMICAL TREATMENT

Chemical Treatment Options	Wood Type and Combinations					
	Mature Heartwood Only	Mature & Immature Heartwood	Heartwood >70% Sapwood <30%	Heartwood 70% to 30% Sapwood 30% to 70%	Heartwood <30% Sapwood >70%	100% Sapwood
AS1604-H1	-	-	0.8	See Note 5	6 *	8 *
AS1604-H2	-	-	1.0	See Note 5	9 *	12 *
AS1604-H3	-	-	1.2	See Note 5	12 *	15 *
AS1604-H4	-	-	1.3	See Note 5	15 *	18 *
AS1604-H5	-	-	1.4	See Note 5	18 *	20 *
AS1604-H6	-	-	1.5	See Note 5	20 *	25 *
Brush on Preservatives	1.5	1.2	1.0	0.7	0.6	0.5
No treatment	1.0	0.9	0.7	0.4	0.2	0.1

Note:
1. Sapwood & Heartwood contents refer to average cross-section contents within any piece.
2. A " - " indicates chemical treatment to AS1604 is not usually an option.
3. The brush on preservative should be of equivalent or better performance to Koppers Timber Protective XJ.
4. An " * " indicates this new score should be used in the following calculations.
5. The adjustment factors for this combination of sapwood and heartwood should be the average value determined from the adjacent columns.

TABLE 31 ADJUSTMENT FOR GRADE, SHAPE & SIZE

Grade No. See note 2 & 3	Shape & Size				
	Circular (dia)		Square or Rectangular (min.dimension)		
	Less than 150mm	Greater than 150mm	Less than 20mm	20 to 200mm	Greater than 200mm
1	0.9	0.8	0.7	0.65	0.6
2	1.0	0.9	0.8	0.75	0.7
3	1.2	1.0	1.0	0.9	0.8

Notes:
1. If the member is gluelaminated multiply by an additional factor of 0.9.
2. Grade 1, contains pockets of incipient decay and many large voids and/or knots.
   Grade 2, contains no incipient decay and medium sized voids and/or knots.
   Grade 3, contains no incipient decay and very small voids and/or knots.
3. Voids are any cavities in the timber which increase the exposed surface area, e.g. splits, shakes, overgrowth of injury, surface checks, etc.

(iii) D_3 shall be determined by the procedure described in Table 32.

TABLE 32 PROCEDURE FOR DETERMINING THE ENVIRONMENTAL AGENT SCORE, D_3

Step	Procedure	Notation
1	Determine a fungal hazard score from the fungal hazard map shown in Figure 21.	H_D
2	Adjust H_D for microclimate influences by multiplying the activity score determined from Figure 13 by H_D	H_M
3	Adjust H_M for the quality of detailing, construction finishing and maintenance practices used. Refer to Table 33 for an adjustment factor.	H_F
4	Determine a termite hazard score from the termite hazard map shown in Figure 14 a & b and from Table 34.	H_I
5	Adjust H_I for the type of construction and the level of compliance with AS3660, using a factor determined from Table 35.	H_T
6	Determine D3 by subtracting (H_T + H_F) from 20. Not to be less than 0.	D_3

FIGURE 21 FUNGI HAZARD SCORE, H_D

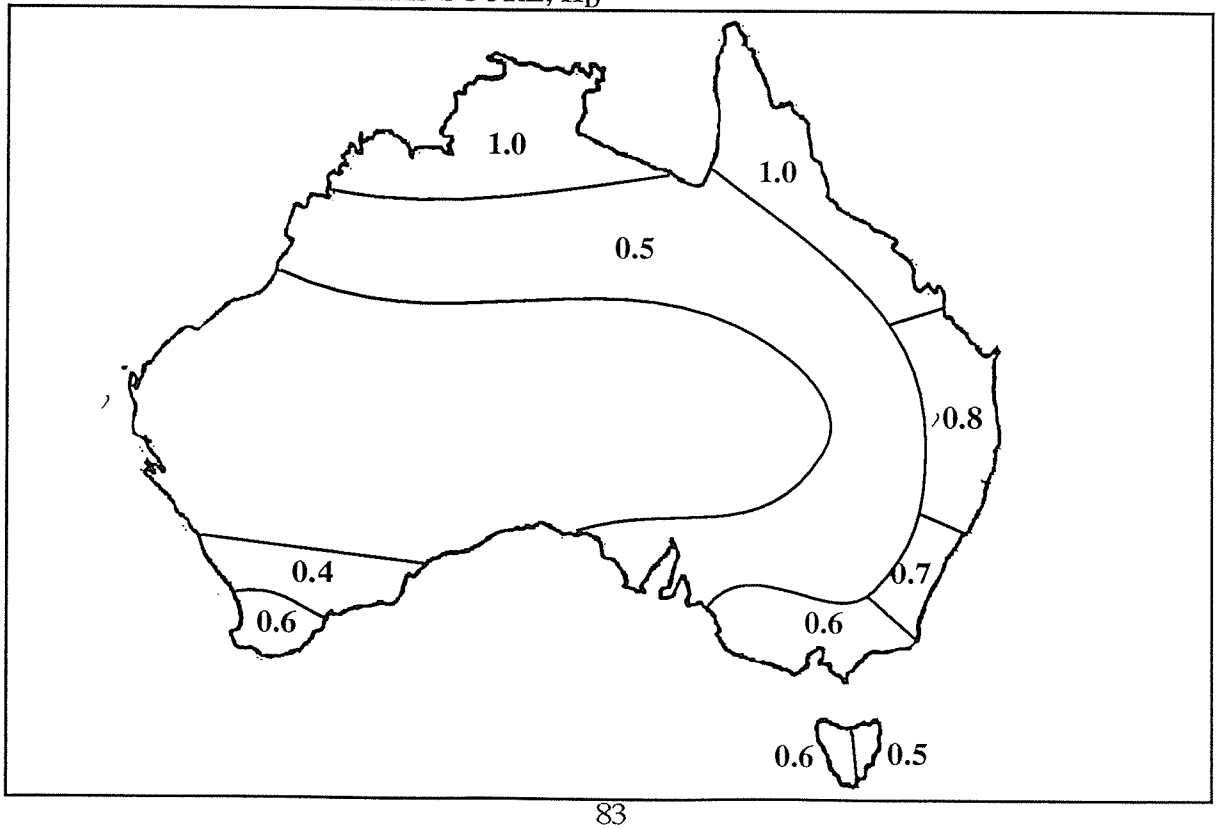


TABLE 33 ADJUSTMENT FACTOR FOR DETAILING, CONSTRUCTION, FINISHING AND MAINTENANCE PRACTICES

Item	Level	Description	Factor
Detailing	1	Min. horizontal contact surfaces, well ventilated joints, no housed joints, end grain shielded from weather, vertical surfaces above ground	0.9
	2	Intermediate detailing practices	1.0
	3	Large horizontal contact surfaces, poor ventilation, housed joints, no end grain protection	1.1
Construction	1	Fully qualified and experienced tradesmen supervised by similarly experienced foremen. Formalised quality system for project.	0.9
	2	Informal quality system in place. Reasonable level of timber competency among tradesmen. Builder has experience with timber structures.	1.0
	3	Tradesmen and supervisor quality unknown, no quality system in place. Builders experience unknown	1.1
Finishing	1	All timber surfaces receive high quality protective coatings in accordance with AS2311. Light coloured finishes only if external	0.8
	2	Paint and stains applied to timber surfaces of unknown quality and performance	1.0
	3	No painting or staining of timber surfaces	1.1
Maintenance	1	Formal maintenance plan prepared and fully implemented. Corrective practices taken as required	0.9
	2	Irregular maintenance practices and corrective action	1.0
	3	No maintenance	1.1
Multiply individual factors corresponding to each level to get total adjustment factor, e.g. Detailing-Level 2, Construction-Level 3, Finishing-Level 1, Maintenance-Level 2. Total factor = 1 x 1.1 x .8 x 1 = .89			

TABLE 34 TERMITE HAZARD SCORE, H_I

Regional Hazard Assessment			Local Hazard Assessment		
Subterranean Termites (See Figure 13a)	Drywood Termites (See Figure 13b)	Major Towns/ Cities	Low Local Hazard	Medium Local Hazard	High Local Hazard (or No Local Assessment)
HIGH	HIGH	Darwin	8	9	10
HIGH	MEDIUM	Cairns, Townsville	7	8	9
HIGH	LOW	Mt Isa, Onslow	6	7	8
MEDIUM	MEDIUM	Brisbane	5	6	7
MEDIUM	LOW	Sydney, Perth, Adelaide	3	5	6
LOW	LOW	Melbourne Hobart	1	1	2

Note: Advice on local termite hazards is generally available from pest control firs, termite consultants and even local authorities.

TABLE 35 ADJUSTMENT FOR CONSTRUCTION TYPE AND AS3660 PROTECTION METHOD

AS3660 Termite Protection Method	New Buildings - Construction Type	
	Slab on Ground	Suspended Floor
Non Chemical only		
- Building Practice	0.6	0.3
- Mesh Barriers	0.4	0.3
- Granite Barriers	0.4	0.3
Chemical only	0.3	0.3
Non Chemical and Chemical	0.2	0.1

B. GEOMETRIC PROPERTY REDUCTION. The reduction in mechanical properties estimated above allows for the change in geometric properties which occurs as a result of wood loss due to either fungal or termite activity. The specific location of the wood loss within the cross-section of a member or joint should also be considered by designers to ascertain if the effect of the wood loss may be greater than suggested by the reduced mechanical properties. In general, loss of wood due to fungal or termite activities occurs in the following general ways.

Fungi - In ground, usually from the circumference of a member inwards or where large voids or incipient decay are present from the inside out.

- Above ground, usually on surfaces which have voids which may hold water, or where joint surfaces create conditions suitable for fungal decay. Non chemically treated sapwood and immature heartwood are usually the first to decay, alternatively heartwood adjacent to chemically treated sapwood may decay first.

Termites - Where the members are exposed to sunlight and central voids or deep surface splits exist, wood loss will generally be from the inside of a member out. In areas where members are in dark spaces or no voids exist attack will generally occur from the surface inwards. Small gaps between adjoining members provide an ideal location for the wood loss to occur from the inside of the joint outwards.

The sensitivity of any structural design to likely variations in the location of the wood loss should be considered.

6.3 Design Examples

The following examples indicate how the proposed design method can be used to estimate the effects of termites and fungi on timber structures.

Example 1 A H5 treated spotted gum round (220 dia) house stump used Sydney

Item	Comments	Value
D_1	Member bending strength only	0.5
T_D	4 sites only. Melb. No data	8.3
T_T	Termite Resistant, plus 20%	10.0
T_W	Heartwood/Sapwood 50:50 Average 10 x 1.4 = 14 and 18	16
D_2	Grade 3, times 1.2	19
H_D	Sydney	0.7
H_M	In ground portion of stump, 0.7 x 10	7.0
H_F	Detailing 1.0, Construction 1.1, Finishing 1.1, Maintenance 1.0	8.5
H_I	No local assessment	6.0
H_T	Non chem. building practice	1.8
D_3	20 - (8.5 + 1.8)	9.7
X	Design service life, (years)	50
K_d	$1+D_1(1-\exp.(x/(D_2+D_3)^{1.5}))$	0.81

This result suggests that the five percentile bending strength of stumps after 50 years in service will be 0.81 of the five percentile bending strength at the time of installation mainly due to fungal activity.

Proceed with a bending strength check to AS1720.1 using K_d to modify basic working stress as a result of the above durability design. Consider the sensitivity of the main wood loss occurring in the centre of the member.

Example 2 Untreated Radiata Pine framing window lintels used in a slab on ground house in Darwin

Item	Comments	Value
D_1	Member stiffness only	0.3
T_D	5 sites	1.8
T_T	Not termite resistant	1.8
T_W	Heartwood/Sapwood 60:40, times .4	0.7
D_2	Grade 1	0.4
H_D	Darwin	1.0
H_M	In wall	2.0
H_F	Detailing 1.0, Construction 1.1, Finishing 1.1, Maintenance 1.1	2.7
H_I	No local assessment	10
H_T	Chemical only	3.0
D_3	20 - (3 + 2.7)	14.3
X	Design service life, (years)	50
J_d	$1+D_1(1-\exp.(x/(D_2+D_3)^{1.5}))$	0.57

This result suggests the relatively high termite and fungal activity coupled with the low resistance of untreated pine framing could mean after 50 years a reduction of 40% in the stiffness of the lintel.

An option to improve the durability performance may be to use a chemically treated lintel, say to H_1. This would increase D_2 to 6 and increase J_d to 0.78 which may be more acceptable.

Example 3 Oregon pergola joint in Brisbane

Item	Comments	Value
D_1	Joint strength - nailed joint	0.6
T_D	5 sites	2.2
T_T	Not termite resistant	2.2
T_W	Brush on preservative, all heartwood	3.3
D_2	Grade 3, 20 to 200mm min. dimension	3.0
H_D	Brisbane	0.8
H_M	Weather exposed, .8 x 6	4.8
H_F	Detailing 1.0, Construction 1.0, Finishing .8, Maintenance 1.0	3.8
H_I	No local assessment	7.0
H_T	Building practice	2.1
D_3	20 - (2.1 + 3.8)	14.1
X	Design service life (years)	15
K_d	$1+D_1(1-\exp.(x/(D_2+D_3)^{1.5}))$	0.86

This result suggests that the five percentile strength of a nailed joint in an oregon pergola will be 0.86 of the initial five percentile joint strength. This result assumes that all nails are adequately durable in this environment and there is no interaction between any corrosive by-product and the timber. In reality this may be difficult to achieve and perhaps a prudent design would amend this result accordingly.

A survey of oregon pergola performance in Brisbane by the author in 1990 showed that decay in the vicinity of non-galvanised fasteners is a common failure mode.

6.4 Calibration of Method

The effectiveness of the proposed design method to predict the loss in strength or stiffness needs to be determined before such a method could gain widespread acceptance among designers. In particular the uncertainty associated with the method needs to be established. At this stage the author has attempted to calibrate the method using personal experience of timber structures and the rate at which they deteriorate due to fungal and termite agents. Based on this limited calibration the uncertainty associated with the method is estimated to be +/- 0.15 in about 75% of durability scenarios examined. In general the calibration of a durability design method such as the one proposed can be undertaken in the following ways.

(i) An analysis of existing service life data for timber structures, e.g. (Tucker & Barnacle 1983). In such reports the strength and stiffness characteristics may not be measured, however loss of cross-section or some other failure criteria may have been used to determine conditions when the timber element becomes unserviceable. Government authorities responsible for timber structures could use their field data to calibrate such methods.

(ii) An extensive survey of existing timber structures involving the sampling and testing of typical members and joints or at the very least an estimate of cross-sectional loss.

(iii) Trialing of timber members and joints under load in controlled conditions. Accelerated field simulators may be useful in such trials as they may allow the required information to be obtained within a more appropriate time scale.

(iv) A survey of timber engineers who have experience with the deterioration of timber structures and the effect of that deterioration on mechanical properties. Such information could be gathered on a standard survey form. A proposed form is included as Appendix D. Designers are encouraged to copy this appendix and complete it for the structures of which they have knowledge. The form should be completed for fungi and termites only and the influence of other agents separated where possible.

Apart from calibration of the method, the accuracy of the prediction method may also be improved where specific research is carried out to better quantify the following matters.

- The relative deterioration influence on member/joint strength and/or stiffness
- Improved fungal and termite resistance values for individual species, e.g. normalised 1st quartile in ground values based on a single site
- The influence of different wood types treated and untreated within the one timber

section.

- The influence of shape, grade and size.
- Improved geographical fungal and termite hazard values.
- The influence of various microclimates on fungal activity.
- The influence of detailing, construction, finishing and maintenance practices.
- The benefits of various AS3660 practices in reducing the risks and consequences of termite activity.
- The influence of fungal and termite activity on geometric properties.

7. CONCLUSIONS

The major conclusions resulting from this study are given below.

(i) Durability design methods can provide a useful means of conveying rationalised durability information to the designers of timber structures.

(ii) Reliability principles can be used to develop durability design methods which more efficiently utilise forest products and associated resources.

(iii) The increased emphasis of structural designers on limit states design and reliability based design necessitates the similar development of durability design.

(iv) Durability research and design methods have for many years focussed heavily on improving the resistance of timber products by chemical treatment.

(v) Durability research and design methods currently focus on timber element performance rather than overall structure performance.

(vi) Durability research and design methods in general do not adequately consider the following:

- The real risks and consequences on a structure of an environmental agent.
- The range of factors which influence the presence and activity of environmental agents in structure.
- Non-chemical methods for influencing the resistance of timber structures to environmental agents.
- The effects of environmental agents on mechanical and geometric properties.
- The interaction of environmental agents.

(vii) The risks and consequences of exotic biological organisms becoming established in Australia are not sufficiently defined to determine appropriate establishment prevention and contingency places.

(viii) Current formalised durability design methods are, in general

- inflexible and stifling of innovation
- represented by a disorganised series of publications
- inadequate at providing information which allows durability performance to be quantified
- not based on reliability principles or defined performance criteria
- not evolving compatibility with structural design
- not encouraging confidence in the durability performance of timber structures
- not strongly influenced by the needs of structural designers
- resulting in the inefficient utilisation of Australia's timber and associated resources.

(ix) Timber designers and society in general will benefit if current design methods were better co-ordinated, promoted innovation, reliability based, and quantified, as much as possible, the many factors influencing timber resistance and environmental agent activity.

(x) Alternative durability design methods have many features which could be adopted or further developed to improve existing design methods.

(xi) The responsible utilisation of Australia's forest products will only advance if innovative methods for durability design and durability enhancement are encouraged by legislators, researchers, timber producers and users.

(xii) In general, the durability research infrastructure does not focus their activities towards the needs of durability designers.

(xiii) Legislation and Australian Standards relating to the durability of timber structures are inadequate, unco-ordinated and urgently need to be reviewed.

8. RECOMMENDATIONS

The major recommendations suggested by this study are given below. Individual groups involved in durability matters have been nominated to implement the recommendations.

(i) Timber producers and durability researchers should better understand the changing needs of durability designers. Section 2 of this report attempts to summarise some of these needs.

Action: Producers & Researchers

(ii) Timber designers and users should be provided with a comprehensive summary of environmental agents and strategies to reduce their effect on timber structures. Section 3 of this report is an attempt to implement this recommendation.

Action: Producers & Researchers

(iii) A Durability Co-ordinating Group should be established with the aim of overseeing the future development of durability related matters in Australia. The specific objectives of the group should include the following

- to ensure that the durability related legislation, standards and other documents are fully focussed on the needs of designers and users.
- to set national durability research priorities which supplement the abovementioned documents.
- to encourage a co-ordinated and co-operative approach among producers, researchers, designers and users.
- to facilitate a national debate on durability issues and their advancement.

Such a group should have a representative and balanced input from organisations which may benefit from the activities of such a group, i.e. representatives from,

- The Timber Producing industry, e.g. species sector groups.
- The Timber Research industry, e.g. CSIRO, State Forest Services, Koppers, other private researchers.
- The Timber Design industry, e.g. engineers, architects and draftsmen.
- The Timber Construction industry, e.g. domestic and commercial builders.
- Consumer Groups, e.g. building owners and management groups, general consumer organisations.

- Legislation & Standard Writers, e.g. building relators, Australian Standards.
- Others, e.g. State Authorities who design construct and use timber structures, i.e. road, rail, electricity and harbour authorities.

Action: All Groups

(iv) Funding of durability research activities should be more equitably proportioned amongst the potential beneficiaries of such work. The building industry in particular needs to become increasingly involved in research projects which develop durability related construction and maintenance technology. Government should also avoid rapid changes in levels of durability research funding which tend to break the "spirit" of durability researchers.

Action: Research Funders

(v) In general durability researchers need to change the focus of their activities so that they better reflect timber producer, designer and user needs.

Action: Researchers

(vi) Increased information about the real risks and consequences of an exotic biological agent becoming established in Australia need to be investigated and appropriate action taken where risks are found to be unacceptably high. Funding for such research and any ongoing prevention activities should be equitably proportioned between potential beneficiaries of such work.

Action: All Groups

(vii) The primary research activities identified in this study which require increased priority are given below.

- Quantification of the "real" risks and consequences of environmental agents on timber structures.
- Coupled with the above, quantification of the factors influencing agent presence and activity.
- Quantification of non-chemical methods for influencing the resistance of timber structures to agents.
- Evaluation of the effects of timber resistance, environmental agents and associated factors on the mechanical and geometric properties of members and joints.
- Interaction of environmental agents.
- Increased evaluation of the natural resistance of timber species to environmental agents.

- Investigation and development of durability design methods as a means of disseminating research information to designers.

Action: Researchers and Research Funders

(viii) Engineers interested in developing the proposed design method in Section 6 of this report can participate in the calibration process by copying the form in Appendix D and completing it for the range of individual applications of which they have some knowledge.

Action: Engineers

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APPENDIX A

List of People Interviewed

Doug Bartlett
Stephen Bolden
Geoff Boughton
Peter Campbell
John Carson
Myron Cause
Bob Chelberg
Jim Creffield
Keith Crews
Ron de Veer
Robin Dowding
John Fletcher
Eric Fox
John French
Greg Hamilton
Charlie Herbert
Tony Hoeft
Jenny Holmes
Boris Iskra
Gary Johnson
Peter Juniper
Bill Keating
John Keith
Mike Kennedy
Cam Kneen
Steve Larner
Peter Law
Bob Leicester
Kevin Lyngcoln
Colin MacKenzie
Borg Madsen
Alan Mann
Mick McDowell
Andy McNaught
Allan Moffat
Bill Muir
Graham Palmer
Peter Passfield
James Peirce
Brenton Peters
Graeme Siemon
Sharon Swan
John Thornton
Dick Van De Molen
Peter Yttrup

APPENDIX B

"THE CYPRESS SYSTEM"

A NATURAL TERMITE CONTROL METHOD

Introduction

The high natural resistance of cypress (Callitris glaucophylla) to both subterranean and drywood termites has been used for many years as a natural method of reducing the susceptability of timber buildings to structural damage due to termite attack. This sheet formalises this use of cypress and recommends a number of associated practices which together reduce the probability of termite damage to a building to a level which is equivalent to or better than the levels currently implied by other termite control systems (ie. AS 1694, AS 2057 or AS XXXX).

This natural system referred to as "the cypress system" requires no use of costly synthetic chemical termiticides but relies on both the natural repellency of the oils and resins contained within cypress and commonsense building design, construction and maintenance practices.

The Building Code of Australia (BCA) requirements are satisfied where **structural** members are protected from attack by **subterranean** termites. The use of cypress in accordance with this sheet will achieve this requirement. In addition, non-structural timber elements in buildings, can also be protected where they are made from cypress. Although BCA is only concerned with subterranean termites, a significant drywood termite hazard also exists within some parts of Australia. The use of cypress is particularly effective at reducing the risk of drywood termite attack. Test results on nearly 200 species from around the world using the infamous West Indian Drywood Termite have shown cypress to be "definitely repellent to termites". Also, Cypress was one of only two species to achieve the maximum termite resistance score of 100 plus.

In Building Note No. 130 (May 1990) the Queensland Local Government Department advised Local Authorities in Queensland that an option in lieu of using chemical termite control is that all structural elements must be of materials that will not support termite attack. Cypress is one such material and is recognised as termite resistant in Appendix B of AS XXXX "Protection of Buildings from Subterranean Termites - Prevention, Detection and Treatment of Infestation".

Cypress Products

The major component of the termite control system described herein is the use of cypress products throughout the building. To satisfy the BCA minimum requirements, structural products, should be of cypress, these include:

Roof Framing - roof trusses, rafters, ceiling joists, roof beams, underpurlins, battens, etc.
Wall Framing - studs, noggings, plates, posts, lintels etc.
Floor Framing - stumps, joists, bearers, flooring, decking.

To reduce the susceptability of non-structural products in buildings to termite attack, "non-structural" cypress products should be used. These include -

Cladding - Weatherboards, Chamferboards
Panelling - Shiplap and VJ profiles etc.
Handrails, Balustrading, Lattice, Laminated Bench Tops
Screens, Fences, Furniture, Stairs.

Information on cypress products is available in other literature or by contacting suppliers directly.

"The Cypress System"

The use of the cypress system in any building involves two main steps. These are:-

Step 1. Determine the termite hazard to which the building is exposed.
Step 2. Based on the level of termite hazard, determine the design, construction and maintenance practices which in association with the use of cypress products will reduce the probability of termite attack in the building.

Step 1. Determine the Termite Hazard

The termite hazards to timber in buildings can be rationalised into the zones shown in Figures 1 and 2. These zones are based on the broad regional activity of termites and generally indicate the increased risk of termite attack in warmer and/or wetter areas. Termite hazards can vary within regions depending on local factors such as soil type and the availability of food or moisture. An assessment of the local termite hazard is desirable if the optimum design, construction and maintenance practices are to be selected. Advice on local termite hazards is generally available from pest control firms, termite consultants or even local authorities. Their assessment of the local termite hazard should be classified as high, medium or low. Following selection of these regional zones for both subterranean and drywood termites and an assessment of the local hazard a termite hazard category can then be selected from Table 1.

Table 1 Termite Hazard Category Selection (A, B or C)

Regional Hazard Assessment			Local Hazard Assessment		
Subterranean Termites (See Figure 1)	Drywood Termites (See Figure 2)	Major Towns/Cities	High Local Hazard (or No Local Assessment)	Low Local Hazard	Medium Local Hazard
HIGH	HIGH	Darwin	A	A	A
HIGH	MEDIUM	Cairns, Townsville	A	B	A
HIGH	LOW	Mt Isa, Onslow	A	B	B
MEDIUM	MEDIUM	Brisbane	B	B	B
MEDIUM	LOW	Sydney, Perth, Adelaide	B	C	B
LOW	LOW	Melbourne Hobart	B	C	C

Step 2. Determine Design, Construction and Maintenance Practices

In addition to the use of cypress products the following practices are recommended to reduce the termite hazard in the specific building under consideration. The practices depend on the type of construction used in the lowest floor in the building ie. either a suspended cypress floor or a concrete slab-on-ground floor. Table 2 summarises the design, construction and maintenance requirements which are explained in more detail in the remainder of this sheet.

Table 2 Building Design, Construction and Maintenance Requirements

Requirements	Termite Hazard Category		
	A	B	C
General			
i) All structural timber to be cypress	✓	✓	✓
ii) Construction Site Inspection	✓	✓	✓
- inspection limits (distance from building)	75 m	50 m	25 m
iii) Site Preparation	✓	✓	✓
iv) Drainage	✓	✓	✓
- slope distance from external wall	2.0 m	1.5 m	1.0 m
v) Building Attachments & Associated Structures	✓	✓	✓
- ground/building clearance	100 mm	75 mm	50 mm
vi) Maintenance Inspections	✓	✓	✓
- inspection frequency	3 months	6 months	12 months
vii) Building and Site Maintenance	✓	✓	✓
Suspended Cypress Floor			
viii) Clearance	✓	✓	✓
- non resistant post & stump clearance	100 mm	75 mm	50 mm
ix) Access	✓	✓	✓
x) Ventilation	✓	✓	✓
- vent area per metre of ext. & int. wall	20,000 mm^2	15,000 mm^2	10,000 mm^2
xi) Shields	✓	✓	N.R.
Concrete Slab-on-Ground Floor			
xii) Concrete Slab	✓	✓	✓
xiii) Slab Edge	✓	✓	N.R.
- exposed, min. distance	150 mm	100 mm	N.R.
- not exposed - cement mortar barrier, or	X	✓	N.R.
- steel mesh barrier	✓	✓	N.R.

A tick (✓) indicates there is a specific requirement which applies.
A cross (X) indicates the requirement mentioned is not appropriate for the termite hazard category.
The letters (N.R.) indicate there is no requirement for this termite hazard category.
Where category specific requirements exist, the minimum requirements are stated above.

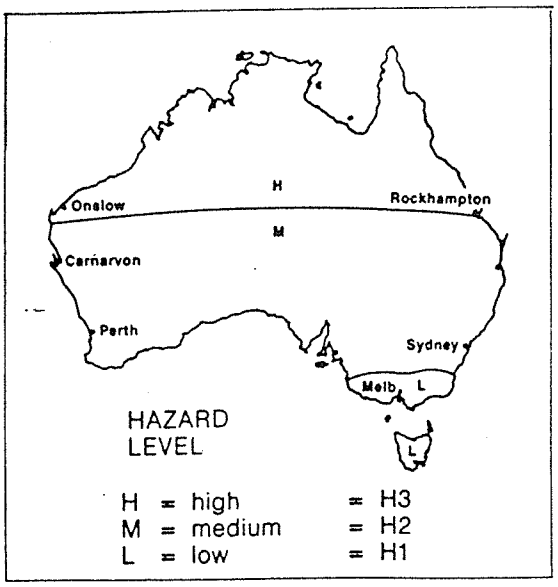

FIGURE 1 SUBTERRANEAN TERMITE HAZARD ZONES

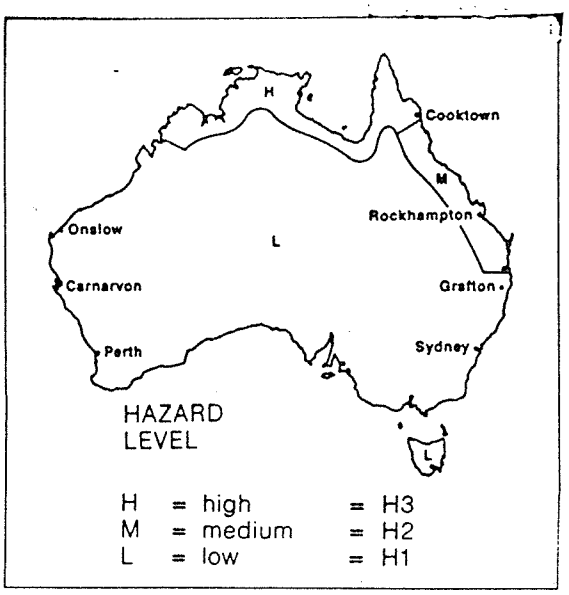

FIGURE 2 CRYPTOTERMITES (DRYWOOD) HAZARD ZONES

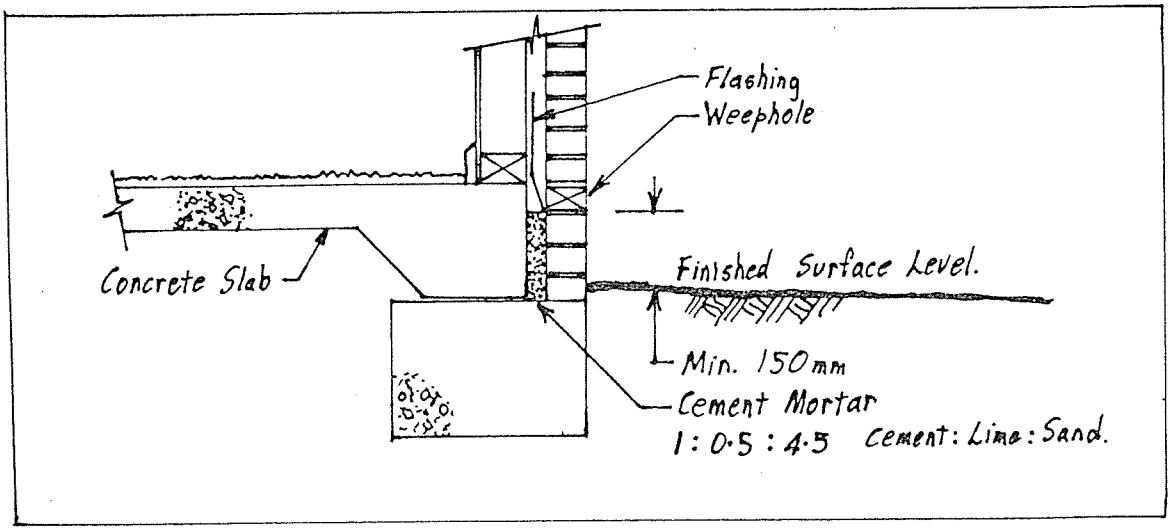

FIGURE 3 SLAB EDGE DETAIL - Mortar Barrier

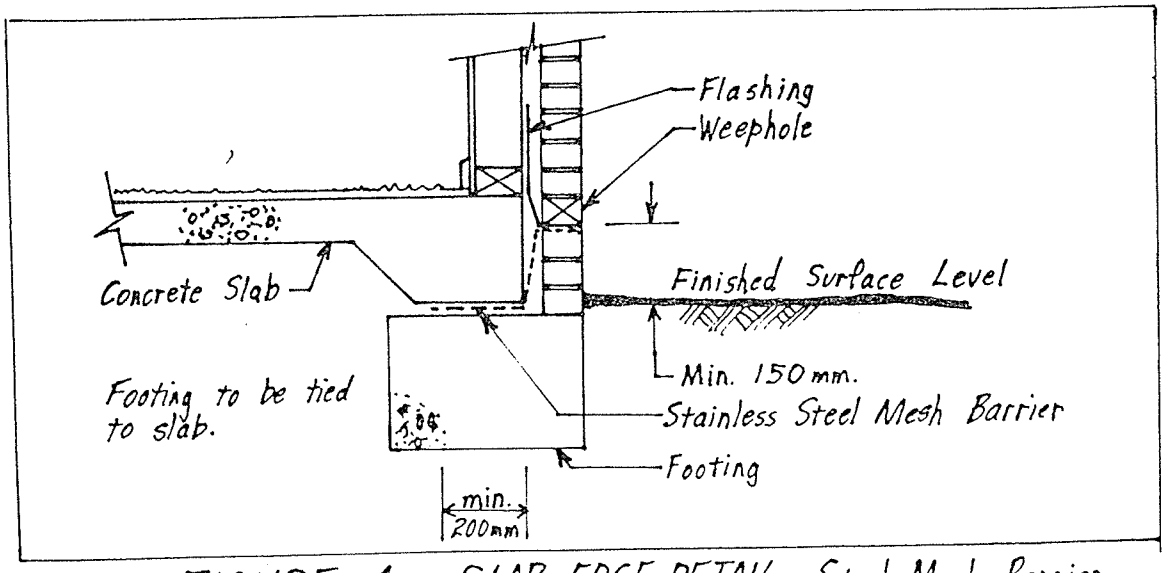

FIGURE 4 SLAB EDGE DETAIL - Steel Mesh Barrier.

General

(i) Structural Timbers:

All structural timber elements in the building shall be cypress. Non-structural timber elements should also be cypress.

(ii) Construction Site Inspection:

The proposed building site shall be inspected prior to, during and immediately after construction for the presence of termite susceptible wood in or near the ground. ie. roots exposed during excavation, tree stumps, logs, used formwork, set out pegs, profiles and any other wooden debris likely to increase the termite hazard to the building. The minimum distance from the proposed building which require inspection shall be 75 m, 50 m and 25 m for termite hazard categories A, B and C respectively.

(iii) Site Preparation:

All termite susceptible wood identified during the construction site inspection in (ii) above shall be removed from the site.

(iv) Drainage:

A suitable drainage system shall be constructed on the site to prevent the ponding of water and to maintain the soil, under or adjacent to the floor as dry as possible. Surface or agricultural drains shall be installed on the uphill side of the building. All ground surfaces adjacent to the external wall of the building shall grade away from the building at a minimum 1:20 slope for a minimum distance of 2 m, 1.5 m and 1 m for termite hazard categories A, B and C respectively.

(v) Building Attachments and Associated Structures:

Attachments to buildings such as steps, pergolas and timber decking, together with associated structures such as fences, retaining walls and other landscaping structures shall be constructed of a termite resistant timber, like cypress, and be separated from either the ground or the building by a minimum distance of 100 mm, 75 mm, 50 mm for termite hazard categories A, B and C respectively.

(vi) Maintenance Inspections:

Following construction of the building and during the entire service life of the building, inspections shall be carried at intervals of 3 months, 6 months and 12 months for termite hazard categories A, B and C respectively. These inspections can be undertaken by pest control firms or consultants. The inspections shall

a) identify any increase in termite hazard due to changes in site drainage, underfloor ventilation and clearance, slab edge exposure, changes in building attachments and/or associated structures, storage or disposal of wooden items, or landscaping practices.

b) detect any termite infestation in the building. Appendix A of AS XXXX provides information on the detection of subterranean termite infestation.

(vii) Building and Site Maintenance

Appropriate maintenance shall be undertaken to reduce the increase in termite hazard identified in (vi) above. Where an infestation is identified, treatment shall be carried out in accordance with Section 5 of AS XXXX.

Suspended Cypress Floor:

(viii) Clearance:

The minimum distance between the finished ground surface and the lowest horizontal floor member shall be 400 mm except on sloping land where a 150 mm clearance is acceptable at the extremity of the building for a distance of 2.4 m. The minimum distance between any masonry wall surface and any structural timber member shall be 50 mm unless shielding is provided (Refer (xi)). All posts and stumps which are not termite resistant shall be supported by a corrosion resistant metal support which provides a clearance of 100 mm, 75 mm and 50 mm for termite hazard categories A, B and C respectively. Where termite shielding is used, the minimum clearance between the shield and the finished ground surface shall be 75 mm.

(ix) Access:

All underfloor spaces shall be provided with an access hole with a minimum size of a 600 mm x 600 mm square.

(x) Ventilation:

All underfloor spaces shall be ventilated with a minimum area of open air flow of 20,000 mm^2, 15,000 mm^2 and 10,000 mm^2 for each one metre of external or internal subfloor walls for termite hazard categories A, B and C respectively. Vents shall be arranged to ensure adequate cross ventilation and to avoid pockets of still air.

(xi) Shields:

Termite gaps or strip shielding shall be installed on all foundation walls, piers, stumps and other substructures except in termite hazard category C where they are not required. Appendix C of AS XXXX provides information on the manufacture and installation of termite shields.

Concrete Slab on Ground Floor

(xii) Concrete Slab:

All slabs shall be constructed in accordance with AS 2870. The concrete shall be compacted mechanically and cured in accordance with the procedures recommended by Construction Note CN5 from the Cement and Concrete Association of Australia, to minimise cracks and voids. Cracking control joints should be used only where cracking due to stress is likely to occur and should be protected by a suitable barrier such as stainless steel mesh or graded granite barriers. Refer to Appendix D and E of AS XXXX for information on these barriers. Access for inspection should be provided where walls cross over control joints.

(xiii) Slab Edge:

Where the slab edge can be exposed to view (ie. timber clad house) the minimum distance of the vertical face of the slab edge exposed shall be 150 mm and 100 mm for termite hazard categories A and B respectively.

For termite hazard category B where the slab edge can not be exposed, (ie. brick-veneer construction) a compacted cement mortar barrier shall be provided between the slab edge and brickwork to a level 150 mm above the finished surface level and less than 25 mm from the top of the slab. Refer Figure 3. An alternative method to the mortar barrier suitable for termite hazard categories A and B is a stainless steel mesh barrier. Where the mesh barrier is used it shall be installed between the footing and the slab for a width of 200 mm and bedded into a mortar joint between brickwork at a distance not less than 150 mm above the finished ground surface. Refer Figure 4.

Notification

Where a termite protection notice is required by building legislation or the building owners/occupiers a notice in accordance with Figure 5, printed with durable materials shall be provided. Such a notice can be located either at the entrance of crawl spaces or in the electrical meter box.

Figure 5 Termite Protection Notice

TERMITE PROTECTION NOTICE

TO THE HOUSEHOLDER

The risk of termite attack and damage resulting from such an attack in this building has been reduced in accordance with the requirements of the publication:-

"THE CYPRESS SYSTEM". A NATURAL TERMITE CONTROL SYSTEM

You are advised to carry out inspections of the building and surrounds at least once every ..... months to

(i) identify any increase in termite hazard due to changes in site drainage, changes in building attachments and/or associated structures, storage or disposal of wooden items, landscaping practices, ..., and to

(ii) detect any termite infestation in the building. Appendix A of AS XXXX "Protection of Buildings from Subterranean Termites - Prevention, Detection and Treatment of Infestation", provides advice on termite detection.

You are also advised to carry out appropriate maintenance to reduce any identified increase in termite hazard or to treat any termite infestation detected.

Note: Pest control firms and consultants offer termite inspection, maintenance and treatment services.

The termite control system used in this building has been installed by,

Name: ..... Signature: .....

Address: .....

.....

References

1. Protecting Buildings from Subterranean Termites
   TRADAC Technical Data Sheet No. 12 November 1990.

2. Building Code of Australia, Australian Uniform Building Regulations Coordinating Council 1990.

3. An Index to the Termite Resistance of Woods by George N. Wolcott. University of Puerto Rico, Agricultural Experiment Station 1950.

4. AS 1694 - Code of Practice for Physical Barriers used in the Protection of Buildings against Subterranean Termites.

5. AS 2057 - Protection of Buildings from Subterranean Termites - Chemical Treatment of Soil for Buildings under Construction.

6. Design for Durability, NAFI Timber Manual National Association of Forest Industries 1990.

7. Protection of Buildings Against Subterranean Termites, in accordance with the provisions of By-Law 48.1 of the Standard Building By-Laws. Building Note No. 130, May 1990. Queensland Local Government Department, Building Services.

8. AS XXXX Protection of Buildings from Subterranean Termites - Prevention, Detection and Treatment of Infestation.

9. Concrete - Placement and Finishing, Construction Note CN5, Cement and Concrete Association of Australia.

10. AS 2870 Residential Slabs and Footings.

APPENDIX C

Extract from New Zealand Building Code (NZBC) contained in the First Schedule of the Building Reglations 1992.

NZBC CLAUSE B2 DURABILITY

OBJECTIVE

B2.1 The objective of this provision is to ensure that a building will throughout its life continue to satisfy the other objectives of this code.

FUNCTIONAL REQUIREMENT

B2.2 Building materials, components and construction methods shall be sufficiently durable to ensure that the building, without reconstruction or major renovation, satisfies the other functional requirements of this code throughout the life of the building.

PERFORMANCE

B2.3 From the time a code compliance certificate is issued, building elements shall with only normal maintenance continue to satisfy the performances of this code for the lesser of; the specified intended life of the building, of any, or:

(a) For the structure, including building elements such as floors and walls which provide structural stability: the life of the building being not less than 50 years.

(b) For services to which access is difficult, and for hidden fixings of the external envelope and attached structures of a building: the life of the building being not less than 50 years.

(c) For other fixings of the building envelope and attached structures, the building envelope, lining supports and other building elements having moderate ease of access but which are difficult to replace: 15 years.

(d) For linings, renewable protective coatings, fittings and other building elements to which there is ready access: 5 years.

APPENDIX D

PROPOSED DURABILITY DESIGN METHOD EVALUATION SHEET

This sheet can be used to record the durability design values determined from the proposed design method described in section 6.2. To assist in calibrating the design method please return a copy of the completed sheet to -

Durability Design Calibration
C/- J W Gottstein Memorial Trust Fund
Private Bag 10
CLAYTON VICTORIA 3168

Application Details:

Item	Comments	Value
D_1	Specify member/joint strength or stiffness.	
T_D		
T_T		
T_W		
D_2		
H_D		
H_M		
H_F		
H_I		
H_T		
D_3		
X	Service Life	
K_d or J_d	Estimated Value from Proposed Method	
K_d or J_d	Expected Value of 75% confidence limits based on knowledge of structure performance.	

Comments:

Suggestions to Improve Method:

Name: Phone No: Date: / /