DURABILITY DESIGN OF STEEL FRAMING IN RESIDENTIAL AND LOW-RISE CONSTRUCTION

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ABSTRACT: *Durability is essential to the satisfactory performance of materials and the efficient function of buildings, yet durability design is left largely to the discretion of the designer.*

Steel framing has been shown to give a long life in residential and low-rise structures provided good design and installation practices are followed. Designers and specifiers are faced with numerous Codes, Standards and Handbooks specifying requirements and giving advice on the durability design of these structures. These documents often use different terminology for similar items and sometimes have inconsistent requirements. Generally they concentrate on exposed steel members and give little guidance on internal steelwork. Framing components in residential and low-rise buildings normally have an implicit design life of 50 years. However most current standards and handbooks limit their recommendations to 25 years and this life may require inspection and maintenance which may be impractical for enclosed or concealed components.

Current regulatory requirements and industry recommendations are reviewed and a durability framework for residential and low-rise steel framing is presented. The framework is based on ISO atmospheric exposure classifications as adapted by AS 4312 for application in the microclimatic variations throughout Australia. In addition to giving recommendations for metallic coated steel members, tables are included for painted systems and connectors which have been shown to give satisfactory performance.

The proposed framework will assist designers to identify critical applications and to develop practical and economical solutions for the delivery of long life, low maintenance residential and low-rise building structures.

KEYWORDS: Durability, design, steel, structural, housing, standards, regulations, residential, framing, buildings

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1 INTRODUCTION

Metallic coated steels and appropriately protected hot- and cold-rolled steels are in general highly durable, long life materials. Using established manufacturing methods and appropriate connection systems, steel framing made from these steels can be adapted to meet to a wide variety of building design challenges. In most service environments in Australian buildings, steel products with appropriate protection will perform their structural function almost indefinitely.

There is a wide range of steel products used in building construction, sourced from local and international suppliers through both trade and retail channels. Product usage ranges from protected internal applications to fully exposed external applications, from small residential buildings to large commercial and industrial projects.

There is an opportunity to improve the available guidance on durability design so that it spans a wider range of environments, applications and products used in residential and low-rise steel framing. The framework presented in this paper is intended to provide that guidance. The solutions presented in Section 6 were developed for the NASH Standard for Residential and Low-rise Steel Framing, Part 2 [1] which was released for public comment on 16th December 2013.

2 DEFINITIONS

The terms *durability*, *design life*, *expected life* and *service life* have the following definitions when used in this paper:

Durability: The capability of a building or its parts to perform a function over a specified period of time. [2]

Design life: The period for which a building, building element or sub-system should fulfil its intended function.

Expected life: The anticipated period of time for which a building, building element or sub-system will fulfil its intended function.

Service life: The actual period of time over which a building, building element or sub-system fulfils its intended function.

The ISO definition of durability is more expansive than used here: *The capability of a structure or any component to satisfy with planned maintenance the design performance requirements over a specified period of time under the influence of environmental actions or as a result of a self-aging process.* [3].

3 REGULATORY FRAMEWORK

3.1 NATIONAL CONSTRUCTION CODE

As noted by MacKenzie et al [4] the durability performance of Australian building structures and their maintenance to achieve a specific design life is not explicitly regulated by the National Construction Code (NCC) [5] or state legislation. There are some limited exceptions which will be noted later. Durability is currently seen as a building quality matter falling within consumer protection, trade practices or contract law, and Australian regulators show no current inclination to regulate durability design or maintenance practice. However, numerous design and material standards referenced in the NCC contain either normative requirements or informative guidance on durability. Furthermore, durability failure may have human safety implications for the structure, which is a primary concern of the NCC. The Australian Building Codes Board (ABCB) has published a non-mandatory Guideline on Durability in Buildings [2] and encourages industries to develop durability solutions relevant to specific construction materials using the generic principles in the Guideline.

By contrast, in New Zealand the durability of building components has been explicitly regulated since 1992 via the New Zealand Building Code (NZBC) [6]. Much of the work in developing the NZBC provisions and associated solutions for specific materials has informed the Australian discussion of durability in residential structures.

3.2 STEEL STANDARDS

Steel specifications and design requirements are covered in as many as 20 separate design, material and protection standards, most of which have evolved from the dominant applications in which the individual products are used. There are three design standards that cover the majority of steel structure design in residential and low-rise buildings: NASH Standard Part 1 [7], AS/NZS 4600 [8] and AS 4100 [9]. All three of these design standards contain durability provisions and/or guidance by reference to protection standards [10] [11]. In New Zealand, NZS 3404.1 [12] covers structural steel design and includes corrosion categories and durability provisions. However, most protection standards limit their guidance to 25 years even though many members and components are inaccessible for inspection and maintenance. There is no durability guidance available that covers all elements of a typical steel-framed house or low-rise structure designed for a 50 year life without maintenance.

A consistent framework for durability design based on limit states principles and with consistent product designations and definitions would improve the current position and contribute to better and more reliable durability design.

The ABCB Guideline on Durability in Buildings [2] notes that:

"In designing for durability, the following factors should be considered –

a) intended use of the structure;

b) required performance criteria;

c) expected environmental conditions;

d) composition, properties and performance of the materials;

e) structural system;

f) shape of the members and the structural detailing;

g) quality of the workmanship and level of control;

h) particular protective measures;

i) maintenance during the design life."

Whilst all these factors are important, in practice it is items (c). (h) and (i) that will have the most significant impact.

4 DESIGN ACTIONS

4.1 NATURAL FORCES AS AN ACTION

The AS/NZS 1170 [13] series of standards describes the types and magnitudes of actions due to natural forces that designers must consider. Environmental degradation actions are currently not included. These actions may arise from four main sources:

- Atmospheric deposition of salt and industrial pollutants;
- Biological hazards including termites, borers and various fungal organisms;
- Soil chemistry including pH extremes, salinity, other salts and Potential Acid Sulphate Soils, and
- Flood- or stormwater-borne contaminants

This paper is concerned mainly with atmospheric action on above-ground steel structural components, and soil composition where it affects subfloor conditions. The magnitude of such action varies with geography, climate and distance from salt water or pollutant sources. These agents may arrive as particles or may dissolve in surface moisture and remain after evaporation, to be reactivated when the electrolyte returns with accumulative potency of the substrate solution.

4.2 ATMOSPHERIC CORROSIVITY CLASSIFICATION

AS 4312 [14] describes Australian atmospheric corrosivity zones based on the definitions of ISO 9223 [15]. The ISO 9223 classification system is based on the first year corrosion rates for mild steel as shown in Table 1.

Table 1: *ISO 9223 Atmospheric Corrosivity Categories*

ISO 9223 Category	Mild Steel Corrosion Rate µm/yr
C1	<1.3
C2	1.3 – 25
C3	25 - 50
C4	50 – 80
C5	80 - 200
CX	> 200

Once any classification system is formulated, it needs to be geographically calibrated. AS 4312 identifies the proximities, directions and topographies that locate corrosion category boundaries in Australia. It is extensively referenced with corrosion studies by the CSIRO and others covering a period of approximately 50 years. The resulting maps depict zone boundaries for major coastal regions, and a table lists estimated corrosion rates and associated references for major localities. The data and their presentation format are similar to that used for wind speeds, rainfall and other climatic data required in building design.

For New Zealand, a similar classification system is presented in NZS 3404.1.

4.3 MICROCLIMATES

Identifying the macro-climate of the locality is the first of two steps, and its boundaries are not precise. Of at least equal importance is the micro-climate, which takes into account local features as well as the geometry and orientation of a structure. Micro-climates do not alter the presence or concentration of corrosive agents in the air, but they significantly alter the way these agents accumulate on, interact with and are removed from surfaces.

For building structure components, the key microclimate factors are:

- the extent of physical enclosure, which affects access to surfaces;
- the likely wetness cycle, including condensation and
- the opportunity for surface cleaning, by rainfall or maintenance.

4.4 DESIGN LIFE

The final parameter in the design task is the design life, as defined earlier. Although largely a matter for the designer in consultation with the owner, the "normal" design life of a building of any class is 50 years. New Zealand building regulations are explicit in this requirement. In Australia, the ABCB Guideline on Durability in Buildings [2] provides a method for determining an appropriate component design life. As shown in Table 2, the minimum design life of a component is a function of:

Table 2: *Building and Component Design Life*

Design life of building (dl_b) (years)		Design life of components or sub-systems (dl_c) (years)		
		Category		
Category	No. of years	Readily accessible and economical to replace or repair	Moderate ease of access but difficult or costly to replace or repair	Not accessible or not economical to replace or repair
Short	$1 < dl_b < 15$	5 or dl_b (if dl_b<5)	dl_b	dl_b
Normal	50	5	15	50
Long	100 or more	10	25	100

- the design life of the building and
- the viability of component repair or replacement.

Examples of design lives for major components and systems in buildings with normal building design life are shown in Table 3 [16].

4.5 DESIGN STRATEGIES

The ABCB Durability Guideline describes three quite different strategies for achieving a particular service life:

1. Design for no maintenance (or "overdesign")
2. Design with periodic repair
3. Design with maintenance

These strategies are illustrated in Figure 2.

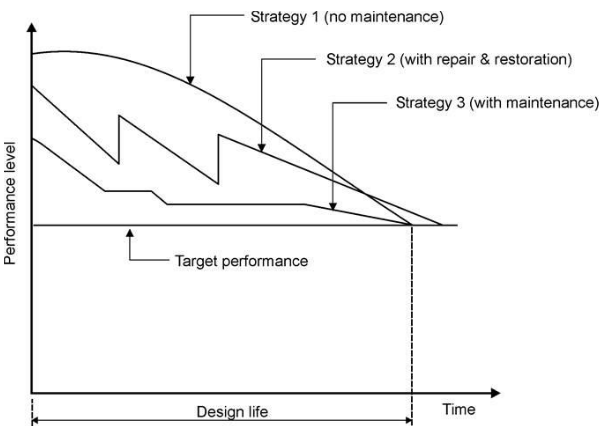

Figure 1: *Durability design strategies*

These three strategies have particular relevance to the applications and locations within the building of various components. The practicality and cost to maintain or repair a deteriorated component will influence the durability design decision.

5 BUILDINGS AND APPLICATIONS

For residential and low-rise construction, typical component applications depicted in Figure 2 with design lives listed in Table 3.

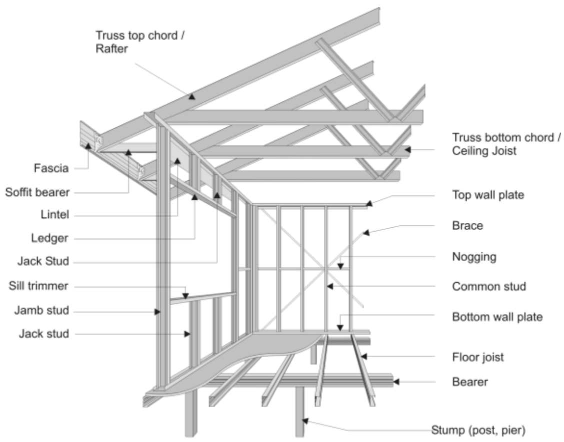

Figure 2: *Structural components of typical residential and low-rise structure [7]*

Table 3: *Component Design Life Examples [16]*

COMPONENT or SUB-SYSTEM	COMPONENT DESIGN LIFE (dl_c) years	COMMENTS
Roof framing system	50	Inspection may be possible, but uneconomical to replace or repair
Wall framing system	50	Inspection usually impractical, and uneconomical to replace or repair
Floor Bearers & joists	50	Inspection possible, but uneconomical to replace or repair.
Decking/balcony – integral (eg cantilevered)	50	Inspection possible, but very difficult and costly to replace or repair due to impact on main structure
Decking/balcony – independent main of structure	15	Accessible and easy - but difficult or costly - to repair or replace.
Verandah roof members	15	Applies to unlined verandahs. For fully lined verandahs, 50 years may be more appropriate.
Posts	15	Accessible but costly to repair or replace. Both ends should be accessible for practical replacement.
Stump & piers	15	If not accessible, 50 years may be more appropriate. Accessible but costly to repair or replace.

6 DURABILITY SOLUTIONS

6.1 HISTORICAL EXPERIENCE

What aspects of steel construction work well at present, and where is improvement possible?

The experience of the steel-framed housing industry is that enclosed and permanently dry steelwork works well everywhere, even when unprotected. External washed areas work well in most environments, while external unwashed components may deteriorate more quickly especially in coastal and heavy industrial locations.

A simple framework, with acceptable solutions for various components, coatings and environments, deployed right across the industry, would assist all practitioners specify and use appropriately durable steel products.

6.2 EXPECTED LIFE

In an ideal construction world, all buildings and their critical components would be designed so that their expected life efficiently matched their design life. Expected life is the predicted period for which a building element or sub-system will be able to fulfil its intended function. The designer should specify materials, systems and construction details so that the component or system remains fit for use during its design life, with appropriate maintenance. Where the design strategy involves maintenance, the designer should identify any maintenance requirements on which expected life is dependent [see Figure 1]. Designers may assume that where the durability of any component is dependent on the long term performance and maintenance of *other components and systems*, those systems regardless of their materials will perform and be maintained for the life of the building. [16]

6.3 SELECTION MATRIX

Having identified the environments and microclimates for which solutions are required, the appropriate design life and the range of system and component applications, a table of solutions was developed covering corrosivity zones C1 to C4. It is recommended that expert opinion be sought for applications in C5 and CX zones.

In developing the selection matrix for residential and low-rise building structures presented in this paper, the range of specific structural applications has been limited to a manageable number. Table 4 divides these applications into 2 groups based on their accessibility for inspection and maintenance, the implication being that for inaccessible components, a minimum 50 year design life is appropriate when used in "normal" buildings. For accessible components, a minimum 15 year design life is more appropriate, recognising greater accessibility and maintainability.

Table 4 drives the selection of durability solutions for each part of the structure. The designations A, B, C and D represent requirements of increasing severity, regardless of the type of component or its protective coating being considered. Durability solutions for each designation are presented in separate tables for materials and fasteners.

Table 5 presents solutions for metallic coated steel components such as structural members and connecting brackets. Local availability may influence the selection for some products.

Table 6 presents solutions for components with additional protective paint coatings over metallic coatings.

Table 7 presents solutions for components with painted coatings over uncoated steel.

Table 8 presents solutions for screws and bolts.

The specifications in Tables 5 to 8 have been adjusted to reflect practical commercial availability. Specifications in horizontally adjoining boxes in the tables are acceptable for that designation but are not necessarily equivalent. In the draft standard [1], the tables have explanatory text to guide interpretation and use. For example, in C4 zones it is recommended that roofs and walls be protected with an appropriate sarking membrane after erection.

Table 4: Protection designations for steel framing components in various atmospheric environments

Designation	**Atmospheric corrosivity category**			
	C1	**C2**	**C3**	**C4**
Description (Refer to AS 4312 and ISO 9223)	**Indoor dry Air-conditioned (not ventilated externally)**	**Most areas of Australia beyond 50 km from the sea but can be as close as 1 km from relatively sheltered waters.**	**In coastal areas with significant surf, this area extends from around 1 km to 50 km, varying significantly with winds, topography and vegetation. Around sheltered bays it extends from around 50 m to 1 km from the shoreline.**	**Occurs mainly on the coast in areas with rough seas and surf, extending from around 300 m to 1 km inland. Around sheltered bays it extends up to 50 m from the shoreline.**
Application				
Components inaccessible for maintenance				
Roof framing system – unventilated	A	A	C	C
Roof framing system – ventilated	-	B	C	D
Wall framing system – unventilated	A	A	C	C
Wall framing system – ventilated	-	B	C	D
Floor bearers and joists including intermediate floors – unventilated	A	A	C	C
Floor bearers and joists - ventilated	-	B	D	D
Decking/balcony – integral (eg cantilevered)	-	C	D	D
Ceiling battens	A	A	C	C
Components accessible for maintenance				
Roof battens	-	B	C	C
Stumps and piers supporting main building	-	C	C	D
Decking/balcony – independent of main structure	-	B	C	C
Verandah beams and rafters	-	B	C	D
Verandah posts and stumps	-	B	C	D
Carport rafters and beams	-	C	C	D
Carport posts	-	B	C	D
Lower storey unlined eaves and pergola rafters and beams	A	B	C	D
Pergola posts	-	B	C	D

Table 5: Metallic coating specifications for steel members

Protection designation (Refer to Table 4)	Metallic coating specifications					
	Hot dip metallic coated strip AS 1397 [17]			Open sections Zinc / Aluminium AS/NZS 4791 [18]	Hollow sections either: Hot Dip Galvanized (ZB, ILG, HDG) or Electroplated (ZE) - Zinc AS/NZS 4792 [19] AS 4750 [20]	Post fabrication hot dip galvanized Zinc AS/NZS 4680 [21]
	Zinc	Aluminium /Zinc	Aluminium /Magnesium /Zinc			
A	Z275	AZ150	AM150	IZA75	ZE50/50	HDG320
B	Z275	AZ150	AM150	IZA75	ZB100/100, ILG100	HDG320
C	Z275	AZ150	AM150	IZA75	HDG300, ILG140, ZB135/135	HDG320
D	Z450	AZ150	AM150	IZA200	HDG300	HDG320

Table 6: Painted coating specifications for metallic coated steel members

Protection designation (Refer to Table 4)	Acceptable paint systems
A and B	Minimum Z100 + 2 pack epoxy phosphate primer (75 µm DFT) + epoxy or polyurethane top coat (40 µm DFT)
C and D	Minimum Z100 + 2 pack epoxy phosphate primer (75 µm DFT) + 2 pack epoxy MIO top coat (125 µm DFT)

Table 7: Preparation and painting specifications for uncoated steel members

Protection designation (Refer to Table 4)	Acceptable paint systems
A	No protection required where steel thickness is > 5 mm thick
B	Class Sa 2½ blast plus epoxy zinc phosphate (75 µm)
C	Class Sa 2½ blast plus epoxy zinc (75 µm)
D	Class Sa 2½ blast plus zinc silicate (75 µm)

Table 8: Protective coating specifications for screws and bolts

Protection designation (Refer to Table 4)	Minimum corrosion resistance classification	
	Screws AS/NZS 3566.2 [22]	Bolts
A	Class 1	Black with bare steel, AS 1897 [23]
B	Class 3	HDG to AS 1214 [24]
C	Class 3	HDG to AS 1214
D	Class 4	HDG to AS 1214

7 SUMMARY AND CONCLUSIONS

Durability design is an important matter for designers in all classes of building. The community has a general expectation that durability has been considered in building design. There is a lack of simple easy-to-use durability solutions for residential and low-rise buildings.

The use of appropriately durable components throughout the structure, having regard to the principles that are outlined in this paper, can ensure acceptable performance without inefficient overdesign.

This paper seeks to provide a simple framework for durability design of steel framing in Australian residential and low-rise buildings for the purpose of:

- Assisting designers to specify an appropriate durability solution for the service environment.
- Helping to align products with the durability requirements of the proposed standard to enhance fitness for purpose..
- Creating a single building durability framework covering all steel materials used in residential and low-rise construction.

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