PLANNING FOR DURABILITY AND LIFE CYCLE MAINTENANCE OF BUILDINGS DURING DESIGN

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ABSTRACT

Many buildings experience durability issues, including water leakage, corrosion, etc. well within their assumed 50 year life. Components may also require routine replacement which is not communicated to the owners or properly planned for. Decisions made at design stage have a profound impact on these in-service performance, maintenance and whole of life cycle issues. Whilst adherence to codes may be sufficient it is not a guarantee that all components will last the distance. It is thus critical that durability is considered as a key input during design. This was recognised for transport infrastructure when Department of Transport and Main Roads, Queensland produced a guideline for durability design of all its infrastructure. This now forms an industry accepted part of DTMR’s project brief. In Australia there is a requirement for structural certification of buildings before occupation. Buildings could also benefit from requiring a durability report as part of certification. This would include assessment of critical durability components and the likely life cycle maintenance and component replacement requirements, certified by an appropriately qualified Engineer, or other qualified professional. It would benefit owners of building portfolios and reduce risk to buyers of units in high rise buildings with complex maintenance requirements that they do not have the background to understand. It would also improve sustainability by ensuring the intended design life is reached. This paper presents some of the typical durability issues that arise on buildings and proposes an outline of how a planned durability approach can be built in to the procurement process.

KEYWORDS

Durability, sustainable design, time dependent performance, leakage, corrosion.

INTRODUCTION

In recent years there has been a significant shift to a greater proportion of high rise units in the new building approvals. This was summarised by Kusher, (2015) based on data produced by the Australian Bureau of Statistics (ABS) in March 2015 as follows:

- 9,767 units approved for construction compared to 9,651 houses,
- This is only the 3rd time units have exceeded houses,
- 45.4% of all building approvals were units in the previous year
- Of those 60.5% were in blocks greater than 4 storeys high.

This is the continuation of a long term trend as illustrated in Figures 1 and 2.

Figure 1 Dwelling Approvals, Houses vs units, National

Figure 1 Dwelling Approvals, Houses vs units, Australia (Kusher, 2015)
This can be observed empirically in the inner suburbs of any Australian city through the presence of tower cranes.

The author’s experience as an Engineer specialising in the investigation and remediation of buildings and other infrastructure with defects is that many of these unit complexes experience significant defects far earlier in their life than would be expected. These defects typically relate to water ingress and corrosion, usually due to a combination of poor detailing, poor material selection and poor workmanship. This is acknowledged in the industry. In a recent article, Williams (2015) states:

“The national survey on strata-titled property conducted by Queensland’s Griffith University, and shown exclusively to Domain, revealed that the unit owners questioned by the author, Professor Christopher Guilding, named building defects as their No. 1 challenge. It was also identified as the most important issue for strata lawyers, and in the top five by resident building managers.”

Population in Australia is projected to grow, employment opportunities will continue to be in the cities, which already experience issues of urban sprawl and lack of public transport. As a result the trend to high rise inner suburb infill development will continue. Ordinary people will buy into developments without the knowledge of the risks that they may be taking on and surveys carried out on prospective unit purchases by surveyors qualified for domestic housing will not pick up issues that will require costly remediation. The industry needs to address this situation if it is not to lead to widespread discontent.

**EXAMPLES OF TYPICAL EARLY DEFECTS**

In the author’s experience, these generally relate to water ingress and its consequences, notably corrosion.

*Façade Detailing*

![Figure 3 Cracking observed due to shrinkage and movement of the blockwork](image-url)
Figure 4 Single skin blockwork leads to water seepage, both outwards from internal bathrooms and inwards from windblown rain

**Planter Boxes**

Figure 5 Poorly waterproofed planter boxes

**Box Gutters**

Figure 6 Inward sloping roofs draining to box gutters again the building façade increasing risk of inward leakage
Inadequate Falls

![Inadequate Falls](image)

Figure 7 Inadequate falls lead to water seeping through the façade and causing corrosion.

Sealing Around Window Openings

![Sealing Around Window Openings](image)

Figure 8 Poorly designed detailing around the window frames leads to temporary sealant fixes.

Use of Inappropriate Materials

![Use of Inappropriate Materials](image)

Figure 9 Use of chloride contaminated board as permanent formwork.
CURRENT INDUSTRY DOCUMENTS ADDRESSING DURABILITY

National Construction Code

The National Construction Code (2015) gives performance based guidelines as to durability. As an example it requires that

“A building must resist:
• rain water, coming through the roof or walls, due to poor waterproofing or flashing;
• surface water, coming through openings which are too low; and
• ground water, which could rise up through porous floors or walls.”

The means by which this is achieved is left very much to the designers and builders, but clearly in many instances the outcome is not as it should be.

Australian Building Codes Board – Durability in Buildings

This gives an excellent guide as the issues to be considered in designing a durable building including performance criteria, factors affecting durability design and designing for durability. It is, however, necessarily high level and a guide only.

Building Certification System

The building certifier has overall responsibility for confirming that the building has been constructed in accordance with the relevant regulations. This is a significant responsibility for one person and typically the certifier calls on specialists to undertake some of those works for them. This is notably the case for the structural elements where the certifier usually requires completion of Forms 15 and 16, referring to design compliance and inspection to confirm construction in accordance with the design respectively by a registered professional structural engineer.

It has been acknowledged that the building certification system in Queensland is in need of upgrading. Barrister at Law, Andrew Wallace (2014) was commissioned by the QBCC to carry out a review of the system and his report is currently being considered for changes to the requirements. It includes, amongst other recommendations, improved accountability of certifiers and all stakeholders in the building industry for the outcomes of the projects in which they are involved. This also includes improved inspection and applicator qualifications, which if acted upon, will go some way to addressing the problems.

INFRASTRUCTURE INDUSTRY APPROACH

A similar situation pertained in the infrastructure sector until recently, with bridges and culverts in particular requiring major repairs and maintenance well within their stipulated design life. This was recognised by Department of Transport and Main Roads (DTMR) who commissioned their Guideline for The Preparation of Road Structure Durability Plans (2009). This provides a framework for design for durability. Details of the guideline and the thinking behind them were presented by the author at the fib conference in Stockholm, Sandeford (2012). This approach is described here. Whilst not completely applicable to buildings, it provides a framework that could be adapted.

DTMR Approach

DTMR’s aim was to provide a standardised guide requiring designers to consider durability as part of the design process in a consistent manner. The guide set out the preferred approach for the development and implementation of road structure durability plans for new construction and the format of summary tables to enable the standardised collation of information. By requiring designers to consider the materials, design detailing, construction methods and operational aspects of structures, the objective of longer lasting, low maintenance structures can be achieved.

The guideline sets out the requirements for the content of durability plan reports to be prepared by the designer and provides the format of summary tables in a series of linked spread sheets to enable the standardised collation of information. These tables complement the durability plan report, and provide a summary of the durability plan requirements which include:
– the identification of deterioration mechanisms and hence durability intent;
– materials selection;
– the development of mitigation measures to ensure that the design intent is met;
– provisions for inspection, maintenance and replacement of components;
– the identification of durability critical construction activities; the verification of constructed components to confirm compliance and;
– construction departures from the specification and remedial measures;

Reports at Various Stages

The durability plan forms a series of reports, namely:

- **Concept Design**: Considers the concept design, environmental information and highlights potential durability issues that will require consideration during the detailed design process. For major components, it defines failure criteria, details those that cannot be maintained or replaced, identifies outline maintenance/replacement methodologies. Includes the development of durability requirements that will significantly affect cost and further investigation of the environment that may be needed for the detailed design.

- **Engineering Design**: Considers durability issues of the Engineering design. It includes comments on compliance of design and supply specifications with requirements for durability. Highlights durability issues that will require Contractor’s consideration and assessment during engineering design process. The report incorporates comments on design, specifications, construction method statements and process review procedures.

- **Construction Records**: Verifies the Quality and Inspection Records and finished product in relation to compliance with the Durability Plan.

The report process should be repeated and the tables added to as repair and maintenance is undertaken. These items and their relation to the asset’s life are illustrated in Figure 10.

Areas to be addressed in the durability plan and the sequence are defined as follows and in Figure 11. At each stage, information generated is added to the summary spreadsheet tables.
Service Life Criteria
The overarching requirement for the project design life, typically 100 years for DTMR, will require further component by component definition. Differing components will have differing design lives and failure criteria. DTMR publish an inspection guidance document which sets out a methodology for subdivision of bridge structures into components; this is referred to as a guide with the caveat that further subdivision may be required. Within the subdivision process, consideration must be given to the “replaceability” or “maintainability” of the component, e.g. foundations vs. hand rails.

Durability limit state for each component will need to be defined. Code definitions of this tend to be very broad. Definition of the condition at which the component is considered to have reached the end of its life is critical, e.g. for reinforced concrete this could be damage significantly reducing the structural strength, first corrosion cracking or corrosion initiation. Linked to this is the intermediate intervention level for maintenance or component replacement.

![Durability Report Process Flow Chart (DTMR, 2009)](image)

Figure 11 Durability Report Process Flow Chart (DTMR, 2009)

Exposure Conditions
Codes give broad guidance on exposure. In AS 3600 and AS 4312 for concrete and steel respectively this is based on proximity to the coast. This does not take into account variations within the structure nor variation in attack/failure mechanism. The structure’s location will need to be broken down into exposure categories, e.g. below ground submerged, below ground above water table, permanently submerged, splash, spray, atmospheric (exposed), atmospheric (sheltered).
Combining the list of components and their design lives with the exposure assessment will highlight a series of potential deterioration mechanisms. All should be listed but typically one mechanism is likely to be governing load case and this will dictate the durability design requirements. A detailed assessment is unlikely to be required for all components, particularly in a benign environment. Conversely, for a critical component or a significant structure, detailed modelling may be required to provide confidence that the durability measures adopted will achieve the design life, e.g. for concrete components, chloride or carbonation modelling, ground water attack, AAR, DEF, early thermal crack modelling, all in relation to the proposed mixes.

**Assessment of Design Solutions**

Where code provisions are assessed as insufficient, additional protective measures must be provided. The full range of solutions should be considered; examples for concrete include: corrosion inhibitors, controlled permeability formwork, cathodic prevention, supplementary cementitious materials, stainless steel reinforcement, fibre reinforcement, surface sealers, or enhanced maintenance regimes. In most cases, it is not envisaged that detailed durability modelling will be required. The level of detail required will depend on a number of factors including: the complexity of the structure, the classification of road carried, and its location. The designer must give careful consideration to:

- Necessary activities to facilitate safe component replacement. Replacement activities should minimise disruption to the use of the structure.
- Buildability; the risk of design intent not being achieved is increased where construction is difficult. Examples include closely packed reinforcing or poor workability concrete.
- Planned inspection, and maintenance activities in terms of safe access with minimised disruption to occupants, defined trigger levels, planned and recorded activities. It may be prudent to include additional protective measures to ensure the durability of components that cannot be readily inspected.
- Additional compliance measures for durability critical activities in the construction phase specification, notably curing and check measurements on cover after casting.

**Verification Report**

The provision of relevant information to the owner and operator of any structure is an important part of asset management. This information can be referred to as the “birth certificate” of the structure and documents design issues, construction and condition of the structure at hand over. On completion of construction, the designer and contractor must compile the durability plan verification report as part of the as built records. This would include an update of the durability plan incorporating any changes necessitated during construction, records of materials used, construction departures and mitigation measures adopted. The updated durability plan summary tables must also be similarly completed to serve as a concise summary of the durability intent, how this was achieved and verified, and the required maintenance and inspection activities. These documents will be then be transferred to the DTMR Bridge Information System.

**DISCUSSION**

**Adaptation of Infrastructure Approach**

The infrastructure industry approach could be used to address key concerns regarding the durability of residential and commercial buildings with modification:

- The level of detail would be reduced. The building envelope (roof and façade) is the element that will require consideration.
- The life of the structure will be reduced; most road infrastructure is designed for a life of 100 years, buildings are likely to be 50 years, unless of a monumental nature.
- Exposure conditions are likely to be less severe, road infrastructure may be in tidal zones, buildings will at most experience exposure to sea spray if built on the beach.
- More flexibility would be required, typically the number of components on a bridge are limited compared with the huge variety of design options and available materials for a building.

The process could utilise similar spreadsheets to this in the DTMR methodology to document the process. At DA stage an outline only would be submitted, consisting of the exposure conditions, key construction materials and how they will reach the required life, especially the need to replace them during that time, e.g. sealants and gaskets around windows, roof waterproof membranes. Necessarily, the approving authority would require much more detailed submission around vulnerable installations such as planter boxes or box gutters. During detailed
design, this would be developed, including clear detailing of specific areas of concern, e.g. window fixing, joints between differing materials in the façade, flat roof waterproofing and drainage details.

On completion, any modifications would be added to the design, and the spreadsheets in a similar manner to the DTMR requirement. This would be a key step in the process. Unlike institutional asset owners, owners of residential developments usually have very poor records of the “as constructed” situation of their buildings. It should be a requirement that the spreadsheets and as built drawings are lodged with a central authority so that they can be accessed in future years by the building owners and the professionals they engage to conduct work for them.

A key factor in this would also be the requirement for the spreadsheets to include the maintenance intervals and activities for the various components, together with current costings. This would then form the basis of the asset management plan and inform the buyers and the building managers of the obligations they have to maintain the building in order that deterioration does not become significant and onerous to deal with. It will clarify the expectation that the building will last for 50 years without significant maintenance.

Examples of Improvements

Some examples of how this might lead to an improved outcome include:

- Seafront residential buildings are subject to salt spray and older buildings are experiencing chloride induced corrosion of reinforcement within the 40-60 year life indicated in AS3600. A considered approach to cover, concrete mix design and coating or waterproofing would address this situation.
- External walls are often single skin concrete block placed directly onto concrete floor slabs, then rendered on the exterior and painted. Movement at this interface leads to cracking and tracking of water back into the building. Simply installing a low step behind the blockwork wall combined with drainage points would prevent moisture ingress to the building.
- Planter boxes against residential walls present a significantly increased risk of water ingress. Waterproofing of these areas can be affected by root growth. This detail should be eliminated or a gap allowed between the building wall and the planter box so that leakage can drain.

CONCLUSIONS

As Australia’s cities have grown, there has been a shift to high rise residential development. This will continue as the population grows and pressure builds for conveniently located accommodation for employment opportunities.

Defects in these strata titled developments are recognised as a significant problem by the industry. If left unaddressed, these defects will lead to a lack of confidence in this type of development, placing further pressure on traditional housing stock. The means by which these high rise developments are approved and certified have also been recognised as requiring improvement.

A parallel exists with the infrastructure industry which in recent years has introduced a requirement for all road infrastructure to have a durability report as part of the design deliverables. In this the designers detail how the asset will reach its required design life and the maintenance and replacement of components needed within that life in order to keep the asset functioning at an acceptable level. This requirement has also been adopted for much water and marine infrastructure.

An opportunity exists to improve the outcomes for buildings by requiring a simplified, but similar approach to building envelopes, such that the designer is required to document the means by which the building will meet its performance requirements over its life and the maintenance and replacement required from the owners.

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REFERENCES


