



LEGACY WAY CONCRETE: ACHIEVING A 100 YEAR SERVICE LIFE

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ABSTRACT

Legacy Way is a five kilometre underground toll road linking the Western Freeway adjacent to the Brisbane Botanic Gardens at Toowong with the Inner City Bypass at Kelvin Grove in Brisbane, constructed by Transcity JV (Acciona / BMD / Ghella) for Brisbane City Council. The project is currently under development involving the design and building of critical infrastructure works, much of which is out of concrete. Construction on the project is expected to take four years and be completed in 2014. In addition to design and construction, the freeway will be operated and maintained for 10 years by Transcity following opening. The project includes the design and construction of two parallel tunnels, one east-bound and one for west-bound, each containing two lanes for traffic. With this will be cross passages between the tunnels located at every 120 metres as well as ventilation systems, fire protection, safety and electronic tolling systems.

The requirement for extended project design life of 100 years necessitated a design that incorporated long-term durability whilst minimising maintenance requirements. This led to the very comprehensive durability assessment and materials engineering. Some key issues identified as part of the review have included optimising binders for concrete including a range of supplementary cementitious materials required to achieve the 100 year service life. A review of current Australian and overseas standards for durability was carried out to obtain best practice and to look at strategies for reducing chloride ingress and carbonation effects in concrete. The specification of concrete for durability was also considered in terms of the role of prescriptive criteria and performance criteria, and to select tests and methods that would be appropriate for design verification, deemed to comply provisioning and also for quality control. Detailed modelling of carbonation and chloride effects was carried out and measures to mitigate or take into account the deterioration developed. This paper presents an overview of the project and the specific durability measures taken for the concrete to achieve the required 100 year design life.

INTRODUCTION

Sustainability is one of the main goals for designs of engineering structures and hence, also of the Legacy Way Tunnel project in Brisbane, Australia. The same principles that apply to sustainable bridge design also apply to the design of underground structures. For the design of the cut and cover structures of the Legacy Way tunnel design principles have been used to achieve a durable design with a 100 year design life for major structural components. An integral structure was designed, in that the main structural components are rigidly connected. As a result, components which require maintenance over its lifetime, expansion joints and bearings, have not been used in the design. Structural integrity is achieved with careful detailed reinforced connections. By using precast members where possible higher quality of structural elements can be expected. As an example, the majority of the roof structures comprise precast, prestressed concrete girders (Super Ts). The composite slab as well as the connections to the headstock is cast in-situ to form a rigid connection.

The project has been constructed by Transcity JV (Acciona / BMD / Ghella) and designed by an alliance of Cardno, GHD and URS. Construction started in April 2011 and completion is planned for the end of 2014.

PROJECT OVERVIEW

General Configuration

The Legacy Way Tunnel is the third major tunnel project in Brisbane in recent years. A previous major tunnel project was the CLEM7 tunnel which connects Brisbane's north with the southern suburbs providing a tunnel under the Brisbane river. Currently also under way is the Airport Link project which connects Brisbane's Domestic and International Airports with the Inner City Bypass. The Legacy Way project is regarded as the continuation of the Airport Link project connecting the Inner City Bypass with the Western Freeway. The basic layout of the tunnel is shown in Figure 1.



Fig. 1 Locality Plan of Legacy Way

Major sections of the Legacy Way are the western connection, the main tunnel and the eastern connection. The western connection comprises the transition from surface level of the Western Freeway to a depth of approximately 10m at the western portal including a 170m long cut and cover structure. This transition comprises the overpass of the Eastbound carriageway of the Western Freeway, an open roof section and the main cut and cover tunnel including the launch box which provides the facilities for launching the Tunnel Boring Machine (TBM) during construction. As a transition of the cut and cover structure a reinforced concrete portal block and a pipe umbrella is constructed which supports the soil near the surface before the tunnel is fully enclosed in rock and the TBM, as well as later precast segments, are sufficient to support the rock. The main tunnel comprises two bored tunnels with a diameter of 12400mm and a length of 4.6km. On the eastern side the tunnel portal enters into a 20m deep cut and cover structure to provide the transition into an open trough structure. In addition, this section supports the Inner City Bypass and the connection to Victoria Park Road.

To provide sufficient clearance for the Inner City Bypass realignment two bridges have to be extended. Of those two bridges the elevated Inner Northern Busway is closer to the cut and cover structure and has to be extended by an additional span of 20m. Parallel, only 5m apart, a pedestrian bridge connecting the Brisbane Grammar School on the southern side with their sport fields on the northern side is extended also by approximately 20m.

Western Connection

The western entry to the Legacy Way Tunnel comprises the transition of an open trough structure constructed with secant pile walls on either side into a partially buried box structure. The secant pile walls are continued in this section and form the abutments of a two span roof structure comprising a reinforced concrete slab with a central support on discrete columns. The western part of the overpass is covered with a landscaping formation accentuating the entrance to the tunnel where the central section accommodates the overpass of the Eastbound of the Western Freeway.



Fig. 2 View on Daylight Portal Western Connection

Before entering the main cut and cover tunnel a section comprising discrete concrete beams is constructed which is similar to a pergola and allows ventilation. This section was introduced to shorten the length required to be artificially ventilated. The pergola beams act as a prop to reduce deflections and moments of the secant pile walls.



Fig. 3 View on pergola section and Western Freeway Overpass

The main cut and cover tunnel is approximately 140m long and comprises secant pile walls, a central support on discrete columns and a roof constructed with prestressed, precast Super T girders completed with a cast in-situ composite slab. A waterproof membrane is provided to protect the structure against water ingress and a 125mm thick concrete protection slab constructed to ensure that the membrane is not ruptured when excavation takes place in the future. A section of approximately 70m is left open during construction to allow assembly of the TBM. A concrete slab is cast as a base slab for the launching procedure. TBM sections and precast segments are lowered into this section with a heavy lift portal crane.

The TBM portal comprises a reinforced concrete block which provides sufficient capacity to withstand the loads acting during the launching process of the TBMs into the main tunnel. Initially, sheet piles are driven into the ground to support the loads of loose soil overlaying rock. Temporary anchors are required to ensure stability of the sheet pile wall. The portal block is constructed in front of the sheet piles. Once the ground anchors and sheet piles corrode, the earth pressure is acting on the portal block which is supported laterally by the secant pile walls and the central column support. In addition, rock dowels are provided to mitigate the risk of wedge failure.

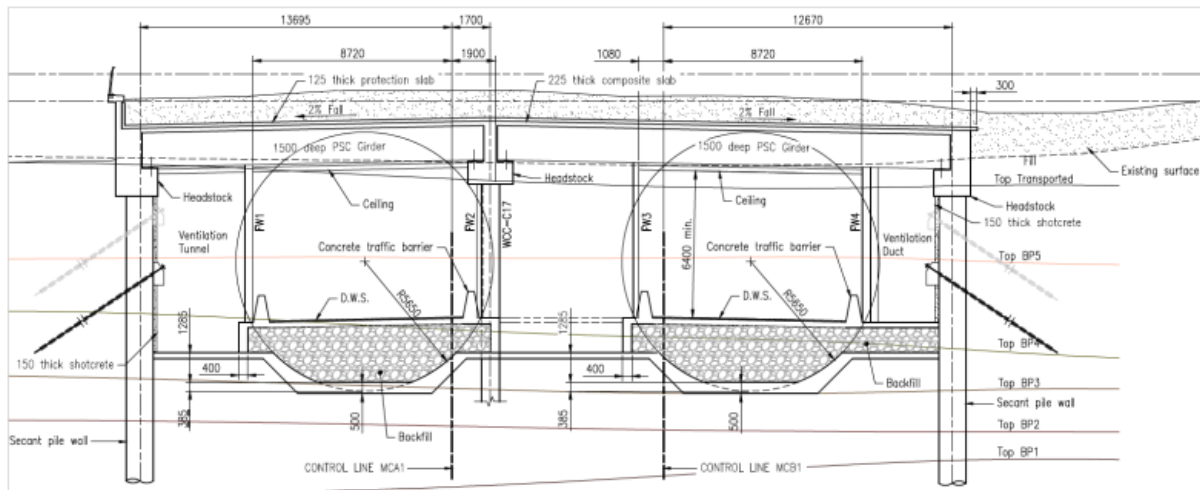


Fig. 4 Cross Section Through Western Cut and Cover Structure

Eastern Connection

Similarly to the western connection the transition at the eastern end is performed with a secant pile wall trough structure which leads into a cut and cover section. However, as the western cut and cover structure covers the same lengths of the East- and Westbound carriageway the covered sections of the Eastern cut and cover structure are significantly different. At the Eastern portal the roof over the westbound carriageway is approximately 125m long and the roof over the eastbound carriageway 63m. Furthermore, the major design constraint for the construction of the eastern cut and cover structure is the interface with the Inner City Bypass (ICB) and hence, the requirement of diligent traffic staging to perform the works. This staging includes that sections of the cut and cover structure have to be provided during construction to divert the traffic before final backfilling and construction of the final road alignment can take place. In addition, recovery of the TBM's is a major constraint which has to be considered. It is planned to disassemble the TBMs just outside the Westbound daylight portal independent of the works occurring on top and around the cut and cover structures.

Other Structures

Both cut and cover structures include a separate tunnel section on the northern side which is used to extract air from the road tunnels. Those ventilation sections are connected to ventilation buildings on either side of the main tunnel with ventilation tunnels with an area of 40m². The ventilation tunnels are constructed cast in-situ as closed box structures. During construction they are used to accommodate construction traffic.

Finally, two bridge extensions are part of the project. Both bridge extensions are required at the eastern end. The extension of the Inner Northern Bus way (INB) bridge comprises a post-tensioned concrete trough structure with precast units spanning laterally. The major benefit of this structural layout is the opportunity of construction with the least impact on bus traffic. The second bridge extension is required for a pedestrian bridge which runs parallel to the end of the Inner Northern Busway bridge and comprises a steel through truss with a composite, concrete slab.



Fig. 5 View on Daylight Portal Eastern Connection

BACKGROUND TO DURABILITY DESIGN

A detailed description of the approach to durability design is beyond the scope of this paper. An excellent guideline is provided by Queensland TMR in their “Guideline for the Preparation of Road Structure Durability Plans” (1) , a summary of which is provided in Figure 6 taken from that document and as described in the following sections.

Service Life Criteria

The overarching requirement for the project design life, typically 100 years for transport infrastructure, will require further component by component definition. Differing components will have differing design lives and failure criteria. Within the subdivision process, consideration must be given to the “replaceability” or “maintainability” of the component, for example requirements for foundations versus hand rails. In this case, the agreement for delivery of the tunnel incorporated client required design lives for various elements such as:-

- Tunnel lining 100 years
- Noise barriers 40 years
- Signage structures 40 years and
- Pavement surfaces 12 years

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. 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.

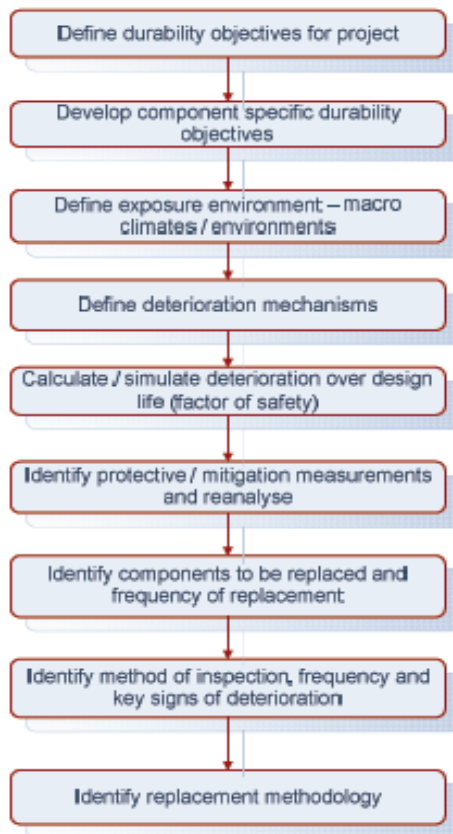


Fig. 6 Durability Planning Template as Described By Queensland TMR (1)

Exposure Conditions

Codes give broad guidance on exposure. In relation to concrete in exterior environments AS 5100.5 (2) 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 needs to be broken down into exposure categories, for example below ground submerged, below ground above water table, permanently submerged, atmospheric (exposed), atmospheric (sheltered). Exposure classifications in Australian Standards for durability are largely based on carbonation and water sorptivity characteristics of concrete. Australian Standard AS3600 was the first Australian concrete design standard to have a section devoted to durability. It was first published in 1988 (3) and has recently been updated with a 2009 edition (4). Parallel developments have been made in bridge design with the publication of the Bridge Design Code AS5100.5 relating to concrete (2). Exposure classifications covering A1, A2, B1 and B2 were derived from and based on work done by Ho and Lewis on carbonation (5) and water sorptivity (6). Water sorptivity was used as the parameter for defining durability requirements for exposure classification criteria for A1, A2, B1 and B2 (7).

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. Examples of critical durability issues for concrete include chloride ion ingress, carbonation, ground water attack, alkali silica reaction, delayed ettringite formation and early thermal cracking.

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 detailed durability modelling will not be required. The level of detail required will depend on a number of factors including: the complexity of the structure, the classification of the piece of infrastructure and its location. The designer must give careful consideration to issues such as:-

- Buildability; the risk of design intent not being achieved is increased where construction is difficult. Examples include closely packed reinforcing or poor workability concrete.
- Early thermal movement and shrinkage of concrete in relation to allowable crack widths and shrinkage in its effect on displacement of other components, e.g. bearings.
- Planned inspection, and maintenance activities in terms of safe access with minimised disruption to traffic, defined trigger levels, planned and recorded activities. It may be prudent to include additional protective measures or remote monitoring equipment 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.

Examples of this process for some concrete components of the Legacy way Tunnel are included in this paper.

ACHIEVING 100 YEAR SERVICE LIFE

Agreed Requirements

The agreement for delivery of the tunnel placed a number of minimum requirements on the concrete durability design. These included, inter alia;

- Compliance with AS5100 (2) for design of bridge concrete with a life of 100 years
- All concrete to be designed to a minimum exposure classification of B2 as defined by AS 5100 (2)
- Maximum exposed crack width of 0.2mm

Exposure Conditions

Key Factors Examined

Key factors examined for assessing durability of the structures included the following:-

- Groundwater
- Tunnel air
- Carbonation in reinforced and steel fibre reinforced concrete, and
- Chloride assessment and permeation.

Groundwater

In relation to concrete cast against ground AS5100 (2) provides limited guidance, defining aggressive soils requiring additional consideration as “permeable soils with a pH less than 4 or ground water containing more than 1g per litre of sulphate ions”. The standard also requires special consideration of concrete immersed in soft or running water. Australian

Standard AS 2159 Piling Design and Installation (8) gives additional guidance in Table 6.4.2(C) as shown in Table 1.

Table 1: Extract from Australian Standard AS2159 (Piling: Design and Installation) Showing Exposure Classification Criteria for Piles in Soil (8)

TABLE 6.4.2(C)
EXPOSURE CLASSIFICATION FOR CONCRETE PILES—PILES IN SOIL

Exposure conditions				Exposure classification	
Sulfates (expressed as SO ₄ [*])		pH	Chlorides in groundwater ppm	Soil conditions A [†]	Soil conditions B [‡]
In soil ppm	In groundwater ppm				
<5000	<1000	>5.5	<6000	Mild	Non-aggressive
5000–10 000	1000–3000	4.5–5.5	6000–12 000	Moderate	Mild
10 000–20 000	3000–10 000	4–4.5	12 000–30 000	Severe	Moderate
>20 000	>10 000	<4	>30 000	Very severe	Severe

* Approximately 100 ppm SO₄ = 80 ppm SO₃
[†] Soil conditions A—high permeability soils (e.g., sands and gravels) which are in groundwater
[‡] Soil conditions B—low permeability soils (e.g., silts and clays) or all soils above groundwater

A key additional consideration is the effect of concentration mechanisms, i.e. where water containing aggressive contaminants is allowed to evaporate thus leaving the dissolved salts in the concrete leading to a more onerous exposure condition. Detailed testing of soil and groundwater chemistry was carried out along the route of the tunnel. This demonstrated that the external concrete was generally in “non-aggressive” conditions as follows:

- Chlorides 100-1300 ppm
- Sulphates 150-300 ppm
- Acidity pH 6-8
- Soft water LSI +1.1 to -0.4

One area had comparatively raised chlorides and sulphates. This was under a small creek that is affected when the Brisbane River floods, here chlorides were 1300-2500 ppm and sulphates 700ppm. Both were within the non-aggressive range as defined by ASS 2159 but required careful consideration if concentration mechanisms were present.

Tunnel Air

The tunnel air environment is classified as an “other environment” in AS 51002 and therefore requires special consideration. The key factor from a concrete durability stand point is the effect of traffic exhaust gases. The concentration of carbon dioxide directly affects the rate of carbonation and the temperature and humidity affect the rate of corrosion of embedded steel once depassivated. However, in common with most road tunnels, specified requirements for ventilation of the Legacy Way tunnel were based around toxic pollutants (CO, NOx and particulates). The ventilation system “reacts” to traffic flow and levels of pollutants to maintain concentrations of these at acceptable levels, keeping fan running time to a minimum to conserve energy. The requirement for durability modelling is an average CO₂ concentration, temperature and humidity over the 100 year design life. This required the consideration of a number of variables:

- Traffic volume and speed varying both throughout a typical day and week
- Traffic volume increasing over the life of the tunnel
- Changes in typical vehicle exhaust emission over the life of the tunnel
- Reaction of the ventilation system to traffic volume and hence dilution as fans cut in.

As can be imagined, these are largely based on forecasts that are by no means certain. The concentration of the CO₂, also varies within the tunnel, increasing as one moves from the inlet portal toward the exhaust extraction point because air is only provided at the inlet portal and the CO₂ is emitted progressively along the tunnel. At the extraction point air is drawn in through the outlet portal and so outlet structures are only exposed to ambient air. The maximum concentration of CO₂ occurs just prior to the extraction point and in the vent duct structures downstream of that extraction point. The highest concentration was determined using:

- Predicted vehicle numbers passing through the tunnel, on an hourly basis,
- Traffic speed modelled taking into account morning and evening peak hours
- A vehicle emission modelling tool (VEPM) to calculate the average pollutant emission for the fleet mix of vehicle type and age.

CO₂ emissions peaking at 2030 levels and remaining constant thereafter (considered conservative as it does not include a reduction for lighter vehicles, alternative fuels such as hydrogen and hybrid or electric vehicles). Calculation of the ventilation requirement for each hour of the day and the average predicted vehicle loading, based on the minimum ventilation required to prevent the pollutant limits being exceeded. The CO₂ concentration at various locations is depicted graphically in Figure 7. For the purpose of durability assessment the criteria used were as summarised in Table 2.

Table 2: Emission Criteria Used for Tunnel Air Durability Assessment

	CO ₂	Temperature	RH
Ambient	320ppm	21 deg C	60%
Peak	1300ppm	26 deg C	70%

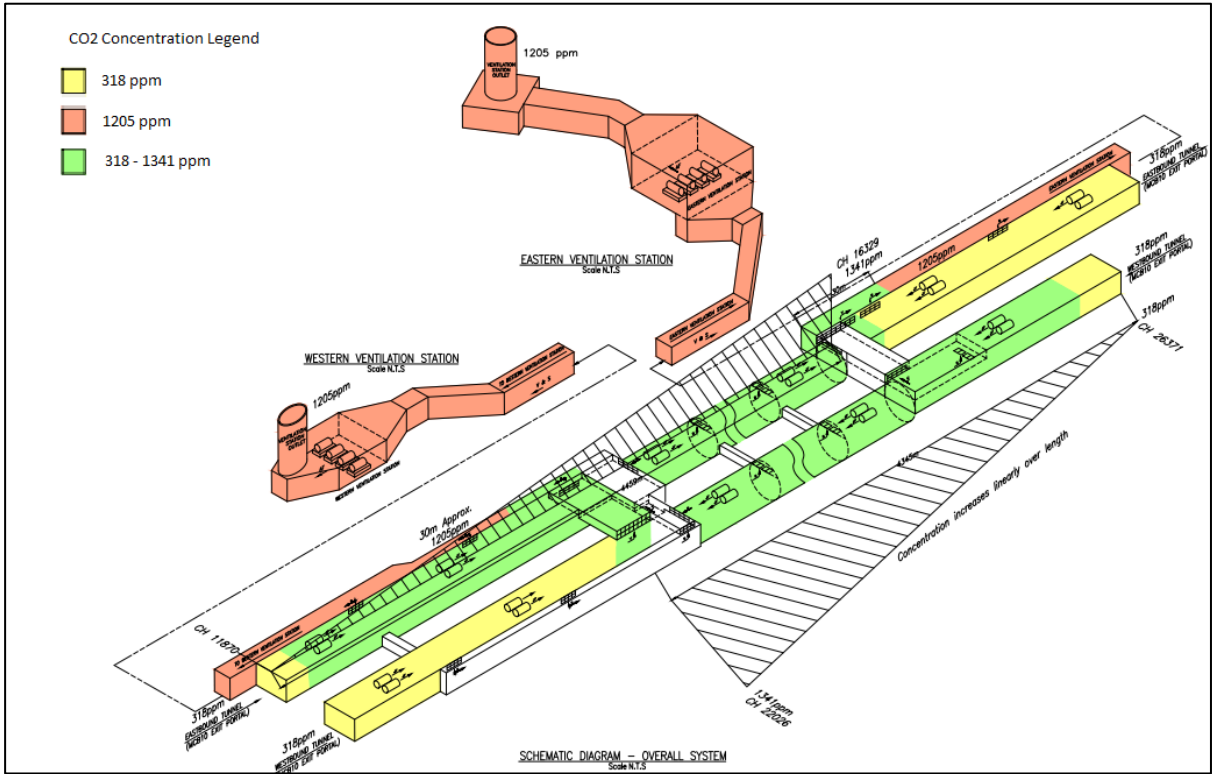


Fig. 7 CO₂ Concentration Diagram

Carbonation Assessment

Carbonation induced corrosion for all components was modelled using CSTR 61 “Enhancing Concrete Durability” (9) on the basis that failure is first crack with a 95% confidence that cracking will not occur. The model takes into account cement content and percentage cement replacement, CO₂ concentration, humidity and curing in assessing rate of carbonation based on the chemical buffering capacity of the concrete. It also takes into account temperature, humidity and bar diameter in time to corrosion induced cracking. Two issues arose with the model. CSTR 61 (9) only accommodates one cement replacement. The Queensland TMR requirements are that all concrete is to have a minimum 20% fly ash, historically used to address the risk of ASR with some Queensland aggregates (10). In order to meet heat generation requirements in large sections, a blend of cement, fly ash and blast furnace slag was used (55%, 25%, 20%). CSTR 61 was modified using a weighted average of the buffering capacity of the blended SCM’s.

CSTR 61 is based on a 95% confidence limit for the time to carbonation activation. However, the time to cracking is deterministic. Investigation of corrosion rates in carbonated concrete was carried out, but information is limited. Much European durability design is based on activation rather than cracking. As pointed out for carbonated concrete in the draft ISO/FDIS 16204 Durability – Service Life Design of Concrete Structures (11) “At the time of publishing this International Standard, no time dependent model with general international consensus is available for the propagation phase”. The agreed approach was that as corrosion rates in the model were based on experience in Europe up to the late 1990’s and therefore mainly plain cement based concrete and that all concrete on the tunnel contained a minimum 25% fly ash. Other models used (12) indicated an increase in resistivity with 15% fly ash replacement after 2-3 years by a factor of at least 3. This is consistent with research conducted on steel corrosion in concrete in Australia (13). The corrosion rates used in CSTR 61 (9) were thus considered conservative.

Cover had to be provided to a minimum of AS 5100 Exposure Classification B2 (2) as stated earlier. Modelling of this with the peak CO₂ concentration indicated time to first cracking of greater than 100 years, providing 3 days wet curing was applied. For programme reasons curing membrane was the preferred solution and permitted by TMR concrete specification. This was modelled as equivalent to 1 day wet curing after some research. For peak CO₂ concentrations this reduced the time to cracking to around 85 years. These areas were mostly in vent duct structures and an anti-carbonation coating has been specified in to give the additional 15 years. As these areas are not visible to the public or subject to weathering the life of the coating is not an issue.

The segments for the tunnel lining were constructed using steel fibre reinforced concrete (SFRC) with some of the more heavily loaded segments including a light cage. The cage was assessed as above. The SFRC required additional consideration. It is widely accepted that steel fibres in concrete do not lead to spalling; their size is such that the expansion arising from corrosion product is insufficient to crack the concrete. However, when relying on their capacity for the design life of the tunnel an assessment of section loss and hence reduction in capacity was required. Wimpenny et al (14) quote a typical value of 20% loss of section after which the effectiveness of the fibre should be ignored. Additionally, work done by Kosa and Naaman (15) tested residual capacity of SFRC beams against measured steel fibre diameter loss. This indicated increased Initial Crack and Peak Stresses but a 30% loss in toughness with 20% fibre section loss and continued contribution from the fibres well beyond 20% section loss. Based on this, assuming no contribution from fibres after 20% section loss is reasonably conservative. Based on time to initiation and corrosion rates from CSTR 61 (9), percentage section loss of fibre at 100 years at various cover depths was calculated. These are summarised for peak CO₂ concentrations in Table 3. Following this analysis, a conservative approach was taken, ignoring the structural effect of the inner 40 mm depth of steel fibres.

Table 3: Percentage of Section Loss of Fibre With Cover Depth (following Ref 9)

Cover	Section Loss
10mm	20%
20mm	19%
30mm	18%
40mm	16%
50mm	14%
60mm	11%

Assessment of Chloride Ion Ingress

Raised chloride levels, classified as non-aggressive in a piling situation, were encountered in one area of the tunnel. Here, even a small leak at joints between segments over the 100 year life of the tunnel, flowing over a localised area of concrete and evaporating could lead to sufficient chloride build up to cause corrosion. Experience has shown that a segmentally lined tunnel immediately under a tidal river that was allowed to leak spalled after 10-15 years. Although leakage into the Legacy Way tunnel is restricted by the agreement it is not excluded completely. In this area additional precautions need to be taken to manage water ingress.

Chlorides could potentially build up at the inner face of the segmental lining as groundwater permeates through the segments and evaporates in the concrete at the inner face. Deposition of chlorides at the reinforcement location within the design life of the tunnel will depend on three mechanisms:-

- Time for the water front to reach the internal face of the concrete segment
- Time for the chloride binding capacity of the intervening concrete to become fully saturated
- Rate of permeation through the segment thereafter depositing chlorides as it evaporates.

The water permeability coefficient of the concrete is a factor in all three issues above and samples of segment concrete were tested for permeability using the "Procedure for Determination of Water Permeability of Concrete, TEL/GHD Method". Whilst this gave a permeability value at 56 days, the pore structure of concrete with 25% fly ash in the binder is known to improve significantly over time. Testing and research has focussed on the result of this for sorption and resistance to chloride diffusion as these are required for the more common tidal/splash/spray chloride induced corrosion durability design. In particular, data are available for chloride diffusion as most durability models are diffusion based.

Data from sorptivity testing up to two years was available from another project. Sorptivity is reliant on porosity and interconnectivity of the pore structure, in a similar way to permeability. Results from this testing were subjected to a curve fitting. Extrapolating from two year data using a similar shaped trend was found to be similar to that for diffusion coefficient over time.

The permeability coefficient developed was then used in Valenta's equation to calculate a time for water under the known head to reach the inside face of 5 years.

Chlorides will, however, become bound to the cement paste as the ground water permeates through. This is most commonly modelled using the Freundlich Isotherm, relating bound chlorides to free chlorides in the pore water. Thomas et al (16) determined binding constants for various cement blends containing supplementary cementitious materials. Values for a 25% fly ash concrete were interpolated from their work and used to calculate the mass of bound chlorides between the extrados and the reinforcement at the intrados. Based on the flow rate calculated using the permeability constant and D'Arcy's equation, concentration of chlorides in the ground water and the binding capacity of the intervening concrete the time to overcome that binding capacity was calculated as 66 years.

Thereafter chloride would be deposited as permeating moisture evaporates. In order to quantify time to initiation, it was assumed that all chloride would be deposited in the cover of 40 mm. Using the flow rate above and chloride concentration in ground water, the time to reach the commonly accepted threshold of 0.06% by weight concrete was calculated to be 12 years. Taking this as sequential,-

- Time for water to reach inside face 5 years
- Time to overcome binding 66 years
- Time for chloride to build up in the cover zone 12 years
- Total time to corrosion initiation at intrados steel 83 years

Whilst this linear approach is a simplification, within the limits of the ability to model the processes it is reasonably conservative given that a characteristic value of water permeability was used and the low values for permeability reduction with age.

Corrosion rates and bar size will extend the time to first crack from activation at approximately 83 years to beyond 100 years, noting that activation after that time will take place in concrete where resistivity in the fly ash concrete would have risen significantly, albeit with some offset of that by deposited chlorides. As regards fibres, the inner 40 mm depth of fibres have been neglected as corrosion arising from carbonation may lead to sufficient section loss to justify this. Any corrosion of the fibres arising from chlorides on the intrados had therefore already been taken into consideration.

POSSIBLE AREAS FOR FURTHER WORK

The durability design has highlighted a number of areas that could be considered for further study:

- The incorporation of CO₂, temperature and humidity estimation in road tunnel ventilation design requirements
- Curing is a key component of concrete durability assessment, most models are based around days of wet curing. Site conditions and project demands make wet curing difficult to achieve in reality. A better understanding of the effect of membrane curing on rate of carbonation/chloride ingress would be useful.
- Much work has been done on the modelling of time to corrosion activation. The time to cracking can be significant, particularly where supplementary cementitious materials are used increasing concrete resistivity. This needs to be better understood.
- A better understanding of the beneficial effect of supplementary cementitious materials on long term permeability of concrete would assist in the durability design of buried structures in saline ground water.

CONCLUSIONS

Significant work has been carried out on ensuring a design life of 100 years on tunnel structure components within the Legacy Way project in Brisbane, Australia. Considerations in design included issues such as:-

- Buildability,
- Early thermal movement and shrinkage of concrete,
- Planned inspection, and maintenance activities, and
- Additional compliance measures for durability.

The agreement for delivery of the tunnel placed a number of minimum requirements on the concrete durability design. These included compliance with AS5100.5 covering bridge design as this was the only Australian Standard for concrete based around a design life of

100 years. In addition, all concrete was designed to a minimum exposure classification of B2 as defined by AS 5100 requiring a characteristic compressive strength of 40 MPa. In addition, a maximum exposed crack width of 0.2 mm was set.

Key factors examined for assessing durability of the structures included and analysis of groundwater, tunnel air, carbonation in reinforced and steel fibre reinforced concrete, and chloride ingress. Detailed analyses were conducted to ensure that a 100 year design life for the concrete was achieved.

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