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THE ASSET MANAGEMENT OF ALKALI-SILICA REACTION IN THE QUEENSLAND ROAD BRIDGE NETWORK AN OWNER'S VIEWPOINT

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ABSTRACT

The Queensland Department of Main Roads has a significant investment in concrete infrastructure in relation to Queensland's transport needs. The financial value of this investment is approximately A$3 billion with the majority invested in concrete bridges followed by drainage structures and concrete roads. This paper traces the history of alkali-silica reaction (ASR) and its impact on the road bridge network. In 1952 the topic was being discussed by the Department as a result of work by Stanton in the USA and Vivian in Australia however no distress was being observed in any field structures due to ASR. It wasn't until the early 1980's that the first documented cases of serious ASR distress were identified. Approximately 105 bridges have now been identified as suffering from ASR. Of these bridges around 10 are classified as severe cases. The risk of deleterious ASR in new concrete structures is controlled by a specification requiring the use of a minimum mass of fly ash of 20%. The main conclusion of this work is that ASR has had an impact on the maintenance of our bridge stock however it is now under control and the risk of problems in the future has been minimized through sensible specifications developed in consultation with the Concrete Industry.

Keywords: Alkali, aggregate, concrete, durability, fly ash, structures

INTRODUCTION

This paper is written from the viewpoint of an owner and manager of a significant concrete structure network in Queensland, Australia. At present in Queensland design codes for road infrastructure require them to be designed, constructed and maintained for a 100 year life. Included in this category are bridges, box culverts and pipes. Concrete roads in comparison have a design life of 40 years. At present alkali-silica reaction (ASR) has not caused any historical issues in relation to older roads and future risk is adequately covered by the flow on effect from existing specifications for concrete structures. Table 1 records the size and value of the road infrastructure asset for each type of structure.

TABLE 1: Summary of Asset Type and Value

Asset Type	No.	Length (km)	Value (A$ billion)
Concrete bridges	2000	115	2
Timber Bridges	600	19	.5
Concrete culverts	7200	100	1
Concrete roads	5	120 (dual lanes)	.15
Total			3.65

Table 1 shows that our investment in concrete roads due to previous construction is low. Currently an 8 lane highway south of Brisbane is being constructed. This highway is 43 km long and half of its length is being built in unreinforced jointed concrete pavement. Hence in 1998 our investment in concrete roads is just starting to increase. All of our current ASR issues have arisen in the bridge infrastructure network and specifically the prestressed bridge components built during the period 1965 to 1992.

Historically asset management of our concrete structures has been demand based. As issues have arisen they have been researched and the fundamental cause of the problem established. Queensland Main Roads has made a significant contribution towards research and development, which has had a major impact on the durability performance of concrete structures in Queensland. This research has also benefited the rest of Australia through technology transfer at a National level. The balance of this paper analyses the performance of the prestressed bridge network in relation to ASR and the subsequent development of strategies to deal with this issue in existing and new structures.

REVIEW OF ASR HISTORY IN QUEENSLAND

Alkali-silica reaction distress emerged as a significant area for concern throughout the world during the period 1973 – 1996. Although extensive information had earlier been published on this topic (Stanton 1940 and Vivian 1947) there was no perceived concern generally around the world and certainly in Australia. In 1952 a general memorandum was sent out to all Main Roads' personnel instructing them to be on the lookout for unusual cracking in concrete structures as a direct result of Stanton's work. However no cases of cracking due to ASR were detected at that time. It wasn't until 36 years later (Carse 1988) when approximately 100 road bridge structures were reported with varying degrees of ASR distress in Queensland that the extent of this issue became apparent. Reports from other Australian States have also been published on ASR distress e.g., (Shayan and Lancucki 1986).

It is interesting to note the first use of prestressed concrete occurred in 1954 and the first bridge structure recognized as suffering ASR distress was built in 1965. Longitudinal cracking was detected in the prestressed beams of this bridge with a maximum crack width of 1.5 mm at an age of 34 years. It is ironic that the correspondence to look for ASR cracking went out in 1952 and in 1954 the conditions required to generate significant ASR distress were being put in place with the move to prestressed concrete bridges. Table 2 contains a summary of the general structure type used for bridge superstructures, the associated period of use and specific comments on each type.

TABLE 2: Changes in Design Concept for Road Bridges

Period	Bridge Type	Comments
1890 – 1920	Mass concrete	Short spans, flat arches with low cement contents
1920 – 1954	Reinforced concrete	Smaller section sizes and inclusion of reinforcement
1954 – 2000	Prestressed concrete	Optimized cross sections, highly stressed prestressing strands, high cement contents and use of steam curing

The trend from mass concrete or thick-sectioned lightly reinforced sections to prestressed concrete resulted in the following consequences:

(i) Increased cement contents from 200 to 500 kg/m3 and corresponding alkali levels from approximately 1.5 to 3.5 kg/m^3
(ii) Increased resistance of the concrete to chloride ion diffusion
(iii) Increased the risk of deleterious ASR

The above consequences show that as the cement content and compressive strength of the concrete increase the resistance to chloride ion diffusion will probably increase. However the risk of deleterious ASR will increase due to the higher alkali level. If ASR cracking occurs, the increase in chloride ion resistance will only be short term and the long term durability of this concrete in a marine environment will be significantly reduced due to the penetration of chloride ions into the ASR crack network. This scenario has occurred in prestressed concrete piles placed in the ocean. Table 3 records a summary of the history of significant events regarding ASR occurrence in Queensland.

SUMMARY OF BRIDGE ASSET CONDITION

Details of Bridge Survey

The Queensland Department of Main Roads has been examining in detail the condition of its road bridges for evidence of alkali-silica reaction since 1985. The bridge asset is administered by 15 separate districts within our Department covering all of Queensland. The total area of the

State of Queensland is 1728000 square kilometres which is twice the size of Texas, U.S.A., and nearly five times the area of Japan. Table 4 and Fig. 1 define the number and location of prestressed concrete bridges suffering ASR distress in Queensland.

TABLE 3: Summary of Significant ASR Events in Queensland

Year	Author/Owner	Event
1940	Stanton	Identification of ASR in USA
1952	Main Roads	Issue of memorandum requesting inspection of structures for ASR cracking
1978	Bulk Sugar Terminals	Construction of Lucinda Jetty 6.5 km long, suffering ASR distress. First detected in 1982
1979	Main Roads	Construction of Houghton highway Bridge 2.65 km long, suffering ASR distress. First detected in 1990 due to marine growth covering cracks and making detection difficult
1985	Carse	Detection of first DMR prestressed concrete structure suffering ASR built in 1965
1986	Carse	Detection of 100 prestressed bridges suffering ASR distress
1986	Main Roads	Use of fly ash to reduce ASR risk
1990	Carse	Detection of ASR in Houghton Highway piles
1993	Main Roads	Accelerated concrete prism test for ASR potential
1999	Main Roads	Alkali limits for fly ash and cement. Use of fly ash mandatory

Magnitude of ASR Distress

As a result of the detailed survey the following parameters were identified as playing a significant role in the level of observed ASR distress:

Structural Design and Detailing – ASR distress was enhanced by detailing which allowed moisture to remain on or in the structure.

Location Within the Structure – eg exterior or interior member and hence exposure to weathering

Concrete Mix Design – Selection of aggregates and cementitious binder systems.

Environment – Prevailing humidity and temperature.

TABLE 4: Summary of Bridges Suffering ASR Distress

Qld Main Roads District No.	Location	No. of Bridges Suffering ASR Distress
1	Nerang	1
3	Toowoomba	1
5	Warwick	2
6	Rockhampton	5
9	Townsville	74
10	Cloncurry	9
11	Cairns	10
12	Bundaberg	2
13	Redcliffe	1
Total		105

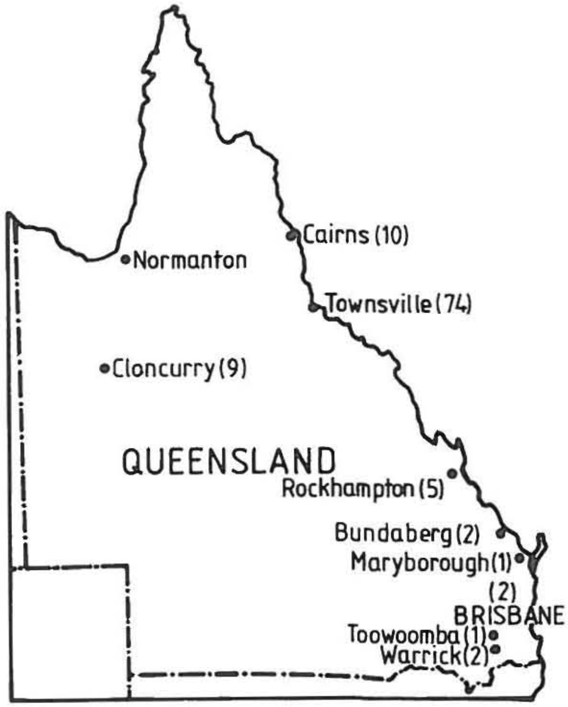

Fig. 1 : Map of Queensland showing incidence of asr distress

It is important to consider the magnitude of ASR distress in relation to the frequency of occurrence. Table 5 defines the criteria used to classify the level of observed cracking due to ASR. Predominantly the type of cracking that occurs in prestressed members is longitudinal along the line or parallel to the stressing tendons. Map cracking may occur during the transmission zones of the tendons, which will confine its occurrence to near bearing support points.

TABLE 5: Frequency of ASR Distress

ASR Crack Classification	Crack Criteria	No. of Structures	Percent
Minor	< 0.3 mm	66	63
Moderate	0.3 to 0.60 mm	29	27.5
Severe	> 0.6 mm	10	9.5

Structural Design and Detailing

All of the recorded cases of ASR in Table 4 have occurred in prestressed concrete elements. The majority of the affected elements are prestressed concrete deck beams. The balance of affected elements are prestressed concrete piles. The prestressed concrete deck beams are each approximately 600 mm in width and usually contain internal voids to reduce their weight. A typical bridge would consist of 15 beams placed side by side with a 30 mm gap which is subsequently grouted. The group of beams is then transversely stressed using 29 mm diameter MaCalloy Bars at 2000 mm centres.

The design compressive strength of these units was 45 MPa with a typical cement content of 500 kg/m^3. The existing cement alkali range at the time of construction was approximately 0.6% to 0.8% Na_2O equivalent yielding a total alkali level per cubic metre of concrete of 3 to 4 kg. Hence the conditions for ASR distress to occur were certainly satisfied in relation to the available alkali. All that was now required was a reactive aggregate source and accessibility to moisture.

Location within the Structure

Observations of ASR distress within a large number of structures indicated that cracking was most severe where temperature and moisture retention were a maximum. External beams in structures generally suffered greater distress than the interior beams due to greater exposure to weathering effects.

Concrete Mix Design

For a given geological and geographical location there is an optimum concrete mix design to prevent or minimize distress due to ASR. The optimization process must take account of all the available options and materials:

Aggregate Selection – select coarse grained intermediate to basic volcanics rather than fine grained acid volcanics.

Utilize Pozzolans – a study of locally available pozzolans is essential to identify economic and technical solutions

Environment – classification of the environment regarding ASR distress will place further importance on the need for efficient mix design and structural detailing.

Environment

Table 6 details the range of climatic conditions within Queensland. Rainfall and associated humidity are seen to vary by a significantly greater amount than the prevailing temperature. Increasing temperature and humidity both result in an increased degree and extent of cracking due to ASR for the same concrete mix design. Hence climatic averages of temperature and rainfall give an indication of aggressive and non-aggressive zones.

TABLE 6: Range of Climatic Conditions

Location	Mean 3 pm Temperature (°C)	Mean 3 pm Humidity (%RH)	Annual Mean Rainfall (mm)
Cloncurry	31.5	25	472
Warwick	23.0	44	716
Maryborough	25.2	56	1187
Townsville	27.3	57	1195
Cairns	27.5	60	2036

Table 4 lists nine cases of ASR occurring in the Cloncurry district. All of these cases are classified as minor in accordance with the criteria in Table 5. Similar concrete mix designs made with the same aggregates in the Townsville region have resulted in five severe cases of ASR. Hence, the dominating effect of humidity is evident for the similar temperature regimes of Cloncurry and Townsville. The ten severe cases of ASR listed in Table 5 have occurred in the locations detailed in Table 7.

The maximum crack width in the bridge structure located at Redcliffe in Table 7 was measured as 8 mm in the prestressed piles . This crack width resulted from two mechanisms of distress. The first and primary mechanism was ASR and the secondary mechanism was expansion of the concrete due reinforcement corrosion. It was estimated that the contribution of each mechanism was about the same at the time of measurement. Hence the individual contribution from ASR was approximately 4.0 mm of the total crack width of 8 mm (Carse 1996).

TABLE 7: Location of Severe ASR Cases

Location	No. of Severe Cases of ASR	Affected Element	Maximum Crack Width (mm)
Rockhampton	1	PSC Piles	1.5
Warwick	1	PSC Beams	1.5
Maryborough	1	PSC Beams	2.0
Somerset Dam	1	PSC Beams	1.0
Townsville	5	PSC Beams and PSC Piles	2.0
Redcliffe	1	PSC Piles	8.0*

*ASR component 4.0 mm balance due to corrosion

FINANCIAL COST OF ASR

Table 8 contains a summary of the financial burden of ASR in relation to dollars actually spent on completing repairs to road bridges. A comparison of Table 4 with Table 8 shows that while a large number of bridges are affected by ASR (5% of bridge stock) the cost of repair is relatively low (0.2% of bridge stock value) due to repairs only being required on substructure concrete. All the costs identified in Table 8 are for the repair of prestressed concrete piles. Cracking in bridge beams due to ASR is monitored and at this stage has not required any repair of removal of affected beams.

TABLE 8: Summary of Financial Cost of ASR ·1980 - 2000

Qld Main Roads District No.	Location	A$ Million
1	Nerang	0
3	Toowoomba	0
5	Warwick	0
6	Rockhampton	0.25
9	Townsville	0.5
10	Cloncurry	0
11	Cairns	0.25
12	Bundaberg	0.1
13	Redcliffe	3*
Total A$		4.1

* Repair of 500 piles by encasement

The prevailing weather conditions in Queensland are generally mild and hence bridge superstructures while significantly cracked due to ASR are able to maintain their load carrying capacity over significant periods of time without any major repairs being required. Obviously if the climate was harsher then the financial burden due to ASR would primarily focus on the rate of degradation of the superstructures. This would result in a ten fold increase in repair costs identified in Table 8. At this stage it is not possible to quantify the reduction in service life (if any) of the structures being repaired or monitored that display significant ASR distress. The repair of the 500 piles by encasement on the Houghton Highway Bridge at Redcliffe is currently being monitored using linear polarization techniques. Future reports on that structure will attempt to assess the magnitude of any reduction in overall service life of the facility in relation to the design intention.

STRATEGY FOR CONTROL OF ASR IN NEW STRUCTURES

Queensland is fortunate to have a readily available local supply of high quality fly ash. Analysis of a wide range of aggregates used in bridge construction confirmed that nearly all are either potentially reactive or deleterious in relation to ASR. Hence it was considered good management policy to assume all aggregates supplied would be reactive to some degree and design a binder system to optimize their performance in relation to ASR. Table 9 details the progression of changes to our concrete specification to control the ASR issue in new structures.

TABLE 9: Summary of Changes to DMR Concrete Specification

Year	Amendment	Comment
1986	Special provision for use in North Queensland requiring the use of fly ash to reduce the risk of ASR	Generated as a response to assessment of ASR in the Lucinda Jetty (6.5 km long jetty near Ingham)
1993	• Acknowledgment of the potential benefits of fly ash, slag and silica fume. • Requirement for a detailed source assessment of concrete aggregates • Control of the alkali level of chemical admixtures • Inclusion of an accelerated test on concrete prisms for prediction of ASR potential	This version of the specification identified the use of fly ash, slag and silica fume in the market place. A detailed source assessment of concrete aggregates was required to ensure material of a suitable quantity and quality.
1999	• Requirement for material source certification for aggregates • Control of the alkali levels of cement, fly ash and blast furnace slag • Use of fly ash mandatory in prestressed concrete	Certificates are now being issued for certified sources. Specific total and available alkali levels have been set for all binder materials.

CONCLUSIONS

(i) The emergence of alkali-silica reaction in concrete structures has been a significant issue for Queensland Main Roads and other authorities around the world. Owners of large infrastructure have by necessity needed to keep pace with this issue and ensure they have an adequate degree of protection against this distress mechanism.

(ii) The Queensland Department of Main Roads has played a significant role in the control of the ASR issue in Queensland and Australia as detailed in Table 3. The Department adopted a position of binder control as most of the local aggregates tested were either potentially deleterious or deleterious in relation to ASR potential. Industry was already moving to the use of fly ash in premixed concrete for economic reasons in the early 1980's. The ASR issue coincidentally meant it was the correct move from a technical viewpoint as well.

(iii) The financial burden of ASR has been limited in Queensland due to the relatively mild environment for concrete structures. The major cost of ASR repairs has been limited to prestressed concrete piles as detailed in Table 8. This expenditure represents approximately 0.2% of the replacement value of the total bridge stock.

(iv) The current issue of globalised trading in binder materials used in concrete has led to tighter controls on the alkali levels of cement, fly ash and blast furnace slag. Owners need to deal with this issue in relation to the adequacy of their existing specifications and National Standards.

(v) Structural designers need to have a better understanding of their local materials and ensure the adopted design concept does not compromise long term durability performance. Road owners now require 100 year design lives from their concrete structures and hence chemical stability of the concretes used in these structures is essential. The current Main Road's specification for concrete has addressed this issue.

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