THE ASSET MANAGEMENT OF A LONG BRIDGE STRUCTURE AFFECTED BY ALKALI-SILICA REACTION

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ABSTRACT

The scope of this project was to diagnose the cause of major vertical cracking in the prestressed piles of a 2716 metre long bridge and propose a suitable asset management strategy. The bridge consists of 99/27.4 metre spans with 98 piers each supported on 5/560 mm octagonal prestressed piles. A total of 490 pier piles were used at an average pile length of 29 metres. In 1992 approximately 210 of these piles were found to be cracked and in need of repair. Detailed analysis of concrete cores extracted from the piles proved that alkali-silica reaction (ASR) was the primary mechanism causing the initial cracking. ASR and corrosion in combination were subsequently widening the cracks to a measured maximum width of 8 mm. The repair strategy developed for this structure addressed both the ASR and corrosion mechanisms. The piles are monitored until the ASR expansion is nearing completion and then they are concrete encased to prevent any significant corrosion damage to the included prestressing strands. The long term analysis of this structure will provide valuable data for the modelling of the performance of ASR affected concrete structures in a marine environment.
Keywords: Alkali, Aggregate, Concrete, Durability

INTRODUCTION

This bridge structure was opened to traffic in 1979 and hence, was 13 years old at the time of a detailed inspection in 1992. This inspection established that alkali-silica reaction (ASR) was the primary cause of vertical cracking in the prestressed octagonal piles supporting this structure. This paper will present the findings of the detailed bridge inspection and discuss the asset management strategy currently being employed. The replacement cost of this structure in 1995 is $30 million.

DETAILED BRIDGE INSPECTION

Field Investigation

Crack Survey. The initial part of this analysis required a detailed crack survey to be undertaken to determine the extent of cracking which had occurred in the precast octagonal piles. Inspection of the piles proved to be a difficult task due to the build up of marine growth (barnacles etc.). Since the marine growth was most severe in the tidal zone it acted as a layer hiding the presence of serious cracks underneath. After removal of the marine growth it would return within several months making continuous inspection of the change in condition of the piles an arduous task.

The following data was determined from the crack survey:

- Approximately 210 of the 490 exposed piles were found to be cracked and in need of repair.
- The observed crack widths varied from 0.1 mm to 8 mm maximum.
- The typical crack orientation was vertical along the axis of the pile and following the line of prestressing force.
- The maximum degree of cracking occurred below high tide level.
- The worst cracked pile in the tidal zone contained seven cracks around its perimeter of width .75, 2, 1, 1, 1, 1 and 8 mm respectively. This yielded a combined crack width of 15 mm indicating a total expansion of 7000 microstrain had occurred.

Selection of Concrete Core Locations. A total of eight concrete cores of diameter 75 mm and nominal length 200 mm were extracted from the piles at Piers 15 and 16. Pier 16 was chosen to represent a location of severe cracking and Pier 15 was selected to represent a relatively crack-free zone. Table 1 identifies the location of each core relative to the associated headstock soffit.

Each pier consists of a reinforced concrete headstock supported on five prestressed piles. The piles have been labelled A, B, C, D, E with pile A on the western side and pile E on the eastern exposed side of the structure.

Table 1 - Core location

Pier No.	Pile Label	Core No.	*Depth Below Headstock Soffit (mm)	Associated Crack Width (mm)
16	D	1	2000	8
16	D	2	1400	2
16	C	3	1630	1
16	C	4	980	0.2
15	D	5	1600	Uncracked
15	D	6	1000	Uncracked
15	B	7	1600	Uncracked
15	B	8	1000	Uncracked

* The approximate depth below the headstock soffit to bed level was 2450 mm at the time of coring in November 1991.

From a hand examination of cores 1 and 2 at the time of extraction it was self-evident they were suffering severe alkali-silica reaction due to:

- Significant Calcium/Alkali-Silica gel filling the available air voids and,
- Significant dark rims around the coarse aggregate fragments.

LABORATORY INVESTIGATION

The following testing was conducted on the cores extracted from Piers No. 15 and 16.

- Petrographic analysis
- Electron Microscope Analysis
- Chloride Ion Analysis

Petrographic Analysis

The main conclusions of the petrographic analysis were:

- The coarse aggregate consisted of pebbles composed mainly of metamorphic quartzite, chert and related jasper, meta-greywacke, vein quartz, greenstone and andesite.
- The sand component consisted of unstrained and mildly strained quartz, mildly to moderately strained quartzite, chert, feldspar and granitoid rock fragments.
- The reactive silica was derived from the strained quartz within the quartzite and finely microcrystalline quartz in the chert and closely related jasper, present as coarse aggregate pebbles and as sand.
- The ASR effects were more pronounced in cores taken from the tidal zone and less obvious in the cores taken above the high tide level.
- ASR was also more pronounced in the cores taken from the eastern side of the bridge i.e, the piles more exposed to the offshore elements of prevailing wind etc.
- The examination of Core No. 5 from Pier 15, Pile D indicated that although cracking was not evident the included air voids were filling with calcium alkali-silica gel. Hence, when the available void space has been consumed these piles will probably crack in a similar manner.

Electron Microscope Analysis

Two polished sections (one from Core No. 1 and one from Core No. 2) were prepared and examined using the EDX (Energy Dispersive X-ray Analysis) capabilities of the electron microscope. Table 2 details the results obtained for the chemical analyses of the associated gel deposits.

Table 2 - EDX analysis of gel deposits

Core No.	Sample	Element Composition (% by mass)				
		Na	Si	Cl	K	Ca
1	A	10.5	51.5	1.9	17.3	18.8
1	B	13.6	52.5	0.7	13.3	20.0
1	C	5.4	55.6	0.8	18.2	20.0
1	D	15.4	49.9	0.9	13.0	20.0
2	E	22.7	50.1	0.3	14.3	12.6

From the results given in Table 2 it is clear that the gel deposits analysed represent the classical calcium/alkali/silica gel complex. The pure alkali-silica gel absorbs calcium as it migrates from the initial reaction site into the calcium rich cement paste region. It then changes from a clear gel into a white gel. Sample A from Core No. 2 contains a large amount of Sodium 22.7% indicating the marine environment is having a significant affect on the extent of the chemical reaction (ASR).

Chloride Ion analysis

An analysis of the acid soluble chloride ion content of the pile concrete was conducted to determine the extent of chloride ion penetration. Four cores were cut in a series of slices to determine the chloride profile. Table 3 details the results obtained.

Table 3 - Chloride ion content (kg/m³)

Pier No.	Core No.	Distance into Pile Cover Concrete (mm)				
		10	30	50	70	Balance
16	1	12.8	11.8	10.7	-	-
16	4	11.0	-	7.5	4.4	1.9
15	7	4.2	2.9	2.0	2.2	1.1
15	8	8.0	4.5	3.8	-	1.4

AS 3600 (1) has defined the maximum level of chloride ions from all sources in freshly placed concrete as 0.8 kg/m³. The clear cover to the 12.5 mm prestressing strands is 65 mm and the 5 mm dia. spiral wire is 60 mm. From Table 3 it can be seen that the chloride ions have significantly penetrated the cover concrete of the piles. The highest concentration of chloride ions was detected in Core No. 1 since it was drilled over a large crack.

The level of chloride ions at the strand location as shown by Core No. 4 is 5 times the allowable level of AS 3600. Hence, the risk of strand corrosion is high at Pier 16. Since Core No. 1 was drilled over the largest crack (width 8 mm) an estimate of actual corrosion was determined from the included prestressing strand. Each strand consists of 7 wires of nominal diameter 4 mm. Table 4 details the measured diameter of each wire.

Table 4 - Corrosion estimate Core No. 1

Wire No.	Corroded Diameter (mm)
1	2
2	3
3	Minor pitting
4	"
5	"
6	"
7	2.5

From Table 4 it is estimated that a 21% loss of strand area has occurred in the individual strands contained in Core No. 1. This is consistent with the very large crack (8 mm) in this location. Fig. 1 shows all the information on chloride ion diffusion in Table 3 plotted graphically.

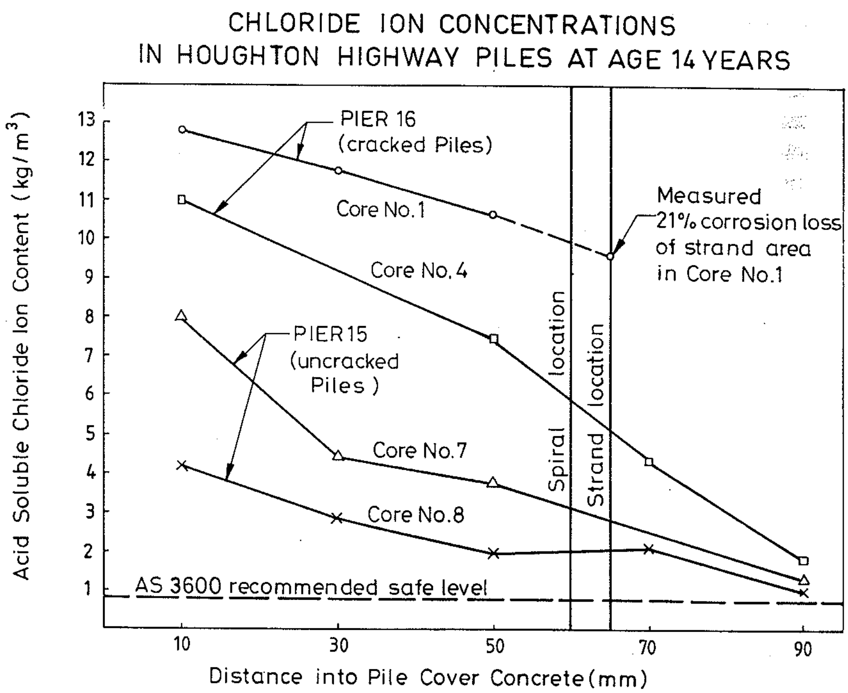

Fig. 1 Chloride Ion concentrations in pier 15 & 16 piles

SUMMARY OF FIELD AND LABORATORY INVESTIGATIONS

The following conclusions are derived from the field and laboratory work:

- The mechanism causing the initial vertical cracking in the prestressed piles is alkali-silica reaction i.e. cement/aggregate reaction. Heat, moisture and especially salt water all help to accelerate this reaction. At this bridge site all three are present in addition to a significant wind effect.
- The crack net work set up the ASR mechanism has allowed a significant penetration of chloride ions (See Fig. 1) leading to subsequent corrosion of the included reinforcement. A corrosion loss of 21% of strand area was measured at Pier 16 in Pile D, Core No. 1. This core was taken over a crack of width 8 mm.
- It is estimated that ASR will induce a vertical crack of width 2-3 mm and subsequent enlargement of this crack is due to reinforcement corrosion.
- The distress increases with depth below the high water mark and appears greater in the piles on the eastern side. (This may be due to the prevailing wind direction).

ASSET MANAGEMENT STRATEGY

Future Life

The future life of this structure will depend significantly on the action taken to inhibit the onset of corrosion of the prestressing strands. Fig. 2 shows diagrammatically the corrosion history that has occurred at pier 16, Pile D. From Fig. 2 it can be seen that unacceptable corrosion damage has already occurred in some of the piles.

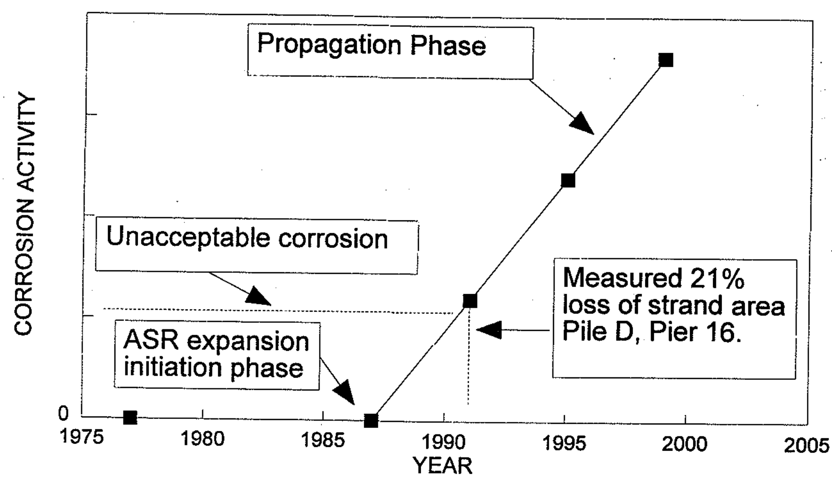

Fig. 2 - Corrosion activity in piles

Repair Strategy

A suitable repair system needs to address the two mechanisms of:

(i) Alkali-silica Reaction and,
(ii) Corrosion of Reinforcement

both of these mechanisms are accelerated in the presence of salt water. Heat and moisture both affect the rate of ASR and, hence, it is postulated that the worst zone of cracking will lie in the region of fluctuating water level and the surface zone of maximum temperature. For corrosion cells to operate they require moisture and oxygen. Hence, corrosion will also be more active in the tidal zone and reduce in activity with depth below ground. Fig. 3 contains a sketch of the repair procedure being used on this project. It was required that the repair penetrate at least 1000 mm below bed level to reduce the risk of corrosion at ground level. Fig. 4 shows a view of a typical pier under repair.

Form Length (mm)	* Nº Req'd
1500	2
1000	1
500	1

* To be confirmed by District 13 personnel

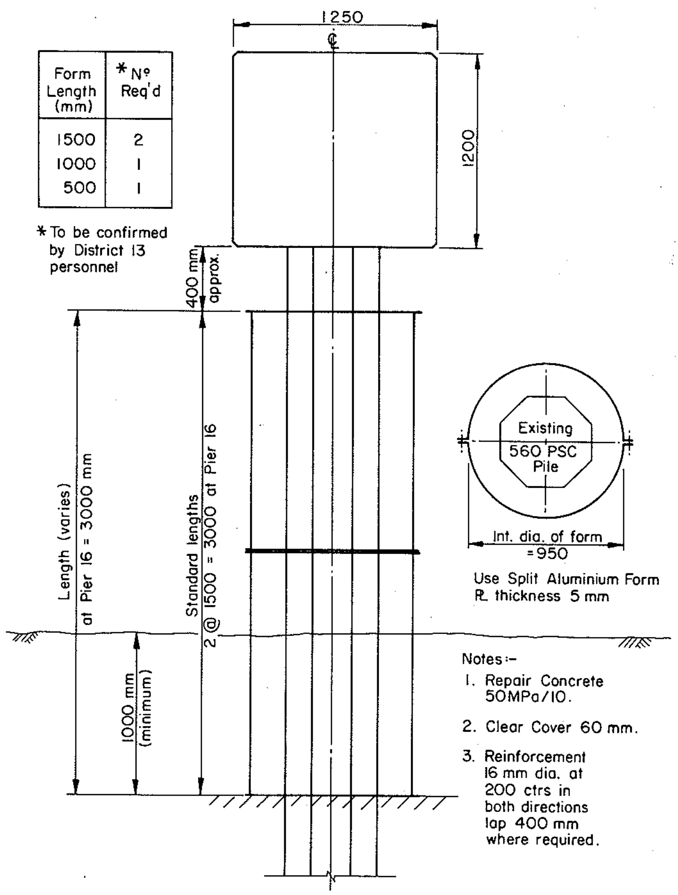

Fig. 3 Proposed repair technique

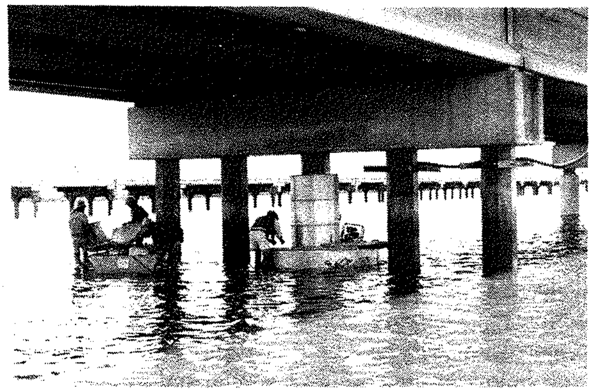

Fig. 4 View of typical pier under repair

The concept of this repair strategy was to only repair piles which were towards the end of their initiation phase (i.e ASR expansion had nearly exhausted itself). An estimate of this time was approximated by selecting piles with individual crack widths in the range 2-3 mm for repair. If piles are repaired too early in their ASR expansion phase then unacceptable cracking will occur in the repair concrete.

Monitoring

A detailed survey of the existing condition of all piles was required to enable selection of the critical piles for immediate repair. The marine growth required removal for an accurate recording of the piles present condition. The future condition of the piles is being monitored on a six monthly basis to detect changes in the observed crack widths and help prevent any serious corrosion damage prior to repair.

CONCLUSIONS

- It has been established that alkali-silica reaction is the primary mechanism causing the observed vertical cracking in the prestressed octagonal piles of this structure. Subsequent corrosion of the included reinforcement is due to the penetration of aggressive substances into the ASR crack network.
- An asset management strategy has been proposed taking account of both the ASR and corrosion mechanisms. At this stage approximately 50 piles have been repaired.
- When all the piles have been repaired the maintenance costs of $2 million will represent about 7% of the current replacement cost of this bridge. This investment is essential to secure an adequate life cycle performance from this structure.

REFERENCE

1. Australian Standard 3600 (1988). Concrete Structures.