BARRON RIVER BRIDGE INVESTIGATION AND DEVELOPMENT OF A REPAIR STRATEGY

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SYNOPSIS: The purpose of this paper is to provide a review of the issues facing the Maintenance Engineer in relation to repairing a bridge structure affected by alkali-silica reaction cracking and chloride induced corrosion. In addition, a discussion of appropriate remedial solutions and contract delivery mechanisms are provided. The bridge structure chosen consists of reinforced concrete piers supported on prestressed concrete piles. This bridge was built in 1977 and consists of 7/25.3 m spans of prestressed concrete I girders. Field inspection indicates the piers are suffering chloride induced corrosion distress and the piles are suffering significant alkali-silica reaction distress. This structure resides in a very aggressive environment in relation to concrete durability and the environment would be classified as type C in relation to the Austroads Bridge Code requirements. The associated river is tidal with mangroves growing on the banks. As a result of the work performed on this bridge, alkali-silica reaction (ASR) was determined as the primary mechanism causing the observed cracking in the prestressed piles with crack widths up to 15 mm. An approach to the rehabilitation of this structure is outlined which had a degree of urgency in relation to the satisfactory long-term performance of this structure. The vertical cracking was proven to have been initiated by ASR distress and most likely widened due to corrosion of the underlying reinforcement and prestressing strands. A new technique of fibre composite encasement was prototyped to arrest the rapid deterioration of these major supporting elements of this structure. However, it has not been possible to obtain commercial production of this solution and the market place is being investigated for further options in relation to the pile repairs. The corrosion in the piers was controlled using a cathodic protection system in the usual manner.

Keywords: alkali-silica reaction, corrosion, chlorides, durability, concrete repair

1. INTRODUCTION

The southbound Barron River bridge (Structure ID No. 7779) on Road 20A Captain Cook Highway (Cairns-Mossman) was built in 1977, making the structure 24 years old at the time of investigation and now 27 years of age in 2004.The bridge consists of 7 spans each 25.3m long. Each span consists of reinforced concrete deck on top of six prestressed I-girders. The substructure consists of piers, each supported by 10 driven prestressed concrete piles (see Figures 1 and 2 below). This bridge was the original crossing of the Barron River, which became the Southbound crossing when a second bridge was constructed alongside in 1988. Visual inspections of this structure by maintenance personnel had identified cracking in the piers, in particular Pier No. 5. In November 2000, 9 cores were extracted from Pier No. 5. Analysis of these cores concluded that chloride induced corrosion of the reinforcement was responsible for the observed defects. As a result of this preliminary analysis it was recommended that additional coring of the remaining piers be undertaken to determine the extent of defects and degradation in the other piers. On the 14-15 November 2001, 13 cores were extracted for laboratory testing from the southbound bridge. An additional 2 cores were extracted from the tidal zone of the northbound bridge which is in good condition for comparison (Structure ID No. 7780). The purpose of this paper is to describe the present condition of this southbound bridge structure and the optimum repair strategies for the substructure and superstructure. A previous paper on this topic (1) reported on a bridge with the ASR distress confined to the superstructure. This paper deals with the treatment of ASR distress in the substructure piles.

Figure I General view of Southbound Barron River Bridge at high tide note girders exhibit some alkali-silica reaction cracking under scuppers

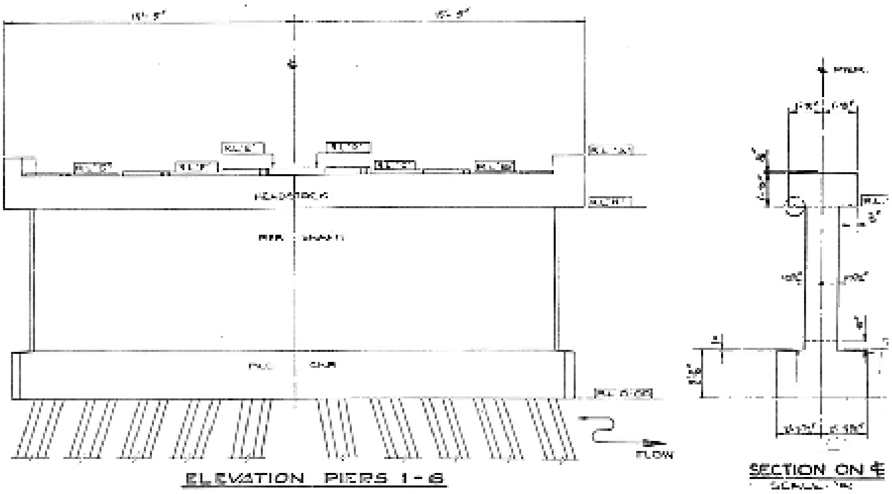

Figure II Elevation and cross section of Piers

2. ANALYSIS OF CORES FROM PIERS

2.1 Density, compressive strength and carbonation depths

For the southbound bridge the average UCS and density results as shown in Table 1 were 28MPa and 2330kg/m^3 respectively. Both the average UCS and density results for the northbound bridge were considerably higher at 54MPa and 2450kg/m^3. The carbonation depths ranged between zero and 22mm in the southbound bridge and between 3 and 12mm for the northbound bridge. The UCS and density testing clearly shows that the concrete used for the northbound bridge is of a significantly higher quality to that used in the southbound bridge.

2.2 Chloride ion profiles

2.2.1 Southbound bridge

Acid soluble chloride ion profiles were extracted from 4 cores using 30mm slices of the cores. Fig. III shows the penetration of chlorides that has occurred over the last 24 years.

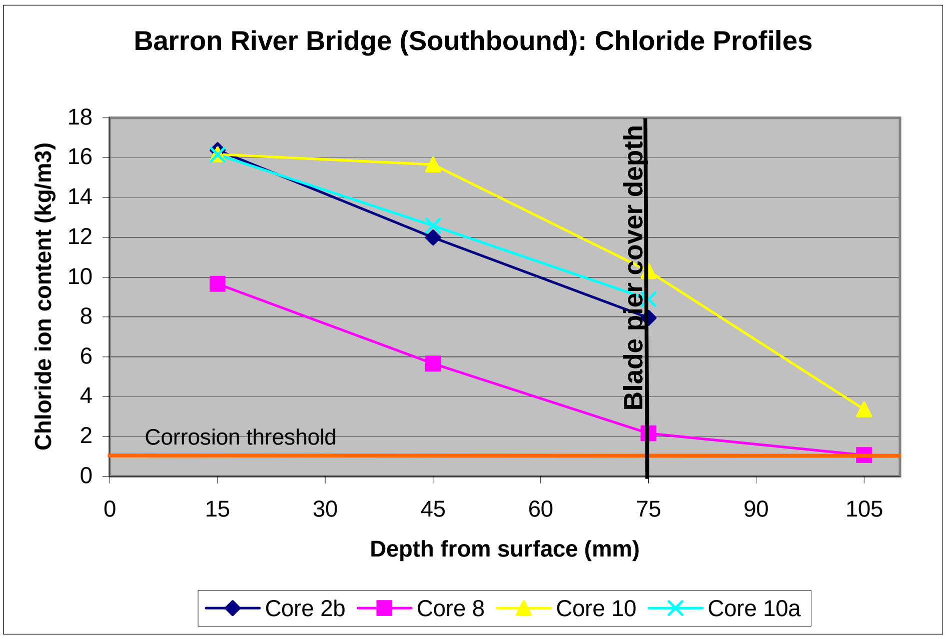

Figure III - Chloride profiles (southbound bridge)

Table I Southbound Barron River Bridge Core testing results

Core no	Bridge	Density	Strength (MPa)	Carbonation depth (mm)	Location / comments
1	Southbound Bridge	2340	29.0	15mm	Pier 1 Span 1 Pier wall 5.9M LHS. Concrete sound, no steel present.
1A	Southbound Bridge	2340	34.0	0mm	Pier 1 Span 1 Pier wall 5.1m LHS. Crack running between reo bars. 82mm cover.
2B	Southbound Bridge			0mm	Pier 1 Span 1 Pile cap 4.0m LHS, 0.3m down. 82mm cover. Sound concrete.
3	Southbound Bridge				Pier 1 Span 1 Headstock. 1.6m LHS 0.25m down. 80mm cover. Concrete sound but discoloured within top 30mm.
8	Southbound Bridge	2320	30.5		Pier 3 Span 4 Pier wall 5.6m LHS 0.35m up from pile cap. Below high tide. 97mm cover. Concrete sound.
9	Southbound Bridge			18mm	Pier 3 Span 4 Headstock. 3.8m LHS of center. 78mm cover. Concrete sound.
10	Southbound Bridge	2320	23.5	12mm	Pier 4 Span 4 Pier wall. 2.1m LHS 1.8m down. 82mm cover. Cracking at level of reinforcement.
10A	Southbound Bridge	2340	30.5	10mm	Pier 4 Span 4 Pier wall 3.0m LHS 1.7m down. Cracking present at typical reinforcement depth.
12	Southbound Bridge			22mm	Pier 5 Span 5 Headstock. 3.15m LHS 0.3m down. Concrete sound.
13	Southbound Bridge	2320	21.0	4mm	Pier 6 Span 6 Pier wall 3.5m LHS 1.95m down. Concrete sound.
14	Southbound Bridge				Pier 6 Span 7 Pier wall 2.5m LHS 1.8m down. 94mm cover. Concrete sound.
Averages:		2330kg/m3	28MPa	0-22mm	
15	Northbound Bridge	2460	65	12mm	Pier 3 Span 4 Pile cap. 4.1m RHS 300mm down. Concrete sound. Cover around 75mm.
16	Northbound Bridge	2440	43.5	3mm	Pier 4 Span 4 Pier wall 2.8m LHS 2.45m down below high tide. Concrete sound. Cover only 35mm.
Averages:		2450kg/m3	54MPa	3-12mm	

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Table II Concrete and cover details from the plans (Southbound Barron River bridge)

Element	Description	Design Concrete Grade	Design Cover Depth
Deck	Reinforced concrete	25MPa/20	38mm (1½")
I-Girders	1118mm (3'-8") deep x 533mm (1'-6") wide	45MPa/20	51mm (2")
piers	Headstock width = 1067mm (3'-6"); Pier shaft 533mm (1'-9") wide; Pile cap 1499mm wide (4'-11").	25MPa/20	76mm (3")
Piles	450mm (18") prestressed octagonal	40MPa/20	51mm (2")

The drawings show that the required concrete Grade for the southbound bridge was 25MPa and that the required cover to reinforcement for the piers was 3" (i.e. 76mm).

Assuming that approximately 280kg/m^3 of cement was used to produce the 25MPa mix, then the corrosion threshold could be expected at around 1.1kg/m^3 (0.4% by mass of cement). As can be seen from Figure III, at the level of reinforcing (i.e. 76mm) the chloride ion levels measured are well in excess of that required for corrosion initiation. Fig.IV shows the spalling damage at Pier No. 5 due to chloride induced corrosion.

Figure IV Spalling of cover concrete at Southbound Pier No.5

2.2.2 Northbound bridge

Chloride ion profiles were undertaken on Cores 15 and 16. The results of these tests are shown in Figure IV. The drawings (dated 1987) show that the required concrete grade was 30MPa/20 and the required cover to reinforcement for the piers was 75mm. The chloride ion profiles obtained from the northbound bridge in Figure V show that at an average of 15mm depth the chloride ion profiles are far greater than the level required for corrosion to occur. However the chloride level rapidly drops off and at an average depth of 45mm is far below the corrosion threshold at less than 0.5kg/m^3. Despite the minimum cover depth noted on the plans core 16 encountered a reinforcing bar at only 35mm depth.

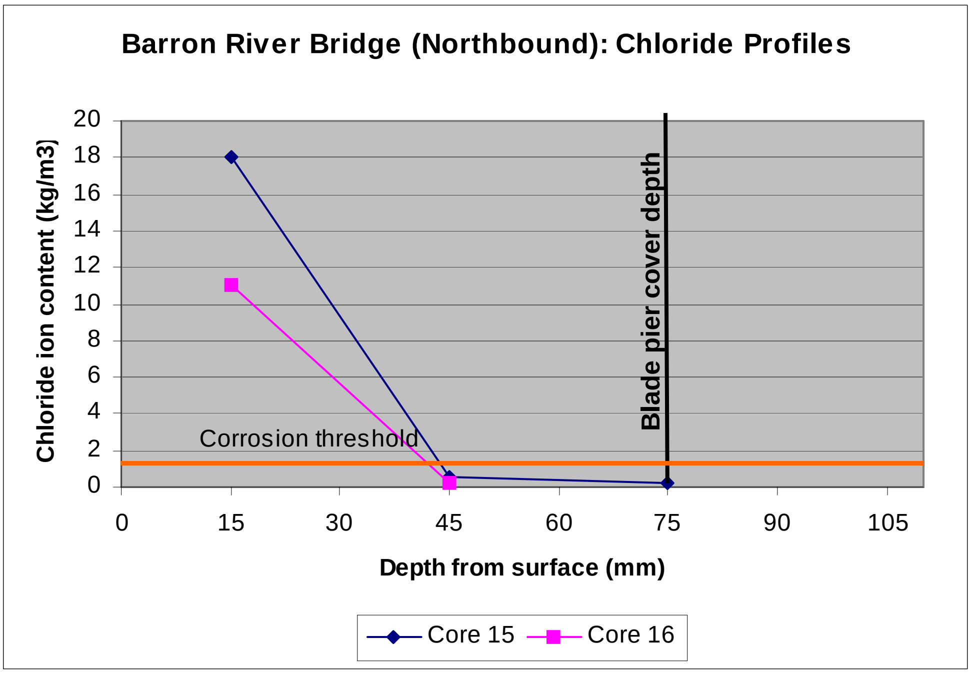

Figure V - Chloride profiles (northbound bridge)

2.2.3 Summary of chloride ion levels

For the Southbound bridge the core results, visible defects on the structure and age of the structure are all consistent with deterioration through chloride-induced corrosion of the reinforcing steel within the piers. This is not surprising near the tidal zone considering the aggressive saline nature of the surrounding environment and the use of a relatively low concrete grade within the piers. The use of a relatively large cover depth (76mm) may have somewhat delayed the onset of the deterioration. The deterioration extends up to around 900mm above the high tide mark in places, probably due to the porous nature of the concrete. Carbonation is unlikely to be the cause of spalling in these areas above the tidal zone, as the largest test measurements at 22mm were still nowhere near the cover depth of 75mm. As chlorides are a catalyst for corrosion it is anticipated that the deterioration of reinforcing steel will continue at an increasing rate with the expanding rust products leading to cracking and additional ingress of oxygen to the steel.

In contrast for the Northbound bridge the level of chlorides at the reinforcement is well below the corrosion threshold. Eventually it is anticipated this bridge will show similar signs of deterioration as the chloride migrate from the surrounding environment through to the reinforcing steel. However the improved concrete quality, as evidenced by the higher compressive strength and rapid drop off of chloride levels through the cover concrete, should delay this for many years to come.

3. ACTIONS TO REMEDIATE BRIDGE PIERS

As a result of the significant penetration of chloride ions into the piers of the southbound bridge it was recommended that cathodic protection (cp) be installed to all the piers as soon as possible. Figure VII describes the asset management strategy being employed in relation to the cp installation and the expected additional life as a result of this intervention work. Figure VII shows an idealised diagram of structure condition versus age. While this is a rather simplistic representation of this structure's lifespan it does illustrate that without intervention this structure is only likely to reach around $^1/_3$ of the design life originally intended. While this diagram only relates to the condition of the substructure (for example it does not consider the effect of ASR issues with the superstructure) it does however illustrate the significant effect on life expectancy, which a CP system is anticipated to have.

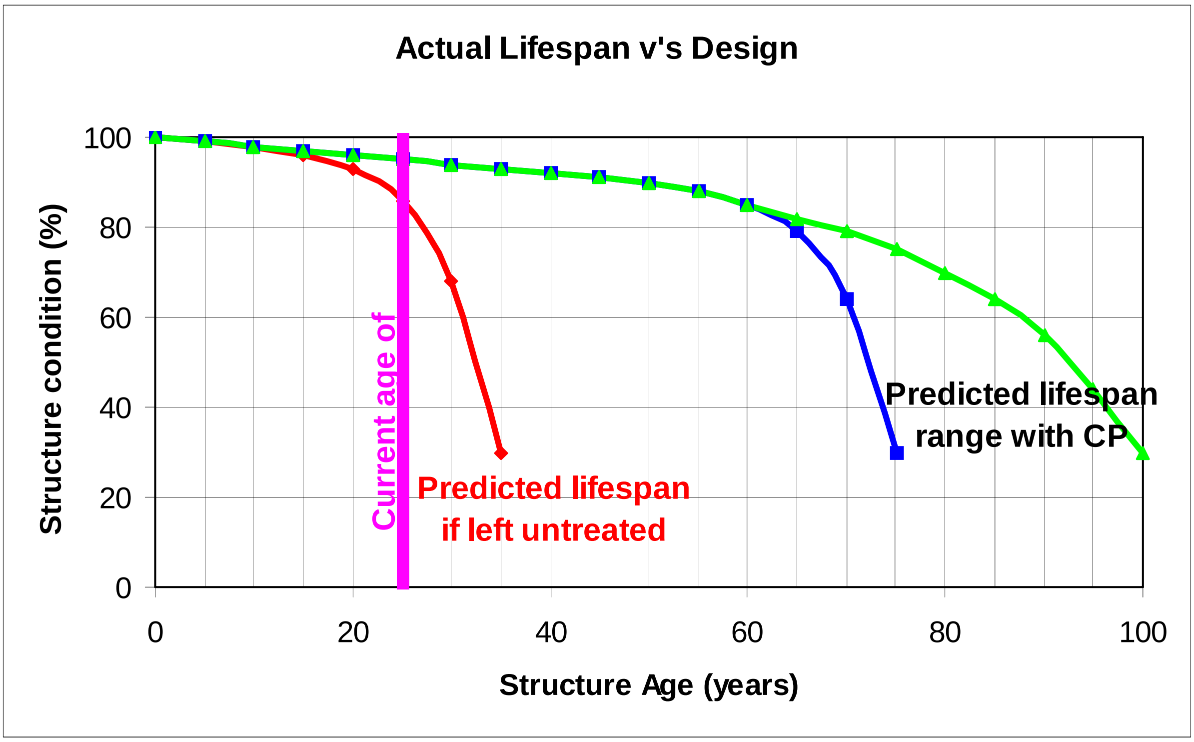

Figure VII Asset management strategy for southbound Barron River bridge piers

The contract delivery mechanism chosen for the repair of the piers consisted of the following components:

(i) Short listing of suppliers of cathodic protection systems
(ii) Selection of top two suppliers based on in house capability
(iii) Invitation to tender with on site visit and measurement costs paid to both tenderers
(iv) Price (50%)/Non Price and Interview assessments (50%) conducted
(v) Awarding of successful tender

At the time of presenting this paper the installation of the cathodic protection system is now complete.

4. ACTIONS TO REMEDIATE PIER PILES

4.1 Review of condition of pier piles

As shown in Figure II each pier is supported on 10/450 mm octagonal prestressed concrete piles. The condition of 15 piles out of a total of 60 piles was ascertained by an underwater diving inspection. Table III contains a summary of the field condition of the piles as reported by the divers. Crack widths were reported as 10mm wide etc.

Table III Summary of the field condition of the Barron River bridge piles

Pile No.	Pier No.			
	1	2	3	4
1	Depth 2.1-2.3m impression 5 mm deep	Depth 1.2-1.4m 3mm wide Depth 1.8-2m 15mm wide 3mm average		Depth 2.4-3.5m 11mm widest 3 mm average
2			General multi hairline cracks Depth 2.5-3.0m 15mm wide Depth 3.4m 4mmwide	
3		Depth 0.5-0.7m 3mm wide		
4		Small local pits	Small local pits	Small local pits
5				Good condition
6		Small local pits	Good condition	
7				
8				
9			Depth 0.2m damaged 10mm wide Depth 3.4m 12mm widest Depth 4m 4mm wide Riverbed 4.4m	

The data in Table III indicated that very significant cracking was occurring in some of the prestressed piles at Piers 2 and 3. From previous research work (2) it was concluded that the most likely cause of this distress was the alkali-silica reaction mechanism.

4.2 Intervention Strategies

Queensland Main Roads is finding a range of bridge structures with prestressed piles cracked due to ASR distress. The intervention strategy depends on:

(i) The amount of distress that has already occurred
(ii) The environment the piles reside in
(iii) The level of the high water mark in relation to the top of the piles

In general, the target intervention time is usually early in the life of the deterioration cycle rather than after an extended level of distress has occurred (some Interstate bridges have had nearly the whole cross section eroded prior to intervention). Figures VIII and IX show the intervention strategy used on the Houghton Highway Bridge (3) at Sandgate near Brisbane. In this particular structure, the overall level of distress was low but would build (without intervention) within 5 years of discovery to be catastrophic. Hence, the intervention strategy adopted for this structure consisted of:

(a) Concrete encase all piles below water and to 500 mm above high water level
(b) Composite fibre encase all piles to the underside of the headstocks
(c) Insert linear polarization probes in selected piles under the composite fibre encasements for monitoring of corrosion currents

The main purpose of the wrapping carried out in (a) and (b) above was to provide a durability wrap rather than additional structural capacity. The concrete encasement was chosen for the section underwater as it would stay continuously wet and not be prone to excessive restrained shrinkage cracking. The composite fibre wrap was chosen for the section above the high water mark as it would be in a wind tunnel environment and needed to remain crack free. In addition, the appearance of the repair would be enhanced by having a slender top section leading into a thicker concrete repair in the water. Figures VIII and IX show views of the repair system and final product where the desired affect has been achieved.

Figure VIII View of Concrete and Fibre Composite Encasement of Piles
Houghton Highway Bridge Sandgate-Redcliffe

For the Barron River bridge one system taken to prototype stage for repair of the piles consisted of a hybrid of materials. The purpose of this composite was to make optimum use of each material and produce a non-corrodible long life solution. The pilecaps of the Barron River Bridge being at water level make the placement of repair concrete very difficult using normal tremie techniques. Hence, the new system used fibre reinforced polymer (FRP) jackets on the outside and a high quality grout as a filler between the jacket and the pile. This filler allows for tolerance variation in both the pile and FRP wrap. In addition no reinforcement is used in the grout as full capacity can be supplied by the FRP external skin for hoop stresses. The grout can be inserted using normal pressure injection techniques which removes the major risk of concrete segregation underwater, which is always present in the usual tremie operations. At this stage it has not been possible to get commercial production of this product at an acceptable price and further options are being investigated.

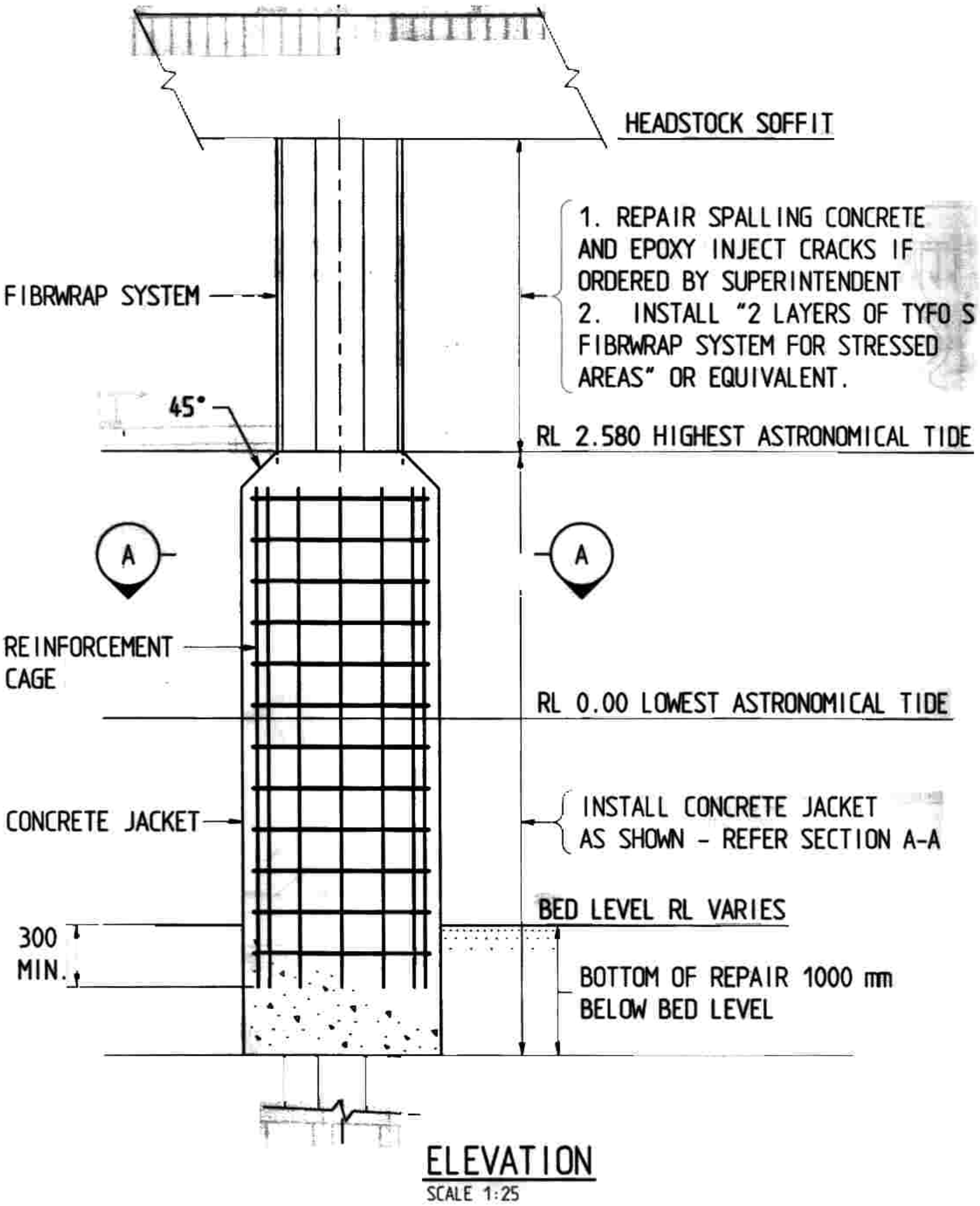

Figure IX View of Concrete and Fibre Composite Encasement System
Houghton Highway Bridge

5 CONCLUSIONS

In relation to the information presented in this paper the following conclusions are made:

(i) Review of the condition of the bridge piers in the Southbound Barron River Bridge indicated in 2002 that cathodic protection of the piers was required for this bridge to reach a 75 year design life.

(ii) Where ASR distress has occurred in the supporting piles of a bridge early intervention is vital to ensure the long-term integrity of the supporting system. Options include concrete encasement and/or composite fibre encasement. Some existing installations are being monitored underneath the composite fibre wraps for the potential build up of corrosion currents.

(iii) The prototype composite fibre wraps have now been discarded as a commercial solution and the market place is being assessed for other viable options in relation to the wrapping of the cracked piles.

6 REFERENCES

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