ASSESSMENT AND MANAGEMENT OF A MARINE STRUCTURE AFFECTED BY ASR

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ABSTRACT

There is little experience in Australia of managing the remediation of structures with ASR. In order to assess the cost effectiveness of remedial options it is essential to gain a full understanding of the nature and rate of ASR induced expansion.

This paper describes the approach that was taken to assess and manage the deterioration of a load out jetty in Western Australia. The main issues that are dealt with are as follows:

° identifying the presence of ASR
° monitoring the ASR induced expansion in situ
° predicting the residual expansion and the rate at which it will occur
° evaluating the impact of present and future expansion on the fitness for purpose of the structure
° addressing remedial actions to maintain fitness for purpose for the desired service life.

Keywords: ASR, Marine, Monitoring, Remediation

INTRODUCTION

The 800 m long load out jetty was constructed in 1954 as a grillage of precast reinforced concrete (RC) elements. A survey in 1992 found that the beams were cracked extensively. Testing confirmed the presence of ASR.

In situ testing demonstrated that the structural capacity of the beams might be significantly reduced as a result of the ASR induced expansion.

This paper describes how a controlled, long term monitoring programme was carried out with the aims of monitoring the rate of expansion, assessing the efficacy of a silane coating for arresting ASR, and predicting the potential future expansion.

The monitoring programme demonstrated that there was the potential for substantial future expansion but that the rate of in situ expansion was slow. It was concluded that the most cost effective remediation strategy would be that which was targeted at those elements whose structural integrity was already reduced sufficiently (and those that would become so within the desired service life of the jetty) to compromise the fitness for purpose of the jetty.

INITIAL SURVEY AND TESTING

Visual appearance

The jetty consists of a grillage of longitudinal and transverse precast reinforced concrete beams bolted together and onto pile muffs. The beams are surmounted by precast reinforced concrete trestles supporting a roadway:

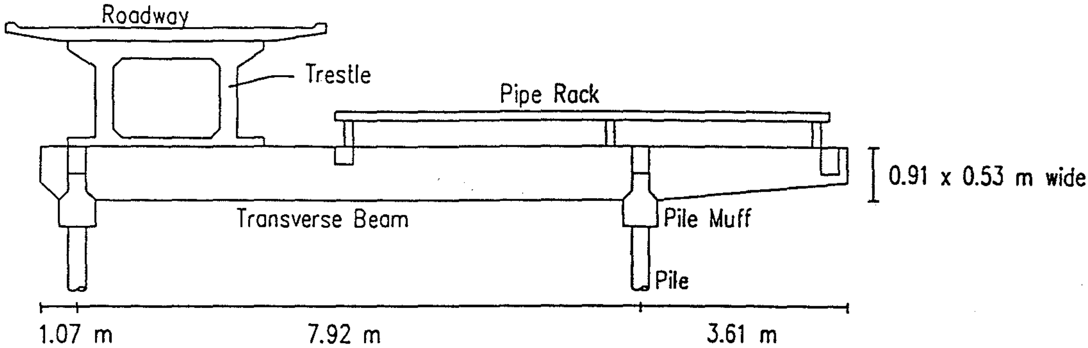

Fig 1 Cross section of jetty

A detailed visual survey was carried out and backed up with the usual array of testing and sampling (chloride drillings, electrochemical potentials etc) to identify the extent and causes of deteriorations.

The beams were found to be cracked extensively. Typical cracks were of width 0.4 to 0.6 mm and were predominantly at mid-face, longitudinal and horizontal. Approximately 50% of the transverse beams and 20% of the longitudinal beams were seen to be affected. The cracks were 50-150 mm deep and were worst at the ends of the beams where some spalling had occurred. In general the concrete between cracks was competent and sound.

Cracking Mechanism

The cracking was not coincident with reinforcement and therefore not related to corrosion. From the location, orientation, depth and width of crack it was also obviously not related to any early age or long term shrinkage of the concrete. An analysis of an expansion related mechanism was identified as consistent with the identified cracks. The incidence of cracks at the outside skin of a concrete element can be explained as follows:

If an expansion mechanism is moisture driven (such as AAR), it will first affect the surface skin of the element, which will go into compression due to restraint from the (relatively) much stiffer core. These compressive stresses can be quite significant, but will creep off with time. As moisture penetrates the element over time, and the expansion mechanism affects the core, the residual compressive stresses in the skin are first dissipated, and then become tensile. Depending on the expansion involved, and the degree of restraint offered by reinforcement, cracking may occur. If cracking does occur, it is likely in the least restrained portions of the element.

An analysis of the beam elements in question identified that the nominal circumferential reinforcement in the beams offers minimal restraint to expansion and hence longitudinal, horizontal cracks are likely to occur mid-height of the beam. The much greater restraint from the main beam steel reduces the likelihood of vertical cracking. Hence it was determined that the observed cracking was consistent with expansion and so further investigations concentrated on identification of such a mechanism.

Laboratory tests

After the elimination of all other possible deterioration mechanisms, core samples taken through typical cracks were subjected to the uranyl acetate staining test (Stark, 1991). Fluorescence under UV light indicated the presence of alkali silica gel, but only at occasional aggregate sites. Thus the presence of ASR was confirmed but not found to be uniformly present throughout the concrete matrix.

In situ tests

The nature and extent of the cracking gave concern as to the structural integrity of the beams. Studies have shown that ASR can affect the capacity and behaviour of reinforced concrete structures (Swamy & Al-Asali, 1989; Ng & Clark, 1992). To quantify the structural effect of the ASR to date, one reinforcement ligature in each of two test beams was exposed by careful cutting into the side of the beam. Ligatures having been previously located by electromagnetic covermeter.

The ligatures were then cut using a hacksaw. The release of elastic tensile strain in the ligatures was measured using electrical resistance strain gauges. One gauge was fixed to each side of the cut and the strains were recorded using a laptop PC and proprietary datalogger.

The gauges demonstrated consistent, smooth strain change as the cut proceeded. A slight "spring back" was measured at the final severing and is thought to be consistent with slight misalignment - of the order ¼ to ½ mm - that remained between the cut ends of the ligatures.

The difference between the initial and final strain readings was used to calculate the elastic tensile stresses that were relieved by the cutting. The four gauges indicated stresses of about 170 MPa - 75% of their probable yield strength, compared with the 10-30% that would be expected under dead loads only, depending on location.

STRUCTURAL IMPLICATIONS OF SURVEY FINDINGS

The extensive cracking and high ligature stresses suggested that there are expansive forces in the beams that are partially restrained by the reinforcement. Experiments (Swamy & Al-Asali, 1989) confirm what theory predicts, that such restrained forces can significantly reduce the ultimate strength of reinforced concrete members, as well as compromising serviceability requirements.

The pattern of cracking is consistent with the extent of restraint. The worst cracking occurs where there is least restraint ie. longitudinal cracking of transverse beams associated with low circumferential restraint (Jones, Clark & Amaski, 1994).

Whilst the longitudinal reinforcement is not likely to be so highly stressed as the ligatures, nevertheless the ultimate shear and bending strength of the beams will have been reduced. Therefore a long term programme of in situ and laboratory monitoring was instigated.

LONG TERM MONITORING

Laboratory monitoring of core samples

Three 100 mm diameter cores were removed from ASR affected areas of the jetty with the aim of measuring how much ASR induced expansion might occur in the future. The cores were subjected to the uranyl acetate staining test, confirming that ASR was present.

The cores were placed in an artificial environment chamber at 38°C, wrapped in wet cloths. This environment provides ample moisture to the samples and should accelerate their expansion. Although the test method was originally based on the philosophy of standard mortar bar potential ASR tests, it was similar to that subsequently published by the British Cement Association (Palmer, 1992) for measurement of residual expansion in core samples.

The expansion was measured using a demountable mechanical strain (DEMEC) gauge. Each core had three pairs of DEMEC studs at 120° spacings around the core so as to measure any non-uniform expansion.

Typical results for one core are shown in Figure 2 as a graph of expansion in microstrains versus time in days:

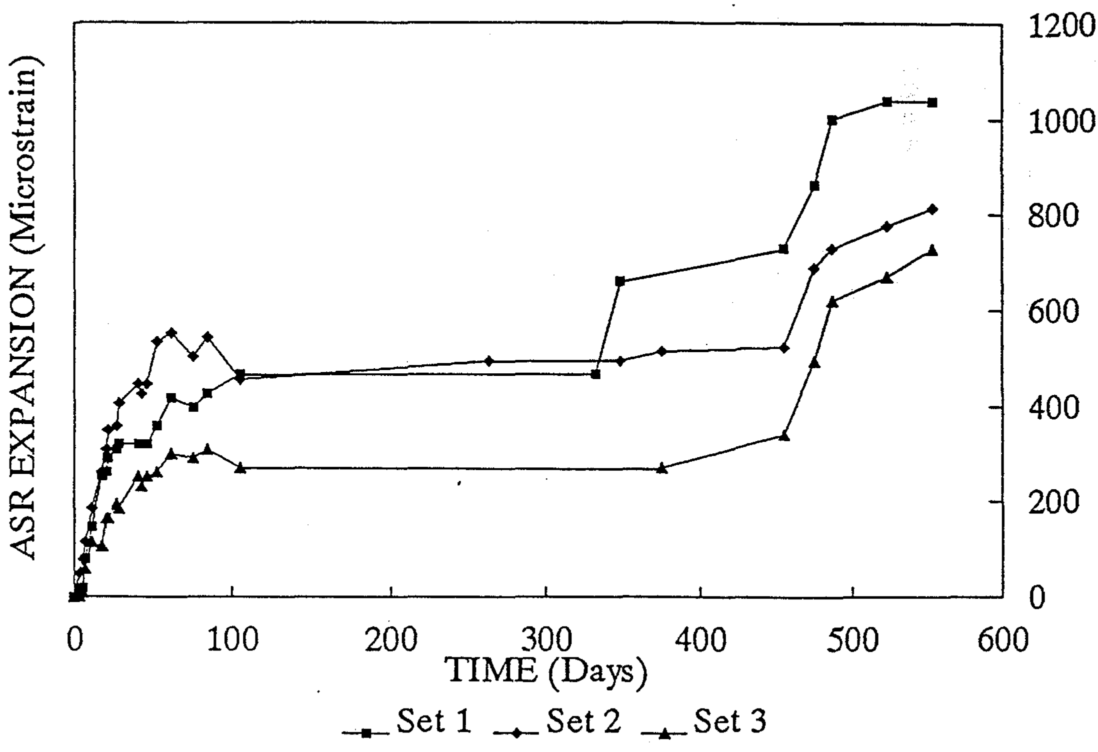

Fig 2 Expansion of ASR core sample

Results from all three cores showed that potential future expansions may be at least 1000 microstrains if unrestrained (ie. 1 mm in 1 m). After expansion appeared to have stopped the samples were removed from the artificial environment. They were later replaced in the environment chamber.

Interestingly, expansion was then found to proceed with a fresh burst. It is thought that the plateau prior to this was due to all the available alklai silica gel having been hydrated. Then when the samples were removed temporarily from the artificial environment, a fresh quantity of gel was produced. The possible preference of the ASR reaction for moderate rather than extreme temperatures/humidity has been reported in the literature (Institute of Structural Engineers, 1992).

Alternatively, the temporary removal cooling and drying of the samples encouraged microcracking which enabled previously restrained elastic strains to be mobilised as permanent plastic deformations (expansion) when the samples were replaced in the artificial environment.

In situ monitoring of beams

Two transverse beams were instrumented, each with seven externally mounted vibrating wire gauges (VWG). The gauges were read fortnightly for two years.

One of the beams was treated with a silane coating. This coating is repellant to moisture so it should reduce the expansion, since the necessary chemical reaction requires moisture to proceed. The second beam was left untreated.

The VWGs were placed, some across cracks, in corresponding positions in the two beams and in various orientations. Each gauge also contained a built in thermistor to enable readings to be corrected for the effect of temperature on the gauge wire.

The gauges performed well and are in full working order after two years in a harsh marine environment. Only one problem with the data - easily corrected - was experienced. That was associated with maintenance work on the pipes running across the beams and caused a uniform and permanent "shift" in all the readings.

The processed readings describe the real changes in the physical dimension of the beam. Typical data are shown in Figure 3 below as a graph of expansion in microstrains versus time in weeks:

The main trend that is evident in Figure 3 is that the concrete strains follow the seasonal temperature. This trend was confirmed by comparing the strain plots with ambient temperature readings at a local weather station. The spikyness of the readings is a result of the daily temperatures at the times of monitoring being not exactly representative of the long term, seasonal variations.

The two curves, representing two corresponding gauges on the silane coated and uncoated beams, diverge gradually. After 1 and 2 years the beams will be of approximately the same dimensions as at the start of monitoring. Any net increase in size can be attributed to ASR. For the treated beam the net strain increases after 2 years were in the range 65 to 180 microstrains, and for the untreated beam 100 to 340 microstrains.

These results, and the divergence in behaviour noted above, confirm the efficacy of the silane coating in reducing expansion due to ASR. The effectiveness of the coating would be expected to increase as the beam dries out further, provided the coating is maintained.

The large variation in results can be attributed primarily to the different locations of the gauges (some over cracks, some not) and the difficulty in ensuring that the test locations are "typical". Nevertheless the global trends were clear.

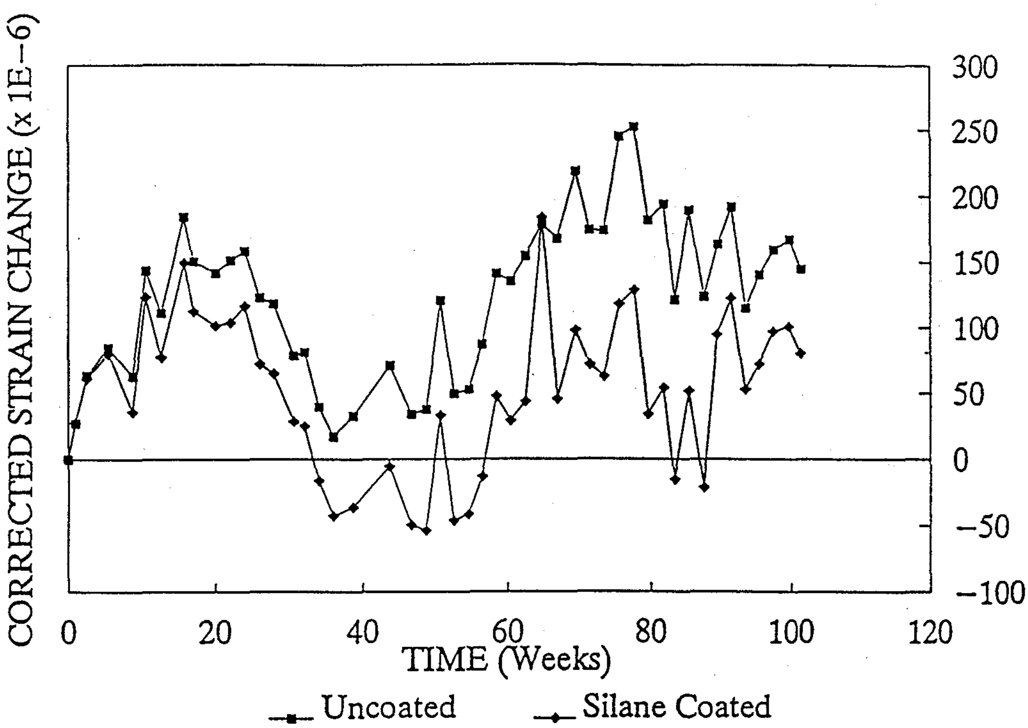

Fig 3 Long term in situ strain changes in test beams

REMEDIATION STRATEGY

The measured expansions and ligature stresses indicate that the structural capacity of the beams may indeed be reduced, since there must be significant restrained strains in the beams as well as the measured expansion strains.

The long term monitoring of cores demonstrated that there is the potential for much more ASR induced expansion than has occurred to date.

The silane coating slowed the rate of expansion as expected. The initial assessment would be to coat the whole structure. The magnitude of the expansions to date and of the measured ligature stresses, however, mean that even with expansion at the lower rate further remediation might be required within a few years in the worst beams.

In contrast, in other beams the rate of expansion and the insignificance of that beam (all beams were mass produced for the worst case location, so much of their strength is redundant in most cases) are such that no remediation will be required within the desired service life.

In order to arrive at the most appropriate, cost effective repair strategy a three part process has been recommended:

- Part A: identify repairs that should be undertaken immediately; mainly a result of local corrosion of reinforcement not ASR.
- Part B: develop and cost the alternative repair options, being silane coating, beam strengthening, beam replacement.
- Part C: structural and operational analysis of the jetty to identify the critical elements. Assess their prognosis for future fitness for purpose, both with and without coating.

Finally the options can be compared over the client's estimate of the remaining working life of the jetty in terms of:

- performance
- discounted cost
- client's projected utilisation of the jetty.

CONCLUSIONS

An ASR affected marine structure in Western Australia has been monitored for two years. The in situ expansions of the test beams were significant over the period.

Cores removed from the structure proved that there is the potential for significant future ASR induced expansion.

A silane coating was shown to be effective in slowing the rate of expansion. Its effectiveness would be expected to increase as the beam dries out.

However, the large expansions to date, together with measured high ligature stresses (induced by the ASR expansion), suggest that for some beams silane coating might not be the most cost effective solution. Even with reduced expansion, critical beams might need replacing anyway at some time in the fairly near future.

The assessment to date has enabled the real behaviour of the jetty to be quantified. As a result the next stage of managing the problem can be put in place in order to arrive at the most cost effective solutions for maintaining the fitness for purpose of the jetty over the required service life.

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