FIELD EVALUATION OF THE MITIGATING EFFECT OF SILANE TREATMENT ON AAR IN CONCRETE RAILWAY SLEEPERS

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ABSTRACT

As part of an investigation into AAR-induced premature failure of pre-stressed concrete railway sleepers in Western Australia, the mitigating effects of treating sleepers with silane water repellent were examined. Three sections of track (of 100 sleepers each) showing varying degrees of deterioration were selected for the trial. After detailed visual assessment, every second sleeper in the selected track sections was treated with isobutyltriethoxysilane after the first assessment. A further three assessments were carried out over a 14 month period, with a final assessment three years after treatment.

To perform the initial visual assessments, a numerical rating system was developed to describe the condition of the sleepers, assigning an arbitrary numerical value to each type of noticeable defect. These individual defect-values were summed to provide the numerical rating for each sleeper at each inspection.

During subsequent assessments, the average rating for the treated sleepers for each track section was compared with the average for the untreated sleepers.

At the initial survey, the average numerical ratings for the treated and untreated sleepers were not significantly different for any of the three sections of track. Over the period of the investigation, the average numerical rating for the untreated sleepers diverged from that for the treated sleepers and at the completion of the study the average numerical ratings for untreated sleepers exceeded those of the treated ones by up to 194%, with the largest increases occurring in the sections of track showing less deterioration initially.

It was concluded that silane treatment had a significant slowing effect on the damage to the sleepers caused by AAR.
Keywords: AAR, concrete sleepers, isobutyltriethoxysilane, silane treatment.

INTRODUCTION

The Eastern Goldfields Railway in Western Australia runs from Perth to Kalgoorlie. Prestressed concrete sleepers were introduced into the EGR track as part of the 1978 to 1982 upgrade, during which the Avon Valley line was converted to dual gauge. The sleepers were made at Meckering, 150 km north-east of Perth, using local aggregate and sand. The sleepers were pre-stressed by 16 strands of high tensile steel wire running along their full length.

Cracking in sleepers commenced not long after, with the earliest observed cracks appearing in the sleepers installed between Northam and Tammin during 1979. Subsequent surveys have shown the problem to be progressive and it is now becoming evident throughout the line, in sleepers of all ages. The latest full line survey completed in 1992 indicated that 8.1% of all sleepers showed cracking to some extent.

The cracked sleepers vary in condition from those only just showing crack initiation to those with fully developed wide cracks along their entire length. Load testing has shown that the cracking has not caused a decrease in load bearing capacity, however failure occurs when the top of the shoulders split off.

INVESTIGATION INTO THE CAUSE OF CRACKING

By 1987 it was realised that the problem was ongoing, and an investigation into the cause of the cracking was commenced by Westrail. From the beginning, it was thought that the problem was possibly due to Alkali Aggregate Reaction (AAR). However early investigations by outside consultants did not find evidence of AAR due to the granite aggregate containing strained quartz, which is only slowly reactive. Subsequent investigations (Shayan *et al.*, 1990; Shayan & Quick, 1992; Salome & Edwards, 1993) have demonstrated that strained quartz AAR is the primary cause of the sleeper failure.

Work by others (Tew, 1990) using dynamic testing on cracked sleepers showed that the AAR had not reduced the structural integrity under typical track loadings. Work by the author (reported elsewhere) showed that the AAR had affected the engineering properties of the concrete, with a reduction in modulus of elasticity correlated to petrographic findings of AAR reaction products and micro-cracking.

The Meckering quarry from which the granitic aggregate was sourced is located in the broad geographical province constituting the SW portion of the Australian Continental Shield which contains mostly granitic rocks of PreCambrian age. This portion of the shield is undergoing a degree of tectonics, ancient in origin but recurrent, characterised by long faults. One of these is the major Darling Fault defining the escarpment to the east of the coastal plain running from Geraldton to Bunbury (and the rift valley continuing further south). The 1978 Meckering earthquake was an event in this tectonic episode.

The granite at Meckering contains up to 25% strained quartz which indicates it has undergone a near-metamorphic transition. Despite early reports indicating potential reactivity, strained quartz only became widely identified as possessing potential AAR reactivity during the mid-eighties. It is now universally recognised as a reactive aggregate, potentially capable of causing AAR, albeit a slower-developing form of AAR than that which results from the presence of more reactive silica (opaline silica, cherts, glass).

MANAGING AAR

Initially, most of the published literature concerned with managing the problems associated with AAR dealt with preventative measures, including careful aggregate evaluation and choice of low-alkali cement. Subsequently, a number of detailed technical papers and reports have been issued, discussing mitigating post-treatments for AAR. One such paper stressed the need to prevent ingress of moisture and warned against trapping moisture in the concrete (Flanagan, 1981).

Examples of managing AAR from around the world include:

- Protection of exposed concrete affected by AAR in Iceland has been accomplished using silane treatment (Asgeirsson, 1986), where it is claimed the AAR stops once the relative humidity inside the concrete falls below 80%.
- An assessment of bridges in the UK (Tordoff, 1990) found that silane treatment was the preferred option where complete shrouding with a ventilated cladding was not practicable. This view is reflected in the UK Department of Transport procedure for investigating and dealing with ASR in their structures, issued in 1990 (UK DoT, BA 35/90) where they state that the only recommended treatment other than replacement is silane application.
- Other studies have examined various types of surface treatment, and evaluated them by measuring growth on mortar bars in the lab (Fujii *et al*, 1989a and 1992). Silane treatment (both with and without MMA overcoating) gave good results on high strength concrete (water/cement ratio 0.5). Simultaneous field studies (Fujii *et al.* 1989b; Miyagawa *et al*, 1992) observing macro-symptoms in treated AAR damaged bridge piers and abutments found no new cracks have developed in 7 years in the sections treated with monomeric silanes.

EVALUATION OF MITIGATING EFFECTS OF SILANE TREATMENT

In order to determine if it was possible to arrest the rate of deterioration of the sleepers, it was decided to carry out a field trial of silane treatment. This paper describes that trial, which consisted of a detailed assessment of the performance of sleepers treated in the field with a 100% monomeric silane (isobutyltriethoxysilane). The silane was applied to the sleepers without lifting them from the ballast bed to simulate practical field conditions. Three sets of 100 sleepers (one at Northam, two near Meckering, all manufactured in 1978 or 1979) were selected for the study, with each set demonstrating a different range of initial sleeper conditions.

Selection and in-situ treatment of sleepers

The trial commenced in May 1992. Three sets of 100 sleepers each were selected at locations which represented a range of observed sleeper conditions, as follows:

- Northam 119 - located at the 119 km marker, to the west of Northam Station. The sleepers in this section covered a range of conditions, from severe cracking to virtually no cracking at all.
- Meckering 156 - located at the 156 km marker, to the east of Meckering Station. This section of track had the highest incidence of cracking recorded, with all sleepers showing cracking to some extent.
- Meckering CBH - located at the Collective Bulk Handling terminal at Meckering Station, adjacent to the junction of the two narrow-gauge tracks. The sleepers in this section were all essentially undamaged.

The sleepers in each trial section were numbered 1 to 100. Every second sleeper (the even numbered sleepers) in each set was treated by applying the silane to the upper face and along the top of the side faces. It was assumed that silane would run down the sides and penetrate the outside faces of the concrete. It was reasoned that where the silane did not reach, water would also fail to penetrate.

Application of silane was carried out using high volume low pressure airless spray at a coverage rate of 0.4 to 0.5 l/m^2, which corresponds to 0.8 to 1.0 litre per sleeper. The odd-numbered sleepers were left untreated.

Method of Visual Evaluation and Numerical Rating

It was necessary to record the condition of the sleepers at the commencement of the trial. To do this, a numerical rating system was developed to assign a numerical value to each type of defect present. Most sleepers demonstrated more than one defect, each of which was assigned its equivalent numerical rating. Each sleeper could then be assigned a total numerical rating reflecting its overall condition at each inspection by adding up the values for each defect found on it.

The visual evaluation of the sleepers consisted of inspection of the upper surface of the sleepers, and also of the upper portion of the sides of the shoulders which usually involved removing some ballast.

A convention was formulated for denoting specific parts of the sleepers, and for depicting the type and severity of failure at each of these locations.

To allow reference to specific parts of each sleeper, the general direction toward Kalgoorlie is called "E(ast)" and the direction of Perth is called "W(est)". Then facing East, the left-hand side is called "N(orth)" and the right hand side "S(outh)". The sleeper was subdivided into the "N" and "S" "Shoulders" (the extension beyond the rails), and the "Centre". The centre was further subdivided into "N", "Mid" and "S" sections. The sides of the shoulders (which were examined by removal of ballast) were denoted as "NE", "NW", "SE" and "SW". The sides of the central section were not examined due to the presence of the ballast.

It was found that cracking generally first manifests itself as a hairline crack in the approximate centre of upper edge at one of the ends. This then develops into map-cracking of one or both of the shoulders (ie. in the anchor zone of the pre-stressing wires). With further time, this gradually resolves into linear cracks, usually appearing first in the shoulder regions and then along the entire length of the sleeper. Linear cracks that begin at one end but do not extend all the way across the surface were referred to as incipient cracks. Linear cracks extending from one end of a visible surface to the other were graded as T(hin), M(edium) or W(ide).

To allow elementary numerical treatment and graphical presentation of the results, a numerical value was assigned to each type of failure, with greater magnitude corresponding to more severe failure. The abbreviated notation used and the numerical values assigned to each type of failure are given in Table 1.

The condition of the sleepers was assessed in detail at the commencement of the trial, followed by three further assessments over a 14 month period. A final assessment was carried out after three years (March 1995). At each assessment, every sleeper was carefully examined and all visible defects were recorded on a field work sheet. The numerical rating for each defect was then entered onto the work sheet, and the total defects summed for each sleeper. Next the average numerical rating was calculated for both the treated (even numbered) sleepers in each section and the odd-numbered untreated sleepers.

Comparing the average ratings for the untreated sleepers provided an indication of the rate of on-going deterioration, whilst comparing the average for the treated sleepers with that for the untreated ones over the entire survey period provided an indication of the mitigating effects of the treatment.

Table 1. Notation and numerical rating of visual defects

Type of Failure	Abbreviation	Numerical Value
Slight Map Cracking Only	SM	1
Extreme Map Cracking	E	2
Incipient Linear Crack	I	3
Thin Linear Crack	T	4
Medium Linear Crack	M	5
Wide Linear Crack	W	6
Two thin cracks combining in a Y	TY	7
Two medium cracks combining in a Y	MY	9

RESULTS

The results for the sleepers at Northam 119 and Meckering 156 are shown in Table 2. The aggregate rating for the entire 50 sleepers in each sub-set are given as well as the numerical average.

Table 2. Sleeper Survey Results for Northam 119 and Meckering 156

Location and Date	Untreated		Treated	
	Aggregate Rating	Average	Aggregate Rating	Average
Northam 119				
19/05/92 (Initial)	510	10.20	481	9.20
25/09/92	687	13.74	515	10.30
17/02/93	962	19.24	479	9.58
05/07/93	964	19.28	612	12.24
06/03/95	981	19.52	740	14.80
Meckering 156				
19/05/92 (Initial)	1344	26.88	1348	26.96
25/09/92	1705	34.10	1551	31.02
17/02/93	2382	47.64	1713	34.26
05/07/93	2552	51.04	1959	39.18
06/03/95	3126	62.52	2075	41.50

For the sleepers at Meckering CBH, the system of numerical ratings could not be applied because initially all of the sleepers had a rating of less than 3, mostly 0. Over the time frame of the surveys, neither group has developed sufficient macro-defects to produce a significant difference according to the system of numerical ratings described.

DISCUSSION

The results showed that the treated sleepers deteriorated at a reduced rate based on a comparison of the average numerical ratings for treated versus untreated sleepers in each set.

Initially the average for the two sets in each trial section were essentially equal. With time, the average for the untreated sleepers progressively increased. The average for the treated sleepers also increased, but at a reduced rate compared to the untreated sleepers.

For Northam, the treated sleepers had an average rating of 14.8 after three years. The untreated sleepers would have had this average at some time between September 1992 and February 1993, ie. some six months after the first survey. Similarly for Meckering 156, the 41.50 average of treated sleepers at three years would have been reached by the untreated sleepers about the end of 1992. Simplistically, this suggests that the rate of deterioration was reduced by almost one-sixth.

It is recognised that the method of evaluation used contains inherent imprecision. The visual survey is subjective especially in assigning width criteria to the cracks. Direct comparison between the result for individual sleepers at separate surveys is therefore subject to a high degree of uncertainty. However such subjective variations even out over the aggregates, and it is thought that the different averages obtained at any one survey reflect a real difference in the overall condition of the sleepers. Since the author personally performed the visual surveys in each instance, the subjectivity of the surveys is also lessened.

Although significant results were not obtained for the sleepers which were in good condition at the commencement of this trial (ie. those at Meckering CBH), it was noticed that minor defects were developing in these sleepers as the trial progressed, with the development of a small crack in the centre of the outer edge of the shoulders, more in the northern side of the sleeper.

The incidence of these precursors to full-scale cracking were more prominent in the untreated sleepers, and by using a modified rating system which discriminated between the number and size of such minor cracks, it was concluded that the untreated sleepers were developing cracking at more than twice the rate of the treated ones.

CONCLUSIONS

Using a system of numerical rating based on arbitrarily assigned values to observed defects associated with cracking in railway sleepers, it is possible to monitor changes in the condition of the sleepers with time.

Such an assessment of sleepers treated with isobutyltriethoxysilane, made over a three year period, has demonstrated that by eliminating water ingress, the rate of deterioration of the sleepers can be substantially reduced.

REFERENCES

Asgeirsson, H. (1986) "Silica fume in cement and silane for counteracting of alkali-silica reactions in Iceland", *Cement and Concrete Research*, 16:423-428

Flanagan, J.C. (1981) "Alkali-aggregate reaction: Practical preventative and remedial measures", *Concrete Beton*, 19-22

Fujii, M., Miyagawa, T., Tomita, M., Imae, M. & Ono, K. (1989) "Effect of coating to inhibit AAR of concrete structures", Proc. 8th Int. Conf. on AAR, Kyoto, 869-874

Fujii, M., Kobayashi, K., Miyagawa, T. & Hisada, M. (1989) "Surface treatment for concrete structures damaged by alkali-aggregate expansion", Proc. 8th Int. Conf. on AAR, Kyoto, Japan .875-880

Fujii, M., Miyagawa, T., Inoue, S. & Uehata, N. (1992) "Effect of concrete surface treatments on expansion due to ASR", Proc. 9th Int. Conf. on AAR, London.

Miyagawa, T., Kobayashi, K., Kojima, T., Nakanu, K. & Yamaguchi, Y. (1992) "Effect of coating to inhibit AAR in concrete structures", Proc. 9th Int. Conf. on AAR, London.

Salome, F. & Edwards, C. (1993) "Investigation of alkali aggregate reaction in concrete railway sleepers", CTI Consultants Pty. Ltd. Report C9134

Shayan, A., Ivanusec, I., Westgate, P. & Diggins, R. (1990) "Final report on investigation of cracking in Westrail concrete sleepers", CSIRO Confidential Report DBCE DOC 90/58(M)

Shayan, A. & Quick, G.W. (1992) "Microscopic features of cracked and uncracked concrete railway sleepers", *ACI Materials Journal*, July-August 1992: 348-361

Tew, G.P. (1990) "Testing of Concrete Sleepers for Westrail", BHP Research and New Technology Report BHPR-ML/CN11/90/001

Tordoff, M.A. (1990) "Assessment of pre-stressed concrete bridges suffering from alkali-silica reaction", *Cement and Concrete Composites*, 12: 203-210

UK DoT Departmental Advice Note BA35/90 (1990) "Inspection and repair of concrete highway structures".