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S252

FIELD SURVEY OF THE EXTENT OF CRACKING AND OTHER DETAILS OF CONCRETE STRUCTURES SHOWING DETERIORATION DUE TO ALKALI-AGGREGATE REACTION IN THE SOUTH WESTERN CAPE PROVINCE

by C J Semmelink*

SYNOPSIS

The paper discusses the information gathered during an extensive field survey of concrete structures in the South Western Cape Province in 1978 to determine the extent of the cracking due to alkali-aggregate reaction.

An attempt was made to establish the source of aggregates and cement in the affected structures and attention was given to the relationship between the cracking of structures and factors such as environmental conditions, exposure conditions and the alkali content of the cements produced in the area.

A value for the present worth of the affected structures was calculated.

SAMEVATTING

In die referaat word die inligting bespreek wat gedurende 'n uitgebreide veldopname in 1978 ingewin is oor betonstrukture in die Suidwestelike Kaapprovinsie om te bepaal in watter mate krake wat aan alkali-aggregaat-reaksie te wyte is, daarin voorkom.

'n Poging is aangewend om die bron van aggregate en sement in die aangetaste strukture vas te stel en die verband tussen die kraak van strukture en faktore soos omgewings- en blootstellingstoestande en die alkali-inhoud van die sement wat in die gebied vervaardig word, het aandag geniet.

'n Syfer is vir die huidige waarde van die aangetaste strukture bereken.

S252/19

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Secretariat: NBRI of the CSIR
P O Box 395, Pretoria 0001, South Africa
Telephone (012) 86-9211 Telegrams Navorsbou
Telex SA 3-630

Sekretariaat: NBNI van die WNNR
Posbus 395, Pretoria 0001, Suid-Afrika
Telefoon (012) 86-9211 Telegramme Navorsbou
Teleks SA 3-630

* *NITRR, CSIR, Pretoria, South Africa*

1. INTRODUCTION

In 1975 the National Institute for Transport and Road Research (NITRR) was approached to determine the cause of the unexpected hair-cracks in the concrete slab of the N2 National Route between the D F Malan Airport and the Strand. It was first necessary to determine the severity and location of the cracking in the concrete pavement itself in order to analyse the possible cause.

No specific recommendations were at that time available as to how the problem should be tackled. After some experimentation the NITRR developed a technique which was very successful and will be described briefly.

2. ANALYSIS OF CRACKS IN CONCRETE PAVEMENTS

Cores removed from the cracked areas of the pavement were impregnated under vacuum with a low-viscosity epoxy resin (Epidermix 365) which had been coloured with an oil-soluble fluorescent dye (BASF FLUORCL 5G). (Approximately 1,5 g of dye powder in a 500 ml epoxy.)

After a 24-hour hardening period the cores were sliced along their length at right angles to the crack visible on the top surface, after which the crack patterns were established on film by a double exposure technique. Firstly the film was exposed for half the normal exposure time for the particular white light source used, to record the aggregate pattern on film, followed by another exposure using an ultraviolet light source in a darkened room to bring out the crack pattern. A yellow filter was used to cut out ultraviolet reflection.

On analysis of the crack patterns it was found that the cracks were mainly orientated horizontally in the cores, which pointed to the fact that the pavement had been subjected to high forces in a horizontal direction which could only have been caused by expansion in the concrete. This result was contrary to previous experience with concrete pavements.

Only then was the possibility of alkali-aggregate reaction considered and other symptoms associated with the alkali-aggregate reaction positively identified in the cores.

3. RESEARCH ON ALKALI-AGGREGATE REACTION

Research efforts on the alkali-aggregate reaction were then combined with those of the National Building Research Institute (NBRI). In conjunction with laboratory research on the problem it was decided to do a survey of concrete structures to determine the extent of the alkali-aggregate reaction problem and factors influencing it.

To achieve this the following information was needed:

(i) The percentage of structures that were affected.

(ii) The extent of the damage to each structure.

(iii) Climatic and environmental conditions.

(iv) The initial cost and year of construction to estimate the present value of the cost of construction.

After the visual inspection a number of damaged structures were selected at random for coring for further investigation in the laboratory.

Data in respect of the following were therefore recorded on a field survey sheet form for each structure:

(a) Severity and pattern of cracking.

(b) Exposure conditions of the cracked elements.

(c) Presence of salt or gel exudations at the cracks.

(d) Condition of surface coatings (if any).

(e) Relevant data on location, age, construction cost, etc.

The severity of cracking was graded into four classes:

Class 1 No cracks.
Class 2 Faint minor cracking or crazing.
Class 3 Definite cracks, small to medium in size.
Class 4 Severe cracks, 1 mm or more in width.

A small piece of concrete was taken from each structure that was examined to determine if any milled granulated blastfurnace slag (slagment) was present in the concrete.

For a meaningful comparison between the structures with regard to deterioration to be made they should be more or less of the same age. Furthermore, because the reaction is slow, the first visible signs of deterioration are often only obvious a few years after construction.

The structures were therefore grouped on the basis of date of commencement of construction in the following five-year periods:

1977 - 1973, 1972 - 1968, 1967 - 1963, 1962 - 1958, 1957 - 1953, 1952 - 1948, 1947 - 1943, 1942 - 1938.

Because it is impractical to examine structures that have some protection over the concrete, the survey was limited to exposed concrete structures (initially only bridges). The year in which construction was started, was taken as the year of construction of the structure.

It was decided that the main effort should be concentrated on a particular period from which a random sample of at least a hundred structures would be examined so that the extent of the problem could be determined with a reasonable degree of accuracy. Unfortunately the number of structures built during any particular period never reached this figure. The period during which the largest number of structures was built was therefore selected, namely 1963 - 1967, and all these structures were examined.

From each of the other periods a sample of ten structures was examined. Where the total number of structures was equal to or less than ten, all of them were investigated and where the total number of structures was more than ten, the structures that were examined were selected at random.

Two cement-producing factories, designated as B and C, were visited to collect all available information on the alkali content of the cement. Because the third factory, designated as A, did not have records of alkali content, it was not visited. However, a few values were obtained for this factory as well. All this information is given in Appendix A.

Because all the cement in the South Western Cape is marketed through a central marketing organization, Cement Sales (Proprietary) Limited, under one name, Eland Cement, it was impossible to determine the exact source of the cement for a particular structure. However, the total sales figures for the Western Cape were analyzed to determine the probability of the cement coming from a particular source.

4. DISCUSSION OF THE FINDINGS

(a) *General.* Not all cracking of structures is due to alkali-aggregate reaction. Features such as closure of expansion joints, spalling, off-setting and warping of structural members accompanying cracking must be looked for. Particularly in the case of younger structures

TABLE 1 : Incidence of cement aggregate reaction in different periods

	Number of Structures examined from specific period of construction							
Reaction Category	77 - 73	72 - 68	67 - 63	62 - 58	57 - 53	52 - 48	47 - 43	42 - 38
(a) Definite signs of the reaction								
SAR & H	2	1	8 +(1)*	2 +(3)	2	3		1
Cape Town City Council		(2)	10 +(2)	(4)	2			
CPA		1 +(4)	10	(1)	1	(1)		
Others		2						1
Total number of structures	2	10	31	10	5	4	0	2
Per cent of structures	17	53	48	83	62,5	50	0	40
(b) Possible signs of the reaction								
SAR & H	2		1					
Cape Town City Council	3		5		1			
CPA			2					
Others	1	5						
Total number of structures	6	5	8	0	1	0	0	0
Per cent of structures	50	26	12	0	12,5	0	0	0
(c) No signs of the reaction								
SAR & H	1	1	4			2	1	2
Cape Town City Council	1		20	(1)	1			
CPA	1	1	3	1		(2)	1	
Other	1	2			1			1
Total number of structures	4	4	26	2	2	4	2	3
Percent of structures	33	21	40	17	25	50	100	60
Grand total of structures	12	19	65	12	8	8	2	5

** Values given in brackets are the results from Mr K E Putterill's survey.*

assessment is not always easy. Therefore, where cracking occurred and signs of expansion were absent or in younger structures where a clear-cut decision could not be made, the structures were not listed with those where it was certain that the cracking was caused by alkali-aggregate reaction. This means that the survey tends to be on the conservative side in respect of structures affected by alkali-aggregate reaction.

(b) *Percentage of damaged structures.* The structures were divided into three categories, namely structures showing definite signs of reaction, structures showing possible signs of the reaction and structures showing no signs of the reaction (see Table 1).

From Table 1 it can be seen that in the age group 1963 - 1967 48 per cent of the structures examined showed definite signs of the reaction and 12 per cent possible signs of the reaction.

In some of the other age groups the percentage of structures showing definite signs of the reaction was even higher (all of these were not necessarily selected at random).

However, it seems fairly safe to conclude that approximately 50 per cent of the exposed concrete structures that have been built since 1950 show definite signs of the reaction. Therefore it is probable that approximately 50 per cent of all other concrete structures which were not inspected also have the potential to be affected by the reaction because the same materials were used.

(c) *Environmental Conditions.* From Table 2 it is evident that moisture plays an extremely important part in so far as it facilitates the reaction and also influences the wet/dry cycle. Temperature also has an influence on the severity of the reaction. This is concluded from the observation that most of the damaged faces of elements are exposed to the sun for some time during the day, thus raising the temperature and possibly accelerating the reaction as well as influencing the wet/dry cycle.

It is likely that concrete which is exposed to wetting and drying, and to heating and cooling will deteriorate faster than concrete which is continually wet or damp, because in the former instance the concrete is exposed to additional stresses.

A M Neville states that 'Other factors influencing the progress of the alkali-aggregate reaction include the availability of non-evaporable water in the paste and the permeability of the paste. Moisture is necessary and the reaction is accelerated under conditions of alternating wetting and drying. The temperature accelerates the reaction, at least in the range 10 to 38 °C (50 to 100 °F).'

In Figure 1 the mean value of daily air temperatures and the mean earth temperatures at a depth of 30 cm are plotted. Because of the mass of these structures it is expected that their internal temperature is likely to be very close to that of the earth, between 14 °C and 26 °C with the surface temperature probably reaching higher values. This is in the active range of temperatures according to Neville.

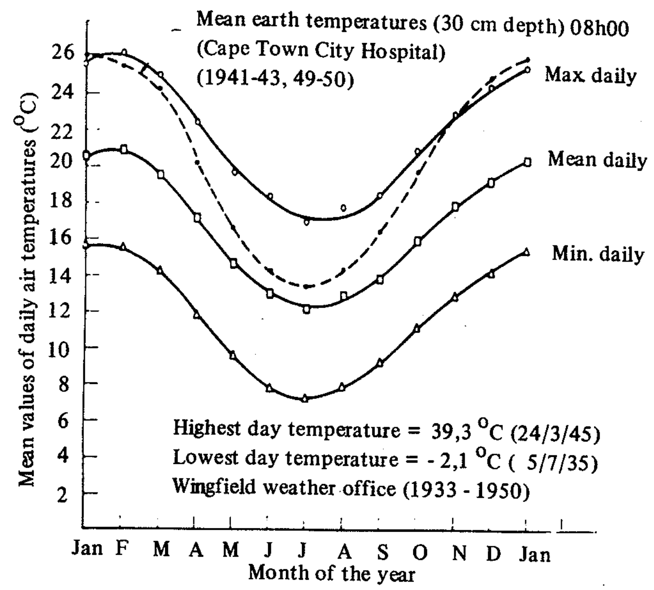

FIGURE 1 : Annual distribution of mean daily temperatures

Figure 2 gives the mean hourly values of temperature and shows that there are also diurnal changes. The cyclic variations in the concrete, however, are likely to be smaller because of the heat retained in the mass of the structure.

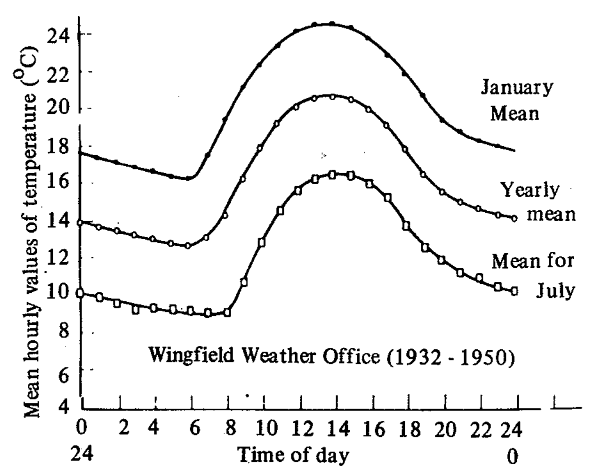

FIGURE 2 : Daily distribution of mean hourly temperature

As far as moisture conditions are concerned the mean monthly rainfall for the period 1937 - 1975 for the Cape Peninsula and environs is plotted in Figure 3. In Figure 4 the average number of days with a precipitation greater than or equal to 0,2 mm is shown. From Figures 3 and 4 it is seen that every month of the year must have cycles of

TABLE 2 : Summary of prevailing exposure conditions of damaged elements

A. Damaged structures constructed in the period between 1963 - 67

Direction	FRONT FACE (FF) (Exposed to atmosphere) – Class of Exposure					BACK FACE (BF) (not exposed to atmosphere) – Class of Exposure					
	P	WD - P	WD	WD-CW	CW	WE*	D	WD-D	WD	WD-CW	CW
N		1	23			9					
NE		1	8			4					
E		2	27			10					
SE			3			1					
S		2	15			7					
SW		1	10			7					
W		2	24			9					
NW			7			4					
Unknown	1	2	3			2					

B. All other damaged structures constructed in the periods other than between 1963 - 67

Direction	FRONT FACE (FF) (Exposed to atmosphere) – Class of Exposure					BACK FACE (BF) (Not exposed to atmosphere) – Class of Exposure					
	P	WD - P	WD	WD-CW	CW	WE*	D	WD-D	WD	WD-CW	CW
N		1	20	2		12	2				
NE			11			5	1				
E	1	1	29			10	2				
SE			3				1				
S			13	2		8					
SW		1	9			3	1				
W		1	36			12	4				
NW			13			2					
Unknown	1	1	5			4					2

* It was assumed that fillmaterial is always moist.

P = protected
WD - P = wet/dry to protected
WD = wet/dry
WD - CW = wet/dry to continuously wet

CW = continously wet
WE = wet earth
D = dry
WD - D = wet/dry to dry

alternating wet and dry conditions which, as has been pointed out earlier, aggravate the effect of the reaction. This, together with the *high* average temperature, is most probably one of the main reasons why the reaction is more rapidly noticeable here than in Nova Scotia, Canada (Dr M G Ducan, personal communication) for instance. Due to the high relative humidity of the air, conditions in the concrete will be conducive to the reaction taking place.

(d) *Influence of slagment.* In Table 3 a summary is given of the cement type and the condition of the structures for the period 1938 - 1972. Of the structures

TABLE 3 : Summary of structures constructed before 1972 according to cement type

Cement Type	Condition of Structure	Cape Town City Council	SAR&H	CPA	Total (per cent)
opc –	Cracked (2 +– 4) Fine cracks (1 – 2) Sound	6 4 8	16 1 6	6 5 0	28 (54) 10 (19) 14 (27)
TOTAL					52 (100)
opc + substantial quantity slag.	Cracked (2 +– 4) Fine cracks (1 – 2) Sound	0 0 1	0 0 2	0 0 0	0 (0) 0 (0) 3 (100)
TOTAL					3 (100)
opc + low quantity slag.	Cracked (2 +– 4) Fine cracks (1 – 2) Sound	5 1 3	0 0 0	1 0 0	6 (60) 1 (10) 3 (30)
TOTAL					10 (100)
uncertain	Cracked (2 +– 4) Fine cracks (1 – 2) Sound	1 1 6	2 0 2	1 1 0	4 (29) 2 (14) 8 (57)
TOTAL					14 (100)

TABLE 4 : Number of structures in different age groups containing slagment

Quantity of Slagment	Condition of Structure	'72 - '68	'67 - '63	'62 - '58	'57 - '53	'52 - '48	'47 - '43	'42 - '38
Substantial	Cracked (2 +– 4) Fine cracks (1 – 2) Sound		0 0 3					
Low	Cracked (2 +– 4) Fine cracks (1 – 2) Sound		6 1 3					
Uncertain	Cracked (2 +– 4) Fine cracks (1 – 2) Sound		3 1 8			1 1		

The fact that structures containing Malmesbury aggregate have cracked in some cases and are sound in others may be due to variable reactivity in the aggregate or the use of low alkali cement.

In the case of the CPA structures listed in Table 5, the sound structures are all in the Peninsula where the cement was most probably supplied by factory A whereas the cracked structures are all further out on N2 where there is a greater probability that cement from factories B and C was used. (There is definite proof that cement from factory C was used in the concrete pavement on N2.)

(g) *Surface coatings.* It would appear, also from overseas experience, that the application of impervious coatings to existing damaged structures would serve little purpose.

Attempts to seal cracks and coat concrete surfaces exhibiting cracking have been made on several road-over-rail structures. The coatings appear to be either of the epoxide or poly-sulphide type. In some instances the filling or coating has sealed the crack successfully, but generally many of the cracks have re-appeared through the coating and are often wider in the coating than in the backing concrete.

In some cases, the coating has aggravated the concentration of salts from cracks, as the bleeding of moisture from behind the coatings has concentrated at places where cracks have re-appeared.

TABLE 5 : Aggregate supplies from quarries on the Malmesbury Group to undermentioned bridge locations

Structures belonging to	QUARRY				
	Q1	Q2	Q3	Q4	Q5
SAR & H	1 (s) 4 (c) 10 (c) 17 19 28 33 (s) 38 (c)	36 53 (c)		12 (c)	9 (c) 54
City Council	104 * 105 106 127 (s) 127a (s) 127b (s) 127c (c) 133 134 (s) 134a (c) 151 (c)	132 (s) 132a (s) 132b (s) 150 (c)		102	117 (s) 119 (s) 120 142 (s) 144 (c) 145 (s) 146 (s)
CPA	201 (s) 202 203 (s) 204 (s) 213 214 (s)		224 (c) 224a (c) 225 (c) 226 (c) 231 (c)		

* (Constructed of) Table Mountain Sandstone
(c) = Cracked
(s) = Sound

containing ordinary Portland cement (o p c) 54 per cent were cracked, 19 per cent had fine cracks and 27 per cent were sound. The three structures which contained a substantial quantity of slagment were sound.

This verifies the laboratory finding that the addition of about 50 per cent (m/m) slagment to o p c effectively reduces expansion. It is of course not known whether the slagment was mixed with a high or a low alkali o p c for the three structures.

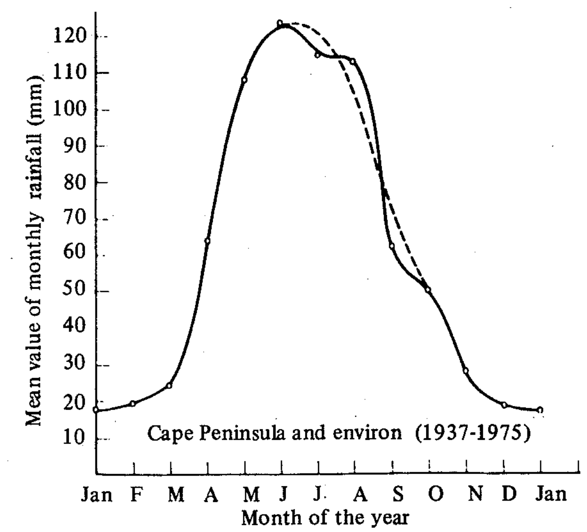

FIGURE 3 : Mean monthly rainfall distribution

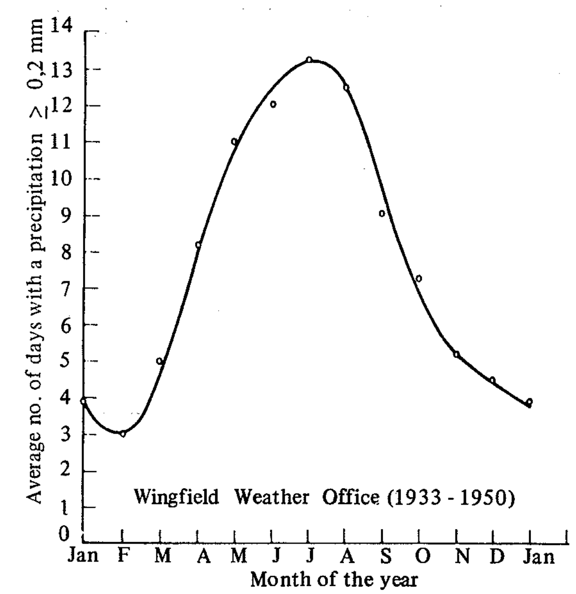

FIGURE 4 : Annual distribution of days with a precipitation $\geq$ 0,2 mm

(e) *Cements.* In Figure 5 the average annual percent Na_2O equivalent of the cements is plotted against time for the different factories. From this it is clear that factories B and C have consistently been producing high-alkali cements since at least 1960, when the determination of alkali contents was begun. The total alkali content for factory A was consistently well below 0,6 per cent until 1977 when the factory changed the source of its limestone. This resulted in an increase in the Na_2O equivalent of their cement to around 0,6 per cent.

In Figure 6 the percentage of ordinary Portland cement supplied by factory A and factories B and C respectively is plotted for the Cape Peninsula, the remaining Western Cape region (excluding the Peninsula) and the Western Cape region as a whole. It is evident from Figure 6 that the bulk of factory A's production was used in the Peninsula and that only a limited amount was supplied to the surrounding area. This means that the cement supplied to the Cape Town City Council was most probably mainly supplied by factory A.

However, in the case of the SAR & H (C F Zietsman, personal communication) and CPA there is reason to believe that the bulk of the cement used by them was supplied by factories B and C, ie a high-alkali cement. This is most probably the main reason why a higher percentage of structures belonging to these authorities show definite signs of the reaction.

From Figure 6 it is also evident that in the period 1963 - 1967 approximately 45 per cent of the cement used in the region as a whole was produced by factory A. This means that the remaining 55 per cent produced by factories B and C, was therefore mainly high alkali cement. One would therefore expect approximately 55 per cent of all structures to show signs of the reaction. This compares well with the value of the survey, namely 48 per cent showing definite signs and 12 per cent showing possible signs of the reaction.

Even in the Cape Peninsula approximately 34 per cent of the cement used (in the period 1963 - 1967) was supplied by factories B and C which would account for the fact that approximately 32 per cent of the structures belonging to the Cape Town City Council show definite signs of the reaction.

(f) *Analysis of aggregate source data.* Although no documentary evidence on the source of aggregate for any structure could be obtained, Dr Jacobs of the Cape Quarries Association (Proprietary) Limited obtained verbal information from the Quarry Owners about the sources of Malmesbury aggregate for 48 structures. This is given in Table 5.

Unfortunately not all of these structures were included in the field survey. However, comparing this information with that of the field survey, revealed the following:

Quarry	Structures Sound	Structures Cracked
Q1	10	6
Q2	3	2
Q3	0	5
Q4	0	1
Q5	5	2

5. EXTENDED SURVEY ON STRUCTURES OTHER THAN BRIDGES

Because the initial survey had been concentrated solely on bridge structures, this was followed up by a smaller survey in which concrete structures other than bridges were investigated.

(a) *Framed structures.* To obtain an objective impression as to whether or not alkali-aggregate reaction is a problem in framed structures it was necessary to find structures where the concrete was not covered by some coating or cladding. For this reason the investigation was limited to industrial buildings, basements and parking garages.

In all of these structures Malmesbury aggregate was used. Although some signs of reaction* were found where external structural components were exposed to the elements, no definite signs could be found on internal structural components which were protected from the elements.

A problem which should receive attention, however, is relationship of the alkali-aggregate reaction to the minimum cover of concrete over reinforcing steel. Quite a number of cases were found where the concrete had spalled due to corrosion of the steel as a result of inadequate cover. More serious attention should therefore be given to proper control of the placing of reinforcing steel to avoid serious problems in future.

(b) *'Dolosse' (Breakwater blocks).* Dolosse alongside the container terminal and the breakwater at the Victoria Basin were inspected. The aggregate used was Malmesbury aggregate.

The alkali-aggregate reaction was found to be fairly general in dolosse alongside the container terminal. There was a definite contrast between those dolosse lying high *above* sea level (where the occurrence of the reaction was fairly general) and those *at* sea level (where no signs of the reaction could be found). The dates of manufacture and serial numbers of these dolosse followed each other closely. Thus it seems fair to assume that the dolosse were manufactured from material from the same sources.

The damaged dolosse were also clustered together at intervals *along* the wall, indicating that most probably both high and low-alkali cements had been used in their manufacture. The dolosse along the container terminal side were manufactured in the years 1971-1972. The dolosse on the breakwater at the Victoria Basin, where no signs of the reaction were evident, were only manufactured in 1977 so that it may be a little early for the reaction to appear.

(c) *Pipes and culverts.* Some pipes and culverts on roads N1, N2 and TR11 were examined. The aggregate used in all cases was Malmesbury aggregate.

Some of the head walls and wing walls of both box culverts and pipe culverts showed signs of the reaction. However, no signs of the reaction could be found inside the box culverts or pipes where they were protected from the elements.

(d) *Reservoirs.* In all of these cases Malmesbury aggregate was used.

With the exception of one reservoir, all the others inspected showed definite signs of the reaction where exposed to the elements.

A subsequent investigation at one of the partly buried reservoirs has shown that the cracks are not visible below ground level.

(e) *Foundations.* One section from the foundations of each of 22 structures was examined. In all the sections examined, Malmesbury aggregate had been used.

The investigation was purposely concentrated on older structures so as to ensure that if the reaction had taken place it would be reasonably visible. Most of these structures showed signs of the reaction above ground level as evidenced by blotched appearance, cracks and exudations from cracks. It is also assumed that in general all the cement that was used in a particular structure was obtained from one source, in other words from one factory. This would mean that if a high-alkali cement had been used for the visible portion of the structure, a high-alkali cement must also have been used for the foundations.

In most of the cases the soil was moist and in quite a number of cases it was saturated to such an extent that the foundations were virtually on the water table. It can therefore safely be presumed that free moisture was available to penetrate into the concrete.

Despite this, visible cracks were only found on four of the foundations. All the other sections that were inspected showed no visible signs of cracking or the reaction whatsoever. (Small cracks may have been overlooked because of the rough surfaces and the dirt therein.)

As permission could not be obtained to core any of the cracked foundations of structures belonging to the Provincial Roads Department, permission was obtained from the Cape Town City Council to core the foundations of some of their structures which had shown definite or possible signs of the reaction in the superstructure.

Inspection of these cores showed that definite signs of the reaction were present in the foundations of two structures. In both these cases the soil at the point of investigation was dry. The foundations are therefore presumably in a zone with both wet and dry periods.

From most of these sections a small piece of concrete was obtained (from foundations, mass concrete bedding layers and in some cases the superstructure). These were tested with dilute hydrochloric acid to determine whether any granulated blastfurnace slag had been used in the cement.

* *Signs of reaction refer to signs of alkali-aggregate reaction as manifested by blotched appearance, cracks and exudations from cracks.*

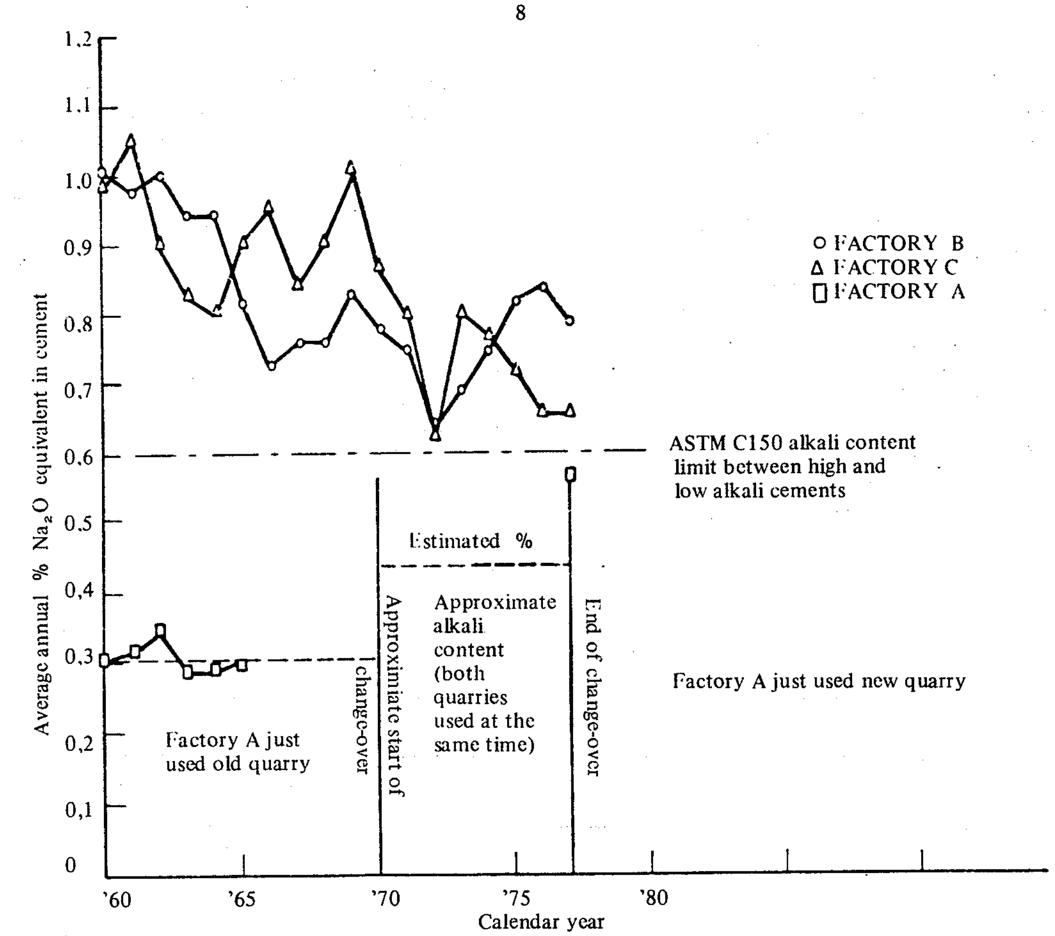

FIGURE 5 : Distribution of average annual per cent Na_2O equivalent from 1960 to 1977

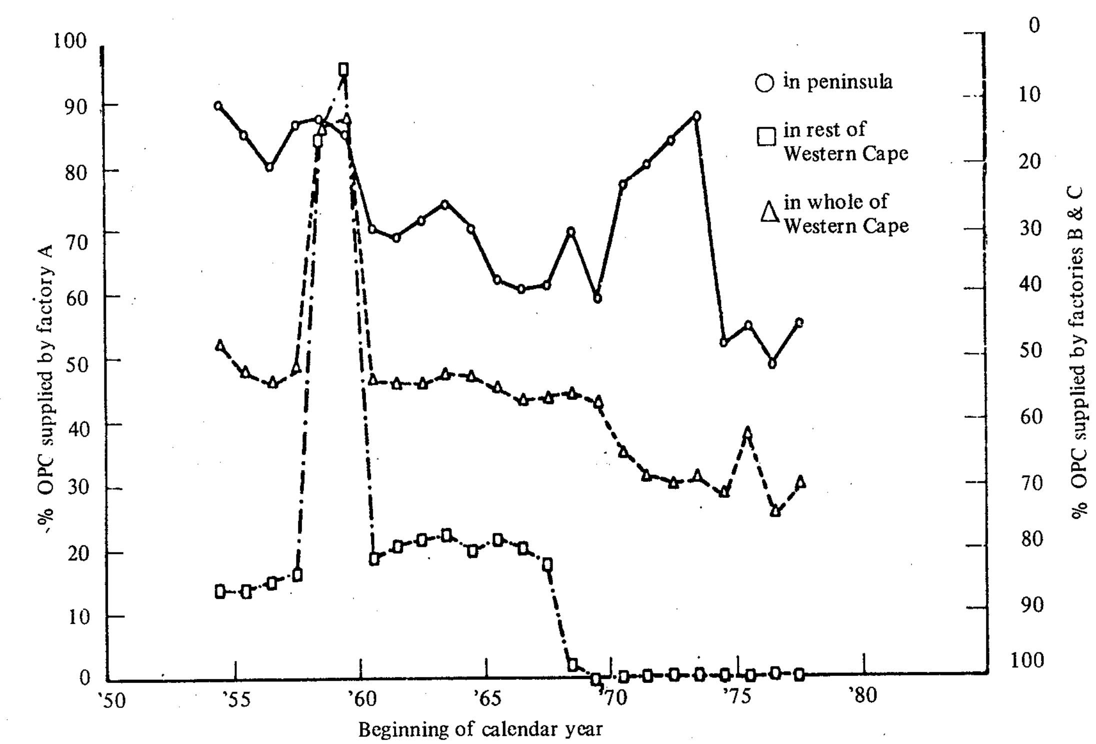

FIGURE 6 : Distribution of per cent OPC supplied by different companies from 1954 to 1977

APPENDIX A

PERCENTAGE Na_2O EQUIVALENT IN CEMENTS

Calender Year	Factory					
	A		C		B	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1960	0,3043	0,0433	0,9850	0,1356	1,0130	0,1372
1961	0,3173	0,0873	1,0582	0,2838	0,9759	0,1017
1962	0,3492	0,0627	0,8988	0,2893	1,0197	0,0960
1963	0,2879	0,0445	0,8262	0,0704	0,9427	0,0941
1964	0,2910	0,0868	0,8019	0,0893	0,9434	0,0709
1965	0,3050	0,0265	0,9058	0,1661	0,8144	0,1062
1966	–	–	0,9566	0,0727	0,7269	0,1062
1967	–	–	0,8435	0,0694	0,7596	0,0882
1968	–	–	0,9088	0,1235	0,7602	0,0518
1969	–	–	1,0073	0,1520	0,8310	0,0282
1970	–	–	0,8740	0,0869	0,7768	0,0859
1971	–	–	0,8037	0,1112	0,7517	0,0965
1972	–	–	0,6369	0,0949	0,6394	0,1102
1973	–	–	0,8077	0,0658	0,6890	0,0577
1974	–	–	0,7702	0,0762	0,7512	0,1099
1975	–	–	0,7160	0,0812	0,8243	0,0684
1976	–	–	0,6600	0,0996	0,8431	0,0453
1977	0,5700	0,0523	0,6567	0,0661	0,7942	0,0519
1978*	0,6043	0,0342	0,5563	0,0550	0,7125	0,0150

* *Values from analysis by J Muller Laboratories, Woodstock to the end of March 1978*

In only one foundation were signs of granulated blastfurnace slag found, in this particular case in reasonable quantities. In all the other cases the test was negative and it seems as though only Portland cement had been used.

6. CONCLUSION

The alkali-aggregate reaction seems to depend on a critical balance between free moisture, temperature, wet/dry cycles and the composition of the mix.

Where framed structures are protected it seems fairly safe to assume that the possibilities of any serious damage occurring as a result of the reaction are very slight. Where they are unprotected it may be wise to keep a watchful eye on them.

All in all, it can be said that the investigation of other structures seems to bear out the initial findings on bridge structures.

As far as foundations are concerned, it seems as though the critical circumstances, which are necessary for the reaction to take place, are absent in most of them. Cracking of the superstructure is far more severe.

The value of the bridge structures involved. It was found to be totally impossible to assess the cost of the damage in terms of replacement cost of the damaged elements. The only value that could be approximately determined was the *present worth* of the structures. The *present worth* of a structure was determined by multiplying the cost of construction of the structure by a *present worth factor;* this was determined by dividing the *construction index* for 1977 by the *construction index* for the year in which the structure was built. On the recommendation of the Department of Statistics, the *construction index* was compiled by combining the building materials price index and the consumer price index in a ratio of 2:1 and dividing by 3, because it was estimated that the labour cost would be approximately one third of the cost of the structure (see Appendix B for present worth factors).

Unfortunately it was not possible to obtain the cost of construction of all these structures. Therefore an average value was calculated to give an indication of the size of the investment. The average *present worth* estimate of a bridge structure in 1977 was approximately R400 990 and the *present worth* estimate of the damaged concrete road was R13 642 719. Taking only those bridges and the concrete road that showed definite signs of the reaction into account, the *present worth* estimate of this investment was R37 301 129 in 1977.

7. RECOMMENDATIONS

From a research point of view one finds more often than not that no information on material sources can be found when a problem is experienced with a particular structure because this information is not kept on record or because the files are destroyed virtually immediately after completion of the project. It is recommended that material source, mix design, and other relevant information be stored for a period of at least 10 years, as this will help the researcher in pinpointing the cause of any problem much more accurately as well as in finding a solution to the problem.

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APPENDIX B

PRESENT WORTH FACTORS

Year of Construction	Building Materials Price Index	Consumer Price Index	Construction Price Index *	Present Worth Factor **
1937	26,2	32,7	28,367	7,741
1938	26,2	33,9	28,767	7,633
1939	26,5	33,9	28,967	7,581
1940	33,2	35,1	33,833	6,491
1941	39,3	36,7	38,433	5,714
1942	44,8	39,9	43,167	5,087
1943	48,5	42,3	46,433	4,729
1944	49,6	43,8	47,667	4,607
1945	49,1	44,9	47,700	4,604
1946	49,0	45,6	47,867	4,588
1947	54,0	47,4	51,800	4,239
1948	57,0	50,2	54,733	4,012
1949	57,2	52,0	55,467	3,959
1950	58,5	54,1	57,033	3,850
1951	68,6	58,0	65,067	3,375
1952	79,5	63,1	74,033	2,966
1953	74,4	65,3	71,367	3,077
1954	75,3	66,5	72,367	3,035
1955	80,2	68,6	76,333	2,877
1956	81,8	69,9	77,833	2,821
1957	81,2	72,0	78,133	2,811
1958	79,3	74,5	77,700	2,826
1959	78,8	75,4	77,667	2,827
1960	80,9	76,4	79,400	2,766
1961	81,5	77,9	80,300	2,735
1962	82,3	79,1	81,233	2,703
1963	84,3	80,0	82,867	2,650
1964	86,2	82,0	84,800	2,590
1965	88,7	85,0	87,467	2,511
1966	91,0	88,1	90,033	2,439
1967	91,5	91,0	91,333	2,404
1968	93,0	92,6	92,867	2,365
1969	96,4	95,3	96,033	2,287
1970	101,0	100,3	100,767	2,179
1971	104,7	106,4	105,267	2,086
1972	109,4	113,3	110,700	1,984
1973	122,1	124,1	122,767	1,789
1974	144,7	138,5	142,633	1,540
1975	176,5	157,2	170,067	1,291
1976	207,4	174,7	196,500	1,118
1977	232,2	194,4	219,600	1,000

* Construction Price Index = $\frac{2}{3}$ Building Materials Index + $\frac{1}{3}$ Consumer Price Index

** Present Worth Factor = $\frac{\text{Construction Price Index for 1977}}{\ldots}$