Repair of Alkali-Aggregate Reaction Damage to the Motorway Structures of the Pell Street Interchange, Port Elizabeth, Republic of South Africa

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ABSTRACT

The paper outlines investigations undertaken to determine the presence and effects of AAR in the concrete structures, in particular the pile caps, of the Pell Street Interchange. Findings, conclusions and the adopted repair method of encapsulating affected pile caps with reinforced and prestressed concrete are described, as are the remedial measures adopted for other affected elements.

1. INTRODUCTION

One of the largest upgrading contracts of its kind in the Republic of South Africa is presently nearing completion on the concrete motorway structures of the Pell Street Interchange in Port Elizabeth. The structures are some 20 years old and the upgrading has involved repair and strengthening of superstructures and substructures of the elevated ramps and carriageways. The foundations are all piled, and the overall strengthening measures adopted were specifically devised so as to avoid costly strengthening work on the piled foundations. Limited excavation to expose the tops of certain pile caps was still, however, required for the construction of additional columns and support of temporary jacking towers. During the course of this work, fairly large width crazing pattern cracking was observed in areas on the top of some pile caps. Examination of cores taken from one such pile cap positively identified alkali-aggregate reaction (AAR) within the existing concrete and it was then concluded that the observed cracking was the result of AAR.

Following this discovery, a comprehensive investigation programme was launched to determine both the degree and extent of the problem on the pile caps. Remedial measures were devised and implemented under the upgrading contract. Investigations of the other parts of the structures were also undertaken and various remedial measures implemented where existing or potential AAR problems were encountered.

2. PILE CAP INVESTIGATIONS AND FINDINGS

2.1 Initial Investigations

When AAR was first identified, excavation to some seven pile caps was

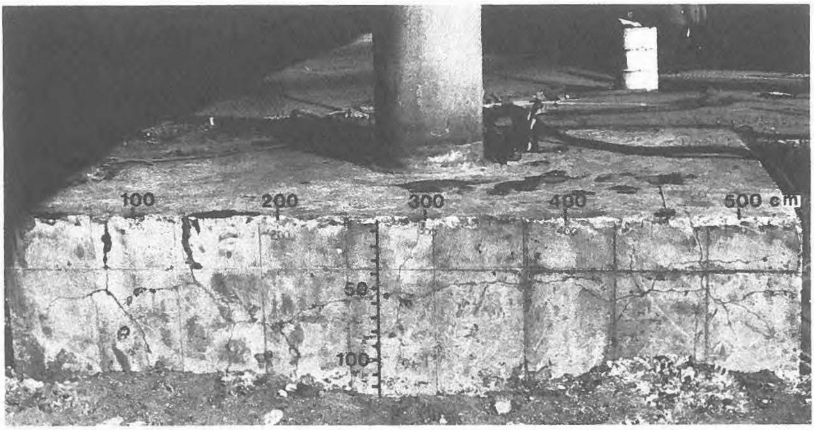

Fig.1 - Typical AAR Cracking to the Side Face of a Column Pile Cap

in progress. All of these were then fully exposed over their top surfaces, cleaned by waterblasting and carefully inspected. Cracking on three pile caps was observed. Further excavation was undertaken to expose limited lengths of the side faces of these pile caps. Cracking was again present, with vertical cracks in some cases continuing to the underside. Partial undermining was then undertaken to trace the extent of these cracks along the underside of the pile caps as well as to inspect the piles themselves.

The observed cracking on the pile caps had widths varying from very fine up to 6 mm wide, with the larger cracks occurring predominantly on the side faces as typically illustrated in Fig. 1. Cracks on the top surfaces were generally confined to the outer edges as well as immediately around the existing columns, such areas being assessed as falling within likely zones of tensile stress development under the action of applied loading. On the pile caps undermined, cracks were observed along the undersides, although their location was such that they were suspected as being structural in origin, rather than directly attributable to AAR. The exposed surfaces of the piles themselves appeared sound and free of cracking.

The above inspections were backed up by an extensive programme of core drilling for the purpose of laboratory examination and testing. A vertical core was taken from the top 200-300 mm surface of all pile caps which had been visually inspected. In addition, a sample pile cap exhibiting the most severe AAR cracking was selected for a more comprehensive coring programme, designed to sample concrete from the various structurally critical parts. These included vertical cores from the top surface at positions of different cracking severity and of varying lengths up to the full depth of the cap and into one of the piles. Horizontal cores were taken from a side face and further vertical cores from the underside of the pile cap.

The cores from the three cracked pile caps all exhibited signs of AAR to varying degrees. Cores from both the top and side surfaces, up to depths of 200-300 mm, of the sample pile cap showed very pronounced effects of AAR. Cracks up to 1 mm wide and which appeared open, were present in the coarse aggregate and continued into the surrounding mortar where they were filled with white reaction product. Other typical features of AAR were present, including white reaction product on fracture surfaces and dark reaction rims around the aggregate although the uncrystalized gel was rarely identified. Generally, cores from greater depths into the pile cap as well as from the underside showed lesser signs of AAR and cracking. The pile core appeared free of AAR. In contrast to the cracked pile caps, cores from the uncracked pile caps showed no definite signs of AAR.

Compressive strength and elastic modulus (E-value) tests were done on selected cores from cracked and uncracked pile caps to assess the magnitude of any structural deterioration of the AAR affected concrete. With compressive strengths, no real distinction could be made between the results, on the basis of the presence, severity or absence of AAR. On the other hand E-values of some cores from the surface of the AAR cracked pile caps were very low in relation to the average. Otherwise, no real distinction could be made between the results from the AAR affected or unaffected cores.

2.2 On-going investigations

Due to time constraints of the contract, the results of the initial investigation were used to devise the remedial measures to the pile caps known at that stage to be affected by AAR. An on-going investigation programme was, however, implemented to determine the condition of other pile caps. This programme is now nearing completion. There are a total of 92 pile caps on the Interchange, 86 of which will have been inspected, either partially or in full, by the end of the investigation programme, those not inspected being virtually inaccessible.

Cracking to varying degrees has been observed to a large number of the pile caps. However, inspection of cores taken from a selected sample of these, have in some cases shown no signs of AAR. The cause of such cracking has been attributed to early drying shrinkage of the concrete. It has been found that such cracking is confined to the top surfaces of the pile caps away from the edges and with depths of 100-200 mm. Many of the cracked pile caps have been found to fall within this non-AAR category. Significant cracking induced by AAR has, however, been found on a further five pile caps to date, two of which are abutment pile caps. The location and pattern of this cracking on the top surfaces was found to vary quite considerably between pile caps and from that found with the initial investigations, although on the side faces, the typical cracking as illustrated in Fig. 1 was consistently observed. In cores from some of the pile caps, signs of AAR were found to commence only 150-200 mm from the surface, the upper depth being free of AAR, which was contrary to the findings of the initial investigation. Pile caps from which such cores were taken, also showed non-typical top surface cracking. It has been concluded that this cracking was probably initiated by early drying shrinkage, allowing ready access of moisture to the interior concrete, with the ensuing expansion associated with AAR, enlarging and propogating these cracks.

2.3 Conclusions from the Investigations

The coarse aggregate in the existing concrete is a crushed quartzite, with the fine aggregate being a mixture of crushed quartzite and dune sand. The occurrence, either actual or potential, of AAR would have been unknown at the time of construction of the Interchange, it being only fairly recently that these particular quartzites have been identified as being potentially reactive. The source of the alkalis must be in the cement, testing of soil and water samples having shown negligible quantities of the deleterious alkalis.

From the initial investigations, it was concluded that pile caps which showed no visible signs of cracking were free of AAR and in view of the elapsed time, would be unlikely to undergo AAR in the future. Where cracking did occur, however, this was attributable to AAR, with the resulting deterioration of the concrete being more severe in the outer 200-300 mm depths of the top and sides. This outer skin had correspondingly low deformation characteristics relative to the internal core and underside of the pile cap, both of which, although showing signs of AAR, still retained adequate structural properties similar to those of an unaffected pile cap. However, despite the age of the concrete it could not be conclusively stated that AAR or the actions of the gel thus formed had as yet reached completion, although, more than likely the major portion would already have occurred. Furthermore, from the observed cracking along the undersides it was considered that the stiffness reduction in the top surfaces had resulted in possible structural weakening, mainly in the bending resistance of the pile cap due to a lessening of its effective depth. Finally, though, the piles themselves would be unlikely to be affected by AAR.

The on-going investigations identified a different category of cracking, not attributable to AAR, which could nevertheless be isolated by visual inspection alone. The origins of such cracks meant that they were dormant and could thus be effectively treated by simply sealing and injecting with epoxy grout. The AAR affected pile caps, although in some cases showing varying conditions from the typical, could nevertheless still be categorised with those from the initial investigations as regards overall effects and required remedial measures.

Other than for natural variations occurring in the concrete and its constituents as well as in the moisture content and retention of the surrounding soil, no definite explanation could be given for the occurrence of AAR in some pile caps and not in others in seemingly similar situations. The pile caps are generally not deeply buried (soil cover less than 300 mm) so that the necessary conditions do exist for the cycles of wetting and drying which are required for the severe manifestation of AAR as observed. Also, the pile caps are generally unreinforced in their top and side surfaces, so that there is little resistance to the cracking observed in these areas.

3. REMEDIAL MEASURES TO AAR AFFECTED COLUMN PILE CAPS

The conclusions reached that both the main core of an AAR affected and cracked pile cap and the supporting piles themselves were still structurally competent, ruled out the need for total replacement. Instead, it was considered that the required remedial measures should reinstate or replace and simultaneously seal the top and side surface skin of the pile cap, and additionally provide positive resistance to further cracking induced by any continuing AAR, as well as a degree of structural strengthening.

The remedial measure adopted was to encapsulate the top and sides of the pile caps with a 200-250 mm thickness of additional high strength reinforced and prestressed concrete as typically illustrated in Fig. 2.

The remedials necessitate the complete undermining of the pile cap. As a safety precaution traffic was either stopped or restricted and monitoring of movement of the pile cap undertaken throughout the remedial operation. Once exposed, all corners of the pile cap, except in the vicinity of the piles, are chamfered to allow for transfer of prestressing forces to the existing concrete. Badly cracked concrete is locally removed from the top and side surfaces which are sandblasted for keying of the new concrete and all visible cracks on the pile cap are then epoxy injection grouted. The new encapsulation is anchored well into the main core of the pile cap through epoxy grouted anchor bars and the new concrete is reinforced with high tensile steel against differential shrinkage and prestressing splitting forces. Horizontal prestressing bars are provided to the top, side and underside of the pile cap distributed so as to give uniform and equal orthogonal prestressing. The bars are post-tensioned as soon as the requisite concrete strength has been reached, in order to achieve the maximum transfer of stress to the existing concrete. The bars to the underside are unbonded and cement grouted in oversized PVC ducting for protection. Elsewhere the bars are conventionally grouted and bonded. Final backfilling of the excavation is done using sand inundated to achieve compaction, with any remaining void to the underside being subsequently cement grouted. In the absense of coded design criteria, the degree of prestressing was derived on the basis of providing additional strength to cover the major portion of traffic loading and net confining pressures of between 0,5 - 1,0 MPa on the existing concrete.

With removal of badly cracked surface concrete and epoxy injection of cracks, the pile cap again becomes reasonably monolithic. The encapsulating

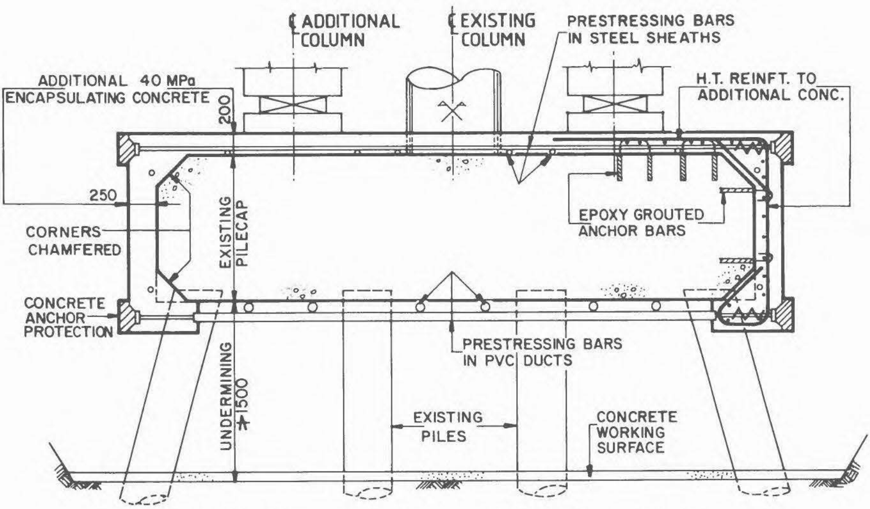

Fig. 2 - Typical Remedial Measures to a Column Pile Cap
(The additional columns shown are part of the overall upgrading)

concrete affords protection against extremes in moisture and thermal variations as well as strengthening to the weaker outer skin of the existing concrete. The horizontal prestressing provides both additional overall strength to the pile cap and active resistance to further cracking of the existing concrete from any continuing AAR. In these ways, the remedial measures adopted satisfy the stated criteria.

The remedial measures described above apply to column pile caps, the required remedials for abutment pile caps still presently being determined.

4. OTHER PARTS OF THE INTERCHANGE STRUCTURES

Inspection of the decks and sample cores have revealed no signs of AAR other than in very local zones at the abutment expansion joints, where rainwater has seeped down the affected concrete faces, a situation very conducive to the development of AAR cracking.

Columns exhibit varying degrees of cracking, mainly attributable to structural and differential shrinkage actions. However, as some signs of AAR have been detected in sample cores, all columns have been treated with a solvent based water repellant silane coating, to inhibit any further possible development of AAR. In more severe cases of cracking, reinforced concrete collars have been provided around the columns to act as confinement for mainly structural reasons.

5. ACKNOWLEDGEMENTS

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