Rehabilitation of a Portland Cement Concrete Pavement Cracked by Alkali-Aggregate Reaction

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ABSTRACT

Alkali-aggregate reaction in a plain jointed concrete pavement initiated structural distress due to a loss in pavement stiffness and an increase in stress in the subbase and subgrade layers. Structural evaluation and field observations indicated that ingress of water through cracked joints and into the pavement layers further aggravated the distress and resulted in punch outs.

Experimental work on joint repairwork indicated that replacing the old cracked concrete in the vicinity of the joint was more successfull in reducing relative vertical movements than undersealing or grouting of the pavement.

Various overlays have been designed and constructed experimentally as alternatives in pavement rehabilitation. Finally after evaluating the experimental sections, taking environmental factors into account, two methods of overlaying proved to be successfull namely a thin asphaltic concrete with asphalt - rubber binder as a short term approach and a continuously reinforced concrete overlay in the long term, the latter also providing structural strength.

BACKGROUND

The freeway from Cape Town to Somerset West, South Africa, was built in 1969 using Malmesbury shale, also locally known as Cape hornfels, as a aggregate and a cement relatively high in alkali content. At the time of construction alkali-aggregate reaction was not considered to be a problem in Southern Africa (Fulton 1964) and strict control over the type of cement was not deemed necessary. Cube strengths were between 32 and 39 MPa and the flexural strengths between 4,3 and 5,6 MPa after 28 days. The mix itself consisted of 273 kg of Portland cement, 35 % sand, an air entraining agent and 119 kg water which gave a water cement ratio of 0,435. The slump was in the order of 50 mm. Cores drilled in solid concrete in 1979 gave a mean strength of 32,7 MPa or equivalent cube strengths of 43,3 MPa (Range from 27,8 to 60,1 MPa).

The pavement was constructed as a 200 mm jointed concrete pavement with transverse joints every 4,5 m but without any dowels. The subbase consisted of 100 mm of cement treated crushed stone and the flexible shoulders were constructed using asphalt concrete on top of cement treated crushed stone as a base. This design was considered adequate to carry 2 500 vehicles (13 % heavy) per day for 25 years at a growth rate of 8 % per year. However the shoulders and subbase created a drainage problem being virtually impermeable and not allowing water that penetrate the joints to drain easiliy.

An unusually high incidence of hairline cracking close to the joints was observed in 1975 and this was recognised as due to alkali-aggregate reaction (Semmelink 1981). Traffic loading aggravated this cracking and by 1979 loose blocks has developed which rapidly became punch outs.

In 1980 a monitoring programme was initiated to investigate the cause of failure and to suggest possible remedial actions that could be considered. As a result of the preliminary study, a method of evaluating structural condition was developed and a hypothesis of the development of distress in the form of cracking in general was put forward (Van der Walt et al 1981). Figure 1 summarizes the factors that influence the development and the visual manifestations of distress as well as possible remedial actions.

STRUCTURAL ANALYSIS

The pavement was originally built as an unreinforced concrete pavement with shrinkage joints at 4,5 m intervals to allow for thermal movements. Since load transfer at joints was only affected by aggregate interlock,

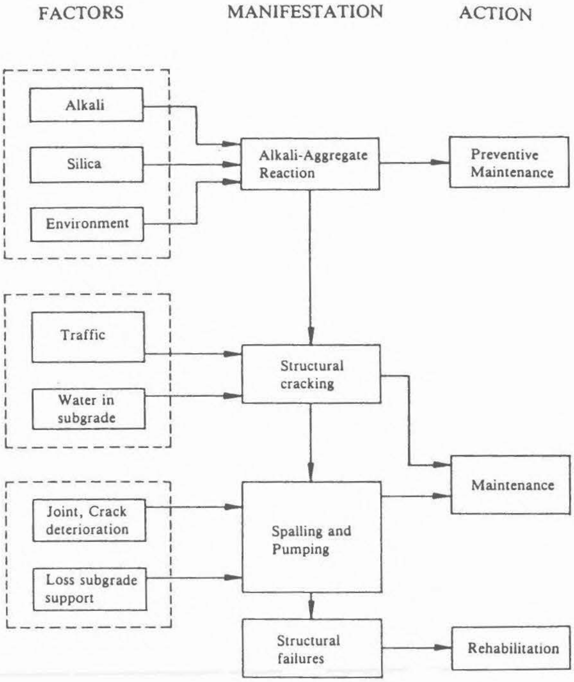

FIGURE 1 - FACTORS LEADING TO STRUCTURAL FAILURE AND APPROPRIATE ACTION

traffic associated stresses in the concrete slab were the highest at the joints. The alkali-aggregate reaction initiated cracks in the surface of the slab thereby effectively reducing its thickness and stiffness, resulting in increased stresses under traffic loading which caused structural cracks to develop rapidly at the transverse joints.

Structural analyses (Van der Walt et al, op cit, 1981)) and field observations have also indicated that the entrance of water through the cracked joints into the subbase and subgrade caused a decrease in slab support and thus an increase in deflections and relative movements at the joints which lead to structural failures. Alternative rehabilitation options therefore had to be considered in the light of the above observation. At the time of this decision-making it was obvious that prevention of alkali-aggregate reaction was not possible any more and that structural rehabilitation was the only option. Two alternatives were therefore considered namely a restoration of subgrade support and the prevention of surface water into cracks and joints.

Alkali-aggregate reaction in the concrete resulted in high expansive stresses within the concrete itself which caused horizontal cracks and thus a laminated slab. Horizontal expansion of the slab put the whole length of pavement in compressive stress which closed up the undeteriorated joints and restricted horizontal thermal movement. The resulting horizontal stresses could theoretically be relieved by putting in expansion joints every say 50 m but relief of these stresses would cause a further loss in load transfer at joints of the slab which could now be regarded a post stressed slab. This is illustrated by the fact that relative movements of joints increased from 0,1 mm to 0,35 mm after installation of experimental expansion joints. Horizontal stresses in the concrete slab was calculated to be in the order of 4,0 MPa and the compressive strength in the order of 24 MPa.

REPAIRING OF EXISTING SLAB AND RESTORATION OF SLAB SUPPORT

Referring to Figure 1 it is obvious that since structural cracking has already occurred by 1980, no preventive maintenance was possible. However, normal maintenance could still be done and several options were attempted on an experimental basis. Table 1 summarizes the results of the different alternatives investigated.

The first option was to replace the concrete at the failed joints by excavating badly cracked concrete, leaving jagged vertical faces and edges to enhance load transfer and adhesion, and replacing it with good quality concrete with low shrinkage properties.

The second approach was to underseal the slab by filling the voids between the slab and subbase. Different materials were used to achieve this goal but the only basic difference between these options was the workability of the grout and this was affected by different admixtures.

The third option was to both underseal the slab and to "freeze" joints and cracks at the same time by the introduction of low viscosity epoxies and in some cases the installation of tiebars which were drilled into the concrete at an angle of 45°.

The success of the above-mentioned options was measured in terms of relative vertical movements after restoration and it is obvious from Table 1 that repairing of joints by excavating old concrete was more effective in reducing relative vertical movements than undersealing or freezing by grouting joints.

However the most important result is the reduction in the standard deviation. Replacing of the old cracked concrete seemed to have been the most successful operation in this respect also.

Table 1 Results of experimental joint repairs

ACTION	RELATIVE VERTICAL MOVEMENT (mm)	
	Mean	Standard Deviation
No	0,102	0,065
Undersealing using different mixes of sand, Portland cement and admixtures	0,107	0,043
Grouting of joints with different types of epoxies, Portland cement and installation of dowels	0,107	0,047
Removing of cracked concrete and replacement with high quality PC concrete	0,090	0,010

STRUCTURAL IMPROVEMENTS

It became evident that the concrete pavement had structurally failed and that normal maintenance would be inadequate in the long term. Furthermore, the effectiveness of undersealing and grouting in reducing relative vertical movements was poor and the associated reliability might result in an unacceptable risk of having too high stresses induced on the sublayers by large vertical movements and deflections which could cause further structural damage.

In order to determine the most cost effective long term structural improvement, designs were prepared for various experimental overlays as indicated on Figure 2. These experimental overlay sections were constructed in 1983. Structural analysis and designs were based on three dimensional finite element analysis using non-isotropic elasto plastic material properties in order to simulate actual field behaviour as closely as possible (Strauss et al 1985). Theoretical models were thus compiled which were calibrated using these experimental sections by comparing actual field behaviour with calculated values of deflection, relative movements, strains etc.

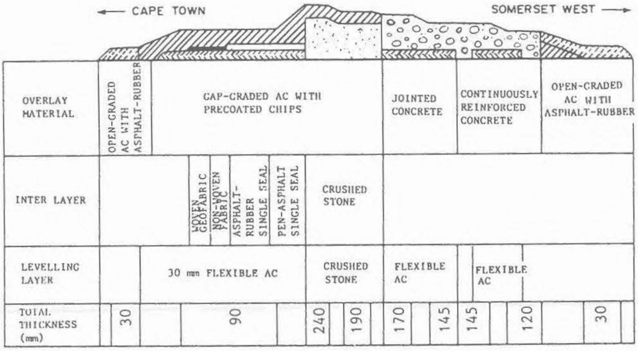

FIGURE 2 - BASIC LAYOUT OF EXPERIMENTAL SECTIONS

FIELD PERFORMANCE AND REHABILITATION

Field performance of experimental sections have been monitored for environmental influences since March 1983 and traffic loading was accelerated by using the heavy vehicle simulator (Strauss et al 1985). In this way predicted performance could be compared with actual performance whereby the theoretical models were calibrated and put to use in actually designing rehabilitation measures. Performance was defined as the success with which the different overlays could withstand reflection cracking, rutting, scuffing and other defects that could affect its long term performance.

As can be observed from Figure 2 the options considered included short and long term approaches. Performance of these sections differed to a great extent but finally it was found that basically two options could be considered for eventual implementation namely the thin asphaltic concrete with asphalt-rubber as binder (the short term option) and the continuously reinforced concrete pavement as a long term option. Other options such as asphaltic concrete with geofabrics did not perform well under environmental stresses and reflection cracking was observed after about 2 years. The jointed concrete overlay on the other hand showed a limited structural life under accelerated loading whilst the asphaltic concrete with asphaltic interlayers performed satisfactory.

Since the asphalt-rubber solution could be considered part of a management programme for this pavement the final decision was made to replace badly cracked concrete at the joints with good quality Portland cement concrete followed by an asphalt-rubber membrane as interlayer with an asphaltic concrete with asphalt-rubber binder on top. The full depth of this overlay is in the order of 45 mm and its expected life is 7 years by which time about 10 % of the cracked joints are expected to reflect. At that time future rehabilitation will be considered but it is expected that a continuously reinforced concrete overlay will be constructed which will give the pavement a further expected life of at least 20 years.

CONCLUSION

Alkali-aggregate reaction resulted in a decrease in slab stiffness which caused, together with the entrance of surface water, an increase in deflection and relative vertical movements at the joints. This increase in slab movement induced higher stresses on the sublayers which destroyed slab integrity and caused structural failures. Two goals in rehabilitation namely the reduction of relative movements at joints and the successful sealing of the pavement had thus to be achieved. The aim of rehabilitation therefore was to avoid cracking in the overlay which was intended as a seal. Two methods of overlaying proved to be successful namely a thin asphaltic concrete with asphalt-rubber binder in the short term and a continuously reinforced concrete overlay in the long term, the latter also provides structural strength.

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