DESIGN CONSIDERATIONS AND FINDINGS OF THE RETEXTURING OF A MAJOR CONCRETE FREEWAY THE SOUTH AFRICAN EXPERIENCE

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ABSTRACT

The main aims of retexturing the continuously reinforced concrete pavement, were to improve the surface drainage and skid resistance whilst also keeping the noise levels down. Retexturing was done by cutting grooves across the road surface, in areas where drainage and skid resistance were poor. Noise levels increased by only 0,9dBA after the retexturing. Drainage improved to such an extent that spray from traffic in wet weather almost disappeared on retextured sections.

INTRODUCTION

The Ben Schoeman Freeway is the major arterial linking Johannesburg in the South to Pretoria in the North and is ± 20 km in length and has an AADT of ± 85 000. In 1989, the Freeway was widened to an average of three lanes per direction and the existing asphalt pavement strengthened with a continuously reinforced concrete overlay (CRCP). The thickness of the CRCP overlay varied between 170 mm on the slow shoulder to 150 mm on the fast lane. To reduce tire/road noise levels to the minimum without neglecting the safety requirements i.e. skid resistance, a study was carried out by Meij (1) for the South African Department of Transport to determine the surface texturing method to be used on the CRCP overlay. Meij (1) compared various surface texturing techniques, i.e.:

- cross brooming (90° and 45°);
- cross tining (90° and 45°);
- longitudinal brooming or tining;
- burlap drag, and
- washing-out of the surface mortar to expose the coarse aggregate.

According to Meij (1) the 90° cross brooming delivered the best combination of results (skid resistance, surface drainage and tire/road noise levels) and was subsequently used. As-built information of the project indicated texture depth (sand patch method) of between 0,2 mm and 1,0 mm with an average of 0,5 mm being obtained with this technique.

Multiple vehicle accidents in 1991/92 on the Freeway resulted in various investigations to determine the causes of these accidents. The investigations identified a lack of adequate surface water drainage (macro-texture) during thunder storms, which combined with the high speeds (+ 120 km/h) on the Ben Schoeman resulted in poor skid resistance, as the major contributing factors to these accidents. As road safety is of extreme importance to the Department it was decided to apply the following safety measures:

- law enforcement to reduce vehicle speed;
- provision of more road signs (warning signs - wet weather);
- provision of improved road marking (to increase following distances), and
- improvement of surface drainage (macro-texture) which will contribute to improved skid resistance.

This paper only discusses the design considerations during the process of selecting an optimum measure to firstly improve the surface drainage and as a secondary benefit to improve the skid resistance without increasing

the tire/road noise substantially. After presenting the design considerations, and construction related aspects the results obtained from the project are presented.

SURFACE DRAINAGE

Since inadequate surface drainage was identified during the preliminary investigations as the primary cause of accidents, subsequent investigations were aimed at identifying the cause of the inadequate surface drainage. These investigations included detail transverse slope evaluations at identified problem areas, as well as texture depth studies. The results from the detailed transverse slope evaluations conducted by rod and level procedures indicated the road has an average cross-fall of 1,86%, with some areas even as low as 1,5% compared to a design cross-fall of 2%. This is not adequate for a 15,1m wide surfaced area, especially during a typical thunderstorm when surface water tends to accumulate in the slow lane. Sulten (2) found that irrespective of the road surface and the groove configuration, frictional force can only be transferred between the tires and the road surface if the layer of water is less than 5 mm thick for speeds of 80 km/h and less.

The texture depth studies were conducted by using the sand-patch method as well as the Transportation Research Laboratory (TRL) Mini Texture Meter (MTM). With the sand-patch method a known volume of dry sand is spread out over the surface. By measuring the area covered by the sand, the texture depth can be calculated from the known volume and area. The MTM uses laser beams which reflects from the road surface to a light sensitive diode. The difference between the widest reflected laser beams represents the texture depth. The two methods correlated fairly well especially on the retextured areas. The results obtained for the texture depth measurements are summarized in Table 1. It is clear that for the limited as-built texture depths available, that the texture depths measured in 1992 were almost half of the depths measured before the road was opened to traffic in 1989. This reduction in texture depth can possibly be attributed to:

- loose material particles or debris lying on the road surface after construction, and measured with the sand-patch method as part of surface texture. It is important that the sand-patch test area be properly cleaned with a steel brush before the test is carried out, and
- loss of surfacing due to abrasion. A granulated blast furnace slag/OPC (50:50) concrete mix was used to reduce cost. Abrasion tests were however carried out during the original construction phase by the Portland Cement Institute (PCI). The abrasion test (wire brush) gives an indication of the wear of the concrete surface by measuring the average depth to which a standard wire brush, under standard conditions, abrades the concrete. Most of the as-built results of abrasion tests carried out by PCI on the Ben Schoeman Freeway were fair to poor; indicating a loss of at least 1,0 mm of surface texture over the life of the pavement. Based on these results the great loss of surface texture between 1989 and 1991 should not be all that surprising. The rate of loss of texture depth has decreased since 1991. This is believed to be a result of the fact that most of the highly erodible blast furnace slag/OPC (50:50) which formed the larger proportion of the surface texture, has eroded and what is left is the aggregate which is more resistant to abrasion.

SKID RESISTANCE

Low skid resistance was the second contributing factor identified during the preliminary investigations as having an influence on the occurrence of accidents. At the time of the evaluation only the Sideways Force Coefficient Routine Investigation Machine (SCRIM) was available in South Africa and subsequently used to measure the skid resistance. The SCRIM measures the Sideways Force Coefficient of Friction (SFC) of a smooth test wheel inclined at 20 degrees to the direction of travel on a wet surface (4). On South African national roads these SCRIM measurements are performed at 80 km/h (SFC_{80}) and the values are classified as follows:

Good	SFC_{80}	>	0,5		
Warning	0,5	<	SFC_{80}	≤	0,4
Severe	SFC_{80}	≤	0,4		

The 1993 SCRIM measurements indicated that out of a total 650 000 m^2 of CRCP, 156 000m^2 had a warning SFC_{80}. As a result of the high vehicle speeds on this section of road, it was decided that any remedial action to be applied will as a first priority address surface drainage problems, and secondly skid resistance.

REMEDIAL ACTIONS CONSIDERED

Since the identified cause was lack of adequate surface drainage (macro-texture) resulting in poor skid resistance, the following remedial actions were considered:

- Porous asphalt overlay, and
- The following methods of retexturing (Grooving):
  a. longitudinal to direction of travel;
  b. at an angle to direction of travel, and
  c. transverse to the direction of travel.

The option of a porous asphalt overlay was abandoned in the initial stages of the study for the following reasons:

- with most of the skid resistance problems being in the slow and middle lanes at isolated positions it was not feasible to only apply porous asphalt over these individual sections, but instead the whole Ben Schoeman had to be overlaid, resulting in too high a project cost;
- with a road cross-fall of 1,86% on average and a carriageway width of 15,1m clogging-up of the porous asphalt was a serious concern to the Department;
- unconfirmed test results from abroad, on porous asphalt surfaces indicated skid resistance problems for the initial period after opening to traffic due to the micro-texture of the aggregate being covered with thicker bitumen coating applied as a precaution for increased oxidation;
- uncertainty of the bonding and shear stresses between the porous asphalt and the smooth CRCP surface;
- the costly sealing of all cracks in the CRCP before overlaying with porous asphalt and the high probability of these cracks reflecting through the overlay with time, resulting in raveling and surface failures, and
- a cost benefit comparison between the retexturing (R10/m^2 , 1$ = R 4,60) and the porous asphalt (R16/m^2) showed the retexturing to be more cost effective.

With porous asphalt being excluded, the only remedial actions still available for detail evaluation were the various methods of retexturing (grooving). Retexturing consists of cutting grooves into the surface of a road to improve surface drainage and skid resistance (friction) in wet weather. The grooves can be cut at different spacings, depths, widths and angles. The aim of the grooves is to improve the internal water drainage between the tires of a vehicle and the road surface. This can best be described by the Horne Hydroplaning Model (3) as illustrated in Figure 1. As shown it is clear that when standing water develops on a pavement during rainstorms, the pavement's surface macro-texture (grooves for concrete pavement) and the tire tread design play the important role of providing escape channels to drain the bulk of the water from Zone 1. The thin layer of water remaining is drained in Zone 2 through the micro-texture of the pavement. Micro-texture refers to the harsh-gritty feel (similar as when touching fine sandpaper) detected when touching the surface, and can normally not be seen by the eye. The pavement micro-texture performs its function by providing the pavement surface with sharp pointed projections that, when contacted by the tire tread, generate high local bearing pressures. This intensive pressure breaks down the thin water film coating the pavement surface in Zone 2, and allows the tire treads to regain dry contact with the high points of the pavement's micro-texture in Zone 3 of the tire footprint, which provides the frictional forces that determine the skid resistance of the pavement. If the macro-texture of the pavement in combination with the tire tread is not able to provide the necessary drainage of bulk water required at a certain speed, aquaplaning occurs resulting in the driver having no control over the vehicle, and also no skid resistance. The influence of speed as well as macro-texture (grooves) on tire/road contact area is shown in Figure 2. For a speed of 80 km/h it is recommended that the layer of water on the road should be less than 5 mm deep to ensure the transfer of frictional forces between the tire and the road surface.

Since 1965 retexturing in the form of grooving has become a standard technique that is widely used to improve the macro-texture of pavements. Despite the frequent use overseas, retexturing has never been used in South Africa on such a scale as what was anticipated on the Ben Schoeman. Although various retexturing methods i.e. longitudinal, angled or transverse grooving were considered, it was decided to groove transversely (perpendicular) with the direction of travel, since this had the following advantages:

- the shortest drainage length for surface water of the three methods;
- no influence on lateral stability of a vehicle;
- easier to perform than angled, and

- retexturing were only required at isolated positions in the slow, middle and fast lane and would tie in with the 90° cross brooming of the existing surface.

Reducing Increases In Generated Tire/Road Noise Levels

Introduction

It is well documented that transverse grooving tends to increase tire/road noise levels both within vehicles as well as alongside the road. Sulten (2) found that the increase in tire/road noise level on transverse grooves up to 4,5 mm wide to be between 0,5 and 1,5 dBA. With 6 to 7 mm wide grooves, the increase in tire/road noise lies between 2 and 4 dBA for the same groove spacing. It is however not only tire/road noise levels that are affected by transverse groove dimension and spacing, but also the surface drainage capabilities and the amount of potential spalling. To reduce the potential increase in tire/road noise levels as a result of transverse grooving the assistance of acoustic and environmental engineers were obtained to assist in the determination of a transverse groove dimension and spacing pattern that would improve the surface drainage without substantially increasing the tire/road noise levels.

Existing tire/road noise levels

The first phase was to determine tire/road noise levels on the existing surface, as well as on a typical asphalt surface for comparison reasons, and then to determine a frequency spectrum of the generated tire/road noise. The results indicated an equivalent continuous sound pressure level for a 5 min period Leq(t) (t = 5) on the CRCP of 80 dBA, which was 1 dBA lower than on the values obtained on the asphalt wearing courses for the same amount of traffic at the test points. This is in line with the type of finishing selected for the CRCP overlay i.e. cross brooming with a high short wave (λ < 10 mm) texture component.

For the second phase a drive-by method was used to determine the distribution of the perceived noise level at a fixed point when a vehicle passes. Three integrated sound level meters were used. These instruments were set to store short Leq(t) readings every 125 ms simultaneously to allow for spectral analysis. Since the aim was to measure the increase in tire/road noise the microphones were placed at 300 mm above the road surface (in comparison to specified 1,2 m to 1,5 m) this was done to limit the influence of other sources of noise (i.e. wind generated by the test vehicle, traffic in adjacent carriageway etc.). The resultant frequency spectrum obtained from the measurements is illustrated in Figure 5. As seen a peak exists at 1000 Hz. This is critical because the higher the frequency, the more annoying it becomes to the human ear which is less sensitive to lower frequencies. For the retexturing to be successful the increase in tire/road noise levels above the 1000 Hz and especially the 2000 Hz level must be kept as low as possible.

Transverse groove dimension and spacing

To obtain a groove dimension and spacing that would satisfy the skid requirements as well as result in minimal increase in tire/road noise the theoretical frequency of the sound wave that a tire would generate when passing over various theoretical groove dimension/spacing pattern combinations had to be calculated. For the calculations the minimum thickness of the cutting blades available was fixed at 3,2 mm, and the minimum spacing between blades at 19 mm to avoid a single 19 mm aggregate being cut in three. Thus only the depth and spacing (larger than 19 mm) could be altered. By increasing the spacing between grooves the period between two groove crossings becomes longer and the tire/road noise frequency generated lower and thus also the annoyance to the human ear. Increasing the spacing between grooves, however, results in a decrease in skid resistance, thus a compromise between required increase in skid resistance and tolerable increase in tire/road noise was required.

The final configuration that provided sufficient drainage with minimal increase in tire/road noise above the 1000 Hz level was a 25-25-22-25-25-22 mm spacing between cutting blades, combined with a groove dimension of 3,2 mm wide and 6 mm deep ± 1,5 mm to allow for construction tolerances as illustrated in Figure 3. Due to a fear of spalling as a result of the transverse crack pattern on the CRCP the groove depth was specified to be only 4,5 mm ± 1,5 mm. This still compared reasonably with the American Concrete Pavement Association's (ACPA) recommendations to the Department of parallel grooves, 2,4 mm wide, 3,2-6,4 mm deep and spaced at 19 mm apart.

The minimum groove cross section dimension of 3,2 by 4,5 mm was the smallest area that could be allowed; any area smaller than this will result in an unacceptable increase of tire/road noise above the 1000 Hz level. This increase in tire/road noise is the result of higher air speed generated when forcing the same volume of air into a smaller area. During expansion of the compressed air this higher air speed results in higher amount of energy

being released in the form of increased tire/road noise. A slight increase in tire/road noise was anticipated should the required minimum depth of 4,5 mm not be achieved.

CONSTRUCTION RELATED ASPECTS

Since this was the first time that retexturing was attempted on such a large scale in South Africa and the fact that the contract required that all work be performed at night between 20h00 and 5h30 due to the high traffic volumes, the following construction related aspects are discussed in detail.

Development Of Plant And Equipment

The locally manufactured machines each weighing 750kg utilized 19 diamond cutting blades fitted on an arbor over a 0,5m width. Each blade had its own nozzle that provided water for cooling during the cutting process. A screw leveling device which acted as a stop on the arbor axle were utilized to maintain the maximum depth of the cut, which was dependent on the hardness of the concrete, the blade diamond matrix and most important the machine speed. If the speed was too high maximum cut depth could not be obtained owing to the fact that the blades did not have sufficient time to cut, causing the machine to lift up. Maximum economy in the order of 120m^2/h was obtained with a optimum texturing speeds of 3,7m/min. This enabled the contractor to texture a total of 260 000 m^2 in 5 months at an average of 2 900 m^2/night, using 4 machines.

Development Of Clean-Up System

The client required that all residue or slurry resulting from a days texturing be removed from the road surface before reopening the next morning. To achieve this a continuous pick up system was developed using a 5,5kW industrial vacuum cleaner incorporating a 1000 litre vacuum tank. The sludge was sucked into the vacuum tank from where a sludge pump, pumped it into a sedimentation tank. The solids in suspension rapidly settled out, without the use of any accelerators. The clean water was skimmed off into another tank, enabling the contractor to re-use 60 to 70% of the estimated 40 000 liters of water needed every night. Of the order of 2 million liters of water was used in the texturing process and 170m^3 (400 tons) of concrete (sludge) was removed.

Practical Problems And Solutions

As this was the first time that retexturing was done on such a large scale in South Africa it was not surprising for practical problems to occur. Although some of these problems might only relate to the specific machines or methods used, it is believed that they are worth mentioning.

Uneven pavement surface

From the outset the uneven pavement surface, especially in the vicinity of the longitudinal construction joint, created problems regarding texture depths. Although the specifications required that the texturing machines should be equipped with a depth control device in order to maintain a constant texture depth, the frame and set up of the machines did not completely allow for this and tended to compensate for surface unevenness. This situation resulted in grooves with shallow or no texturing on the other side of any bump on the pavement surface preventing the improvement of skid resistance in these areas.

After numerous discussions it was decided that these grooves would be accepted provided a continuous fall was achieved along their length across the pavement width, instead of the constant depth specified. Although this would create untextured or shallow textured areas as described above, it was noticed on site that these areas were fairly small (200 by 400mm) and widely spaced and would not cause severe skid resistance problems. If groove depths were kept constant, however, it could have created many low spots in the grooves which could have silted up and reduced the effectiveness of the grooves in terms of drainage.

Texturing up to edge of shoulder

In order to achieve the first objective of the texturing, namely to improve surface drainage, it was essential that the texturing was performed up to the edge of the pavement to enable surface water to run off the pavement completely.

The majority of the texturing required was on the slow shoulder and the slow and middle lanes. In order to achieve maximum production and minimum changes in accommodation of traffic it was essential for the contractor

to texture as many lanes as possible with any one machine pass and/or road closure. To achieve these objectives various options, each with there own problems, existed. These included the following:

- To work from the shoulder towards the fast lane, thereby texturing the full width with one pass. A problem occurred where the machine had to move off the concrete surface to be able to start texturing from the edge of the concrete. The ground was uneven and deformed under the dynamic effects and weight of the texturing machine and the machine was unable to move off the surface at guardrails and other obstructions.
- To work from the middle of the section to be textured towards the edges. This created a problem, in that the textured grooves had to be matched up in the middle of the section.

After numerous discussions and practice runs with different options the following method was decided upon; The machine started on the slow shoulder and textured up to the sawn joint between the middle and fast lanes. The small section (approximately 900mm long) on the shoulder that was left untextured was textured in a separate operation not influencing the production rates on the bulk of the work.

A problem that was more difficult to solve was when the fast lane also needed to be textured. This had to be done as a separate process due to the restrictions regarding the accommodation of traffic, i.e. to always have one lane in each direction open to traffic. The only workable solution was to leave a small gap (50 to 100mm) in the texturing at the longitudinal sawn joint between the middle and fast lanes. Although this layout created a certain amount of rain water damming in the fast lane, it was more cost effective and less time consuming regarding the alignment of machines with the existing grooves each time. It also removed the risk of heavy spalling due to mismatched grooves.

Keeping grooves perpendicular to the centre line of the road

The contractor's alignment system consisted of two operations. Firstly a guide line was set out for each machine, at the start of each section, by two workers using a set square and straight edge. The machine operator started off by using a pointer that was fixed to the machine to follow this line for the first pass. He then used the last textured groove of each pass as a guide for the next pass. Three problems emerged at an early stage, namely:

- The permanent overhead lighting system did not provide sufficient illumination for the operators to be able to follow the guide lines or grooves. This was solved by installing a spot light on the front of the machine illuminating the pointer and guide line or groove.
- With only one pointer at the front of the machine, a pass could be started not being parallel to the previously cut grooves or not perpendicular to the centre line of the road. This created a creeping effect in the distance between the last groove of the previous pass and the first groove of the next pass. A similar problem occurred at the end of each pass where the pointer had to be picked up to prevent it from running into the open traffic lane. The cheapest and easiest way solving both problems were by adding a second illuminated pointer at the back of the machine.
- From the outset it was realized that extra guide lines would have to be provided wherever texturing through horizontal curves was to be done. It was, however, soon realized that due to the large radii of horizontal curves as well as other factors like human error and "creep", guide lines would have to be set out at shorter intervals. A workable solution that took production rates and personnel requirements into account, was to set out guide lines every 5 meters on fairly straight sections and every 2 meters as soon as a horizontal curve starts. This ensured that small wedges occurred every 2 meters and did not have an adverse effect on skid resistance or drainage and was aesthetically pleasing.

Although this seems to be fairly simple, the following points need to be kept in mind:

- The machine operators and assistants were all on a learning curve. The working at night, long shifts (Monday to Saturday; 20h00 to 5h30) and cold weather conditions for South Africa (air temperatures of -3°C; wind-chill equivalent temperature of -12°C) also influenced working capabilities.
- Guide lines could not be set out too far ahead of the machines because human error as well as "creep" could cause texturing to run over these lines.
- The large amount of sludge and other residue produced, created problems because it was not always possible to see guide lines or grooves and sludge often ran across untextured areas where lines had to be set out.
- The level of illumination provided by the permanent overhead lighting masts was insufficient for the operators to perform their work and also influenced the setting out of the work thus increasing the possibility of errors.

Process And Quality Acceptance Control System

Background

No South African based process and quality acceptance control system for texturing existed prior to the start of this contract, it was therefor only possible to start developing the system once the actual texturing started.

Factors influencing groove measurements

CRCP: The continuously reinforced concrete pavement was designed to crack transversely which influenced groove depth because of possible spalling.

Paving equipment: Three different concrete pavers were used to construct the road, each leaving its own type of surface finish and unevenness on the road as well as longitudinal construction joints.

Concrete mixes: Two different concrete mixes were used, each with its own characteristics, e.g. sand content and strength.

Texture machines: The weight, weight distribution, horsepower, speed, arbor speed, water supply, etc. of each machine used.

Texture blades: The blade life, hardness and diamond matrix of the cutting edge of a blade.

Statistical Control Procedure

It was almost impossible to evaluate the texturing without a statistical control procedure, especially if it is taken into account that in the order of 80km single groove was cut every night (11 000km in total for the contract) and needed to be evaluated. It was clear from the outset that groove depth was the critical component that needed to be evaluated constantly.

Random sampling with roughly hourly intervals was utilized to advice the contractor to continuously reset his machines during the night to enable him to cut within the specification. The above procedure was beneficial to both the contractor (avoiding the cutting of unnecessary and costly deep grooves) and provided the best results for the client with regard to optimum depth and minimum spalling due to grooves being too deep. The control procedure resulted in average groove depths between 4,2 and 4,5mm with maximum depths between 5,8 and 6,2mm and minimum depths between 2,8 and 3,2mm.

COMPARISON BETWEEN BEFORE/AFTER MEASUREMENTS

The main aim of the retexturing of the Ben Schoeman freeway was to improve its surface drainage by increasing the macro-texture. The results obtained for before and after macro-texture measurements are summarized in Table 2. As seen there is a vast improvement in texture as measured with a Mini Texture Meter (MTM). The average improvement in texture over the whole project was from 0,3 mm to 0,9 mm. The average value of 0,9 mm obtained over the retextured areas compares favorably with the values (0,85 mm to 0,99 mm) obtained for semi-gap graded asphalt and are even better than the values (0,45 mm to 0,65 mm) for continuously graded asphalt layers with pre-coated rolled-in chips measured in the vicinity. The benefit of this improvement in surface drainage (macro-texture) is even visible with the naked eye during a thunder storm, through the reduction in spray on the textured areas.

Skid Resistance

A secondary effect of improving the surface drainage was the improvement of the skid resistance by increasing the dry tire contact area which determines the frictional forces providing skid resistance as illustrated in Figure 2. It is important to remember that the retexturing cannot improve the existing micro-texture of the pavement, but only the macro-texture and subsequently skid resistance since it is a function of both the micro-texture and macro-texture.

The SFC_{80} values obtained for a typical test section where noise level measurements were also conducted with the SCRIM are summarized in Table 3 for both before and after retexturing. As seen for the SCRIM results there seems to be no improvement at all in the skid resistance measured. This is not all that surprising since studies have shown that the SCRIM measurements are more influenced by the micro-texture than by the macro-texture. Since nothing was done to the micro-texture no measurable improvement could be expected. As soon as the GripTester (Braking Force device with a fixed-slip), became available in the country the opportunity was

used to re-measure the skid resistance on the Ben Schoeman. The results obtained (GripNumber at 80 km/h), was converted to SFC_{80} and are also shown in Table 3 as well as illustrated in Figure 4.

As seen from the GripTester results the improvement of the macro-texture did indeed improve the skid resistance on the retextured pavement sections to levels similar to those obtained on the asphalt sections. From the GripTester results the difference between un-textured and retextured sections is also easily discernible.

Tire/road noise levels

After retexturing noise measurement was re-conducted with the same test vehicle at the exact same location. The resulting noise distribution obtained after retexturing is illustrated in Figure 5. As seen there was a slight increase of 0,9 dBA in the noise measured alongside the road after retexturing. The reason for this slight increase in noise is an increase in noise levels above the 1000 Hz level. This increase was the result of an average groove depth obtained over the project of 4,2 mm, which is 0,3 mm less than the specified minimum. Despite this small increase it is believed that the aim of the project to improve the surface drainage and skid resistance while keeping generated noise levels low was realized, especially if comparing the increase in tire/road noise levels with those of similar projects overseas.

CONCLUSIONS AND RECOMMENDATIONS

The results presented in this paper have shown that it is possible to cost effectively, on selected areas of a concrete pavement:

- improve the macro-texture from an average of 0,3 mm before to an average of 0,9 mm after;
- improve the skid resistance from an average SFC_{80} of 0,35 (un-textured areas used as reference) to an average SFC_{80} of 0,46 for the whole project, as measured with the GripTester, and
- prevent a significant increase in tire/road noise levels (only increase of 0,9 dBA) by means of transverse grooves spaced at 25-25-22-25-25-22 mm etc. with dimensions of 3,2 mm wide by 4,2 mm deep.

From the results presented the following recommendations can be made:

- The results obtained with the South African SCRIM should be carefully evaluated, and the factors contributing to the inconsistent results should be identified and quantified;
- The use of a 50:50 granulated blast furnace slag:OPC mix is not recommended for concrete roads which are built to reduce noise levels i.e. broom finish texture depth less than 1 mm;
- When retexturing by means of transverse grooving is considered in the future, a groove spacing of 25-25-22-25-25-22 mm etc. should be used with minimum groove dimensions of 3,2 mm wide by 4,5 mm deep. Wider (4,5 mm) and deeper (6,0 mm) grooves will both improve macro-texture and reduce tire/road noise;
- The increase of cross-fall on roads with pavements wider than 12 m to values above 2 %, to improve surface drainage on high volume roads, should be investigated, and
- The rest of the CRCP on the Ben Schoeman should be retextured to reduce spray and to improve macro-texture and skid resistance in wet weather.

TABLE 1: COMPARISON BETWEEN TEXTURE DEPTH MEASUREMENTS ON THE SLOW LANE
TABLE 2: BEFORE AND AFTER TEXTURE MEASUREMENTS WITH THE MTM
TABLE 3: BEFORE AND AFTER TEXTURE VALUES AS MEASURED WITH SCRIM AND GRIPTESTER

TABLE 1: Comparison Between Texture Depth Measurements On The Slow Lane

N1/21S Km	Texture Depth (Sand-Patch) (mm)	
	1989	1992[1]
6,7	0,33	0,22
6,9	0,25	0,13
7,4	0,32	0,16
7,6	0,33	0,19
11,8	0,35	0,17
12,0	0,36	0,19
Average	0,32	0,18

1 Road surface was properly cleaned with steel brush before tests

TABLE 2: Before And After Texture Measurements With The MTM

Kilometre	Measured texture depth (mm)		Average Groove Depth (mm)
	Before Retexturing	After Retexturing	
9,00	0,46	0,90	3,9
9,11	0,35	0,79	-
9,12	0,37	0,75	-
9,13	0,35	0,98	4,0
9,14	0,35	0,97	-
9,15	0,46	0,98	3,7
9,16	0,26	0,76	3,9
9,17	0,48	0,73	4,4
9,18	0,34	0,69	-
9,19	0,38	1,08	-
9,20	0,44	1,00	-
Average	0,39	0,88	3,98

\- Not Measured

TABLE 3: Before And After Texture Values As Measured With SCRIM And Griptester

N1/21 S	SCRIM (SFC_{80})		GripTester(GN_{80})
Km	Before (22/7/93)	After (25/10/94)	After
9,100	0,516	0,580	0,420
9,120	0,516	0,520	0,480
9,140	0,446	0,480	0,460
9,160	0,418	0,490	0,440
9,180	0,486	0,560	0,480
9,200	0,546	0,510	0,420
Average SFC_{80}	0,483	0,500	0,450

FIGURE 1: HORNE (3) TYRE FOOTPRINT HYDROPLANING MODEL
FIGURE 2: INFLUENCE OF SPEED/GROOVES ON TYRE FOOTPRINT AREAS (3)
FIGURE 3: TRANSVERSE GROOVE DIMENSION/SPACING AS CALCULATED FOR MINIMUM INCREASE IN NOISE
FIGURE 4: BEFORE/AFTER SKID MEASUREMENTS WITH SCRIM AND GRIPTESTER (ONLY AFTER)
FIGURE 5: FREQUENCY SPECTRUM ANALYSIS BEFORE AND AFTER RETEXTURING

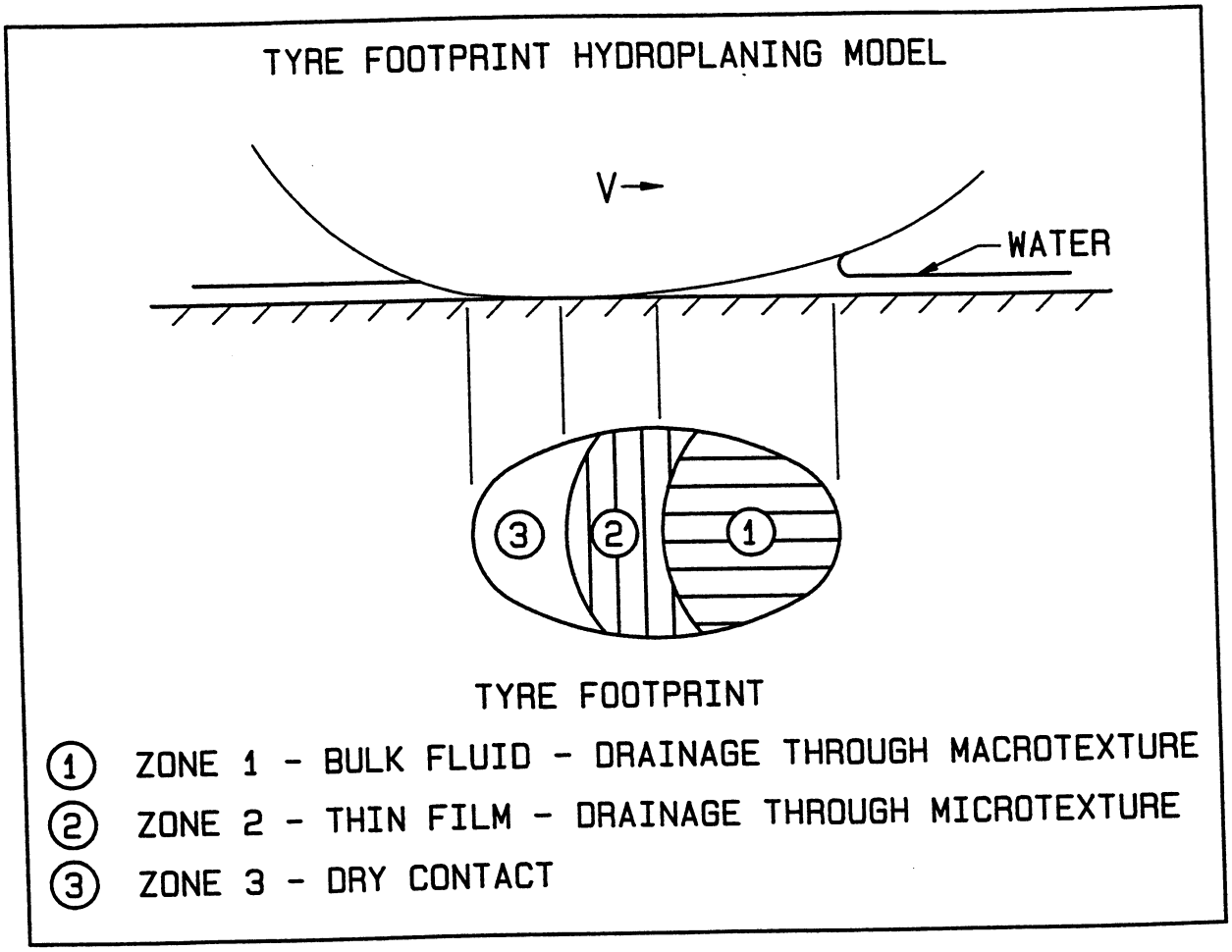


Figure 1: Horne (3) tire footprint hydroplaning model

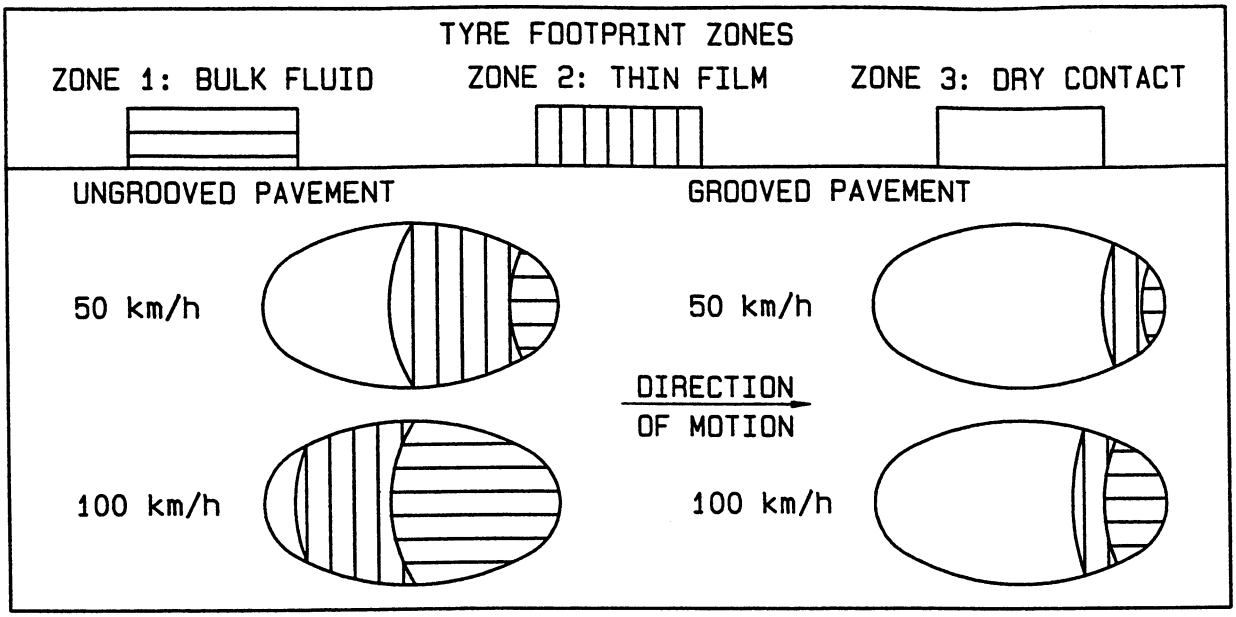


Figure 2: Influence of speed/grooves on tire footprint areas (3)

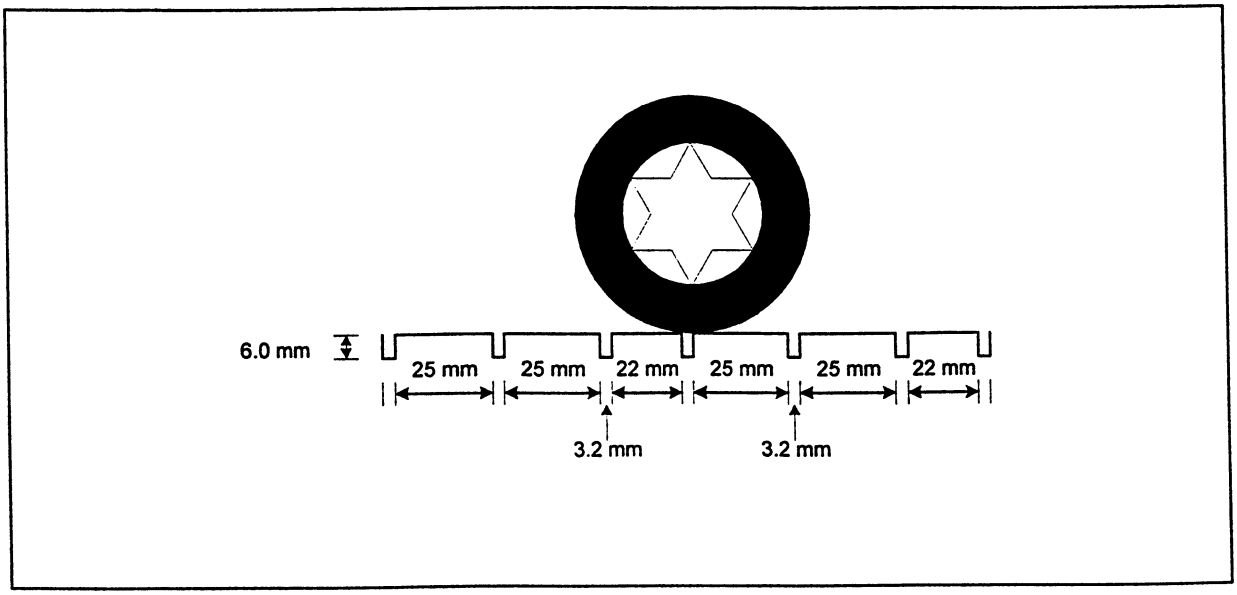


Figure 3: Transverse groove dimension/spacing as calculated for minimum increase in noise

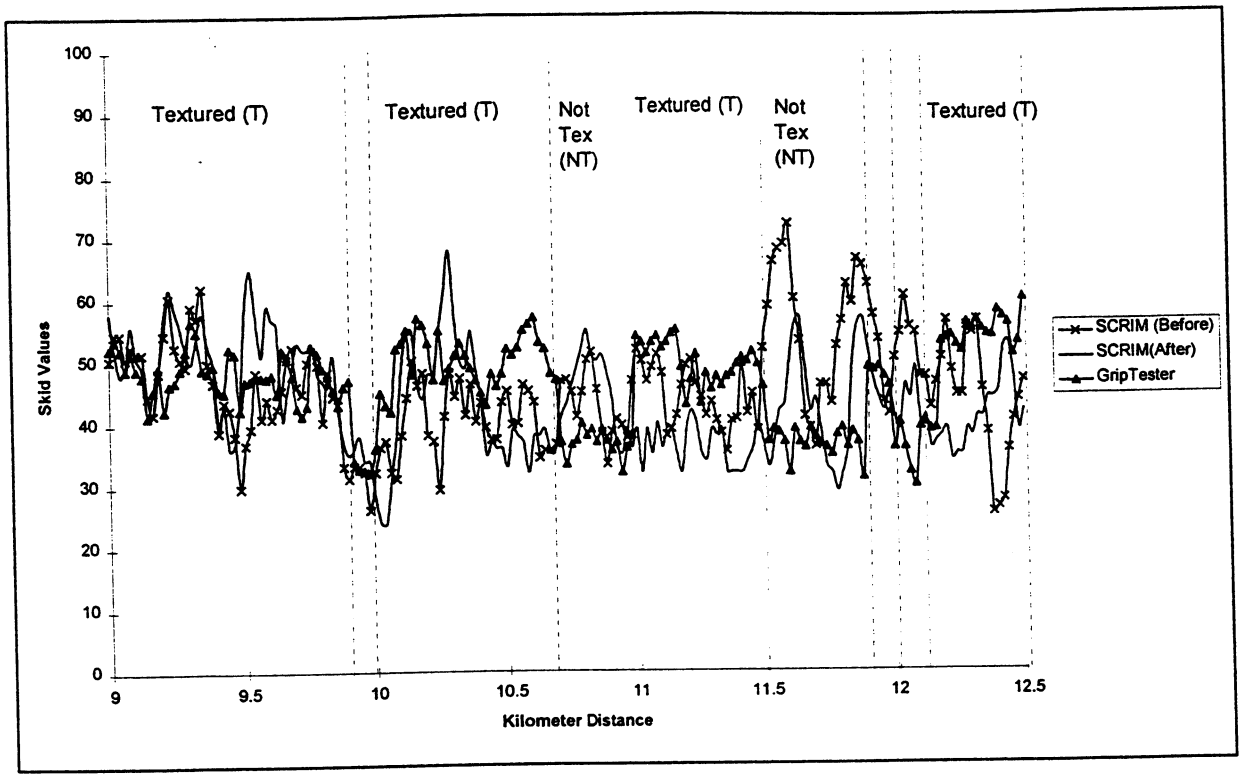


Figure 4: Before/After Skid Measurements with SCRIM and GripTester (only after)

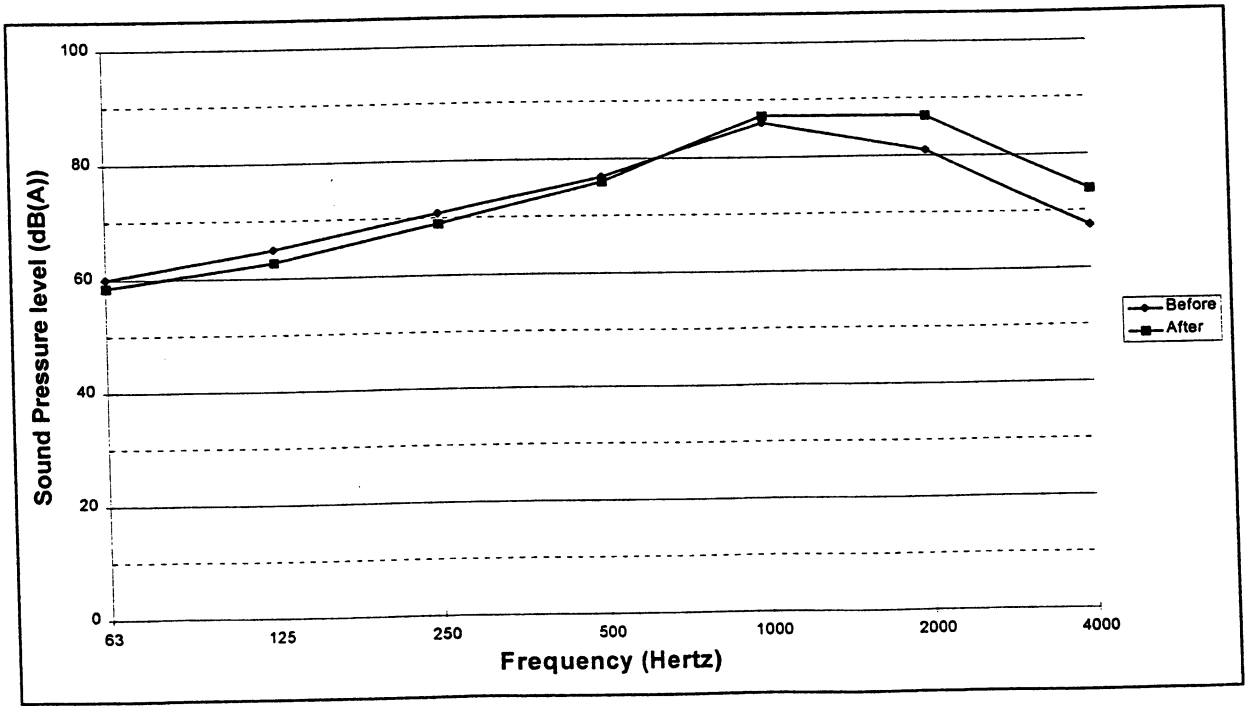


Figure 5: Frequency spectrum analysis before and after retexturing

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DISCLAIMER

This paper is presented with the approval of the Chief Director: Roads. The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the South African Department of Transport .

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