

THE USE OF POROUS ASPHALT ON MAJOR ROADS IN JOHANNESBURG

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Abstract

Roads with high traffic volumes are synonymous with high road related noise levels. In Johannesburg road related noise pollution is recognised as a negative environmental impact. The Noise Pollution Unit of Johannesburg City Council regularly measures noise levels in various settings. Innovative noise attenuation techniques such as traffic calming measures and noise barrier trials and investigations have been tried with mixed success. Lately noise absorbent road surfacings have proved to be a promising road noise attenuation measure.

Porous asphalt is a new generation noise absorbent road surfacing. Research and development were done on this specific noise absorbent asphalt surfacing type by the Division for Roads and Transport Technology of the CSIR. The use of new modified binders enabled minimum specified voids content of 20 per cent for porous asphalt. Previously the noise absorbent road surfacings were known as open graded asphalt or "popcorn". In general they had lower voids contents and did not use modified binders. The improved technology and its transfer were enhanced with new engineering and performance related laboratory tests. Rehabilitation projects on major roads in Johannesburg offered the opportunity to transfer this new technology to the road construction industry at large. Noise level measurements before and after the successful implementation proved that significant road noise level reductions are possible as was anticipated.

1. INTRODUCTION

Road traffic is a major cause of noise pollution. Road noise is a sound which is perceived by the human ear as a series of pressure fluctuations and is measured and expressed on a logarithmic decibel scale [dB]. The level of noise

generated by traffic depends on factors such as traffic flow rate, smoothness of traffic flow, percentage of heavy vehicles in the traffic, average speed, gradient of road and type of surfacing [Reeves, 1]. The road surface/tyre interaction is not necessarily the primary source of road related noise. Recent advances in vehicle design [wind noise] and engine design [engine/exhaust noise] have led to a remarkable reduction in motor related noise [IRF, 2]. Innovative development of tyre designs [tyre/road interaction noise] also contributed to a significant reduction in overall vehicle related noise on roads.

Road related noise has increasingly been identified as a major environmental pollution impact. This needs new and innovative measures to attenuate and control. In the United Kingdom [UK] a number of new environment laws have been passed with the specific purpose of "putting people first" [Abbot and Nelson, 3]. These laws, since their introduction in 1975, have led to in excess of an estimated £60 million being spent on various forms of traffic noise insulation in the UK.

In South Africa road related noise is addressed by various regulations and standards of measurement. The SABS Code of Practice 0210 of 1986 is such a standard which is currently under revision. The recently promulgated Environmental Conservation Act of 1989 further enhances the awareness of noise pollution in South Africa. [Rossouw, 4]. Regulations allow urban authorities at present to control noise levels adjacent to roads in declared "controlled areas". Various municipalities have adopted these noise control regulations. Johannesburg has not yet adopted these regulations, but is awaiting the outcome of a proposed revision of the regulations. [Rossouw, 4].

Johannesburg has some of the busiest urban traffic routes in Africa. Noise level measurements are taken on a regular basis near roads and industrial settings by the Noise Pollution Unit of the Directorate Health, Housing and Urbanisation. Johannesburg City Council has gained experience in various methods of road noise attenuation. This includes traffic calming measures and noise barrier investigations [Horak et al, 5]. This paper however focuses on the use of new technology noise absorbing road surfaces as a successful noise attenuation measure.

2. NOISE ABSORBENT ROAD SURFACINGS

The ideal road surfacing from a noise attenuation point of view, would be one which significantly absorbs tyre and surface contact noise and even possibly engine related noise. [Reeves, 1] Road surfacings are, however, usually designed with other structural and functional properties such as fatigue resistance [to prevent fatigue related cracking], deformation resistance [to prevent rutting] and safety related properties like good skid resistance [CSRA, 6]. Over the last 20 to 40 years the latter issue promoted the use of open graded asphalt [OGA] surfacings to improve skid resistance. [Visser et al, 7]. OGA surfacings normally use a maximum stone size of 9mm or 13mm with an average void content of 15 per cent. The relatively high void content of OGA gives it a typical "Swiss cheese" appearance. Due to its appearance OGA was

also referred to as "Popcorn" asphalt in South Africa. [Visser et al, 7]. The added benefit of acting as a drainage layer in wet weather became more obvious over time and with experience in their use. OGA layers have better skid resistance in wet weather with resultant safer wet weather visibility and even more pronounced noise attenuation abilities. The latter abilities of these OGA layers were however limited by the following factors:

- relatively low resistance to permanent deformation [lowering of voids content]
- loss of porosity and ability to drain quickly [voids content related] over time [clogging up with detritus]
- low recycling potential [a maintenance aspect specifically related to the use of bitumen rubber]
- stone loss due to binder ageing and brittleness [ravelling]
- maintenance related problems [pothole patching, etc].

A new generation of highly porous OGA surfacings have increasingly been used over the last 15 years in the United Kingdom, Europe and Australia [Glazier and Samuals, 8]. These new generation OGA surfacings are collectively referred to as porous asphalt. In general these porous asphalts also typically use a maximum stone size of 9mm or 13mm, but with a minimum void content specified of 20 per cent [Verhaeghe, 9]. Overseas practice has found that 20 per cent air voids is a threshold value. Porous asphalts with air void values below 20 per cent are more prone to clog up over time and lose its positive noise attenuation and drainage abilities. OGA layers were in the past generally applied in relatively thin layers of about 20 mm in South Africa [Thompson, 10], while porous asphalt is now generally applied with layer thicknesses of 40 mm or more. The development and use of modified asphalt binders with polymers and rubber modifications over the recent 5 to 10 years further enabled porous asphalt to overcome virtually all the aforementioned shortcomings of the first generation OGA surfacings.

The effect of road surfacing type on noise attenuation is commonly measured by means of a "coast by" method with a disengaged motor vehicle at various speeds [IRF, 2]. The United Kingdom codes also recognise texture depth in the correction formula which they use to adjust noise levels for various surface types [DOT, 11]. Recent studies done in South Africa on various surfacing types confirmed the relative impact on noise levels by the various surface types. A field study by Meij [12] showed for example that OGA surfacings have noise levels of up to 9dBA lower than single seals. This study also found that the noise level on national route N1-20 through Sandton could be reduced by as much as 11.7 dBA from the existing grooved concrete surfacing by using a bitumen rubber OGA surfacing. Even after 5 years the improvement was found to be about 6dBA. In general porous asphalt reduces road noise levels with about 4 dBA versus standard dense graded asphalt surfacings and achieve reductions of about 7dBA if applied over transversely grooved concrete surfacings [Van Heystraeten and Moraux, 13; Issenring et al, 14; Nelson and Abbot, 15; Perez-Jimenez and Gordillo, 16]. This ability to attenuate road noise

levels have led to the new generation porous asphalt being referred to as "whisper" course asphalt.

Recent research on porous asphalt in South Africa by the Division for Roads and Transport Technology [DRTT] of the CSIR for the South African Bitumen and Tar Association [SABITA] enabled the South African road construction industry to become more familiar with porous asphalt. [Verhaeghe, 9]. The recently completed rehabilitation investigations of the M2 and M1 motorways in Johannesburg required a new surfacing as part of the recommended rehabilitation measures. The Roads Directorate of Johannesburg saw this as the ideal opportunity to implement the research information and new technology to the field of practical application.

3. TECHNOLOGY TRANSFER MANAGEMENT

The Roads Directorate of Johannesburg City Council is actively pursuing new and appropriate technology as one of their strategic thrusts. This Directorate sees itself as a client body in the ideal position to act as technology transfer partner for the research community. Technology transfer is a co-operative effort and needs proper planning and management.

This technology transfer operation was project managed to enhance the associated risk management and achieve maximum exposure of various parties to the new technology. A project team was made up of Roads Directorate personnel in the fields of motorway maintenance, management, asphalt production, asphalt surfacing laying and laboratory, researchers from DRTT, consultants, asphalt suppliers and the Noise Pollution unit of the Health Housing and Urbanisation Directorate.

The aim was to lay porous asphalt on the first 3km of the west bound M2 motorway as part of the planned rehabilitation [CED,17]. In order to limit associated risk of the use of a then yet unproved technology in South Africa, the construction of such sections on the M2 in the public eye were preceded with well designed and planned experimental sections on Rifle Range Road. This was followed by a demonstration project on Oxford Road in Rosebank before the actual construction was done on the M2 motorway [Van Heerden, 18]. Various modified asphalt binder types were used in the mix designs of the porous asphalt/whisper course. This included the use of styrene-butadiene-styrene [SBS], rubber crumbs [dry mix], bitumen rubber blend [wet mix], cellulose fibre and two penetration asphalt binders [eg. 60/70 and 40/50 Pen.].

4. MIX DESIGN

The essence of the design philosophy with porous asphalt mixes is the recognition that it is the volumetric properties which reduce noise levels and improve the drainage capacity [Verhaeghe, 9]. Void content should therefore form the basis of the mix design strategy. Binder type and content are

important factors in any asphalt mix design, [CSRA, 6], but in porous asphalt they have perhaps a more significant effect on the structural integrity and inter-relationship with the grading of the mix. Durability and abrasion resistance are important aspects and are dependent on the above factors and in turn indirectly dependant on the viscosity properties of the binder/filler matrix.

The aggregate type and binder types used in the initial experimental sections on Rifle Range Road are as shown in Table 1.

Table 1: Aggregate and binder types for Rifle Range Road

Aggregate	Binder	Supplier
Andesite	40/50 Pen + 6% SBS	Johannesburg : Roads
Andesite	60/70 Pen + 2% SBS + fibres	Johannesburg : Roads
Reef Quartzite	Dry method bitumen rubber	Protea Asphalt
Reef Quartzite	Wet method bitumen rubber	Protea Asphalt

A void content of 20 per cent minimum was specified with the proposed three mix designs achieving it as shown in Table 2.

Table 2: Design Gradings

Sieve Size [mm]	Percentage Passing		
	Mix A	Mix B	Mix C
19	100	100	100
13.2	97	94	90
9.5	44	32	35
4.75	15	13	6
2.36	12	11	4
1.18	9	10	4
0.600	8	9	3
0.300	6	6	3
0.150	5	5	3
0.075	3	3	2

Mix A and B differs from Mix C essentially in terms of the 4.75mm sieve opening percentage passing. The significance of this will be highlighted in discussions to follow.

The selection of the binder content was further determined by optimising the conflicting demands of abrasion resistance, durability and hot storage drainage resistance. [Verhaeghe, 9]. Typical results for the selected 5 per cent binder content is summarised in Table 3 for the SBS modified mixes. Detailed information on the wet process bitumen-rubber porous mix is reported elsewhere [Verhaeghe and Rust, 19]. This wet process bitumen-rubber porous

mix was subsequently selected for the porous asphalt mix that was laid on the Ben Schoeman/ M1 road widening/rehabilitation of the Transvaal Provincial Administration after the M2-West sections were successfully constructed with the 6 per cent SBS mix and a short section of the wet process bitumen-rubber porous asphalt.

Table 3: Summary of mix design properties

Binder Type	Bulk Density	Voids [%]	Abrasion loss [%]	Binder Drainage [%]
40/50 Pen + 6% SBS	2.053	23.5	16.4	3
60/70 Pen + 2% SBS + 0.3% Fibre	2.050	23.0	37.8	1

The Contabro abrasion test limit was initially set at 20 per cent. The mix with cellulose fibres did not meet this criteria. The Schellenberger binder drainage or segregation tests were done at 140° C and 160° C [Verhaeghe 9; Van Heerden, 18]. No limits were given, but for this project any drainage more than 5 per cent was seen as significant.

5. MIX PROPERTIES FROM CONSTRUCTED SECTIONS

Detailed control tests were done on the four experimental sections on Rifle Range Road, the two demonstration project sections on Oxford Road and the M2-West motorway. The latter section was 3 km long and varied between 3 and 4 traffic lanes. Typical average test results of the various sections on Rifle Range Road and M2-West are shown in Table 4. [Van Heerden, 18]. Based on these results and the initial mix design results specification limits are also suggested.

Short experimental sections [Rifle Range Road] have led to typical construction related problems in some cases. Problems with correct grading and mixing temperature were adjusted [Van Heerden, 18], but caused the two bitumen rubber mixes in particular to not reach the specified 20 per cent void limit. Subsequently results of the wet-mix method used on the M2-West did achieve this void limit. It is significant that in all cases the bitumen-rubber had high resistance to abrasion loss being well below the Cantabro mass loss limit. The SBS binder mix with cellulose fibres marginally failed this test but it was better than the laboratory prepared mix [See Table 3]. It was general consensus that this mix was by far the most user friendly to work with.

Table 4: Typical test results and proposed specifications

TEST	RIFLE RANGE ROAD				M2-WEST		PRO-POSED
	40/50 Pen	60/70 Pen	Bitu- men- rubber	Bitu- men- rubber	40/50 Pen	Bitu- men- rubber	SPECIFI- CATION LIMIT
[Ver- haeghe, 9].	+ 6% SBS	+ 2% SBS + Fibre	Dry Process	Wet Process	+ 6% SBS	Wet Process*	
Voids content [%]	24.2	26.2	18.6	18.5	25.6	21.5	> 20
Film thickness [microns]	15.8	24.2	17.3	27.3	18.3	27.0	> 15
Cantabro Mass loss [%]	16.4	27.5	8.5	6.3	13.9	4.34	< 25
In Situ drainage test seconds	N.A	N.A	N.A	N.A	7.4	12.8	< 20

* Only a short experimental section laid, N.A. Not available.

The significance of the percentage passing the 4.75 mm sieve opening is demonstrated in Figure 1 and 2 in a further detailed analysis of the control tests results on the M2-West. In Figure 1 it is shown that the minimum air void content was reached with percentage passing the 4.75 mm sieve opening of less than 15.5 per cent. The grading of Mix B and C as shown in Table 3 would, therefore, be preferred in future. The modified binder mixes used on the M2-West met the Cantabro abrasion test criteria in general. In Figure 2 it is shown that higher percentages passing the 4.75 mm sieve opening tended to improve abrasion resistance even more. This clearly demonstrates that air void content and durability are conflicting demands on a porous asphalt mix. Durability or abrasion resistance as measured by the Cantabro test may be perceived as excessively harsh and possibly unrepresentative of the actual mechanism of ravelling of porous asphalt on a road surface, but recent results on the Ben Schoeman validates this test and the criteria set. Thicker film thicknesses can be seen in general terms as an insurance against ageing, brittleness, ravelling and other durability aspects. Film thickness can be viewed

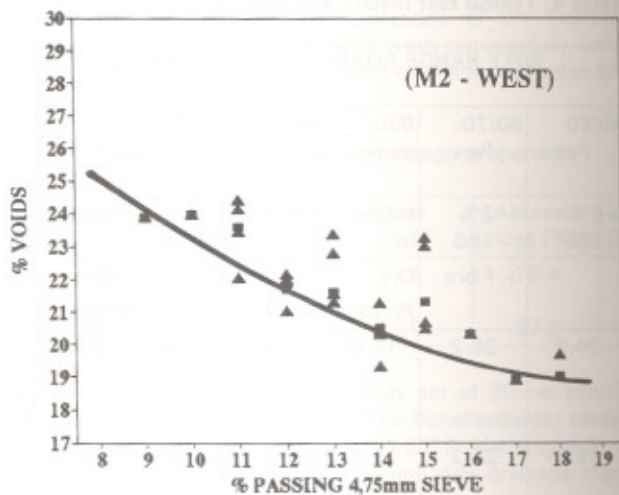


FIGURE 1 VOIDS CONTENT VERSUS PERCENTAGE PASSING THE 4,75mm SIEVE

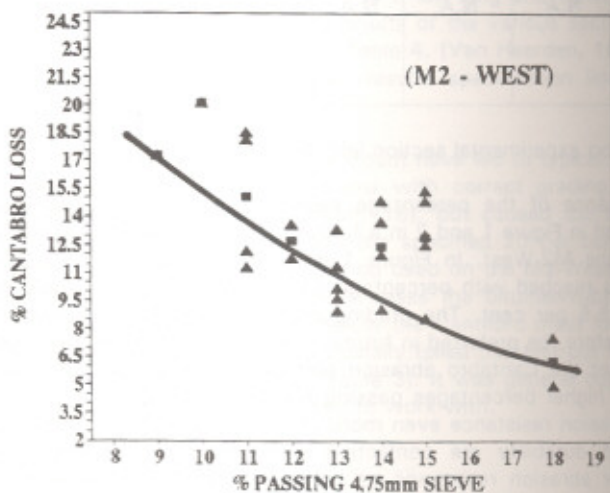


FIGURE 2 CANTABRO ABRASION RESULTS VERSUS PERCENTAGE PASSING ATHE 4,75 mm SIEVE

as an indirect reflection of a combination of factors such as binder content, type and grading.

6. NOISE LEVEL MEASUREMENTS

Noise level measurements were taken on Rifle Range Road and the M2-West by the Noise Pollution Unit of the Health, Housing and Urbanisation Directorate before and after the construction of the porous asphalt layers. The SABS Code of Practice 1013 of 1983 for "The Measurement and Rating of Environmental Noise with respect to Annoyance and Speech Communication" was used and the "Franco-German" method was used in the analysis of the noise levels [Van Heerden, 18].

In Figure: 3 typical average noise level results are shown for both Rifle Range Road and the M2-West over a 24 hour period. This is expressed as constant noise levels for a given period of time which is equivalent to the effect produced by the actual evolutive noise [L_{Aeq}]. [Reeves, 1]. The average layer thickness, traffic volume and noise level reduction are summarised in Table 5.

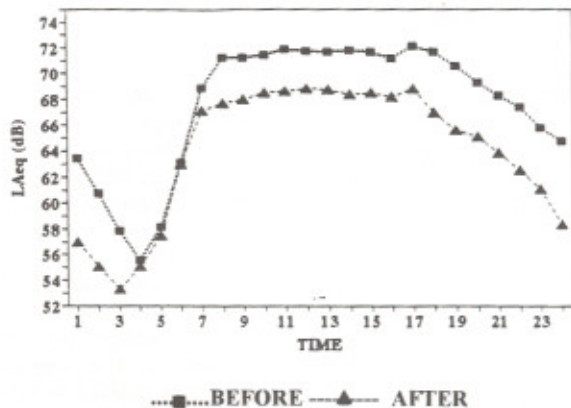
Table 5: Average noise level reduction, traffic volume and layer thicknesses

Road	Traffic Volume [Vehicles per day]	Layer Thickness [mm]	Noise Level Reduction L_{Aeq} [dBA]
M2-West	50 000	50	5.9
Rifle Range	13 000	30	3.6

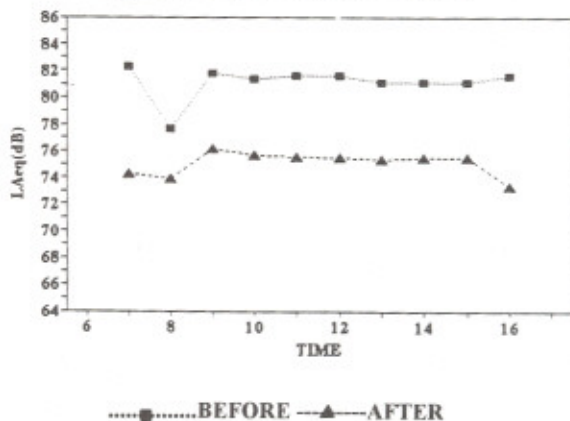
The noise reductions in both cases can be viewed as significant to highly significant [Rossouw, 4]. The M2 only had porous asphalt in the Westwards direction with the background noise of the Eastwards direction still at the normal high noise level with a normal asphalt surfacing. Thicker porous asphalt layers have greater noise level attenuation potential in general. [Hiersche and Freund, 20]. This is confirmed in Table 5 with the thicker layer on the M2-West having the higher noise attenuation. This is also because of the higher traffic volumes and resultant higher initial average noise levels on the M2-West than on Rifle Range Road. The logarithmic relation between traffic volume and noise level [Reeves, 1] means that this reduction of 5.9 dBA in noise level is more significant than the 3.6dBA reduction of Rifle Range Road where the average pre-treatment noise level was lower. In laymen perception terms this reduction of noise level on the M2-West is equivalent to more than halving the offending traffic volume [Reeves, 1].

Riding quality measurements were taken with a Linear Differential Integrator [LDI] instrumented vehicle, skid resistance with the Sideway-Force Coefficient Resistance Investigation Machine [SCRIM] and rut measurements by the mechanised equipment of DRTT, CSIR. In Table 6 the average values plus indications of variability are given for the various lanes and directions of Rifle

**POROUS ASPHALT - RIFLE RANGE ROAD
NOISE LEVEL MEASUREMENTS ALL SECTIONS**



**M2 WEST MOTORWAY - POROUS ASPHALT
NOISE LEVEL MEASUREMENTS**



**FIGURE 3 BEFORE AND AFTER NOISE LEVEL MEASUREMENTS
ON RIFLE RANGE ROAD AND M2-WEST**

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Range Road and M2-West. In general riding quality on the M2-West is acceptable. The riding quality of Rifle Range Road is also acceptable for such a class of urban road. No measurements of the pre-overlay situation is available, but the perception is that the porous asphalt overlay significantly improved riding quality.

**Table 6: Riding quality, skid resistance and rut measurements
[Rifle Range Road and M2-West]**

Road	Riding Quality. PSI-value		Skid Resistance Sideways Force Coefficient [SFC ₅₀]			Rut 2m straight edge [mm]	
	Av.	Std.Dev.	Av.	Max..	Min.	Av.	Max.
M2-West							
Fast lane	3.46	0.27	0.45	0.57	0.19	2.31	15.0
Middle lane	3.68	0.27	0.45	0.60	0.23	1.88	7.8
Slow lane	3.59	0.41	0.47	0.66	0.16	2.92	9.4
Rifle Range							
Eastwards	2.73	0.65	0.42	0.62	0.10	2.60	13.9
Westwards	2.75	0.52	0.34	0.45	0.17	2.36	13.5

The skid resistance measured at 50 kph [SFC₅₀ value] for the M2-West Motorway is about 0.45 on average. If the proposed target levels for freeways and highways [Gordon, 21] are used, the skid resistance marginally make the 0.45 level. If this same level of 0.45 SFC₅₀ is used for Rifle Range Road, both directions have SFC₅₀ values which fail. The latter case can be because the SCRIM operated at an average speed of 40 kph and not 50 kph as prescribed.

Measurements with the TRRL portable pendulum tester taken on Rifle Range Road show average values as summarised in Table 7. This confirms the relatively low skid resistance initially for all the mixes as compared to the normal 30 per cent gap graded mix.

Table 7: Portable Pendulum Skid Resistance Results [Rifle Range Road]

Mix type	Gap Graded	40/50 Pen + 6% SBS	2% SBS + fibres	Bitumen-Rubber [dry process]	Bitumen-Rubber [wet process]
Skid number	58	59	63	62	55

SFC₉₀ measurements on the slow lane of the M2-West 6 months after construction show an increase to 0.55. The results on the M2-West and Rifle Range Road seem to confirm statements that porous asphalt are initially recording low skid resistance due to lack of aggregate exposure. This micro texture effect would need further investigation though.

No wet weather accidents before and after treatment are available to confirm downward trends [Visser et al, 7 and Smith, 22]. Wet weather accidents expressed as a percentage as calculated with a relationship with SFC_{60} developed for Johannesburg [Gordon, 21] indicate that 17.3 per cent wet weather accidents can be expected. This will also be monitored over time to establish trends.

Rut measurements are acceptable for the relevant road classes. This will be monitored over time to check on densification and consolidation behaviour of the porous asphalt. On the M2-West it is, however, a vast improvement on the rut measurements recorded before rehabilitation started which were on average in excess of 10 mm [CED, 17]. This densification behaviour will obviously influence porosity or air void content and therefore drainage ability [permeability] and noise attenuation ability.

Rolling straight edge measurements were taken over a 1 km constructed length and a limit of 4 mm used showed only 2 points exceeding it over the length measured. Both points were transverse construction joints. The measured length did however make the specified 6 mm level with no points exceeding. [SSI, 23].

7. MAINTENANCE ISSUES

Clogging up of the voids of the porous asphalt with detritus occurs over time. Hiersche and Freund [20] proved that thicker porous asphalt layers [and multi-layers] have a better resistance to clogging-up than thinner layers. Experience in South Africa has shown that thin layers [20 mm] of porous asphalt clogged up over a period of 1 to 3 years [Thompson, 10].

The M2-Motorway runs past large mine dumps. This would be a very aggressive test for porous asphalt porosity over time due to possible clogging up by wind blown sand. Permeability reduces with time with any filter or drainage medium [Van der Merwe and Horak, 24] as porosity reduces. The relationship between porosity [or air voids if expressed as percentage] calculated with the empirical Moulton formula [Van der Merwe, 25] and permeability is shown in Figure 4. This was calculated as shown for a typical high quality crushed stone base material [CSRA, 6] without consideration of binder content to illustrate the principle of porosity/permeability relation. This figure confirms that in general a void content increasing above about 20 per cent shows a dramatic increase in permeability while void contents of about 20 per cent and below shows an insensitivity to permeability. This clearly shows the advantage in significant improvements to permeability [drainage ability] if porosity values are increased above 0.2 or air voids above 20 per cent.

The in-situ drainage test [Verhaeghe, 9] is a strong indicator of porosity or void content and permeability. Average drainage times of this test on the M2-West after 3 months showed to be constant at about 8.5 seconds. This is within the specified limit [Table 4] and will be monitored on a regular basis to see if there

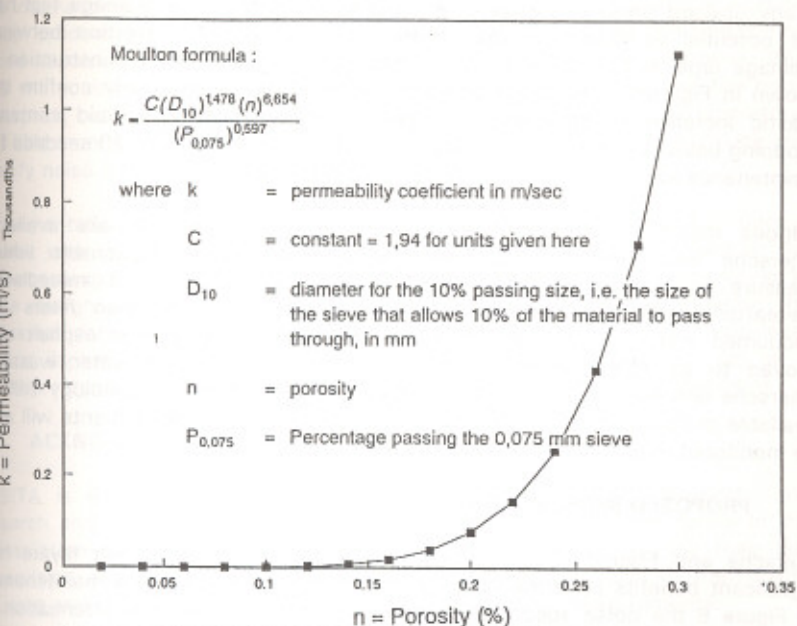


FIGURE 4 CALCULATED PERMEABILITY VERSUS POROSITY FOR A HIGH QUALITY CRUSHED STONE BASE MATERIAL

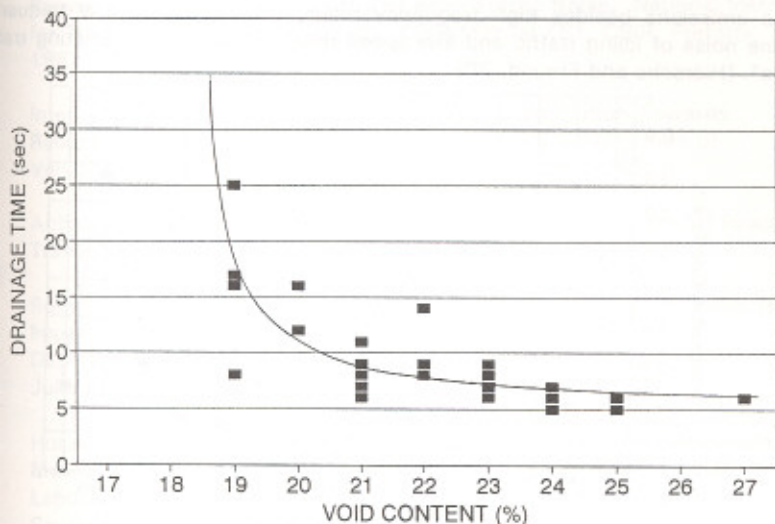


FIGURE 5 IN-SITU DRAINAGE TIME VERSUS AIR VOID CONTENT

is any upward trend [drainage time]. It is believed that this drainage test has the potential to determine maintenance intervention. The relation between drainage time and porosity or void content as measured after construction is shown in Figure 5. The curve fitted to these initial values clearly confirm the drastic increase in drainage time [loss of permeability] for void contents dropping below 20 per cent. A suggested average level of 15 to 20 seconds for maintenance interventions is suggested at this stage.

Various maintenance procedures to unclog porous asphalt are available [Hiersche and Freund, 20]. Sophisticated mechanised equipment which pressure jets water into the porous asphalt and vacuums it immediately thereafter [while the detritus is still in suspension] and then filters the vacuumed water, is available overseas. Fire hosing the porous asphalt also proved to be effective albeit time consuming, costly and water wasteful [Hiersche and Freund, 20]. It is anticipated that the former technology will be available in South Africa in the near future. Noise level measurements will also be monitored over time for possible trends.

8. PROPOSED IMPROVEMENTS

Hiersche and Freund [20] found that multi-layer porous asphalt layers had significant benefits in terms of noise attenuation/absorbing and maintenance. In Figure 6 the noise absorption coefficient clearly shows that attenuation of two distinct frequencies as done on a twinlayer porous asphalt system. [Jongens, 26] with two different methods. This confirms that "multi-layer porous pavements, constructed with high air void mixes, are able to reduce noise emissions besides high frequency rolling traffic noises, low frequency engine noise of idling traffic and low speed driving noise or accelerating traffic noise". [Hiersche and Freund, 20].

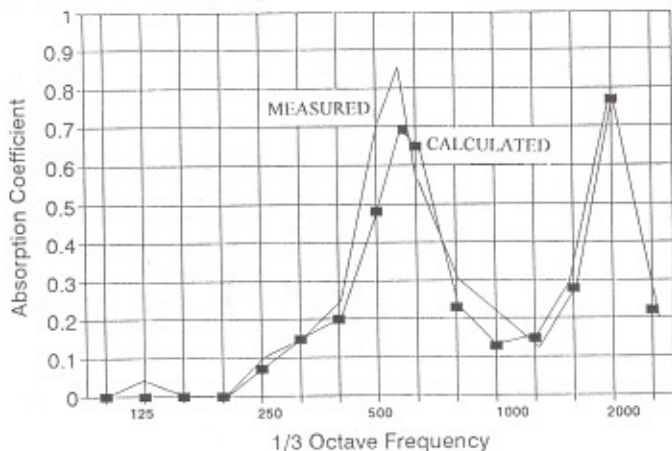


FIGURE 6. NOISE ABSORPTION COEFFICIENT MEASURED ON A DOUBLE LAYER POROUS ASPHALT [JONGENS, 1995]

The international Organisation for Standardisation [ISO] currently has a working group producing an international standard titled "Procedure for measuring sound absorption properties of road surfaces: In-situ method" [Jongens, 26]. This will enable the use of a portable, rapid, in-situ measurement of the noise absorption coefficient of any road surface or sample. Design [in the laboratory] and field monitoring can then possibly use direct measurements to evaluate and specify noise attenuation abilities or noise absorption levels.

Experimentation has already started to mix and construct multi-layers of porous asphalt with increasing maximum stone size in depth of the pavement at the Johannesburg Roads Directorate. Structural stability also need to be achieved in these designs. Apart from the obvious advantage to noise attenuation the increased drainage capabilities offers the possible use of such multi-layer porous asphalt on parking areas. This can, if properly designed, act as a valuable retention facility in urban areas enhancing stormwater management.

9. ACKNOWLEDGEMENTS

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