LONG-TERM PAVEMENT PERFORMANCE EXPERIMENTS: A PERSONAL EXPERIENCE

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ABSTRACT

The author shares his experience over the last 40 years of the design, monitoring and final evaluation resulting from 23 purpose-built road experiments consisting of over 200 individual sections plus many observation sections in Botswana, Namibia and South Africa. The purpose-built LTPP experiments and the lengths of existing road selected as observation sections are of four types. The first three are intended to show how to make the best use of local, low-cost materials for low to medium volume roads in the dry and moderate macroclimatic zones of southern Africa – some two-thirds of the region:

- Bases and subbases of marginal to substandard (mostly G5-G7) calcrete, weathered granite, weathered basalt, neat (G7), cement- and bitumen-treated Kalahari sands, and sulphide- and acidic sulphate- contaminated gold and copper mine waste rock.
- Brack, saline and sea water for compaction of all layers including the base and in the slurry of a Cape seal.
- Selected calcrete as chippings in various types of seal coats in the Kalahari where conventional stone does not occur.

The fourth type is intended to provide proven countermeasures to eliminate or at least mitigate the damage to roads on expansive clay roadbeds – apart perhaps from drainage-related failures the most common form of roadbed-related distress in southern Africa.

In all cases control sections of G3 crushed stone, G4 gravel, stabilized gravel, fresh water, or with no countermeasures as appropriate were included as part of the experiments. These experiments are proving – by means of monitoring over periods in excess of 20 years – that, for example, and depending upon traffic, substandard calcretes with PIs of 20, sulphidic and acid-saline mine rock, seawater and even unsound basalt can all be used successfully in the base course, and that the effects of expansive clays can be greatly reduced without incurring increased maintenance costs provided that certain precautions are taken. The design requirements and the problems of preserving and monitoring such long-term experiments are discussed.

The advantages and disadvantages of LTPP vs HVS trafficking are discussed and it is concluded that a judicious mix of both is necessary.

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1. INTRODUCTION

Long-term pavement performance (LTPP) experiments were the traditional methods of evaluating material and pavement designs before the use of accelerated trafficking – and especially before the advent of the heavy vehicle simulator (HVS) in the 1970s.

Whilst invaluable in providing rapid traffic- and to a limited extent water- and temperature-related answers, HVS testing and other accelerated trafficking cannot simulate medium- and long-term effects.

Such effects include the possible in-service deterioration of basic rocks – in contrast to the possible self-cementation of pedogenic materials – loss of cementation and/or increase in plasticity of cement- and lime- stabilized materials, seasonal cyclic and longer term moisture changes and their effects, and the deterioration of bituminous surfacings. For these, long-term (5 – 20 year) experiments are necessary – as well as providing the "real" performance by which to calibrate HVS-derived models.

On the other hand, the disadvantages of long-term experiments are also substantial:

- solutions to the immediate problem cannot always wait;
- long-term estimates of cumulative traffic loadings are problematic;
- after some conservative stopgap solution is applied, the initial enthusiasm for the experiment usually wanes, it may be viewed as longer necessary, funding dries up, and monitoring is neglected or even ceases;
- with changes or retirement of staff, signage and markings are neglected or even removed (sometimes for political reasons), the experiments are forgotten and lost under reseals and/or changes in log datums, regarded as a nuisance, or even destroyed by accidental or deliberate rehabilitation with the rest of the road, whether or not they needed it;
- lastly, an experiment is of course the property of the relevant road authority and not the researcher, and they can do what they like with it – and they do.

All of these have occurred to the "author's" experiments and all were good reasons for developing a HVS!

It is not the purpose of this paper to provide a general review of LTPP experiments, nor to discuss in detail their outcome, nor to compare the results of such experiments with those of accelerated trafficking, but simply to share the author's experience over the last 40 years of the design, monitoring, preservation and final evaluation of such experiments. Whilst most of the points made might seem obvious, they have all created problems on at least one experiment and were at the time not obvious to those concerned.

2. SCOPE OF "AUTHOR'S" LTPP EXPERIMENTS

The author has been personally involved from design to final evaluation in some 23 purpose-built road experiments comprising a total of over 200 individual sections ranging in size from small, 5 m^2 salt-damaged surfacing repair measures to up to 300 m-lengths of road pavement as well as a total of over 100 km of selected observation sections on pre-existing roads in Botswana, Malawi, Namibia and South Africa.

The purpose-built LTPP experiments and the lengths of existing road selected as observation sections are of four types. The first three are intended to show how to make the best use of local, low-cost materials for low to medium volume roads in the arid and semiarid zones of southern Africa – some two-thirds of the region:

- Bases and subbases of marginal to substandard (mostly COLTO (1998) G5-G7 quality) calcrete, weathered granite, weathered basalt, Kalahari sand, and sulphide and acidic salt- contaminated gold and copper mine waste rock.
- Brack, saline and sea water for compaction of all layers including the base and in the slurry of a Cape seal.
- Selected calcrete as chippings in various types of seal coats in the Kalahari where conventional stone does not occur.

The fourth type is intended to provide proven countermeasures to eliminate or at least mitigate the damage to roads on expansive clay roadbeds – apart perhaps from drainage-related failures the most common form of roadbed-related distress in southern Africa.

In all cases control sections of standard materials or with no countermeasures as appropriate were included as part of the experiments.

Some of these experiments are believed to be unique, both in their type, in the length of monitoring (mostly over 20 years) and in that the designer (the author) has been involved from start to finish.

These experiments are proving – by means of such long-term monitoring – that, for example, and depending upon traffic, substandard calcretes with PIs of up to 20, neat Kalahari sand, sulphidic and acidic saline mine rock, seawater, and unsound basalt can all be used in the base course and that the effects of expansive clays can be greatly reduced without incurring increased maintenance costs provided that certain precautions are taken

The range of base course grading modulus (GM), plasticity index (PI) and strength of some of the purpose-built test sections evaluated is shown in Table 1.

The need for the calcrete base experiments arose out of the necessity for checking the relaxed material quality specifications derived by the author by means of a back-analysis of some existing roads in the Western and Eastern Cape (Netterberg, 1971, 1982).

The need for the weathered basalt base experiments arose out of the widespread problems arising out of the use of unstabilized basic rocks as base course (e.g. Weinert, 1980). Sections of non-durable basalt were therefore treated with sand, cement and even lime in an unsuccessful attempt to render them non-plastic as required (Netterberg, 2004a). It is hoped that these experiments will finally provide a definite answer as to whether the PI of such material can increase in service and, if so, how to prevent or minimise it.

The neat, cement- and bitumen- treated Kalahari sand base experiments arose out of the need to make the best use of such sand in the vast areas of southern Africa where conventional gravels do not exist (e.g. Netterberg and Elsmere, 2015; Paige-Green et al 2015).

Table 1. Some LTPP base course experiments

Base type	Quality [1]		Expts	Sections		Macro-climate	Mean GM	Mean PI	Mean CBR / Vane shear strength	Age	Traffic
	Test	Control		Test	Con-trol	COLTO (1996)	[2] [3]	[2] [3]	[3] [4]		[3]
			No.	No.	No.			%	% / kPa	Years	Cum. M E80
Calcrete	G4-G10	G3; C4	4	20	13	Dry	1,8-2,6	NP-18	25-160 %	30-35	0,5-1,2
Calcrete	G6-G7	G3; C3	2	6	6	Moderate	1,3-2,4	SP-12	45-80 %	30; 35	0,5; 3
Basalt [5]	G4	G4L	1	8	4	Moderate	2,1-2,6	NP-4	140-180 %	15	(0,5)
Kalahari											
sand neat	G7	C4; BT3	2	3	4	Dry	0,8; 1,1	NP	50; 50 %	50; 20	1,0; 0,3
+ cement	C3-C4	G7; G3	2	5	2	Dry	(0,8)	(NP)	> 150 %	50	1,0
+ cutback or foamed	BT3	G4	1	11	2	Dry	(0,9)	(NP)	70-450 kPa	14	0,4
+emulsion	BT3	G4	1	11	2	Dry	(1,1)	(NP)	26-62 % (>200 kPa)	20	0,3

NOTES

[1] NITRR (1985) ; COLTO (1998). The poor G- classification of some is largely only due to the high PI. G4L = lime treated G4.
[2] Figures in brackets are for the neat material used.
[3] Figures in brackets are estimates.
[4] CBR of gravels at 98 %, sands at 100 % MAAASHO; vane shear strength at 100 % MAASHO or in-situ.
[5] Non-durable according to battery of laboratory tests and local experience.

Not listed are some twelve purpose-built experiments totalling 54 sections intended to find ways of using seawater for the compaction of all layers, including slurries (Netterberg, 2004b) and base course (Netterberg, 2013) and of using base materials contaminated with common salt (NaCl), gypsum ($CaSO_4.2H_2O$), sulphides, or acidic sulphates in excess of the COLTO (1998) limits.

Also not listed are several experiments to find ways of rehabilitating intractable salt-blistered and cracked surfacings with conventional (Netterberg, 1979 a,b), modified and bitumen- rubber seals, asphalt and crushed stone overlays (Netterberg, 1979 a,b, 2015), calcrete and silcrete as seal coat chippings (Paige-Green et al, 2002), and countermeasures on roads on expansive clays (Netterberg and Bam, 1984).

These experiments are slowly being finalised and written up as funding becomes available.

3. VARIABLES

The basic essential is that one should try only to change one variable at a time, i.e. each section on the experiment should only differ from the adjacent one in one particular property. For example, if one is evaluating the effect of PI, only this (and, almost inevitably, usually also LL and LS) should vary between – and not within – the sections, and the grading, CBR, relative compaction, thickness, supporting layers, etc., should be kept as constant as possible. In practice of course some variability is inevitable, but this can be reduced by stockpiling and mixing, testing the stockpile, mixing again thoroughly on the road, and by taking and testing sufficient samples from the layer.

On the positive side, on one sand-asphalt base experiment the many localised failures were found to be due largely to construction defects in the form of poor mixing and poor thickness control. By investigating a selection of both failures and good areas it was possible to derive performance-related criteria for that particular design sooner than would otherwise have been possible.

3.1 Climate

It has been realised for many years that environmental factors such as climate, drainage and the nature of the roadbed are more important than traffic in the case of low volume roads. For example, it has been suggested that at, for example, traffic levels of 0,25; 0,5; 0,75 and one million (M) E80, about 90, 75, 60 and 50 % respectively of a road's performance is due to the nature of its environment rather than its traffic (SADC, 2003).

For this reason particular care should be taken to characterise the environment in terms of climate, weather, drainage, topography, geology and roadbed soil as thoroughly as possible.

In order to make the results conservatively applicable to the whole of the relevant macroclimatic region the site should preferably be selected so as to be close to the wetter rather than the drier boundary of the zone.

The site must also not be in a microclimate significantly different from that of the macroclimate of the region.

Climatic parameters that should be recorded include Thornthwaite's Moisture Index, e.g. from Emery (1984, 1992) or CSIR (2009), Weinert's (1980) N-value, the "normal" (i.e. 30-year mean) or long-term mean annual rainfall and its variability, and whatever other information is available, such as the mean annual Class A pan evaporation, the mean annual temperature and its variability, and the design surfacing temperature.

The pavement design macroclimatic region (e.g. COLTO, 1996; SANRAL 2013) surfacing design temperature region, and Thornthwaites' (e.g. Schulze, 1958) and Köppen's (e.g. Schulze, 1947; Kruger, 2004) climatic classification should be recorded.

Good sources of climatic and/or weather records include the Weather Service, Schulze et al (1997), agricultural co-operatives, and local farmers.

3.2 Weather

Climate is merely a representation of the long-term average weather pattern in a particular area or of a particular site of which, for example the 30-year average annual rainfall "normal" is usually an important part. If it is believed that climate is an important factor in the performance of a road pavement it follows that any LTPP experiment must continue for a sufficiently long period of time to include the normal variations in weather – in this case periods of both drought and especially above normal rainfall – at the site.

In southern Africa an 18-year oscillation consisting of approximately 9-year wet and 9-year dry spells is common throughout the summer rainfall area (Tyson, 1987). A wet spell is simply a run of years during which, **on average**, more higher than normal rainfall totals occur, and vice versa. However, within these spells years of both higher and lower than normal rainfall do occur, and the oscillation seldom accounts for more than 30 % of the local rainfall variance (Tyson, 1987).

Apart from traffic-related effects, the period over which a LTPP experiment should run would depend upon its response time to the particular environmental changes which affect it. If the environmental factor is rainfall and the response time is short, such as for an old road overdue for a reseal, then even a few weeks may suffice. If it is long, such as for a well-maintained new road, then the minimum duration should probably be a full 9-year wet spell, which should yield conservative results.

On the other hand, optimistic conclusions might result if the experiment was constructed near the start of a 9-year dry spell. This would be worsened still should this coincide with an El Nino dry cycle, which seems to be the case at present – to which must be added the vagaries of climate change.

Monitoring for at least 20 years should therefore include both at least one 18-year oscillation as well as the usual 20-year structural design life and at least 30 years would also include the full analysis period

3.3 Alignment

The road should be straight and as level as reasonably possible unless these are intended as variables in the experiment.

Any deviation from the straight and level affects the drainage and traffic loading and complicates both the construction and the monitoring.

3.4 Roadbed

Depending upon the proposed pavement design, the roadbed soil profile should be characterised to a depth of at least 0,5 -1,5 m for a “normal” profile and should be uniform over the entire length of the experiment. It should not possess any unusual geotechnical properties such as potential expansion, shrinkage, significant settlement, or collapse, unless one of these is intended to be a variable in the experiment.

A potentially expansive profile may require much deeper characterisation.

The details of any pretreatment used such as prewetting or deep compaction must be recorded.

The sections should not be constructed over an existing road unless this is intended to be part of the experiment.

In such a case they should also not be aligned so that the old road is only under one lane of the new road unless this is intended to be part of the experiment.

3.5 Drainage and drainage structures

If possible, there should be no drainage structures on the experiment.

If such structures cannot be avoided they should be placed at the joints between sections rather than in them and definitely not in the central non-destructive testing (NDT) zone.

The drainage design should be that normally used for that category of road and not unusually good or bad, and should be as uniform as possible.

The distance on each side of a drainage structure over which the drainage might differ from the rest of the section(s) either as-built or later, e.g. due to blockage, should be minimised and the transition zone lengthened if necessary.

4. LAYOUT

Each base course or pavement LTPP section should preferably be either 150, 200 or 300 m in length and be further divided into subsection lengths according to their intended use (Table 2).

Table 2: Examples of LTPP section layout

Total Length (m)	150	200	300
Subsection purpose	**Length m**	**Length m**	**Length m**
Transition section (not used)	0 - 10	0 - 25	0 - 50
Sampling and destructive tests [1])	10 - 25	25 - 50	50 - 100
Non-destructive tests	**25 - 125**	**50 - 150**	**100 - 200**
Sampling and destructive tests [1]	125 - 140	150 - 175	200 - 250
Transition section (not used)	140 - 150	175 - 200	250 - 200

Note:
[1] Also monitored instrumentally until destructive testing done. Thereafter only visual and manual measurements may be useful.

This means that, as far as possible, **the middle 100 m is reserved for non-destructive tests** such as for riding quality, deflection, rut depth and visual observations. As far as possible, destructive work such as sampling, investigation of distress or failure and even DCP tests are only carried out in the adjacent 25 or 50 m subsections. The outermost 10, 25 or 50 m subsections are regarded as transition sections possibly contaminated by the adjacent section and/or less evenly constructed, and are not normally used except as possible backup. A 300 m test section is the ideal minimum length for ease of construction and long-term monitoring. However, shorter 150 or 200 m sections can be used in order to study as many variables as possible provided that extra care is taken during construction to minimise the length of the transition zone and contamination from one to the other. Sections shorter than about 150 m are difficult to construct and carry the risk of significant contamination from one to the other.

For example, on one of the author's base course experiments to which salt (NaCl) and/or gypsum was deliberately added the sections were reduced to only 60 m in length in order to study the 21 variables required. In spite of assurances that such short lengths were feasible and special instructions being given to minimise carryover (such as lifting the grader blade), it was estimated that up to 50 % carryover took place in the first 10 m in some sections, 20 % in the next 10 m and 10 % in the third 10 m, i.e. in some sections even the middle of the section contained 10 % of the different base from the adjacent sections. This was also clearly visible in the sample holes. Individual pieces of base course aggregate were observed to be carried for a distance up to 50 m when cutting final levels and minor salt damage also occurred on some "clean" sections up to 50 m from where salt had been added.

Some or all of this salt contamination also appeared to have resulted from slushing the base on a 2,5 % longitudinal fall when only a "water roll" should have been used.

Destructive investigation should be carried out in the middle subsection before the final evaluation only if distress or failures occur only there and not in the adjacent sections reserved for such destructive work. In this case it must be well-recorded, well-patched and due allowance made for it during non-destructive testing.

Each experiment should be marked by means of signboards and each section by paint marks and durable beacons, and their construction stake values (SV, also incorrectly called “chainage”), co-ordinates and final log kms recorded.

A subsign reading “No maintenance – consult Research Engineer” with a telephone number should be added to the signage. The provision of such a notice saved one LTPP experiment from being destroyed – but one only saying “consult HQ” did not save another from resealing – and the complete absence of such a notice led to a third one being destroyed.

The positions of SV and log km zero and those of any nearby features such as culverts and intersections must also be recorded. Neglect of these simple precautions led to two sets of LTPP experiments being lost for many years.

The signage, markings and beacons must be repainted and reinstated as necessary from time to time.

5. ROAD MANAGEMENT SYSTEM

The sections should be entered into the road management system (RMS) and the road file with instructions that they should be monitored separately and more intensively whenever the road as a whole is monitored.

They should also be flagged with a note that no maintenance of any kind other than grass cutting and clearing of culverts should be carried out without the permission of the research engineer.

Over the years stake value (“chainage”) plates are taken down, stolen or become illegible, brass and steel plates set into the road are stolen, beacons are destroyed when finishing the reserve, by workers laying fibre optic cables, and by farmers removing the fence to increase tractor working space, signage is removed by the road authority or stolen, log kms can be changed, and the original plans with coordinates are lost or deliberately destroyed as no longer useful. All of this has happened!

However, now at least we have a global positioning system (GPS)!

6. CONSTRUCTION

All aspects which might affect the short- or long-term performance of the section and/or the construction of any such future pavements should be recorded, e.g:

- any unusual methods used;
- any problems;
- type and duration of any curing;
- water content of upper base (state depth) just before priming;
- dates of construction of each layer;
- construction stake value and GPS coordinates at the start and end of each section and subsection and at SV zero;
- final log km at the start and end of each section and subsection and location of km 0.

7. SITE CONTROL

7.1 Specification

It goes without saying that the specification for all layers as well as finish, riding quality, etc., must be recorded, as well as the actual materials and results achieved.

7.2 Methods

The test methods used for determining the levels, thicknesses and material properties should be recorded, for example:

- whether thicknesses were calculated from levels or measured in holes;
- whether densities were determined by sand replacement, nuclear gauges or both;
- if by nuclear gauge the offset used for water content should be stated and the correlation supplied;
- whether samples for compaction and CBR tests were taken after the base was placed, i.e. after mixing, watering and spreading but before compaction, or after compaction;
- at what stage were the indicator samples taken, e.g. after final compaction but before cutting final levels, or by enlarging the water content holes at the nuclear density measurement sites;
- exactly what laboratory test methods were used, e.g. TMH 1 (National Institute for Transport and Road Research (1986) wet preparation Method A1(a); whether a sand bath or oven was used for drying after wet preparation; which particular LL method was used; whether the compaction samples and CBR were conditioned beforehand and, if so, for how long; the compensation used for oversize, e.g. all or part (how much?) of the plus 20 mm fraction was crushed in, or was it simply scalped at 37,5 mm, etc.;
- any other unusual methods used or unusual behaviour in testing.

Although much of the foregoing is usually taken for granted, experience has shown that all of these aspects add additional variables, the effects of which may go unnoticed unless recorded.

Differences in standard test procedures between different countries for determining what might be assumed to be the same property can result in significantly different results being obtained, for example:

- whilst it is usual in South Africa to only use the CBR at 2,54 mm penetration after 4 days of soaking, in most other countries the higher of that at 2,54 or 5,08 mm is used, and they are not always soaked;
- on average, the CBR of most unstabilized materials at 5,08 mm penetration is about 1,27 times that at 2,54 mm (Pinard and Netterberg (2012);
- the extensive, premature failure of one new road was ascribed to crushing in all the oversize, and localised failures on another to only using rapid, dry sieving for the soil indicator tests;
- on another road with a weathered basalt base it was found that limiting the amount of the oversize crushed in to a maximum of 30 % of the total sample usually reduced the CBR by about one-third and slightly increased the indicator test results after compaction in the mould, especially the percentage passing 75 µm (P075) and the plasticity index modulus (PIM), i.e. the P425 x PI.

7.3 Frequency

The number of tests carried out on each individual section should be at least equal to those required for a lot. One should always consider the number of test results that one would like to have on which to base the design of say 50 km of road!

The complete, actual results and their stake values and offsets (preferably not just left, right or centreline) should be recorded in the traditional way e.g. as in DoT (1958), as well as the statistics of selected parameters as in most current practice, e.g. as in TMH 10 (CSRA, 1993).

7.4 Archive samples

Consideration should be given to the potential value of archive samples for checking the as-built results and for material quality deterioration, and for testing by new methods. Although successful long-term storage of such samples is difficult, such a materials reference library is maintained by the Federal Highway Administration in the USA as part of their LTPP study

8. MONITORING

8.1 Importance

Proper monitoring must not be neglected. A full-scale road experiment such as this must be regarded as a representative sample of some possible substantial length of future road. The roads authority must continually consider the question "would we be prepared to construct 50 km of road based upon the performance and number of tests on this short test section?"

It is unlikely that simply extracting the data from monitoring at network level will be satisfactory unless special attention is given to the accurate location of the sections and subsections and to obtaining a sufficient number of measurements on each.

All sections should be entered into the road management system and monitored whenever the rest of the road is monitored, using the same methods, but increasing the frequency as appropriate for such short sections and locating them accurately.

The maintenance staff should be alerted to the existence of the sections and forbidden to carry out any significant maintenance without the permission of the research engineer. Notices to this effect should be erected at the start and end of the experiment.

Before such permission is given at least a visual evaluation should be carried out by competent staff and the results recorded. Good records must be kept of all maintenance, especially patching, including the reason for and location of each patch (SV or km) to the nearest l m and 0,1 m on offset. The reason for any failures must be properly investigated. The research engineer should be involved in any such investigations. **We want some failures – without failures we will never learn the limits of the designs**.

There is a very real danger of losing significant value or even the whole experiment even by resealing. If no inspection is carried out, performance-related information will be lost and dangerously erroneous conclusions may be drawn. For example, if say cracking and potholing is well-repaired and resealed, subsequent inspection may not detect it and erroneously conclude that the performance was satisfactory.

8.2 Frequency

Monitoring should preferably be carried out every 1 - 2 years initially for the first five years or so, and every 3 - 5 years thereafter, depending upon performance. If there is little change, monitoring need only be at the greater intervals. However, if distress of any kind is noticed it should be as frequent as is necessary to determine the structural capacity and life of each section. The following intervals are recommended as a guide.

Visual inspections: on foot according to TMH 9 (CSRA, 1992) and whatever else the project and the road authority requires: 1 - 2 years initially, extending to 3 – 5 years, and whenever the road as a whole is assessed, whichever is the shorter, and before resealing, rejuvenating, rut filling or anything other than **minor** crack filling or **minor** surfacing or edge patching.

Rut depths: maximum rut depths approximately in all four wheelpaths and its distance from the edge of the seal, yellow line or centreline, using a 2,0 m long straight edge and a wedge at 5 m intervals, with one end of the straight edge placed on the edge of the chippings, the yellow line or the centreline as appropriate whenever a visual inspection is carried out and also instrumentally whenever the road as a whole is measured. The author has used a 20 mm-wide wedge on all the Botswanan, Namibian, and South African LTPP experiments which he has monitored over the last 35 years. The COLTO (1998) Clause 8111 wedge is unsuitable for such work.

Riding quality: whenever the road as a whole is measured. If an instrument capable of reading in intervals of only 100 m is used the sections and subsection must be marked out by means of cones or other markers, the readings accurately located and the mean of several runs used.

Deflections: whenever the road as a whole is measured. If a falling weight deflectometer (FWD) is used all the parameters must be calculated. If a deflectograph is used the radius of curvature must also be calculated. Radius of curvature and base layer index measurements are more useful than maximum surface deflections on base course experiments, and if a Benkelman beam is used the radius of curvature of the deflection bowl must also be measured either with the beam or with a Dehlen curvature meter. Deflections should not be done within 5 m of a culvert or 2 m of a patch. They should be marked with a spot of paint for possible later DCP tests and/or profiling and sampling.

Radii of curvature and to a lesser extent deflections can be greatly influenced by the distance from the edge of the seal as well as by the time of the year and rainfall and in some cases by the daily temperature cycle, even with a thin seal on a granular or lightly cemented base (Netterberg and Haupt 2003). The time of day and the surfacing temperature must therefore be recorded, preferably at each measurement. Checks for temperature sensitivity should also be made by at least three repeat measurements on at least one marked spot on each section during the day to cover the full range of surface temperature.

Special investigations: whenever any distress or failure occurs which requires anything other than minor maintenance. For example, loss of the seal in a few small areas can simply be patched, but premature potholes into the base, shear failures, or ruts deeper than about 15 mm should be investigated before patching or filling. Destructive work which might affect rut depth or riding quality should, if possible, not be carried out in the middle 100 m until the final pavement evaluation.

Final pavement evaluation: at end of design life and/or analysis period unless failure of the whole section occurs before then – failure being defined as reaching a particular percentage of any form of distress as defined for that particular category of road. Consideration should include the necessity for profiling, density testing, sampling and laboratory testing in (to obtain performance-related results) and/or outside the wheelpaths in order to check the as-built results and the reseals. In this respect nuclear density tests must often be regarded as minimum values because of the excessive roughness of the excavated surface and the large amount of levelling sand that must therefore be used.

8.3 Methods

The methods used to include those for visual assessment must be compatible over the full 20 or 30 year monitoring period envisaged. This means that it is essential that the method used be recorded and that, where necessary, more than one method be used and/or a correlation established between the two. The methods used must also keep up with the changing demands of pavement evaluation and design, e.g. TRH 12 (COLTO, 1997) and TRH 4 (COLTO, 1996).

8.4 Lengths monitored

Each section and subsection must be accurately located to the nearest 0,1m and must be monitored separately. The middle 100 m of each section must be reserved for as long as possible for non-destructive tests **(**Table 2). In the case of 300 m sections the middle 200 m, i.e. including the 50 m on each side of the central 100 m, should also be monitored for as long as possible in the same way as the central 100 m in order to monitor as long a length as possible. However, the results must be recorded in such a way that they can be separated at any stage, e.g. if destructive testing has to be carried out in the 50 m subsections. This should also be done in the case of the shorter sections if feasible.

This means that the GPS coordinates must be accurate and that **good markings must be maintained** in order that surveillance contractors can find and record the start and end of each subsection accurately.

In addition to the formal sections for intensive monitoring, a length of 1,0 km on each side should preferably also be monitored at a less intensive level similar to that of the network, in order to ensure that the performance of the adjacent short control sections is similar to that of the rest of those particular designs.

8.5 Level

The long (1 km) informal observation sections can be monitored at the normal network level. However, the short test and control sections have to be monitored at an intensive level.

In considering the detail and spacing necessary for intensive monitoring it is useful to consider a test section as a representative sample of a possible long length of future road. For example, this means that **every pothole, crack and patch has to be recorded,** with an assessment of its cause, a TMH 9-type assessment form (CSRA 1992) has to be completed for **each section** showing lanes and subsections separately if different in performance, that deflection measurements be at intervals of about 10 m and manual rut depth measurements at 5 m, in **both** lanes. This will give 11 deflection and 21 rut depth measurements over the middle 100 m in each lane which probably can be continued for 10 or 20 years. Measurements in the adjacent subsections should also be carried out at the same intervals until they become too disturbed.

As most modern monitoring instruments record according to latitude and longitude rather than only a km position, the latitude, longitude and elevation of the start and end of each section and subsection and the nearest salient points (e.g. signage, culverts and intersections) must be established by surveying or a GPS device. However, even culverts and intersections – let alone signage – have been moved!

9. TRAFFIC

Obtaining accurate traffic information is one of the biggest problems with LTPP experiments.
Regular, standard, split traffic counts supplemented by occasional axle weighing or weigh-in motion (WIM) surveys should be carried out and the installation of long-term piezoelectric cables considered. Without these only wild estimates of the cumulative number of standard axles can be made.

10. REPORTS

A laying (i.e. as-built and construction method) report should be prepared as soon after construction as possible. This should include all the relevant information already discussed as well as a first round of visual and rut depth monitoring of the as-built condition.

A monitoring report should be prepared after each round of monitoring. This should also include traffic data and any deflection, etc., surveys.

Special reports should be prepared covering any failures, which should be investigated by DCPs, profiling, sampling and laboratory testing, etc., as necessary.

An interim report can be prepared after say 10 years when a reasonable indication of the performance can be expected. This should include the rainfall record and an estimate of the traffic carried to date in each lane, including the cumulative E80.

A final report should be prepared after the appropriate design life of say 20 years. This should include the rainfall record and an estimate of the traffic carried, as well as proposed performance-related pavement and material designs derived from the experiment.

A supplementary report should be prepared after 30 years in order to cover the normal analysis period.

11. CONCLUSIONS

- In spite of the tremendous advances in pavement engineering made with the heavy vehicle simulator, long-term pavement performance experiments remain an important part of pavement research.
- Only such experiments can provide the definitive answers to long-term performance with which to calibrate the results of HVS testing and to evaluate non-traffic associated-deterioration such as in-situ weathering of surfacings, basic rocks, carbonation of cement- and lime- stabilized layers, and salt damage.
- Whilst the design, initial monitoring and evaluation of LTPP experiments are relatively straightforward, the successful maintenance of monitoring and finalisation over the normal design life of 20 years and analysis period of 30 years is very difficult.
- However, a judicious mix of both short-term HVS tests and LTPP experiments should always provide the best results.
- LTPP experiments should be entered into the RMS and road file and flagged with a cautionary warning regarding maintenance and monitoring to prevent them being neglected.

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