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MID TERM PAVEMENT CONDITION MONITORING OF THE RURAL ROAD SURFACES RESEARCH

Technical Paper 1
Visual Condition Assessment of RRSR Trial Road Options

DRAFT

SEACAP 27

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Technical Paper 1

Visual Condition Assessment of RRSR Trial Road Options

Dr J Rolt (TRL Ltd)

Dr J Cook (OtB Engineering Ltd)

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Approvals

Dr J Rolt

Team Leader

Dr J R Cook

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Executive summary

Introduction

The SEACAP 27 project was a logical extension of the SEACAP 1 research and was concerned primarily with the continued collection and analysis of pavement performance information from the RRST I and RRST II trial road sections. Mid-term pavement monitoring provides information on early performance and deterioration and is vital if the reasons for deterioration are to be recognised and understood. This is because once a pavement has failed it is often difficult to determine the original causes. Thus mid-term monitoring is an essential link in the analysis of performance which will only be completed following the future longer term monitoring.

This Technical Report provides an evaluation of the condition of the RRST monitoring sections based primarily on an analysis of the visual condition surveys undertaken up to and including those completed in July 2008. The survey completed in February 2009 has not been formally included in this evaluation, although a cross checks have been undertaken to ensure that the reported results from this survey are generally consistent with the conclusion of this report

Performance Analysis

Road pavements are surprisingly complex structures that can deteriorate in many different ways. The main reason for this is that, unlike most civil engineering structures, roads are not designed with a large factor of safety.

In order to design LVRRs economically it is important to understand how and why they deteriorate so that the design and construction procedures can be tailored to minimise deterioration. Some structures will naturally last longer than others and some will be better suited to particular conditions. As a result, the best available solution will vary with the environmental conditions. Thus the purpose of analysing the performance of the trial roads is to understand how and why the deterioration of each type is taking place, to determine the factors on which it depends, to quantify the effects so that the behaviour of the roads can be predicted, and to determine the vital factors that need to be controlled to achieve adequate performance in different situations.

The manifestation of deterioration in road pavements depends to some extent on the type of structure but usually includes cracks visible on the surface, deformation in the wheeltracks (ruts), potholes, erosion, loss of surface material, and general surface deformation. Whilst some of these symptoms are common to many types of failure, the type, extent, position and nature of the symptoms and their combination provide vital clues to the causes of the deterioration.

The need to take into account a range of factors, collectively know as the “Road Environment”, when selecting rural road pavements and surfacing has been an important tenet of the RRSR programme and its outputs. The road environment factors are considered to have a significantly greater relative impact on LVRR road performance as compared to higher categories of road. It follows that these factors should be taken into account when interpreting the condition of the RRST road sections. In particular, the analytical process is complicated by construction quality. As mentioned previously, the behaviour of roads always shows great variability. Two roads built to nominally the same design in similar conditions and with good quality control may differ greatly in performance. Poor performance resulting from poor quality control is a fact of life and the demonstration of the impacts of poor construction techniques or poor materials was an integral part of the overall trials programme

Classifying the causes of deterioration is helpful. One way to do this is to start from a consideration of the *agent* responsible for the deterioration. The two primary post-construction agents for deterioration are water and traffic. A key step in classifying deterioration is to list the effects of water and traffic on the road pavement as a whole and on the materials within it. But first, identifying how these agents are able to ‘attack’ the road identifies important secondary causes of deterioration, for example, poor drainage and poor waterproofing. The process is completed by identifying the effects of the agents on the pavement materials and determining which of these, or their magnitude, constitutes unacceptable and detrimental effects, for example, materials that are too weak when wet. For each type of pavement a different set of causes will be needed although many will be common to all types.

A summary of the traffic data for all the sites is included in Technical Paper in terms of equivalent standard axles.

Concrete pavements

Three types concrete road have been constructed and monitored under the RRST programme; bamboo reinforced; steel reinforced; and non reinforced. The performance of these types is reviewed primarily with respect cracking of the concrete slabs, which is the primary manifestation of failure of roads with concrete surfaces. Relative movement of adjacent slabs giving rise to ‘steps’ at the joints is another type of failure that can occur when slabs are not connected by dowels across the joints but all the trials in this project incorporated dowels.

The age of the trial sections range from about 24 months to a maximum of 37 months whereas the ‘life’ of a concrete pavement is expected to be 20 years or more, hence the trial sections are quite young. Because of this the deterioration rates determined at this time must be considered as early estimates only. It is important to distinguish between general in-service deterioration of sections constructed to specification and the damage or deterioration resulting from specific events or circumstances which, in the context of the concrete sections, are likely to be:

- Flood erosion damage
- Poor construction (eg wet concrete; poor aggregate)
- Periods of heavy traffic

The trials of concrete pavements have shown that 15 out of 24 trial sections are performing well with little or no deterioration in the form of cracking of the slabs after 24 or 37 months of service. However almost all sections show considerable deterioration in terms of joint condition and erosion indicating the need for maintenance.

Nine sections are performing badly in terms of cracking and the rate of deterioration of several of these is very high. The reasons for the poor performance have been investigated using the data from the regular monitoring surveys that have been carried out and it has been shown that traffic is an important factor. Two principal causes stand out, poor quality concrete and poor support for the concrete slabs.

The results of the trials of bamboo reinforced concrete in Vietnam (together with the results obtained in Cambodia) show conclusively that bamboo reinforcement in pavement slabs fulfils no useful purpose.

Flexible pavements

This category includes monitoring sections constructed with bitumen and bitumen emulsion seals over a variety of stabilised and non-stabilised bases and sub-bases. In general terms the bitumen sealed option were designed to local standards and used as a comparison control on the bitumen emulsion sealed options designed to especially drawn-up trial specifications.

The manifestations of deterioration of flexible road pavements with bituminous surfaces include cracks of all types, deformation in the wheeltracks (ruts), potholes, aggregate loss from the surfacing, edge failures and problems with the shoulders. The overall performance of the monitored trial sections is assessed in the light of the normal practice to identify structural failures caused by traffic loading and surfacing failures that may arise from a combination of traffic and environment or merely from environmental effects. The reason for this is that structural failures require rehabilitation to correct whereas surfacing failures, at least in the early stages, require only a maintenance intervention. However, if surfacing failures are not corrected, structural failures will follow.

The assessment shows that basic surfacing failures are more common than structural failures. Only 3 sites show symptoms of structural failure but 11 sites are exhibiting surface problems. A further 10 sites are showing a combination of both surfacing and structural problems. The deterioration history of these 10 sites indicates that on at least 5 of them surface deterioration preceded structural deterioration. The overall conclusion is that surfacing failures are by far the most common for these LVRRs.

Specific events or circumstances likely to be causing damage or deterioration to the flexible sections are likely to be:

- Flood erosion damage
- Poor construction (eg poor materials, poor compaction)
- Periods of heavy traffic
- Subgrade/earthwork failure

Poorly performing sections are looked in detail and the following conclusions were drawn with regard to the RRST flexible pavements

1. There is evidence that the DBST(e) seals are performing better than the Vietnamese standard hot bitumen DBST seals. Although it may be truer to say that the combination of DBST(e) over DBM is performing better than the Vietnamese standard option of DBST over WBM.
2. The penetration macadam option is performing better than either DBST or DBST(e) seals.
3. The single sand emulsion over SBST(e) seals are showing distinct signs of erosion.
4. The performance of a significant number of the poorly performing sites is being influenced by base, sub-base or subgrade issues,
5. Poor construction is major issue with the flexible pavement sites, particularly with regard to the seals.

Block pavements

This category includes sections made with fired clay bricks and concrete bricks but also includes two block stone sections; one of dressed stone and one of cobble stones. These block layers were constructed over a variety of sub-bases.

The types of deterioration that occur for block pavements have some similarities with those of concrete pavements and flexible pavements but also some major differences. For example, although cracking across or along the carriageway can occur most types of ‘cracking’ will be concerned with the behaviour of the joints between individual blocks rather than the behaviour of the blocks themselves. This performance of these joints is in a most cases closely reacted to the integrity of an overlying single emulsion sand seal.

The general behaviour of the 11 block sections is examined in detail and the following conclusions are drawn;

1. The single sand seals have performed very poorly.
2. The use of mortared joints may appear to have some advantages over sealed sand joints in high erosion environments; however, there is a major disadvantage in the loss of inter-block flexibility.
3. The minimum strength requirement of 20-25MPa for manufactured engineering quality bricks is important. The high compressive strength (75MPa) of Hue (H) dressed stone (basalt) and the Ninh Binh (NB) cobble stone (limestone) ensured their good performance.

4. Recorded difficulties in ensuring contractor compliance with specifications are reflected in the relative performance of some sections.
5. No effective maintenance has been carried out on any of the block trial sections and timely routine maintenance carried on the joints and seals could have mitigated significant deterioration.

Unsealed surfaces

A total of 8 unsealed trial control sections were selected for monitoring; five sections surfaced with gravel and three with waterbound macadam. All sections were designed to existing Vietnamese specifications.

Each of the 8 control sections is assessed and although its is a small sample for determining deterioration trends it served to highlight some important points, many of which were raised during the SEACAP 1 and SEACAP 4 projects, namely:

1. Traffic alone is not determining factor in unsealed road performance
2. The gradient- rainfall erosion impact is a key factor in unsealed road performance
3. There are areas where unsealed road are a sustainable LVRR option provided they are constructed correctly (eg Gia Lai), but maintenance is of over riding importance.
4. All remaining roads have lost cross-sectional shape; an indication that no effective maintenance appears to have been undertaken on any of the trial roads (apart from those in Tien Giang, which were sealed)
5. Unsealed WBM is not a realistic option because of loss of cohesive fines and surface loosening.
6. Poor construction magnifies poor in-service performance

SEACAP 27 Technical Paper 1

Visual Condition Assessment of RRSR Trial Road Options

1 Introduction

1.1 The RRSR programme.

In response to the increasing recognition that gravel surfacing is not a universal solution for rural roads in Vietnam, the Ministry of Transport (MoT) in 2002 requested studies of alternative surfaces for rural roads as part of the World Bank-funded Rural Transport Programme 2 (RTP2). These studies became known as the Rural Road Surfacing Research (RRSR) initiative, through which the Rural Road Surfacing Trials (RRST) were carried out. This research programme and its extensions were subsequently incorporated into the DfID-funded South East Asia Community Access Programme (SEACAP).

The aim of the RRSR programme was to establish a range of sustainable road surfaces and paving technologies as alternatives to unsealed gravel that would improve overall rural access while making better use of local resources, minimise whole-life-costs and support the Vietnam Government's poverty alleviation and road maintenance policies.

1.2 The Rural Road Trials programmes

The RRST studies contained two main phases of trial construction between 2004 and 2006 with a total construction cost of US$4,400,000 and which together comprised over 140 km of trial roads from which 107 representative sections of between 80m to 200m length were selected for ongoing performance and whole-life-cost monitoring. Key aspects of the two phases are as follows:

RRST-I. The RRST programme was concentrated on four roads in the Mekong Delta and the Central Coastal area. Short lengths (100-200m) of different pavement options appropriate to the province were constructed on each trial road under the close instruction and supervision of the specialist consultants. Each trial road had, in addition, short lengths (100m) of control sections of unsealed road or penetration macadam sealed road.

RRST-II. The RRST-II programme was undertaken in a wider set of physical environments in the Northern Highlands, Central Highlands and the Red River Delta as an extension of the RRST-I programme. It involved much longer lengths of trial and control section, from 500m to more than 2 km and was seen as an important step in the roll out and mainstreaming of sustainable and appropriate rural surfacing solutions.

The SEACAP 1 project included initial as-built condition surveys and some initial condition monitoring up to March 2007. The SEACAP 27 project was a logical extension of the SEACAP 1 work and was concerned primarily with the continued collection and analysis of pavement performance information from the RRST I and RRST II trial road sections. Mid-term pavement monitoring provides information on early performance and deterioration and is vital if the reasons for deterioration are to be recognised and understood. This is because once a pavement has failed it is often difficult to determine the original causes. Thus mid-term monitoring is an essential link in the analysis of performance which will only be completed following the future longer term monitoring.

A total of 12.67km are included in the monitoring programme with section lengths of between 90m and 200m. Table 1.1 lists the distribution of the monitoring sections.

Table 1.1 RRST Trial Roads

Province	Constructed Roads (No.)	Monitored Roads (No.)	Monitoring Section (No.)
RRST-I			
Hue	1	1	7
Tien Giang	1	1	8
Dong Thap	1	1	9
Da Nang	1	1	5
RRST-II			
Tuyen Quang	5	2	7
Ha Tinh	6	3	10
Quang Binh	3	2	8
Ninh Binh	10	4	13
Hung Yen	5	4	11
Gai Lai	5	2	9
Dak Nong	1	1	11
Dak Lak	3	3	9

1.3 Document objectives

This Technical Report provides an evaluation of the condition of the RRST monitoring sections based primarily on an analysis of the visual condition surveys undertaken up to and including those completed in July 2008. The survey completed in February 2009 has not been formally included in this evaluation, although a cross checks have been undertaken to ensure that the reported results from this survey are generally consistent with the conclusion of this report.

A parallel document interprets the outcomes of this report in terms of specific technical requirements of the project, such as recommended modifications to the SEACAP 1 pavement selection, maintenance and whole life cost models

2 Principles of performance analysis

2.1 The deterioration of road pavements

Road pavements are surprisingly complex structures that can deteriorate in many different ways. The main reason for this is that, unlike most civil engineering structures, roads are not designed with a large factor of safety. This is because, first of all, they are relatively expensive (and most countries need quite a lot of them) and, secondly and most importantly, their slow deterioration and subsequent failure is not a major life-threatening event. Therefore 100% reliability is not mandatory. Indeed, economic analysis shows that the optimum design of roads will guarantee that some roads will deteriorate much faster than we would like but, conversely, others will last longer than we expect. This is because the very nature of roads and the materials that we use to construct them means that their performance is extremely variable. Designing for high levels of reliability increases their costs considerably and designing for no failures is prohibitively expensive. Nevertheless, for the most important roads in a country the level of reliability is usually set to a high level commensurate with what can be afforded, often 98% reliability. In other words, about 2% of the roads will reach the defined failure condition before the design life is reached. For such roads many of the potential causes of deterioration are eliminated. For low volume rural roads (carrying low levels of traffic) such high levels of reliability are not economically justified. Thus the 'safety factor' for the design of LVRRs is relatively low and this means that there are more ways in which they can deteriorate. In particular, the impact of environmental factors is greater.

In order to design LVRRs economically it is important to understand how and why they deteriorate so that the design and construction procedures can be tailored to minimise deterioration. Some structures will naturally last longer than others and some will be better suited to particular conditions. In principle, the least cost option that is available in a particular location should be selected but this should be based on whole life costs so that the durability and maintenance costs of each option are taken properly into account. As a result, the best available solution will vary with the environmental conditions. A low cost option suitable for a straight, level stretch of road that is not subject to seasonal flooding (i.e. a favourable location) will not be suitable for a steep hill in a high rainfall area. Similarly a design suitable for the latter will almost certainly be a conservative high cost option for more favourable conditions. Thus the purpose of analysing the performance of the trial roads is to understand how and why the deterioration of each type is taking place, to determine the factors on which it depends, to quantify the effects so that the behaviour of the roads can be predicted, and to determine the vital factors that need to be controlled to achieve adequate performance in different situations.

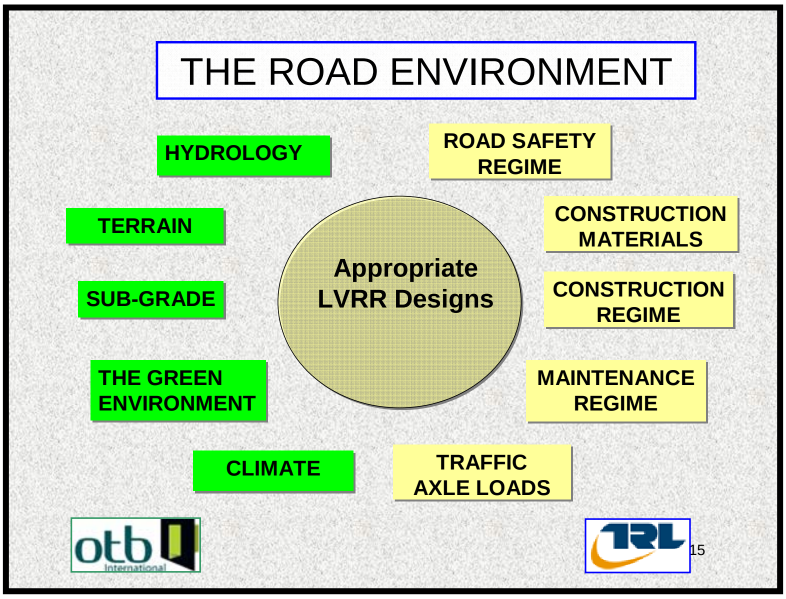
The manifestation of deterioration in road pavements depends to some extent on the type of structure but usually includes cracks visible on the surface, deformation in the wheeltracks (ruts), potholes, erosion, loss of surface material, and general surface deformation. Whilst some of these symptoms are common to many types of failure, the type, extent, position and nature of the symptoms and their combination provide vital clues to the causes of the deterioration. For example, cracks can be transverse, longitudinal, block, parabolic or 'crocodile' in nature and can be located at edges, wheeltracks, or centrally on the road. They may not be associated with ruts or they may occur before or after deformation begins. The precise symptoms and the timing of their occurrence leads to knowledge of the causes of deterioration and, most importantly, knowledge of how to minimise deterioration and how to define specification limits. One implication of this is that the different types of deterioration should be kept separate in the detailed analysis of performance. Combining the types of deterioration into an aggregated index is a useful method of assessing the overall condition of the roads for comparative purposes but is not so useful in detailed analysis.

The analytical process is complicated by construction quality. As mentioned previously, the behaviour of roads always shows great variability. Two roads built to nominally the same design in similar conditions and with good quality control may differ greatly in performance. If poor quality control is also included, then even greater variability will be observed. The danger is that a structure that is basically sound and a good choice may be wrongly rejected if a trial is carried out with poor quality control so that the performance of the trial is poor. Fortunately, in this project the trial designs have been repeated a sufficient number of times so that the overall results are never dependent on small, unrepresentative samples. Nevertheless, poor performance resulting from poor quality control is a fact of life and the demonstration of the impacts of poor construction techniques or poor materials was an integral part of the overall trials programme. Defining what is or is not a reasonable level of quality control to expect in the construction of LVRR's is a problem that needs to be addressed.

2.2 The rural road environment

The need to take into account a range of factors, collectively know as the "Road Environment", when selecting rural road pavements and surfacing has been an important tenet of the RRSR programme and its outputs. The road environment factors (Figure 2.1) are considered to have a significantly greater **relative impact** on LVRR road performance as compared to higher categories of road.

Figure 2.1 The Road Environment Factors



It follows that these factors should be taken into account when interpreting the condition of the RRST road sections.

2.3 Identifying causes of deterioration

Classifying the causes of deterioration is helpful. One way to do this is to start from a consideration of the *agent* responsible for the deterioration. The two primary post-construction agents for deterioration are water and traffic. Without one or both of these, roads would last a very long time indeed. Vegetation will eventually destroy them as will physical and chemical weathering, assuming that earthquakes and seismic activity do not destroy them first. However, from our point of view in the following analyses, only water and traffic are important, although it will be necessary to take relative account of other road environmental factors such as the construction techniques, materials and the maintenance regime.

The next step in classifying deterioration is to list the effects of water and traffic on the road pavement as a whole and on the materials within it. But first, identifying how these agents are able to 'attack' the road identifies important secondary causes of deterioration, for example, poor drainage and poor waterproofing. The process is completed by identifying the effects of the agents on the pavement materials and determining which of these, or their magnitude, constitutes unacceptable and detrimental effects, for example, materials that are too weak when wet. For each type of pavement a different set of causes will be needed although many will be common to all types.

2.4 Traffic

A summary of the traffic data for all the sites is shown in Appendix A. For evaluating the overall damaging effect of traffic on road pavements it is usual practice to measure the traffic in terms of equivalent standard axles. As part of another project (SEACAP 24)[1] an axle loading survey was conducted from 4th to 6th March 2008 on the Buon Ho Trial Road and on Provincial Road No 683 in Dak Lak Province. In total, 30 mini and large buses, 146 light trucks (2-axles), 169 medium trucks (2-axles), 61 heavy trucks (3-axles) and 7 heavy trucks (4-axles) were weighed. The survey found the average conversion factors for each type of vehicle is as follows:-

Mini bus	0.006 esa
Large bus	1.64 esa
Light truck 2-axles	0.02 esa
Medium truck 2-axles	8.12 esa
Heavy truck 3-axles	12.26 esa

The roads were not typical of the LVRRs in this study because the Buon Ho road acted as a short cut for traffic on the provincial road network. As a result, the average truck loading was almost certainly high compared with that on a typical rural road. On the other hand, some individual heavily loaded trucks have been observed on many of the rural roads.

It can be seen that only buses and medium and heavy trucks contribute to the loading of the road structure. On the project roads there were very few of these vehicles and therefore, in percentage terms, the differences in counts between each traffic survey are often very high. Fortunately there have been several traffic counts on each road and therefore the average values for the number of trucks travelling along the roads each day has been calculated.

Estimating the probable traffic loading on the trial roads is hampered by the fact that the traffic counts carried out as part of this study did not distinguish between the various sizes of truck greater than 5 tonne. Thus all trucks greater than 5 tonnes were counted together although some of them may have been large 3-axle and 4-axle trucks weighing considerably more.

It is anticipated that the next traffic count will distinguish between truck sizes but, in the meantime, an average of 8.0 esa has been assumed for all trucks greater than 5 tonnes. This is almost certainly an overestimate but serves to distinguish the loading classification of the project roads, as follows;

Light traffic only	< 20 esas per day
Medium traffic	20 – 100 esas per day
Heavy traffic	100 – 500 esas per day

[1] - *Case Study of Dak Lak RRST pavement and surface deterioration*)

3 Concrete surfaces

3.1 The Concrete trial roads

Three types concrete road have been constructed and monitored under the RRST programme:

Bamboo reinforced;	design thickness 150mm
Steel reinforced;	design thickness 150mm
Non reinforced;	design thickness 200mm

Other key aspects of the trials' designs are as follows:

- Pavement slabs were constructed in 5m long slabs to full carriageway width (3.5m) with the exception of some roads which were constructed with a split carriageway (Figures 3.1, 3.2).
- Slabs were designed for a minimum concrete compressive strength of 20Mpa (28-day cure) to be founded on a sand bedding over sub-base.
- Sand and bitumen filled contraction joints of 10mm width were constructed at 5m intervals and expansion joints at 250m intervals. All joints were designed with load transfer steel dowels of 14 mm diameter and 500mm length, placed at 250mm centres. At expansion joints the dowel bars were anchored into the concrete at one end and the other end coated with bitumen and fitted into a PVC sleeve.

Figure 3.1 Full width concrete slab

Figure 3.2 Half width concrete slabs

3.2 General Behaviour

The primary manifestation of failure of roads with concrete surfaces is cracking of the concrete slabs themselves. Relative movement of adjacent slabs giving rise to 'steps' at the joints is another type of failure that can occur when slabs are not connected by dowels across the joints but all the trials in this project incorporated dowels.

Cracking of the concrete slabs is followed by relative movement of the broken slabs in both lateral and vertical directions, further cracking, and spalling of the cracks and general disintegration until, eventually, the road becomes very uneven, the ride becomes very uncomfortable and dangerous, and average vehicle speeds decrease dramatically. (Figures 3.3 - 3.4) If cracking can be prevented, concrete roads can last for a very long time.

Figure 3.3 Single crack in RRST slab

Figure 3.4 Typical final deterioration of concrete slab (non RRST road)

3.3 Cracking of the slabs

The conditions of the concrete trial sections after the survey in July-August of 2008 are shown in Appendix B. The results are summarised below.

There are a total of 645 concrete slabs in the monitored sections representing 24 distinct experimental sections of road in 12 provinces. Of these, 133 slabs showed some form of cracking as shown in Table 3.1.

Table 3.1 Apparent performance of all the concrete sections

Type of reinforcement	Number of cracked slabs	Total number of slabs	Percentage
Bamboo	49	255	19
Steel	21	130	16
Unreinforced	63	260	24

However, these basic data can be misleading because several other factors need to be considered. First of all there are nine sections that clearly performed very badly for reasons that are examined in paragraph 3.5 below. These sections performed so badly that they form a distinct population of their own and are not simply the worst performers within a continuous spectrum. These sections are;

Bamboo reinforced	TG02, TG09, TQ1-2
Steel reinforced	GL1-2
No reinforcement	QB2-2, GL2-3, DL3-1, DN1-5, HT2-2

If these sections are omitted from Table 3.1, Table 3.2 is obtained. The performances of the remaining 15 sections are much better, and are as might be expected.

These Tables show the number of cracked slabs irrespective of the length of cracks (Extent) or the number of distinct cracks in each slab (Intensity). Thus the Tables include slabs that may contain a single short crack less than one metre long (i.e. Intensity = 1 and Extent = 1). However, examination of the data shows that almost all of the recorded cracks are longer than one metre. Furthermore, if only the slabs containing more than one crack are counted (Intensity >2), excluding those in the nine sections that have been identified as performing particularly badly, then only 2 slabs out of 155 (1.3%) of the bamboo reinforced slabs, 1 slab out of 110 (0.9%) of the steel-reinforced slabs, and 2 out of 140 (1.4%) of the unreinforced slabs have reached a deterioration level equivalent to a crack Intensity greater than or equal to 2.

Table 3.2 Performance of the well-constructed concrete sections

Type of reinforcement	Number of cracked slabs	Total number of slabs	Percentage cracked
Bamboo	7	155	4.5
Steel	4	110	3.6
Unreinforced	6	120	5.0

For the sections not showing severe problems, an important conclusion is that the performances of the sections with and without bamboo reinforcement are identical. Although the bamboo reinforced slabs are nominally 50 mm thinner than the unreinforced slabs, it seems unlikely that the bamboo has performed any useful function up to this time. Given that the bamboo is expected to decay within the pavement in a few years, it can be concluded that bamboo reinforcement is not worthwhile. This issue is examined in more detail below but this conclusion confirms the results obtained in a study of bamboo reinforced concrete roads completed under SEACAP 19[2].

3.4 Severity of cracking

The number and length of cracks are not the only measures of deterioration of concrete slabs. Indeed, provided that the cracked slabs are properly supported so that rocking does not occur, a cracked slab can perform well as an LVRR for many years. This is especially true of slabs with steel reinforcement because the steel will reduce the relative movement of adjacent parts of a cracked slab to negligible levels thereby keeping the width of the cracks small, minimising the spalling that occurs at the edges of cracks and, most importantly, minimising the amount of water that can penetrate the cracks and cause weakening of the layers below the concrete. Such a function cannot be performed by bamboo reinforcement because the elastic modulus of bamboo is too low thereby allowing any cracks to open wide. Furthermore, bamboo in concrete road slabs is unlikely to survive for more than a few years[2].

Therefore another important measure of deterioration is the width of existing cracks. Allied to this is the condition of the joints which, in many ways, are simply ‘controlled’ cracks. Crack severity/width has been measured in each slab as follows; Level 1 (<1mm), Level 2 (1-3mm), Level 3 (>3mm) and Level 4 (spalling).

Table 3.3 shows the overall performance in terms of the number of wide cracks of severity levels 3 and 4. The steel reinforcement seems to have been successful in keeping the width of cracks to a low level, but the sample is small. The bamboo appears to have had no effect on crack widths in comparison with the unreinforced slabs, but this is as expected[3].

[2] (Technical Paper No. 1, *Bamboo Reinforced Concrete Pavements*).

Table 3.3 Performance of all the concrete sections by crack severity

Type of reinforcement	Number of cracked slabs	Number of slabs with wide cracks	Total number of slabs	Percentage with wide cracks
Bamboo	49	19	255	7.5
Steel	21	3	130	2.3
Unreinforced	63	13	260	5

Table 3.4 shows the number of wide cracks that exist in the sections (excluding the anomalous poor performers). The numbers are small and no significance should be attached to the *differences* in percentages in the last column. It appears that about half of the cracks in these sections are wide but this may simply be the consequences of evolution and the fact that the sections are of relatively similar age.

Table 3.4 Performance of the concrete sections excluding poor performers

Type of reinforcement	Number of cracked slabs	Number of cracked slabs with wide cracks	Total number of slabs	Percentage with wide cracks
Bamboo	6	3	155	1.9
Steel	4	3	110	2.7
Unreinforced	6	4	120	3.3

3.5 Deterioration rates

In the foregoing paragraphs the current condition of the concrete pavements has been reviewed. However, it is the rate of deterioration that is of most importance. The age of the trial sections range from about 24 months to a maximum of 37 months whereas the 'life' of a concrete pavement is expected to be 20 years or more, hence the trial sections are quite young. Because of this the deterioration rates determined at this time must be considered as early estimates only, especially for the sections that are performing well and showing little deterioration at this time. Furthermore, deterioration, however measured, is not expected to be linear. Usually the deterioration rate is slow to begin with and then increases with time but sometimes deterioration will apparently slow down. This happens if a section is of variable quality such that parts of a section are 'weak' whilst other parts are strong.

Thus identifying a single deterioration rate for each section after only 2-3 years is a simplification that needs to be borne in mind. For this report, deterioration rates have been defined as the number of slabs that have cracked after 24 months. The results for all the sites are summarised in Table 3.5. In addition, site TQ1-5 has 20% of its slabs cracked but these appear to be unchanging and could stem from construction problems, so no rate can be determined.

The sites fall into two distinct categories namely those that are deteriorating rapidly and those that are not. The boundary seems to be at about 12% (in Table 3.5). Although several sites have an apparent rate of about 10%, these are not changing rapidly at this time whereas all the sites with rates exceeding 15% are changing quite quickly. The progress of deterioration for the nine worst sites is shown in Figure 3.5.

Table 3.5 Rates of deterioration – condition after 2 years

Site	Cracked slabs %	Performance category/comments
GL1-2	85	Very poor
TQ1-2	65	Very poor
DL3-1	58	Very poor Rapid increase in cracking in last 5 months.
TG02	35	Very poor. Cracking mainly between blocks 1 and 15.
GL2-3	30	Very poor
DN1-5	23	Poor
QB2-2	20	Poor
TG09	18	Poor
HT2-2	15	Poor
DaN02	11	Fair performance to date
HT1-1	10	Fair performance to date
HT1-2	10	Fair performance to date
HT2-3	10	Fair performance to date
NB1-2	5	Good performance to date
TQ1-4	5	Good performance to date
H02	0	Good performance to date
DT02	0	Good performance to date
QB1-3	0	Good performance to date
HY1-1	0	Good performance to date
TG03	0	Good performance to date
DT03	0	Good performance to date
HY1-2	0	Good performance to date
HT3-2	0	Good performance to date

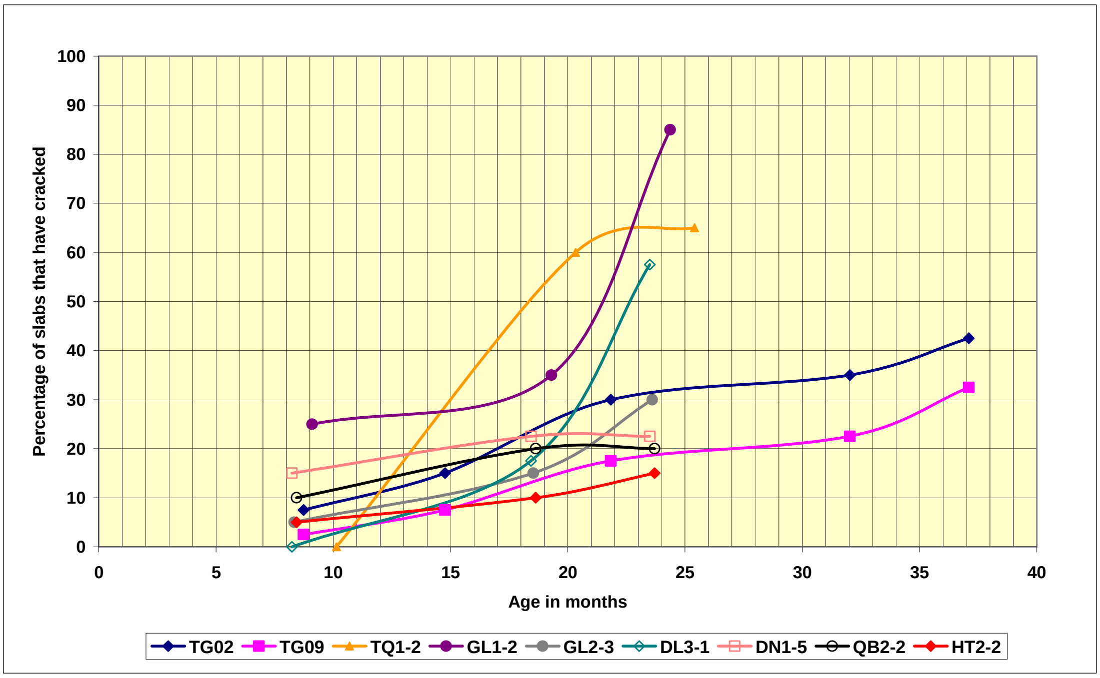


Figure 3.5 Progress of cracking for the worst sites

3.6 The Sections showing rapid deterioration

The sections of road showing relatively rapid deterioration comprise three sections with bamboo reinforcement, one section with steel reinforcement, and five sections with no reinforcement and are located in six provinces. It is therefore unlikely that the type of reinforcement is significant. There are many possible causes for the poor performance of road pavements and one of the problems in identifying a primary cause is that one type of 'failure' rapidly leads on to other types, thereby masking the original cause. For each type of pavement there will be a different set of causes although many will be common to all types. Those for concrete pavements are summarised in Table 3.6.

Viewed in this way the problem is simplified. The difficult part is to determine the criteria that will determine whether something is inadequate. This is the function of specifications. For the most common materials and environments, such specifications should have evolved over time and should be reliable, but in less familiar situations this will not be the case. Deriving specifications that are appropriate for LVRRs in which innovative methods are being tested in parallel with more traditional methods used for higher volume roads, is the purpose of this project.

Table 3.6 Principal causes of concrete road pavement failures

Agent or primary cause	Secondary cause	Comments
Ingress of water from the ground	Poor drainage	(Note: many aspects of drainage must be considered)
	Wet material is too weak	Fails to provide support and to spread traffic loads
	Material is prone to erosion	Causes voids under concrete, for example
Ingress of water from above	Poor waterproofing	Surfacing does not provide a good seal
	Poor joint sealing	Joints at running surface/shoulder, joints between concrete slabs, etc
	Material prone to erosion	Support is lost
	Wet material is too weak	Fails to provide support and spread loads
Traffic	Inadequate design	Too thin and/or too weak, therefore inadequate support and load spreading
	Poor quality materials	Materials too weak. Inadequate support and load spreading
	Poor quality construction	Layers too weak. Inadequate support and load spreading
		Allows water to enter the road (see above)

There appears to be one relatively common factor namely that four of the worst six sections are founded on what are called natural gravel sub-bases. Usually such materials in Vietnam have a high proportion of clay and this would be prone to 'pumping' under traffic thereby creating voided space under the concrete. This will eventually cause the concrete to crack through lack of support.

See Section 3.11 for a fuller review of possible reason for poor performance.

3.7 Traffic

Table 3.7 shows the traffic on the concrete roads. Where the total traffic is shown as unity (i.e. 1000 esa) it simply means that no vehicles exceeding 5 tonnes were recorded in the traffic surveys, hence no traffic induced damage is expected.

Perusal of the Table indicates that the traffic is generally much higher on the Sections whose performances are rated as 'poor' and 'very poor' (average traffic 176,000) and very much lower on Sections rated as 'good' (average 48,000). The average traffic on the Sections rated as 'fair' is 100,000.

Table 3.7 Traffic on the concrete roads

Site	Reinforcement	Performance To date	Months in service	Esa per day	Total esa (thousands)
GL1-2	Steel	Very Poor	24	246	210
TQ1-2	Bamboo	Very Poor	25	102	90
DL3-1	None	Very Poor	24	237	200
TG02	Bamboo	Very Poor	37	0	1
GL2-3	None	Very Poor	24	390	330
DN1-5	None	Poor	24	301	260
QB2-2	None	Poor	24	341	300
TG09	Bamboo	Poor	37	0	1
HT2-2	None	Poor	24	231	200
DaN02	Steel	Fair	24	0	1
HT1-1	Bamboo	Fair	24	118	100
HT1-2	None	Fair	24	118	100
HT2-3	Bamboo	Fair	24	231	200
NB1-2	None	Good	24	0	1
TQ1-4	None	Good	25	102	90
H02	Bamboo	Good	37	1	1
DT02	Bamboo	Good	36	5	6
QB1-3	Bamboo	Good	25	143	130
HY1-1	Bamboo	Good	24	1	1
TG03	Steel	Good	37	0	1
DT03	Steel	Good	36	5	6
HY1-2	None	Good	24	1	1
HT3-2	None	Good	24	275	240

This traffic effect is even more apparent if sites TG02 and TG03 are removed from the analysis. The average traffic for the poor performers increases to 225,000 esas. These two sites suffered from rapid and serious erosion of the sub-base and this led to considerable cracking despite the fact that the traffic was very light.

Only three of the sites performing well (no cracking to date) have relatively high traffic levels. Nevertheless it is apparent that the traffic effect on cracking is strong despite the fact that, if constructed properly to standards that should be readily achievable, none of the concrete sites should be cracking after such a short time. The conclusion is that if a road is not constructed properly, then it will deteriorate more rapidly if the traffic is heavier and more frequent. This is not a surprising conclusion but the number of Sections that are not performing adequately is cause for concern.

3.8 Joints

The quality of joints was originally assessed on a scale from 1 to 5 but has been normalised so that zero represents a joint in good condition and 5 represents a joint that has completely failed. Thus, in the 20 slabs making up a Section, the worst score is 100 and the best is 0. A comparison between the condition of the joints after 24 months in service between the nine Sections performing badly (from the point of view of cracking) and the fifteen Sections performing satisfactorily reveals no significant difference between the two (Table 3.8) although the standard deviations are high.

Table 3.8 Condition indicators

Item	Values	Sites performing well	Sites performing badly
Joint condition	Mean	48	37
	Standard dev.	29	27
Shoulder erosion	Mean	45	44
	Standard dev.	25	23
Shoulder run-off	Mean	13	4
	Standard dev.	10	7

3.9 Erosion of the shoulders

The erosion of shoulder material was assessed on a scale from zero to 5 hence no normalisation is required. A score of 100 for a Section of 20 slabs represents more than 20mm of erosion covering the whole length of the Section whereas a score of zero represents no erosion at all. Erosion has been considered over the whole shoulder area but is also expected to affect the area between the edge of the concrete slab and the shoulder itself. Severe erosion here ought to provide a path for water to permeate into the joint between the carriageway and the shoulder. Comparison of the erosion scores between the Sections performing well and those performing badly from the point of view of cracking indicated no significant difference (Table 3.8).

3.10 Run-off of surface water

Another way that the field surveys might have identified the possible cause of infiltration of water into the pavement is through the assessment of run-off. If run-off is impeded, water will remain on the surface and permeate the structure. Run-off was assessed as either unimpeded (0) or impeded by poor crossfall (1) or by vegetation and debris (2). Comparison of the run-off assessments between the Sections performing well and those performing badly (from the point of view of cracking) indicated no significant difference (Table 3.8).

3.11 Causes of poor performance

It is important to distinguish between general in-service deterioration of sections constructed to specification and the damage or deterioration resulting from specific events or circumstances which, in the context of the concrete sections, are likely to be:

- Flood erosion damage
- Poor construction (eg wet concrete; poor aggregate)
- Periods of heavy traffic

The influence of the deterioration agents of traffic and water have been examined as far as is possible from the survey data. The likely ingress of water through joints and shoulders does not seem to differ between Sections that are performing well and those that are not. Where water has been identified as a major primary cause of rapid deterioration, it is essentially from the ground rather than infiltration from above. Thus road sections in low lying ground and in flood prone areas are at risk if the road materials and quality of construction are inadequate.

Taking into account all available evidence including site investigation notes, design reports, on-site construction discussions and as-built survey site notes, it is possible to arrive at a set probable causes for the early deterioration of the nine poorly performing concrete trial sections. Table 3.9 gives details of the poorly performing sections and Table 3.10 lists specific causes of deterioration.

Table 3.9 Details of Sections that have cracked excessively

Sections	Reinforcement	Sub-base	Age months	Cracked slabs[1] %	As Built Inspection		
					Slabs	Shldr	Material
TG02	Bamboo	Lime stab soil (120mm)	39	35	-	-	-
TG09	Bamboo	Sand (100mm)	39	18	-	-	-
TQ(1)-2	Bamboo	Quarry run (120mm)	27	65	B	C	A
GL(1)-2	Steel	Natural gravel (150mm)	26	85	B	B	A
QB(2)-2	None	Crushed stone (120mm)	26	20	B	B	B
GL(2)-3	None	Natural gravel (150mm)	26	30	A	B	B
DL(3)-1	None	Natural gravel (100mm)	26	58	B	B	B
DN(1)-5	None	Natural gravel (100mm)	26	23	B	C	-
HT2-2	None	Water Bound Macadam	26	15	A	A	A

The as-built inspection was undertaken as part of the contract completion process for the RRST-II roads only and included a general classification of a number of key factors, some of which are included in Table 3.9 above. The classification was in general terms as follows: A: satisfactory; B: below specification but acceptable; C: significant problems, not acceptable.

As regards the assessment of the RRST-II poor performers, 5 out of the 7 had some apparent defects in the construction of the slabs and 6 out the 7 had defects in the shoulder construction. The one site with a totally satisfactory as built visual inspection was HT(2)-2.

Table **3.10** Probable causes of poor performance

Site	Cracked slabs %	Comments/probable causes
GL1-2	85	Poor quality concrete suspected allied to possible plastic sub-base.
TQ1-2	65	Poor quality concrete suspected. The contractor is also known to have used rounded unbroken river gravel as an aggregate. There are doubts about the accuracy of the submitted cube strengths, Figures 3.6- 3.7
DL3-1	58	Rapid increase in cracking in last 5 months. Heavy trucks noted on this road, therefore possibly traffic related allied to plastic sub-grade. Figure 3.8
TG02	35	Cracking mainly between blocks 1 and 15. Erosion of the sand bedding layer during flooding at one end of the site is the likely cause, Figure 3.9.
GL2-3	30	Possible water entry between shoulder and concrete slab leading to weakening of sub-base. Figure 3.10
DN1-5	23	Possible shoulder erosion leading edge cracking. Also noticeable cracking adjacent to central joint in half width slab construction, Figure 3.11
QB2-2	20	Probable heavy truck usage allied to shoulder erosion, Figure 3.12
TG09	18	Cracking mainly between blocks 23 and 33. Possible sub-base erosion in a flood-prone section.
HT2-2	15	Poor quality concrete suspected. The PDoT was given a formal note on the perceived poor construction techniques being employed.

Figure 3.6 TQ(1)-2. Indication of poor construction technique – reinforcement exposed.

Figure 3.7 TQ(1)-2. Indication of disintegrating poor quality concrete with rounded aggregate. .

Figure 3.8 DL(3)-1. Saturated plastic shoulder gravel in contact with sub-base of same material. .

Figure 3.9 TG2-. Single crack running along centre-line of slabs . .

Figure 3.10 GL(2)-3 .**Shoulder erosion cracking between shoulder and slab**

Figure 3.11 DN(1)-5 .**Cracking adjacent to central joints**

Figure 3.12 DN(1)-5 .Evidence of heavy vehicle erosion of shoulder leading to edge cracking

3.12 Conclusions

The results of the trials of bamboo reinforced concrete in Vietnam (together with the results obtained in Cambodia) show conclusively that bamboo reinforcement in pavement slabs fulfils no useful purpose.

The trials of concrete pavements have shown that 15 out of 24 trial sections are performing well with little or no deterioration in the form of cracking of the slabs after 24 or 37 months of service. However almost all sections show considerable deterioration in terms of joint condition and erosion indicating the need for maintenance.

Nine sections are performing badly in terms of cracking and the rate of deterioration of several of these is very high. The reasons for the poor performance have been investigated using the data from the regular monitoring surveys that have been carried out and it has been shown that traffic is an important factor. However, the primary reasons for poor performance stem from the original construction and quality control about which detailed and reliable information is lacking. The project team has therefore based the conclusions about causes on evidence obtained during their own site visits. Two principal causes stand out, poor quality concrete and poor support for the concrete slabs.

4 Bituminous surfaced pavements

4.1 The Trial roads

This category includes monitoring sections constructed with bitumen and bitumen emulsion seals over a variety of stabilised and non-stabilised bases and sub-bases, Table 4.1. In general terms the bitumen sealed option were designed to local standards and used as a comparison control on the bitumen emulsion sealed options designed to specially drawn-up trial specifications.

Table 4.1 Sealed flexible monitoring sections

Description		Number of sections	Comment
Seals			
Sand seal on single bitumen emulsion chip seal	SS-SBST(e)	8	Trial specification
Penetration Macadam	Pen Mac	7	Vietnamese specification
Double hot bitumen chip seal	DBST	13	Vietnamese specification
Double bitumen emulsion chip seal	DBST(e)	26	Trial specification
Triple hot bitumen chip seal	TBST	2	Vietnamese specification
Bases			
Dry-bound macadam	DBM	19	Trial specification
Water-bound macadam	WBM	23	Vietnamese specification
Lime stabilised soil	LSS	2	Trial specification
Cement stabilised soil	CSS	3	Trial specification
Graded crushed stone aggregate	CSA	7	Trial specification
Sub-bases			
Dry-bound macadam	DBM	10	Trial specification
Water-bound macadam	WBM	20	Vietnamese specification
Lime stabilised soil	LSS	2	Trial specification
Cement stabilised soil	CSS	6	Trial specification
Emulsion stabilised soil	ESS	1	Trial specification
Graded crushed stone aggregate	CSA	2	Trial specification
Natural gravel	NG	13	Trial specification
Natural Sand	NS	1	Trial specification

Individual base or sub-base layer thicknesses generally varied from 100 to 150mm depending on the design requirements of the particular road. An exception was the sealed armoured laterite option where a thin 70mm layer of CSA was laid over sub-base quality natural gravel.

A full listing of the detailed designs is containing in the RRSR database and this is summarised in Appendix C to this report

4.2 Analysed data

The manifestations of deterioration of flexible road pavements with bituminous surfaces include cracks of all types, deformation in the wheeltracks (ruts), potholes, aggregate loss from the surfacing, edge failures and problems with the shoulders. On the field survey form and in the database, the measurements of severity and extent often use different scales. In order to simplify comparisons, the scales have been normalised so that zero represents no occurrences of that particular defect in a 5-metre block whilst a score of 5 represents a realistic maximum.

Table 4.2 Sealed flexible pavement condition codes

Defect	Database scale	Normalised scale	Notes
Crack Intensity	0 No cracks 1 Single 2 >1 not connected 3 >1 connected 4 Interconnected (crocodile) 5 Interconnected (loose blocks)	0 1 2 3 4 5	No change. A crack in every block (score = 20) is the beginning of deterioration but must be combined with crack extent exceeding 40
Crack Width	0 No cracks 1 <1mm 2 1-3mm 3 >3mm 4 Spalling	Total for 5-metre block x 1.25	A high value may arise from a single crack in each block
Crack Extent	0 No cracks 1 <1m 2 1-5m 3 >5m	Total for 5-metre block x 1.67	A score of 100 means more than one crack along the whole 100m or crocodile cracking along at least 50m
Ruts	0 <10 1 Maximum rut= 10-20mm 2 Maximum rut= 20-50mm 3 Maximum rut= 50-100mm 4 Maximum rut= 100-200mm 5 Maximum rut >200mm	0 1 2 3 4 5	A score of >20 indicates the beginning of failures. Ruts of 50-100mm usually indicate base and surfacing failure thus 60/100 is a serious condition
Potholes	0 None 1 1 pothole in 5 metre block 2 2 – 3 potholes 3 >3 potholes	Total for 5-metre blocks x 1.67	A score of 15 is a warning level. One pothole every 5 metres is serious therefore score of 33 or more is serious
Aggregate loss	0 None 1 0 – 10% 2 10 – 50% 3 >50%	Total for 5-metre blocks x 1.67	Applies to surface dressings and similar
Edge failures	0 None 1 0 – 10% 2 10 – 50% 3 >50%	Total for 5-metre blocks x 1.67	
Shoulder erosion	0 None 1 Loss 5-20mm, area <10% 2 Loss 5-20mm, area= 10-50% 3 Loss >20mm, area >10% 4 Loss > 20mm, area >50% 5 Shoulder failure	0 1 2 3 4 5	No change

Thus, for a 100-metre section of road a total score of 100 means that that particular defect is present at its effective maximum extent or magnitude whilst a score of zero means that it does not occur at all.

4.3 General behaviour

In pavement assessment it is normal practice to identify structural failures caused by traffic loading and surfacing failures that may arise from a combination of traffic and environment or merely from environmental effects. The reason for this is that structural failures require rehabilitation to correct whereas surfacing failures, at least in the early stages, require only a maintenance intervention. However, if surfacing failures are not corrected, structural failures will follow.

A particular problem has arisen in the interpretation of the deterioration of penetration macadam surfacings. The construction of such roads and their subsequent behaviour is somewhat different to that of roads built with more modern methods and it has proved to be difficult to classify the surface condition into the familiar categories of ravelling, potholes, bleeding and so on. A better description of the most general deterioration is perhaps 'loss of matrix' but this is not strictly correct either. The top surface seems to abrade away exposing the tops of the larger stones below, Figure 4.1. The depth of this abrasion is often not sufficient for the affected area to be strictly described as a pothole, yet its appearance is rather different from the generally accepted description of ravelling.

Figure 4.1 .Pothole in PenMac in Ea Soup road DL(3)-2

In this study the field teams have usually described the deterioration as 'potholes' and hence the number of potholes on such roads appears excessive and could be mistakenly interpreted as a very advanced stage of deterioration. In reality, the deterioration is usually not so serious and describing it as 'ravelling' would convey a more accurate picture. This problem is not unique to this study, similar problems have occurred on other projects and in other countries. For example, in Indonesia it was concluded that the primary mode of deterioration of penetration macadam roads is actually a form of ravelling affecting those areas of the surfacing that are deficient in bitumen.

The type of cracking which commonly occurs on penetration macadam roads is also rather different from other bitumen sealed options. Since the voids in the material are high, cracks tend to be anything but uniform in their individual characteristics. Although crocodile cracking is probably the best description, it sometimes appears to be a type of reflection cracking, possibly mirroring the position of the very large stones that form the first layer of many of the roads, Figures 4.2. Deciding on the width of cracks and whether the cracks are structural in nature (i.e. caused directly by traffic loading), the result of hardening of the bitumen at the surface, or movement of the underlying stones has proved difficult.

Figure 4.2 .Cracking in PenMac in Ea Soup road DL(3)-2

4.4 Overall performance

The sealed flexible condition codes are presented in Table 4.2 and the associated performance definitions in Table 4.3. The performance data for the 56 sections of sealed flexible pavements are shown in detail Appendix C and summarised in Table 4.4.

Table 4.3 Definitions of the key performance codes

Condition index	Range of each condition index			
	Good	Fair	Poor	Very poor
Crack Intensity	<5	5 -15	15-30	>30
Crack Extent	<10	10-20	20-40	>40
Crack Width	NC	NC	NC	NC
Ruts	<5	5-15	15-30	>30
Potholes	<5	5-15	15-25	>25
Aggregate loss	See note	See note	See note	See note
Edge failures	NC	NC	NC	NC
Shoulder condition	NC	NC	NC	NC

Notes 1 NC = Not critical for defining overall performance

2 Aggregate loss was too subjective to be useful. It indicates a surface problem but not precisely what it is.

Table 4.4 Performance of the sealed flexible pavements to date

Performance ranking	Number of sections	Surface problem	Structural problem	Indefinite at this stage
Good – no deterioration	26	0	0	0
Fair – some minor deterioration	13	3 (+ 2)	2 (+ 2)	6
Poor	6	3 (+ 2)	1 (+ 2)	0
Very poor - failing	11	5 (+ 6)	(+ 6)	0

Note The figures in brackets (+X) are the number of sites showing both surface and structural deterioration

Table 4.4 Performance shows that basic surfacing failures are more common than structural failures. Only 3 sites show symptoms of structural failure but 11 sites are exhibiting surface problems. A further 10 sites are showing a combination of both surfacing and structural problems. The deterioration history of these 10 sites indicates that on at least 5 of them surface deterioration preceded structural deterioration. On 5 sites both surface and structural problems developed quickly and it has not been possible to identify the primary cause. However, the overall conclusion is that surfacing failures are by far the most common for these LVRRs.

Since the majority of the deterioration is primarily surfacing rather than structural, it is instructive to compare the performance of each type of surfacing. The trials comprise the five surfacings shown in Table 4.5 PeThe data from the Buan Ho site in Dak Lak province is not included in this table as performance was influenced by an anomalous heavy traffic pattern. The Buon Ho sites (DL2-1, DL2-

2, DL2-3 and DL2-4) were the subject of a special investigation because of the early failure of much of the road on which they were situated[4] (2008). Three of these sites were surfaced with a double surface treatment two of which were rated as very poor and one was rated as fair (the fourth was a sand seal on a single surface treatment and was also rated as very poor). The results of this special investigation showed that the performances of the three double surface treated sections were not primarily related to the seal itself. The main causes of poor performance were essentially structural, being caused by extremely heavy traffic loading made worse by the use of materials that were of marginal quality that did not meet the appropriate specifications.

Table 4.5 Performance of the sealed flexible pavements to date

Surfacing	Number of sections	Very poor	Poor	Fair	Good
SS+SBST(e)	7	4 (58%)	1(14%)	1(14%)	1(14%)
Pen Mac	7	-	-	1(14%)	6 (86%)
DBST	13	2[1](15%)	2 (15%)	5(39%)	4(31%)
DBST(e)	23	2[1](8%)	1(4%)	4(17%)	16 (70%)
TBST	2	-	-	1(50%)	1(50%)

Notes 1 = cracking probably caused by subgrade movement

The single surface treatment with a sand seal has not performed well, 72% of the sites being rated as poor or very poor. Both types of double surface treatments performed much better than sand seal and single chip seal combinations, with 80% initially being rated as good or fair. However, two of the sites that were rated as very poor (HY3-1 and HY3-2) were cracked longitudinally as a result of subgrade movement within a fill area and hence the surfacing was not to blame.

Of specific interest to the RRST research is the comparative performance of the hot bitumen and bitumen emulsion chip seal. Table 4.5 Pe indicates that the DBST(e) seems to be working better than the DBST sections made with hot bitumen; 86% fair to good as compared to 69% fair to good. However these figures are not yet statistically significant at this stage.

Neither of the two sites where a triple surface treatment was used has performed poorly but the sample size is much too small to draw firm conclusions concerning the reliability of triple seals in comparison with double seals.

The best performance has been provided by the sites where the surfacing was penetration macadam. All seven of the analysed sites are performing well.

4.5 Impacting Factors

As discussed in the previous chapter, it is important to distinguish between general in-service deterioration of sections constructed to specification and the damage or deterioration resulting from specific events or circumstances which, in the context of the flexible sections, are likely to be:

- Flood erosion damage
- Poor construction (eg poor materials, poor compaction)
- Periods of heavy traffic
- Subgrade/earthwork failure

[4] *Case study of Dak Lac RRST pavement and surface deterioration: Buon Ho road.* SEACAP 24. TRL

Almost all of the hot bitumen DBST seals were constructed to local practice on top of a standard Vietnamese WBM base. Vietnamese WBM differs from normal international practice in having an intermediate sized stone in addition to the coarse and fine aggregate. Local practice also appears to allow much coarser aggregate than the normally specified 50 or 37mm material (this may be a reason for the introduction of the intermediate aggregate). Observations on site also indicated a reluctance to adequately choke the surface with sufficient fine aggregate and then wash it into the body of the macadam. As a result of these local practices, the WBM is more like a poorly graded crushed stone than a “locked in” macadam layer. It is reasonable to expect, therefore, that some of the poorer performance of the hot bitumen DBST may be related to inadequacies in the base layer. There was also a problem with oversize material on some DBM sites but the process of vibrating in the fines is likely to have achieved a more adequate ‘locking’ of the macadam

Other construction issues that were noted were:

- Poor sealing aggregate size and shape
- Poor finished visual condition to surface seals
- Use of heavy steel rollers on seals

Table 4.7 summarises the traffic to August 2008 on the analysed flexible pavement sites together with results from the as-built QA survey (only conducted for RRST-II roads).

Table 4.7 Traffic and construction quality

Ref. No.	Traffic esa x1000	Surface Condition	Inspection Pit	Lab Tests	As-Built Comments
D5-7	5				
DaN 3-5	1				
DL(1)-1	215	C	C	A	Poor seal
DL(2)-1	265*	A	A	B	
DL(2)-2	265*	B	A	B	poor sand seal
DL(2)-3	265*	B	A	A	
DL(2)-4	265*	A	A	B	
DL(3)-1	205	B	A	B	
DL(3)-2	205	B	B	A	
DN(1)-1	260	C	C	B	poor seal,
DN(1)-2	260	C	C	B	poor seal
DN(1)-3	260	B	A	B	poor seal
DN(1)-4	260	C	A	0	poor seal
DN(2)-1	260	B	A	0	
DN(2)-2	260	A	A	0	
DN(2)-3	260	B	A	0	poor seal
DN(2)-4	260	C	A	0	poor seal
GL(1)-1	210	B	A	A	
GL(1)-3	210	B	A	B	
GL(2)-1	330	B	A	B	
GL(2)-3	330	B	A	B	
H4,9	1				
HT(1)-3	100	A	A	B	
HT(1)-4	100	B	A	A	
HT(1)-5	100	A	A	A	
HT(2)-1	200	B	A	A	
HT(3)-1	200	B	A	A	
HY(2)-3	3	A	A	A	
HY(2)-4	3	A	A	A	
HY(3)-1	18	A	A	A	
HY(3)-2	18	A	A	A	
NB(1)-1	1	B	0	A	
NB(2)-1	1	A	A	B	
NB(2)-3	1	A	0	B	
NB(3)-1	1	B	C	A	
NB(3)-2	1	A	A	A	
NB(4)-1	1	A	0	A	
QB(1)-1	130	A	A	0	
QB(1)-2	130	A	A	0	
QB(2)-1	300	B	A	A	
QB(2)-3	300	A	A	A	
QB(3)-1	300	B	A	B	
QB(3)-2	300	B	A	B	
TG5-7	1				
TQ(1)-1	90	B	A	B	
TQ(1)-3	90	A	A	B	
TQ(2)-1a	195	C	C	B	poor seal,poor subgrade

The classification was in general terms as follows: A: satisfactory; B: below specification but acceptable; C: significant problems, not acceptable.

4.6 Comment on specific sites

Table 4.8 summarises available information from site inspections, supervision notes and testing on the poorest performing sites

Table 4.8 Comment on specific sites with poor and very poor performance

Site	Comments/probable causes
D05	Poor performance of sand seal, erosion pattern may be linked to poor construction technique, Figure 4.3
DaN03	Possible erosion of sand seal impacted by tropical storms and associated flooding. Significant cracking of intact seal influenced by possible cracking of cement stabilised base, Figure 4.4
DaN04	Possible erosion of sand seal impacted by tropical storms and associated flooding, Figure 4.5
DL1-1	Poor as-built seal and out of specification materials in base and sub-base
DL2-1 DL2-2 DL2-3	All sections of this road badly effected by heavy traffic and axle overloading within 1 year of construction[5], Figure 4.6
DN1-4	Poor quality seal recorded in as-built survey. DN trial road has shown a significant increase in traffic since construction, Figure 4.7
DN2-3	Below specification seal reported in as-built survey. DN trial road has shown a significant increase in traffic since construction
GL1-3	Below specification seal noted in as-built survey.
HY2-4 HY3-1 HY3-2	Longitudinal cracks likely to have been caused by subgrade movement. Construction satisfactory for these sections, Figure 4.8,
TG05	Erosion of sand seal on SBST. Some centreline cracking that may be the result of sub-grade movement, Figure 4.9
TG06	Erosion of sand seal on SBST and development of potholes over weak areas in lime-stabilised base and sub-base. DCP testing indicates strength deterioration with time, Figure 4.10
TQ1-3	Seal deterioration,
TQ2-1	Poor quality seal recorded in as built survey. In addition, as-built survey recorded weak saturated sub-base and sub-grade materials, Figure 4.11,

[5] Buon Ho Paper

Figure 4.3 .D05. Deterioration of emulsion sand seal which may be related to labour based construction techniques

Figure 4.4 .DaN03. Large scale cracking related to cracking in underlying cement stabilised sand

Figure 4.5 .DaN05. Rapid deterioration of surface seal following a number of tropical storms and associated flooding

Figure 4.6 .DL(2)-2. Pavement failure caused by excessive traffic over-loading

Figure 4.7 .DL(1)-4. Deterioration of initially very poor quality seal

Figure 4.8 .HY(2)-4. Longitudinal cracking associated with probable sub-grade movement

Figure 4.9 .TG05. Centre line longitudinal cracking

Figure 4.10 .TG05. Potholing probably related to localised strength deterioration in stabilised base

Figure 4.11 .TQ(2)-1. Cracking probably related to recorded weakness in sub-base and sub-grade.

4.7 Conclusions

The following conclusions may be drawn from the mid-term review of the RRST flexible pavements

1. There is evidence that the DBST(e) seals are performing better than the Vietnamese standard hot bitumen DBST seals. This is, as yet, not conclusive due to the possible influence of structural defects. It may be truer to say that the combination of DBST(e) over DBM is performing better than the Vietnamese standard option of DBST over WBM.
2. The penetration macadam option is performing better than either DBST or DBST(e) seals.
3. The single sand emulsion over SBST(e) seals are showing distinct signs of erosion. However it is worth noting that most of these seals are now over 3 years old and that current international advice recommends a second layer of sand seal should be laid within six months of construction.
4. The performance of a significant number of the poorly performing sites is being influenced by base, sub-base or subgrade issues,

Excessive traffic	DL(2)-1; DL(2)-2; DL(2)-3; DL(2)-4
Sub-grade movement	HY(2)-4; HY(3)-1; HY(3)-2; TQ(2)-1a
Cracking in cement stabilised base	DaN03; DaN04
Degradation of lime stabilised base	D06;

5. Poor construction is major issue with the flexible pavement sites, particularly with regard to the seals. Only 41% of sites achieved a satisfactory as-built survey, with 14% noted as being unacceptable

5 Block pavements

5.1 The Trial Roads

This category includes sections made with fired clay bricks and concrete bricks but also includes two block stone sections; one of dressed stone and one of cobble stones (Figures 5.1- 5.4). Table 5.1 summarises the block properties. The block layers were constructed over a variety of sub-bases, as shown in Table 5.2. .

Figure 5.1 Clay Bricks

Figure 5.2 Concrete Bricks

Figure 5.3 Dressed Stone blocks

Figure 5.4 Cobble Stones

Table 5.1 Block properties

Block Type	Dimension	Strength	Comment
Clay Brick	200x100x70mm	Crushing strength >20MPa (TCVN 6355-5-98)	Laid with 200mm thickness
Concrete Brick	200x100x80mm	28-day cube strength of 25MPa.	Laid with 100mm thickness
Dressed Stone	300x200x100mm	Uni-axial compressive strength: >75MPa LAA value:<25%	Laid with 200mm thickness and smooth upper surface
Cobble Stone	Cubic in the range 100-150mm.	Uni-axial compressive strength: >75MPa LAA value:<25%	Smoothest face uppermost

Table 5.2 The block pavements

Site Ref	Surfacing	Roadbase	Joints	Subbase
D10	None	Clay bricks	Mortared	Cement stabilised sand
D11	Sand seal	Clay bricks	Sand	Cement stabilised sand
D12	Sand seal	Clay bricks	Sand	Dry-bound macadam
H06	Sand seal	Concrete bricks	Sand	Natural gravel
H07	Sand seal	Concrete bricks	Sand	Dry-bound macadam
H11	None	Dressed stones	Mortared	Natural gravel
HY2-1	Sand seal	Concrete bricks	Sand	Dry-bound macadam
HY2-2a	Sand seal	Clay bricks	Sand	Dry-bound macadam
HY2-2b	Sand seal	Clay bricks	Sand	Dry-bound macadam
HY4-1	Sand seal	Clay bricks	Sand	Dry-bound macadam
NB2-2	None	Cobble stones	Fine aggregate	Dry-bound macadam
NB2-2a	None	Cobble stones	Fine aggregate	Dry-bound macadam

5.2 Analysed Data

As in previous sections, the differing assessment scales have been normalised in order to simplify comparisons so that zero represents no occurrences of that particular defect in a 5-metre block whilst a score of 5 represents a realistic maximum. Thus for a 100-metre section of road a total score of 100 means that that particular defect is present at its effective maximum extent or magnitude whilst a score of zero means that it does not occur at all.

Table 5.1 Block pavement condition codes

Defect	Database scale		Normalised scale	Notes
Cracks	0	No cracks	0	No change. This only defines the type of cracking. It is extent that is important.
	1	On joints only	1	
	2	On blocks only	2	
	3	Transverse across blocks and joints	3	
	4	Longitudinal across blocks &joints	4	
	5	Both transverse and longitudinal	5	
Crack Extent	0	No cracks	Total for 5-metre sections x 1.67	A score of 100 means more than 100m^2 of pavement is cracked along the section. This represents about 30% of every 5m subsection.
	1	0-10% or total area < 1m^2		
	2	10 – 50% or total area 1-5m^2		
	3	>50% or total area > 5m^2		
Block condition	1	Sound	0	Similar to the measure of cracking of blocks. A score of 100 means that more than 50% of blocks in every 5m are loose or broken – a very serious condition indeed.
	2	0-5% loose or broken	1	
	3	5-10% loose or broken	2	
	4	10-25% loose or broken	3	
	5	25-50% loose or broken	4	
	6	>50% loose or broken	5	

Joint condition	1 2 3 4 5 6	Sound 0-5% cracked or missing 5-10% cracked or missing 10-25% cracked or missing 25-50% cracked or missing >50% cracked or missing	0 1 2 3 4 5	Similar to the measure of cracking of joints. A score of 100 means that more than 50% of joints in every 5m are cracked or missing.
Ruts	0 1 2 3 4 5	<10 Maximum rut= 10-20mm Maximum rut= 20-50mm Maximum rut= 50-100mm Maximum rut= 100-200mm Maximum rut >200mm	0 1 2 3 4 5	A score of >20 indicates the beginning of failures. Ruts of 50-100mm usually indicate base and surfacing failure thus 60/100 is a serious condition
Potholes	0 1 2 3	None 1 pothole in 5 metre block 2 – 3 potholes >3 potholes	Total for 5-metre blocks x 1.67	A score of 15 is a warning level. One pothole every 5 metres is serious therefore a score >33is serious
Shape	1 2 3 4 5 6	As built Good – camber 2-4% Flat <2% Uneven Bowl shaped Super-elevation	0 1 2 3 4 x 1.25	A score of 100 means that every 5m sub section is dished. Super-elevation is not part of the progressive deterioration and is ignored
Kerb condition	1 2 3 4 5 6	Sound 0-5% loose or broken 5-10% loose or broken 10-25% loose or broken 25-50% loose or broken >50% loose or broken	0 1 2 3 4 5	Kerbs are important to contain the blocks. Poor kerb condition will inevitably cause subsequent failure of the running surface.
Seal condition	0 1 2 3 4 5 6	No seal Sound 0-5% cracked or missing 5-10% cracked or missing 10-25% cracked or missing 25-50% cracked or missing >50% cracked or missing	- 0 1 2 3 4 5	Unity deducted from field score
Shoulder and drainage		As for flexible pavements		

5.3 General Behaviour

The types of deterioration that occur for block pavements have some similarities with those of concrete pavements and flexible pavements but also some major differences. For example, although cracking across or along the carriageway can occur, possibly caused by subgrade movement, most types of ‘cracking’ will be concerned with the behaviour of the joints between individual blocks rather than the behaviour of the blocks themselves, Figures 5.5, 5.6. This is essentially a measure of the deterioration of the joints most of which are simply filled with a sharp, sand-sized, material. This performance of these joints is closely reacted to the integrity of the overlying single emulsion sand seal. Details on the performance data are included in Appendix D.

Figure 5.5 Cracks in mortared joints with intact clay bricks (D10)

Figure 5.6 Eroded sand joints with intact concrete bricks (H07)

Table 5.2 shows the relationship between the measured conditions and the performance descriptions of ‘good’, ‘fair’, ‘poor’ and ‘very poor’. The performance of the sections are summarised in Table 5.3.

Table 5.2 Definitions of the key performance codes

Condition index	Range of each condition index			
	Good	Fair	Poor	Very poor
Crack Extent	<10	10-20	20-40	>40
Block condition	<5	5-15	15-50	>50
Joint condition	<5	5-15	15-50	>50
Depressions	NC	NC	NC	NC
Ruts	<5	5-15	15-30	>30
Potholes	<5	5-15	15-25	>25
Shape	NC	NC	NC	NC
Kerb condition	<5	5-15	15-50	>50
Seal condition	<5	5-15	15-50	>50
Shoulder condition	NC	NC	NC	NC

Notes 1 NC = Not critical for defining overall performance

Table 5.3 Performance of the block pavements sections to date

Province-Section	Annual Rainfall mm/yr)	Type	Traffic (esa) x 1000	Age Months	% Deterioration		
					Joint	Block	Sand Seal
D10	1500	Mortared clay brick	6	36	33	1	NA
D11	1500	Sealed clay bricks	6	36	36	6	70
D12	1500	Sealed clay bricks	6	36	38	2	75
H06	3000	Sealed concrete brick	1	38	28	0	100
H07	3000	Sealed concrete brick	1	38	22	0	100
H11	1400	Dressed stone	1	38	24	5	NA
HY2-1	1400	Sealed concrete brick	2	24	100	6	100
HY2-2a	1400	Sealed clay bricks	2	24	100	25	100
HY2-2b	1400	Sealed clay bricks	2	24	100	23	100
HY4-1	1400	Sealed clay bricks	1	24	100	5	100
NB2-2	1600	Cobble stone	1	24	5	5	NA

Table 5.4 Summary of block pavement performance

Performance ranking	Block condition	Joint condition	Seal condition	Overall performance
Good – no deterioration	3	0	0	1
Fair – some minor deterioration	5	1	0	3
Poor	2	6	0	4
Very poor	0	4	11	3

The above Tables would seem to indicate that, overall, the block paving has not performed particularly well. However it is important to note that the overall poor performance indicator is heavily influenced by the deterioration of the emulsion sand seals which have not worked well under the existing environment conditions. The aim was to waterproof the surface and prevent erosion of the sand between the blocks (Figure 5.7). The condition of the seals and of the joints indicates that this has not been successful.

Figure 5.7 recently completed sand sealed concrete block pavement (H07)

Previous studies of the performance of block paving have shown that interlock normally develops between the blocks after trafficking provided that the dimensions of the blocks are reasonably uniform, the gaps between blocks are small and suitable ‘sharp’ sand is used to fill the gaps between blocks. It seems that this process has generally not worked. Evidence indicates that the sand between the blocks has simply been eroded by rain and floods and that the poor performance of the joints is now leading directly to movement of the blocks and the subsequent deterioration of the road surface as an integral structure.

The blocks themselves have a good to fair performance rating with the exception of one road in Hung Yen; this is discussed in detail in the section below.

5.4 Comment on specific sections

Taking into account all available evidence including site investigation notes, design reports, on-site construction discussions and as-built survey site notes, it is possible to examine performance of the block sections under three sub-divisions; clay bricks; concrete brick and stone blocks, Table 5.5.

Table 5.5 Comment on specific trial sections

Province; Region	Sections	Comment on Performance
Clay Bricks		
Dong Thap; Mekong Delta	D10,	The mortared option appears to operate more as a rigid pavement then flexible one. Extended cracking of the pavement is a feature of some areas in the trial, Figure 5.8.
	D11, D12	Although poorly performing joints and badly eroded seals are a feature of these sections the clay bricks themselves are generally performing well, Figure 5.9.
Hung Yen; Red River Delta	HY(2)-2a, HY(2)-2b HY(2)-4	Seal and joints are in an extremely poor condition and the bricks in two sections are in poor condition. Site notes and the as-built survey indicate poor compliance with brick strength, poor seals and on the HY(2) sections in particular, poor construction technique, Figure 5.10.
Concrete Bricks		
Hue; Central Coastal	H06, H07	Although seals have been totally eroded and the joints are in poor condition, the bricks themselves remain in good condition. The impact of intense rainfall and flooding has most probably had a significant influence on these sections. The most recent data indicates a further deterioration of some joints to such an extent in some areas that there is a loss of pavement integrity, Figures 5.11.
Hung Yen; Red River Delta	HY(2)-1	Total seal loss and extreme degradation of seals may be linked to poor construction technique compared to the condition of the older Hue sections above in harsher environment.
Stone Blocks;		
Hue; Central Coastal	H11	This section has suffered significant joint deterioration mainly due to surface cracking of the mortar (Figure 5.12). The pavement as a whole however has stood up well to severe rainfall and flood conditions, Figure 5.13
Ninh Binh; Red River Delta	NB(2)-2	Overall this section is in good to fair condition. Site notes and the as-built survey indicate satisfactory construction.

Figure 5.8 Mortared clay brick pavement (D10) exhibiting extended cracking similar to that in adjacent concrete sections (cf Figure 3.9)

Figure 5.9 Sand joint clay brick pavement (D11) exhibiting significant seal loss after more than 3 years of service

Figure 5.10 Sand joint clay brick pavement HY(2)-2 exhibiting significant seal loss and brick deterioration after 2 years of service

Figure 5.11 Sand joint concrete brick pavement (H07) exhibiting total seal and joint deterioration with consequent loss of pavement integrity. January 2009, following rainy season with intense tropical storms

Figure 5.12 Dressed stone pavement (H11) in fair condition with cracked mortared joints

Figure 5.13 Dressed stone pavement (H11) maintained integrity despite severe erosion of shoulder and edge of sand bed layer following tropical storm floods after 1 year of service.

5.5 Conclusions

The following conclusions may be drawn from the condition of this diverse group of trial sections;

6. **Seals**; The single sand seals have performed very poorly. Recent international advice recommends a second layer of sand seal should be laid within six months of construction. This however, would add to the cost without any guarantee of improvement in high rainfall and flood environments.
7. **Mortared Joints:** The use of mortared joints may appear to have some advantages over sealed sand joints in high erosion environments; however, there is a major disadvantage in the loss of inter-block flexibility.
8. **Block Strength**: The minimum strength requirement of 20-25MPa for manufactured engineering quality bricks is important. There were difficulties in obtaining suitable clay bricks in Hung Yen (HY) and the lower strength 15-20MPa used in some areas HY(2) is reflected in their poor performance. The high compressive strength (75MPa) of Hue (H) dressed stone (basalt) and the Ninh Binh (NB) cobble stone (limestone) ensured their good performance.
9. **Construction Control**. The recorded difficulties in ensuring the contractor for section HY(2) followed required procedures and used appropriate materials is reflected in the relative performance of the HY(2) and HY(4) clay bricks.
10. **Maintenance.** No effective maintenance has been carried out on any of the block trial sections. It is suggested that timely routine maintenance carried on the joints and seals of the Hue and Dong Thap block sections could have mitigated their now significant deterioration.

6 Unsealed wearing course surfaces

6.1 The Trial Roads

Unsealed trials were constructed with two main research objectives in mind;

1. To act as control sections for performance comparison with the "new" alternative options being proposed
2. To provide deterioration information on unsealed roads as a continuation to the parallel SC4 RRGAP studies

A total of 8 unsealed trial sections were selected for monitoring; five sections surfaced with gravel and three with waterbound macadam.

DaNang province	1 section WBM
Dong Thap province	1 section WBM
Gia Lai province	2 sections gravel
Hue province	1 section gravel
Tien Giang province	1 section gravel; 1 section WBM

All sections were designed to existing Vietnamese specifications with a 200 mm thickness, to be constructed in two layers.

6.2 Analysed Data

As with the other pavement types, the field visual survey form and the database use measurements of condition severity and extent that need to be normalised in order to simplify comparisons and analysis. This has been done in such a way that zero represents no occurrences of that particular defect in a 5-metre block whilst a score of 5 represents a realistic maximum. Thus for a 100-metre section of road a total score of 100 means that that particular defect is present at its effective maximum extent or magnitude whilst a score of zero means that it does not occur at all. The defects and the scales are described in Table 6.1.

In the case of the unsealed trial sections additional information on surface deterioration, surface shape and gravel loss can be obtained from levelled cross sections at 20-25m intervals. Figure 6.1 is typical example of this data from the unsealed section in Hue.

Additional data is included within the RRSR database

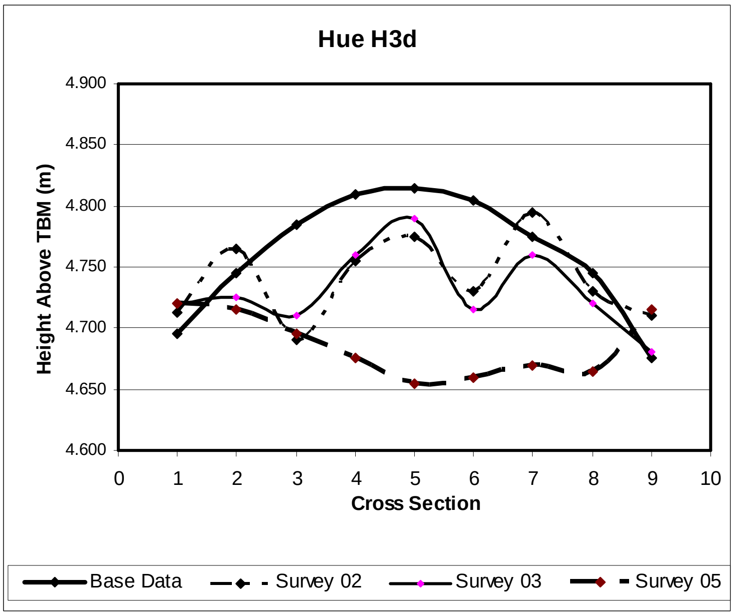


Table 6.1 Unsealed pavement condition codes

Defect		Database scale	Normalised scale	Notes
Visual appearance	1	Good surface shape – no aggregate protrusion	0	
	2	Some deterioration – aggregate protrusion	1	
	3	>75% of surface intact	2	
	4	50-75% of surface intact	3	
	5	25-50% intact	4	
	6	<25% of surface intact	5	
Loose material	1	Negligible	0	Total for 100m section x 1.67
	2	<15mm loose thickness	1	
	3	15-50mm loose thickness	2	
	4	>50mm loose thickness	3	
Corrugations	1	Negligible	0	Similar to the measure of loose material. Total for 100m section x 1.67
	2	<15mm deep	1	
	3	15-50mm deep	2	
	4	>50mm deep	3	
Erosion	1	Negligible	0	Total for 100m section x 1.25
	2	Slight (loss 5-20mm, <10% of area)	1	
	3	Moderate (loss 5-20mm, 10-50% of area)	2	
	4	Severe (material loss >20mm, area >10%	3	
	5	Very severe (material loss >20mm, area >50%	4	
Ruts	0	<10	0	A score of >20 indicates the beginning of failures. Ruts of 50-100mm usually indicate base and surfacing failure thus 60/100 is a serious condition
	1	Maximum rut= 10-20mm	1	
	2	Maximum rut= 20-50mm	2	
	3	Maximum rut= 50-100mm	3	
	4	Maximum rut= 100-200mm	4	
	5	Maximum rut >200mm	5	
Potholes	0	None	Total for 5-metre blocks x 1.67	A score of 15 is a warning level. One pothole every 5 metres is serious therefore score of 33 or more is serious
	1	1 pothole in 5 metre block		
	2	2 – 3 potholes		
	3	>3 potholes		
Shape	1	As built	0	A score of 100 means that every 5m sub-section is dished. Super-elevation is not part of the progressive deterioration and is ignored
	2	Good – camber 2-4%	1	
	3	Flat <2%	2	
	4	Uneven	3	
	5	Bowl shaped	4	
	6	Super-elevation	x 1.25	
Shoulder and drainage		As for flexible pavements		

6.3 Overall performance

The data from these sections are summarised in Appendix E. The deterioration has been rapid on six of the sections, all of which reached a poor visual state within a few months. Serious rutting and potholes took longer to develop but after 24 months all sections were in a very poor state indeed.

6.4 Impacting Factors

Previous research on unsealed road has indicated the significant influence of key road environment factors such as rainfall, gradient and traffic on the performance of gravel roads. Table 6.2 summarises these factors for the unsealed trial sections in relation to material loss. Table 6.3 summarises related visual deterioration:

Table 6.2 Road Environment factors and gravel loss

Province-Section	Annual Rainfall (mm/yr)	Section Gradient	Traffic (esa) x 1000	Material	Average Gravel Loss mm/yr
Da Nang DaN06	2200	0%	1	WBM	40
Dak Nong DN(1)-5b	2700	4.6%	260	Gravel	58
Dong Thap D08	1500	0%	6	WBM	15
Gia Lai GL(1)-4	2100	0.5%	246	Gravel	28
Gia Lai GL(2)-2a	2100	2%	330	Gravel	12
Hue H03	3000	0%	1	Gravel	21
Tien Giang TG08	1400	0%	<1	WBM	30
Tien Giang TG10	1400	0%	<1.0	Gravel	59

Table 6.3 Summary of key visual assessment condition

Province	Material	Age: Months	Cross sectional Shape	Potholes	Maximum Rut Depth (mm)
Da Nang DaN06	WBM	24	Flat	2-3 per 5m	>200mm
Dak Nong DN(1)-5b	Gravel	24	Flat to uneven	None	20-100
Dong Thap D08	WBM	36	Flat	2-3 per 5m	50-100
Gia Lai GL(1)-4	Gravel	24	Flat	1 per 5m	20-50
Gia Lai GL(2)-2a	Gravel	24	Flat to uneven	None	20-50
Hue H03	Gravel	30	Bowl	2-3 per 5m	100-200
Tien Giang TG08	WBM	15	Good	2-3 per 5m	<10
Tien Giang TG10	Gravel	15	Flat	None	<10

6.5 Comments on specific sections.

Taking into account all available evidence including site investigation notes, design reports, on-site construction discussions and as-built survey site notes, it is possible to examine performance of the limited number of trial sections in detail, Table 6.4.

Table 6.4 Comments on performance of specific trial lengths

Province	Section	Comment
Da Nang	DaN06	The unsealed WBM has performed poorly despite extremely low traffic. Key impacting factors have been: (1) **severe tropical storms** and associated flooding (2) ongoing difficulties with the **contractor** during an extended construction period. Figure 6.1.
Dak Nong	DN(2)-5	The gravel on this section has shown unsustainable gravel loss. Key factors are likely to have been (1) **gradient** of 4% in high **rainfall** area (2) Significant **traffic. Construction problem**s were noted with respect to carriageway, shoulder and possibly material quality, Figure 6.2.
Dong Thap	D08	Despite light traffic the unsealed WBM has suffered from severe **erosion** of non cohesive fine materials, Figure 6.3.
Gia Lai	GL(2)-2	Despite significant traffic, this section has performed reasonably well and would be marginally sustainable with appropriate maintenance
Gia Lai	GL(2)-4	Despite significant traffic this section has performed well and would be sustainable with appropriate maintenance. Figure 6.4.
Hue	H03	This gravel in this section has suffered from rapid shape deterioration and consequent soaking and deformation within the first six months, despite very light traffic. Major cause of deterioration has been high **rainfall** (including a number of **tropical storms**) allied to poor **drainage** and complete lack of **maintenanc**e on carriageway shape), Figure 6.5.
Tien Giang	TG10	Following significant deterioration in the first 15 months this section of gravel was rehabilitated and sealed as per the agreement with the district authorities
Tien Giang	TG08	Following significant deterioration in the first 15 months this section of WBM was rehabilitated and sealed as per the agreement with the district authorities.

Figure 6.1 Trial DaN06 showing loose eroded surface. Vegetation indicates the low level of traffic.

Figure 6.2 Trial DN(2)-5 showing eroded surface and out-specification grading.. No effective side drainage

Figure 6.5 Trial H03 1 year and 1 rainy season after construction.

6.6 Conclusions

Eight sections of road is a small sample for determining deterioration trends but the sections served to highlight some important points, many of which were raised during the SEACAP 1 and SEACAP 4 projects, namely:

1. Traffic alone is not determining factor in unsealed road performance
2. The gradient- rainfall erosion impact is a key factor in unsealed road performance
3. There are areas where unsealed road are a sustainable LVRR option provide they are constructed correctly (eg Gia Lai), but maintenance is of over riding importance.
4. All remaining roads have lost cross-sectional shape; an indication that no effective maintenance appears to have been undertaken on any of the trial road (apart from those in Tien Giang, which were sealed)
5. Unsealed WBM is not a realistic option because of loss of cohesive fines and surface loosening.
6. Poor construction will magnify inherent poor in-service performance

7 Summary

The mid term condition of the RRST I and RRST II monitoring sites has been reviewed primarily with respect to visual condition under the following grouping:

1. Concrete pavement
2. Sealed flexible pavement
3. Block pavement
4. Unsealed wearing course surface

The review has highlighted key issues with respect the deterioration of poorly performing sites within each group, some of which are common to all groups, namely:

1. Sub-standard construction procedure or poor compliance with specifications has been shown to have a marked impact on the performance of all options. There is therefore an urgent need to address the issue of quality control and as –built quality assurance in the rural road sector in Vietnam.
2. None of the trial roads (apart from two that have been upgraded) have had any significant maintenance carried out on them.
3. Poor road management, either in identifying clearly the road task or in subsequently controlling overloaded traffic, has been shown to have a major impact on pavement performance.

The review has reinforced the views expressed previously in SEACAP 1 and related papers that the impact of factors such as rainfall and flooding must be taken into account in selecting pavement options. Some surfaces, for example unsealed gravel, emulsion sand seal, have been shown to be particularly vulnerable to tropical storms and associated flooding.

The implications of the conclusions in the Technical paper with respect to maintenance and whole life asset costs, and in the selection of LVRR pavement options, are summarised in the parallel SEACP 27 Technical Paper 2.

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MID TERM PAVEMENT CONDITION MONITORING OF THE RURAL ROAD SURFACES RESEARCH

Technical Paper 1

Visual Condition Assessment of RRSR Trial Road Options

Appendices

A: Traffic

B: Concrete Pavement Summary Data

C: Flexible Pavement Summary Data

D: Block Pavement Summary Data

E: Unsealed Wearing Course Surface Data

Appendix A Traffic Summary

PROVINCE	ROAD	Date of Survey	VEHICLE			ESAs			esa (12 Hours)	esa (24 Hours)	esa to Aug08
			Bus	Truck>5t	Truck<5T	Bus esa	Truck>5t esa	Truck<5t esa			
		esa factor				1.5	8	0.1			
Dong Thap	Tan Thuan Tay(1)	Nov. 2004	0	0	0	0	0	0	0	0	
	DT	Oct. 2006	0	0	0	0	0	0	0	0	
		Oct. 2006	0	0	0	0	0	0	0	0	
	Tan Thuan Tay	Feb. 2008	0	1	7	0	8	0.07	8	10	
	DT	Aug. 2008	0	0	3	0	0	0.03	0	0	5,249
Tien Giang	My Phuoc Tay	Nov. 2004	0	0	3	0	0	0.03	0	0	
	TG	Oct. 2006	0	0	2	0	0	0.02	0	0	
		Feb. 2008	0	0	0	0	0	0	0	0	
		Aug. 2008	0	0	0	0	0	0	0	0	0
Da Nang	Binh Ky	Nov. 2004	0	0	2	0	0	0.02	0	0	
	DaN	Oct. 2006	0	0	0	0	0	0	0	0	
		Jan. 2008	0	0	2	0	0	0.02	0	0	
		Aug. 2008	0	0	0	0	0	0	0	0	9
Hue	Thong Nhat	Nov. 2004	0	0	0	0	0	0	0	0	
	H	Oct. 2006	0	0	0	0	0	0	0	0	
		Jan. 2008	0	0	4	0	0	0.04	0	0	
		Aug. 2008	0	0	6	0	0	0.06	0	0	67
Gia Lai	Xa Trang	July 2005	0	19	17	0	152	0.17	152	183	
	GL(2)	Jan. 2008	0	48	60	0	384	0.6	385	462	
		Aug. 2008	0	48	53	0	384	0.53	385	461	332,264
Gia Lai	Ia Pnol	Sept. 2006	0	29	12	0	232	0.12	232	279	
	GL(1)	Jan. 2008	0	29	32	0	232	0.32	232	279	
		Aug. 2008	14	29	32	21	232	0.32	253	304	209,796
Dak Nong	Kien Duc	July 2005	0	38	27	0	304	0.27	304	365	
	DN	Feb. 2008	0	41	33	0	328	0.33	328	394	
		Aug. 2008	45	25	30	67.5	200	0.3	268	321	257,528
Dak Lak	Cu Ne	Sept. 2006	0	9	20	0	72	0.2	72	87	
	DL(1)	Jan. 2008	0	10	11	0	80	0.11	80	96	
		Aug. 2008	0	53	0	0	424	0	424	509	217,776
Dak Lak	Buon Ho	July 2005	0	10	8	0	80	0.08	80	96	
	DL(2)	Jan. 2008	0	51	90	0	408	0.9	409	491	
		Aug. 2008	0	26	1	0	208	0.01	208	250	266,505
Dak Lak	Easoup	Jan. 2008	0	8	12	0	64	0.12	64	77	
	DL(3)	Aug. 2008	0	51	0	0	408	0	408	490	203,956
Hung Yen	Hung Long	Sept. 2006	0	2	3	0	16	0.03	16	19	
	HY(3)	Jan. 2008	0	0	7	0	0	0.07	0	0	
		Aug. 2008	1	5	15	1.5	40	0.15	42	50	18,023
Hung Yen	Nhat Quang	July 2005	0	2	31	0	16	0.31	16	20	
	HY(2)	Jan. 2008	0	0	37	0	0	0.37	0	0	
		Aug. 2008	4	0	29	6	0	0.29	6	8	2,877
Hung Yen	Thuy Loi	Sept. 2006	0	0	0	0	0	0	0	0	
	HY(4)	Jan. 2008	0	0	15	0	0	0.15	0	0	
		Aug. 2008	0	0	0	0	0	0	0	0	65
Hung Yen	Tan Hung	July 2005	0	45	48	0	360	0.48	360	433	
	HY(1)	Jan. 2008	0	0	11	0	0	0.11	0	0	
		Aug. 2008	0	0	0	0	0	0	0	0	48
Ninh Binh	Yen Trach	July 2005	0	0	0	0	0	0	0	0	
	NB(2)	Jan. 2008	0	0	28	0	0	0.28	0	0	
		Aug. 2008	0	0	23	0	0	0.23	0	0	220
Ninh Binh	Yen Tu	Oct. 2006	0	0	3	0	0	0.03	0	0	
	NB(3)	Jan. 2008	0	0	1	0	0	0.01	0	0	
		Aug. 2008	0	0	11	0	0	0.11	0	0	52
Ninh Binh	Ninh Van	Sept. 2006	0	0	3	0	0	0.03	0	0	
	NB(4)	Aug. 2008	0	0	39	0	0	0.39	0	0	181
Ninh Binh	Dong Huong	July 2005	0	0	0	0	0	0	0	0	
	NB(1)	Jan. 2008	0	0	0	0	0	0	0	0	
		Aug. 2008	0	0	0	0	0	0	0	0	0
Tuyen Quang	Lang Quan	July 2005	0	21	23	0	168	0.23	168	202	
	TQ(1)	Aug. 2008	3	12	14	4.5	96	0.14	101	121	116,152
Tuyen Quang	Y La	Sept. 2006	0	92	4	0	736	0.04	736	883	
	TQ(2)	Jan. 2008	4	14	24	6	112	0.24	118	142	
		Aug. 2008	0	3	6	0	24	0.06	24	29	61,474
Tuyen Quang	Hoang Khai	Jan. 2008	7	17	60	10.5	136	0.6	147	177	
	TQ(3)	Aug. 2008	0	1	28	0	8	0.28	8	10	67,124
Quang Binh	Cam Lien	July 2005	0	6	5	0	48	0.05	48	58	
	QB(2)	Jan. 2008	2	41	81	3	328	0.81	332	398	
		Aug. 2008	3	41	100	4.5	328	1	334	400	287,414
Quang Binh	Ngu Hoa	July 2005	0	6	25	0	48	0.25	48	58	
	QB(1)	Sept. 2006	0	43	29	0	344	0.29	344	413	
		Jan. 2008	2	15	39	3	120	0.39	123	148	
		Aug. 2008	2	19	43	3	152	0.43	155	187	120,450
Ha Tinh	Chu Le - Dia Loi	Sept. 2006	0	33	0	0	264	0	264	317	
	HT(3)	Jan. 2008	0	50	5	0	400	0.05	400	480	
		Aug. 2008	3	18	13	4.5	144	0.13	149	178	237,030
Ha Tinh	Hong Loc - Thu Loc	Sept. 2006	0	164	5	0	1312	0.05	1312	1574	
	HT(2)	Jan. 2008	0	25	29	0	200	0.29	200	240	
		Aug. 2008	3	31	56	4.5	248	0.56	253	304	195,847
Ha Tinh	Thach Minh - Thach	Aug. 2005	0	14	1	0	112	0.01	112	134	
	HT(1)	Jan. 2008	0	25	13	0	200	0.13	200	240	
		Aug. 2008	0	4	21	0	32	0.21	32	39	100,371

Appendix B Condition of concrete sections

Site	Date of construction	Date of survey	Age (months)	Reinforcement	Joint condition normalised	Left side								Right side								Total number of slabs	No of cracked slabs	% No of cracked slabs
						Carriageway					Shoulder		Drain	Carriageway					Shoulder		Drain			
						Cracks			Surface	Edge	Erosion	Run-off		Cracks			Surface	Edge	Erosion	Run-off				
						Intensity	Width	Extent						Intensity	Width	Extent								
H02	May-05	Feb-06	9	Bamboo	6	0	0	0	0	0	0	44	35	0	0	0	0	0	0	42	43	40	0	0
H02	May-05	Aug-06	15	Bamboo	21	0	0	0	0	0	3	35	35	0	0	0	0	0	2	40	43	40	0	0
H02	May-05	Mar-07	22	Bamboo	23	0	0	0	0	0	13	14	0	0	0	0	0	0	10	17	7	40	0	0
H02	May-05	Jan-08	32	Bamboo	43	0	0	0	0	0	39	14	0	0	0	0	1	0	41	18	7	40	0	0
H02	May-05	Jun-08	37	Bamboo	60	1	2	2	0	0	33	14	0	4	2	2	1	0	38	18	7	40	1	5
TG02	May-05	Feb-06	9	Bamboo	23	3	3	2	1	0	0	11	0	2	3	2	1		0	3	0	40	3	8
TG02	May-05	Aug-06	15	Bamboo	14	4	4	3	2	0	17	11	0	3	6	4	2	0	12	10	0	40	6	15
TG02	May-05	Mar-07	22	Bamboo	26	10	11	12	7	0	56	1	0	8	11	17	7	0	55	0	0	40	12	30
TG02	May-05	Jan-08	32	Bamboo	54	17	13	18	14	0	58	20	0	17	14	18	7	1	64	12	0	40	14	35
TG02	May-05	Jun-08	37	Bamboo	54	19	17	20	15	0	58	20	0	17	15	19	7	1	64	12	0	40	17	43
TG09	May-05	Feb-06	9	Bamboo	13	1	1	1	11	1	0	29	0	1	1	1	11	0	0	28	0	40	1	3
TG09	May-05	Aug-06	15	Bamboo	13	1	2	1	11	1	0	28	0	2	3	2	11	0	0	26	0	40	3	8
TG09	May-05	Mar-07	22	Bamboo	19	2	4	4	12	1	23	10	0	4	6	8	14	0	40	5	0	40	7	18
TG09	May-05	Jan-08	32	Bamboo	21	3	4	5	18	2	29	18	0	5	8	8	17	0	46	13	0	40	9	23
TG09	May-05	Jun-08	37	Bamboo	24	6	7	8	21	1	37	22	0	11	15	15	17	0	56	14	0	40	13	33
DT02	Jul-05	Jan-06	6	Bamboo	4	0	0	0	0	0	17	14	0	0	0	0	0	0	12	10	0	35	0	0

DT02	Jul-05	Jul-06	12	Bamboo	39	0	0	0	0	0	23	21	0	0	0	0	0	0	27	21	0	35	0	0
DT02	Jul-05	Mar-07	20	Bamboo	44	1	3	3	1	0	25	17	0	1	3	3	1	0	25	13	0	35	1	3
DT02	Jul-05	Jan-08	30	Bamboo	47	1	2	1	0	0	27	15	0	1	2	1	0	0	22	13	0	35	1	3
DT02	Jul-05	Jun-08	35	Bamboo	71	1	2	2	0	0	30	24	0	1	2	2	0	0	30	19	0	35	1	3
QB(1)-3	May-06	Mar-07	10	Bamboo	19	0	0	0	0	10	0	0	5	0	0	0	0	3	0	0	0	20	0	0
QB(1)-3	May-06	Jan-08	20	Bamboo	28	0	0	0	0	1	15	0	16	0	0	0	0	0	7	0	0	20	0	0
QB(1)-3	May-06	Jun-08	25	Bamboo	36	0	0	0	0	5	32	0	20	0	0	0	0	10	28	0	0	20	0	0
HY(1)-1	Jun-06	Mar-07	9	Bamboo	30	0	0	0	0	0	13	11	0	0	0	0	0	0	10	6	0	20	0	0
HY(1)-1	Jun-06	Jan-08	19	Bamboo	28	0	0	0	0	0	20	15	1	0	0	0	0	0	13	9	0	20	0	0
HY(1)-1	Jun-06	Jun-08	24	Bamboo	40	0	0	0	0	0	32	16	1	0	0	0	0	0	44	10	0	20	0	0
HT(1)-1	Jun-06	Mar-07	8	Bamboo	78	0	0	0	0	0	38	5	0	2	4	2	2	0	41	0	40	20	2	10
HT(1)-1	Jun-06	Jan-08	18	Bamboo	100	0	0	0	0	0	77	4	0	2	4	2	2	0	87	0	13	20	2	10
HT(1)-1	Jun-06	Jun-08	23	Bamboo	89	0	0	0	0	0	82	0	19	2	4	3	2	0	85	0	19	20	2	10
TQ(1)-2	May-06	Feb-07	9	Bamboo	14	0	0	0	2	0	11	0	0	0	0	0	2	0	8	0	0	20	0	0
TQ(1)-2	May-06	Dec-07	19	Bamboo	25	23	19	22	12	22	8	0	0	13	9	11	6	4	8	4	0	20	12	60
TQ(1)-2	May-06	May-08	24	Bamboo	25	37	35	35	15	24	7	0	0	12	16	15	15	14	3	0	0	20	13	65
HT(2)-3	Jun-06	Mar-07	8	Bamboo	23	7	11	12	5	4	17	2	0	11	13	12	5	0	23	9	0	20	4	20
HT(2)-3	Jun-06	Jan-08	19	Bamboo	48	6	11	12	25	24	17	22	0	11	13	12	25	20	23	29	0	20	1	5
HT(2)-3	Jun-06	Jun-08	24	Bamboo	43	3	4	4	7	1	52	5	0	4	5	5	3	16	53	1	0	20	2	10
TG03	May-05	Feb-06	9	Steel	4	0	0	0	8	0	23	18	0	0	0	0	8	0	20	20	0	40	0	0
TG03	May-05	Aug-06	15	Steel	9	0	0	0	8	0	34	17	0	0	0	0	8	0	42	18	0	40	0	0
TG03	May-05	Mar-07	22	Steel	21	0	0	0	8	0	61	2	0	0	0	0	8	0	72	8	0	40	0	0
TG03	May-05	Jan-08	33	Steel	28	0	0	0	20	2	64	13	0	0	0	0	18	4	75	7	0	40	0	0
TG03	May-05	Jun-08	38	Steel	39	0	0	0	18	2	66	11	0	0	0	0	16	3	74	14	0	40	0	0
DT03	Jul-05	Feb-06	7	Steel	0	0	0	0	0	0	12	16	0	0	0	0	0	0	14	22	0	35	0	0
DT03	Jul-05	Aug-06	13	Steel	31	0	0	0	0	0	15	6	0	0	0	0	0	0	14	9	0	35	0	0

DT03	Jul-05	Mar-07	20	Steel	55	0	0	0	0	0	23	3	0	0	0	0	0	0	25	5	0	35	0	0
DT03	Jul-05	Jan-08	30	Steel	64	0	0	0	2	0	24	11	0	0	0	0	1	0	26	11	0	35	0	0
DT03	Jul-05	Jun-08	36	Steel	75	0	0	0	2	0	30	19	0	0	0	0	1	0	34	15	0	35	0	0
DaN02	Jun-06	Mar-07	9	Steel	47	2	3	2	0	0	71	31	0	1	2	1	0	0	11	40	0	35	2	6
DaN02	Jun-06	Jan-08	19	Steel	72	2	3	2	1	0	79	38	0	1	2	1	1	0	60	40	0	35	2	6
DaN02	Jun-06	Jun-08	24	Steel	74	3	6	3	1	0	81	34	0	1	3	1	1	0	66	40	0	35	4	11
GL(1)-2	Jun-06	Feb-07	8	Steel	0	4	8	5	3	0	20	0	40	5	8	6	3	3	20	0	40	20	5	25
GL(1)-2	Jun-06	Jan-08	19	Steel	10	5	10	8	4	0	23	0	53	9	14	10	7	3	20	10	51	20	7	35
GL(1)-2	Jun-06	Jun-08	24	Steel	18	27	31	31	17	9	41	0	36	38	35	44	17	12	42	0	32	20	17	85
NB(1)-2	Jun-06	Mar-07	8	None	80	1	2	1	0	0	32	1	0	0	0	0	0	0	11	3	0	20	1	5
NB(1)-2	Jun-06	Jan-08	18	None	84	1	3	1	2	0	29	19	0	0	0	0	0	0	10	24	0	20	1	5
NB(1)-2	Jun-06	Jun-08	23	None	86	1	3	1	3	0	71	5	0	0	0	0	2	0	39	24	0	20	1	5
QB(2)-2	Jun-06	Mar-07	8	None	8	2	4	4	0	2	43	20	0	0	0	0	0	14	44	20	0	20	2	10
QB(2)-2	Jun-06	Jan-08	19	None	9	4	11	10	4	0	59	0	0	2	5	6	2	2	57	0	0	20	4	20
QB(2)-2	Jun-06	Jun-08	24	None	14	4	11	10	4	16	71	2	0	2	5	6	2	11	70	1	0	20	4	20
GL(2)-3	Jun-06	Mar-07	8	None	4	1	2	2	1	0	20	0	20	0	0	0	0	0	20	0	30	20	1	5
GL(2)-3	Jun-06	Jan-08	19	None	16	3	8	7	3	0	33	0	35	1	2	2	1	0	11	4	20	20	3	15
GL(2)-3	Jun-06	Jun-08	24	None	30	8	13	9	6	0	65	2	37	8	9	8	5	0	29	4	20	20	6	30
DL(3)-1	Jun-06	Mar-07	8	None	3	0	0	0	0	0	20	0	20	0	0	0	0	0	19	0	0	40	0	0
DL(3)-1	Jun-06	Jan-08	18	None	25	32	5	10	4	4	20	0	23	20	4	7	3	3	19	0	20	40	7	18
DL(3)-1	Jun-06	Jun-08	24	None	56	65	21	33	2	17	25	0	37	20	24	36	3	12	20	0	44	40	23	58
DN(1)-5	Jun-06	Mar-07	8	None	73	4	8	3	4	18	20	0	0	2	4	2	0	20	20	0	0	40	6	15
DN(1)-5	Jun-06	Jan-08	18	None	100	7	17	9	17	1	46	0	0	2	4	2	6	1	41	0	56	40	9	23
DN(1)-5	Jun-06	Jun-08	24	None	100	8	15	9	17	15	80	0	20	1	2	1	11	10	77	0	40	40	9	23
HY(1)-2	Jun-06	Mar-07	9	None	56	0	0	0	0	0	26	0	0	0	0	0	0	0	13	6	0	20	0	0
HY(1)-2	Jun-06	Jan-08	19	None	64	0	0	0	0	0	33	8	0	0	0	0	0	0	19	16	0	20	0	0

HY(1)-2	Jun-06	Jun-08	24	None	65	0	0	0	0	0	50	13	0	1	4	1	1	0	47	33	0	20	0	0
HT(1)-2	Jun-06	Mar-07	8	None	76	1	2	3	1	1	47	1	18	4	3	4	2	1	62	1	20	20	2	10
HT(1)-2	Jun-06	Jan-08	18	None	98	1	2	3	1	1	80	2	0	4	3	4	2	1	70	3	39	20	2	10
HT(1)-2	Jun-06	Jun-08	23	None	80	1	2	3	2	0	75	16	0	1	2	3	2	1	71	21	43	20	2	10
HT(3)-2	Jun-06	Mar-07	8	None	0	0	0	0	0	0	20	0	8	0	0	0	0	0	20	0	8	20	0	0
HT(3)-2	Jun-06	Jan-08	19	None	4	2	4	4	2	0	48	0	0	2	4	4	2	0	40	2	6	20	0	0
HT(3)-2	Jun-06	Jun-08	24	None	9	1	3	2	1	0	56	6	0	1	3	2	1	4	46	16	6	20	0	0
TQ(1)-4	May-06	Mar-07	9	None	4	0	0	0	4	5	6	2	33	0	0	0	0	1	4	10	23	20	0	0
TQ(1)-4	May-06	Jan-08	19	None	13	0	0	0	12	9	9	15	66	2	4	2	8	3	7	22	51	20	2	10
TQ(1)-4	May-06	Jun-08	24	None	0	0	0	0	2	12	29	10	73	1	3	1	6	5	16	20	60	20	1	5
TQ(1)-5	May-06	Mar-07	9	None	9	2	6	4	0	2	3	2	0	3	9	5	0	2	3	2	22	20	3	15
TQ(1)-5	May-06	Jan-08	19	None	16	2	8	4	6	2	7	5	15	6	14	6	8	2	3	13	69	20	4	20
TQ(1)-5	May-06	Jun-08	24	None	18	2	7	6	2	4	25	14	12	3	10	6	3	9	25	14	79	20	3	15
HT(2)-2	Jun-06	Mar-07	8	None	25	1	2	2	1	1	18	1	32	1	2	2	1	1	17	6	29	20	1	5
HT(2)-2	Jun-06	Jan-08	19	None	43	2	5	6	2	1	36	1	34	4	5	6	2	1	39	3	24	20	2	10
HT(2)-2	Jun-06	Jun-08	24	None	41	5	7	8	3	2	50	1	40	5	7	8	3	1	45	3	42	20	3	15

Appendix C

Flexible Pavement Structure

Site	Surface	Base	Sub-base
DN(1)-1	Triple BST	WBM (120)	Gravel (200)
DN(2)-1	Triple BST	DBM (120)	Gravel (200)
D05	Sand seal on SBST (e)	DBM (200)	Crushed fine aggregate(120)
D06	Sand seal on SBST (e)	Lime stab soil (150)	Lime stab soil (150)
DaN03	Sand seal on SBST (e)	Cement stab sandy soil (150)	Cement stab sandy soil (150)
DaN04	Sand seal on SBST (e)	Cement stab sandy soil (150)	Emul stab sandy soil (150)
DL(2)-2	Sand seal on SBST (e)	DBM (100)	DBM (100)
H09	Sand seal on SBST (e)	Crushed stone (70)	Gravel (200)
TG05	Sand seal on SBST (e)	DBM (200)	Sand (120)
TG06	Sand seal on SBST (e)	Lime stab soil (150)	Lime stab soil (150)
DL(1)-2	Pen Mac (60)		WBM (100)
D07	Pen Mac (60)	WBM (100)	WBM (100)
DaN05	Pen Mac (60)	WBM (100)	WBM (100)
DL(3)-2	Pen Mac (60)		WBM (100)
DN(2)-2	Pen Mac (60)	WBM (100)	WBM (100)
H04	Pen Mac (60)	WBM (100)	WBM (100)
TG07	Pen Mac (60)	WBM (100)	WBM (100)
DL(1)-1	DBST (e)	DBM (100)	DBM (100)
DL(2)-1	DBST (e)	DBM (100)	DBM (100)
DL(2)-3	DBST (e)	DBM (100)	Gravel (200)
DL(2)-4	DBST (e)	DBM (100)	Gravel (200)
DN(1)-2	DBST (e)	WBM (120)	Gravel (200)
DN(1)-3	DBST (e)	DBM (120)	Gravel (200)
DN(1)-4	DBST (e)	DBM (120)	Gravel (200)
DN(2)-3	DBST (e)	DBM (120)	Gravel (200)
DN(2)-4	DBST (e)	DBM (120)	Gravel (200)
GL(1)-1	DBST (e)	DBM (100)	DBM (150)
GL(1)-3	DBST (e)	DBM (100)	DBM (150)

GL(2)-1	DBST (e)	DBM (100)	DBM (150)
GL(2)-3	DBST (e)	DBM (100)	DBM (150)
HT(1)-3	DBST (e)	DBM (100)	DBM (100)
HT(1)-4	DBST (e)	WBM (80)	WBM (100)
HT(2)-1	DBST (e)	WBM (100)	WBM (150)
HT(3)-1	DBST (e)	WBM (100)	River gravel (120)
HY(3)-1	DBST (e)	Cement stab sand (150)	Cement stab sand (150)
NB(3)-1	DBST (e)	WBM (150)	Soil (150)
NB(4)-1	DBST (e)	WBM (150)	Soil (150)
QB(1)-1	DBST (e)	Crushed stone (100)	Cem St sandy soil (150)
QB(1)-2	DBST (e)	DBM (120)	DBM (120)
QB(2)-1	DBST (e)	Crushed stn (100)	Crushed stn (150)
QB(2)-3	DBST (e)	Crushed stn (100)	Crushed stn (150)
QB(3)-1	DBST (e)	DBM (100/120)	DBM (120)
TQ(1)-1	DBST (e)	WBM (120)	WBM (120)
HT(1)-5	DBST	WBM (100)	WBM (100)
HY(2)-3	DBST	Crushed stone (150)	Cement stab sand (150)
HY(2)-4	DBST	WBM (100)	WBM (150)
HY(3)-2	DBST	Crushed stone (120)	Cement stab sand (150)
HY(3)-2a	DBST	Crushed stone (120)	Cement stab sand (150)
NB(1)-1	DBST	WBM (100)	WBM (150)
NB(2)-1	DBST	WBM (100)	WBM (150)
NB(2)-3	DBST	WBM (100)	WBM (150)
NB(3)-2	DBST	WBM (100)	WBM (150)
QB(3)-2	DBST	WBM (100)	WBM (100)
TQ(1)-3	DBST	WBM (100)	WBM (100)
TQ(2)-1	DBST	WBM (100)	WBM (100)
TQ(2)-1a	DBST	WBM (120)	WBM (120)

Flexible Pavement Condition: Mid 2008

Site	Intensity	Width	Extent	Ruts	Potholes	Aggregate loss	Edge	Shoulder		Traffic (1000esa)	Intensity	Extent	Ruts	Potholes	OVERALL	Rate of deteriration
								Cracks	Erosion							
DN(1)-1	15	10	13	7	0	67	67	0	63	260	F	F	F	G	F	S
DN(2)-1	0	0	0	0	0	67	75	0	61	1	G	G	G	G	G	S
D05	0	0	0	0	36	44	36	9	30	6	G	G	G	VP	P	M
D06	7	14	15	5	19	35	36	8	35	6	F	F	G	P	F	M
DaN03	44	58	59	6	4	67	53	0	64	1	VP	VP	F	G	VP	F
DaN04	39	53	78	1	19	100	48	0	68	1	VP	VP	G	P	VP	F
DL(2)-2	25	24	43	27	61	100	63	0	55	270	P	VP	P	VP	VP	VF
H09	0	0	0	0	2	67	55	0	71	2	G	G	G	G	G	S
TG05	25	26	29	2	0	21	54	11	54	1	P	P	G	G	VP	F
TG06	38	35	44	4	3	20	61	15	58	1	VP	VP	G	G	VP	F
DL(1)-2	0	0	0	3	0	67	33	0	29	215	G	G	G	G	G	S
D07	0	0	0	0	0	84	21	16	25	6	G	G	G	G	G	S
DaN05	0	0	0	0	0	67	33	0	64	1	G	G	G	G	G	S
DL(3)-2	0	0	0	0	0	33	33	0	20	200	G	G	G	G	G	M
DN(2)-2	0	0	0	0	0	100	65	0	71	1	G	G	G	G	G	S

H04	0	0	0	1	?	33	35	0	39	2	G	G	G	VP	F	S
TG07	0	0	0	0	0	67	7	0	59	1	G	G	G	G	G	S
DL(1)-1	0	0	0	0	38	98	90	0	63	215	G	G	G	VP	F	S
DL(2)-1	69	65	90	60	57	94	72	0	76	270	VP	VP	VP	VP	VP	VF
DL(2)-3	36	33	47	27	20	78	52	0	51	270	VP	VP	P	P	VP	VF
DL(2)-4	0	0	0	10	3	62	36	0	45	270	G	G	F	G	G	M
DN(1)-2	0	0	0	0	0	67	0	0	0	260	G	G	G	G	G	S
DN(1)-3	0	0	0	13	1	100	63	0	69	260	G	G	F	G	G	S
DN(1)-4	37	23	28	0	7	100	78	0	72	260	VP	P	G	F	VP	F
DN(2)-3	0	0	0	0	40	100	65	0	60	1	G	G	G	VP	P	S
DN(2)-4	0	0	0	0	0	100	24	0	64	1	G	G	G	G	G	S
GL(1)-1	0	0	0	3	1	67	67	0	45	210	G	G	G	G	G	S
GL(1)-3	12	21	28	0	0	67	52	0	67	210	F	P	G	G	P	F
GL(2)-1	0	0	0	0	0	99	63	0	46	335	G	G	G	G	F	M
GL(2)-3	0	0	0	0	0	20	20	0	20	335	G	G	G	G	G	S
HT(1)-3	7	4	6	3	10	73	44	0	81	100	F	G	G	F	F	M
HT(1)-4	0	0	0	5	0	68	8	0	37	100	G	G	G	G	G	S
HT(2)-1	0	0	0	1	0	68	35	0	31	200	G	G	G	G	G	S
HT(3)-1	0	0	0	1	0	67	35	0	31	240	G	G	G	G	G	S
HY(3)-1	23	34	53	1	0	67	1	0	23	20	P	VP	G	G	VP	F
NB(3)-1	0	0	0	0	0	0	0	0	4	1	G	G	G	G	G	S

NB(4)-1	0	0	0	6	0	33	8	0	32	1	G	G	F	G	G	S
QB(1)-1	0	0	0	0	1	38	33	0	46	130	G	G	G	G	G	S
QB(1)-2	0	0	0	0	0	97	18	0	40	130	G	G	G	G	G	S
QB(2)-1	2	1	3	12	5	67	25	0	46	290	G	G	F	F	F	M
QB(2)-3	0	0	0	6	3	67	5	0	52	290	G	G	F	G	G	M
QB(3)-1	0	0	0	1	0	33	16	0	35	290	G	G	G	G	G	S
TQ(1)-1	0	0	0	7	0	67	8	0	20	90	G	G	F	G	G	M
HT(1)-5	0	0	0	6	0	68	34	0	56	100	G	G	F	G	G	S
HY(2)-3	9	11	15	11	0	67	17	0	34	5	F	F	F	G	F	M
HY(2)-4	13	13	19	22	1	62	12	0	33	5	F	F	P	G	P	F
HY(3)-2	22	23	34	6	0	67	3	0	22	20	P	P	F	G	VP	F
HY(3)-2a	6	7	9	15	0	57	0	0	18	20	F	G	F	G	F	M
NB(1)-1	0	0	0	18	0	67	14	0	38	1	G	G	P	G	F	M
NB(2)-1	0	0	0	16	0	42	18	0	40	3	G	G	P	G	F	M
NB(2)-3	0	0	0	13	0	66	1	0	51	3	G	G	F	G	F	M
NB(3)-2	0	0	0	3	0	67	1	0	33	1	G	G	G	G	G	S
QB(3)-2	0	0	0	0	0	67	13	0	47	290	G	G	G	G	G	S
TQ(1)-3	23	16	32	8	0	38	7	0	27	90	P	P	F	G	P	F
TQ(2)-1	33	26	38	22	0	67	11	0	15	90	VP	P	P	G	VP	F
TQ(2)-1a	0	0	0	4	0	67	15	0	29	90	G	G	G	G	G	S

G=Good; F = Fair; P=Poor; VP= Very poor. S=Slow; M=Moderate; F=Fast; VF=Very Fast Deterioration

Appendix D Block Pavement Condition: Mid 2008

Site	Left side									Right side									Condition code							
	Carriageway									Carriageway																
	Extent	Block condition	Joint condition	Depressions	Ruts	Potholes	Shape	Kerb condition	Seal	Extent	Block condition	Joint condition	Depressions	Ruts	Potholes	Shape	Kerb condition	Seal	Extent	Block condition	Joint condition	Ruts	Potholes	Kerb condition	Seal	Overall
D10	28	2	30	8	0	0	35	1		40	1	37	13	0	0	30	1	-	P	G	P	G	G	G	-	F
D11	47	12	36	0	0	0	20	0	70	53	2	40	5	1	0	23	0	81	VP	F	P	G	G	G	VP	P
D12	23	3	41	0	0	0	20	0	79	18	1	36	0	0	0	20	0	64	P	G	P	G	G	G	VP	F
H06	0	0	25	0	0	0	20	0	100	39	0	31	0	0	0	20	0	100	F	G	P	G	G	G	VP	F
H07	58	0	23	0	0	0	20	0	63	55	0	20	0	0	0	20	0	63	VP	G	P	G	G	G	VP	P
H11	25	1	22	22	6	0	22	21		26	10	27	11	2	0	25	22	-	P	F	P	G	G	P	-	P
HY(2)-1	2	9	100	0	20	0	20	2	100	2	6	100	0	24	0	20	0	100	G	F	VP	P	G	G	VP	P
HY(2)-2	32	37	100	0	20	0	20	0	100	28	30	100	0	20	0	19	0	100	P	P	VP	P	G	G	VP	VP
HY(2)-2a	30	24	100	2	20	3	22	3	100	32	21	100	0	17	0	22	1	92	P	P	VP	P	G	G	VP	VP
HY(4)-1	0	0	31	0	6	0	20	2	100	0	0	27	0	11	0	20	0	100	G	G	P	F	G	G	VP	G
NB(2)-2	0	18	100	0	0	0	20	40		0	21	100	0	0	0	20	26	-	G	P	VP	G	G	P	-	VP

G=Good; F = Fair; P=Poor; VP= Very poor. S=Slow; M=Moderate; F=Fast; VF=Very Fast Deterioration

Appendix E Unsealed Pavement Data Summary

Site	Date of survey	Left hand side							Right hand side						
		Visual appearance	Loose material	Corrugations	Erosion	Ruts	Potholes	Shape	Visual appearance	Loose material	Corrugations	Erosion	Ruts	Potholes	Shape
GL(1)-4		20	0	0	0	20	0	26	20	0	0	0	20	0	25
GL(1)-4	Feb-07	20	0	5	0	19	0	26	20	0	5	0	20	0	25
GL(1)-4	Jan-08	21	0	35	26	22	0	33	20	0	35	27	25	0	32
GL(1)-4	Jun-08	100	33	68	100	38	3	58	100	33	68	100	40	3	59
GL(2)-2	Aug-06	14	0	0	0	20	0	28	15	0	0	0	20	0	28
GL(2)-2	Mar-07	20	0	33	25	20	0	25	20	0	33	25	20	0	28
GL(2)-2	Jan-08	20	33	33	25	22	0	25	20	0	33	25	30	0	31
GL(2)-2	Jun-08	28	33	40	40	41	0	69	34	12	45	51	44	0	64
DN(2)-5	Aug-06	6	0	5	0	20	0	28	6	0	5	0	20	0	28
DN(2)-5	Mar-07	60	33	33	25	40	0	28	60	33	33	25	40	0	25
DN(2)-5	Jan-08	60	67	33	75	46	0	50	60	67	33	75	46	0	50
DN(2)-5	Jun-08	100	67	67	100	39	0	60	100	67	67	100	42	0	60
H03	May-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H03	Feb-06	100	0	95	100	77	100	100	100	0	100	100	73	98	100

H03	Aug-06	100	0	90	100	84	100	100	100	0	100	100	80	95	100
H03	Mar-07	100	0	100	100	82	100	100	100	0	100	100	79	100	100
H03	Jan-08	100	0	100	100	75	100	100	100	0	100	100	73	100	100
TG10	?														
TG10	Jan-06	20	33	33	0	20	0	25	20	33	33	0	20	0	25
TG10	Jul-06	34	33	33	0	20	0	50	34	33	33	0	20	0	50
TG10	Mar-07	34	33	33	0	20	0	50	34	33	33	0	20	0	50
TG10	Jan-08	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TG08															
TG08	Jan-06	68	67	10	33	0	0	13	62	67	5	29	0	2	14
TG08	Jul-06	83	37	18	41	0	30	14	76	67	13	38	0	2	16
TG08	Mar-07	83	37	18	41	0	30	14	76	67	13	38	0	2	16
TG08	Jan-08	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D08	Jun-05	0	0	0	0	0	0	25	0	0	0	0	0	0	25
D08	Jan-06	69	33	0	0	0	0	25	68	33	0	0	0	0	25
D08	Jul-06	100	33	0	25	0	9	25	100	33	0	7	0	13	25
D08	Mar-07	100	83	0	100	0	94	46	100	80	0	100	0	94	46
D08	Jan-08	100	100	100	100	100	100	50	100	100	100	100	100	100	50
D08	Jun-08	100	100	100	100	100	100	50	100	100	100	100	100	100	50
DaN06	Jul-06	20	42	0	0	0	0	25	20	33	0	0	0	0	25
DaN06	Mar-07	20	33	0	25	60	0	25	20	33	0	25	0	0	25
DaN06	Jan-08	100	100	100	100	100	100	50	100	100	100	100	100	100	50
DaN06	Jun-08	100	100	100	100	100	100	50	100	100	100	100	100	100	50