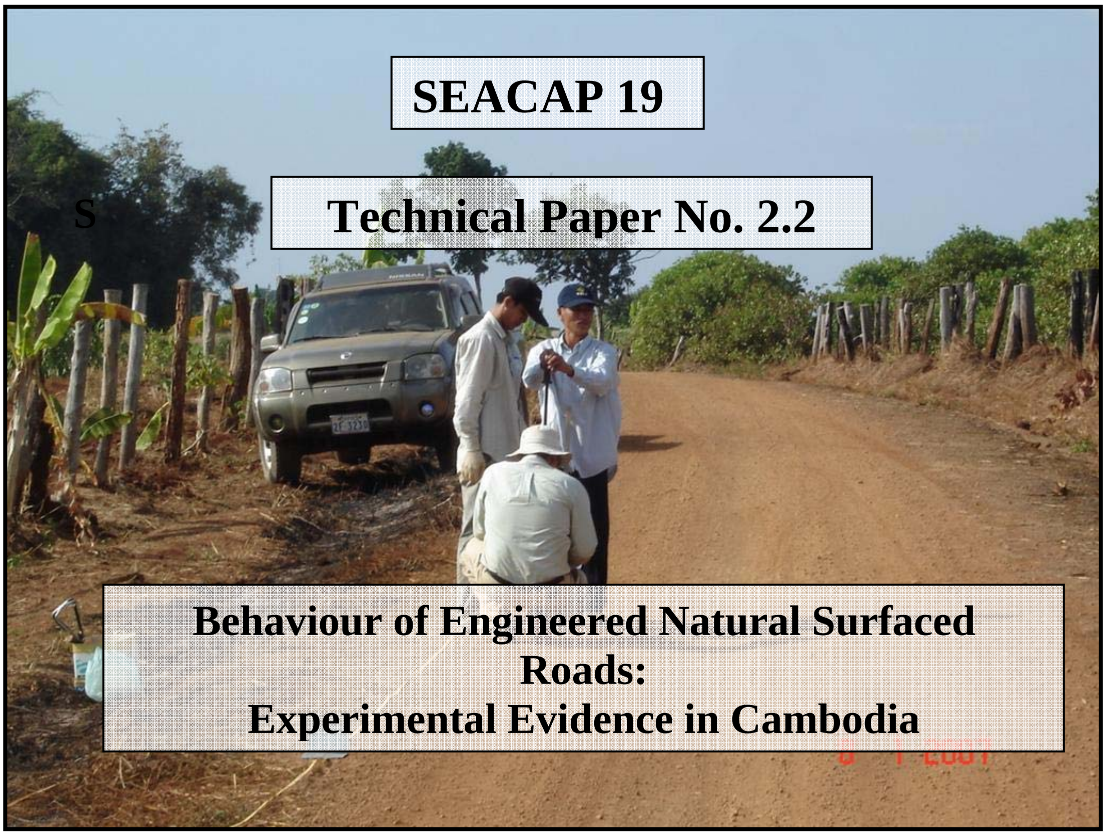
ROYAL GOVERNMENT OF CAMBODIA

SOUTH EAST ASIA COMMUNITY ACCESS PROGRAMME

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS



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SOUTH EAST ASIA COMMUNITY ACCESS PROGRAMME

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

SEACAP 19 Technical Paper No 2.2

Behaviour of Engineered Natural Surfaced Roads: Experimental Evidence in Cambodia

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ABBREVIATIONS AND TERMINOLOGY

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic (sum of both directions)
CBR	California Bearing Ratio
ENS	Engineered Natural Surface
ENSR	Engineered Natural Surfaced Roads
GC	Grading Coefficient
GVW	Gross Vehicle Weight
HDM 4	Highway Development Model version 4
Ip	Plasticity Index
km	kilometre
KN	Kilo Newtons
LS	Linear Shrinkage
LVRR	Low Volume Rural Roads
m	metres
mm	millimetres
MMP	Mean Monthly Precipitation
MN	Mega Newtons
Pavement	Roads comprising only unmodified in situ material are often called unpaved roads because no additional material is added. However, in the context of an ENSR (and this review) the term ‘pavement’ is used to describe the ‘engineered’ layers of the road in the normal way.
P##	Passing sieve size ##
PP	Plasticity Product
PI	Plasticity Index
PSD	Particle Size Distribution
psi	pounds per square inch
SEA	South East Asia
SEACAP	South East Asia Community Access Programme
ToR	Terms of Reference
US	United States
vpd	vehicles per day

SEACAP 19: Technical Paper No. 2.2

Behaviour of engineered natural surfaced roads: Experimental Evidence in Cambodia

1 ABSTRACT

This report forms part of Task 2 of the SEACAP 19 programme. It is concerned with the behaviour of engineered roads with only the natural soil as surfacing (ENS roads). The objective is to define the conditions under which an earth surface is a reasonable choice of road surface type to use. A review of the subject was carried out earlier (Technical Paper No 2.1, '*Behaviour of engineered natural-surfaced roads'*) the purpose of which was to identify the principal factors on which the performance of an earth road depends so that a field survey of actual performance in Cambodia could be designed to record values of the important variables and to help define critical limits. This report outlines the field survey that was undertaken and the results of a comprehensive analysis of behaviour.

A slice-in-time method' of study was adopted in which the performances of existing roads were quantified and their properties measured. In this way a much larger sample of roads could be studied with the resources available and therefore a much wider range of the key variables could be included.

In total, 91 sites were surveyed in late 2007; 21 sections in Kampot, 17 sections in Kandal, 35 sections in Ratanakiri and 18 sections in Siem Reap. A second survey was made of 66 of the sections in March/April, 2008. More than 45 factors associated with each site were measured or recorded for use in the performance analysis.

The study adequately quantified the way that the deterioration of the sites in terms of physical damage such as potholes, erosion and rut depth develops with time and with engineering design factors. The mathematical performance models that were derived allow the predicted behaviour of an ENS to be calculated provided that the conditions are similar to the conditions covered in the survey. By defining limiting criteria it was possible to determine the properties of an ENS road that would provide satisfactory performance and to derive specifications.

However the study was not able to quantify lack of accessibility caused by slipperiness, flooding or any other reason that was not measurable by the survey staff during the surveys themselves. Although not ideal, any specifications designed to cope with these particular problems must be adapted or copied from specifications derived elsewhere.

Although drainage factors were not as dominant in the models as expected, it was concluded that the main reason for this was that they tend to form a critical path comprising, camber, longitudinal slope, ease of run-off, crown height and good side drains. Any one of these could be sufficiently deficient to cause drainage problems and in that case the others would not appear to be significant in a statistical analysis. The most significant 'drainage' factorwas the run-off factor. This is a somewhat subjective factor but it is something that can be corrected relatively inexpensively by local, regular maintenance and, if necessary, spot improvements.

Despite the size of the survey, there are many materials and conditions that could not be included and it is important to remember that the results of any experimental study are only valid within the range of the variables. For example, all the surfacing materials in the study were finer than 26.5mm maximum particle size. Also, since traffic itself did not prove to be a strong determinant of performance (although age of the road did) the results are only valid where traffic has similar characteristics to those observed in the study. In particular, heavy trucks were largely absent and most motorised vehicles would have had relatively low tyre pressures. This has important implications for

design; the designer must be confident that heavy traffic will not use his road, or effective methods must be devised to guard against it.

The study did not address the issue of dustiness and the problems that this causes to local people. In general, all soils that contain sufficient fine material will cause dust and this problem gets worse very quickly as vehicle speeds increase and as materials dry out.

The study has illustrated the complexity of performance of ENS roads and highlighted the reasons why deriving general specifications has proved elusive. It has confirmed the need for locally derived flexible specifications that are relevant to the local materials and the road tasks. The results of the study have been encouraging and have indicated that, with longer term monitoring, the outstanding questions can be resolved

2 INTRODUCTION

This Task (Task 2 of the SEACAP 19 programme) is primarily concerned with the basic behaviour of the road ‘pavement’ itself, defined in this context as the road surfacing and the layers of natural in situ materials in the zone below the surface. The Task concentrates on ‘earth’ materials, or those materials whose quality could be categorised as lower than that which is normally acceptable for use as an unsealed gravel wearing course. Within this definition the overall objective of Task 2 is to define the conditions under which an earth surface is a reasonable choice of road surface type to use.

Information concerning the overall performance of earth roads surfaces is not abundant in South East Asia and information concerning the way that performance depends on all the factors that influence it is, therefore, even less well documented. The overall passability of a road or the ability of a complete road to allow the passage of traffic is usually dominated by factors concerned with drainage and water crossings and so less attention has been given to the behaviour of the running surface of the road itself. Clearly, if an earth road is to be a viable option then the water crossings have to be adequate. Thus for the purposes of this study it is assumed that along the route the water crossings are adequate for all-year access and that, provided the earth surface is sufficiently durable and socially acceptable, then such a solution can be viable.

3 EXPERIMENTAL DESIGN

3.1 Introduction

The objective is to determine the influence of each of the important factors (or variables) on performance and therefore the experimental design requires that the sample of roads that are studied include at least two values of each of these variables, a high and a low value for example.

One method of study is to build experimental sections in which these factors are controlled and to monitor the performance of these sections over a period of time. This method has several disadvantages. First of all some of the key factors are concerned with rainfall hence, to determine the influence of these, at least two sets of test sections with distinctly different rainfall patterns need to be built. Secondly, the properties of the surface materials are also important hence a range of materials need to be used. Since only one material is likely to be local to each site, and the number and range of important material properties are large, most of the materials will need to be imported. This will be expensive. Thirdly, the geometry of the road is important, particularly longitudinal gradient, hence the trial sites will need to repeated in different terrains. In summary, the number of key variables is large and therefore a suitable experimental matrix of artificially constructed test sections that will cover them properly (scientifically) would be prohibitively expensive. Any realistic experimental design in which trial sections are constructed could only examine a small sub-set of all of the factors and would be inadequate to fulfil the objectives of the Task. Furthermore, to obtain results the performance of the trial sections will need to be monitored for several years.

An alternative method of study is the so-called ‘slice-in-time method’. In this method the performances of existing roads are quantified and their properties measured. Thus all the effort is concerned with *measuring* existing roads rather than *building* trial sections. In this way a much larger sample of roads can be studied and therefore, potentially, a much wider range of the key variables can be included. This is a very important advantage but the disadvantage of this method is that ‘control’ of many of the variables is lost – the experimenter has to accept what is there and this may not cover the range of a particular variable adequately.

Another particular difficulty concerns the construction history of the roads. In a specifically constructed trial it is possible to eliminate, to a large extent, any major differences in construction procedure or, alternatively, to include them as a trial variable. In the ‘slice-in-time’ approach it is unlikely that there will be sufficient information available about the construction history of each road to identify potential causes of good or bad performance that may be dependant on the construction procedures. In a recent SEACAP project, for example, two sections of the same road built at the same time in the same terrain in the Central Highlands of Vietnam and carrying the same traffic performed very differently (TRL-OtB, 2008). The two sections had been built by two different contractors. The quality of construction is an important factor that is most easily quantified at the time of construction. Testing an already constructed road that has already deteriorated to some extent can provide information about construction quality, but it is much more difficult at this stage.

Nevertheless it was concluded that the ‘slice-in-time’ approach was the most likely to be successful. Once again it is necessary to monitor the sections chosen over a period of time although, with this approach, it was thought that some early results may be obtained, as described below.

3.2 Methodology

One of the problems with identifying the initial cause or causes of particular road behaviours is that there are often several possible contributory factors. Thus using the slice-in-time approach does not readily allow the primary reason to be determined. For example, one reason why a road is now deeply rutted could be that it originally had inadequate camber to ensure that surface water ran off quickly but, in the deeply rutted state, it is impossible to determine the original camber. Another possible reason might be the passage of heavy vehicles that would have caused ruts whatever the camber. Other hypotheses could be formed to explain the rutting but the point here is that it is difficult to know which hypothesis is correct. There are many examples of this type of problem that can only be resolved by monitoring performance over a period of time.

Another similar problem is caused by the interactive nature of many types of deterioration. Thus the key to understanding performance is to determine what came first. For example, a road may be in poor condition because erosion damaged the shape of the surface which then allowed water to pond. The pond areas, being weak, then quickly became pot holes and then ruts. In other words, one form of deterioration leads on to others, often quite quickly. By the time the road is badly damaged the original form of deterioration that triggered the others may be obscured completely.

One way to help resolve some of the problems of this kind is to examine the condition of different sections of the same road. This is because many of the key variables will be the same for an individual road, e.g. climate, traffic, and some of the other variables could reasonably be assumed to be the same if all the road was constructed at the same time e.g. material, ditch depth, camber. For example, if most of the road is in good condition but sections with steeper longitudinal gradients are in poor condition, it can be concluded that for the material, climate, traffic level, etc., the performance is adequate only if the longitudinal gradient is not too steep. Comparing sections of the same road in this way can resolve some of these problems.

In this study the approach used was to select a wide variety of roads in different parts of the country to cover the effects of climate, terrain and so on and, on each road, to identify sections showing differential performance. This method has allowed the widest possible coverage of the key variables to be made and provides the best chance of a successful outcome, but there is really no substitute for long-term monitoring and this experimental design has provided a good base for further research.

4 DATA COLLECTION, MANAGEMENT AND REVIEW

4.1 Field survey form

The factors that need to be measured were identified in Technical Paper No 2.1, '*Behaviour of engineered natural-surfaced roads'*, and a field survey form was drafted. This was trialled in the field and modified several times before the final version (shown in Appendix A) was obtained.

The form has been designed to record several different types of data. These are classified as,

Type A Background data or data that are not key factors affecting performance or measurements of performance itself; e.g. class of road, location, etc.

Type B Reported data pertaining to the *whole* road. Some of these data were obtained from interviewing local engineers and people living along the road. This includes items concerning the year round passability of the whole road and reasons for limited or restricted access such as flooding. It also includes the observations of the survey team concerning the whole road but excludes any physical measurements.

Type C Key independent variables expected to influence performance of selected short sections of each road; e.g. rainfall, camber, traffic, drainage features, material strength (Dynamic Cone Penetrometer), etc..

Type D Performance data (dependent variables) pertaining to the selected short sections of each road; e.g. rut depth, pot holes, erosion.

Table 4.1 lists the data of type A, **Error! Reference source not found.** lists all the data of type B and **Error! Reference source not found.** lists the data of types C and D obtained from the field surveys.

Table 4.1 Background data for whole road

Data	Description	Scale	
		'Good'	'Bad'
Location information	Province, district, commune, name, grid coordinates etc..	NA	NA
Road designation	Tertiary through to field road	1	5
Road surface type	Four categories, earth to gravel	NA	NA
Terrain	1 = 'Flat' to 6= 'Mountainous'	1	6
Traffic type	1 ='Local 2-wheel only' to 5 ='heavy vehicles dominate'	1	5
Traffic volume	1 =< 20 4-wheeled/day' to 4 = >150 4-wheeled/day'	1	4

4.2 Survey procedure

Suitable roads were identified in the four provinces of Kandal, Kampot, Siem Reap and Ratanakiri, Figure 4.1 These provinces were chosen to cover the widest range of topography and climate as shown in Table 4.4.

On each road, short lengths of road showing relatively good or relatively poor performance were identified and suitable 50-metre lengths for detailed measurement were selected on these short lengths. These 50-metre lengths are referred to as 'sites'.

The first phase of field surveys took place between October 2007 and January 2008. In total, 91 sites were surveyed representing 46 different roads; 21 sections in Kampot, 17 sections in Kandal, 35 sections in Ratanakiri and 18 sections in Siem Reap. A second survey was made of 66 of the sections in March/April, 2008.

Table 4.2 Performance data for whole road

Data	Description	Scale 'Good'	Scale 'Bad'
Reported access	'No difficulty' to 'severe limitations'	1	5
Reported days closed to traffic*	Number of days that traffic cannot pass	low	high
Reported passability problems	Causes identified	NA	NA
General condition from drive over survey	No defects to defects covering > 75% of road	1	5
Maintenance*	Good to none	1	3
Rainfall	Millimetres per year	low	high
Age	Years	low	high

NA = not applicable
= difficult to obtain, incomplete

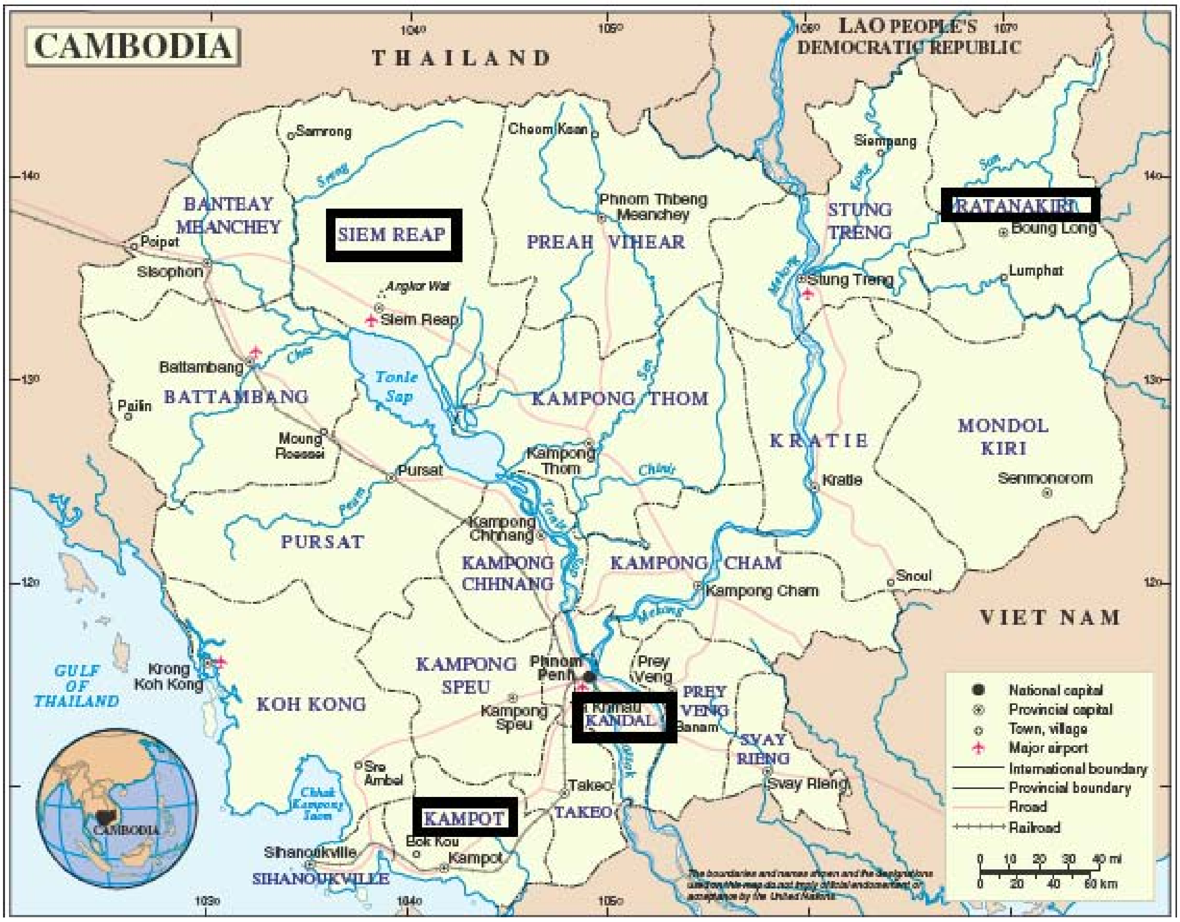

Figure 4.1 Provinces for the ENS study

Table 4.3 Field survey data from selected test sections

Data	Description	Scale	
		Good	Poor
Section Data			
Width	Metres		
Longitudinal gradient	Percentage	low	high
Horizontal curvature	‘Straight’ to ‘90 degree bend’	1	4
X-fall	Percentage left and right	high	low
X-section	Good to poor	1	6
Appearance	Good to poor	1	5
Water table*	Minimum and maximum depth	large	small
Repairs	Local maintenance identified	good	none
Material	General material types	NA	NA
Passability (existing)	‘All vehicles pass with no difficulty’ to ‘no vehicles pass’	1	5
Passability risk	Identifies what is likely to cause passability problems	NA	NA
Weather	‘No recent rain’ to ‘rain in last few hours’	1	4
Side drains	‘None’, ‘drain in good condition’ to ‘drain in poor condition’	1	5
Run off potential	Unimpeded to impeded by shape and shoulder	1	4
Repairs	Local maintenance activities identified	good	none
Block Data			
Visual condition	No defects to defects covering > 75% of block	1	5
Loose material*	‘None’ to ‘more than 50mm’	1	4
Corrugations	‘None’ to ‘more than 50mm’	1	4
Erosion (running surface)	‘None’ to ‘interconnected rills > 50mm deep’	1	5
Erosion (shoulder)	‘None’ to ‘interconnected rills > 50mm deep’	1	5
Size of pot-holes	‘None’ to ‘> 200mm deep’	0	5
Extent of pot holes	‘None’ to ‘75% of length’	0	5
Ruts	Maximum depth in ‘block’ in millimetres	low	high
Crown height	Distance in metres to lowest drain point	high	low
Shape	‘Embankment/camber’ to ‘dished’	1	5
Strength (with DCP)	Quantified at depths of 0, 100, 300 and 500mm.	high	low

NA = not applicable

* = difficult to obtain, incomplete

Some of the subjective data listed in the Tables appeared to be unsatisfactory for one reason or another. For example, the maintenance history was very unreliable or incomplete as was the reported number of days that a road was impassable during the year. In addition, some of the data that were potentially measurable were also unreliable or incomplete, for example, the minimum and maximum depth of water table was difficult to determine. Data that were considered unsatisfactory for any reason have been marked with an asterisk in the Tables.

Table 4.4 Physical Setting of ENS Provinces

Province	Geology	Terrain
Kandal	Quaternary sands, silts, and clays. Occasional isolated igneous "islands"	Flat terrain.
Kampot	Quaternary sand silts and clays with isolated clastic sedimentary and limestone rock outcrops.	Isolated hill and flat terrain
	Clastic sedimentary and limestone	Highland terrain
Siem Reap	Quaternary sands. Interbedded sandstone &siltstone with tuffs. Some granite and rhyolite.	Low lying flat terrain with moderate hills
Ratanakiri	Metamorphic schist and gneiss with andesites and basalts. Some clastic sedimentary and limestone areas.	High hills to mountainous terrain

4.2.1 Surface condition

Where possible, the condition factors were measured but some could only be evaluated subjectively. The survey form (Appendix A) was designed to minimise subjective assessments and also to simplify the survey procedure as much as possible to minimise the risk of errors and operator bias. This section of the report briefly describes how each of the condition factors were measured or evaluated and should be read in conjunction with Appendix A.

Longitudinal gradient was measured using a simple Abney type level. It is accurate to only about 1%.

Camber/crossfall was measured using a long straight edge, a spirit level and a simple depth gauge or ruler.

Crown height was measured from the bottom of any drainage ditch present or from the ground level where water would sit. A surveying staff, long straight edge and spirit level were used. The method was quite quick and for low values (less than 500mm) it was accurate to about 100mm but accuracy decreased for high values.

Horizontal curvature was evaluated subjectively (Appendix A). The sites were only 50m long and this method was accurate enough.

Cross-section and Surface Shape were both measured subjectively by matching diagrams with visual observation (Appendix A).

Ditch condition was also evaluated subjectively (Appendix A)

Run-off was evaluated subjectively as described in Appendix A. Great care was exercised to make sure that run-off was judged independently of surface deterioration since almost all forms of deterioration also impede run-off

Rut depth was measured with a depth gauge and 2-metre straight edge. The maximum value in each 10-metre block was recorded.

Size of potholes. Pothole size was simply a measure of their depth. The maximum value on each 10-metre block was recorded

Extent of potholes is simply a measure of the percentage of the length of each 10-metre block that was affected by potholes. This was often done subjectively to an accuracy of about ±10% but if in doubt a tape measure was used.

Erosion is measurable in terms of the depth of rills but the overall measure of erosion is fairly subjective as shown in the survey form.

Loose material was measured as a thickness but, because it is generally formed by the ravelling of the non-plastic, low fines material under traffic, it was not a significant factor in the ENS field surveys.

Corrugations are generally the result of material displacement under moving vehicle tyres due to loose surface material and vehicle dynamics, consequently this was not a significant factor in the ENS field surveys. Where they occurred they were directly measure in terms of depth.

Although the measurements were specific to each 10-metre section, average values of most of the measured variables for the whole 50-metre section were used for the analysis.

4.2.2 Dynamic cone penetrometer measurements

Three DCP measurements were made in each section, in blocks 1, 3 and 5. For analysis purposes the values of CBR at the surface and at depths of 100mm, 300mm and 500mm have been tabulated in Appendix B. In order to simplify further, for the initial appraisal of the data, the average values for each test section were calculated.

Some roads are genuine earth roads in that the material for the pavement has simply been borrowed from the side of the road alignment in the traditional way whereas others consist of a layer of better material imported from relatively close by. In most cases strength decreases with depth, however some roads have been built up on top of an older road or track that may have been well compacted in the past and hence there is a strong layer at depth below the current road. Subsequent analysis did not indicate that the presence of a strong layer at depth had any influence on performance.

4.3 Laboratory data

The soil samples were tested in geotechnical laboratories at:

Institute of Technology Cambodia (ITC)

Ministry of Public Works and Transport (MPW&T)

Ministry of Water Resources and Meteorology (MWRM)

The laboratory data comprise a combination of standard classification, soil index and strength tests undertaken on samples taken from either the top ‘layer’ of the road or from the overall pavement structure, Table 4.5

Table 4.5 Laboratory Tests

Laboratory Test	Designation
Particle Size Distribution	ASTM D422
Atterberg Limts	ASTM D4318
Moisture Content	ASTM D2216
Linear Shrinkage	BS 1377:2,:6.5
Compaction	ASTM D1557
CBR	ASTM D1883
Soil Classification	ASTM D2487

Derived values of Grading Coefficient, Plasticity Product and Shrinkage Product were also obtained (Technical Paper No 2.1, ‘*Behaviour of engineered natural-surfaced roads’*).

4.4 The database

The Engineered Natural Surfaces Database is based on the Microsoft Access® platform. The advantage of using Access is that it is simple to develop and widely available as a desktop application. Since the ENS Database is relatively small and limited to single user access, the choice of Access as a platform should not pose any problems. Should the database increase in size beyond the Access’ 2GB maximum, migration of the database to an improved platform will be required but it is extremely unlikely that this will be required within the scope of this project.

The database comprises four main data tables and associated data entry forms, with associated supporting look-up tables. The main data tables are as follows:

- tblRodInfo – ‘Road Information’ table containing data for the roads on which the surveys were carried out.
- tblSitData – ‘Site Data’ table containing data on the site surveys. Data are recorded in the field on the ‘Engineered Natural Surfaced Roads Field Data Sheet’ and then populated into the database.
- tblFieldTest – ‘Field Tests’ table containing data from tests carried out in the field (principally DCP tests)
- tblLabTest – ‘Laboratory Tests’ table containing data from laboratory materials tests of samples collected from the field.

The database creates a table for linking to an external GIS system. Named ENGIS this table can be manually linked to the ArcView® GIS package to provide mapping of the field study sites. To map the data correctly the correct co-ordinate system must also be loaded. Additional mapping layers not included in the database provide information on the provincial boundaries and the Cambodian road network.

The advantage of using a relational database such as Access® instead of a series of individual files to store the data is that data records (rows) from different tables can be defined as being interrelated in some fashion. A good database structure therefore is one which does not duplicate data unnecessarily and is organised so that no restrictions are placed on the amount of data that can be stored.

Converting data into a database structure with minimal duplication is a process called normalisation. The structure of the Materials Database is such that it is already normalised to a degree. Logical separations of field tests, laboratory tests and site survey data have already been made and many of the fields are coded using lookup tables.

The ENS database includes five reports showing the road information, site survey data, site sketches, laboratory testing results and field tests. Adding additional reports to the database is relatively simple.

4.5 The laboratory data

Anomalies invariably seem to occur in laboratory data and 100% accuracy is difficult to achieve. Figure 4.2 shows the relationship between soaked and unsoaked CBR at 95% of Proctor density. All data should lie above the line of equality – a soaked CBR cannot be greater than the unsoaked value. Three anomalies are apparent but detailed review of the test data sheets indicated that they were probably the consequence of laboratory procedural errors such as not removing the oversize particles as required by the CBR test.

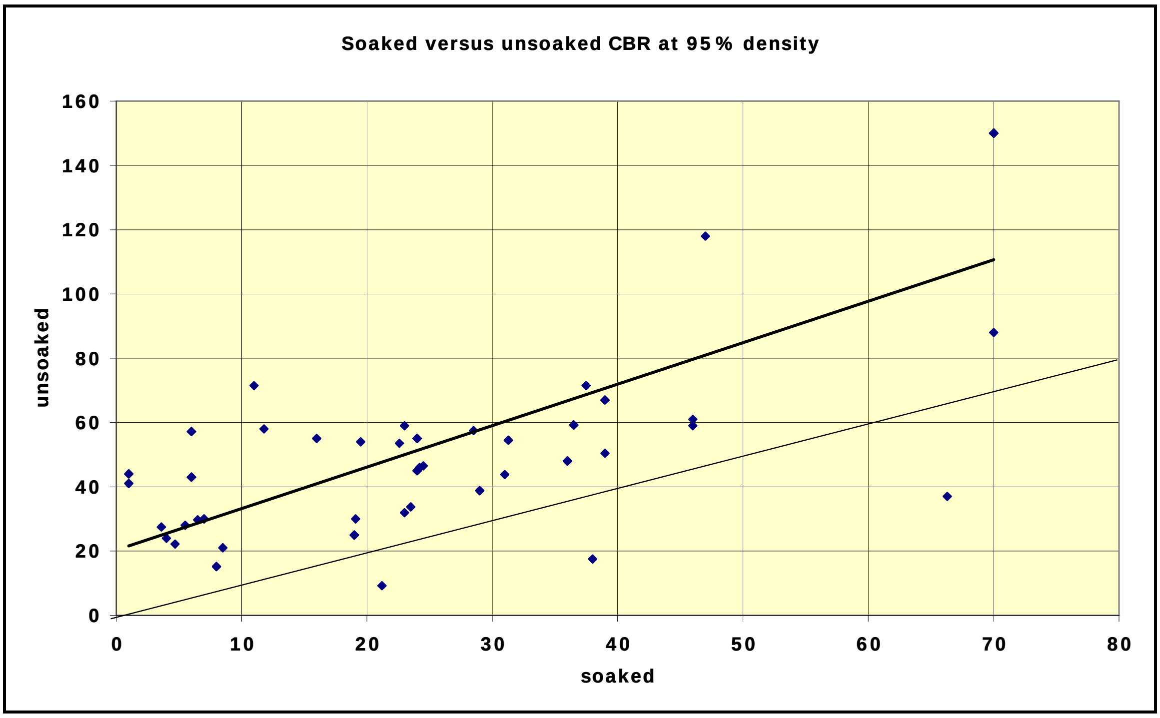

Figure 4.2 Relationship between soaked and unsoaked CBR

Figure 4.3 shows the relationship between Linear Shrinkage and Plasticity Index. Generally the relationship is expected to be linear with a slope of about 0.5. The Figure shows a slope of 0.63 but the simple linear relationship breaks down when PI exceeds about 20. Such a linear relationship is not expected to be applicable to residual (chemically weathered) clay soils where the influence of the active clay minerals is dominant.

Linear Shrinkage and Plasticity Index refer to the properties of a fraction of the soil. The effect on performance is also expected to be related to the quantity of material that possesses the plasticity or shrinkage properties and therefore it is usual to compute the Shrinkage Product and the Plasticity Product by multiplying the LS or PI values by the percentage of material passing the appropriate sieve. Thus the Shrinkage Product and Plasticity Product are expected to correlate better with performance than PI alone. These two values are also expected to correlate with each other; Figure 4.4 shows the relationship. It remains to be seen which of these two variables will be the best determinant of performance; both cannot be used in the same regression equation because the strong correlation would invalidate the regression analysis.

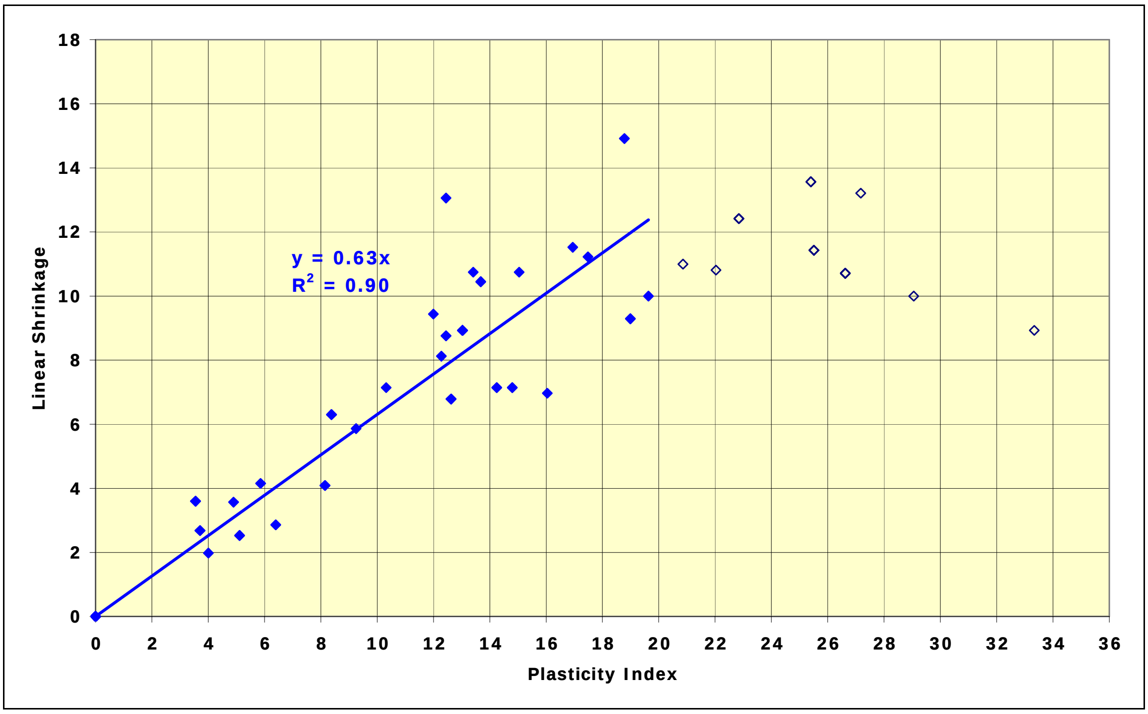

Figure 4.3 Relationship between Linear Shrinkage and Plasticity Index

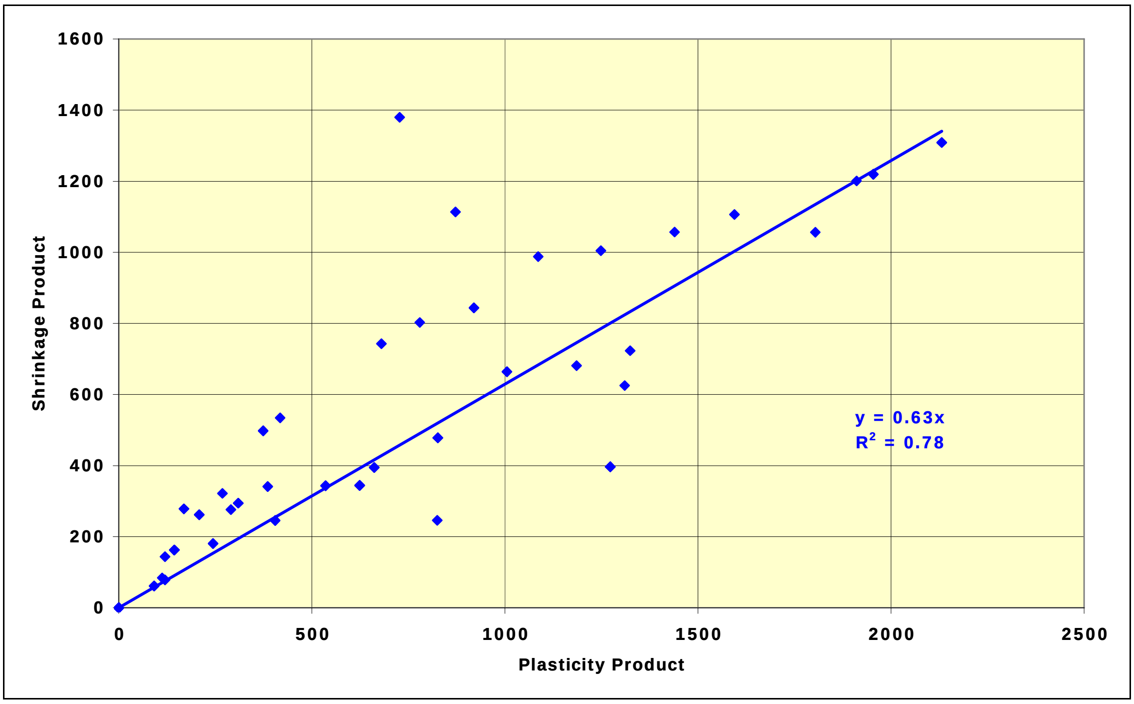

Figure 4.4 Relationship between Shrinkage Product and Plasticity Product

4.6 Data range

The range of the data for each factor is shown in Table 4.6 together with the Mean Values and Standard Deviations.

Table 4.6 Field survey data for analysis

Data	Description	Min	Max	SD	Mean
Traffic type	'local 2-wheel only' (1) to 'heavy vehicles dominate' (5)	1	4	0.6	2.2
Traffic volume	1 = '< 20 x 4-wheeled per day' to 4 = '>150 x 4-wheeled per day'	1	3	0.6	1.3
Reported access	1 = 'No difficulty' to 5 = 'severe limitations'	1	4	1.1	2
Rainfall	millimetres per year	1030	2307	507	1805
Age	years	1	10	2.3	3.1
Longitudinal gradient	percentage	0	27	4.7	2.1
X fall	percentage left and right	0	10	2.6	3.5
Loose material	'none' to 'more than 50mm'	1	4	0.6	1.9
Corrugations	'none' to 'more than 50mm'	1	4	0.6	1.3
Erosion (carriageway)	'none' to' interconnected rills >50 mm deep'	1	5	0.6	1.3
Erosion (shoulder)	'none' to 'interconnected rills > 50mm deep'	1	5	0.7	1.4
Size of pot-holes	'none' to '> 200mm deep'	0	5	1.0	0.7
Extent of pot-holes	'none' to '75% of length'	0	5	1.1	0.8
Ruts	maximum depth in millimetres	0	200	27	30
Crown height	distance in metres to lowest drain point	0	2.0	0.42	0.55
Shape	'Embankment/camber' to 'dished'	1	5	1.0	2.7
Side drains	'none', 'drain in good condition' to 'drain in poor condition'	0	5	1.2	0.7
Run off potential	'unimpeded' to 'impeded by shape and shoulder'	1	5	0.8	1.4
Existing Passability	1 = 'All vehicles pass with no difficulty' to 5 = 'no vehicles pass'	1	3	0.7	1.4
Weather	1 = 'No recent rain' to 4 = 'rain in last few hours'	1	3	0.8	1.45
Strength (with DCP)	100 mm	12	160	25	41
	300 mm	3	68	14	24
Soil water content/optimum	ratio	0.2	1.7	0.3	0.7
Plasticity Index	percentage	0	40	11.4	12.6
Linear Shrinkage	percentage	0	14	4.7	6.2
Grading Coefficient		0	50	16	16
Plasticity Product		0	2100	610	575
Shrinkage Product		0	1380	395	415
Maximum particle size	millimetres	0.05	20	9	9
Retained on 2.36mm	percentage	0	83	28	26
Passing 0.075mm	percentage	6	86	24	42
Soaked CBR @ 95%	percentage	1	70	19	26
Unsoaked CBR @ 95%	percentage	9	88	19	46
MDD	Mg/m^3	1.495	2.490	0.22	2.02
OMC	percentage	5.7	28.2	5.8	12.1

The following points should be noted.

1. Traffic is very light (by weight). Few of the roads carried any vehicles over 4t laden weight.

2. The full range of the variables is represented in most cases although there are several variables whose range is not covered as uniformly as would be ideal. For example, there is only one soil with a Grading Coefficient in the range 10 to 20 and,
3. The soils are relatively fine-grained with none having particles larger than about 20mm in size and many being classified as sands or clays.

4.7 Soil strength

Soil strength is expected to be a particularly critical factor and it is useful to know the likely minimum values both in the dry season and the wet season. Figure 4.5 is a cumulative frequency plot showing the in situ strength values as measured by the DCP. The Figure shows that there are less than 5% of in situ values below about 15% CBR, the value at which an in situ soil can be expected to carry many thousands of vehicles with tyre pressures as high as 0.5 MN/m^2 (Technical Paper No 2.1, '*Behaviour of engineered natural-surfaced roads*').

Figure 4.6 shows the results of laboratory strength tests at 95% Proctor compaction. Comparison of the unsoaked values with Figure 4.5 indicates that the strengths are very similar. The 10th percentiles are about 20% CBR in both cases and the medians are 42% and 46% respectively. Appendix B shows that the in situ moisture contents were generally less than the optimum moisture content for Proctor compaction hence the in situ densities must, on average, be less than 95%. This implies that if and when the soils become soaked, they are likely to be weaker in situ than the soaked CBR laboratory values shown in Figure 4.6. Thus more than 30% of the road sections might exhibit CBRs below 15% at some time during the year. In this condition they are likely to be damaged if they are trafficked by a sufficient number of vehicles with tyre pressures of 0.5 MN/m^2 or more (Technical Paper No 2.1, '*Behaviour of engineered natural-surfaced roads*').

However, a more realistic value of representative tyre pressure for the small trucks that make up most of the 'heaviest' traffic on the surveyed roads is only about 0.25-0.3 MN/m^2. Much less damage is likely to be sustained by the majority of the roads under these conditions, even if the soil is soaked, nevertheless about 25% of the soils might still be at risk.

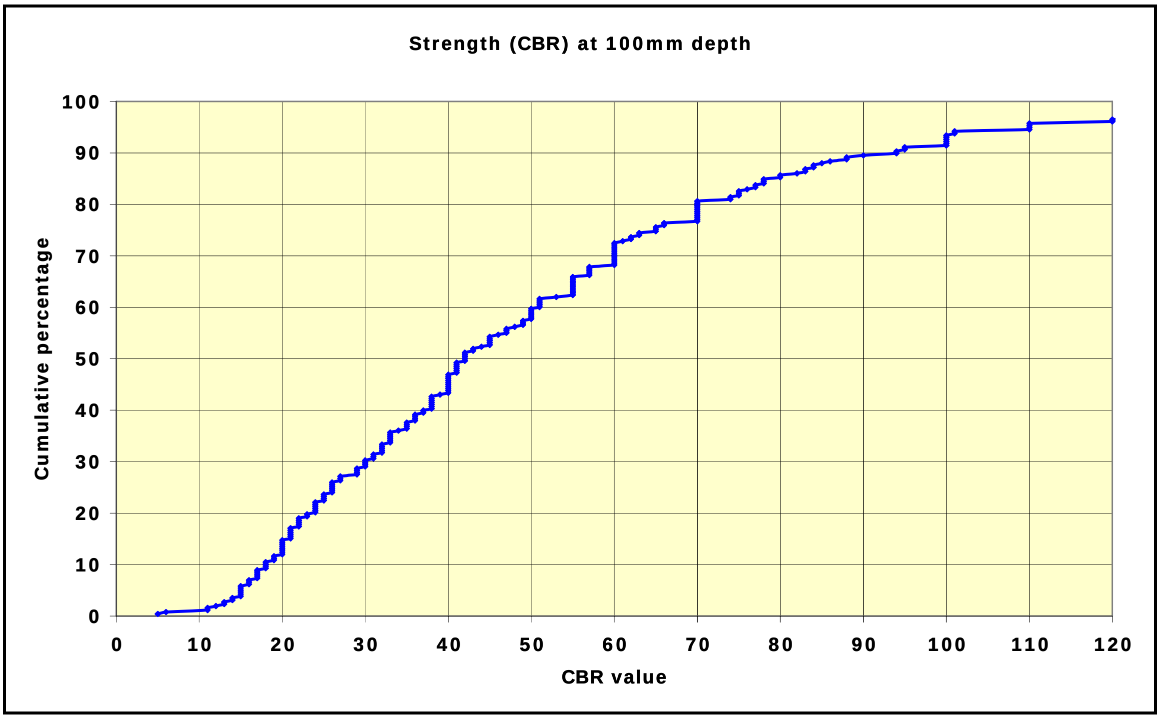

Figure 4.5 In situ strength of the surfacing materials

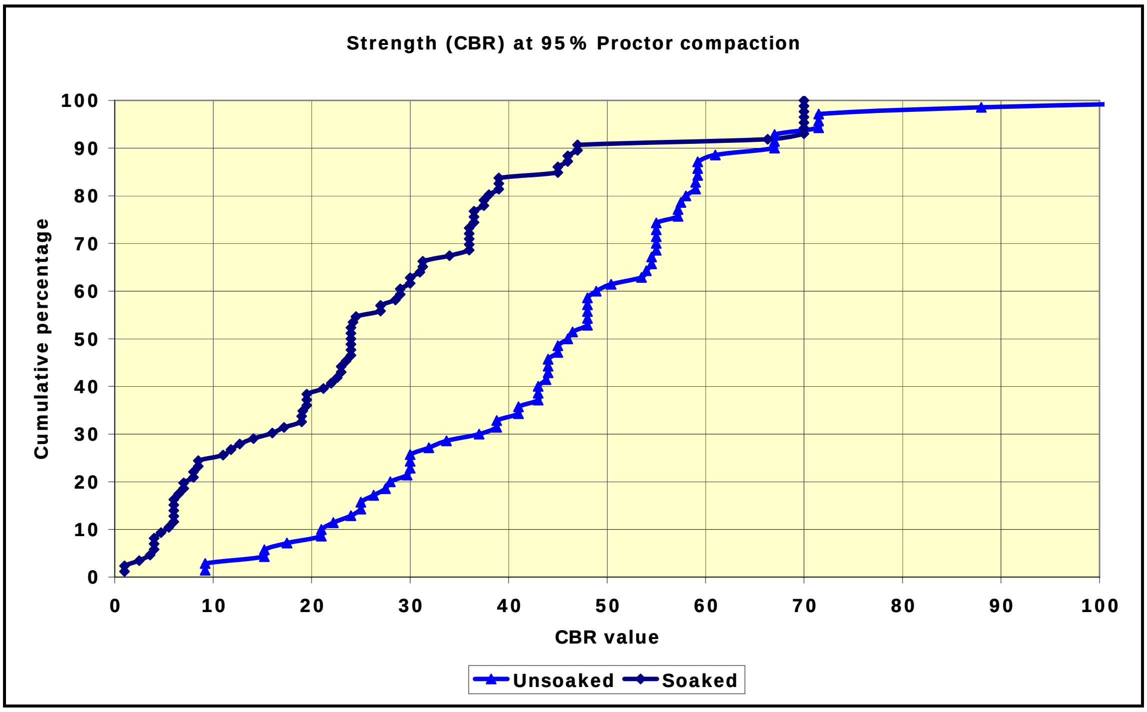

Figure 4.6 Strength of the surfacing materials at 95% compaction

5 REVIEW OF PERFORMANCE DATA

As discussed in Section 4.4 the data have been collated and stored in the ENS relational database. For analysis purposes, they have been exported from this database into a spreadsheet, which is included in Appendix B.

5.1 Performance of the whole road

Table 5.1 indicates the reasons for lack of access and the percentage of roads that were reported to suffer from each cause and their severity. Although some of the flood problems may be caused by sheet flooding, it is very likely that much of the reported flood problems are relatively localised and associated with water crossings. Thus nearly 25% of the passability problems are related to crossing water.

Table 5.1 Reported access problems

Cause of poor access	Percentage of roads with problem	Percentage with severe problem (i.e. very limited access or no access in the wet season)
Water crossing	5.3	1.1
Flooding	8.5	4.4
Erosion and surface deterioration	9.6	7.5
Lack of traction (slippery)	32	8.6
Landslide	0	0
Good access all year	44.6	NA

Nearly half (44.6%) of the roads were reported as providing satisfactory access all through the year but 32% were reported as being too slippery when wet. Of these, about 25% were reported as severe, providing only limited access or worse in the wet season.

The laboratory testing of the materials of the road surface should identify those materials that are too slippery when wet to provide sufficient traction. However, although the surfacing material of many of the roads is probably the same from one end of the road to the other, this cannot be assumed for all roads, hence the soil data from the short test sections may not always be the same as for the problem areas of the road. Nevertheless, the roads that were reported to lack traction usually had a low Grading Coefficient (<12). There were only two exceptions to this (out of 32 short test sections) both of which were described as very silty material.

The Grading Coefficient is a complex variable in that different soils can have the same value but quite different particle size distributions and different behaviours. It is defined as

$$GC = P4.75*(P26.5 - P2.0)/100$$

and has a minimum value of zero and a maximum value of 100. Low values occur when only gravel sizes are present (e.g. P4.75 is near zero) but also when only fine material passing the 2.0mm sieve is present (e.g. P26.5 = P2.0). Low values also occur when there is an abundance of material larger than 26.5mm. High values occur when only coarse sand is present (i.e. all the material lies between 4.75mm and 2.0mm). Thus both high and low values indicate material that is unlikely to perform well.

The Plasticity Product was usually high (>600) for the roads (Table 5.1) that had limited access in the rainy season because of slipperiness, but there were many more exceptions to this general rule (about 45%) than for the Grading Coefficient rule. However, for the roads with *very* severe access problems in the wet season because of slipperiness, the Plasticity Product was usually very high also (>1000).

Table 5.1 shows that *severe* problems of access occurred on about 21% of the roads but that on 5.5% of the roads the problem was caused by flooding or water crossings. Thus it is probable that many of the remaining 16% of the roads could achieve better performance if better material were to be used for the surfacing.

5.2 General performance of the test sections

The reported access problems for the whole road can be compared with the engineers' assessments of the likely performance of the test sections. This will determine the level of agreement and help to assess how representative the test sections are. To make such a comparison the engineer's assessment of the risk of passability problems and his estimate of the likely cause, both tabulated in the field forms, need to be converted to the same scale as the reported problems with the road obtained from the local interviews.

When this conversion was done it was found that for 63% of the test sections the engineer's assessment agrees with that obtained from the interviews. This may appear to be a poor correlation but there are several simple explanations. First of all, water crossing problems do not occur on the test sections because they were selected to avoid them. Secondly the engineer perceives potential problems that may not in fact be severe enough to cause a restriction in year-round access. In other words the engineer is essentially conservative. In general, however, there is good agreement between the perceived causes of passability problems and those reported from the field interviews.

5.3 Correlation matrix

One of the first tasks is to carry out a basic correlation analysis between all the variables. Naturally it is the relationship between the performance variables and the independent variables that we expect to determine performance that are of most interest. However the full correlation matrix is shown in Appendix D.

The main performance variables are shown in Table 5.2 together with their correlation with those factors that are expected to influence performance. Only correlations with an R^2 coefficient greater than 0.3 are shown. Comments on the performance variables and their correlations are shown in Table 5.3.

Several variables did not correlate sufficiently well with any other and are not shown in Table 5.2. These are listed in Table 5.4.

It is surprising that most of the variables related to drainage did not correlate with performance at all. The ‘run-off’ variable is the exception and can clearly dominate the others. In other words, irrespective of how good the camber of the running surface or the effectiveness of the side drains are, if run-off is impeded then performance will be poor and the correlation of performance with camber or the effectiveness of side drains will not be readily apparent. This is illustrative of a general problem when so many factors are involved. Lack of strong correlation with performance does not necessarily mean that a particular factor is not important, only that its effect is not apparent in the data set because other factors have come into play earlier. In other words, if, by good design, the values of these other factors are made favourable, then the effect of poor camber or inefficient side drains should be apparent. Unfortunately the run-off variable is not an entirely independent variable. It is inevitably influenced by aspects of deterioration despite the care taken in its assessment.

Table 5.2 Correlations between variables

Only correlations with coefficients > 0.3 are shown. Those > 0.4 are in bold	**Overall Performance**	**Loose material**	**Appearance**	**Corrugations**	**Carriageway erosion**	**Shoulder erosion**	**Pot hole size**	**Pot hloe extent**	**Ruts**	**Passability**
Terrain				-0.37						-0.33
Traffic Type				0.34						
Rainfall	**-0.42**		-0.33	-0.34			**-0.48**	**-0.55**		**-0.43**
Age in years	**0.40**		0.31					0.35		0.36
Longitudinal gradient %					0.34				0.37	
Run off (average)	**0.50**	0.39	**0.40**		**0.42**	0.38	0.33	0.36	**0.55**	
Recent weather	0.33						**0.49**	**0.60**		
Water content/optimum		0.30		0.30						
DCP 100mm average				-0.38		-0.33				
Liquid Limit	**-0.47**		-0.35	-0.32	-0.30		-0.37	-0.39		
Plastic Limit	**-0.45**		-0.36				-0.34	-0.36	-0.33	
Plasticity Index	**-0.43**			-0.31	-0.32		-0.34	-0.37		-0.35
Linear shrinkage	-0.38				-0.31					-0.33
Grading coefficient	**-0.54**		-0.39	**-0.45**		-0.30	**-0.45**	**-0.50**		**-0.42**
Retained on 2.36mm	**-0.53**		-0.39	**-0.46**		-0.30	**-0.44**	**-0.48**		**-0.43**

It was thought possible that the effects of the other drainage factors could be more readily identified by investigating separately only those sections with good run-off characteristics. However, when this was done, only crossfall was significant and its effect was very weak.

The primary importance of run-off identified in this study agrees with one of the key results of SEACAP 4, the Rural Road Gravel Assessment Programme.

The effect of rainfall seemed to be the opposite of expectations. There are several possible reasons for this. The first of these is that accurate rainfall figures for each road are difficult to determine. The annual 5-year averages where obtained from measurement stations that were in the general area of the road sections but not necessarily so close to ensure that the rainfall measured was the same as that experienced by the roads; local variations can be significant. Secondly, the annual rainfall varies from year to year and so a relatively new road in a nominally wet area may not have experienced the rainfall expected from the 5-year average figures quoted in the data sheets. Thirdly, the sample did not include many roads in very high rainfall areas.

Another important reason is that there is a high correlation of 0.69 in this data set between rainfall and Grading Coefficient (see the correlation matrix in Appendix D). This means that roads that perform well because of a good Grading Coefficient are also more likely to be found in high rainfall areas. This may be a coincidence but it is very significant statistically in trying to separate the effects of all the influencing factors.

Finally, storm intensity, although loosely correlated with total rainfall, is also a significant factor that was not measured.

Despite the apparent anomaly shown in the simple correlation matrix, it is shown later in the detailed modelling that high rainfall is usually detrimental, although the effect was weak.

Many of the observations in Table 5.3 are expected. The improvement in performance as plasticity increases is expected because some plasticity is advantageous, but the fact that neither Plasticity Product nor Shrinkage Product were significant is puzzling because over 70% of the roads were surfaced with material containing more than 30% finer than 0.075mm. A possible reason is the fact that as PP and SP increase, performance initially improves but then gets worse. This is examined later.

Table 5.3 Performance variables and their correlations

Variable	Comments
Overall Performance and Appearance	Improves, as grading coefficient and plasticity increases but deteriorates with age and with impeded run-off.
Loose material	Deteriorates as run-off is impeded
Corrugations	Deteriorates as traffic gets heavier, terrain gets flatter, material gets less cohesive and the CBR@100mm gets weaker. Improves as material gets coarser
Erosion	Increases as gradient increases and as run-off gets worse. Decreases as CBR@100mm increases and as Plasticity increases.
Size and Extent of Potholes	Increases with age, and as run-off gets worse. Decreases as plasticity increases, and as material gets coarser. Depends strongly on recent weather.
Ruts	Increases with gradient (could be erosion channels on steep sections) and as Run-off deteriorates. Decreases as plasticity increases
Current Passability	Deteriorates with age. Improves with plasticity and coarseness

The other purpose of the correlation matrix is to identify strong correlations between the *independent* variables themselves because two independent variables that are highly correlated cannot both be used in a regression analysis. The variables shown in Table 5.5) were found to be highly correlated hence only one from each row can be selected in any one regression analysis. However, each one can be used in turn to determine which works best in a particular model.

Table 5.4 Factors that did not correlate with performance

Factor	Comment
Reported access problems	This is probably because some of the problems do not occur on the tested sections but elsewhere on the road
Traffic volume	Traffic type appears to be more important
Horizontal curvature	The range was too small and most sections were straight
Cross-fall	This is unexpected but run-off is shown to be the critical factor
Cross-section	This is also a little unexpected but provided the road is well shaped and run off is not impeded the effect of this is hidden.
Effectiveness of side drains	This is surprising, but once again the effect of side drains may be secondary to other drainage features, particularly run-off potential.
Crown height	This is surprising also, but crown height will not be effective if other aspects of drainage are not functioning properly. Subsequently crown height was found to be significant in some of the regression models
CBR @ 0mm and 300mm depth	The CBR at the surface reflects recent rain rather than longer term strength. The CBR @ 100mm correlated better but not well enough to be a significant factor in any of the regression models.
% passing 0.075mm sieve, Plasticity Product and Shrinkage Product	The Atterberg limits were significant so it is surprising that these related variables were not. The probable reason is the non-monotonic nature of the relationships
Laboratory CBRs (soaked and unsoaked)	The soil strength does not seem to be a strong factor for the type of traffic being carried by the surveyed roads. For light traffic with low tyre pressures, good traffic carrying capacity does not need particularly high CBRs. Also the effect of slipperiness needs to be considered when traffic cannot travel.
MDD and OMC	MDD is not expected to correlate but OMC reflects plasticity and a reasonable correlation might be expected

Table 5.5 Highly correlated independent variables

1	Liquid Limit, Plastic Limit, Plasticity Index, Linear Shrinkage
2	Plasticity Product, Shrinkage Product
3	Grading Coefficient and Percentage Retained on 2.36mm sieve

5.4 Ranking of performance

The influence of several of the independent variables on performance is not expected to be monotonic (i.e. as the value of the variable increases, performance initially improves but eventually deteriorates again) therefore a simple correlation is not expected to be very revealing. Alternatively, the performance of the sections of road can be ranked and compared with the values of these variables to determine whether the behaviour is, indeed, multi-valued. Figure 5.1 illustrates the effects that have been observed in the drier climate of southern Africa.

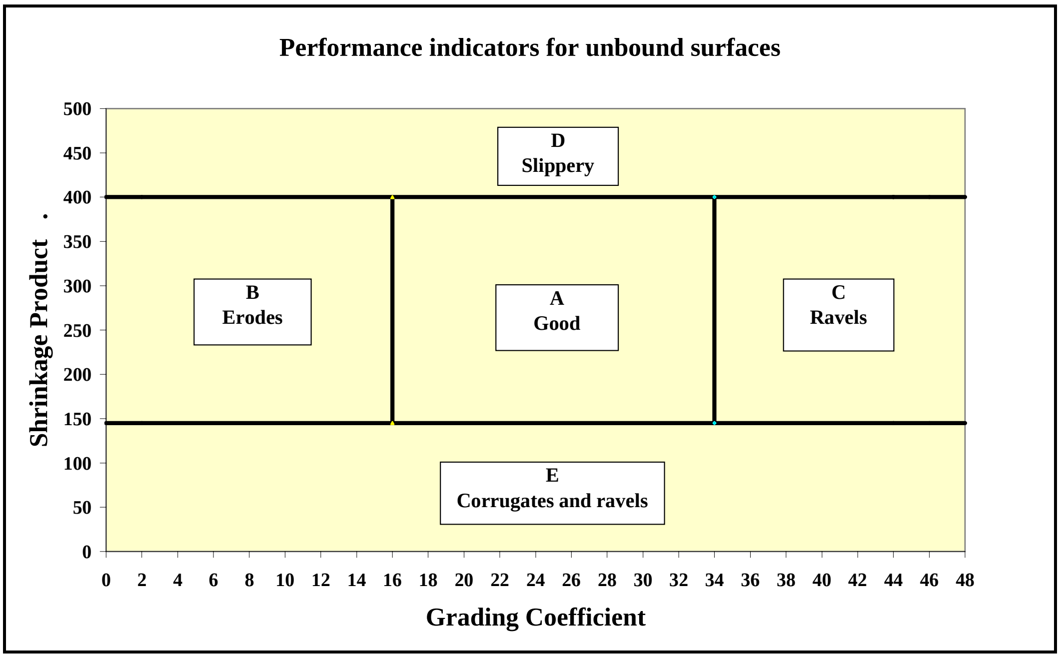

Figure 5.1 Performance trends with Shrinkage Product and Grading Coefficient (Source: P Paige-Greene, 2007)

The following Figures illustrate the corresponding results from Cambodia based on various different performance rankings. Before studying these Figures it is worth remembering that there are many other variables that affect performance and this makes reading the Figures slightly difficult. For example, the age of a section is a strong variable and sections range from only one year old to over ten. This means that although some sections may have performed well to date, this may be irrespective of the value of the key variables of GC and SP simply because the roads are relatively new; they may not perform well in the longer term. Therefore, in reading the Figures, it is the position on the chart of the sections that have performed poorly that is the most important.

Other variables such as rainfall, gradient and so on will also influence performance. For example, a section on a steep slope will perform poorly under most circumstances and thus its performance will not appear to depend on GC and SP in the same way as that of flat sections of road. The Figures are designed for comparison with the international literature and to help identify some of the important variables. A fuller appreciation of the effects of all the variables acting together will only be achieved when the key variables are identified and a proper statistical analysis using modelling techniques has been carried out.

Figure 5.2 illustrates the performance based on the extent of potholes and shows that poor performance only arises when the Grading Coefficient is less than 7. The scale for the severity of the extent of potholes is defined in Table 6.1 Poor performance was defined as pothole extent >2, moderate performance as pothole extent between 1 and 2 and good performance as pothole extent <1. The value of Shrinkage Product does not seem to have much effect and all sections with a GC > 10 have performed adequately to date.

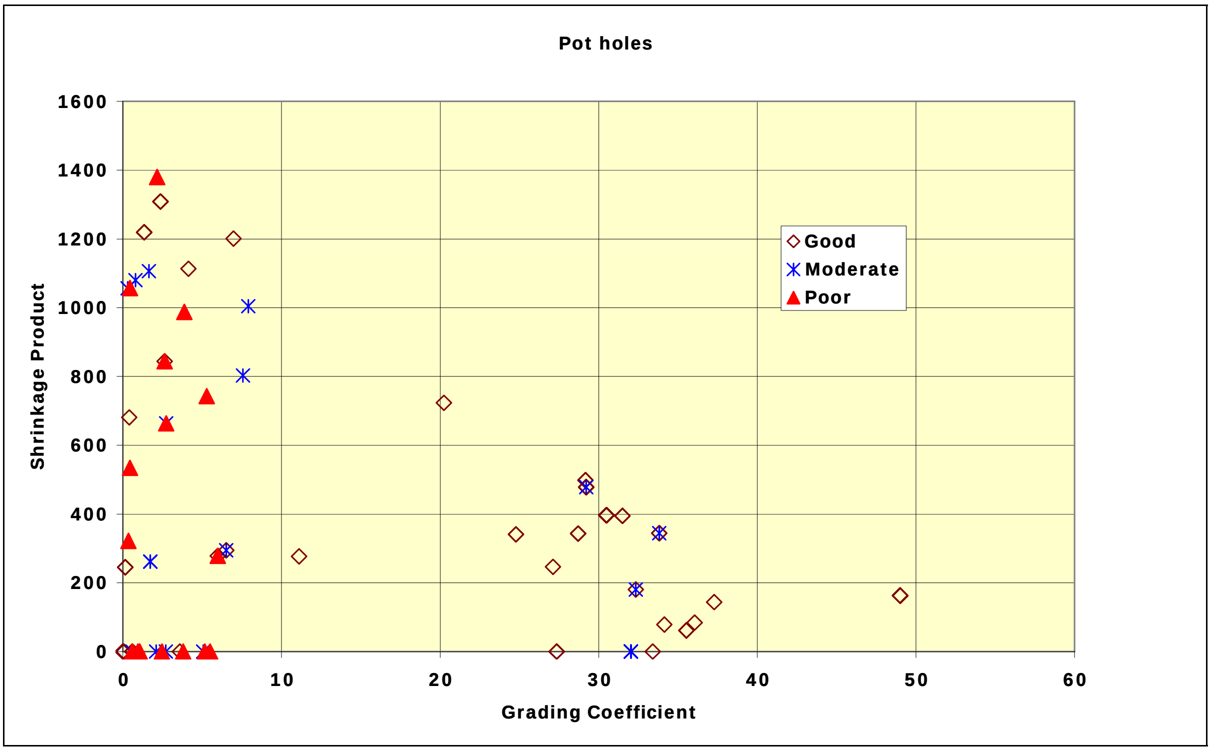

Figure 5.2 Performance ranking based on the extent of potholes

Figure 5.3 shows the performance based on the severity of rutting. Very poor performance was defined as ruts >75mm deep, poor performance as ruts 50-75mm deep, moderate performance as ruts 25-50mm deep and good performance as ruts <25mm deep.

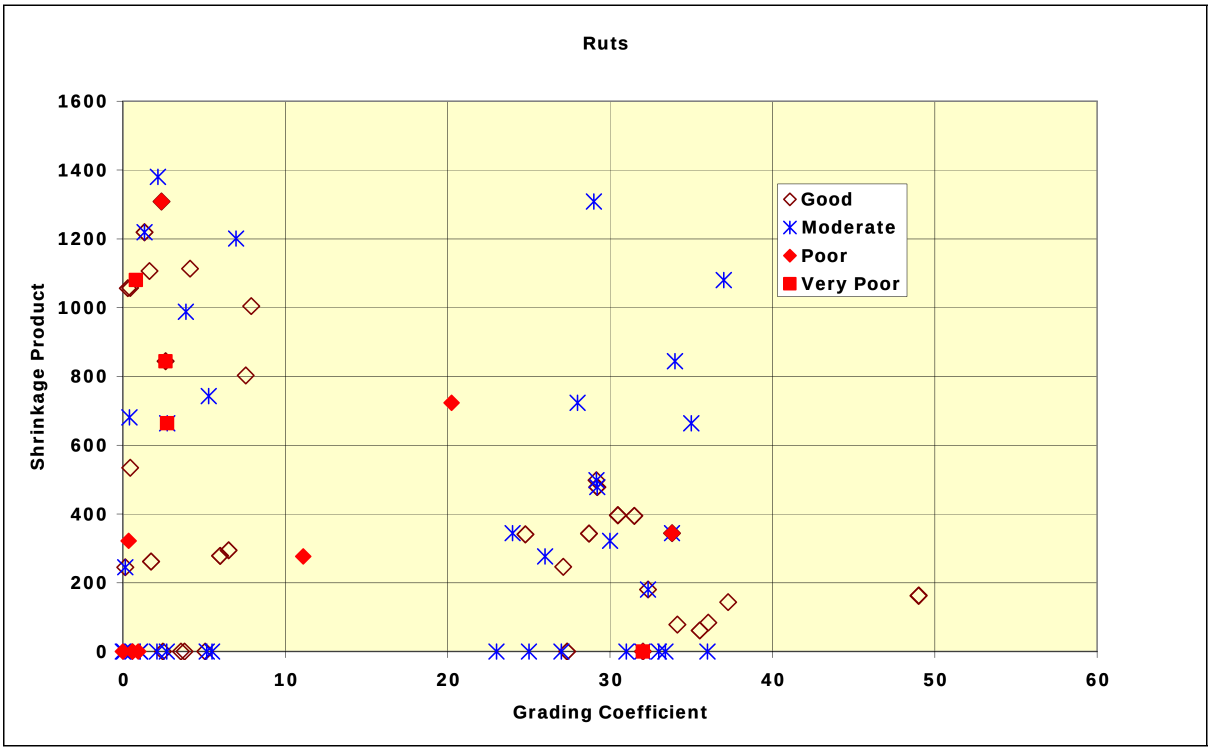

Figure 5.3 Performance ranking based on the severity of rutting

The pattern is similar to Figure 5.2 except that there are four exceptions (sections that have rutted but fall into the area of the chart where performance is expected to be good. Two of these are very steep indeed (site numbers 45 and 46) and the ruts have been exacerbated by longitudinal erosion. One of the other two sections is fairly old. There is no obvious explanation of why the fourth section has not performed well.

Figure 5.4 shows the performance based on severity of erosion. The scale for the severity of erosion is defined in Table 6.1. Very poor performance was defined as erosion >3, poor performance as erosion between 2 and 3, moderate performance as erosion between 1 and 2 and good performance as erosion <1. This is a very subjective measure but few sections suffered severely. Once again the poor performers had GC values less than 7. The single exceptions are the very steep sections (45 and 46) which were also deeply rutted.

Figure 5.5 shows overall performance based on a combination of pothole size, pothole extent, rutting and erosion. The scale for overall performance is obtained by summing the individual values for each defect defined in Table 6.1. The maximum value is 17. Very poor performance was defined as >8, poor performance as 5-8, moderate performance as 2-5 and good performance as <2. Once again poor performance is related to low values of GC with very few exceptions.

Shrinkage Product seems to have less effect than expected. Although non-plastic materials seem slightly worse than those with some plasticity, the effect is weak.

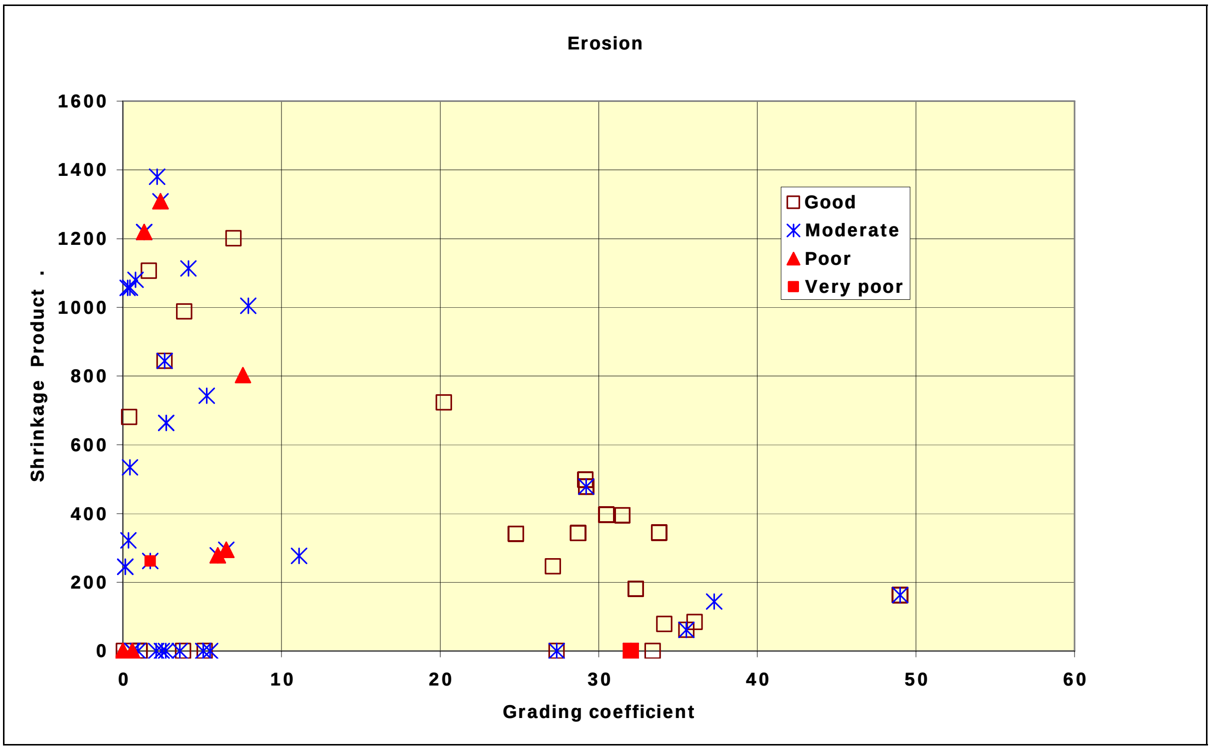

Figure 5.4 Performance ranking based on the severity of erosion

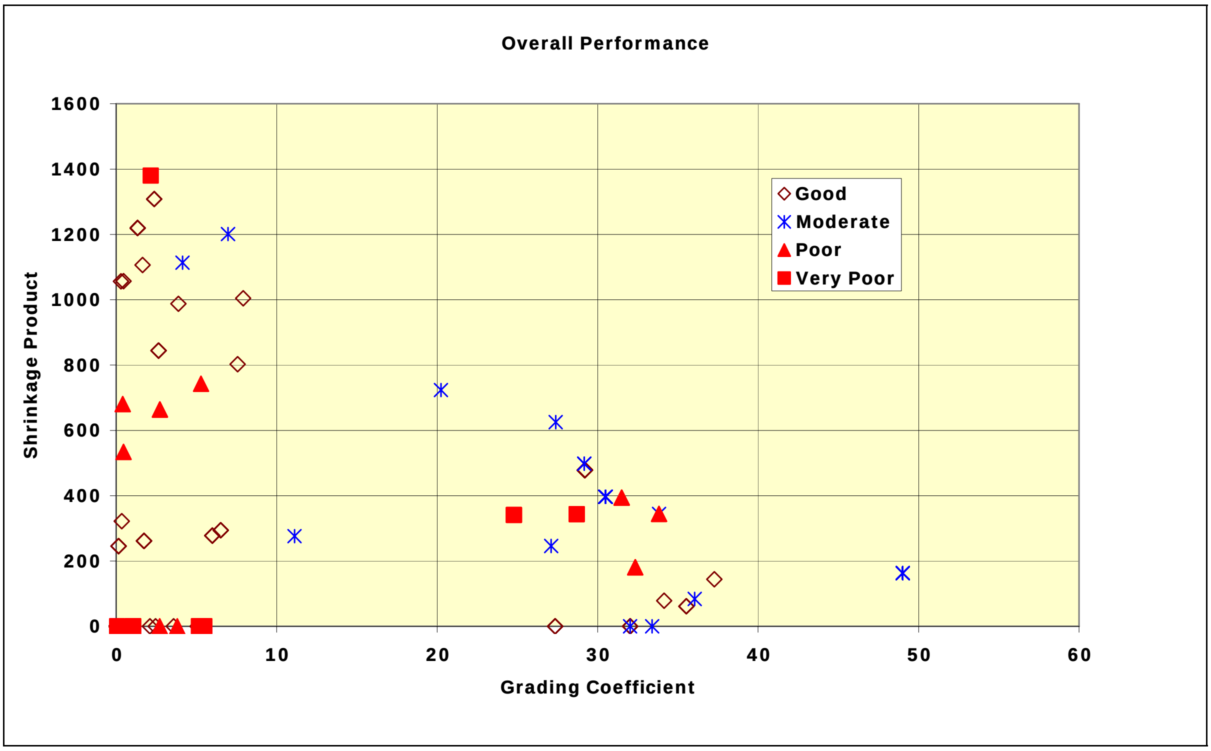

Figure 5.5 Overall performance ranking

5.5 Comparisons within each road

For most of the roads in the survey, two or more 50-metre sections of the road showing different levels of deterioration were selected for evaluation. For any particular road, many of the independent variables will be the same (e.g. rainfall, traffic, materials) and hence the reasons for different levels of performance on the same road ought to be easier to determine. However, there are likely to be differences in several of the independent variables between the sections and each comparison represents only one effective data point, hence considerable care is needed in determining the most likely cause or causes of the deterioration effects.

The most successful cause and effect determinations are most likely to arise where the differences between sections are greatest. Where the differences are small and/or within experimental error, it is unlikely that any cause and effect can be determined. Therefore the differences in overall performance between sections of the same road were calculated and the roads ranked in order of these differences. Appendix C summarises this information. The following paragraphs comprise an analysis of the causes of the differences for each road.

5.5.1 Very large differences in performance.

Sites 1 and 2. Site 1 has deteriorated rapidly whereas site 2 has hardly deteriorated at all in four years. A difference in performance between these two sections is expected because site 2 had a larger crown height, higher camber and slightly better drain conditions but the run-off potential was rated as similar. The *magnitude* of the performance difference is puzzling. One explanation might be that some unrecorded maintenance was carried out on site 2.

Sites 40 to 46. Sites 45 and 46 performed poorly but these had very high longitudinal gradients and therefore this result is expected. The performances of the other five sections were relatively similar but a slight improvement is apparent as crown height and camber increase and as the cross section changes from flat to that of a low embankment commensurate with improved crown height. The grading coefficient of the material was about 30 which, from studies elsewhere and from the regression analysis in the next Chapter, is thought to be ideal. As a result, the overall deterioration rate was low.

Sites 31 and 32. Site 31, with a gradient of about 4%, performed much better than site 32 with a gradient of 1%. On site 32 considerably more potholes developed and, surprisingly, more erosion was apparent. The effectiveness of the drains on site 32 were also ranked as slightly worse than on site 31. However, the crossfall was good and this value seems to be at variance with the classification of shape, which was flat for site 31 and uneven for site 32.

5.5.2 Large differences in performance

Sites 78, 79 and 80. Site 78 has performed well whereas site 80 has performed poorly. Site 79 was intermediate. The causes of the differences are difficult to identify with certainty. It appears that several relatively small differences in the values of some of the independent variables may have combined to cause the significant differences in performance that were observed, but there are anomalies in the data that make any interpretation unsatisfactory. First of all the materials varied in their size distribution and plasticity. The non-plastic material on site 78 seems to have been the best but site 78 also had a small longitudinal gradient whereas the other sites were horizontal. At the time of the survey, site 78 was also considerably drier. The crown heights were all good and the drains were satisfactory. Curiously, the camber on the best site (78) was almost flat and considerably lower than on the other two sites.

5.5.3 Medium differences in performance

Sites 18 and 19. There is no obvious reason for differences in performance between these two sites because the values of the independent variables were almost identical. Site 19 deteriorated at a fast rate whereas the rate of deterioration of site 18 was near the average. The crossfall of both sites was high but their longitudinal gradient was low. The grading coefficient of the materials was zero which is usually associated with relatively rapid deterioration. The soils were silty sands with no plasticity and hence they were prone to erosion

Sites 22 and 23. Site 22 performed better than site 23. The grading coefficient, crossfall, and crown height are all slightly better for site 22. Although the differences are small, site 23 is essentially flat whereas site 22 has a low drain on one side thereby permitting reasonable drainage.

Sites 24, 25, and 26. These sites were similar to sites 22 and 23. Sites 25 and 26 performed better than site 24, and the differential performance was relatively large, but there is no reason that is apparent in the values of the variables that identifies the primary cause. Once again the sections with a small but non-zero horizontal gradient seemed to perform better despite the fact that the crossfall was also good on all three sites. The drains appeared to be effective but the run-off potential was poor for two of the sites including the worst performer (site 24). Crown height was good on one of the two sections that performed well but not on the other.

5.5.4 *Small differences in performance.*

Sites 33, 34 and 35. Site 34 performed better than sites 33 and 35. No obvious reasons for the differences are apparent in the values of the variables. The crossfall was good for all three sites. The drains appeared to be effective on sites 33 and 35 but appeared to be a little deficient on the best performing site (34). Crown height was adequate but was actually best on site 33 not 34. Once again there are no clear conclusions.

Sites 68, 69 and 70. The rate of deterioration on these sites was low and the grading coefficients were high. Site 70 performed best and site 68 the worst. Site 68 had zero horizontal gradient whereas sites 69 and 70 had a small gradient.

Sites 91 and 92. Site 92 was worse than 91 but both sites were fairly new and the level of deterioration was low. The independent variables were almost identical and no conclusions can be drawn.

For all other pairs of sites the differential performance was either zero or small and therefore the effect of the independent variables could not be identified.

5.6 Conclusions from the comparisons

This analysis has proved to be a little disappointing and illustrates the problems of research into the performance of ENS roads, namely the high natural variability of performance and the large number of contributory factors (and their interactions) that determine behaviour. Only where the differences in performance were large could the causes be identified with confidence and, in general, these mostly agreed with expectations based on engineering judgement.

A consistent result was that a small longitudinal gradient seems to be beneficial. Sites which were horizontal in the longitudinal direction usually performed less well than those with a small gradient irrespective of the value of crossfall (camber). This latter point was surprising because good camber has been shown to be essential for good performance of ENS roads in East Africa; here it did not seem to be so important on many roads but, conversely, seemed to be the controlling factor in explaining the large difference in performance between sites 1 and 2.

6 REGRESSION ANALYSIS

6.1 Overall performance

6.1.1 Overall Performance Scale.

The key performance indicators are the size and extent of potholes, depth of ruts and degree of erosion. **Error! Reference source not found.** shows that potholes were measured on a scale from 0 to 5, erosion was measured on a scale from 1 to 5 and rut depth was measured as a maximum value in millimetres in each 20m section. In order to summarise the performance of a section of road comprising 5 x 10m blocks, the average value of the defect measurement was calculated for each section, thus fractional values were obtained. In order to assess overall performance, the values assigned to these defects needed to be converted to a rational scale and then combined. This was done by first ranking all the road sections in terms of each defect separately and devising a revised scale for each defect as shown in Table 6.1. This revised scale was based on ensuring that there were always some sections of road occupying each of the bands in the scale.

The maximum score for a very badly deteriorated road is 17. This is an inconvenient number, but increasing or decreasing the scales arbitrarily to provide a more convenient scale is not possible at this stage.

A score of 5 or more can be a serious level of deterioration, especially if confined to one defect. However it is more usual for a road to display several defects at the same time and under these circumstances such a score is acceptable. The cumulative frequency graph (Figure 6.1) shows that according to this criterion, about 75% of the sections of road were in an acceptable condition and, conversely, 25% were not. The range covered by the performance variable and the independent variables in the study should permit a statistical analysis to be successful.

Multiple linear regression analyses were carried out using different combinations of the independent variables in a stepwise approach. Models were developed for overall performance (i.e. a combination of rutting, size of potholes, extent of potholes and extent of erosion), for pothole deterioration only (both for extent of potholes, for size of potholes, and for size and extent combined), and for rut depth deterioration only.

Table 6.1 Revised scale for defects

Defect	Scale used in measurements	Description	Range	Revised Scale
Extent of potholes	0	None	0	0
	1	< 10% of section	0.1- 1.4	1
	2	10-25% of section	1.5 – 2.4	2
	3	25-50% of section	2.5 – 3.4	3
	4	50-75% of section	3.5 – 4.4	4
	5	>75% of section	4.5 - 5	4
Size of potholes	0	None	0	0
	1	Just visible	0.1 – 1.9	1
	2	< 25mm deep		1
	3	25 – 100mm	2.0 – 2.9	2
	4	100 - 200mm	3.0 - 3.9	3
	5	>200mm	4.0 – 5.0	4
Erosion	1	None	0 – 1.4	0
	2	Rills < 15 mm deep	1.5 – 2.4	1
	3	Rills 15 – 50 mm deep	2.5 – 3.4	2
	4	Rills > 50 mm deep	3.5 – 4.4	3
	5	Rills interconnecting	4.5 -5	4
Rut depth	Maximum depth	0 – 10 mm	0 – 10 mm	0
		11 – 24 mm	11 – 24 mm	1
		25 – 49 mm	25 – 49 mm	2
		50 – 74 mm	50 – 74 mm	3
		75 – 99 mm	75 – 99 mm	4
		> 100 mm	> 100 mm	5

Models for corrugations and erosion were not successful. For corrugations this is not surprising (see Section 4.1). Considerable research has been carried out on this problem in the past and the occurrence of corrugations has been found to be related to the particle size distribution of the material and to the nature of the traffic. However the research has not been conclusive and reliably identifying materials that will not corrugate has proved difficult. The general conclusions of a review of the subject (Heath, W and R Robinson, 1980) are that;

(a) corrugations are less likely in materials that are more tightly bound (containing cohesive fines)

(b) corrugations are less likely in wet areas. .

(c) materials containing rounded particles corrugate more readily than those with angular particles

Table 6.2 below indicates the most successful models.

Figure 6.1 Range of performances observed

s

Table 6.2 Regression models

Model Identifier	Dependant Variable		Constant	Age	Age x Traffic Type	Rainfall	Rainfall^2	Gradient	Gradient^2	Run-off	Grading Coefficient	(Grading Coefficient)^2	Plasticity Product/100	(Plasticity Product/100)^2	Crown Height	R^2
1	Overall performance	Coefficient	**1.718**	**0.349**		**0.783**		**0.081**		**1.038**	**-0.109**		**-0.112**			**0.584**
	Scale = 0 - 17	*t'*	*1.54*	*3.96*		*1.471*		*1.71*		*3.48*	*6.82*		*3.27*			
2	Overall performance	Coefficient	**2.5**	**0.331**		**0.62**		**-0.349**	**0.021**	**0.814**	**-0.16**	**0.00124**	**0.091**	**-0.011**		**0.652**
	Scale = 0 - 17	*t'*	*2.32*	*4.01*		*1.24*		*2.64*	*3.6*	*2.83*	*3.38*	*1.16*	*0.89*	*1.895*		
3	Potholes	Coefficient	**2.5**	**0.248**				**-0.252**	**0.012**	**0.401**	**-0.116**	**0.00122**	**0.083**	**-0.0081**	**-1.405**	**0.514**
	Scale = 0 - 9	*t'*	*3.72*	*3.51*				*2.2*	*2.38*	*1.72*	*2.9*	*1.33*	*0.93*	*1.67*	*3.12*	
4	Potholes	Coefficient	**-4.32**	**0.233**		**9.51**	**-3.065**	**-0.148**	**0.0084**	**0.411**	**-0.103**	**0.00145**	**0.132**	**-0.01**	**-1.722**	**0.552**
	Scale = 0 - 9	*t'*	*1.10*	*3.38*		*2.06*	*2.2*	*1.22*	*1.65*	*1.66*	*2.63*	*1.61*	*1.48*	*2.03*	*3.65*	
5	Potholes	Coefficient	**-3.71**		**0.091**	**8.54**	**-2.73**	**-0.194**	**0.0103**	**0.395**	**-0.106**	**0.0015**	**0.164**	**-0.0011**	**-1.63**	**0.552**
	Scale = 0 - 9	*t'*	*1.00*		*3.36*	*1.83*	*1.94*	*1.6*	*2*	*1.59*	*2.69*	*1.66*	*1.83*	*2.34*	*3.45*	
6	Rut depth	Coefficient	**-8.4**	**1.68**		**21.8**		**-4.71**	**0.303**	**7.32**	**-0.773**		**-0.676**			**0.625**
	Scale = millimetres	*t'*	*0.80*	*1.94*		*4.56*		*3.71*	*5.41*	*2.53*	*5.41*		*2.15*			
7	Rut depth	Coefficient	**-9.71**		**0.621**	**22.8**		**-4.86**	**0.308**	**7.52**	**-0.769**		**-0.638**			**0.625**
	Scale = millimetres	*t'*	*0.93*		*1.91*	*4.73*		*3.81*	*5.48*	*2.6*	*5.37*		*2*			

6.1.2 Overall Performance

Figure 6.2 illustrates Model 1 for overall performance. It should be remembered that the performance was measured by increasing values assigned to the road characteristics as they deteriorate hence low values are ‘good’ and high values are ‘poor’. Values above 5 are unacceptable (see 6.1.1).

The key variables proved to be; Grading Coefficient, Plasticity Product, Gradient, Age and Run-off. Rainfall also had an effect but it was weak.

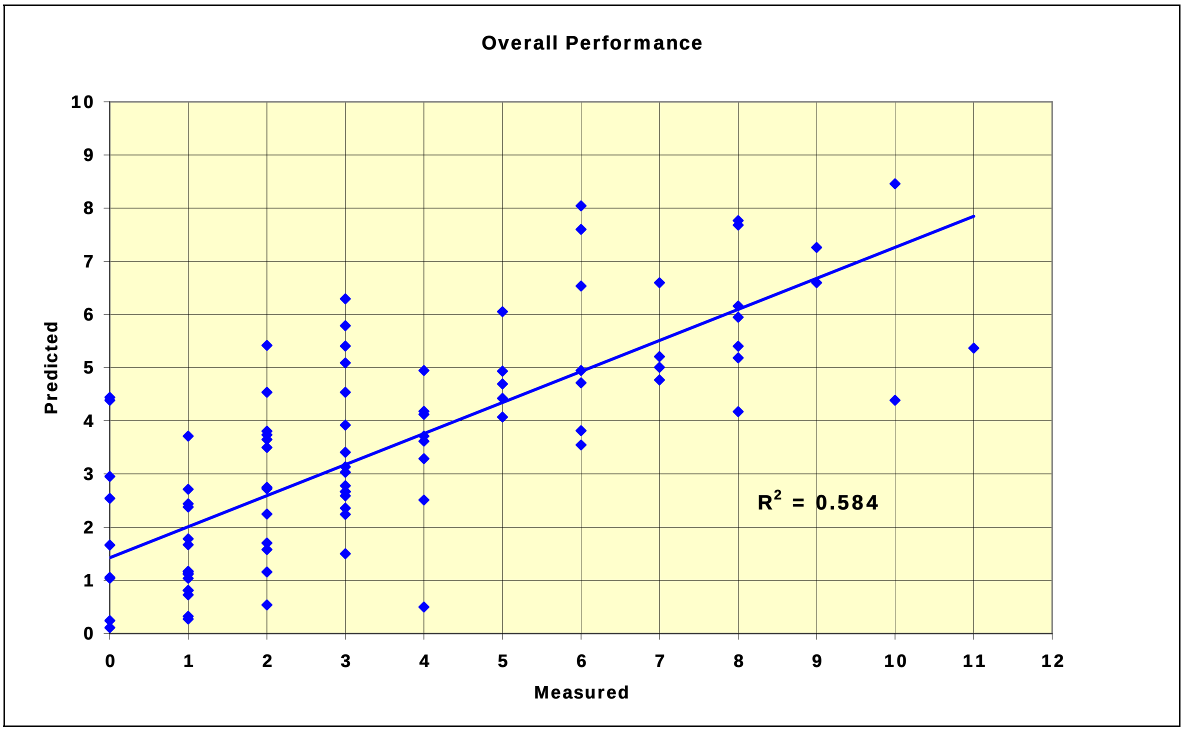

Figure 6.2 Overall performance (Model 1)

Model 1 shows considerable bias in that the residuals are generally positive for low values of deterioration and negative for high values. By introducing quadratic terms into the modelling (Model 2) to allow for relationships that are not monotonic, the R^2 value increases from 0.584 to 0.652 and the residual plot is more uniform, but some bias still remains. Model 2 is shown in Figure 6.3

In the following paragraphs the effect of the individual terms in Model 2 are shown on the left hand side of the Figures. The right hand side of each Figure shows a simple correlation of the raw performance data with the variable in question together with the best-fit trend line. It should be noted that the simple correlations will often appear to be quite poor because the number of variables that influence performance is high. Outlying points may simply be sections of road with extreme values of another important variable. The important aspect to note is the correspondence between the scale of the model’s predictions and that of the trend lines as the variable in question increases from its lowest to highest value. The model and the trend lines ought to be similar.

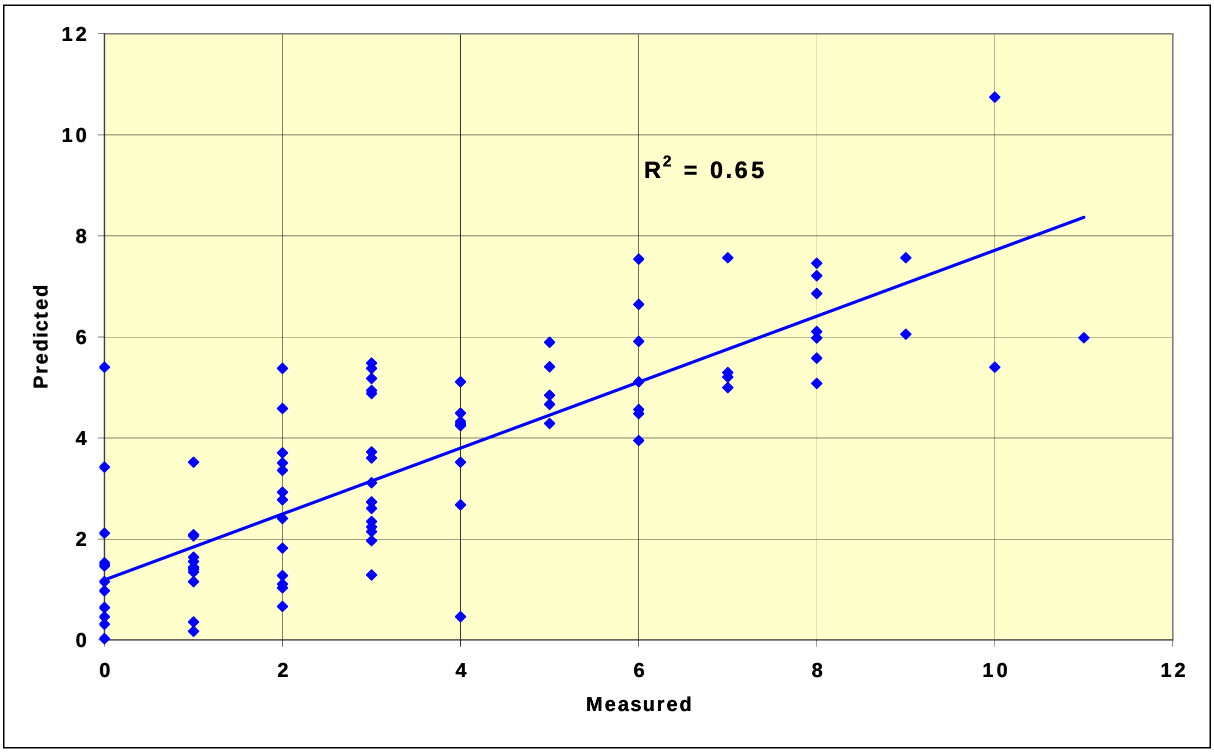

Figure 6.3 Overall performance model with quadratic terms (Model 2)

Grading Coefficient (Figure 6.4)

Grading Coefficient was the variable that featured most strongly in all of the models. The general trend is non-linear but not two-valued, at least up to the values of Grading Coefficient observed on the test sections. It should be noted that the model values range from 6.0 to 1.0 whereas the trend line ranges from 5.0 down to about 1.0; essentially quite close agreement.

It was expected (see Technical Paper No 2.1) that the best performance would occur when 15<GC<35 but improvement in performance seems to continue to higher values of GC.

This behaviour agrees with the general conclusions from the Rural Road Gravel Assessment Programme carried out in Vietnam as part of SEACAP 4 where coarse materials (higher GC) were more resistant to gross deterioration although they were more susceptible to minor erosion of interstitial fines.

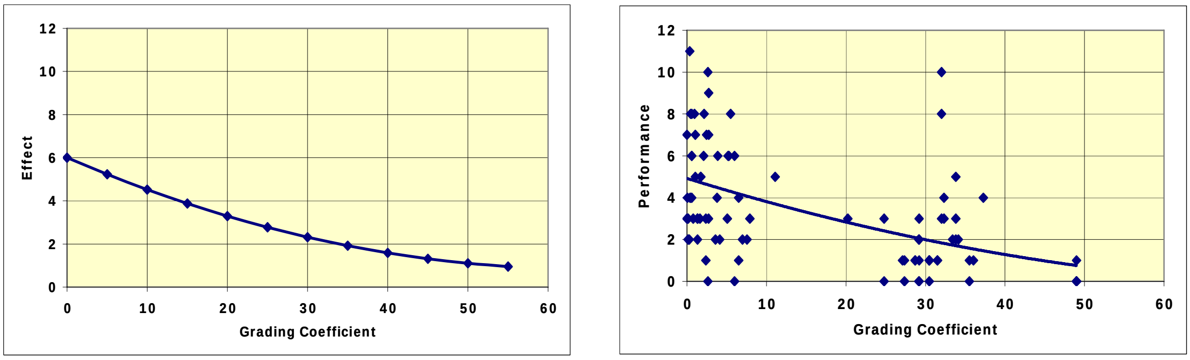

Figure 6.4 The effect of Grading Coefficient on performance

Plasticity Product (Figure 6.5)

The best model form was quadratic and two-valued over half the range. Sections with high values of PP (above 1000 i.e. PP/100 >10) are expected to lack wet strength and to perform badly but there was no evidence of this. In fact the sections with PP/100 above 10 appear to perform better but the effect is relatively weak statistically. Such materials are likely to be very slippery when wet. Under such conditions a considerable reduction in traffic is expected, thereby decreasing the rate at which traffic induced deterioration occurs.

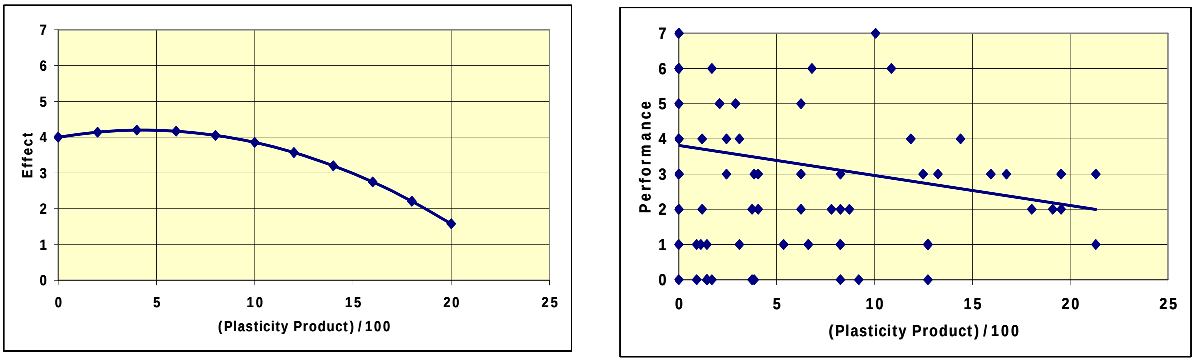

Figure 6.5 The effect of Plasticity Product on overall performance

Age (Figure 6.6)

Age was another strong variable. Unfortunately Age is highly correlated with many other time dependent variables such as ‘cumulative traffic’, ‘cumulative rainfall’, ‘length of time that a road is inundated with water’ and so on. It is almost impossible to separate these time-dependent effects in a ‘slice-in-time’ analysis; only long-term monitoring is likely to be successful and, even then, it is difficult. The model indicates that the magnitude of the effect is very slightly less than the trend line might suggest.

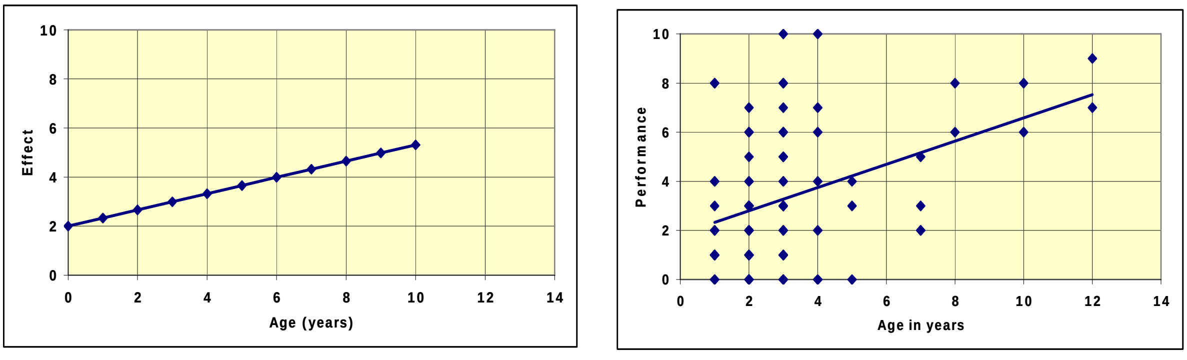

Figure 6.6 The effect of Age on performance

Gradient (Figure 6.7)

The effect of Gradient appears to be non-linear and two-valued. Performance appears to be slightly worse in flat terrain and improves slightly as gradient increases before getting rapidly worse at steep gradients. The trend line shows a larger effect than the model and the optimum gradient appears to be higher. In the absence of good camber and good run-off characteristics, there is no doubt that some longitudinal gradient ought to be beneficial because it will ensure that surface water runs off somewhere. Too much gradient, however, will encourage erosion. The model indicates an optimum at about 7%, which is very high in comparison to recent recommendations on limiting gradient for unsealed roads. However, there is really very little difference in average performance across a wide range of gradients from 0 to about 15%. Furthermore the sample of roads with gradients above 4% is very small and the shape of the model is very dependant on just two sections of road with very high gradients indeed. Thus a true optimum cannot be determined with any precision from this data set. More data are required from roads with gradients in the range from 4% to 15% to establish the magnitude of this effect with greater statistical confidence.

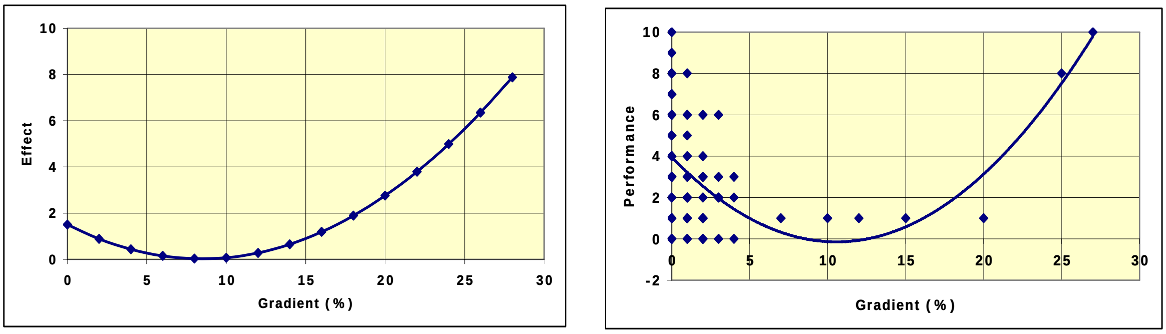

Figure 6.7 The effect of Gradient on performance

Run-off (Figure 6.8)

The Run-off potential (or Run-off coefficient) has proved to be a strong variable. Unfortunately it is not primarily an independent variable since it is unavoidably influenced by pot holes, ruts and erosion as well as by camber, gradient, quality of drains and crown height, all of which correlated to some extent with it. Nevertheless it was the only variable concerned with drainage that seemed to have sufficient effect for inclusion in a model. Various combinations of the drainage-related variables were also tried, including a single variable defined as 'quality of drainage' and related to all the drainage variables together, but none was as statistically significant as the Run-off coefficient.

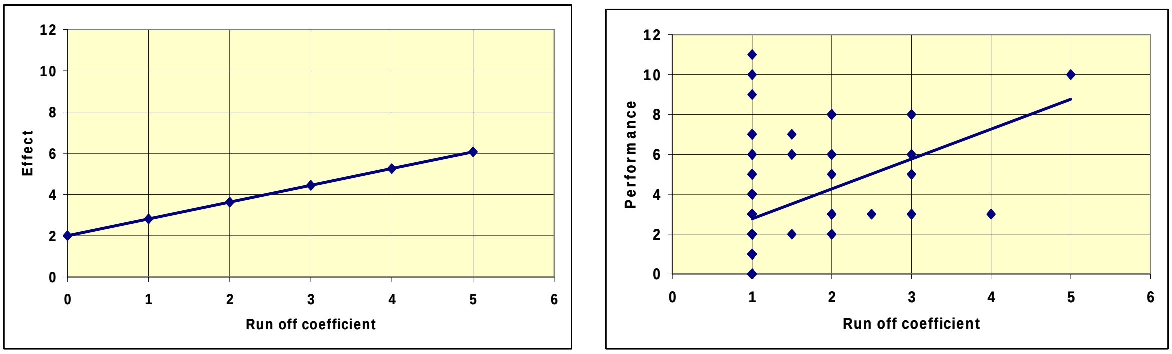

Figure 6.8 The effect of Run-off on performance

Rainfall (Figure 6.9)

Rainfall is expected to influence performance but it has proved difficult to demonstrate an effect. There are several possible reasons why this might be so as discussed in Section 5.3. In an attempt to improve this, the average rainfall for each site was calculated using an averaging period equal to the age of the road. Thus, if a road is three years old, the average rainfall over the last three years was used in the calculation rather than the 5-year average. Unfortunately this did not improve the model. Because the effect of rainfall is weak, the trend line is not very firmly based and the trend is being strongly influenced by other factors. Nevertheless, the relationship derived from the regression analysis is in the expected direction (more rainfall, poorer performance) but the effect is very small. Rain patterns, and rain intensity in particular, can be very localised and therefore rain gauges at the individual road sites may be the only way to identify the differential effect of different rainfall.

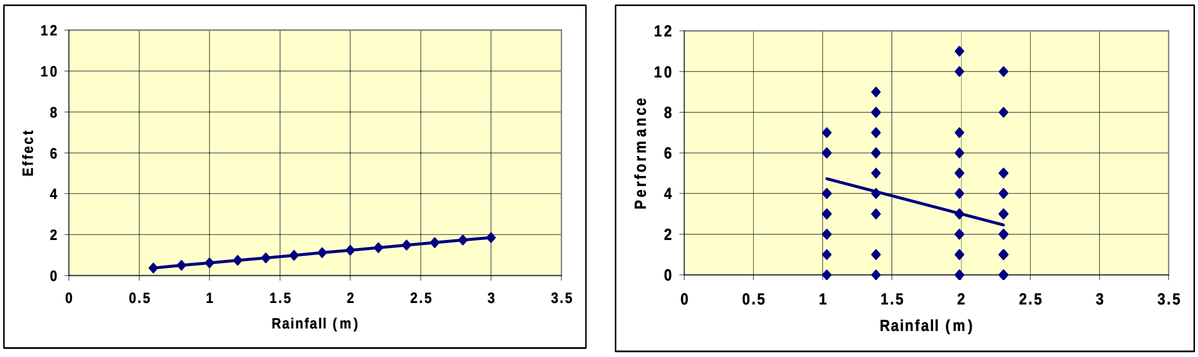

Figure 6.9 The effect of Rainfall on performance

The overall performance model has an R^2 of 0.65 and is probably as good as one could expect at this stage.

6.2 Potholes (Models 3, 4 and 5)

Potholes have been measured in terms of ‘extent’ and ‘size’. As expected, the two correlate closely with each other as shown in Figure 6.10 and a combination ‘size + extent’ was used in the analysis.

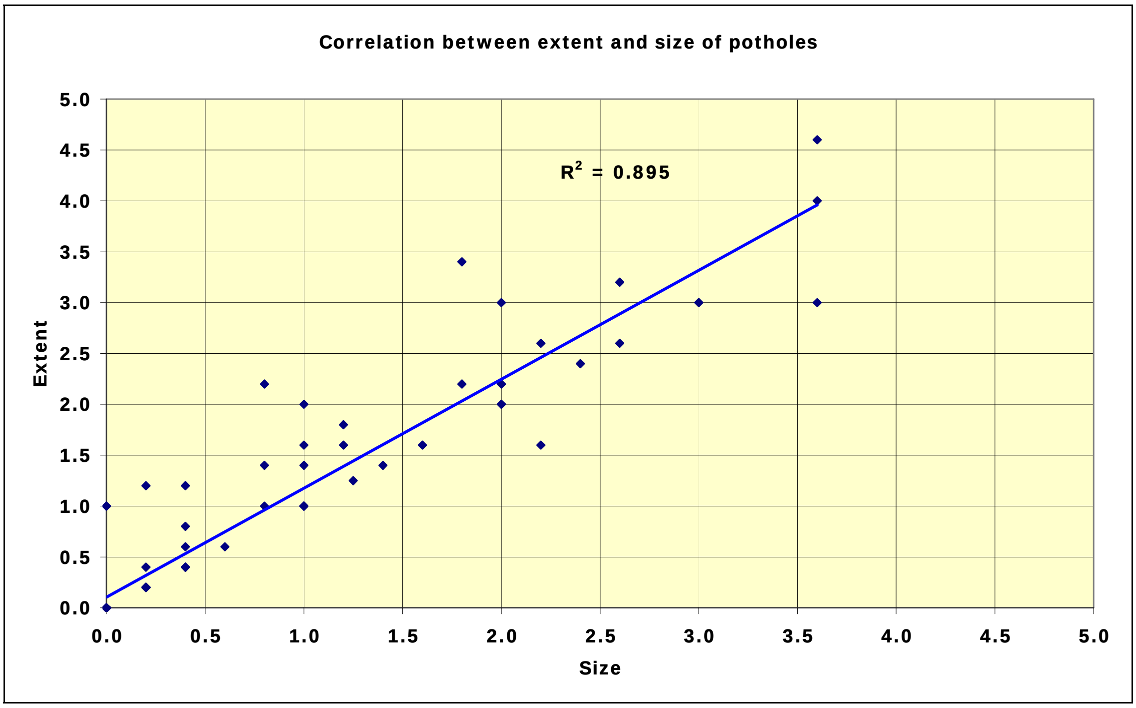

Figure 6.10 Relationship between the extent of potholes and their size

The best model is illustrated in Figure 6.11 but the bias is quite large. The model ‘over’ predicts the lower values of deterioration and ‘under’ predicts the higher values. The key variables are similar to those for the overall performance models (Models 1 and 2) and quadratic terms were required for most of them. The variables are Age, Run-off coefficient, Grading Coefficient, Plasticity Product, Gradient, Rainfall and Crown Height.

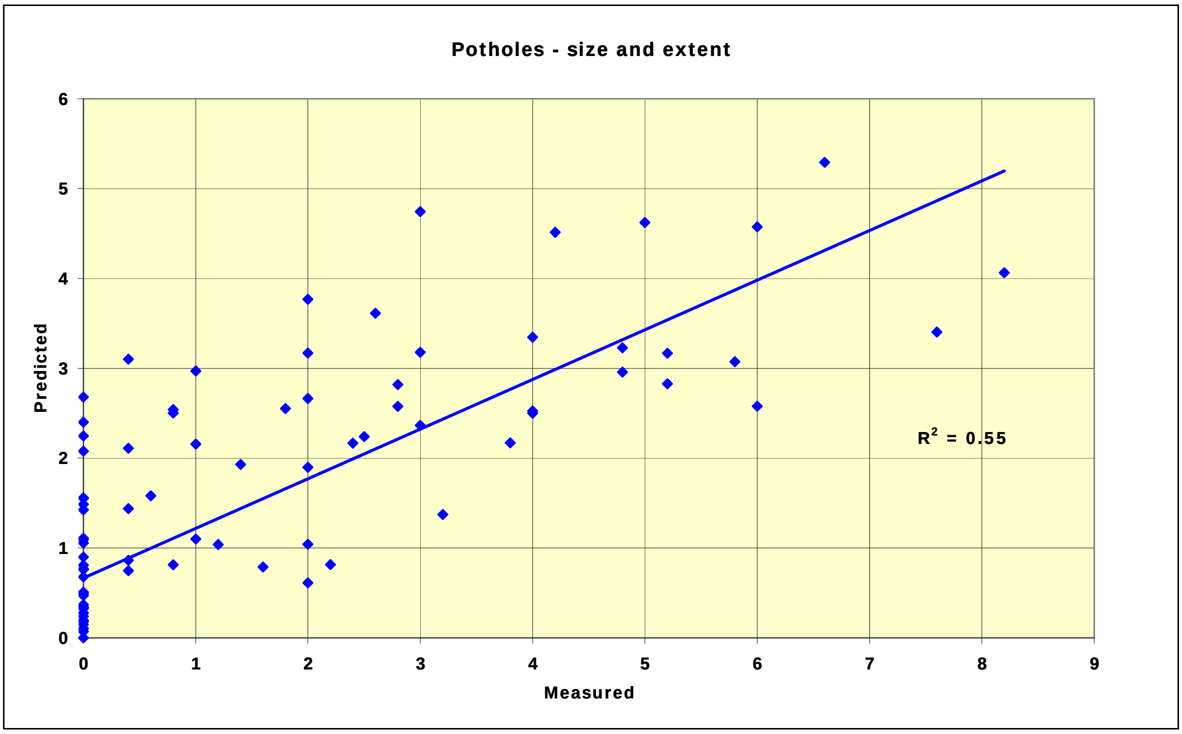

Figure 6.11 Potholes – size plus extent (Model 4)

Grading coefficient (Figure 6.12)

Grading Coefficient is a strong variable and the best road performance is obtained when it lies in the range 25 to about 45. This is similar to but not identical with the results obtained in the drier environment of southern Africa (Figure 5.1).

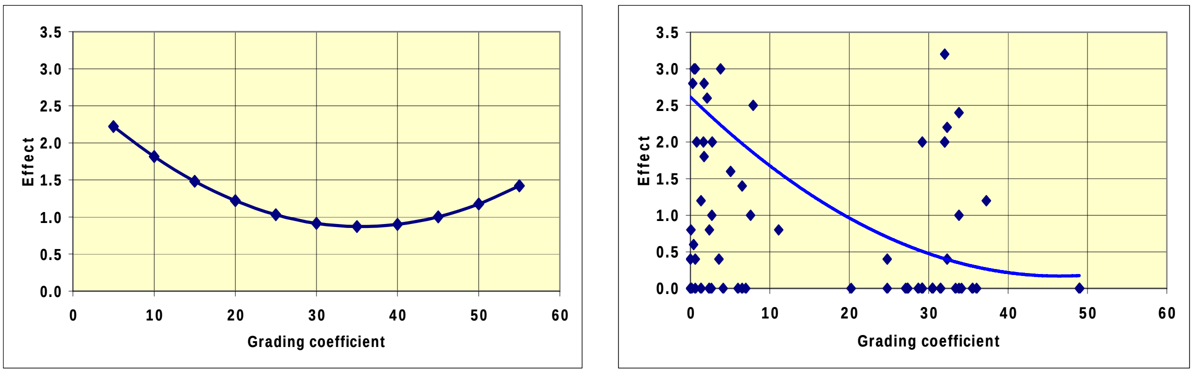

Figure 6.12 The effect of Grading Coefficient on pothole formation

Plasticity Product (PP) (Figure 6.13)

There is some slight indication that best performance occurs at low and high values but the effect at low values is small and probably not significant. It is expected that poor performance will occur if the

PP values are low and therefore there is probably a plateau between 0 and 10 where performance is relatively poor but indistinguishable across this range with improvements in performance occurring as PP increases above this.

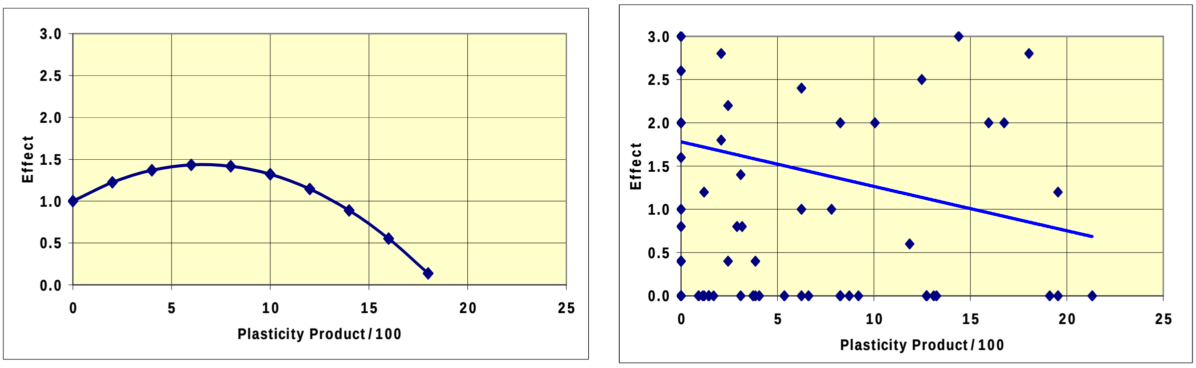

Figure 6.13 The effect of Plasticity Product on pothole formation

Age (Figure 6.14)

Age was another strong variable. Unfortunately, as described earlier, Age is highly correlated with other time-dependant variables such as 'cumulative traffic', 'cumulative rainfall', 'length of time that a road is inundated with water' and so on. It is difficult to separate these time dependant effects in a 'slice-in-time' analysis; only long-term monitoring is likely to be successful and, even then, it is difficult. The model indicates that the effect is slightly less than the trend line might suggest.

An alternative model (Model 5) included a cumulative traffic term (Age x Traffic Type) instead of Age alone. The model had an identical R^2 value (0.552) and was very similar in all respects to Model 4. Using the term Age x Traffic Volume gave a poorer relationship indicating that the overall volume of all traffic is not as significant as that of the larger vehicles.

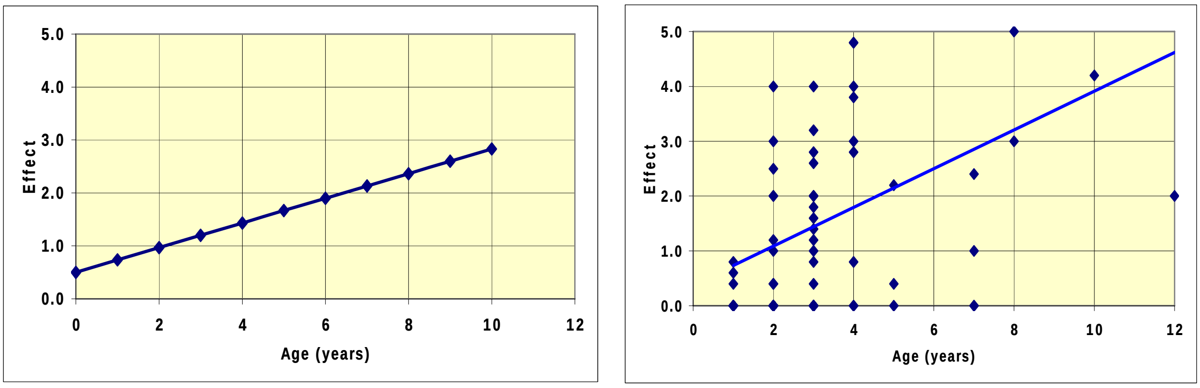

Figure 6.14 The effect of Age on pothole formation

Gradient (Figure 6.15)

The effect of Gradient on pothole deterioration is very similar to its effect on overall performance. The effect is non-linear and two-valued. Performance is slightly worse in flat terrain and improves slightly as gradient increases before getting rapidly worse at steep gradients. The trend line shows a slightly larger effect than the model and the optimum gradient appears to be higher. There is no doubt that in the absence of good camber and good run-off characteristics some longitudinal gradient ought to be beneficial because it will ensure that surface water runs off somewhere. Too much gradient, however, will encourage erosion. The model indicates an optimum at about 7%, but too much should not be written into this for the reasons stated in Section 6.1.2.

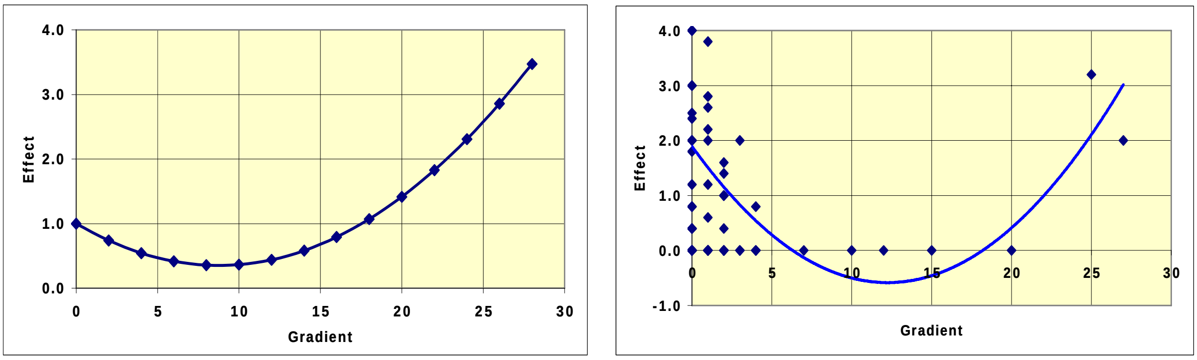

Figure 6.15 The effect of Gradient on pothole formation

Run off coefficient (Figure 6.16)

The Run-off coefficient again proved to be a strong variable. Its effect covers a range of about 2 on the performance axis. It was the only variable concerned with drainage that seemed to have sufficient effect for inclusion in a model.

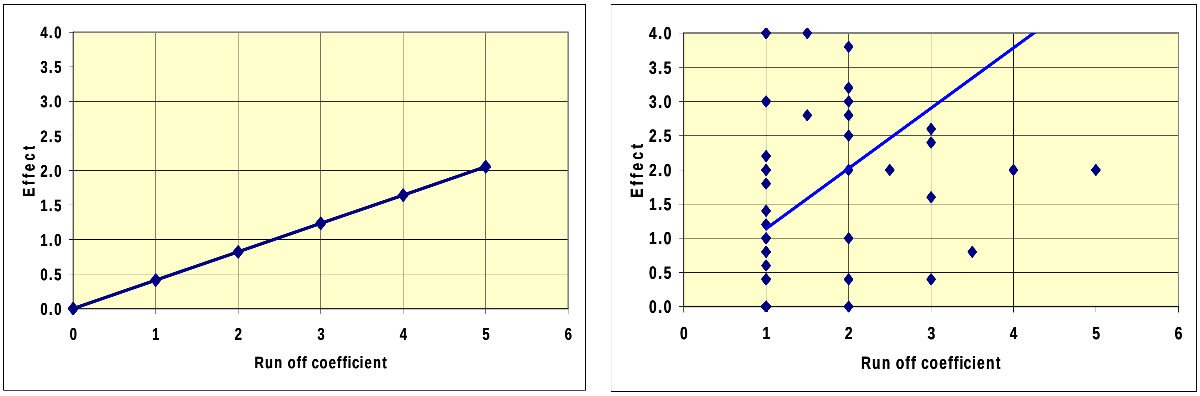

Figure 6.16 The effect of Run-off coefficient on pothole formation

Rainfall (Figure 6.17)

The effect of rainfall has been difficult to determine because the performance of roads in high rainfall areas has been as good as, if not better than, roads in drier areas. Thus rainfall appears to improve performance. There are several reasons for this as discussed in Section 5.3. The a relatively high correlation of 0.69 between rainfall and Grading Coefficient (see the correlation matrix in Appendix D) may be a consequence of the coincidence of better graded material being available in high rainfall areas and hence the two effects cannot be separated. Repeating the regression analysis without rainfall as an independent variable gives Model 3 which has an R^2 of 0.51 compared with 0.55 when rainfall is included.

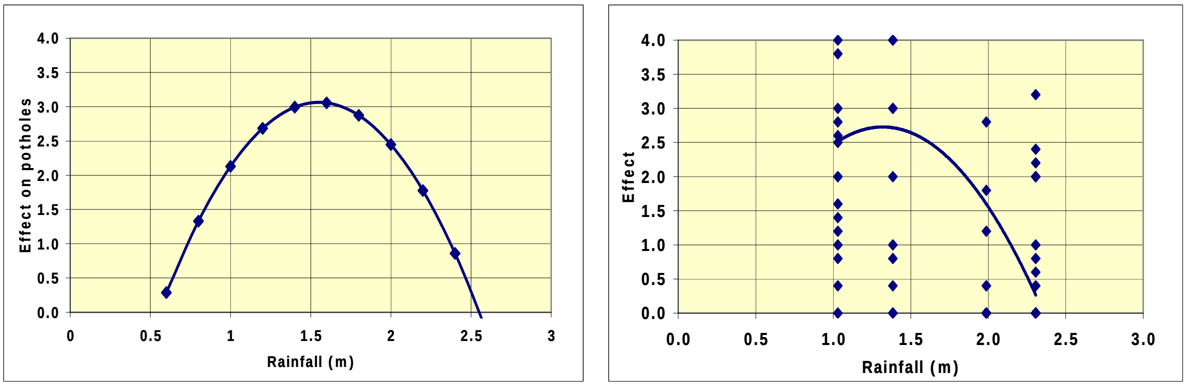

Figure 6.17 The effect of Rainfall on pothole formation

Crown height (Figure 6.18)

The regression analysis showed that Crown Height has a strong effect on pothole development although the correlation plot shows a weaker relationship.

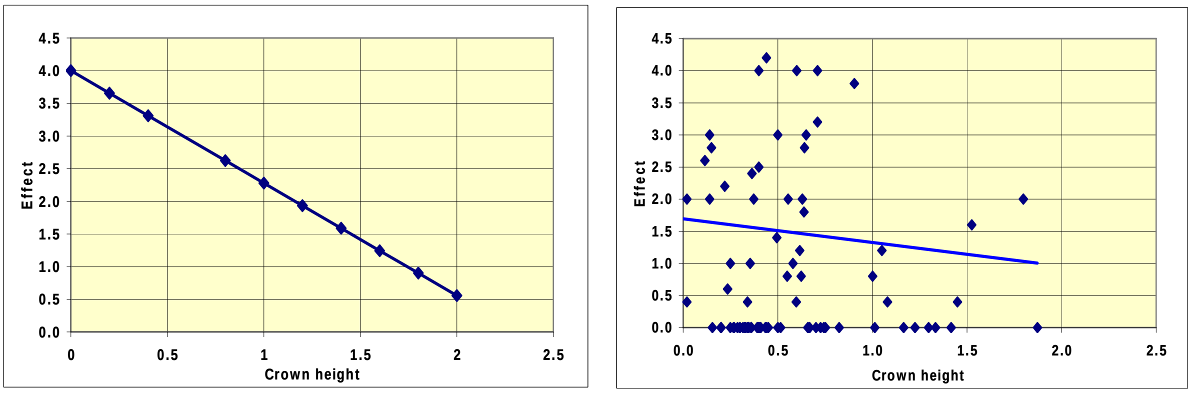

Figure 6.18 The effect of Crown Height on pothole formation

6.3 Rut Depth (Model 6)

The best model for Rut Depth is shown in Figure 6.19. In this case the actual rut depths in millimetres have been used instead of a performance classification into broad classes.

The key variables are similar to those in other models and the relationships between Rut Depth and the independent variables are also similar. They are shown in Figure 6.21.

The model is heavily influenced by the high value of rut depth observed on just one site. This site has an extremely high gradient and some of the deterioration measured as rut depth was also a result of severe channel erosion. This data point is therefore unusual and, together with the lack of additional data with high values of rut depth, renders the model relatively unreliable statistically compared with the models for overall performance and for potholes where the data covered the full range more uniformly.

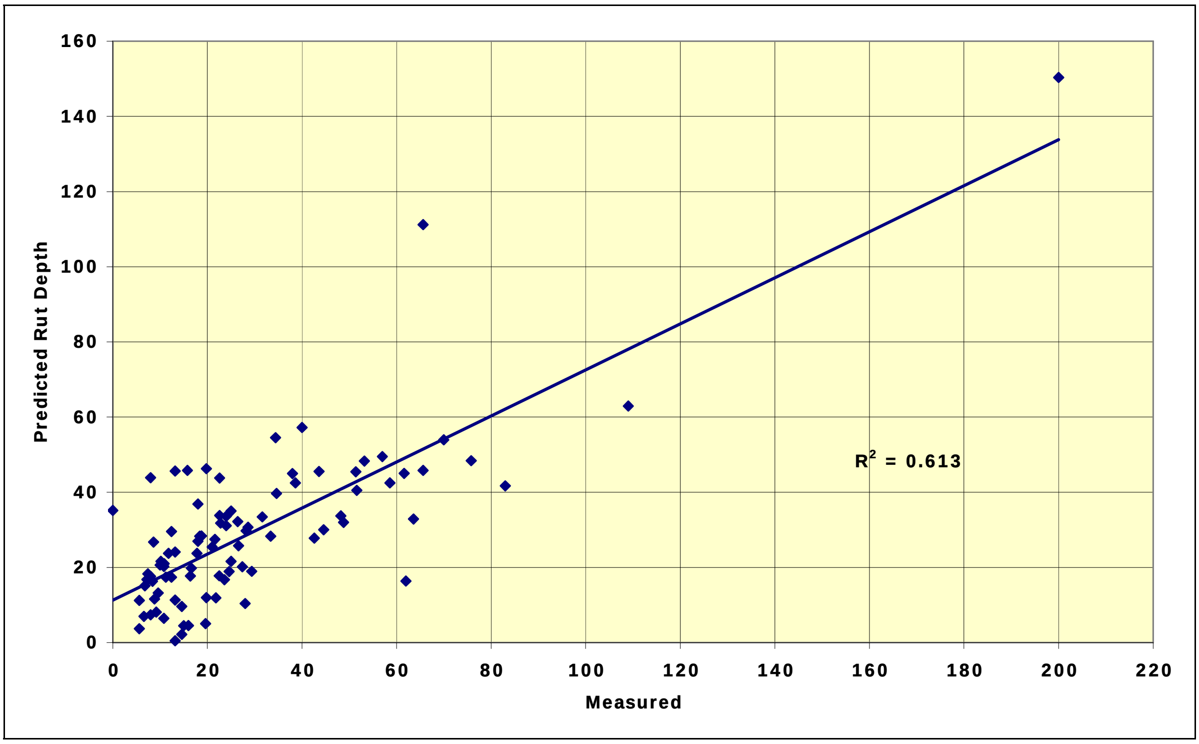

Figure 6.19 Rut depth model (Model 6)

As with the model for pothole deterioration, a cumulative traffic variable, Age x Traffic Type, was included instead of Age alone because such a variable has regularly been used successfully in other studies to describe the development of ruts. The result is Model 7 (Table 6.2) where it can be seen that no significant improvement over Model 6 was achieved.

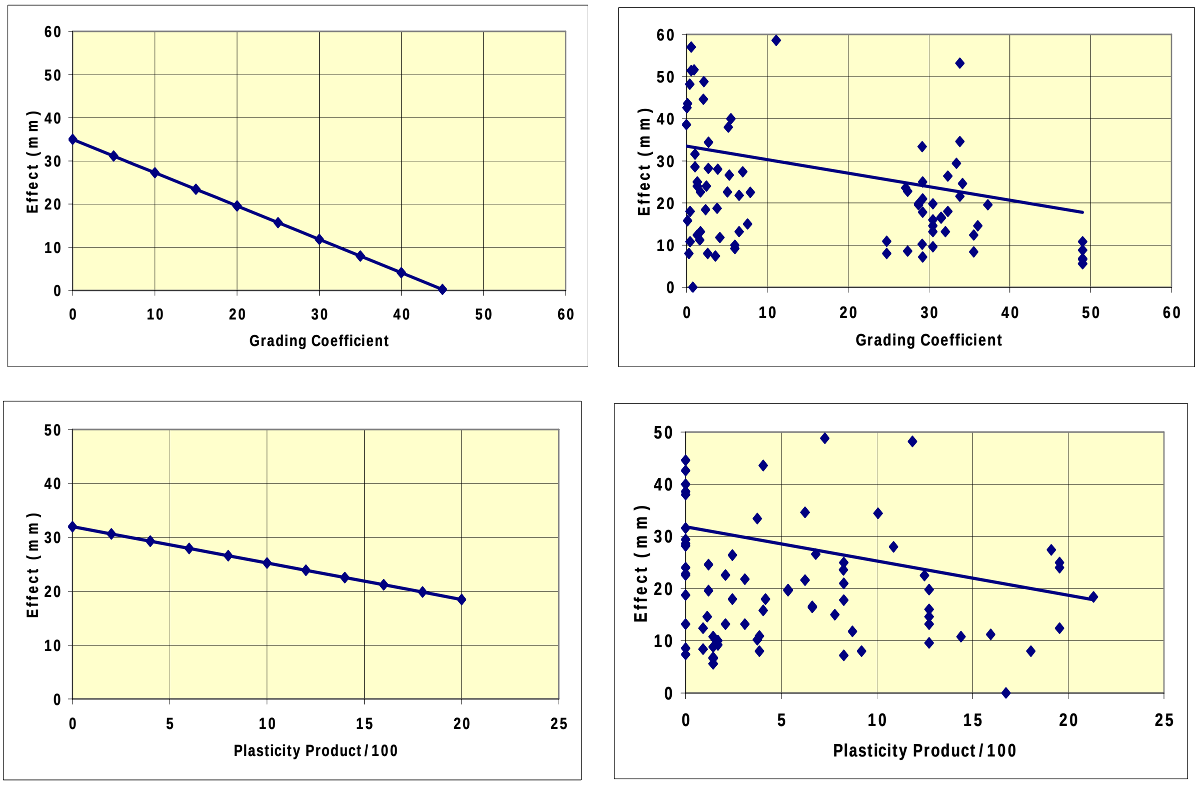

Figure 6.20 Relationships between Rut Depth and the independent variables

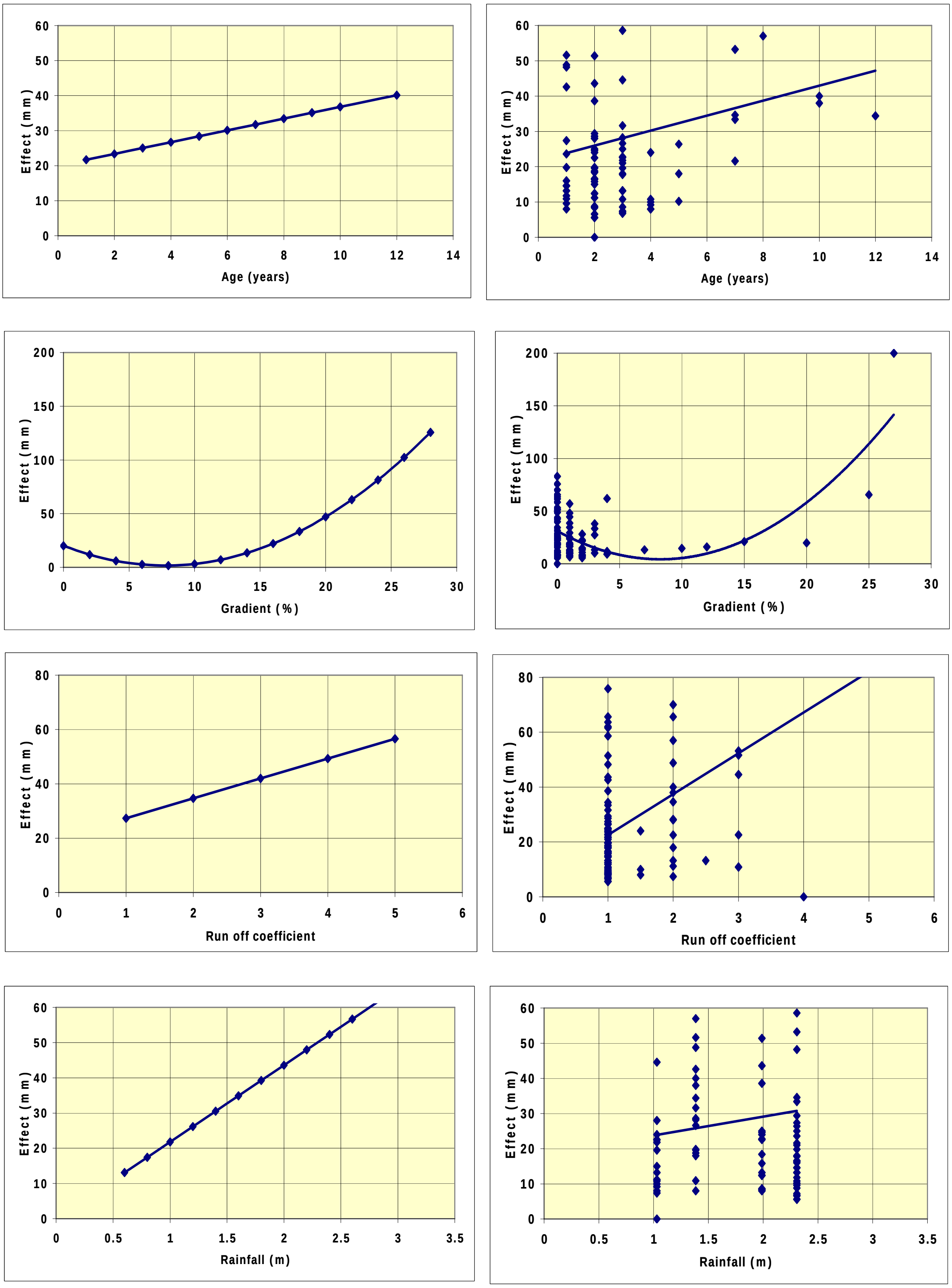

Figure 6.21 Relationships between Rut Depth and the independent variables (continued)

6.4 Erosion and Corrugations

No successful models have been developed for erosion or for corrugations.

6.5 Variables that did not affect performance

The variables that have affected performance have been identified and reasonable models have been developed to predict the performance of an ENS road. However, a number of variables that were expected to influence behaviour do not appear to do so. The principal variables in this category are as follows;

(1) Terrain

(2) Traffic volume

(3) Traffic type

(4) Strength (as measured in situ by DCP) of the pavement materials

(5) Strength (as measured in standard laboratory tests) of the pavement materials

(6) The drainage factors of Crown Height, Ditch Condition, Camber

Terrain. The probable reason for this is that the study has concentrated on the behaviour of short stretches of road, whereas terrain as defined is a broader assessment of the landshape in which the road is situated. Terrain specifically affects average gradients but gradient has been included separately as an independent variable in the analysis. It has been found to be significant and therefore terrain is also significant in this context.

Traffic volume and type. Traffic is generally light and, despite its volume, it does little damage to the road in dry conditions. Damage occurs when the roads are wet but no *differential* behaviour based on traffic volume could be identified. This could be because the range of traffic flows that occurred *when the roads were wet and weak* was too narrow so all the roads were essentially carrying similar traffic. Traffic itself is clearly important and its cumulative effect is captured in the Age term which is extremely significant in all the models. However, the Age term reflects the damage created by *all* time dependant factors and therefore includes the cumulative effect of rainfall as well.

Strength of the materials and strength of the overall pavement. The in situ strength of the roads was measured with a DCP at a particular time of the year. None of the pavements were sufficiently weak at the time they were measured to suffer damage from the traffic that was normally using the road, hence the measures of in situ strength were not significant.

7 THE SECOND SURVEY

A second survey of 66 of the test sections was carried out after the rainy season in March and April of 2008 . The data were treated in the same way as for the first survey and a comparison was made between the results of the two surveys (Figure 7.1 - note that there are multiple points at the same coordinates). It is to be expected that the sites would have deteriorated and therefore most of the data points should lie above the line of equality.

Examination of the data reveals that 22 of the 66 test sections show no change and 31 show some deterioration. Of these, 16 show a change of one unit, 8 show a change of 2 units and 7 show changes of 3 or more units. However, 13 test sections appeared to show improvement. Of these, 7 show a difference of one unit and 6 show a difference of two. The accuracy of the measurements is considered to be ±1 hence these results are as expected.

Model No. 2 was used to predict the overall performance of the 66 test sections for the second survey. The results are shown in Figure 7.2. Not surprisingly, the 'fit' is similar to that of the first survey (Figure 6.3). A longer period of time between repeat surveys is required to refine the modelling.

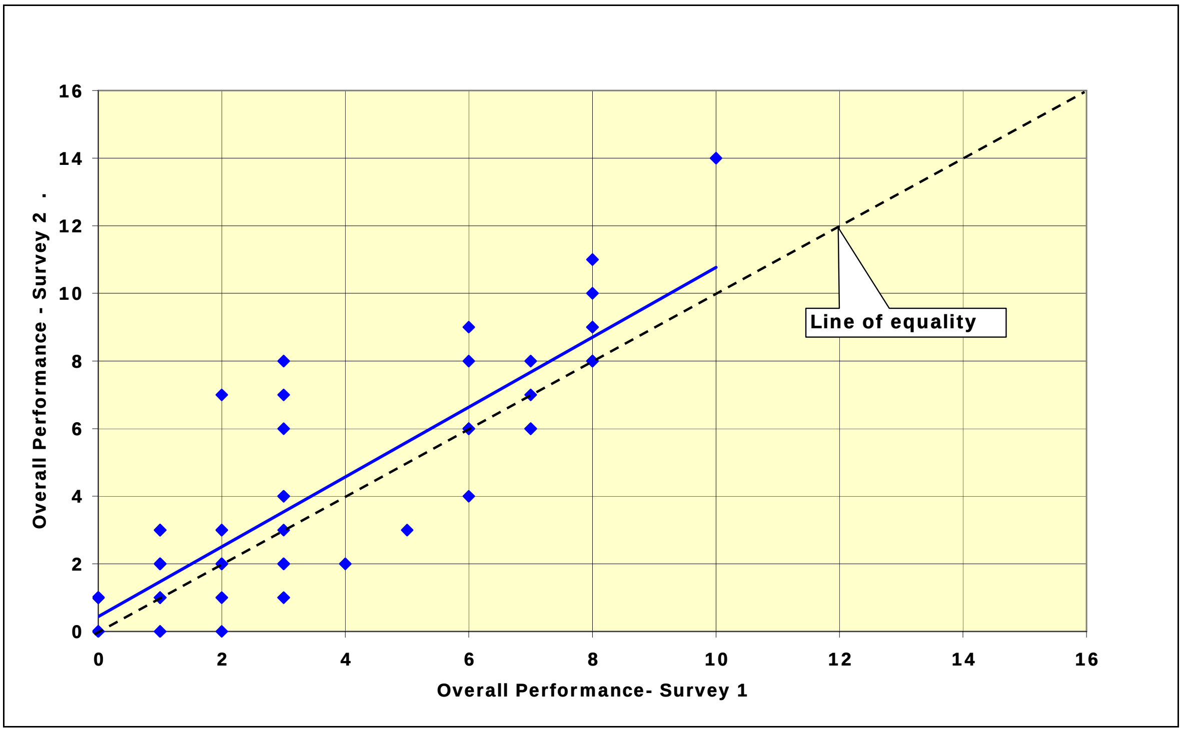

Figure 7.1 Comparison of overall performance between survey 1 and survey 2

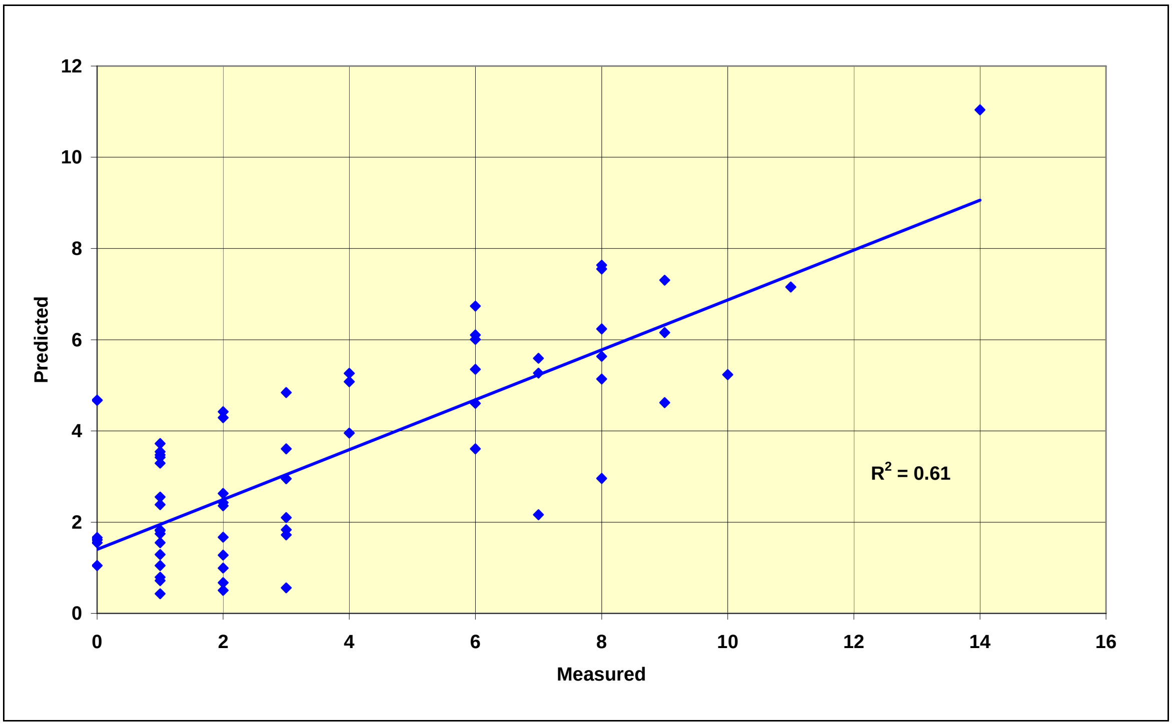

Figure 7.2 Model No. 2 (overall performance) applied to the second survey

8 CONCLUSIONS

8.1 Performance of ENS roads

The study has illustrated the complexity of performance of ENS roads and highlighted the reasons why deriving generally agreed specifications has proved elusive and confirmed the need for locally derived flexible specifications that are relevant to the local materials and the road tasks. Nevertheless the results have been encouraging and have indicated that, with longer term monitoring, the outstanding questions could be resolved.

Despite the size of the survey, there are many materials and conditions that could not be included and it is important to remember that the results of any experimental study are only valid within the range of the variables. For example, all the surfacing materials in the study were finer than 26.5mm maximum particle size. The range of all the variables is summarised in Chapter 3.

Although the effect of some of the factors (and their interactions) that affect performance could not be quantified in the performance models, much of the ‘unexplained’ deterioration was quantified in the ‘age’ term in the models. This term captures all the time dependant deterioration that always occurs and which is usually ascribed to a cumulative traffic variable (e.g. cumulative commercial vehicles or cumulative equivalent standard axles), but it is equally likely to depend also on cumulative rainfall, number of cycles of inundation, or any other time dependant effects or combinations thereof.

Since traffic itself did not prove to be a strong determinant of performance (although age did), the results are only valid where traffic has similar characteristics to those observed in the study. In particular, heavy trucks were largely absent and most motorised vehicles would have had relatively low tyre pressures. This has important implications for design; the designer must be confident that heavy traffic will not use his road, or effective methods must be devised to guard against it.

The study adequately quantified the deterioration of the roads in terms of physical damage such as potholes, erosion and rut depth and therefore limiting values of these could be set for design purposes and suitable specifications developed. However the study was not able to quantify lack of accessibility caused by slipperiness, flooding or any other reason that was not measurable by the survey staff during the survey itself. In other words *quantitive* information that had to be obtained by interviewing local residents or engineers tended to be unreliable (e.g. ‘how many days per year is your road impassable?’). Although not ideal, any specifications designed to cope with these problems must be adapted or copied from specifications derived elsewhere.

The study did not address the issue of dustiness and the problems that this causes to local people. In general all soils that contain sufficient fine material will cause dust and this problem gets worse very quickly as vehicle speeds increase and as materials dry out.

Although drainage factors were not as dominant as expected it was concluded that the main reason for this was that they tend to form a critical path comprising, camber, longitudinal slope, ease of run-off, crown height and good side drains. Any one of these could be sufficiently deficient to cause drainage problems and in that case the others would not appear to be significant in a statistical analysis. The study contained examples of each of these individually being the likely cause of problems. However the most significant was the run-off factor. Admittedly this is subjective and was almost certainly influenced by other factors, but it is something that can be corrected relatively inexpensively by local, regular maintenance and, if necessary, spot improvements.

8.2 Implications for specifications for LVRR

The models allow the predicted behaviour of an ENS to be calculated provided that the conditions are similar to the conditions covered in the survey. By defining limiting criteria it is possible to determine the properties of an ENS road that would provide satisfactory performance. For example, a reasonable criterion is that a road should remain in a satisfactory condition for 7 years. If we define a satisfactory condition as one in which the overall performance factor is less than 5 (see Section 6.1.1), the criteria for satisfactory performance are as shown in Table 8.1.

This Table presupposes that there is sufficient maintenance to ensure that the run-off of water remains unimpeded. Under the current maintenance regime for rural roads in Cambodia this is unrealistic and therefore a more relevant assumption is that run-off will be impeded for some of the time, as it was on the roads in this study. In this case Table 8.2 shows more conservative criteria that should ensure satisfactory performance.

Table 8.1 Minimum Grading Coefficient when maintenance is adequate

Gradient %	Low rainfall 1000mm/yr	Medium rainfall 2000mm/year	High rainfall 3000mm/year
0 - 4	10	15	20
4 - 6	15	20	25
6 - 8	20	25	30
8 - 10	25	30	35
10+	30	40	NA

Table 8.2 Minimum Grading Coefficient when maintenance is poor

Gradient %	Low rainfall 1000mm/yr	Medium rainfall 2000mm/year	High rainfall 3000mm/year
0 - 4	25	30	40
4 - 6	30	35	45
6 - 8	35	40	NA
8 - 10	40	NA	NA
10+	NA	NA	NA

Current advice on unsealed roads in the S E Asian region (Intech-TRL, 2006, TRL-LTEC,2008) is that unsealed gravel roads become unsustainable in terms of erosion and gravel loss above 6% gradient. Below this gradient the limiting factor is that rainfall must be below 2000mm per year.

The surface material will also benefit from some plasticity. Changing the Plasticity Product over a practical range does not affect the criteria in these Tables because the maximum range of PP is equivalent to a change in Grading Coefficient of less than 5.

The study has not been able to measure performance criteria based on ‘slipperiness’, however, slipperiness is likely to be a problem if the Plasticity Product exceeds about 550.

The strength of the material was not a significant factor in the performance analysis. The range of in situ soil strength values measured in dry conditions during the study is shown in Figure 4.5 and the laboratory values, both soaked and unsoaked (at a density of 95% of Proctor compaction) are shown in Figure 4.6. The discussion in Section 4.7 indicates that despite the weakness of a considerable number of the soils in the wet season, the nature of the traffic has meant that *serious* traffic-related deterioration has not occurred, although time-related deterioration, which is largely traffic related, is a feature of all the models and accounts for about 40% of the deterioration that occurs.

It would therefore be prudent to include a strength criterion in the specifications. The information in Technical Paper No 2.1, '*Behaviour of engineered natural-surfaced roads*', indicates that a minimum soaked CBR of 15% at 95% of Proctor compaction is more than adequate to cater for the types of vehicles using the surveyed roads However, almost all soils with a Grading Coefficient meeting the specifications described above will exhibit a soaked CBR in excess of 15% (in this study 90% of the soils did so) hence although a strength criterion is recommended, it is primarily a safety precaution.

8.3 Recommendations for further research

8.3.1 Selected ongoing monitoring and additional sites

There is significant additional benefit to be gained by continuing to monitor a selected group of about 40-50 of the existing ENS road sections. The selected sections will need to be identified through a filtering process to ensure sample balance and to exclude roads or sections with obvious problems of data interpretation. A further 20-30 sites could be added to this group to improve statistical balance in some categories such as gradient, road curvature and material type

This monitoring should be undertaken on a yearly basis following the rainy season. Data should be entered into the database and the principal statistical models re-run to identify significant changes and improvements.

8.3.2 Specifically Constructed ENS Trial Roads

Consideration should also be given to construct specific ENS trials to address questions that cannot be answered simply by monitoring the performance of existing roads. The current research has acknowledged that lack of information on construction procedure and maintenance history is a drawback in isolating key performance criteria.

Using the results of the SEACAP 19 programme, a limited matrix of test sections could be designed which focused on key issues or areas where there was a perceived lack of good data. For example, results from a number of test sections on a single road built on differing gradients to the same design could be of significant practical value.

8.3.3 Amendments to Data Collection and Management

The project has identified a number of improvements that could be made to the data collection and data management procedures, as follows;

Data Collection:

1. Rationalisation of the performance indicator scales (see Section 6.1)
2. Removal of non-relevant indicators – eg loose material, corrugations
3. Rationalisation of passability assessments (see Section 5.2)
4. Review of drainage indicators and, in particular, the assessment of run-off

Data Management

1. Amendments to the database file structure to more easily accommodate multiple surveys on the same road section
2. Introduction of a hierarchical database access system
3. Increased links to in situ and laboratory test data sheets

4. Improvements to data reporting options
5. Inclusion of cross-checks into the data input procedure (Input Masks)
6. Improve GIS links to increase dissemination options

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The fieldwork was undertaken by Thai Kheang, Heng Kackada and Ross Sobunn from KACE and the database design was directed by Mao Hat (KACE), ably supported by the TRL Specialist Trevor Bradbury.

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Appendix A Field survey form

PART 1 INFORMATION ABOUT THE ROAD AND SELECTION OF SECTIONS

Province		
District		
Commune		
Road Name		
Road Reference Number	Project ref. a.	MWPT/MRD ref. b.
Start Point Easting and Northing	E	N
End Point Easting and Northing	E	N
Road From	*Commune/road junction*	
Road To		

Road Designation *Tick appropriate box*

1	Tertiary	
2	Sub-tertiary 1	
3	Sub-tertiary 2	
4	Sub tertiary 3	
5	Village/field	

Road type *Tick appropriate box*

1	Gravel surface	
2	Weathered rock surface	
3	Engineered earth surface	
4	Earth track	

Terrain

Choose category

1	Flat coast, delta		4	High hills	
2	Flat inland - padi		5	Inter mountain plain	
3	Rolling small hills		6	Mountaineous	

Traffic

Traffic type

1	Local two wheel only (+ trailer)		*Tick appropriate box*
2	Mixed 2-wheel & light 4-wheel (<4t)		
3	Light 4-wheel (<4t), occ heavier		
4	Mixed light & heavy		
5	Heavy dominates		

Motorised Traffic Volume

1	< 20 4-wheeled vehicles per day		*Tick appropriate box*
2	21- 50 4-wheeled vehicles per day		
3	51-150 4-wheeled vehicles per day		
4	> 151 4-wheeled vehicles per day		

Reported Access

1	All year no difficulty		*Tick appropriate box*
2	All year with occasional difficulty		
3	All year 4-wheel drive only		
4	Limited access in wet season		
5	Severe access limitations		

Days closed	General number of days per year that the road is impassable to the Standard Vehicle (2-wheel drive pick up)	

Access Problems

Tick box

1	River/stream crossing		4	Weak/slippery road	
2	Flooding		5	Landslide	
3	Road collapse/eroded		6	None	

Rainfall	Annual rainfall from nearest recording station	

General Condition of road link as perceived from drive over survey

Tick box

1	No visible defects	
2	Isolated minor defects	
3	Isolated significant defects	
4	Recurring defects along road	
5	Extensive significant defects along the whole road	

Construction History	Dates of construction/upgrading		

Maintenance

Tick two boxes

Routine		
1	Regular	
2	Occasional	
3	Not done	

Periodic		
1	Regular	
2	Occasional	
3	Not done	

Survey Sections

List by chainage

	From	To
1		
2		
3		
4		
5		
6		

Comments	Operator	
	Date	

PART 2 DATA FROM SURVEY SECTIONS

Road Ref No.		Survey Site No		From		To	
Unique road reference				*GPS*		*GPS*	

Geometry

Width	Looking up chainage	Shoulder		=		metres
		Carriageway		=		metres
		Shoulder		=		metres
Longitudinal gradient along road				=		%
Curvature – horizontal curvature See Fig 1				=		#
Cross fall	With spirit level, straight edge, tape	Left		=		%
		Right		=		%
Cross section	Shape of the ground either side of road Fig 2			=		#

Visual Condition (this is estimated for each 10-metre block

Chainage	0 - 10	10 – 20	20 – 30	30 – 40	40 - 50
Block No.	1	2	3	4	5

Appearance					

Code

1	Good – only minor deterioration
2	10 – 25 % of surface deterioration
3	25 – 50% of surface deterioration
4	50 – 75% of surface deterioration
5	> 75% of surface deterioration

Choose category for each block

Loose material					

Code

To measure depth of loose sand, for example

1	None
2	< 15 mm
3	15 – 50 mm
4	> 50mm

Choose category for each block

Corrugations					
Code	**Depth of corrugations.** ***Do not confuse with unevenness or erosion***				

1	**None/negligible**
2	**< 15 mm**
3	**15 – 50 mm**
4	**> 50mm**

Choose code/ category for each block

Carriage way erosion					
Codes	***Visual assessment of erosion on the carriageway***				

Choose code/ category for each block

1	**None**
2	**Rills < 15 mm deep**
3	**Rills 15 – 50 mm deep**
4	**Rills > 50 mm deep**
5	**Rills interconnecting/complete disintegration**

Shoulder erosion					
Codes	***Visual assessment of erosion on the shoulder***				

Choose code/ category for each block

1	**None**
2	**Rills < 15 mm deep**
3	**Rills 15 – 50 mm deep**
4	**Rills > 50 mm deep**
5	**Rills interconnecting/complete disintegration**

Ruts					
Maximum depth of rut in the section measured with straight edge and tape. A rut must be reasonably continuous unlike an extended pot hole					

Crown height - metres	**Left side**					
	Right side					
Height of road centre above bottom of side drain or bottom of embankment. Measured with spirit level, very long straight edge and tape						

Potholes and depressions	**Size =**					
	Extent					

Code

Choose code/category for each block for 'Size' and 'Extent'

Size	
0	None
1	Just visible
2	Small depressions < 25 mm deep
3	Large depressions 25-100 mm deep
4	Large depressions 100-200mm deep
5	Very large > 200 mm deep

Extent	
0	None
1	< 10% of section
2	10-25% of section
3	25-50% of section
4	50-75% of section
5	> 75 %

Shape of carriageway					

Code **See Figure 3**

Choose code/category for each block

1	As built
2	Slight deterioration. Camber remaining
3	Flat
4	Uneven
5	Dished – bowl shaped

Drainage

Side drain	**Left side**	=	**Right side**	=

Codes **Side drain codes**

Choose code/ category for each side of road

0	No side drain
1	Good shape and level, clean
2	Adequate shape & level – minor silting only
3	Defects/silting evident but can function
4	Significant defects/silting – drainage impaired
5	Serious scouring/defects – no longer effective

Water table

Estimated depth of water that affects the pavement below the crown height of road. Negative values for flood height	**WT – minimum =**		**metres**
	WT – maximum =		**metres**

Run off	**Left side**	**=**	**Right side**	**=**
Codes *Choose code/ category for each side of road*	**Run off codes**			

1	**Unimpeded**
2	**Impeded by road shape**
3	**Impeded by shoulders**
4	**Impeded by shoulders & road shape**

Repairs	**Carriageway**	**=**	**Shoulder**	**=**	**Embankment**	**=**
Codes *Choose code/ category for each element*						

1	**Infill/repair with local soil**
2	**Infill/repair with stone**
3	**Infill/repair with waste brick**
4	**Repair with wood/vegetation**
5	**Vegetation planting**
6	**None visible**

Material	**Type =**	
Description	*Colour/grain size/*	

Choose code/ category for the surfacing

1	Laterite gravel		**6**	Gravel & clay	
2	‘Hill’ gravel		**7**	Weathered rock	
3	Alluvial gravel		**8**	Silty clay	
4	Sandy clay		**9**	Silty sand	
5	Sand		**10**	Clay	

Passability

Passability	Existing condition	=	Risk	=	Problems	=
Risk = likely future worst case (wet season) passability – use same codes as below						

Codes

Passability for standard 2-wheel drive pick up vehicle

Choose code/ category for existing condition and future risk

1	All vehicles passing with no difficulty
2	Vehicles have to slow down to pass site
3	Vehicles passing with considerable difficulty
4	Vehicles only passing with assistance
5	No vehicles passing

Factors likely to cause passability problems

Choose code/ category for likely cause of passability problems

1	High overall roughness
2	Deep ruts
3	Severe corrugations
4	Potholes
5	Slipperiness – loss of traction
6	Standing water

DCP Ref					
Samples					
Photo Refs					

Weather = code	
1	*No rain in last month*
2	*Significant rain in last week*
3	*Rain in last 24 hrs*
4	*Significant rain now*

Operator	Date of survey

SKETCH SHEET

Road Ref No.		Survey Site No.		From		To	

Cross Section (s)

Condition Sketch						
Scale	Drn (L)	Sh (L)	Carriageway Left	Carriageway Right	Sh (R)	Drn (R)

Engineer	Date

FIGURES

Figure 1

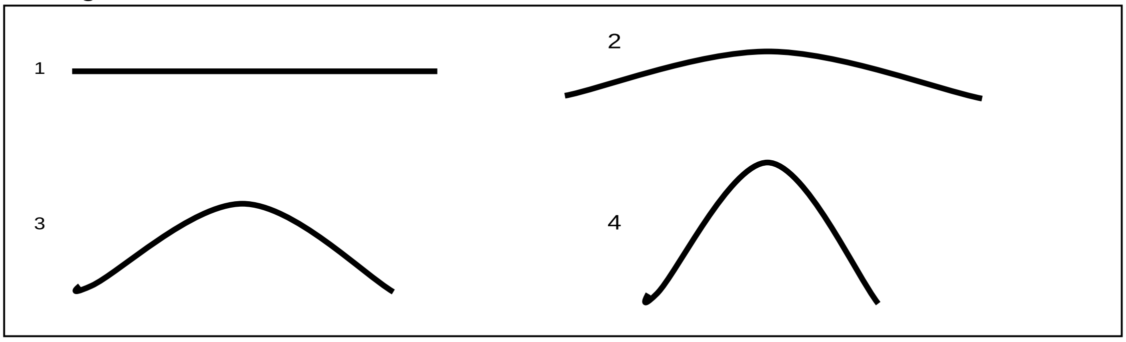


Figure 2

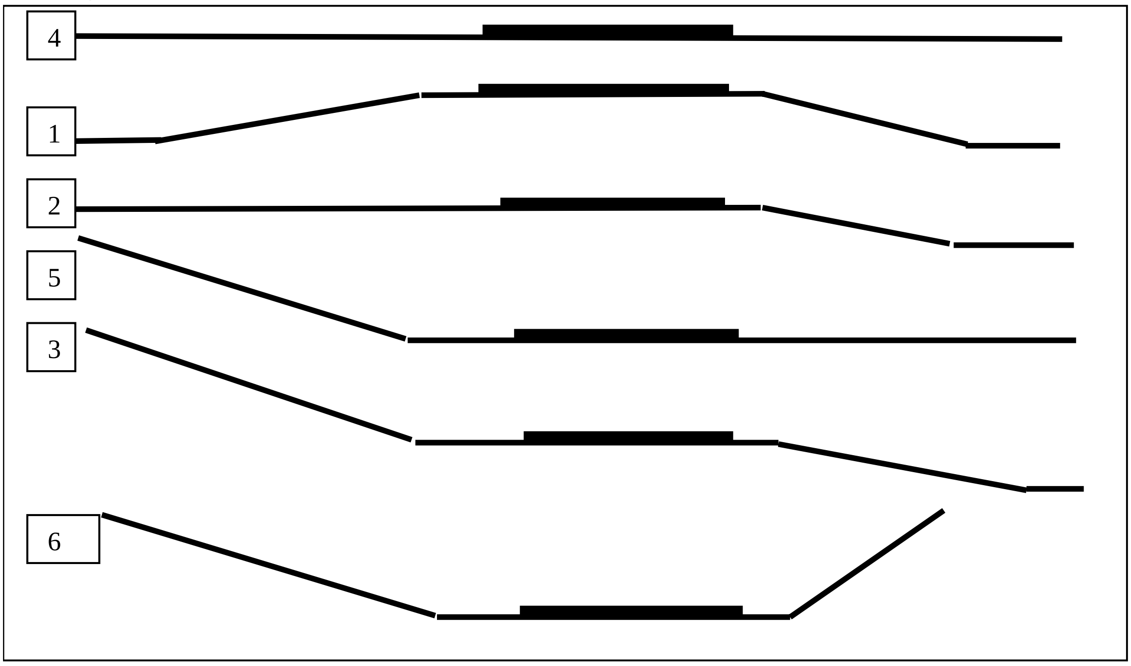
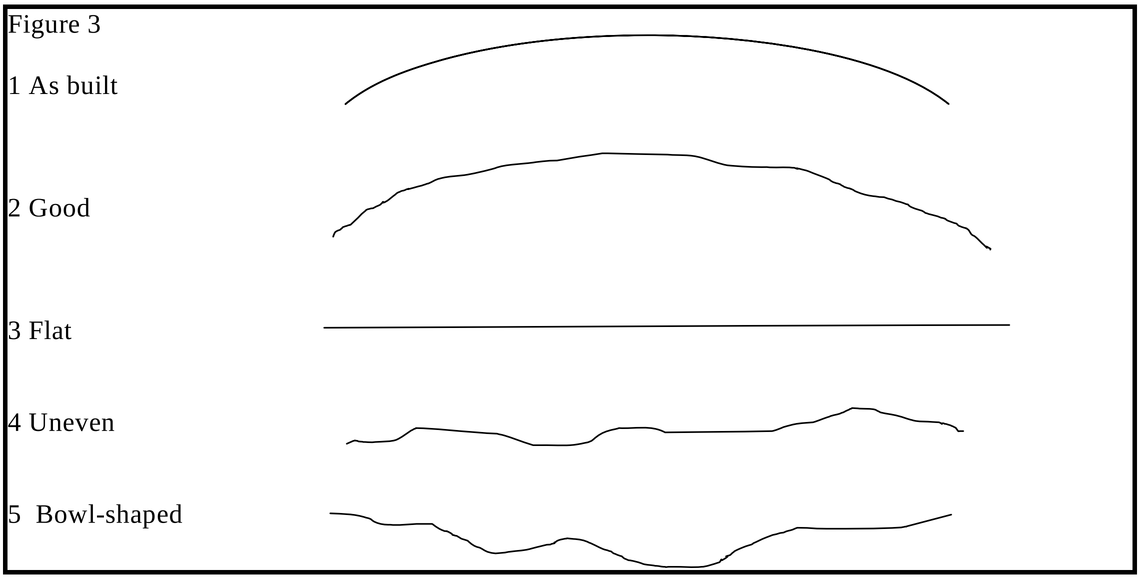


Figure 3



Appendix B Summary of data

Number of Site	Province	Site Reference	Terrain	Traffic type	Traffic volume	Reported access	Access problem (road)	Rainfall	General condition of road	Construction year	Age in years	Maintenance (routine)	Longitudinal Gradient %	Horizontal curvature	Crossfall (average) %	X-section	Appearance (Average)	Loose material (average)	Corrugations (average)	Carriageway erosion (average)	Shoulder erosion (average)	Pothole size (average)	Pothole extent (average)	Ruts (average) mm	Crown height left (m)	Crown height right (m)	Shape of carriage way	Drain function (average)	Run-off (average)	Carriageway repairs	Shoulder repairs	Material	Passability (existing condition)	Passability Risk	Passability problem	Average H2O content (%) at DC	Average H2O content/optimum	DCP 0mm (average) %	DCP 100mm (average) %	DCP 300mm (average) %	DCP 500mm (average) %
1	Kampot	70100101	2	2	1	2	4	1988	4	2004	4	3	0	2	1.5	1	2.2	2.2	2.4	2.2	1.0	2.2	2.6	83	0.48	0.37	4	1.5	1	6	6	8	3	4	5	6.3	0.7	39	12	8	7
2	Kampot	70100102	2	2	1	2	4	1988	4	2004	4	3	0	1	3.75	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	8	0.79	0.69	2	1	1	6	6	8	2	1	5	5.5	0.6	13	12	7	7
3	Kampot	70100201	2	4	2	1	6	1988	2	2006	2	2	0	1	2.75	1	1.0	1.4	1.0	1.0	1.0	0.0	0.0	25	0.43	1.08	2	0	1	1	6	1	1	1	4			73	72	38	33
4	Kampot	70200101	2	1	1	2	4	1988	2	2006	2	3	0	2	8	1	1.6	1.4	2.0	2.0	1.2	0.0	0.0	44	0.59	2.00	4	0.5	1	6	6	4	3	3	5	6.4	0.7	52	28	9	4
5	Kampot	70200102	2	1	1	2	4	1988	2	2006	2	3	0	1	7.5	1	1.4	1.0	1.8	1.6	1.0	0.0	0.0	16	0.67	2.00	3	1	1	6	6	4	3	3	5	4.6	0.5	49	27	16	12
6	Kampot	70200201	2	3	1	1	6	1988	1	2005	3	2	0	3	3.5	1	1.0	2.0	1.0	1.0	1.2	0.0	0.0	23	1.37	1.47	2	0	1	1	1	1	1	1	2	4.4	0.7	83	77	46	41
7	Kampot	70200202	2	3	1	1	6	1988	1	2005	3	2	2	1	4.75	1	1.0	1.2	1.0	1.0	1.0	0.0	0.0	9	1.83	1.91	2	3	1	1	1	1	1	1	2	3.1	0.5	65	55	15	103
8	Kampot	70200301	2	2	1	4	4	1988	1	2006	2	2	1	1	6	1	1.4	1.0	1.6	1.6	1.6	0.0	0.0	12	0.71	0.63	2	0	1	6	6	8	1	4	5	10.0	0.8	21	14	6	3
9	Kampot	70200302	2	2	1	4	4	1988	1	2006	2	2	0	1	7.5	1	2.0	1.6	1.0	2.2	3.0	0.0	0.0	25	0.93	0.72	2	0	1	6	6	10	1	3	5	11.0	0.9	25	12	3	3
10	Kampot	70200401	2	2	1	4	4	1988	2	2006	2	3	0	1	7.5	1	2.0	1.2	1.0	1.4	2.0	0.4	0.8	24	0.52	0.71	2	0	1	6	6	10	1	3	5	8.8	0.7	21	10	6	4
11	Kampot	70200501	2	2	1	1	6	1988	1	2005	3	3	1	1	4	2	1.0	2.0	1.4	1.8	1.6	1.2	1.6	13	1.20	0.08	3	0	2	6	6	9	1	2	4	3.1	0.3	51	32	17	75
12	Kampot	70200502	2	2	1	1	6	1988	1	2005	3	3	0	1	4	1	2.4	2.6	1.8	3.0	3.4	0.8	1.0	23	0.70	0.58	3	0	1	6	6	4	1	4	5	7.1	0.8	35	13	9	13
13	Kampot	70200601	2	2	1	2	4	1988	2	2006	2	3	1	1	4	1	1.6	1.0	2.0	1.4	1.2	0.0	0.0	18	0.78	0.63	3	0	1	6	6	10	1	2	5	14.2	0.7	33	21	19	13
14	Kampot	70200602	2	2	1	2	4	1988	2	2006	2	3	0	1	5	1	2.0	1.6	2.0	1.4	2.6	0.0	0.0	64	0.83	0.63	4	0	1	6	6	10	1	3	5	13.0	0.7	38	21	8	4
15	Kampot	70300101	2	2	1	1	6	1988	2	2006	2	2	0	1	4.5	1	2.6	3.0	2.4	2.2	1.6	0.0	0.0	62	0.88	1.14	4	0	1	1	6	4	1	1	2	4.3	0.7	0	0	0	0
16	Kampot	70300102	2	2	1	1	6	1988	2	2006	2	2	0	3	7.5	1	2.2	2.6	1.4	1.8	2.4	0.2	0.2	51	0.86	1.30	4	0	1	6	6	4	1	1	2,5	2.2	0.4	0	0	0	0
17	Kampot	70700101	2	2	2	1	6	1988	4	2004	4	3	0	1	4.25	1	2.8	2.6	2.6	2.0	1.0	3.6	4.0	66	0.42	0.36	4	2.5	1	6	6	9	2	3	4	16.9	2.5	33	40	25	13
18	Kampot	70700201	2	3	2	2	4	1988	2	2006	2	3	1	1	8	1	1.8	3.6	1.6	1.8	2.6	0.0	0.0	39	1.06	1.39	2	0	1	6	6	4	1	3	5	8.2	1.2	37	26	12	5
19	Kampot	70700202	2	3	2	2	4	1988	2	2006	2	3	0	1	8	1	3.0	1.4	2.4	2.0	2.8	0.2	0.2	76	1.83	1.07	3	0	1	6	6	4	3	2	2,5	3.8	0.5	125	36	17	9
20	Kampot	70700301	2	2	3	1	6	1988	1	2006	2	3	0	3	4.75	1	1.2	1.2	1.0	1.0	1.2	0.0	0.0	12	0.69	0.63	2	0	1	6	6	1	1	1	4	2.9	0.4	72	40	13	8
21	Kampot	70700302	2	2	3	1	6	1988	1	2006	2	3	0	1	4	2	1.0	1.0	1.0	1.0	1.0	0.0	0.0	8	0.80	0.20	2	0	1	6	6	1	1	1	4	3.0	0.4	56	40	18	8
22	Kandal	80100101	2	3	2	2	6	1030	2	2006	2	3	2	2	6.5	2	1.0	1.0	1.0	1.0	3.0	0.0	1.0	15	0.00	0.50	1	0	1	6	6	4	1	1	1	5.5	0.5	19	18	27	34
23	Kandal	80100102	2	3	2	2	6	1030	2	2006	2	3	2	1	4	4	2.4	3.2	1.6	1.0	1.0	1.8	3.4	28	0.00	0.00	4	0	2	6	6	4	2	4	2,4,5,6	8.7	0.6	35	23	68	18
24	Kandal	80100201	2	2	1	2	4	1030	2	2005	3	3	1	1	5.5	4	1.2	2.8	1.2	2.0	1.4	1.0	1.6	45	0.00	0.23	4	0	3	6	6	9	1	3	2,4,5	5.7	0.6	73	45	56	32
25	Kandal	80100202	2	2	1	2	4	1030	2	2005	3	3	2	2	5.5	4	1.0	2.0	2.0	1.2	1.0	0.2	0.2	7	0.02	0.02	2	0	2	6	6	9	1	3	5			81	68	63	
26	Kandal	80100203	2	2	1	2	4	1030	2	2005	3	3	2	1	3.5	1	1.4	2.0	1.6	1.2	1.2	0.4	1.2	23	1.55	1.50	1	0.5	3	6	6	9	1	1	4						
27	Kandal	80300101	2	2	1	2	6	1030	2	2006	2	3	1	1	5	1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	11	0.36	0.75	1	0	2	6	6	10	1	3	5	13.6	0.8	22	19	11	4
28	Kandal	80300201	2	3	1	2	6	1030	2	2004	4	3	1	1	5	4	1.0	1.0	1.0	1.0	1.4	1.4	1.4	8	0.14	0.16	1	0	1.5	6	6	10	1	3	5	10.3	0.7	23	23	23	30
29	Kandal	80300301	2	2	1	2	4	1030	2	2004	4	3	0	1	4.5	4	1.0	1.0	1.0	1.0	1.6	0.8	2.2	11	0.14	0.14	2	0	1	6	6	10	1	3	4,5	7.1	0.5	21	26	18	67
30	Kandal	80300401	2	2	1	1	6	1030	2	2004	4	3	0	1	7	4	2.0	2.0	1.0	2.6	1.0	2.0	2.0	24	0.36	0.84	2	0	1.5	6	6	9	1	2	1	3.5	0.5	39	33	19	150
31	Kandal	80800101	2	4	1	4	4	1030	3	2004	4	3	4	1	4.75	4	1.0	2.0	2.0	1.4	1.2	0.0	0.0	9	0.20	0.20	3	0	1	6	6	9	3	3	5	2.8	0.4	52	27	26	16
32	Kandal	80800102	2	4	1	4	4	1030	3	2004	4	3	1	1	4.5	2	2.6	2.2	2.2	2.8	2.0	2.4	2.4	10	0.16	0.20	4	2	1.5	6	6	9	3	3	5	3.3	0.5	83	63	20	53
33	Kandal	80800201	2	2	1	2	4	1030	2	2005	3	2	1	2	4.5	1	1.6	2.0	1.0	1.6	1.0	0.6	0.6	20	1.10	1.00	2	0	1	6	6	6	1	1	5						
34	Kandal	80800202	2	2	1	2	4	1030	2	2005	3	2	2	3	5.5	1	1.0	2.0	1.2	1.4	1.4	0.0	0.0	13	0.50	0.32	2	2.5	1	1	6	4	3	3	5	6.1	0.8	72	29	21	51
35	Kandal	80800203	2	2	1	2	4	1030	2	2005	3	2	2	1	8	1	1.8	2.0	1.4	2.2	2.2	0.2	1.2	22	0.50	0.49	2	0	1	1	6	4	3	3	5	4.4	0.5	41	24	33	28
38	Kandal	81000101	1	1	2	2	4	1030	3	2006	2	3	0	1	0	1	3.0	1.0	1.0	1.0	2.0	1.0	1.0		0.70	0.56	4	0	4	6	6	4	1	3	5			28	17	4	2
39	Kandal	81000102	1	1	2	2	4	1030	3	2006	2	3	0	1	0	2	4.0	2.3	1.0	1.0	2.5	1.3	1.3	23	0.40	0.40	4	0	2	6	6	4	2	4	2,5	15.2	1.2	17	13	13	13
40	Rotanak Kiri	160200101	4	2	1	4	3	2307	2	2005	3	3	2	1	1.5	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	7	0.26	0.14	3	3.5	1	6	6	1	1	1	3	14.9	0.6	49	47	28	10
41	Rotanak Kiri	160200102	4	2	1	4	3	2307	2	2005	3	3	0	1	1	4	1.0	2.0	1.0	1.0	1.0	1.0	1.0	18	0.02	0.02	3	2	1	6	6	1	1	1	3	16.5	0.7	37	38	21	11
42	Rotanak Kiri	160200103	4	2	1	4	3	2307	2	2005	3	3	1	1	0	1	1.2	1.0	1.0	1.2	1.0	0.0	0.0	25	0.23	0.46	3	1	1	6	6	1	1	1	3	5.2	0.2	52	43	32	17
43	Rotanak Kiri	160200104	4	2	1	4	3	2307	2	2005	3	3	15	2	0	2	1.2	2.0	1.0	1.0	1.0	0.0	0.0	21	0.45	0.45	3	3	1	6	6	1	1	2	5	16.0	0.7	38	38	21	13
44	Rotanak Kiri	160200105	4	2	1	4	3	2307	2	2005	3	3	3	1	0	4	1.2	2.0	1.0	1.0	1.2	1.0	1.0	13	0.03	0.25	3	2.5	2.5	6	6	1	1	3	5	14.5	0.6	42	47	28	16

Number of site	Province	Site reference	Terrain	Traffic type	Traffic volume	Reported access	Access problem (road)	Rainfall	General condition of road	Construction year	Age (years)	Maintenance (routine)	Longitudinal gradient %	Horizontal curvature	Crossfall (average) %	X-section	Appearance (average)	Loose material (average)	Corrugations (average)	Carriageway erosion (average)	Shoulder erosion (average)	Pothole size (average)	Pothole extent (average)	Ruts (average) mm	Crown height left (m)	Crown height right (m)	Shape of carriage way	Drain function (average)	Run-off (average)	Carriageway repairs	Shoulder repairs	Material	Passability (existing condition)	Passability Risk	Passability problem	Average H2O content (%) at DCP	Average H2O content/optimum	DCP 0mm (average) %	DCP 100mm (average) %	DCP 300mm (average) %	DCP 500mm (average) %
45	Rotanak Kiri	160200106	4	2	1	4	3	2307	2	2005	3	3	27	1	0	1	4.4	3.8	1.0	4.0	4.6	1.0	1.0	200	0.32	0.42	4	5	5	6	6	1	2	3	1,2,5	20.8	0.9	32	30	20	14
46	Rotanak Kiri	160200107	4	2	1	4	3	2307	2	2005	3	3	25	1	5	1	2.2	2.2	1.0	3.0	3.0	1.6	1.6	66	0.96	0.46	4	0	2	6	6	1	2	3	1,2,5	16.0	0.7	51	48	34	20
47	Rotanak Kiri	160300101	4	2	1	1	6	2307	1	2007	1	3	1	1	3.5	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	10	0.40	0.41	1	2	1	6	6	1	1	1	3	18.9	1.1	56	51	29	28
48	Rotanak Kiri	160300102	4	2	1	1	6	2307	1	2007	1	3	12	1	2.5	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	16	0.14	0.40	1	1.5	1	6	6	1	1	1	3	18.8	1.1	34	38	28	22
49	Rotanak Kiri	160300103	4	2	1	1	6	2307	1	2007	1	3	2	1	4.5	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	15	0.39	0.48	1	2	1	6	6	1	1	1	3	16.3	0.9	40	54	26	21
50	Rotanak Kiri	160300104	4	2	1	1	6	2307	1	2007	1	3	7	1	3.5	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	13	0.45	0.58	1	2	1	6	6	1	1	1	3	14.5	0.8	39	53	24	17
51	Rotanak Kiri	160300105	4	2	1	1	6	2307	1	2007	1	3	20	1	4.5	1	1.0	3.0	1.0	1.0	1.0	0.0	0.0	20	0.32	0.36	2	2	1	6	6	1	1	1	1,5	16.3	0.9	22	30	13	8
52	Rotanak Kiri	160300201	5	2	1	1	6	2307	1	2007	1	3	1	1	3.5	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	24	0.30	0.30	3	2	1	6	6	1	1	1	1	15.9	1.0	30	37	45	20
54	Rotanak Kiri	160500101	2	2	1	1	2	2307	1	2006	2	3	1	1	0	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	7	0.27	0.30	3	1	1	6	6	1	1	5	6	6.2	0.6	81	70	55	25
55	Rotanak Kiri	160500102	2	2	1	1	2	2307	1	2006	2	3	2	1	2.5	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	6	0.33	0.39	2	1	1	6	6	1	1	5	6	8.8	0.9	62	40	10	11
56	Rotanak Kiri	160500103	2	2	1	1	2	2307	1	2006	2	3	0	1	3	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	9	0.31	0.32	2	0	1	6	6	1	1	5	6	4.9	0.5	66	65	41	15
57	Rotanak Kiri	160500104	2	2	1	1	2	2307	1	2006	2	3	0	3	3.5	4	1.0	2.0	1.0	1.0	1.0	0.0	0.0	6	0.25	0.28	2	0	1	6	6	1	1	5	6	5.8	0.6	53	42	24	11
58	Rotanak Kiri	160500201	2	2	1	4	2	2307	1	2005	3	3	0	2	3	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	7	0.38	0.40	2	0	1	6	6	1	1	5	6	4.8	0.5	93	77	43	22
59	Rotanak Kiri	160500202	2	2	1	4	2	2307	1	2005	3	3	2	1	3	1	1.0	2.0	1.0	1.0	1.6	0.0	0.0	11	0.29	0.36	2	1	1	6	6	1	1	5	6	14.9	1.6	86	80	36	26
60	Rotanak Kiri	160500301	3	2	1	1	4	2307	1	2007	1	3	4	1	4	1	1.0	1.0	1.0	1.6	1.0	0.0	0.0	12	0.32	0.40	1	0	1	6	6	1	1	2	5	19.6	0.7	49	38	23	16
61	Rotanak Kiri	160500302	3	2	1	1	4	2307	1	2007	1	3	10	1	0	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	15	0.40	0.40	1	0	1	6	6	1	1	2	5	12.2	0.6	51	47	20	15
62	Rotanak Kiri	160500303	3	2	1	1	4	2307	1	2007	1	3	3	1	3.5	1	1.2	2.0	1.0	1.0	1.0	0.0	0.0	27	0.40	0.39	2	0	1	6	6	1	1	1	1	5.6	0.5	31	33	14	7
63	Rotanak Kiri	160500401	3	1	1	4	2	2307	3	2005	3	3	0	1	0	1	2.4	2.0	1.0	1.0	1.4	0.4	0.4	59	0.50	0.60	4	0	1	1	6	8	1	1	2,5	8.5	1.0	66	33	11	6
64	Rotanak Kiri	160500402	3	1	1	4	2	2307	3	2005	3	3	4	1	4.5	1	2.2	2.0	1.0	1.0	1.0	0.0	0.0	62	0.37	0.32	4	1	1	6	6	1	1	2	6	8.8	0.8	110	57	19	25
65	Rotanak Kiri	160700101	5	2	1	1	6	2307	2	2006	2	3	1	1	5.5	1	2.0	2.0	1.0	1.0	1.0	0.0	0.0	29	0.36	0.30	4	0	1	6	6	2	1	1	2	10.1	0.5	78	91	37	17
66	Rotanak Kiri	160700201	5	2	1	1	6	2307	1	2003	5	3	3	1	1.5	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	10	0.20	0.20	3	1.5	1	6	6	2	1	1	1	9.3	0.4	58	49	21	15
67	Rotanka Kiri	160700301	5	2	1	1	6	2307	1	2001	7	2	3	1	2	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	33	0.30	0.30	3	0	1	6	6	1	1	1	1	9.2	0.4	52	45	29	15
68	Rotanak Kiri	160900101	5	2	2	1	6	2307	3	2001	7	2	0	1	2.5	1	2.2	2.0	1.0	1.0	1.0	1.0	1.4	53	0.31	0.42	4	0	3	6	6	1	1	2	6	3.9	0.3	160	158	56	29
69	Rotanak Kiri	160900102	5	2	2	1	6	2307	3	2001	7	2	2	1	0	1	2.0	2.0	1.0	1.0	1.0	0.4	0.6	22	0.30	0.41	3	0	1	1	6	1	1	1	2	5.3	0.4	62	60	43	16
70	Rotanak Kiri	160900103	5	2	2	1	6	2307	3	2001	7	2	1	1	2	1	1.4	2.0	1.0	1.0	1.0	0.0	0.0	35	1.08	0.26	3	0	2	1	1	1	1	2	5	9.4	0.7	25	39	23	12
71	Rotanak Kiri	160900201	5	2	1	4	4	2307	2	2007	1	3	1	1	5	1	1.2	2.2	1.0	1.0	1.0	0.2	0.4	48	0.29	0.18	3	0	1	6	6	8	1	3	5	6.5	0.5	39	43	24	15
72	Rotanak Kiri	160900301	5	2	1	1	6	2307	2	2003	5	3	1	1	0	1	1.4	1.8	1.0	1.0	1.0	0.8	1.4	18	0.20	0.24	3	0	1	6	6	1	1	1	2	5.7	0.7	50	49	21	8
73	Rotanak Kiri	160900302	5	2	1	1	6	2307	2	2003	5	3	0	1	0	1	1.4	1.0	1.0	1.0	1.0	0.2	0.2	26	0.34	0.34	4	0	1	6	6	3	1	1	2	3.8	0.4	102	79	38	17
74	Rotanak Kiri	160900401	5	2	1	1	6	2307	1	2006	2	3	1	1	1.5	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	16	0.31	0.41	1	0	1	6	6	1	1	1	3	6.8	0.7	57	69	31	25
75	Rotanak Kiri	160900402	5	2	1	1	6	2307	1	2006	2	3	1	1	2	1	1.0	2.0	1.0	1.0	1.0	0.0	0.0	17	0.58	0.74	3	0	1	6	6	1	1	1	2	6.5	0.7	74	67	33	21
76	Siem Reap	170200101	2	3	1	2	6	1385	1	2000	8	3	1	1	0	1	2.4	2.4	3.2	1.0	2.2	2.0	3.0	57	0.44	0.54	4	0	2	6	6	4	2	3	4	6.2	1.0	18	14	11	19
77	Siem Reap	170200102	2	3	1	2	6	1385	1	2000	8	3	0	1	0	1	2.6	2.2	1.0	1.0	1.4	1.2	1.8	70	0.54	0.46	4	0	2	6	6	4	2	3	4	6.6	1.1	18	11	21	41
78	Siem Reap	170200201	2	3	1	1	6	1385	3	2005	3	3	2	1	1	1	1.0	1.0	1.0	1.0	1.2	0.0	1.0	28	0.68	0.48	2	1.5	2	6	6	4	1	2	1,2,4	4.0	0.5	20	20	17	7
79	Siem Reap	170200202	2	3	1	1	6	1385	3	2005	3	3	0	1	8.5	1	3.0	2.0	4.0	1.0	2.4	2.0	2.0	27	0.40	0.40	2	0	1	2	6	6	2	4	2,4,5	12.4	1.1	26	9	4	18
80	Siem Reap	170200203	2	3	1	1	6	1385	3	2005	3	3	0	1	5	1	5.0	4.0	1.0	1.0	1.6	3.6	4.6	18	0.45	0.45	4	0	2	6	6	4	3	4	2,4,5	9.7	1.2	30	12	7	30
81	Siem Reap	170400101	2	2	1	4	1	1385	2	2006	2	3	0	1	0	1	2.0	2.0	2.0	1.0	1.0	1.0	2.0	19	0.70	0.60	2	0	1	6	6	4	1	2	4	12.9	1.2	13	6	1	1
82	Siem Reap	170400201	2	2	1	4	4	1385	4	1996	12	3	0	1	0	1	2.6	2.6	1.0	1.6	1.0	3.6	3.0	34	0.76	0.37	4	0	1	6	6	8	2	3	4	2.7	0.3	49	45	24	24
83	Siem Reap	170400202	2	2	1	4	4	1385	4	1996	12	3	0	1	0	1	3.4	3.0	1.0	1.0	2.2	1.0	1.0	109	1.84	1.76	4	0	1	6	6	8	3	3	2	6.2	0.7	45	27	9	5
84	Siem Reap	170700101	2	3	1	2	1	1385	5	2007	1	3	0	1	5	1	2.0	2.6	3.0	1.0	2.4	2.6	3.2	52	0.88	0.60	2	1.5	3	6	6	4	1	1	2,4,6	6.0	0.9	20	9	40	46
85	Siem Reap	170700102	2	3	1	2	1	1385	5	2007	1	3	0	1	4.75	1	2.0	2.0	3.0	1.0	2.2	3.0	3.0	49	1.20	0.76	3	1.5	2	6	6	4	1	2	2,5	7.0	0.9	15	13	4	45
86	Siem Reap	170700301	2	2	2	2	4	1385	4	2005	3	3	0	2	1.5	1	5.0	2.0	1.0	1.0	1.0	2.6	2.6	32	0.69	0.65	4	0	1	6	6	4	2	2	2	5.1	0.7	39	79	43	44
87	Siem Reap	170700401	2	2	3	2	6	1385	2	2006	2	3	0	2	3.15	1	1.0	2.0	1.0	1.0	1.0	1.8	2.2	29	0.81	0.61	3	0	1	6	6	8	1	2	5	4.0	0.5	99	62	16	75
88	Siem Reap	170700501	2	2	2	2	4	1385	2	2007	1	3	0	1	8.15	1	2.0	2.0	1.0	1.0	1.0	0.4	0.4	43	0.44	0.81	2	0	1	6	6	5	1	1	2	4.1	0.5	46	61	18	67
89	Siem Reap	170700601	2	3	3	1	6	1385	2	2006	2	3	0	1	4	1	1.0	1.0	1.0	1.0	1.0	0.0	0.0	20	0.11	0.20	2	0	1	6	6	2	1	1	1						
90	Siem Reap	170700602	2	3	3	1	6	1385	2	2006	2	3	0	1	5.25	1	1.0	1.0	1.0	1.0	1.0	0.0	0.0	20	0.82	1.51	2	0	1	6	6	2	1	1	1						
91	Siem Reap	170700701	2	2	2	1	6	1385	2	2007	1	3	0	1	4.5	1	1.0	1.0	1.0	1.0	1.0	0.0	0.0	8	0.17	0.71	2	1	1	6	6	2	1	2	5						
92	Siem Reap	170700702	2	2	2	1	6	1385	2	2007	1	3	0	3	6	1	1.0	1.0	1.0	1.0	1.0	0.2	0.2	11	0.49	0.70	2	0	3	6	6	2	1	2	5						
93	Siem Reap	171100101	2	3	2	2	1	1385	5	1998	10	3	0	1	6.5	1	3.2	2.2	3.0	1.0	2.0	3.0	3.0	40	0.60	0.60	4	1	2	1	1	4	3	4	2,4,5,6	10.4	1.3	22	19	33	31
94	Siem Reap	171100102	2	3	2	2	1	1385	5	1998	10	3	3	1	0	1	2.0	2.0	2.8	1.0	1.0	2.0	2.2	38	0.40	0.48	4	1	2	1	1	4	2	3	4	9.4	1.2	23	24	17	13

Number of Site	Province	Site Reference	P26.5	P4.75	P2.36	P2.0	P1.0	P0.425	P0.250	P0.125	P075	Liquid limit	Plastic limit	Plasticity Index	Linear Shrinkage	Grading coefficient	Plasticity Product	Shrinkage Product	Soaked CBR @ 95% Proctor	Unsoaked CBR @ 95% Proctor	MDD	OMC	Group symbol
1	Kampot	70100101	100	99.4	97.6	97.4	97.0	96.4	94.8	83.9	73.9	28	16	12	9	2.6	920	844	1	41	1.948	9.2	CL or OL
2	Kampot	70100102	100	99.4	97.6	97.4	97.0	96.4	94.8	83.9	73.9	28	16	12	9	2.6	920	844	1	41	1.948	9.2	CL or OL
3	Kampot	70100201	100	75.2	57.0	54.6	46.1	39.7	37.0	32.8	29.9	17	13	4	2	34.1	120	78	47	67	2.092	8.0	CL or ML
4	Kampot	70200101	100	100.0	99.9	99.9	99.4	97.1	94.0	85.8	79.3	15	10	5	3	0.1	405	245	24	45	2.000	8.6	CL or ML
5	Kampot	70200102	100	100.0	99.9	99.9	99.4	97.1	94.0	85.8	79.3	15	10	5	3	0.1	405	245	24	45	2.000	8.6	CL or ML
6	Kampot	70200201	100	36.4	25.8	24.9	23.2	21.3	18.8	14.1	11.5	0	0	0	0	27.4	0	0	39	67	2.257	6.6	SM
7	Kampot	70200202	100	36.4	25.8	24.9	23.2	21.3	18.8	14.1	11.5	0	0	0	0	27.4	0	0	39	67	2.257	6.6	SM
8	Kampot	70200301	100	99.0	98.7	98.7	98.4	98.2	97.9	92.9	85.6	42	20	23	12	1.3	1954	1219	1	44	1.897	12.2	CL or OL
9	Kampot	70200302	100	99.0	98.7	98.7	98.4	98.2	97.9	92.9	85.6	42	20	23	12	1.3	1954	1219	1	44	1.897	12.2	CL or OL
10	Kampot	70200401	100	99.0	98.7	98.7	98.4	98.2	97.9	92.9	85.6	42	20	23	12	1.3	1954	1219	1	44	1.897	12.2	CL or OL
11	Kampot	70200501	100	98.9	98.4	98.3	97.9	97.6	97.3	74.6	56.2	20	16	4	3	1.7	208	262	7	30	1.968	9.3	MH or OH
12	Kampot	70200502	100	98.9	98.4	98.3	97.9	97.6	97.3	74.6	56.2	20	16	4	3	1.7	208	262	7	30	1.968	9.3	MH or OH
13	Kampot	70200601	100	98.5	97.7	97.6	97.1	96.4	94.4	87.2	83.9	43	18	25	14	2.4	2131	1309	4	-	1.730	19.4	CL-OL
14	Kampot	70200602	100	98.5	97.7	97.6	97.1	96.4	94.4	87.2	83.9	43	18	25	14	2.4	2131	1309	4	-	1.730	19.4	CL-OL
15	Kampot	70300101	100	99.8	99.5	99.4	97.7	73.9	43.3	30.1	26.4	0	0	0	0	0.6	0	0	27	-	1.960	5.7	SM
16	Kampot	70300102	100	99.8	99.5	99.4	97.7	73.9	43.3	30.1	26.4	0	0	0	0	0.6	0	0	27	-	1.960	5.7	SM
17	Kampot	70700101	100	100.0	99.7	99.7	98.3	90.1	79.3	61.0	54.8	15	10	5	4	0.3	268	322	22	-	1.990	6.8	CL-ML
18	Kampot	70700201	100	100.0	100.0	100.0	99.3	88.4	76.5	54.6	46.3	0	0	0	0	0.0	0.0	0	30	-	2.020	7.1	SM
19	Kampot	70700202	100	100.0	100.0	100.0	99.3	88.4	76.5	54.6	46.3	0	0	0	0	0.0	0.0	0	30	-	2.020	7.1	SM
20	Kampot	70700301	100	51.2	33.3	30.6	25.0	21.4	18.8	15.3	14.3	18	11	6	3	35.5	92	61	45	-	2.060	6.9	CL-ML
21	Kampot	70700302	100	51.2	33.3	30.6	25.0	21.4	18.8	15.3	14.3	18	11	6	3	35.5	92	61	45	-	2.060	6.9	CL-ML
22	Kandal	80100101	100	97.0	93.2	92.2	88.4	85.1	82.9	72.9	65.0	30	18	12	9	7.6	780	803	4	24	1.973	10.7	CL
23	Kandal	80100102	100	98.2	96.5	96.1	94.1	91.9	90.3	85.4	81.0	31	17	13	11	3.9	1087	988	6	28	1.885	13.7	CL
24	Kandal	80100201	100	99.8	98.5	97.9	93.9	83.0	65.2	60.3	50.5	0	0	0	0	2.1	0	0	11	72	1.994	9.6	SM
25	Kandal	80100202	100	99.6	97.4	96.4	90.7	77.9	62.7	51.9	43.1	0.0	0.0	0.0	0.0	3.6	0	0	14.1	48.9	2.0	9.7	SM
26	Kandal	80100203	100	99.4	96.4	94.9	87.5	72.8	60.2	43.4	35.6	0	0	0	0	5.1	0	0	17	26	2.036	9.9	SM
27	Kandal	80300101	100	99.5	98.6	98.4	97.4	96.0	95.3	94.5	94.1	45	28	17	12	1.6	1594	1106	4	28	1.765	16.6	ML
28	Kandal	80300201	100	99.9	99.8	99.7	99.2	97.8	95.6	86.2	81.9	44	22	22	11	0.3	1804	1056	31	44	1.835	14.1	CL
29	Kandal	80300301	100	99.9	99.7	99.6	99.1	98.4	97.7	96.5	95.7	32	17	15	11	0.4	1439	1057	7	30	1.923	13.4	CL
30	Kandal	80300401	100	98.3	97.7	97.5	95.9	83.9	65.3	49.5	41.3	0	0	0	0	2.5	0	0	66	37	2.080	7.1	SM
31	Kandal	80800101	100	98.1	95.3	93.9	87.57	77.3	69.1	56.3	47.5	18	15	4	4	6.0	169	278	29	39	2.118	7.3	SC
32	Kandal	80800102	100	98.1	95.3	93.9	87.57	77.3	69.1	56.3	47.5	18	15	4	4	6.0	169	278	29	39	2.118	7.3	SC
33	Kandal	80800201	100	72.1	50.8	48.3	41.4	34.7	30.9	24.6	20.4	21	15	6	4	37.3	120	144	13	9	2.191	6.5	SC-SM
34	Kandal	80800202	100	97.9	95.2	93.4	84.5	72.0	60.4	44.4	38.0	23	14	8	4	6.5	310	294	8	15	2.131	8.0	SC
35	Kandal	80800203	100	97.9	95.2	93.4	84.5	72.0	60.4	44.4	38.0	23	14	8	4	6.5	310	294	8	15	2.131	8.0	SC
38	Kandal	81000101	100	99.6	99.3	99.2	98.8	98.2	97.7	88.5	80.3	37	16	21	11	0.8	1675	1080	-	-	-	-	CL
39	Kandal	81000102	100	94.7	92.1	91.7	90.6	89.5	88.3	75.7	71.4	35	17	17	11	7.9	1249	1005	5	22	1.957	12.3	CL
40	Rotanak Kiri	160200101	100	58.7	51.4	50.3	47.7	44.7	38.3	32.4	31.0	56	29	27	11	29.2	826	478	24	55	1.760	24.4	CH
41	Rotanak Kiri	160200102	100	58.7	51.4	50.3	47.7	44.7	38.3	32.4	31.0	56	29	27	11	29.2	826	478	24	55	1.760	24.4	CH
42	Rotanak Kiri	160200103	100	58.7	51.4	50.3	47.7	44.7	38.3	32.4	31.0	56	29	27	11	29.2	826	478	24	55	1.760	24.4	CH
43	Rotanak Kiri	160200104	100	58.7	51.4	50.3	47.7	44.7	38.3	32.4	31.0	56	29	27	11	29.2	826	478	24	55	1.760	24.4	CH
44	Rotanak Kiri	160200105	100	55.8	44.6	42.6	35.4	27.9	23.5	18.2	15.5	0	0	0	0	32.0	0	0	37	59	1.495	24.3	GM
45	Rotanak Kiri	160200106	100	55.8	44.6	42.6	35.4	27.9	23.5	18.2	15.5	0	0	0	0	32.0	0	0	37	59	1.495	24.3	GM

Number of Site	Province	Site Reference	P26.5	P4.75	P2.36	P2.0	P1.0	P0.425	P0.250	P0.125	P075	Liquid limit	Plastic limit	Plasticity Index	Linear Shrinkage	Grading coefficient	Plasticity Product	Shrinkage Product	Soaked CBR @ 95% Proctor	Unsoaked CBR @ 95% Proctor	MDD	OMC	Group symbol
46	Rotanak Kiri	160200107	100	55.8	44.6	42.6	35.4	27.9	23.5	18.2	15.5	0	0	0	0	32.0	0	0	37	59	1.495	24.3	GM
47	Rotanak Kiri	160300101	100	52.8	43.7	42.3	40.8	39.6	37.2	32.8	31.7	61	20	40	10	30.5	1273	396	36	48	2.000	17.5	CH
48	Rotanak Kiri	160300102	100	52.8	43.7	42.3	40.8	39.6	37.2	32.8	31.7	61	20	40	10	30.5	1273	396	36	48	2.000	17.5	CH
49	Rotanak Kiri	160300103	100	52.8	43.7	42.3	40.8	39.6	37.2	32.8	31.7	61	20	40	10	30.5	1273	396	36	48	2.000	17.5	CH
50	Rotanak Kiri	160300104	100	52.8	43.7	42.3	40.8	39.6	37.2	32.8	31.7	61	20	40	10	30.5	1273	396	36	48	2.000	17.5	CH
51	Rotanak Kiri	160300105	100	52.8	43.7	42.3	40.8	39.6	37.2	32.8	31.7	61	20	40	10	30.5	1273	396	36	48	2.000	17.5	CH
52	Rotanak Kiri	160300201	100	38.4	30.5	29.4	28.5	27.6	26.8	25.3	24.7	61	28	33	9	27.1	825	246	46	61	1.950	15.6	CH
54	Rotanak Kiri	160500101	100	67.7	32.9	27.6	20.8	18.2	15.6	12.2	11.1	29	15	13	9	49.0	144	163	70	-	2.310	9.5	CL
55	Rotanak Kiri	160500102	100	67.7	32.9	27.6	20.8	18.2	15.6	12.2	11.1	29	15	13	9	49.0	144	163	70	-	2.310	9.5	CL
56	Rotanak Kiri	160500103	100	67.7	32.9	27.6	20.8	18.2	15.6	12.2	11.1	29	15	13	9	49.0	144	163	70	-	2.310	9.5	CL
57	Rotanak Kiri	160500104	100	67.7	32.9	27.6	20.8	18.2	15.6	12.2	11.1	29	15	13	9	49.0	144	163	70	-	2.310	9.5	CL
58	Rotanak Kiri	160500201	100	67.7	32.9	27.6	20.8	18.2	15.6	12.2	11.1	29	15	13	9	49.0	144	163	70	-	2.310	9.5	CL
59	Rotanak Kiri	160500202	100	67.7	32.9	27.6	20.8	18.2	15.6	12.2	11.1	29	15	13	9	49.0	144	163	70	-	2.310	9.5	CL
60	Rotanak Kiri	160500301	100	99.6	97.1	95.9	90.4	85.3	80.5	72.9	70.1	50	38	12	13	4.1	872	1113	12	58	1.548	26.2	MH
61	Rotanak Kiri	160500302	100	41.5	16.8	13.1	9.4	8.4	7.9	6.3	5.7	51	31	20	10	36.0	113	84	16	55	1.790	19.6	MH
62	Rotanak Kiri	160500303	100	95.5	93.1	92.7	91.8	90.9	80.9	72.4	70.3	41	14	27	13	7.0	1911	1201	3	-	2.140	12.1	CL
63	Rotanak Kiri	160500401	100	99.4	90.2	88.8	58.5	38.7	33.0	29.4	28.1	26	15	10	7	11.1	290	276	34	-	2.340	8.5	CL
64	Rotanak Kiri	160500402	100	83.6	76.8	75.8	74.0	72.3	56.7	47.7	45.6	51	22	29	10	20.2	1324	723	70	88	2.490	10.5	CH
65	Rotanak Kiri	160700101	100	65.8	51.2	49.2	45.6	43.4	41.4	37.1	34.6	0	0	0	0	33.4	0	0	46	59	1.745	18.7	SM
66	Rotanak Kiri	160700201	100	78.6	65.0	62.9	56.6	47.7	40.6	31.8	27.4	48	34	14	10	29.2	374	498	6	57	1.640	22.4	SM
67	Rotanka Kiri	160700301	100	78.6	65.0	62.9	56.6	47.7	40.6	31.8	27.4	48	34	14	10	29.2	374	498	6	57	1.640	22.4	SM
68	Rotanak Kiri	160900101	100	52.5	37.8	35.6	32.8	30.1	27.8	25.2	24.5	47	21	26	11	33.8	624	344	6	43	2.280	13.6	CL
69	Rotanak Kiri	160900102	100	52.5	37.8	35.6	32.8	30.1	27.8	25.2	24.5	47	21	26	11	33.8	624	344	6	43	2.280	13.6	CL
70	Rotanak Kiri	160900103	100	52.5	37.8	35.6	32.8	30.1	27.8	25.2	24.5	47	21	26	11	33.8	624	344	6	43	2.280	13.6	CL
71	Rotanak Kiri	160900201	100	100.0	99.7	99.6	99.1	97.8	94.4	81.2	73.9	30	14	16	7	0.4	1185	681	20	54	1.835	13.1	CL
72	Rotanak Kiri	160900301	100	50.2	37.5	35.6	28.8	25.3	23.2	18.7	17.1	30	16	14	7	32.3	244	181	31	55	2.300	8.8	CL
73	Rotanak Kiri	160900302	100	50.2	37.5	35.6	28.8	25.3	23.2	18.7	17.1	30	16	14	7	32.3	244	181	31	55	2.300	8.8	CL
74	Rotanak Kiri	160900401	100	59.4	48.6	47.0	44.3	42.5	40.1	35.9	34.8	38	19	19	9	31.5	662	394	20	-	2.420	10.0	CL
75	Rotanak Kiri	160900402	100	59.4	48.6	47.0	44.3	42.5	40.1	35.9	34.8	38	19	19	9	31.5	662	394	20	-	2.420	10.0	CL
76	Siem Reap	170200101	100	99.7	99.5	99.4	98.8	88.8	69.6	54.1	32.2	0	0	0	0	0.6	0	0	38	72	2.122	6.0	SM
77	Siem Reap	170200102	100	99.7	99.5	99.4	98.8	88.8	69.6	54.1	32.2	0	0	0	0	0.6	0	0	37.5	71.5	2.122	6.0	SM
78	Siem Reap	170200201	100	98.4	97.5	97.3	95.8	83.9	66.9	42.6	32.3	0	0	0	0	2.7	0	0	47	118	2.114	7.4	SM
79	Siem Reap	170200202	100	96.2	94.7	94.5	93.9	91.4	86.0	67.0	55.4	27	15	12	8	5.3	680	743	24	34	1.976	11.4	OL
80	Siem Reap	170200203	100	99.8	99.6	99.6	98.8	91.2	75.2	54.1	45.2	20	11	9	6	0.4	418	534	23	59	2.070	8.1	SC
81	Siem Reap	170400101	100	98.6	96.6	96.2	94.9	92.8	90.0	79.3	69.7	0	0	0	0	3.8	0	0	24	46	1.930	11.2	SM
82	Siem Reap	170400201	100	99.1	97.5	97.2	96.2	93.0	86.5	72.4	67.9	24	10	15	7	2.7	1005	664	19	25	2.180	9.0	CL
83	Siem Reap	170400202	100	99.1	97.5	97.2	96.2	93.0	86.5	72.4	67.9	24	10	15	7	2.7	1005	664	19	25	2.180	9.0	CL
84	Siem Reap	170700101	100	99.5	99.2	99.1	98.3	88.9	68.4	43.0	32.7	0	0	0	0	0.9	0	0	29	58	2.135	6.6	SM
85	Siem Reap	170700102	100	98.1	97.9	97.8	97.3	92.5	80.7	55.0	38.8	40	21	19	15	2.2	728	1380	23	32	1.957	8.3	SC
86	Siem Reap	170700301	100	99.6	99.0	98.9	96.7	76.5	44.1	25.3	19.9	0	0	0	0	1.1	0	0	9	21	2.070	7.7	SM
87	Siem Reap	170700401	100	99.6	99.0	98.9	96.7	76.5	44.1	25.3	19.9	0	0	0	0	1.1	0	0	9	21	2.070	7.7	SM
88	Siem Reap	170700501	100	100.0	100.0	99.9	99.1	86.2	56.2	27.0	18.9	0	0	0	0	0.1	0	0	38	18	2.112	8.8	SM
89	Siem Reap	170700601	100	70.6	61.2	59.4	54.6	50.55	48.4	44.8	42.5	21	9	13	7	28.7	536	343	-	-	-	-	CL or OL
90	Siem Reap	170700602	100	70.6	61.2	59.4	54.6	50.55	48.4	44.8	42.5	21	9	13	7	28.7	536	343	-	-	-	-	CL or OL
91	Siem Reap	170700701	100	74.7	68.1	66.8	62.9	58.1	54.1	48.9	46.1	22	14	8	6	24.8	386	341	-	-	-	-	SC
92	Siem Reap	170700702	100	74.7	68.1	66.8	62.9	58.1	54.1	48.9	46.1	22	14	8	6	24.8	386	341	-	-	-	-	SC
93	Siem Reap	171100101	100	96.4	95.2	94.3	89.2	76.4	60.9	40.2	31.8	0	0	0	0	5.5	0	0	25	47	2.056	8.2	SM
94	Siem Reap	171100102	100	96.6	94.9	94.7	93.5	88.1	76.3	55.2	44.5	0	0	0	0	5.2	0	0	23	54	2.120	7.9	SM

Appendix C Comparisons within individual roads

	Dependant								Independent																						
Site number	Overall Performance	Ruts (average) mm	Pothole Size (Average)	Pothole Extent (Average)	Loose material (Average)	Corrugations (average)	Carriageway erosion (average)	Shoulder erosion (average)	Age in years	Average run off condition	Grading coefficient	Longitudinal gradient %	Rainfall (m)	Average crown height	X-section	Average side drain condition	Average cross fall	Shape of carriage way	Plasticity product	Shrikage Product	Max particle size (approx)	Retained 2.36	Passing 0.075	DCP 100mm average	DCP 300mm average	Passability (Exist. Condt.)	Passability Risk	Average ratio MC/OMC	Soaked CBR @ 95% Proctor	Unsoaked CBR @ 95% Proctor
1	10	83	2.2	2.6	2	2	2	1	4	1	3	0	2.0	0.4	1	1.5	1.5	4	920	844	0.2	2	74	12	8	3	4	0.7	1	41
2	0	8	0.0	0.0	2	1	1	1	4	1	3	0	2.0	0.7	1	1.0	3.8	2	920	844	0.2	2	74	12	7	2	1	0.6	1	41
45	10	200	1.0	1.0	4	1	4	5	3	5	32	27	2.3	0.4	1	5.0	0.0	4	0	0	20.0	55	15	30	20	2	3	0.9	37	59
46	8	66	1.6	1.6	2	1	3	3	3	2	32	25	2.3	0.7	1	0.0	5.0	4	0	0	20.0	55	15	48	34	2	3	0.7	37	59
41	3	18	1.0	1.0	2	1	1	1	3	1	29	0	2.3	0.0	4	2.0	1.0	3	826	478	20.0	49	31	38	21	1	1	0.7	24	55
44	3	13	1.0	1.0	2	1	1	1	3	2.5	32	3	2.3	0.1	4	2.5	0.0	3	0	0	20.0	55	15	47	28	1	3	0.6	37	59
42	2	25	0.0	0.0	1	1	1	1	3	1	29	1	2.3	0.3	1	1.0	0.0	3	826	478	20.0	49	31	43	32	1	1	0.2	24	55
43	1	21	0.0	0.0	2	1	1	1	3	1	29	15	2.3	0.5	2	3.0	0.0	3	826	478	20.0	49	31	38	21	1	2	0.7	24	55
40	0	7	0.0	0.0	2	1	1	1	3	1	29	2	2.3	0.2	1	3.5	1.5	3	826	478	20.0	49	31	47	28	1	1	0.6	24	55
32	6	10	2.4	2.4	2	2	3	2	4	1.5	6	1	1.0	0.2	2	2.0	4.5	4	169	278	1.2	5	48	63	20	3	3	0.5	29	39
31	0	9	0.0	0.0	2	2	1	1	4	1	6	4	1.0	0.2	4	0.0	4.8	3	169	278	1.2	5	48	27	26	3	3	0.4	29	39
80	8	18	3.6	4.6	4	1	1	2	3	2	0	0	1.4	0.5	1	0.0	5.0	4	418	534	0.4	0	45	12	7	3	4	1.2	23	59
79	6	27	2.0	2.0	2	4	1	2	3	1	5	0	1.4	0.4	1	0.0	8.5	2	680	743	0.4	5	55	9	4	2	4	1.1	24	34
78	3	28	0.0	1.0	1	1	1	1	3	2	3	2	1.4	0.6	1	1.5	1.0	2	0	0	0.8	3	32	20	17	1	2	0.5	47	118
19	7	76	0.2	0.2	1	2	2	3	2	1	0	0	2.0	1.5	1	0.0	8.0	3	0.0	0	0.4	0	46	36	17	3	2	0.5	30	
18	3	39	0.0	0.0	4	2	2	3	2	1	0	1	2.0	1.2	1	0.0	8.0	2	0.0	0	0.4	0	46	26	12	1	3	1.2	30	
23	6	28	1.8	3.4	3	2	1	1	2	2	4	2	1.0	0.0	4	0.0	4.0	4	1087	988	0.3	4	81	23	68	2	4	0.6	6	28
22	2	15	0.0	1.0	1	1	1	3	2	1	8	2	1.0	0.3	2	0.0	6.5	1	780	803	1.0	7	65	18	27	1	1	0.5	4	24
24	6	45	1.0	1.6	3	1	2	1	3	3	2	1	1.0	0.1	4	0.0	5.5	4	0	0	0.8	2	51	45	56	1	3	0.6	11	72
26	3	23	0.4	1.2	2	2	1	1	3	3	5	2	1.0	1.5	1	0.5	3.5	1	0	0	1.2	4	36	68	63	1	1		17	26
25	2	7	0.2	0.2	2	2	1	1	3	2	4	2	1.0	0.0	4	0.0	5.5	2	0	0	1.0	3	43.1	68	63	1	3		14.1	48.9
33	4	20	0.6	0.6	2	1	2	1	3	1	37	1	1.0	1.1	1	0.0	4.5	2	120	144	10.0	49	20	40	40	1	1		13	9
35	4	22	0.2	1.2	2	1	2	2	3	1	7	2	1.0	0.5	1	0.0	8.0	2	310	294	1.8	5	38	24	33	3	3	0.5	8	15
34	1	13	0.0	0.0	2	1	1	1	3	1	7	2	1.0	0.4	1	2.5	5.5	2	310	294	1.8	5	38	29	21	3	3	0.8	8	15
68	5	53	1.0	1.4	2	1	1	1	7	3	34	0	2.3	0.4	1	0.0	2.5	4	624	344	22.0	62	24	158	56	1	2	0.3	6	43
69	3	22	0.4	0.6	2	1	1	1	7	1	34	2	2.3	0.4	1	0.0	0.0	3	624	344	22.0	62	24	60	43	1	1	0.4	6	43
70	2	35	0.0	0.0	2	1	1	1	7	2	34	1	2.3	0.7	1	0.0	2.0	3	624	344	22.0	62	24	39	23	1	2	0.7	6	43
92	3	11	0.2	0.2	1	1	1	1	1	3	25	0	1.4	0.6	1	0.0	6.0	2	386	341	20.0	32	46	50	50	1	2			
91	0	8	0.0	0.0	1	1	1	1	1	1	25	0	1.4	0.4	1	1.0	4.5	2	386	341	20.0	32	46	50	50	1	2			
14	3	64	0.0	0.0	2	2	1	3	2	1	2	0	2.0	0.7	1	0.0	5.0	4	2131	1309	0.2	2	84	21	8	1	3	0.7	4	
13	1	18	0.0	0.0	1	2	1	1	2	1	2	1	2.0	0.7	1	0.0	4.0	3	2131	1309	0.2	2	84	21	19	1	2	0.7	4	
16	6	51	0.2	0.2	3	1	2	2	2	1	1	0	2.0	1.1	1	0.0	7.5	4	0	0	0.8	1	26	54	18	1	1	0.4	27	
15	4	62	0.0	0.0	3	2	2	2	2	1	1	0	2.0	1.0	1	0.0	4.5	4	0	0	0.8	1	26	36	9	1	1	0.7	27	

Site number	Overall Performance	Ruts (average) mm	Pothole Size (Average)	Pothole Extent (Average)	Loose material (Average)	Corrugations (average)	Carriageway erosion (average)	Shoulder erosion (average)	Age in years	Average run off condition	Grading coefficient	Longitudinal gradient %	Rainfall (m)	Average crown height	X-section	Average side drain condition	Average cross fall	Shape of carriage way	Plasticity product	Shrikage Product	Max particle size (approx)	Retained 2.36	Passing 0.075	DCP 100mm average	DCP 300mm average	Passability (Exist. Condt.)	Passability Risk	Average ratio MC/OMC	Soaked CBR @ 95% Proctor	Unsoaked CBR @ 95% Proctor
63	5	59	0.4	0.4	2	1	1	1	3	1	**11**	0	2.3	0.6	1	0.0	**0.0**	4	**290**	276	2.4	10	28	33	11	1	1	1.0	34	
64	3	62	0.0	0.0	2	1	1	1	3	1	**20**	4	2.3	0.3	1	1.0	**4.5**	4	**1324**	723	8.0	23	46	57	19	1	2	0.8	70	88
76	8	57	2.0	3.0	2	3	1	2	8	2	1	1	1.4	0.5	1	0.0	0.0	4	0	0	0.4	1	32	14	11	2	3	1.0	38	72
77	6	70	1.2	1.8	2	1	1	1	8	2	1	0	1.4	0.5	1	0.0	0.0	4	0	0	0.4	1	32	11	21	2	3	1.1	*37.5*	*71.5*
82	9	34	3.6	3.0	3	1	2	1	12	1	3	0	1.4	**0.6**	1	0.0	0.0	4	1005	664	0.3	3	68	45	24	2	3	0.3	*19*	*25*
83	7	109	1.0	1.0	3	1	1	2	12	1	3	0	1.4	**1.8**	1	0.0	0.0	4	1005	664	0.3	3	68	27	9	3	3	0.7	19	25
93	8	40	3.0	3.0	2	3	1	2	10	2	5	0	1.4	0.6	1	1.0	**6.5**	4	0	0	1.0	5	32	19	33	3	4	1.3	25	47
94	6	38	2.0	2.2	2	3	1	1	10	2	5	3	1.4	0.4	1	1.0	**0.0**	4	0	0	0.8	5	45	24	17	2	3	1.2	23	54
4	3	44	0.0	0.0	1	2	2	1	2	1	0	0	2.0	1.3	1	0.5	8.0	4	405	245	0.2	0	79	28	9	3	3	0.7	24	45
5	2	16	0.0	0.0	1	2	2	1	2	1	0	0	2.0	1.3	1	1.0	7.5	3	405	245	0.2	0	79	27	16	3	3	0.5	*24*	*45*
6	1	23	0.0	0.0	2	1	1	1	3	1	27	0	2.0	1.4	1	0.0	2.0	2	0	0	20.0	74	12	77	46	1	1	0.7	39	67
7	0	9	0.0	0.0	1	1	1	1	3	1	27	2	2.0	1.9	1	3.0	4.8	2	0	0	20.0	74	12	55	15	1	1	0.5	*39*	*67*
9	3	25	0.0	0.0	2	1	2	3	2	1	1	0	2.0	0.8	1	0.0	7.5	2	1954	1219	0.1	1	86	12	3	1	3	0.9	1	44
8	2	12	0.0	0.0	1	2	2	2	2	1	1	1	2.0	0.7	1	0.0	6.0	2	1954	1219	0.1	1	86	14	6	1	4	0.8	1	44
20	1	12	0.0	0.0	1	1	1	1	2	1	36	0	2.0	0.7	1	0.0	4.8	2	92	61	20.0	67	14	40	13	1	1	0.4	45	
21	0	8	0.0	0.0	1	1	1	1	2	1	36	0	2.0	0.5	2	0.0	4.0	2	92	61	20.0	67	14	40	18	1	1	0.4	*45*	
37	9	82	0.4	0.4	2	1	4	1	4	3.5	2	4	1.0	1.0	1	3.0	0.0	5	317	282	0.9	2	40	97	27	2	3	0.5	39	50
36	8	47	2.2	1.6	2	2	3	3	4	2	1	1	1.0	0.9	1	3.0	0.0	4	0	0	0.9	1	17	73	39	3	2	0.3	21	9
60	2	12	0.0	0.0	1	1	2	1	1	1	4	4	2.3	0.4	1	0.0	4.0	1	872	1113	1.0	3	70	38	23	1	2	0.7	12	58
62	2	27	0.0	0.0	2	1	1	1	1	1	7	3	2.3	0.4	1	0.0	3.5	2	1911	1201	0.4	7	70	33	14	1	1	0.5	3	
61	1	15	0.0	0.0	2	1	1	1	1	1	36	10	2.3	0.4	1	0.0	0.0	1	113	84	23.0	83	6	47	20	1	2	0.6	16	55
73	4	26	0.2	0.2	1	1	1	1	5	1	32	0	2.3	0.3	1	0.0	0.0	4	244	181	22.0	62	17	79	38	1	1	0.4	31	55
72	3	18	0.8	1.4	2	1	1	1	5	1	32	1	2.3	0.2	1	0.0	0.0	3	244	181	22.0	62	17	49	21	1	1	0.7	*31*	*55*

Appendix D Correlation matrix

	Overall Performance (0=good)	Appearance (Average)	Loose material (Average)	Corrugations (average)	Carriageway erosion (average)	Shoulder erosion (average)	Pohole Size (average)	Pot hloe extent (average)	Ruts (average) mm	Road Designation	Road Type	Terrain	T. Type	T. Volume	Rainfall	General condition	Age in years	L. Gradient %	Hori. Curvature	Cross fall (average)	X-section	Crown height (average)	Shape of carriage way	Side drain (average)	Run off (average)	Passability (Exist. Condt.)	Passability Risk	Weather 1st survey	Average (water content/optimum)	Average water Content (%) at DCP	DCP 100mm average	DCP 300mm average	LL	PL	PI	LS	Grad coef	Plast Prod	Retained 2.36	SP	CBR @ 95% Proctor soaked	MDD	OMC	Passing 0.075
Overall Performance (0=good)	1.00																																											
Appearance (Average)	0.74	1.00																																										
Loose material (Average)	0.44	0.50	1.00																																									
Corrugations (average)	0.47	0.28	0.10	1.00																																								
Carriageway erosion (average)	0.52	0.39	0.26	0.12	1.00																																							
Shoulder erosion (average)	0.45	0.48	0.27	0.31	0.57	1.00																																						
Pohole Size (average)	0.82	0.62	0.41	0.49	0.19	0.22	1.00																																					
Pot hole extent (average)	0.80	0.58	0.40	0.48	0.13	0.21	0.94	1.00																																				
Ruts (average) mm	0.68	0.60	0.44	0.18	0.52	0.53	0.27	0.24	1.00																																			
Road Designation	0.19	0.16	-0.08	0.42	0.07	0.25	0.26	0.35	-0.06	1.00																																		
Road Type	0.44	0.33	0.05	0.52	0.15	0.31	0.47	0.55	0.09	0.76	1.00																																	
Terrain	-0.21	-0.22	0.04	-0.37	-0.12	-0.25	-0.30	-0.33	0.04	-0.65	-0.66	1.00																																
T. Type	0.27	0.16	0.13	0.34	0.18	0.22	0.29	0.30	0.05	0.11	0.16	-0.21	1.00																															
T. Volume	0.22	0.25	0.00	0.03	0.11	0.06	0.17	0.14	0.12	-0.14	-0.03	-0.13	0.29	1.00																														
Rainfall	-0.42	-0.33	-0.07	-0.34	-0.18	-0.23	-0.48	-0.55	-0.03	-0.47	-0.71	0.61	-0.45	-0.24	1.00																													
General condition	0.64	0.54	0.22	0.47	0.14	0.16	0.65	0.58	0.36	0.18	0.41	-0.21	0.29	0.29	-0.44	1.00																												
Age in years	0.40	0.31	0.18	0.15	0.01	0.02	0.40	0.35	0.28	0.05	0.17	0.00	0.16	0.10	-0.22	0.45	1.00																											
L. Gradient %	0.06	0.05	0.29	-0.17	0.34	0.28	-0.10	-0.13	0.37	-0.42	-0.32	0.30	-0.06	-0.14	0.25	-0.14	-0.12	1.00																										
Hori. Curvature	-0.16	-0.13	-0.10	-0.07	-0.08	-0.11	-0.11	-0.11	-0.12	0.05	0.00	-0.22	-0.07	0.15	-0.06	-0.10	-0.10	-0.06	1.00																									
Cross fall (average)	-0.03	-0.06	-0.14	0.26	0.13	0.21	-0.05	-0.02	-0.15	0.32	0.42	-0.32	0.00	-0.03	-0.21	-0.07	-0.36	-0.14	0.03	1.00																								
X-section	-0.04	-0.17	-0.01	-0.05	0.00	-0.09	0.08	0.14	-0.21	0.14	0.16	-0.16	0.10	-0.06	-0.34	-0.04	-0.02	-0.06	0.10	0.09	1.00																							
Crown height (average)	0.14	0.19	-0.05	0.15	0.18	0.22	-0.02	-0.07	0.24	0.22	0.20	-0.32	0.11	0.15	-0.11	0.15	0.09	-0.12	0.06	0.16	-0.39	1.00																						
Shape of carriage way	0.61	0.63	0.42	0.21	0.33	0.21	0.46	0.40	0.55	0.01	0.11	0.07	0.09	0.20	-0.07	0.49	0.50	-0.02	-0.15	-0.30	-0.09	0.06	1.00																					
Side drain (average)	0.07	0.04	0.21	0.00	0.28	0.09	0.03	-0.05	0.26	-0.38	-0.31	0.25	0.12	-0.03	0.15	0.12	-0.11	0.40	-0.04	-0.22	-0.09	-0.03	0.10	1.00																				
Run off (average)	0.50	0.40	0.39	0.14	0.42	0.38	0.33	0.36	0.55	-0.03	0.10	-0.02	0.24	0.14	-0.32	0.32	0.17	0.32	-0.17	-0.17	0.14	0.02	0.33	0.30	1.00																			
Passability (Exist. Condt.)	0.49	0.55	0.27	0.41	0.38	0.29	0.43	0.39	0.33	0.26	0.43	-0.33	0.27	0.13	-0.43	0.47	0.36	0.00	0.07	0.13	-0.06	0.24	0.43	0.12	0.12	1.00																		
Passability Risk	0.21	0.27	0.23	0.24	0.23	0.25	0.25	0.25	0.07	0.44	0.35	-0.52	0.04	-0.09	-0.22	0.08	0.14	-0.07	0.08	0.12	0.18	-0.11	0.21	-0.14	0.13	0.34	1.00																	
Weather 1st survey	0.33	0.28	-0.02	0.28	-0.19	0.14	0.49	0.60	-0.01	0.39	0.50	-0.38	0.21	0.12	-0.63	0.30	0.04	-0.18	-0.03	0.07	0.24	-0.08	-0.03	-0.21	0.20	0.03	0.10	1.00																
Average (water content/optimum)	0.24	0.29	0.30	0.30	-0.02	0.15	0.32	0.32	0.16	0.17	0.16	-0.14	-0.09	-0.05	0.06	0.15	0.01	0.05	-0.13	0.04	-0.19	-0.07	0.11	0.17	-0.04	0.13	0.28	0.20	1.00															
Average water Content (%) at DCP	-0.07	-0.05	0.14	-0.04	0.01	0.06	-0.06	-0.09	0.12	-0.34	-0.27	0.37	-0.22	-0.31	0.43	-0.20	-0.21	0.49	-0.22	-0.03	-0.10	-0.29	-0.14	0.41	-0.03	-0.19	-0.05	-0.10	0.55	1.00														
DCP 100mm average	-0.15	-0.10	-0.02	-0.38	-0.02	-0.33	-0.19	-0.27	-0.05	-0.48	-0.60	0.44	0.02	0.25	0.31	-0.11	0.02	0.00	0.09	-0.25	-0.07	-0.12	0.14	0.09	0.01	-0.20	-0.16	-0.35	-0.30	-0.14	1.00													
DCP 300mm average	-0.07	-0.12	0.11	-0.19	-0.08	-0.23	-0.04	-0.03	-0.09	-0.29	-0.32	0.27	0.12	0.12	0.05	-0.04	0.03	0.01	0.10	-0.17	0.25	-0.36	0.12	0.01	0.15	-0.10	0.00	-0.08	-0.22	-0.09	0.63	1.00												
LL	-0.47	-0.35	-0.20	-0.32	-0.30	-0.28	-0.37	-0.39	-0.29	-0.28	-0.39	0.47	-0.33	-0.27	0.47	-0.29	-0.21	0.10	-0.15	-0.10	-0.09	-0.37	-0.29	0.12	-0.37	-0.35	-0.21	-0.24	0.04	0.46	0.05	-0.02	1.00											
PL	-0.45	-0.36	-0.25	-0.29	-0.24	-0.26	-0.34	-0.36	-0.33	-0.23	-0.35	0.41	-0.28	-0.26	0.41	-0.29	-0.17	0.03	-0.11	-0.10	-0.05	-0.40	-0.25	0.06	-0.37	-0.29	-0.14	-0.21	-0.03	0.37	0.03	-0.03	0.92	1.00										
PI	-0.43	-0.29	-0.12	-0.31	-0.32	-0.26	-0.34	-0.37	-0.22	-0.30	-0.38	0.48	-0.33	-0.25	0.47	-0.26	-0.21	0.14	-0.17	-0.08	-0.12	-0.30	-0.29	0.16	-0.33	-0.35	-0.24	-0.23	0.09	0.49	0.06	-0.01	0.95	0.75	1.00									
LS	-0.38	-0.26	-0.22	-0.24	-0.31	-0.18	-0.27	-0.28	-0.25	-0.04	-0.24	0.29	-0.31	-0.27	0.37	-0.19	-0.16	-0.03	-0.14	-0.07	-0.05	-0.34	-0.23	-0.05	-0.34	-0.33	0.00	-0.10	0.05	0.35	-0.03	-0.07	0.91	0.87	0.84	1.00								
Grad coef	-0.54	-0.39	-0.04	-0.45	-0.28	-0.30	-0.45	-0.50	-0.22	-0.52	-0.85	0.50	-0.21	-0.09	0.69	-0.46	-0.13	0.27	0.11	-0.36	-0.08	-0.28	-0.19	0.18	-0.15	-0.42	-0.08	-0.43	-0.10	0.21	0.52	0.36	0.35	0.31	0.34	0.25	1.00							
Plast Prod	-0.21	-0.12	-0.25	-0.14	-0.15	-0.03	-0.18	-0.18	-0.11	0.10	0.09	0.10	-0.26	-0.25	0.13	-0.12	-0.18	-0.01	-0.19	0.16	-0.02	-0.14	-0.21	-0.04	-0.26	-0.20	-0.06	0.00	0.08	0.36	-0.24	-0.24	0.72	0.57	0.76	0.78	-0.17	1.00						
Retained 2.36	-0.53	-0.39	-0.06	-0.46	-0.27	-0.30	-0.44	-0.48	-0.20	-0.52	-0.85	0.53	-0.19	-0.07	0.69	-0.46	-0.14	0.30	0.12	-0.37	-0.10	-0.18	-0.21	0.20	-0.14	-0.43	-0.20	-0.43	-0.09	0.23	0.51	0.34	0.34	0.28	0.36	0.20	0.96	-0.16	1.00					
SP	-0.08	-0.02	-0.24	0.00	-0.10	0.07	-0.02	-0.01	-0.09	0.28	0.23	-0.06	-0.16	-0.23	-0.02	0.04	-0.13	-0.12	-0.16	0.19	0.02	-0.13	-0.12	-0.14	-0.21	-0.10	0.08	0.14	0.07	0.22	-0.34	-0.30	0.60	0.58	0.55	0.80	-0.29	0.89	-0.32	1.00				
CBR @ 95% Proctor soaked	-0.19	-0.13	0.05	-0.15	-0.07	-0.17	-0.15	-0.20	-0.04	-0.22	-0.44	-0.03	0.06	-0.06	0.25	-0.22	-0.12	0.10	0.07	-0.10	0.03	-0.04	-0.08	0.15	-0.04	-0.16	0.19	-0.11	0.10	0.02	0.29	0.17	-0.16	-0.21	-0.09	-0.23	0.55	-0.41	0.49	-0.50	1.00			
MDD	-0.09	-0.02	0.04	-0.03	-0.24	-0.26	-0.04	-0.02	-0.14	0.17	-0.09	-0.15	0.05	0.12	-0.04	0.08	0.19	-0.38	0.15	-0.09	-0.14	0.15	0.02	-0.26	-0.17	0.02	0.09	-0.05	0.02	-0.51	0.29	0.15	-0.12	-0.20	-0.04	-0.08	0.18	-0.24	0.16	-0.28	0.38	1.00		
OMC	-0.26	-0.20	-0.06	-0.30	-0.03	-0.04	-0.28	-0.31	0.01	-0.52	-0.43	0.58	-0.30	-0.29	0.46	-0.29	-0.20	0.48	-0.20	-0.17	0.05	-0.36	-0.10	0.34	0.01	-0.32	-0.24	-0.21	-0.08	0.69	0.06	0.07	0.56	0.55	0.50	0.45	0.33	0.38	0.32	0.29	-0.17	-0.73	1.00	
Passing 0.075	0.16	0.11	-0.18	0.22	0.12	0.15	0.11	0.17	0.01	0.55	0.66	-0.33	-0.10	-0.18	-0.34	0.16	-0.01	-0.23	-0.17	0.38	0.14	0.06	-0.02	-0.25	-0.10	0.19	0.18	0.26	0.10	0.04	-0.51	-0.36	0.15	0.16	0.13	0.30	-0.70	0.66	-0.71	0.73	-0.58	-0.29	0.01	1.00